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Khanji Harijan
Editors

Energy, Environment and Sustainable Development

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Preface

The First International Conference on Energy, Environment and Sustainable Development for Growing Economies (EESD2009) was held in Jamshoro, Pakistan, between May 4 and 6, 2009. The event was organized by Mehran University of Engineering and Technology (UET), Jamshoro, in collaboration with Higher Education Commission, Government of Pakistan. The conference brought together academicians, researchers, engineers, policy makers, governmental officials, end users, and people involved in the energy and environmental industries. More than 300 participants registered for the conference from 20 countries. EESD2009 has provided a platform to the experts to present their papers, share their expertise, establish new contacts, and discuss a range of energy and environmental technologies for sustainable development.

The EESD2009, the first ever event at Mehran UET, was successful in getting response from public and private sectors, universities, research organizations, stake holders, and industries from all over the world in the field of energy, environment, and sustainable development. More than 100 papers in the major theme of the conference were received. Seventy experts presented their papers, scrutinized and accepted by the technical committee, in the eight technical sessions of the conference. Also, prominent foreign and local experts delivered keynote speeches and plenary lectures in the conference.

This book contains the selected revised manuscripts presented at EESD2009 in the six main conference themes: energy management and conservation, environmental engineering and management, renewable and emerging energy systems, biological and chemical treatment, waste treatment and management, and energy and environmental sustainability. The book provides new information/methods on possibilities of managing the energy crisis and protecting the environment sustainably in the growing economies to the broader public, especially students and researchers who are interested to involve in the research in this area, manufacturers, policy makers, and planners. This book is believed to be the first by Springer to be published in Pakistan on energy, environment, and sustainable development.

The editors wish to acknowledge the Mehran UET, Jamshoro, for organizing and the Higher Education Commission, Government of Pakistan, for sponsoring this very successful conference.

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Keynote Speech: The Advantages of Involving Women in Sustainable Development Planning

Susan Buckingham

In order to work toward sustainable development, it is important for a country to first decide what its development goals are, in social, economic, and environmental terms. These need to be articulated with international goals, for example, the United Nations Millennium Goals, post-Kyoto climate change agreements and Conventions such as those on the Rights of the Child, and the Elimination of all forms of Discrimination against Women. Any expansion of energy production must focus on minimizing environmental – particularly environment health – damage, and ensure environmental justice, whereby no sector in society – and especially already vulnerable sectors – is disadvantaged by energy decisions taken.

An energy policy that is socially, economically, and environmentally fair and sustainable will be sensitive to the sustainability of the sources of this energy, the efficiency of the energy used, and the impacts of using different kinds of energy sources. Energy decisions must take place in the context of effective environmental and social impact assessment, as well as long-term economic assessment.

In this presentation, I will illustrate the importance of taking a gender perspective in making decisions about planning for sustainable development. From Pakistan, I will use examples of how different forms of energy generation have specific gendered impacts and consequences, and that these usually work against women, children, and other vulnerable members of society. Drawing on international examples, I will discuss the importance of involving more women in decision making on sustainable development, including energy. As well as being an equal opportunities strategy in itself, gender-balanced decision making is becoming increasingly recognized as producing better, more creative, decisions. More broadly, I will discuss how creating equal opportunities for women can be expected to create more sustainable development in the long term, which is of benefit to society as a whole.

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Keynote Speech: Development of Solid Waste Management

Nie Yong-Feng

This invited lecture is about development of solid waste management. The state of art development stages of municipal solid waste (MSW) management system from early 1970 to date are reported. Various MSW management technologies and their merits and demerits are described. He emphasized that decision makers should employ/adopt MSW management technology carefully otherwise all resources will go waste. The lecture explains the hybrid system of pyrolysis and gasification to recover the refused derive fuel (RDF) and gas from the waste. This technology is being used to treat the hazardous waste and MSW for energy recovery purposes. China is recovering the landfill gas from the landfills and utilizing for electricity generation, leachate treatment and also converting it to compressed natural gas (CNG).

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Plenary Lecture: Tariff – Its Importance for Sustainability of Power Sector

Shah Zulfiqar Haider

Electricity supply is a service. Utilities should run on "No-Loss-No-Profit and again on Sound financial basis." This requires proper tariff, as revenue from consumers is the main source of income for any utility. New lines should be constructed on revenue criteria. The revenue earned from these lines should be reasonable to recover the capital, operational, maintenance, and other costs in due time. Again all areas of the country or Utility are to be brought under electrification, i.e., "Area coverage electrification program" irrespective of revenue. The two concepts are contradictory. Again Politicians sometimes commit to provide electricity free of cost to its Consumers (voters) in irrigation areas or to the poor, but who will actually pay for this free electricity.

The tariff is not rational or cost effective. The rich countries sometimes provide subsidy to its Utilities, whereas developing or poor countries are discouraged to provide subsidy because of mismanagement. Cost of electricity and tariffs are not in harmony. Why? The Utilities have to keep the cost at minimum.

Another important aspect is to always procure or install best quality electrical products. Electricity is sometimes considered as Goods and by some as Service. In any case, it is such a product whose quality cannot be ascertained before its delivery to its consumers. We need to provide best quality electricity. Again Electricity is a service, which is required round the clock. For Off Grid areas we need Renewable energy, which is expensive. Best thing will be to provide one time subsidy to them. Often we have to go for Privatization mainly due to inefficient management of state-owned Utilities. In any case, the tariff should be such that the total cost of providing electricity is recovered from total sale of electricity at its minimum possible tariff.

We also need a complete Infrastructure and Energy master plan for the whole country.

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Plenary Lecture: South Asia and Management of Energy Security

Musarrat Jabeen

In current international relations, the energy realism has become the main arena for political conflict. Energy defines the pursuit of state power; international economic relations have dominant tinge for the purpose of energy security. The international or regional energy systems are not managed via economic forces only; they are manipulated by political systems. But it has to work with public economics linking energy security with the welfare of human beings in a holistic manner in different regions of the world. This paper is significant to flash South Asia in international energy system as growing economically, and shaping the future development of world as well. The tapestry of conflict related to energy security vis-à-vis South Asia with horizontal and vertical perspectives leads to propose 3D strategy for management of energy security for South Asia. 3D strategy includes the Management of Regional Interests at National Level, Management of Regional Interests at Regional Level, and Management of Regional Interests at International Level.

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Modeling of Energy and Environment for Sustainable Development

B.K. Bala

Abstract Previous efforts on modeling of energy and environment are critically examined and the structure of energy and environment system model is described. The modeling of energy and environment for sustainable development using Bangladesh as a case of illustrative example is presented. The computer model essentially consists of a system dynamics model in combination with Long-range Energy Alternatives Planning (LEAP). The output of the system dynamics model is fed into the LEAP model. The model projects energy supply and demand and its contribution to global warming. Simulated results show that the energy demands in all sectors of the economy are increasing with time. The demand for electrical energy is also increasing and there is shortage of electric power. The performance of the electric power generation and utilization can be improved through reduction of system loss and introduction of end-use efficiency improvement devices. However, generation capacity needs to be increased for sustainable development with gradual transition to renewable energy resources. Power cannot reach everywhere and mini-grids for supply of energy, information, and communication for rural development and economic growth for isolated areas such as islands are advocated. Bangladesh is responsible for a small fraction of the total anthropogenic contribution of CO_2 but could be seriously affected by climatic change. LEAP in combination with a system dynamics model is more effective than LEAP alone for energy and environmental planning for sustainable development.

Keywords Climate change • Emission • Energy • Energy scenarios • Environment • LEAP • Modeling • Simulation • System dynamics

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1 Introduction

Energy is needed to meet the subsistence requirement as well as to meet the demand for economic growth and development. Per capita consumption of energy is a measure of physical quality of life [1, 2]. Though the regional average has increased in the recent years, it is far below the world average and it continues to remain far below the regional average in Bangladesh (4.4 GJ per year). Per capita consumption of electrical energy is also a measure of physical quality of life [1, 2] and it is low in Bangladesh (148 kWh per capita per annum). Access to electricity in Bangladesh is one of the lowest in the world and it covers about 33% of the total population.

Global economic growth for the period 2002–2030 is estimated at 3.2% per year, with China, India, and Asian countries expected to lead the peak and the population worldwide is put at more than 8 billion in 2030 from 6.2 billion in 2002. World energy demand expands by 45% between now and 2030 – an average rate of increase of 1.6% per year – with coal accounting for more than a third of the overall rise. World electricity demand increased at an average annual rate of 4.5% from 1971 to 1992 and doubled to 4,800 TWh. By 2010, it is projected to increase more rapidly to 20,323 TWh. World electricity generation is projected to grow by an average rate of 2.5% in the twenty-first century.

The trend of commercial energy consumption over the last 10 years in Bangladesh suggests that 70% of total commercial energy consumption was provided by natural gas, with remainder almost entirely supplied by imported oil plus limited amount of hydropower and coal. South Asia's regional picture was 43% coal, 35% petroleum, 13% natural gas, 8% hydroelectricity, and 1% nuclear in 1999. However, there are significant variations within the region. For instance, Bangladesh's energy mix is dominated by natural gas (71% in 1999), while in India it is coal (51%). Sri Lanka is overwhelmingly dependent on petroleum (75% in 1999), while Pakistan is dependent on oil (42% in 1999), natural gas (40%), and hydroelectricity (13%). But Maldives is fully dependent on petroleum. Bhutan and Nepal have high shares of hydroelectric power in their energy consumption [3].

South Asia is also home to several of the most polluted cities and these cities are Calcutta, Dhaka, Mumbai, Delhi, and Karachi. However, the total emission in the region accounts for a small fraction (3%) and this region is responsible for a small contribution to global warming and climate change. Contribution of Bangladesh for global warming and climate change is also a very small fraction (per capita contribution is 0.50 ton/annum) [4–7].

In the 1970s, the primary focus was on the relationship between energy and economics. At that time, the linkage between energy and the environment did not receive as much attention. An institutional structure to deal with environmental problems emerged after the 1970s in each country in the world. In the academic community, concern about problems of pollution and the wasteful use of raw materials and energy, of course, developed much earlier. If we briefly look at the environmental problems associated with the use of various energy sources, the major concern is the greenhouse effect due to carbon dioxide (CO_2) emissions from burning of fossil fuels, which play a leading role. Also, sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emitted by fossil fuel burning contribute to acid rain and to air pollution. However, nuclear energy is associated with health risks to nuclear industry workers and to the people living around the power stations, as well as with the long-lasting waste disposal problems and the hazards of disastrous accidents. Hydro-energy can cause enormous disruption to the natural environment and is by no means an altogether benign form of energy.

Energy production and use can be major sources of serious environmental impacts. The impacts, in turn, can threaten the overall social and economic development and objectives that energy use is expected to promote. At regional and global levels, fossil fuel consumption leads to acid rain and most likely to global warming; both phenomena could disrupt normal system and economic productivity. At the local level, continued reliance on traditional biomass fuels in many developing countries such as Bangladesh can place added stress on wood lands and farm lands. As a result, the relative humidity of the air will decrease and environmental degradation will result [2].

In recent years, the issue of global warming and energy-related CO_2 emissions has been at the forefront of environmental policy. For developing countries, it is a conflict between development, which means a greater energy demand, and environmental protection, which limits the use of fossil fuels. Over the past few decades, the increasing use of energy has created our concerns from local or regional to global energy-related environmental problems particularly in developing or newly industrialized countries, where energy growth rates are typically high. About 97% of the projected increase in emissions between now and 2030 comes from non-OECD countries – three quarters from China, India, and the Middle East alone.

The industrialized countries are mainly responsible for air pollution, ozone depletion, and carbon emissions and the developing countries contribute a small fraction. However, in developing countries there is a great potential to use energy efficiently since energy use is much less efficient in developing countries. It is clear that there is a need to make major changes in the production and use of energy. For this reason, some national and international programs are taken into account, such as promotion of energy transition, increase of energy efficiency in terms of conservation, promotion of renewable energy technologies, and promotion of sustainable transport systems.

Energy consumption is intimately bound up with the natural environment. The environmental consequences of the growth in world energy demand would indeed be catastrophic, with far-reaching economic consequences. The use of renewable energy sources and alternative fuel substitution can offer a partial solution, but it is believed that the easiest, most effective, and cheapest way is the use of energy conservation technologies.

The optimal development and management of an integrated energy system is a complex, dynamic, and multifaceted problem depending not only on available technology but also on economic and social factors. Experimentation with an actually existing energy system may be costly and time consuming or totally unrealistic. By substituting energy system by computer models, one can conduct a series of experiments. The computer models clearly are of great value to understand the dynamics of the complex systems and the systems approach is the most appropriate technique to handle such problems.

Self-reliant development of a country/region should consider not only population control measures and increased production policies but also the need to take into account the planned and integrated use of energy for improving quality of life and self-sufficiency in energy. A rational approach striving for the self-reliance in food and energy should consider an integrated approach to the food production through a sagacious use of the available amount of energy. This is the background for energy planners where the computer models have great potential to help understanding in better decision-making processes.

In view of the fact that energy consumption is a major contributor to environmental degradation, decisions regarding energy policy alternatives require comprehensive environmental analysis. To the extent that it is practical, environmental impact data must be developed for all aspects of energy systems and must not be limited to separate components.

Management of energy and environment for sustainable development is a highly complex system containing technological, environmental, and socio-economic components. The problem cannot be solved in isolation; an integrated and systems approach is needed. For clear understanding of this complex system before its implementation, it must be modeled and simulated.

Here, we present a computer model of energy and environment for sustainable development using Bangladesh as an illustrative example for projection of energy demands and emission of greenhouse gases and also report the potentials of Long-range Energy Alternatives Planning (LEAP) with proper data inputs from system dynamics model as a tool for energy planning for sustainable development in Bangladesh.

2 Computer Modeling

Energy planning is required for sustainable development and effective environmental management due to the limitations of fossil fuel resources, the high capital costs of renewable energy development, and various concerns about energy supply and demand. This requirement has motivated a number of studies on the development of energy system models and their applications in the planning of energy activities at different levels. Also, there has been an upsurge of interest among the researchers and planners in the modeling of energy systems since the oil embargo of the mid-1970s. Today, many energy system models are available, which have been developed for the planning of large energy systems on national or regional levels. These models can be classified into two main categories – simulation models and optimization models. The simulation models simulate the dynamics of energy systems, i.e., scenarios for management strategies, while optimization models find the optimum system within constraints of available resources.

Huq [8] initiated energy modeling in Bangladesh. The model proposed by Huq was further developed for integrated rural energy system in Bangladesh using system dynamics approach [9, 10]. Alam et al. [11] developed a system dynamics model for integrated rural energy system. The potentiality of this model was illustrated in the microlevel by using the data of a village in Bangladesh. The system dynamics model for integrated energy system was also applied in agriculture for macrolevel policy analysis [1, 12]. The model prediction has a great relevance with the historical behavior and it is a very useful tool for policy analysis and planning.

Nail [13] reported an integrated model of US energy supply and demand, which is used to prepare projections for energy policy analysis in the US Department of Energy's Office of Policy, Planning and Analysis. This model represents one of the real success stories of system dynamics modeling. This model was implemented at the Department of Energy in 1978 as an in-house analytical tool and has been used regularly for national energy policy analysis since that time. Nail et al. [14] employed the model to explore a wide range of policy options intended to address the effects of energy use on global warming.

Bala [4, 5] and Bala and Khan [6] presented projections of energy supply and demand and assessed the contributions to global warming for both rural and entire Bangladesh. Bala [15] also reported a computer model of energy and environment for Bangladesh for projections of energy supply and demand and assessing its contribution to global warming. The computer model essentially consists of a system dynamics model in combination with LEAP. The output of the system dynamics model is fed into the LEAP model. Bangladesh is responsible for a small fraction of the total anthropogenic contribution of CO_2 but could be seriously affected by climatic change. LEAP in combination with a system dynamics model is more effective than LEAP alone for energy and environmental planning for sustainable development.

Recently, several optimization models have been developed for energy systems planning [16–18]. Li et al. [18] reported a multistage interval-stochastic regional-scale energy model (MIS-REM) developed for supporting electric power system (EPS) planning under uncertainty. The developed MIS-REM is based on a multi-stage interval-stochastic integer linear programming approach. It can deal with uncertainties expressed as probability distributions and interval values existing in energy system planning problems. Moreover, it can facilitate capacity expansion planning for conversion technologies within a multi-period and multi-option context and can reflect effects of economies of scale in capacity expansion costs through the introduction of fixed-charge cost functions. It can also analyze policy scenarios that are associated with economic penalties when regulated targets are violated.

Recently, several system dynamics models also have been reported for energy systems planning [19–21]. Liu et al. [20] reported a system dynamics model for USA that suggests a decline in all of the consumption sectors in the next 20–30 years. The model makes a strong case for renewable forms of energy being developed now. Jager et al. [21] reported a system dynamics model for German electricity market to address the impacts of economic and environmental related constraints on the German electricity spot market. This model is based on a similar model for the Nordic electricity market [22], which was transferred, adapted, and calibrated for German conditions.

Ko et al. [23] adopted the MARKAL-MACRO energy model to evaluate economic impacts and optimal energy deployment for CO_2 emission reduction scenarios and developed a series of carbon dioxide (CO_2) emission abatement scenarios of the power sector in Taiwan. This study includes analyses of life extension of nuclear power plant, the construction of new nuclear power units, commercialized timing of fossil fuel power plants with CO_2 capture and storage (CCS) technology, and two alternative flexible trajectories of CO_2 emission constraints. This study also shows the economic impacts in achieving Taiwan's CO_2 emission mitigation targets and reveals feasible CO_2 emission reduction strategies for the power sector.

Ford [24] provided a short summary of an introductory computer model to simulate the impacts of a cap and dividend approach to carbon policy. The illustrative simulations focus on the impacts of the CLEAR Act in the western USA. The simulations portray the volatility of the carbon market due to variations in the price of natural gas and the design of the price collar.

2.1 Description of Energy and Environment System

A typical energy and environment system often consists of various components such as energy supply/demand, processing and transformation technologies, electricity generation, and emissions to environment. Energy supply options are typically classified as fossil or renewable resources. Fossil resources include coal, crude oil, and natural gas; renewable resources usually include biomass, hydro, solar, geothermal, and wind energy. When the supply of mined resources and renewable resources cannot meet the end-use demands, import becomes necessary. When the productions are greater than domestic demands and exporting is profitable, export becomes possible.

In an energy system, technologies are utilized to deal with supply- and demand-side options. On the supply side, only a small group of energy resources can be used directly; a large number of energy resources need to be converted or processed before it can be utilized by consumers or technologies. Processing technologies are used to transform energy resources into usable forms of energy carriers; for example, crude oil is converted into gasoline, diesel, alcohol, etc. With respect to demand-side technologies, all energy carriers including electricity can be used by end users with various devices. Different technologies have different characteristics regarding energy efficiency, GHG emission, capital investment, and operation/maintenance cost.

Electricity is an important component in an energy system. It can be used not only to satisfy end-use demands but also to drive other technologies. A large amount of electricity is generated from fossil resources such as coal, natural gas, and fuel oil; nuclear power is a popular alternative to provide electricity with large-scale capacity in many energy systems; and electricity generations from renewable sources are encouraged because they are much more sustainable and cleaner in comparisons with fossil resources. Among the options based on renewable resources, hydropower has been developed extensively in the past, and the installations of wind, solar, and biomass power facilities are still at high costs. This leads to limited utilization of renewable resources other than hydro-energy.

2.2 Structure of Energy and Environment System Model

To mathematically express the energy activities within an energy system, LEAP-based system dynamics model is developed to support energy systems planning, policy analysis, and environmental management. The developed model consists of five main components that reflect energy flow and emissions to the environment. Figure 1 shows the basic interactions between energy production and supply including the effects of energy use on global warming. The first component is the set of energy supply options that provides energy sources including mined resources and renewable energy to the system. Three types of mined resources (oil, coal, and natural gas) are included in the model. The second component is the energy demand sector, which is characterized by demography, economy, technology advancement, and environmental conditions. It includes economic activities that consume energy as end uses. This sector is categorized into five subsectors: agricultural, transportation, industrial, residential, and commercial sectors. The third component is the set of supply-side technologies. Three groups of such technologies are considered in this model, i.e., coal, oil, and natural gas mining and/or recovery technologies including various enhanced oil recovery technologies (EOR); electricity conversion technologies that convert fossil, renewable, and nuclear energy into electricity; and processing technologies that transform energy sources into fuels such as gasoline and diesels. The fourth component is the set of demand-side technologies that drive energy consumptions by end users. The fifth component is emission factor. The emission sector computes the energy-related emission of carbon dioxide, methane, and nitrous oxide. Every part of the energy consumption and use produces emissions. The environmental loadings are computed by multiplying environmental loading factor for the fuel from Environmental Data Base (EDB) by the amount of fuel consumed or used.

2.3 Illustrative Model

The system dynamics model in combination with LEAP developed by Bala [15] is considered as an illustrative example. LEAP is a tool that models energy and environmental scenarios and it is used to project demand situations. In LEAP demand sector, each of the major energy consuming sectors – residential, industrial, and transportation – is represented separately and energy demands are compiled

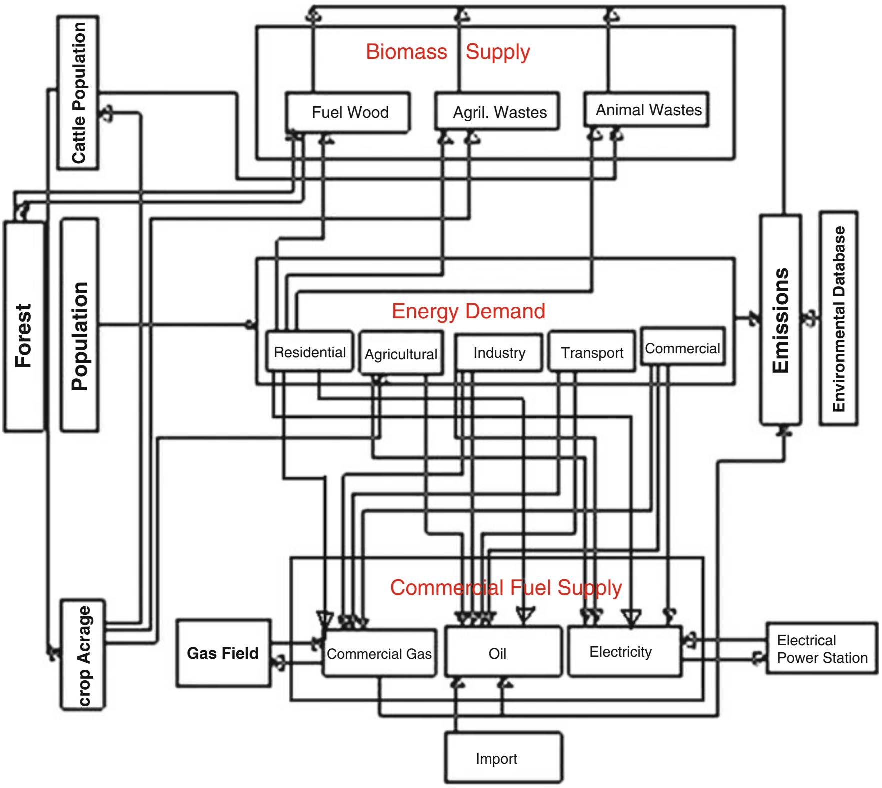

Fig. 1 The interactions between energy production and consumption

using bottom-up approach. The energy demand in each sector is computed using the following relation:

$$E_{st} = \sum_{j} A_{st} \times I_{st} \tag{1}$$

where E_{st} = energy demand, A_{st} = activity, and I_{st} = energy use intensity.

System dynamics model is used to project population, cow dung, and agricultural wastes and these data are fed into the LEAP model [2, 25]. The system dynamics approach emphasizes information feedback and icon-based modeling with a clear portrayal of the "stocks" and "flows." Figure 2 illustrates with a STELLA diagram of a model to simulate the wood growth. The stocks are the state variables in the system. They represent the cumulative effect of the flows that have acted on them. The flows are the action variables that change the position of the stocks. The remaining variables are called constants or auxiliaries. System dynamics models

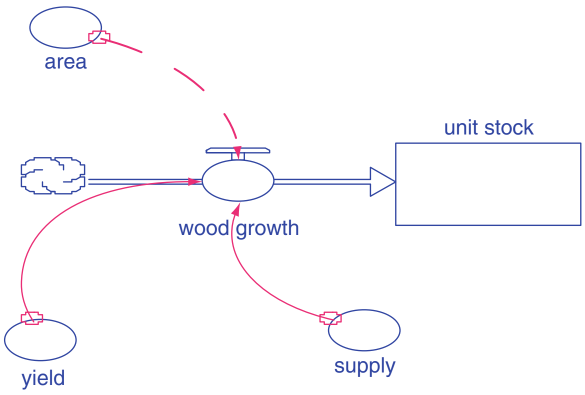

Fig. 2 STELLA diagram of a model to simulate the wood growth

are mathematically equivalent to a coupled set of first-order differential equations, with a separate equation for each stock in the model. The STELLA flow diagram in Fig. 2 represents the computation of wood stock at any time t from wood stock at time $t - 1$ and net growth and it is in the finite difference form:

$$\text{Unit stock } (t) = \text{Unit } (t-1) + \text{Wood growth } (t-1) \times \Delta t. \tag{2}$$

The total growth of wood for the next period is

$$\text{Wood growth } (t) = \frac{\text{Yield } (t) - \text{Supply } (t)}{\text{Area } (t)}. \tag{3}$$

Input data for the base year were collected from secondary sources. Energy demand is projected from activity level and energy intensity, which are based on either interpolation or growth using the software LEAP [2]. A system dynamics model was used to provide the input data on cropped area, crop production, and cattle population to project agricultural wastes and animal wastes [25] and these were used as input to LEAP to project crop and crop wastes, and animal wastes.

3 Simulated Results

3.1 Energy Scenarios

Demands for biomass fuels, natural gas, oil, and electricity in Bangladesh in 1995 were 67.25%, 16.51%, 9.66%, and 3.55%, respectively. Computer projections of energy demand by fuel type are shown in Fig. 3. The major share of energy is from biomass and that of commercial energy from natural gas. Biomass fuels such as

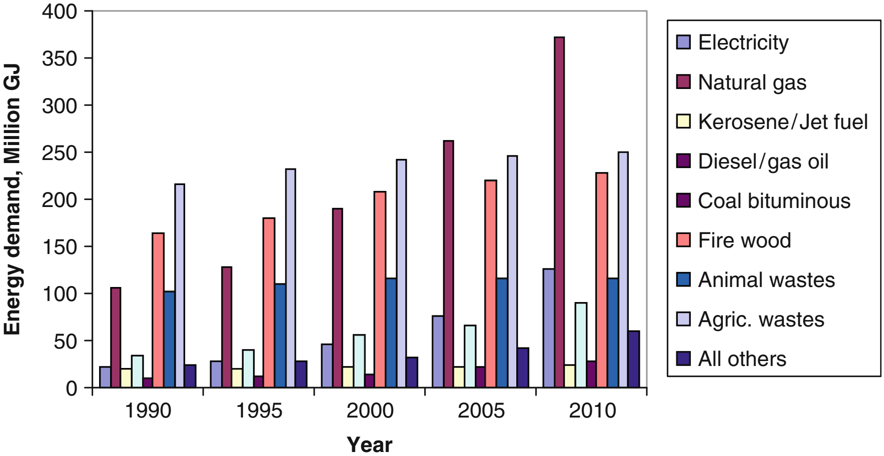

Fig. 3 Energy demand by fuel type in Bangladesh

agricultural wastes and animal wastes are limited resources in Bangladesh and there is a shortage of fuel wood. These resources are used most inefficiently for cooking in rural areas. Thus, conservation of these biomass fuels through end-use efficiency improvement needs immediate attention. Demand for natural gas increases from 105.11×10^6 to 372.09×10^6 GJ during the simulation period. The availability of natural gas at low price in Bangladesh and relative scarcity of other commercial energy resources govern the predominant use of natural gas. Oil is imported to meet the requirements and the demand for the imported oil increases from 34.15×10^6 to 90.10×10^6 GJ during the simulation period. Thus, the deficit increases by more than 2.5 times and this deficit demands immediate attention to conserve energy and reduce emissions through end-use improvement, cogeneration, and adoption of renewable technology such as solar and wind energy.

On the supply side, total demand of natural gas is supplied from local reserves and oil demand is met by importation. It is estimated that Bangladesh's net recoverable reserves of natural gas are in the range of 0.34–0.44 Tcm (trillion cubic meter). Simulated results show that the demands for biomass fuels are increasing with time (Fig. 3). Since cropped land is a limited resource and there is a limited scope for further increase of cattle population, the supply of crop residues and animal waste (dung) is almost constant [25]. Hence, there is a tremendous pressure on rural forests for fuelwood and the fuelwood supplies cannot cope with the demands for energy for cooking. To avoid such crisis, energy conservation through end-use improvement, massive afforestation programs, and introduction of renewable energy are essential. Furthermore, the traditional cooking stoves used in cooking in the rural areas are the most inefficient and the efficiency is less than 10%. Hence, considerable amount of biomass fuels can be saved using improved stoves. This will also improve the working environment of the rural women.

Sector-wise projections of electric power demand in Bangladesh are shown in Fig. 4. The energy demand for residential sector is increasing at a faster rate in

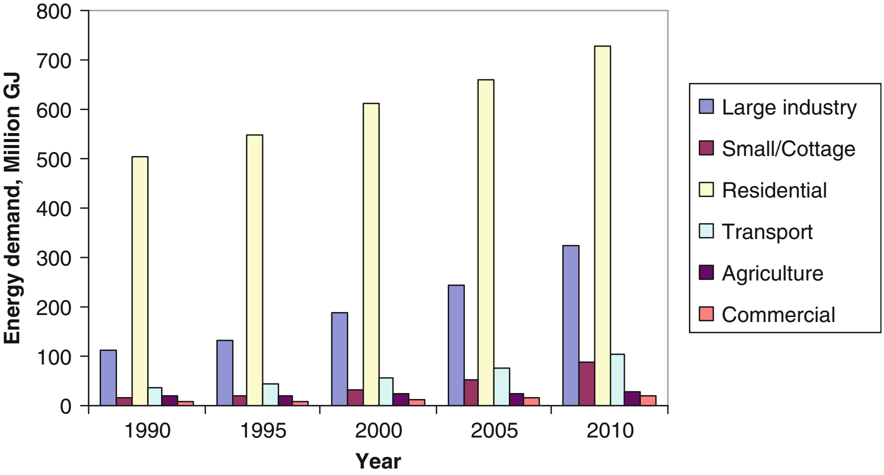

Fig. 4 Energy demand by sector in Bangladesh

comparison to the energy demand for large industry. This is mainly due to higher population growth and relatively poor industrial development. There is a shortage of electricity (1,000–1,200 MW) to meet energy requirements and the system loss is considerably high. Also, only 16% of the households in the rural areas are fortunate to have electrical connection. To cope with this situation gradual transition to renewable energy sources, i.e., central to distributed power systems, needs immediate attention for sustainable development and also reducing system loss and using end-use efficiency improvement devices can save considerable amount of electric energy [26].

The power grid cannot reach everywhere. Yet, there are alternatives and these are mini-grids for supply of energy, information, and communication using renewable energies for rural development and economic growth [27]. Since Bangladesh has an abundance of solar radiation and the total solar energy available in the whole country is estimated to be 691.47×10^3 PJ (Peta Joule), there is a great potential of photovoltaic mini-grids for power generation for rural development and economic growth. Wind energy is another long-term possibility largely in the 724 km long coastal belts of Bangladesh. Hence, solar wind hybrid mini-grid is a promising prospect for electric power generation in the isolated islands of Bangladesh where extension of national electric grid is not economic. Bala and Siddique [28] designed an optimal design of a solar PV-diesel hybrid system for an isolated island using genetic algorithm and this study suggests that the design of the hybrid systems must be optimized for both economy and emission reduction. Furthermore, a successful sustainable development of energy and environment system requires management to be carried out in a participatory approach. An artificial society of energy and environment system actors are to be built using multi-agent system approach for developing scenarios to provide the management strategies to increase the sustainability of the energy and environment system.

3.2 Environmental Effects

Emissions of greenhouse gases for energy consumption in Bangladesh are shown in Table 1. The emissions of these gases are increasing with time. Emissions of carbon dioxide for energy consumption in Bangladesh are shown in Fig. 5. Environmental emissions of nonbiogenic CO_2 increase from 12.19 million tons in 1990 to 36.06 million tons in 2010, while biogenic CO_2 increases from 49.11 million tons in 1990 to

Table 1 Emissions of greenhouse gases for energy consumption in Bangladesh

Air emissions (ton)	1990	1995	2000	2005	2010
Carbon dioxide (10^6)					
Nonbiogenic	12.19	14.88	20.52	26.70	36.06
Biogenic	49.11	52.95	57.33	59.12	60.36
Carbon monoxide (10^3)					
Total	4,139.31	4,465.65	4,826.05	4,957.70	5,036.75
Hydrocarbons (10^3)					
Total	55.80	62.38	73.12	81.71	91.66
Methane	122.53	138.14	183.58	252.67	358.14
Nitrogen oxide (10^3)					
Total	133.79	159.84	220.16	275.42	348.86
Sulfur oxides					
Total (10^3)	67.93	73.24	78.06	79.86	81.46
Sulfur dioxide	3,696.1	4,047.19	4,579.58	4,642.06	4,425.04
Particulates					
Total (10^3)	957.67	1,025.60	1,085.16	1,098.73	1,100.93

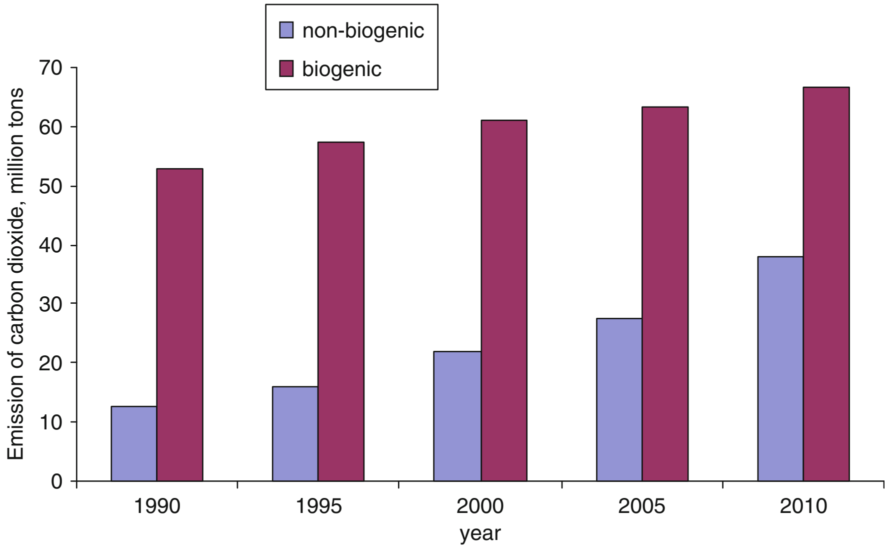

Fig. 5 Emissions of carbon dioxide for energy consumption in Bangladesh

60.36 million tons in 2010. Per capita contribution of CO_2 to global warming of Bangladesh is 0.50 ton/annum, while the world average is 4.0 tons/annum. However, the contribution to global warming is small and Bangladesh is responsible for a small fraction of the total anthropogenic contribution of CO_2 but could seriously be affected by climatic change. However, emissions can be controlled through application of a suitable carbon tax and high tax levels would result in a substantial penetration of renewable energy technologies, for example, solar energy technologies in Bangladesh.

4 Conclusions

Simulated results show that the major share of energy is from biomass and that of commercial fuel is from natural gas. The residential sector has the largest demand for biomass-based fuels for cooking and large industry sector has the largest demand for natural gas.

There is a tremendous pressure on rural forests for fuelwood, and to avoid such crisis, energy conservation through end-use improvement, massive afforestation programs, and introduction of renewable energy are essential.

The traditional cooking stoves used in cooking in the rural areas are most inefficient and the efficiency is less than 10%. Hence, considerable amount of biomass fuels can be saved using improved stoves. This will also improve the working environment of the rural women.

The demand for electrical energy is also increasing with time and there is a shortage of electric power. To cope with this situation, gradual transition to distributed power systems from central power systems needs immediate attention. The performance of the electric power generation and utilization can be improved through reduction of system loss and introduction of end-use efficiency improvement devices.

Power cannot reach everywhere and mini-grids for supply of energy, information, and communication for rural development and economic growth for isolated areas such as islands are advocated.

Bangladesh contributes a very small amount of CO_2 on a per capita basis but could be seriously affected by climate change.

LEAP in combination with a system dynamics model is more effective than LEAP alone for energy and environmental planning for sustainable development.

5 Policy Implications

- To provide energy for sustainable growth.
- To meet energy needs of the different parts of a country/region.
- Better utilization of gas and coal with gradual transition into the renewable technologies, i.e., from central power systems to distributed power systems.

- Electricity sector seems best suited to make of solar, wind, biomass and nuclear.
- To ensure optimum use of renewable energy resources.
- To ensure environmentally sound sustainable programs.
- Energy security requires the reduction of fossil fuels either through improved efficiency measures or through substitution through non-fossil fuels.
- To ensure public and private participation since community participation is one of the prerequisite for sustainable development.
- Finally a national policy on sustainable development should be supported at administrative level.

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Sustainable Development Indicators for Energy in Pakistan

Abdul Khalique Ansari and Imran Nazir Unar

Abstract The strong challenges of sustainable development are as diversified and complex as the human societies and natural ecosystems around the world. Sustainable development requires the participation of diverse stack holders, with the idea of reconciling different and sometimes opposing values and goals toward a coordination of mutual action to achieve required goals. Energy sector issues and developments continued to severely constrain Pakistan's economy in 2009–2010. Against a backdrop of a sharp increase in the international price of oil through the calendar year 2009, which put enormous upward pressure on the cost structure in the power generation (and transport) sector, in particular, large domestic supply shortages of electricity and gas occurred. Lower accumulation of water reserves in dams compounded the severity. The cumulative effect of the energy crisis on the economy is estimated at upward of 2% of gross domestic product (GDP) during 2009–2010 alone.

Brundtland Commission and others provide the background for the approach we have chosen to structure the indicators. Sustainability indicators are generally designed to illustrate the economic, environmental, and social dimensions of sustainable development.

Policymakers need methods for measuring and assessing the current and future effects of energy use on human health, human society, air, soil, and water. Energy indicators for sustainable development: guidelines and methodologies, IAEA (Energy indicators for sustainable development: guidelines and methodologies, Vienna, 2005) are focused here. Some guidelines are recommended for the sustainable development of energy in Pakistan.

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1 Introduction

Pakistan is currently facing biggest energy challenges not encountered before in its history. This crisis is translating into poverty and unemployment as major manifestation on economic side, and occasional blackouts due to load shedding of electricity and gas on the energy side. Moreover, due to the disturbance in the national energy balance, the national industry is suffering badly. Some units have closed and many others have suffered high losses in industrial production.

It sounds imperative to start from the first principles to know the causes of energy crises. After the causes are identified, next in sequence fall the effects. Sustainable energy is a form of energy, which is considered sustainable, meaning that the usage of such energy can potentially be kept up well into the future without causing harmful effects for future generation. A number of types of energy can be thought of as sustainable, and many governments promote the use of sustainable energy and the development of new types of energy generating technology, which fit within this model. In this regard, the sustainable development indicators are necessary to use so that all integral themes of sustainable development, such as social, economic, and environment, are properly focused.

2 Historical Development of Energy Sector

The development in the energy sector of Pakistan has been reviewed by different experts in different eras of history of Pakistan. The development from 1947 to 1994 can be seen on the Website of Ita Translators [1]. In this period, the energy economy is said to have made considerable progress and exhibit a transformation from a wood-burning base to the use of modern energy resources. This transformation is not yet complete. The experts referred above say that bagasse, which is the residue left after extraction of sugar juice from sugarcane, dried animal dung, and firewood covered about 32% of total national energy resource demand in the financial year 1988 and were the sole suppliers of energy to the households with some exceptions where there was a shift to natural gas and kerosene oil. There was an increase in this shifting in 1990 as graph of above resources fell to 23%. The commercial energy demand was mostly met from the domestic energy resources such as natural gas, oil, hydroelectric power, and imported oil and oil products.

Crude oil production increased sharply in 1980s, from almost 4.0 million barrels in FY 1982 to 22.4 million barrels in FY 1992. This increase was the result of the discovery and development of new oil fields. Despite this expanded production, however, about 28 million barrels of crude oil were imported annually in the early

1990s. The production from domestic oil refineries also rose in 1980s, reaching 42 million barrels annually in the early 1990s. However, oil products accounted for about 30% of the value of all oil imports. Pakistan did very well in oil exploration in the 1980s and the early 1990s and was able to make a number of new discoveries particularly in southern Sindh. The drilling of oil from new fields translated into an increase of total output over the years. The current production of oil from domestic sources as reported by Ministry of Finance is 67 million barrels [2].

The coal reserves were there, but unfortunately the pace of energy extraction from these reserves has been very poor due to the constraints such as low calorific value of coal and a high ash and sulfur content. The reserves were boosted substantially in May 1992 due to discovery of a large coal mine in Thar, Sindh. The major reason is that the bulk production is accomplished from small privately owned mines whose owners generally lack funds, expertise, and interest in increasing output, while only about 20% of output is being accomplished by Pakistan Mineral Development Corporation (PMDC: a public sector corporation). The total reserves were estimated as 185 billion m ton, which include 175 billion m ton of Thar coal.

The major component has been thermal which is oil based and thus not environment friendly. In spite of this risk, there are many other problems that translate into big losses. The major problem in the first instance is that of line losses. To it intensely adds the problem of illegal connections and theft of electricity. In 1993, World Bank reported that 28% of electricity generated in Pakistan was lost due to illegal transmission and distribution. The involvement of WB and IMF led to an increase in the prices of electricity beyond even the paying capacity of the common man.

Mirza et al. [3] discussed the past, the present, and the future of wind energy use in Pakistan and concluded that Pakistan needs to develop its indigenous energy resources such as hydropower, solar, and wind and to effectively make use of this cheap renewable energy source. They reported that more than 1,000 km long coastline in south and some places in northern mountainous areas provide an excellent resource of wind energy. This vast potential can be exploited to produce electricity on both community and farm scales. Applications other than electricity production, such as water pumping, also have prospects.

3 Energy Scenario

The future forecast of electricity is depicted in Fig. 1. Pakistan is among the countries that are to face big energy challenges in near future. It is not only in Pakistan, but world as a whole is going to face big energy crises as there is the likelihood that world energy demand may double in next 20 years. The changing trend of world energy consumption mix is exhibited in Fig. 2.

After a number of reviews of energy situation in Pakistan by various experts, e.g., 2007, there is a consensus on the point that the most appropriate strategy to

Fig. 1 Available capacity and computed demand of electricity in mW/h. Source: The Pakistan Economic Survey [2]

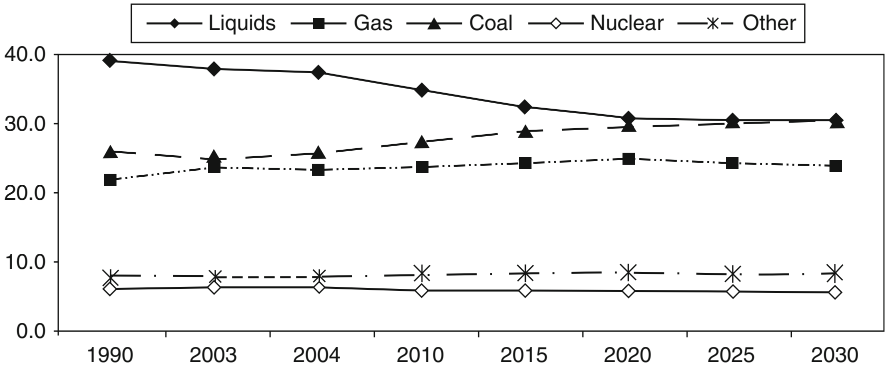

Fig. 2 World total energy consumption, high oil prices (%age share). Source: The Pakistan Economic Survey [2]

meet future energy demand is exploitation of existing hydropotential and exploring renewable sources of energy: wind, solar, tidal, geothermal, biomass, etc. These are equipped with a huge power generation potential and are also environment friendly. These resources have been successfully used for power generation in different countries and some experts even believe that the only solution to the electricity crisis in Pakistan may be the domestic power generation through solar or wind–solar hybrid systems.

It has been reported that the total solar energy available to earth is approximately 3,850 zeta joules (ZJ) per year, while the worldwide energy consumption was 0.471 ZJ in 2004, which is a very minute fraction of total energy supplied by the sun. Similarly, by the end of 2007, the worldwide capacity for generation of power from wind was 94.1 giga watts (GW), while at present it is producing just over 1% of worldwide electricity use from this source. This accounts for 19% of electricity production in Denmark, 9% in Spain and Portugal, and 6% in Germany and the Republic of Ireland, approximately (2007). The government should invest substantial amount for wind and solar energy.

Tidal power is yet to be widely utilized in the world, yet it is equipped with the potential for generation of electricity in future. Pakistan is gifted with over 700 km of tidal coastline, which offers a partial solution to the power crisis. Similarly, geothermal energy is also an important consideration. In 2007, geothermal power supply component was less than 1% of the world's energy supply. That is not all. There are other sources that are worth highlighting here as these are gaining tremendous importance in other parts of the world. These include biofuels, biomass, and wave power, which can be better exploited in context of supply of electricity to remote areas of Pakistan and even for industry and agriculture. It is pathetic to note that large amount of municipal, industrial, and hospital solid waste produced daily in Pakistan is burnt either on the road side or in incinerators without thinking that it is the national wealth that is being set to fire without harnessing energy along with the production of secondary air pollutants responsible for causing not only social damage in terms of health and disease but also to ozone layer and causing global warming. It may not be out of place to narrate that City of Lahore only is producing around 5,700 m ton solid waste per day. If other big cities such as Karachi, Multan, Peshawar, and Faisalabad are brought to focus, the total tonnage of solid waste can be well imagined. To it add agricultural solid waste and imagine the figure. It causes a lot of damage to the public health if transported to the dump sites called landfills. This waste can be utilized as a source of thermoelectric power using thermal electricity generation technology [4–5]. The production of thermoelectric power from solid wastes has been successfully studied by some educational institutions of Lahore and MUET Jamshoro [6–8].

Future development should be planned according to Agenda 21, which can be considered as a sacred document provided it is obligatory to both East and West in spirit and practice. Advisors from the West giving sermons to the East for cutting down use of fossil fuels while not initiating this process at home should be discouraged to nip the evil in the bud. Speaking realistically the best concept given by Agenda 21 is that of "Sustainable Development." The essence of this concept is that all the existing resources should be used most economically and their wastage should be avoided to the extent it is humanly possible and every waste is in no more a waste as it can be assigned an economic value.

4 Energy Resources and Supply

Primary energy supply and per capita availability of energy witnessed a decline of 0.64% and 3.09%, respectively, during July–March 2009–2010 over the same period last year (see Table 1). This decrease in the primary energy supply and per capita availability during the first 9 months of the current fiscal year is higher than its decrease in the full year of 2008–2009 when primary energy supply and per capita availability narrowed down by 0.58% and 2.27%, respectively. The decrease in energy supply during current period can be attributed to intercorporate circular debt problem.

Table 1 Primary energy supply and per capita availability

	Energy supply		Per capita	
Year	Million (TOE)	Change (%)	Availability (TOE)	Change (%)
1998–1999	41.72		0.31	
1999–2000	43.19	3.51	0.32	1.28
2000–2001	44.40	2.82	0.32	0.63
2001–2002	45.07	1.50	0.32	−1.25
2002–2003	47.06	4.41	0.32	2.86
2003–2004	50.85	8.06	0.34	5.25
2004–2005	55.58	9.26	0.36	6.45
2005–2006	58.06	4.18	0.37	2.48
2006–2007	60.62	4.33	0.38	2.61
2007–2008	62.92	3.78	0.39	2.86
2008–2009	62.55	−0.58	0.38	−2.27
July–Mar				
2008–2009	47.1		0.29	
2009–2010E	46.8	−0.64	0.28	−3.09

Source: Hydrocarbon Development Institute of Pakistan*TOE* tons of oil equivalent, *E* estimated

5 Component Wise Performance of Energy

5.1 Petroleum Product

The petroleum product energy supplies during July–March 2009–2010 increased to 16.3 million tons from 14.2 million tonnes in the same period last year, thereby witnessing the 14.6% growth during the period. Due to increased petroleum product energy supplied, the overall consumption of petroleum products exhibits an increase of 8.1% during July–March 2009–2010 against the same period last year.

5.2 Natural Gas

The supply of gas has exhibited an increase of 1.6% during July–March 2009–2010. The increase in supply owes to higher production of 1.6% in natural gas during the period under review. Due to this increase in availability of natural gas, the overall consumption of gas remained higher during the period. Furthermore, the sector wise consumption of gas suggests that the household, commercial, fertilizer, and transport sector witnessed positive growth in consumption of gas during 2008–2009.

5.3 Electricity

For reasons discussed earlier, the overall electricity consumption has followed a declining trend since 2008–2009, as overall electricity consumption in the country has witnessed a negative growth of 1.7% during July–March 2009–2010 over the same period last year.

5.4 Coal

Pakistan has coal resources estimated at over 185 billion tons, including 175 billion tons identified at Thar coalfields in Sindh province. Pakistan's coal generally ranks from lignite to subbituminous. After witnessing a decline of 17.0% in 2008–2009, the total production of coal has increased by 10.0% during July–March 2009–2010 over the corresponding period last year. This improvement owes to increased import of coal during the period as indigenous production of coal witnessed a decline 6.5% during the period under review.

6 Current Energy Development Projects in Pakistan

The Oil and Gas Development Company Ltd. (OGDCL) discovered four large oil and natural gas reserves in Sindh and Balochistan and was planning to install gas processing and LPG recovery facilities about 8 years back. The contract award for the construction of these facilities is under litigation in the Supreme Court leaving the country with a massive shortage. The Pakistan's current hydrocarbon production is about 3,100 MMSCFD natural gas, 61,000 BPD crude oil, and 1,400 TPD of LPG. The Hydrogen Development Institutes reports that Pakistan energy demand would reach over 360 million tons of oil equivalent in 2030, which is six times the present needs. In recent years, some following initiatives have been taken by the Government of Pakistan:

1. New Park Energy Ltd. (NPEL) in Thatta district of Sindh has launched the first wind energy project. It will produce 45 MW as first step toward becoming the 100 MW pilot project.
2. Asian Development Bank (ADB) has approved $5.3 billion for 60 ongoing development projects for Pakistan, which included a financing of $2.166 billion for energy projects. The ongoing loans included $510 million for renewable energy, $800 million for power transmission, and $810 million for power distribution enhancement.
3. ADB has recently concluded technical assistance program for the development of Thar coalfields and provision of technical support to office of energy advisor to Prime Minister. In addition, ADB is also investing in private sector energy projects including Fauji Kabirwala, Dharki Power, New Bong Hydro, Rajdhani, Winpower, and LNG projects.
4. Pakistan and Germany have recently signed two agreements for producing solar and wind energy, and work will be started before the end of the year on these projects.
5. Almost 12 solar energy panels of 3,600 W have electrified remotely located villages of Ziarat district of Balochistan. International Union for Conservation of

Table 2 Some approved energy projects of Pakistan

Name of project	PSDP year	Province	Cost (Rs. in millions)
132 KV substation Deep Sea Port Gwadar	PSDP 2009–2010	Balochistan	235
132 KV substation Down Town Gwadar	PSDP 2009–2010	Balochistan	312
132 KV substation Sangar Housing Scheme Gwadar	PSDP 2009–2010	Balochistan	371
132 KV substation Sangar Housing Scheme Gwadar	PSDP 2009–2010	Balochistan	371
220 KV D/C T/L from Chashma to Ludewala for interconnection of Chashnupp-2	PSDP 2009–2010	Punjab	2,057
220 KV DC TL Chashma to Ludewala for interconnection of Chashnupp-2	PSDP 2009–2010	Punjab	2,057
220 KV Grid Station at Kassowal	PSDP 2009–2010	Punjab	2,067
220 KV Grid Station at Kassowal	PSDP 2009–2010	All provinces	2,067
220 KV Rohri substation and associated transmission lines for dispersal of power from IPPs of Fauji Foundation and Engro near Daharki	PSDP 2009–2010	Punjab	4,847
220 KV D/C T/L Chashma to Ludewala for interconnection Chashnupp-2	PSDP 2009–2010	Punjab	2,057
220 KV Grid substation at Ghazi Road Lahore	PSDP 2009–2010	Punjab	2,591.62
220 KV Rohri substation and associated transmission lines for dispersal of power from IPPs of Fauji Foundation and Engro near Daharki	PSDP 2009–2010	Punjab	4,847
220 KV TL Chashma-Ludewala Chashnupp-2	PSDP 2009–2010	Punjab	2,057
26 MW Hydropower Project at Shagarthan, Skardu	PSDP 2009–2010	AJK	5,281.982
450–500 MW combined cycle power plant at Chichoki Mallin	PSDP 2009–2010	Punjab	18,050
Balochistan effluent disposal into RBOD (RBOD-III) infrastructure development	PSDP 2009–2010	Balochistan	6,535.97

Source: Official website of planning commission of Pakistan

Nature (IUCN) and Pakistan Council for Renewable Energy Technologies (PCRET) have collaboratively installed the solar energy panel systems which have also electrified six schools and six mosques in selected villages.

Table 2 shows some current energy projects approved by planning commission of Pakistan.

7 Energy Indicators for Sustainable Development

The indicators in the energy indicators for sustainable development (EISD) core set are discussed in this chapter according to dimensions, themes, and subthemes following the same conceptual framework used by the United Nations Commission on Sustainable Development (CSD). Table 3 lists the indicators that make up the EISD core set. There are 30 indicators, classified into three dimensions (social, economic, and environmental). These are further classified into 7 themes and 19 subthemes. Note that some indicators can be classified in more than one dimension, theme or subtheme, given the numerous interlinkages among these categories. Also, each indicator might represent a group of related indicators needed to assess a particular issue.

8 The Indicators as a Measure of Progress

Some of these indicators are unequivocal measures of progress; they clearly distinguish between desirable and undesirable trends. Most of the social and environmental indicators fall into this category, including such indicators as SOC4 (accident fatalities), ENV3 (air pollutant emissions from energy systems), and ENV6 (rate of deforestation attributed to energy use). However, some of these indicators also must be taken in context; for example, depending on the development choices made, there may be a temporary rise in undesirable effects until a higher level of development is achieved, representing a larger benefit that could outweigh the interim disadvantages. Another example is when the availability of commercial fuels – for example, kerosene – in developing countries increases the share of a household's income spent on energy (SOC2). This may not indicate a negative development from a social perspective, since the collection of noncommercial fuelwood often involves significant losses of productive time and the burning of the wood often has important health consequences.

Other indicators are not designed to distinguish between "good" and "bad," but rather describe and give an indication of an aspect of energy use. Most of the economic indicators fall into this category. They include ECO1 (energy use per capita) and ECO3 (efficiency of energy conversion and distribution). Energy use per capita might be low in a given country because that country is very poor or because there is high energy efficiency and the economy is based on services rather than on heavy industry. The ratio of final to primary energy might be high because the country has a rudimentary energy system where primary and final energy are the same, or it might be high because the country has an advanced economy and efficient energy transformation.

The indicators need to be read in the context of each country's economy and energy resources. An economy that is dominated by primary extraction and

Table 3 List of EISD

Theme	Subtheme	Energy indicator		Components
		Social		
	Accessibility	SOC1	Share of households (or population) without electricity or commercial energy, or heavily dependent on noncommercial energy	• Households (or population) without electricity or commercial energy, or heavily dependent on noncommercial energy • Total number of households or population
	Affordability	SOC2	Share of household income spent on fuel and electricity	• Household income spent on fuel and electricity • Household income (total and poorest 20% of population)
Equity	Disparities	SOC3	Household energy use for each income group and corresponding fuel mix	• Energy use per household for each income group (quintiles) • Household income for each income group (quintiles) • Corresponding fuel mix for each income group (quintiles)
Health	Safety	SOC4	Accident fatalities per energy produced by fuel chain	• Annual fatalities by fuel chain • Annual energy production
		Economic		
	Overall use	ECO1	Energy use per capita	• Energy use (total primary energy supply, total final consumption, and electricity use) • Total population
	Overall productivity	ECO2	Energy use per unit of GDP	• Energy use (total primary energy supply, total final consumption, and electricity use) • GDP
	Supply efficiency	ECO3	Efficiency of energy conversion and distribution	• Losses in transmission systems including losses in electricity generation, transmission, and distribution
		ECO4	Reserves-to-production ratio	• Proven recoverable reserves • Total energy production
	Production	ECO5	Reserves-to-production ratio	• Total estimated resources • Total energy production
		ECO6	Industrial energy intensities	• Energy use in industrial sector and by manufacturing branch • Corresponding value added
		ECO7	Agricultural energy intensities	• Energy use in agricultural sector • Corresponding value added
		ECO8	Service/commercial energy intensities	• Energy use in service/ commercial sector • Corresponding value added
Use and production patterns	End use	ECO9	Household energy intensities	• Energy use in households and by key end use • Number of households, floor area, persons per household, appliance ownership

(continued)

Table 3 (continued)

Theme	Subtheme	Energy indicator		Components
		ECO10	Transport energy intensities	• Energy use in passenger travel and freight sectors and by mode • Passenger-km travel and tone-km freight and by mode
		ECO11	Fuel shares in energy and electricity	• Primary energy supply and final consumption, electricity generation, and generating capacity by fuel type • Total primary energy supply, total final consumption, total electricity generation, and total generating capacity
		ECO12	Noncarbon energy share in energy and electricity	• Primary supply, electricity generation, and generating capacity by noncarbon energy • Total primary energy supply, total electricity generating, and total generating capacity
		ECO13	Renewable energy share in energy and electricity	• Primary energy supply, final consumption, and electricity generation and generating capacity by renewable energy • Total primary energy supply, total final consumption, total electricity generation, and total generating capacity
	Prices	ECO14	End-use energy prices by fuel and by sector	• Energy prices (with and without tax/subsidy)
Security	Imports	ECO15	End-use energy prices by fuel and by sector	• Energy imports • Total primary energy supply
	Strategic fuel stocks	ECO16	Stocks of critical fuels per corresponding fuel consumption	• Stocks of critical fuel (e.g., oil and gas) • Critical fuel consumption
Environmental				
	Climate change	ENV1	GHG emissions from energy production and use per capita and per unit of GDP	• GHG emissions from energy production and use • Population and GDP
		ENV2	Ambient concentrations of air pollutants in urban areas	• Concentrations of pollutants in air
Atmosphere	Air quality	ENV3	Air pollutant emissions from energy systems	• Air pollutant emissions
Water	Water quality	ENV4	Contaminant discharges in liquid effluents from energy systems including oil discharges	• Contaminant discharges in liquid effluents
	Solid quality	ENV5	Soil area where acidification exceeds critical load	• Affected soil area • Critical load
Land	Forest	ENV6	Rate of deforestation attributed to energy use	• Forest area at two different times • Biomass utilization

(continued)

Table 3 (continued)

Theme	Subtheme	Energy indicator		Components
		ENV7	Ratio of solid waste generation to units of energy produced	• Amount of solid waste • Energy produced
		ENV8	Ratio of solid waste properly disposed of to total generated solid waste	• Amount of solid waste property disposed-off • Total amount of solid waste
	Solid waste generation and management	ENV9	Ratio of solid radioactive waste units of energy production	• Amount of radioactive (cumulative for a selected period of time) • Energy produced
		ENV10	Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste	• Amount of radioactive waste awaiting disposal • Total volume of radioactive waste

Source: Energy indicators for sustainable development: guidelines and methodologies. International Atomic Energy Agency, Vienna [9]

processing will have relatively high energy use per unit of GDP no matter how efficient it is. This does not mean that the country should abandon development of its resource base.

Structural changes to the economy must also be taken into account. For example, building a large modern aluminum smelter in a country that previously relied on subsistence farming and foreign aid would result in a large increase in the ECO6 indicator (industrial energy intensities), but would also generate export revenues and hence improve income levels.

When environmental issues are discussed, efficiency is expressed in terms of lower emissions or less used of natural resources or energy in the production of certain goods or services. Measurements of efficiency in social developments often make indirect use of economic terms, for example, number of employees per person in elder care. Such measures, however, pose problems of interpretation because the qualitative consequences are difficult to measure. Nevertheless, increasing efficiency will be necessary in order to meet many of the challenges of sustainable development, including prosperity and well-functioning ecosystems. Efforts are being made to increase efficiency in economic, environmental, and social terms. Profits in terms of saved resources can be used according to political or personal preferences. We can now produce more goods and services with less input of energy and labor. The increase in production has resulted in more waste, while we are, however, able to better manage. There has been an increase in the share of students who are not qualified for upper secondary school. It is still too early to determine the welfare effects of rationalization programs in the public sector. Some of the budget cuts might have resulted in increased efficiency, while others might have had the opposite effect. Efficiency and positive economic development are important, but probably not sufficient conditions for obtaining sustainable development. An equal distribution of prosperity enables a broader-based contribution and can also influence the development of both the economy and the environment.

A society characterized by involvement and concern can boost its potential for productive, efficient, and environmentally responsible action. Equality in terms of decreasing injustice – between rich and poor, men and women, ethnic groups, age groups, or people living in different regions – is also an important aspect of the idea of sustainable development. The contributions from all sections of the population are important because many of the changes that need to be made affect people's everyday lives and because broad understanding and responsibility are keys to changing consumption patterns and behavior. The economic recession in the early 1990s and a growing market orientation in Sweden have led to negative development in some of the traditional welfare indicators. However, in Sweden there is great involvement in the ongoing local development among NGOs, enterprises, municipalities, and consumers. This has also led to an increase in the number of environmentally certified enterprises and in the sale of ecolabelled products. The increase in trade has resulted in increased transport. The share of those means of transport that have a negative effect on the environment has increased. Society as a whole has the potential to develop and adapt new technologies and to make adjustments in how things are done in response to new conditions. Individuals, enterprises, and organizations in particular have a vast potential in this area and have vital roles to play in maintaining sustainability in the economic, ecological, and social fields [10].

9 Conclusions

In Pakistan, the energy projects have not been sustainable as all stakeholders were not taken into confidence. When choosing energy fuels and associated technologies for the production, delivery, and use of energy services in developing countries, it is essential to take into account, social, economic, and environmental consequences.

In poor countries like Pakistan, up to 6 h a day is required to collect wood and dung for cooking and heating, and this task is usually done by women, who could be otherwise engaged in more productive activities. Addressing energy security is one of the major objectives in the sustainable development criteria of many countries.

There are 30 indicators, classified into three dimensions: social – 4, economic – 16, and environmental – 10 as pointed out by Energy indicators for sustainable development: guidelines and methodologies, IAEA [9].

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Status and Need of Energy Education: The Case of Pakistan

Umar K. Mirza, Khanji Harijan, and Tariq Majeed

Abstract Energy is the basis of a modern standard of living. Conventional energy education has generally failed to provide basic understanding about issues relevant to energy supply, its use, and energy–environment interaction. Renewable energy offers the opportunity to displace fossil fuels and it is likely to have a major role in our future energy supply. The sudden surge of growth which has occurred in renewable energy industry in recent years has caught the educators unprepared. A serious shortage of skilled professionals is already apparent. There are signs that energy studies is rapidly emerging as a new discipline. Many universities around the globe have started offering courses in renewable/sustainable energy. Pakistan suffers from a lack of appropriately qualified energy professionals as visible from its very low productive use of energy per capita and rapidly degrading environment. In 2005, Quaid-e-Awam University of Engineering, Science and Technology became the first institution in the country to offer a full-fledged bachelors degree course in energy studies. Other universities are following suit now. The article gives an overview of the current status of energy education around the globe and in Pakistan. Further, it gives recommendations on how to promote energy education in Pakistan.

Keywords Energy education • Renewable energy • Pakistan

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1 Introduction

Energy is the basis of a modern standard of living. Energy is directly associated with all three aspects of sustainable development – economy, environment, and social welfare. The demand for energy continues to escalate as more and more people in developing nations are getting access to modern-day energy services. Mostly the reliance is on fossil fuels to provide energy for everyday needs. Fossil fuels are likely to be available for coming few decades, yet by all odds they are not a sustainable source of energy.

The efforts to increase power supply to meet the needs of development and a burgeoning human population have begun to cause irreversible damage to the biosphere. The evils of air pollution and ecological damage have surfaced because of burning fossil fuels in motor vehicles, homes, factories, and power stations. Global warming now appears to be underway as a result of the enhanced greenhouse effect, which is partly caused by the extensive use of fossil fuels. As concern about climate change and global warming intensifies, society is demanding greater efficiency in energy production and use. Demand management is a very effective way of reducing greenhouse gas emissions [1, 2].

Concern about environmental problems has risen sharply over the past couple of decades and international action is now underway to address the causes. Fundamental social and technological changes are required to tackle these problems. Conventional energy education has generally failed to provide basic understanding about issues relevant to energy supply, its use, and energy–environment interaction. Most energy professionals have been trained in either the technical or economic aspects of conventional energy conversion and until recently, the technical aspects of energy efficiency and renewable energy technology (RET) have been largely ignored. Very few energy professionals have any formal training in energy policy or the social and ecological aspects of energy production and use [2, 3].

1.1 Renewable Energy Education

Renewable energy offers the opportunity to displace fossil fuels and it is likely to have a major role in our future energy supply. The use of renewable energy is growing rapidly as the technology matures. The growth of the renewable energy industry is dependent on the availability of appropriately trained manpower. The sudden surge of growth which has occurred in the industry in recent years has caught the educators unprepared. A serious shortage of skilled renewable energy professionals is already apparent. Utilities and industry are finding it hard to recruit scientists, engineers, and technicians who are qualified to design, install, repair, and maintain renewable energy systems. Teachers need in-service training to acquaint themselves with renewable energy. In addition, they require relevant courseware to use in schools. The governments need staff with experience in energy management and they are looking for short training courses where their technical staff can acquire these skills. The public also needs up-to-date, independent advice about renewable energy systems. There is currently a high level of public support for renewable energy resources but a lack of detailed knowledge about the options available and their relative costs [1, 3].

Developing countries are turning to renewable energy as a clean, reliable option for their rural electrification programs but they are limited by a shortage of suitably trained engineers, technicians, and policy analysts [1].

Education and training have a key role in the development of the renewable energy industry, although so far not much recognition has been given to these areas by the concerned circles, i.e., industry and the governments. Education can assist the development of the industry in the following ways [1, 3]:

1. Promoting development of renewable energy industry through dissemination of information about RET.
2. Promoting greater public awareness of the technology and building consumer confidence in renewable energy systems by means of exhibitions and demonstrations.
3. Ensuring availability of technical advice and support services essential for the industry.
4. Training of engineers, scientists, and researchers who will continue development of the technology.
5. Training of policy analysts who will be able to create effective policies for the development of industry.

1.2 Environment and Energy Education for Engineers

The course contents of most engineering degree courses in universities worldwide just concentrate on the technical and scientific aspects and almost completely neglect the sustainability issues, whether economic, environmental, or social. Engineering graduates need skills which are not being provided by traditional engineering courses. Prominent among these skills is the ability to practice engineering in an environmentally sustainable manner. Equally important is an appreciation of the socio-political environment [4].

The decisions and activities of engineers are often intimately connected with the choice of energy systems and their far-reaching effects on society and the environment. Yet, energy education is effectively missing from general engineering education. Engineers might get some input regarding energy issues as it relates to their particular specialization but the social, political, and environmental context are rarely touched upon. Whatever related courses are available, they term demand-side issues, like energy conservation and energy efficiency, as nontechnical and therefore not engineering tasks [4].

2 Renewable/Sustainable Energy-Related Degree Courses Offered Worldwide

There are positive signs that the engineering profession and educators have begun to acknowledge engineering's key role in the protection of environment. Several universities around the globe have started offering environmental engineering degrees while many engineering courses now include a compulsory subject on "Environment and Society" [4].

In addition, energy studies is rapidly emerging as a new discipline of relevance to meeting future energy needs within the context of sustainable development [2]. Some of the degree courses offered by the universities worldwide in the areas of renewable/sustainable energy are presented in Table 1.

3 The Case of Pakistan

Pakistan meets 88.6% of its commercial energy needs from fossil fuels [5]. The energy consumption nearly tripled between 1980 and 2001 [6]. In general, the country is notably inefficient in its use of energy. Its energy use per unit of goods or services produced is quite high. High energy wastage, combined with the need to import fossil fuels, results in a very low productive use of energy per capita. The challenge in Pakistan is to create the right incentives to conserve energy, and to develop relatively clean indigenous energy sources, notably hydro-electricity and solar energy [7]. The scope of harnessing wind energy potential in the coastal areas is also immense.

There are a total of 138 universities and degree-awarding institutes in Pakistan in public and private sectors [8]. In 2005, Quaid-e-Awam University of Engineering, Science and Technology (QUEST), Nawabshah, Sindh, became the first institution in the country to establish Department of Energy and Environment Engineering and started offering a Bachelor of Engineering (B.E.) in Energy and Environment [9]. It is a full-fledged four-year undergraduate course designed to provide broad spectrum of technical knowledge through theory classes supported by tutorials, laboratory experiments, and field experience. Department of Energy and Environment Engineering, QUEST, Nawabshah has also started the Master of Engineering program in Energy and Environment.

Hamdard University in Karachi has been offering four-year BS degree program in Environment and Energy Management since last year [10]. University of Engineering and Technology, Lahore, is in the process of initiating B.Sc. Engineering degree program in Energy and Power Engineering at its Kala Shah Kaku campus [11].

Department of Mechanical Engineering of NED University of Engineering and Technology in Karachi offers Masters of Engineering with specialization in Energy Systems [12]. Karachi Institute of Power Engineering has been offering Master of Science degree in Nuclear Power Engineering [13]. University of Engineering and

Table 1 Examples of energy-related degree courses offered worldwide

University/Institution	Courses Offered
Murdoch University, Perth, Australia http://www.eepe.murdoch.edu.au/areas/energy	Bachelor of Science in Sustainable Energy Management Bachelor of Applied Science in Energy Studies Master of Science (Renewable Energy) M.Phil. and Ph.D. Research Degrees in Energy Studies
The Australian National University, Canberra, Australia Center for Sustainable Energy Systems http://cses.anu.edu.au/	Bachelor of Engineering (Sustainable Energy Systems)
The University of New South Wales, Sydney, Australia School of Photovoltaics and Solar Energy Engineering http://www.pv.unsw.edu.au	Bachelor of Engineering in Photovoltaics and Solar Energy Bachelor of Engineering in Renewable Energy Engineering
Royal Institute of Technology, Stockholm, Sweden Department of Energy Technology http://www.kth.se/itm/inst/energiteknik	M.Sc. in Sustainable Energy Engineering
Delft University of Technology, Delft, Netherlands http://www.tudelft.nl/live/pagina.jsp?id=e874db1d-4e15-4236-90a4-79271beefcf5&lang=en	M.Sc. in Sustainable Energy Technology
Aalborg University, Aalborg, DenmarkDepartment of Development and Planning http://www.energyplanning.aau.dk/	M.Sc. in Sustainable Energy Planning and Management
Leeds University, UK http://www.leeds.ac.uk/fuel/msc/mtp/mtp_home.htm	M.Sc. in Combustion and Energy M.Sc. in Combustion and Emissions Control M.Sc. in Environmental Pollution Control
University of Cape Town, South Africa http://www.erc.uct.ac.za/education/masters-1.htm	M.Sc. (Eng.) in Sustainable Energy Engineering
Tribhuvan University, Lalitpur, Nepal Center for Energy Studies, Institute of Engineering http://www.tribhuvan-university.edu.np/faculty/ioe.htm	Master of Science in Renewable Energy Engineering
University of Massachusetts Lowell, USA http://www.uml.edu/college/engineering/Mechanical/energy.html	Master of Science in Engineering – Solar Engineering Option
Oregon Institute of Technology, Portland, USA http://www.oit.edu/portland/programs/renewable-energy-engineering/overview	Bachelor of Science in Renewable Energy Systems
University of Delaware, Newark, USA http://ceep.udel.edu/ceep.html	Master of Energy and Environmental Policy Ph.D. in Energy and Environmental Policy

Technology, Lahore, offers M.Sc. Thermal Power Engineering degree at its main campus [14]. Department of Electrical Engineering, Mehran University of Engineering and Technology (MUET), Jamshoro, offers Masters of Engineering in Power Engineering. This year Department of Mechanical Engineering, MUET, Jamshoro, has started a two-year masters program in Energy Systems Engineering [15].

Balochistan University of Information Technology, Engineering and Management Sciences, in December 2005, announced plans to set up Center of Excellence in Environment and Renewable Energy (CEERE) at BUITEMS Takatu Campus. The proposed mandate of CEERE would include programs and procedures for quality standards control of RET components and systems, and on-job training and capacity building in RET implementation and operations [16].

In May 2007, the Higher Education Commission approved the establishment of Renewable Energy Research and Development Center (RERDC) at University of Engineering and Technology, Taxila. The setting up of RERDC would facilitate effective research activities in the energy sector generally focusing on renewable energy. The project included building infrastructure and provision of appropriate research training and education facilities which would help produce 30 MS and six Ph.D. graduates annually after the completion of the project. The Center would undertake fundamental and applied research and development projects aimed at renewable energy implementation in the long, medium, and short term. It would create and strengthen formal and informal university–industry linkages [17, 18].

Fifteen universities and colleges, mostly in public sector, offer courses in environmental science, environmental engineering, environmental management, environmental design, environmental law, and environmental control [19]. The courses are offered at diploma, bachelors, masters, and doctorate level. A few university departments actively conduct research in the field of renewable energy technologies without offering a degree specifically in energy studies. They include College of Electrical and Mechanical Engineering of National University of Sciences and Technology in Rawalpindi, and Department of Environmental Sciences of COMSATS Institute of Information Technology at Abbottabad.

3.1 Barriers to Energy Education

The major barriers to energy education in Pakistan can be listed as follows:

1. Academics lack expertise in energy issues, particularly on nontechnical issues (e.g., demand management, social and environmental aspects, political perspectives).
2. Big industry (fossil fuel-based) provides traineeships to students and is an attractive source of jobs. The smaller renewable energy industry often does not have the resources to provide significant student placement opportunities.
3. There is an inappropriately high focus on technical content in engineering curriculum at the expense of social, environmental, and management issues.

3.2 Recommendations

By understanding the role of education in the growth of renewable energy, appropriate programs can be developed to address the needs of industry and the community. The renewable energy education program should aim to address the need for renewable energy education at all levels – from primary school to continuing professional development. Outside the formal education system, it should also provide information for the community and help to develop confidence in renewable energy products. It should attempt to reach the widest possible audience using the most cost-effective means. This implies the use of modern educational technology, and cooperation with educational networks and training agencies. Furthermore, the focus on energy education needs to be global and long term [1].

Graduate and undergraduate studies in universities can include internships and placements in renewable energy industry with students working on research and development projects. The graduate/undergraduate level courses in renewable/sustainable energy can be offered in the areas of energy and environment; energy and society; energy management; energy economics; energy policy; renewable energy resources; and renewable energy systems design. Moreover, there is a need to integrate energy education across the curriculum of various undergraduate engineering disciplines. Furthermore, universities/institutions can incorporate energy efficiency and renewable energy ideas in their own campuses as a living example to students [4].

The rapid development of RET has created a demand for specialized short courses and workshops on technical and policy issues. A variety of courses can be offered to the in-service professionals (practicing scientists, engineers, energy managers, and technicians) on topics such as renewable energy applications; passive solar design; grid-connected renewable energy systems and net metering; installation and maintenance of renewable energy systems; site selection for wind farms; and remote area power supply systems. The courses on energy auditing and energy efficient lighting systems can prove useful in building an energy conservation culture.

There is a substantial demand from the community for reliable information about environmental issues and renewable energy. This includes all aspects of energy generation, storage and power conditioning plus energy management and energy-efficient appliances. Alternative Energy Development Board (http://www.aedb.org) can cater to a wide section of this market by providing information on internet and by distributing information about its demonstration projects with the help of government funding and private sponsors. Other educational projects for the community can include conferences and workshops [1].

School education is another major area of demand which is, at present, underserviced. It is essential for the younger generation to learn about energy and environment, and their mutual interactions. Experiments, demonstrations, lesson plans, and teaching aids can be developed for use in schools. There is a need to train the teachers who could then transfer their knowledge to their students.

3.3 Role of Professional Organizations

The Pakistan Engineering Council (PEC) is the accreditation authority for all engineering degree programs in the country. The role and influence of the PEC in the development of energy education is significant. PEC is in need of broadening to include greater input from sustainable energy and energy efficiency industries in their decision making. One provision is ongoing energy education for practicing engineers. PEC should produce and disseminate energy education teaching aids to educators. Furthermore, PEC should help introducing separate full-fledged sustainable energy engineering courses and also integrating energy and environment education across other engineering disciplines, viz. civil, electrical, mechanical, industrial, chemical, etc. The professional organizations, Institution of Engineers Pakistan and Pakistan Engineering Congress, should also acknowledge the role of energy engineering in sustainable development.

4 Conclusion

Energy education emerges as one of the major absences in the existing education system, especially in engineering education which is still not preparing the engineers to deal with nontechnical issues related to energy production and use. Energy professionals, in general, lack formal training and skills needed to undertake work on renewable energy systems and energy management. However, energy studies is rapidly emerging as a new discipline. Many universities worldwide have started offering courses in energy studies and renewable/sustainable energy engineering. Quaid-e-Awam University of Engineering, Science and Technology is the first university in Pakistan to start a full-fledged B.E. course in Energy and Environment. Other universities are following suit now. It is recommended that energy education be included in the current curriculum at every level of education – from primary school to university. Organizing relevant workshops and conferences can play a vital role in increasing public awareness about renewable energy.

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Survival of Textile Sector Through Energy Management and Monitoring

Asad Mahmood

Abstract Intimidating resource limitations, increasing energy prices, and consumer requirements for environment friendly products are some of the issues faced by the industry in Pakistan. People have to set for the ambitious target of attaining Energy Efficiency by reducing energy losses thus reducing the productivity-energy efficiency scarcity of the industry. In Pakistan, the textile industry being an energy intensive segment is open to a higher energy loss rate across various processes resulting in elevated energy cost and losses in productivity which have significant financial impact and making us less competitive. Energy-efficient environmentally sound technologies utilization and implementing cleaner production techniques will help Textile Industry in Pakistan remain competitive worldwide. According to benchmark figures, 10–15% energy-saving potential is envisaged in spinning sector which can be substantiated by the results of energy audits.

Keywords Energy conservation • Energy efficiency • Energy monitoring • Environmental pollution • Spinning mills • Textile industry

1 Importance of Energy Monitoring in Spinning Mills

The ring frame spinning primary purpose is to convert roving of natural and/or man-made fibers into yarn. For this the roving is drafted to its ultimate single thread size where it is then twisted to bind the fibers together and finally packaged on a bobbin. In total, power requirement of spinning mills and the energy consumption of ring department is the major part of requirement. The imported second-hand

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Table 1 Common problems resulting in increased energy consumption

Points	Factors responsible
Energy for driving spindles	Spindle weight, Lubrication, spindle bearing
Spindle tape bending resistance	Tape width or Tape stiffness
Tape surface air friction	The finished Surface
Tension of jockey pulley	Tension load

machinery or new machines which have more number of spindles with more speed thus have a critical impact on energy consumption.

During energy audits trials were carried out for estimation of cost of the power consumption in ring frames. These trials show that the energy consumption depends on weight of traveler, spindle speed, spindle gauge, ring diameter, package diameter, lift, spindle wharves diameter, motor rating, type of spindle tape used, maintenance of ring frames, front roller speed, etc. (Table 1).

Escalating energy costs in recent years has propelled energy cost to the top among the cost parameters in manufacturing. The term UKG depicts the energy units used for spinning 1 kg of yarn and is mostly noted as UKG. So it is vital that information on energy consumed per kg (UKG) of yarn produced should be noted and compared on daily basis. The values of UKG show variance from mills' ring frame to ring frame. From the mills normal UKG values for individual ring frame have to be checked for any divergence [1].

1.1 Typical Spinning Processes and Energy Use

See Fig. 1.

1.2 Vital Factors for Energy Conservation in Spinning

The following section would help the industries to keep into consideration the factors highlighted while doing in-house energy audits.

1. Gas generator sets
   Optimize loading, generate steam/hot water/power and absorption chiller or preheat process or utility feeds use waste heat, regularly clean air filters, maintain the GG set room temperature, proper exhaust is essential, for process needs use jacket and head cooling water, insulate exhaust pipes to reduce GG set room temperatures.
2. Waste heat recovery
   Waste heat could be used for fuel oil heating, outside air heating, etc., use thermal wheels, air-to-air exchangers, heat pipe systems and run-around systems, preheat hot water use chiller waste heat, use heat pumps and

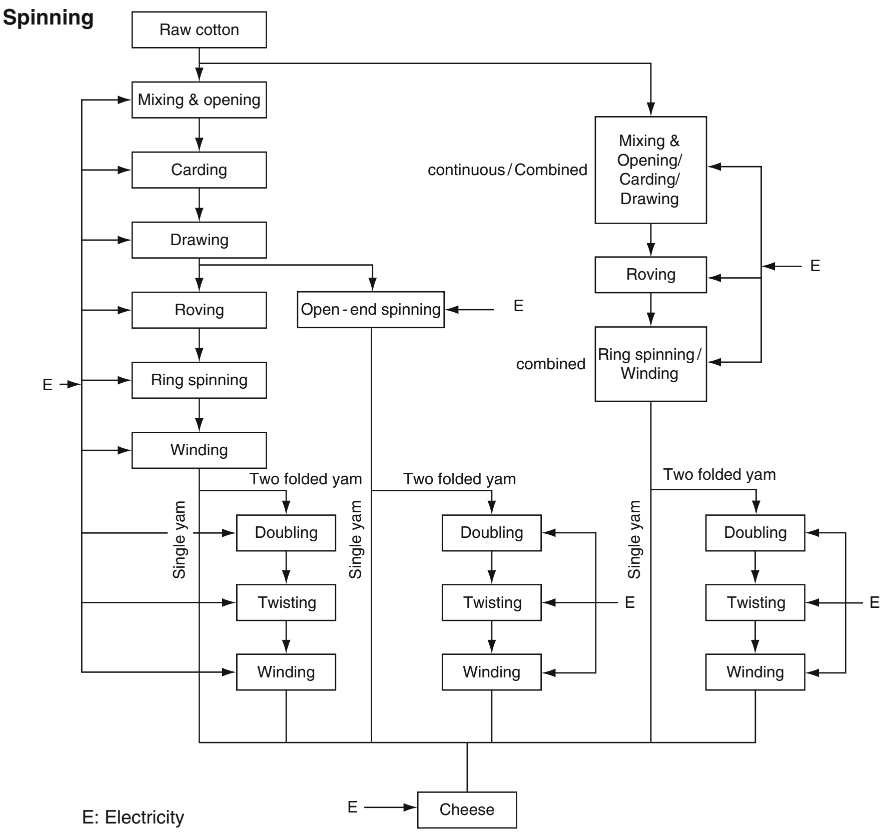

Fig. 1 Spinning flowchart

absorption refrigeration, heat from engine cooling water, flue gas and engine exhaust should be recovered.

3. Electricity distribution system
By using automatic demand controller minimize maximum demand, in case of DISCOs services shift loads to off-peak times if possible, for on-peak high load periods use standby electric generation equipment, to maintain a high load factor schedule your operations, for equipment with large starting currents to minimize load peaking stagger start-up times, under rated load conditions correct power factor to at least 0.95, transformers should be relocated close to main loads, transformer working parameters should be optimized, when not in use shut off unnecessary equipments, transformer taps should be set to optimum settings, proper electric load management system should be considered, on-site electric generation or cogeneration should be considered, if you have any surplus in your captive generation. Export power to grid, utility electric meter should be checked with your own calibrated meter.

4. Motors
   For optimum efficiency properly size to the load, where economical use energy-efficient motors, to improve power factor use synchronous motors, check alignment, provide proper ventilation, check for under-voltage and over-voltage conditions. As per need use Soft-starter and Star-Delta transition, balance the three-phase power supply, after motor rewinding demand efficiency restoration.
5. Fans
   For fan air intakes use smooth, well-rounded air inlet cones, at the fan inlet avoid poor flow distribution, use inverters to serve to eliminate damper positioning, obstructions minimization at fan inlet and outlet, regularly check filters, clean screens and fan blades, leaks in ductwork should be eliminated, to clean the ducts set schedule, usage of aerofoil-shaped fan blades, replacing old Aluminum fan blades with new FRP (Fiber Reinforced Plastic) blades, variable pitch pulleys should be eliminated, low-slip or flat belts usage, regularly check belt tension, for continuous or near-continuous operation use energy-efficient motors, bends in ductwork should be minimized, when not needed turn fans off.
6. Drives
   Eddy current couplings should be eliminated, use high-efficiency gear sets and precision alignment, for large variable loads use variable-speed drives, regularly check belt tension, use flat belts as alternatives to v-belts. eliminate variable-pitch pulleys, use synthetic lubricants for large gearboxes.
7. Blowers
   Use smooth, well-rounded air inlet ducts or cones for air intakes, minimize blower inlet and outlet obstructions, clean screens and filters regularly, minimize blower speed, use low-slip or no-slip belts, check belt tension regularly, eliminate variable pitch pulleys, use energy-efficient motors for continuous or near-continuous operation, eliminate ductwork leaks, turn blowers off when they are not needed.
8. Pumps
   Near best efficiency point Operate pumping system, to minimize flows and reduce pump power requirements balance the system, to eliminate valve control use inverters, add an auto-start for an on-line spare or add a booster pump in the problem area. Running both pumps should be stopped, for small loads requiring higher pressures use booster pumps, to minimize water waste repair seals and packing, to minimize throttling modify pumping, to reduce pumping rates increase fluid temperature differentials.
9. Compressed air
   To determine the most-efficient mode for operating multiple air compressors Study part-load characteristics and cycling costs, Modulation-controlled air compressors load up, to coordinate multiple air compressors install a control system, match the connected load and avoid over sizing. Until the back-up air compressor is needed keep it turned off, to minimize heatless desiccant dryer purging use a control system, use the highest reasonable dryer dew point

settings, when the air compressors are off turn off refrigerated and heated air dryers, to the lowest acceptable setting. Reduce air compressor discharge pressure, to reduce electrical demand charges consider engine-driven or steam-driven air compression, minimize purges, leaks, excessive pressure drops, and condensation accumulation, instead of continuous air bleeds through the drains use drain controls, from the coolest (but not air conditioned) location take air compressor intake air, to heat building makeup air in winter use an air-cooled after cooler, when major production load is off use a small air compressor, across suction and discharge filters clean or replace filters on time upon alarm supervise pressure drops, use a right sized compressed air storage receiver, minimize disposal costs by using lubricant that is fully demisable and an effective oil–water separator, lubricating oil temperature should not be too high (oil degradation and lowered viscosity) and should not be too low (condensation contamination), to power an absorption chiller or preheat process or utility feeds use waste heat from a very large compressor, rather than pneumatic controls consider alternatives to compressed air such as blowers for cooling, hydraulic rather than air cylinders, electric rather than air actuators, and electronic, for cleaning and parts ejection use transvector nozzles for amplifying air flow rather than blowing with open compressed air lines use nozzles or venturi-type devices, on compressed air filter/regulator sets check for leaking drain valves, compressed air efficiency-maintenance program should be launched [2–3].

10. Cooling towers

    Cover hot water basins (to minimize algae growth that contributes to fouling), control to the optimum water temperature as determined from cooling tower and chiller performance data, periodically clean plugged cooling tower water distribution nozzles, use two-speed or variable-speed drives for cooling tower fan control if the fans are few. Stage the cooling tower fans with on–off control if there are many, turn off unnecessary cooling tower fans when loads are reduced, control cooling tower fans based on leaving water temperatures, balance flow to cooling tower hot water basins, optimize cooling tower fan blade angle on a seasonal and/or load basis, install new nozzles to obtain a more-uniform water pattern, replace splash bars with self-extinguishing PVC cellular-film fill, on old counter flow cooling towers, replace old spray-type nozzles with new square-spray ABS practically nonclogging nozzles, replace slat-type drift eliminators with high-efficiency, low-pressure-drop, self-extinguishing, PVC cellular units, if possible, follow manufacturer's recommended clearances around cooling towers and relocate or modify structures, signs, fences, dumpsters, etc., that interfere with air intake or exhaust, correct excessive and/or uneven fan blade tip clearance and poor fan balance, use a velocity pressure recovery fan ring, divert clean air-conditioned building exhaust to the cooling tower during hot weather, reline leaking cooling tower cold water basins. Check water overflow pipes for proper operating level, optimize chemical use, consider side stream water treatment, restrict flows through large loads to design values, shut off loads that are not in service, cooling tower efficiency-maintenance program should be established, start with an energy audit and follow-up, then make a cooling tower efficiency-maintenance program a part of your continuous energy management program, to minimize ice build-up implement a cooling tower winterization plan, to prevent fan operation when there is no water flow install interlocks.

11. Illumination
    Reduce background illumination and use task lighting and aggressively control lighting with clock timers, delay timers, photocells, and/or occupancy sensors, efficient alternatives to incandescent lighting should be installed, mercury vapor lighting, etc. efficiency (lumens/watt) of various technologies range from best to worst approximately as follows: low-pressure sodium, high-pressure sodium, metal halide, fluorescent, mercury vapor, incandescent, up gradation from Obsolete fluorescent systems to Compact fluorescents and electronic ballasts or LED Lights, daylight, skylight savings should be considered, excessive illumination levels reduction to standard levels using switching, delamping, etc. (Know the electrical effects before doing delamping.), select ballasts and lamps carefully with high power factor and long-term efficiency in mind, painting the walls in lighter colors and using less lighting fixtures or lower wattages should be considered exterior lighting strategy, type, and control should be re-evaluated and should be controlled aggressively.
12. Diverse measures
    Meter any unmetered utilities to know what normal efficient use is and to track down causes of deviations, turn off idling, spare or unneeded equipment, all of the utilities to redundant areas are turned off – including utilities like compressed air and cooling water, automatic control should be installed to efficiently coordinate multiple air compressors, chillers, cooling tower cells, boilers, etc., buying utilities from surrounding firms should be considered, particularly to handle peaks, unnecessary flow measurement orifices should be eliminated.

1.3 Vital Factors for Energy Conservation in Processing

Textile processing in general is considered as an art not science by the workers who have learnt this art from their seniors and enhanced it by getting field experience. They carry out textile processing with conventional techniques and hardly adopt best practices or anything different from their natural working style. Due to lack of education and training, they are unable to understand the chemistry behind each process. They cannot understand that these chemical processes are based on certain process parameter such as temperature, concentration and PH. Slight variation in these parameters can result into either excess use of chemicals or deterioration of fabric quality, in most of the cases. In the absence of the feeling of their importance among workers, they consider controlling, monitoring, and reading them in daily log sheets less important.

The following generic norms interpret various consumption parameters *p*/kg of fabric:

1. Water Consumption Norms (per kg)
   (a) World Consumption
       50–100 l/kg of fabric
   (b) National Consumption
       Sindh 50–80 l/kg of fabric
       Punjab 200–300 l/kg of fabric

2. Steam Consumption Norms (per kg)
   6–8 kg of steam/1 kg of fabric
3. Electricity Consumption Norms (per kg)
   0.8–1.5 kWh/1 kg of fabric
4. Natural Gas Consumption Norms (per kg)
   0.35 m^3 gas/kg of fabric

The following section has been prepared to help the processing industries to keep into consideration the factors highlighted while doing in-house energy audits.

1. Boilers optimization
   Add an economizer to preheat boiler feed water using exhaust heat, if permitted burn wastes, on large boiler combustion air fans with variable flows use variable speed drives, clean nozzles, burners, strainers, etc., for proper oil temperature inspect oil heaters, close burner air and/or stack dampers when the burner is off to minimize heat loss up the stack, waste heat should be used to preheat combustion air, use boiler blowdown to help warm the back-up boiler, exposed heated oil tanks should be insulated, deaerator venting should be optimized, inspect door gaskets, study part-load characteristics and cycling costs to determine the most-efficient mode for operating multiple boilers. Optimize boiler water treatment, oxygen trim control should be improved, boiler efficiency-maintenance program should be established, energy audit and follow-up should be started, then make a boiler efficiency-maintenance program a part of your continuous energy management program, steam condensate should be recycled, multiple or modular boiler units should be preferred instead of one or two large boilers [4].
2. Steam system optimization
   To produce lower steam pressures use back pressure steam turbines, boiler blow down should be recovered, condensate leaks and steam leaks should be fixed, lowest acceptable process steam pressures should be maintained, hot water wastage to drain should be reduced, remove or blank off all redundant steam

piping, condensate should be returned or reused in the process, correct control of process temperatures should be ensured, boiler feed-water should be preheated, check operation of steam traps, air from indirect steam using equipment should be removed, steam efficiency-maintenance program should be established, energy audit and follow-up should be started, then make a steam efficiency-maintenance program a part of your continuous energy management program, to optimize the utilization of water the Water management system should be in place, inspect steam traps regularly and repair malfunctioning traps promptly, recovery of vent steam should be considered, use waste steam for water heating, use an absorption chiller to condense exhaust steam before returning the condensate to the boiler, use electric pumps instead of steam ejectors when cost benefits permit.

3. Insulation
   Any hot or cold metal should be insulated, damaged insulation should be repaired, wet insulation should be replaced, for cold wall areas during cold weather or hot wall areas during hot weather use an infrared gun, all insulated surfaces should be cladded with aluminum, all flanges, valves and couplings should be insulated, open tanks should be insulated.
4. Desizing and singeing
   Avoid over speeding during batching of desized rollers, avoid excessive use of desizer in desizing bath, avoid long batching time, otherwise fungus will attack to enzymes, flame angle should be adjust according to the width of the fabric. Do not fix flame length (intensity). Best practice for gas consumption is 0.35 m^3 gas/kg of fabric, try to dip the selvedges of fabric in water before connecting flame, try to switch off one burner in case of shorter width fabric, regular monitoring needed for maintaining pH of desizing bath.
5. Bleaching
   Make sure removal of solid metallic particles in water and fabric, which can result in pin holes in fabric, ensure the temperature of more than 80°C in prewasher, balance the recipe with benchmarking consumption of Caustic and Hydrogen per Oxide, the mechanical squeezing effect through mangles may be maximized to reduce heat/steam load in dryers, regular titration needed against recipe of existing quality of fabric, even in case of automatic dosing system, regular monitoring needed for chemical dozing system, over speeding of machine to be avoided to protect from wear and tear effects, regular monitoring needed for water lock system of bleaching machine, avoid direct steaming on fabric in washing chamber, turbulence effect, condensate dropping effect can damage fabric quality, regular monitoring needed for maintaining the roof temperature otherwise, condensate dropping on fabric will damage quality.
6. Mercerization
   Ensure clean environment near alkali storage tanks, proper setting required for Bome B° concentration for specific qualities of fabric. This will help in saving caustic consumption, avoid low concentrated supply of weak alkalis to CRU, otherwise more steam will be required for evaporating weak solution.

7. Pad steam
   Avoid excessive drain of more water from water lock system of this machine. Try to maintain upto 45–50°C in the tray. This will help to reduce condensation and heat losses, maintain roof temperature for avoiding turbulence and condensation effects of steam on fabric.
8. Thermosol
   Proper dissolving of dyes and auxiliaries needed in mixing dyes, ensure optimized system for Infrared (IR), so that water molecules should dry rather than dye molecules, as per the concept of low energy and high wave length, ensure low temperature for high reactive dyes and high temperature for low reactive dyes [5].

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Forecasting Electricity Demand for Agricultural and Services Sector of Pakistan

Gordhan Valasai, Mohammad Aslam Uqaili, Hafeez ur Rehman Memon, and Khanji Harijan

Abstract Electricity has brought many things that surely have made many wonders and life would seem so hard without it. Electricity powers our light, heating, electronic appliances such as computers and television, pumping water, and a host of essential services that we take for granted.

The demand of electricity in Pakistan is increasing rapidly despite its disrupted supply. Its demand in the Agricultural and Services sectors of the country is dependent on GDP and the past year's electricity demand. Various models have been developed to forecast the demand. Autotendential models have been used for first approximation; then different energy economic models have been used. Finally, statistically significant MDEE model has been used. Durbin–Watson *d*- and *h*-statistic, adjusted R^2 values, and *F*-statistic have been found statistically significant. The Modified Dynamic Energy Economic model used in this study takes Ordinary Least Squares (OLS) technique into account.

This chapter forecasts the electricity demand for the Agricultural and Services sectors, under different scenarios for the period 2007–2030. It results in that the demand will be in the range of 82,000–122,000 GWh in the year 2030.

Keywords Agricultural and Services • Pakistan • Electricity demand

1 Introduction

Pakistan is an agricultural country and ranks fifth in the Muslim world and 20th worldwide in farm output. About 25% of Pakistan's total land area is under cultivation and is watered by one of the largest irrigation systems in the world.

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Notwithstanding its declining share in GDP (Gross Domestic Product), agriculture is still the single largest sector, contributing 21% to GDP and employing 44% of the workforce. More than two thirds of Pakistan's population live in rural areas and their livelihood continues to revolve around agriculture and allied activities. The share of agriculture sector to the GDP has reduced from 25.9 in the year 1999–2000 to 20.9% in the year 2007–2008 [1]. Pakistan's service sector accounts for about 53.2% of GDP, transport, storage, communications, finance, and insurance account for 24% of this sector, and wholesale and retail trade about 30%. The share of services sector to total GDP has increased from 50.7% in the year 1999–2000 to 53.2 in the year 2007–2008 [2, 3].

Electricity consumption plays an important role in economic growth and social progress. Being an easiest form of energy to use, handle, and transport, it has become a key factor to the people's quality of life. In Pakistan, approximately two thirds of the population live in rural areas, most of them have no access to electricity, and per capita supply is about 235 kWh [3, 4].

2 Electricity Sector of Pakistan

The electricity sector in Pakistan is facing many crises these days, such as financial crisis, big gap between supply and demand of electricity, load shedding, technical losses, and electricity theft, which are uncontrollable under current circumstances.

At the time of independence, Pakistan had only 67 MW of installed generation capacity. But due to rapid industrialization, increase in per capita income, and improvement in living standards, installed generation capacity also increased. Currently, the installed generation capacity in the country is 19,786 MW; still we are unable to meet the demand. Figure 1 shows the trend in the installed generation capacity in Pakistan since 1960 [5, 6].

The main sources of electricity generation in Pakistan are hydropower, oil, gas, and nuclear energy. About 34.3% of power generation of country is met by utilizing indigenous gas, whereas oil about 32.1%, hydropower 29.9%, and a small proportion goes to nuclear, 3.4%. The country is blessed with more than 185 billion tonnes of coal; still Pakistan generates only less than 0.1% electricity using coal [4, 7]. In 2007–2008, the fuel oil import bill mounted to US $11 billion. Increase in oil prices and heavy expenditure on import of oil are affecting adversely every sector of the national economy. This situation certainly suggests us to rely on our own available natural sources [8, 9].

The demand of electricity is increasing in every sector of Pakistan. Over past several years, the consumers are facing shortage of electricity, resulting into load shedding (forced power cuts) [10].

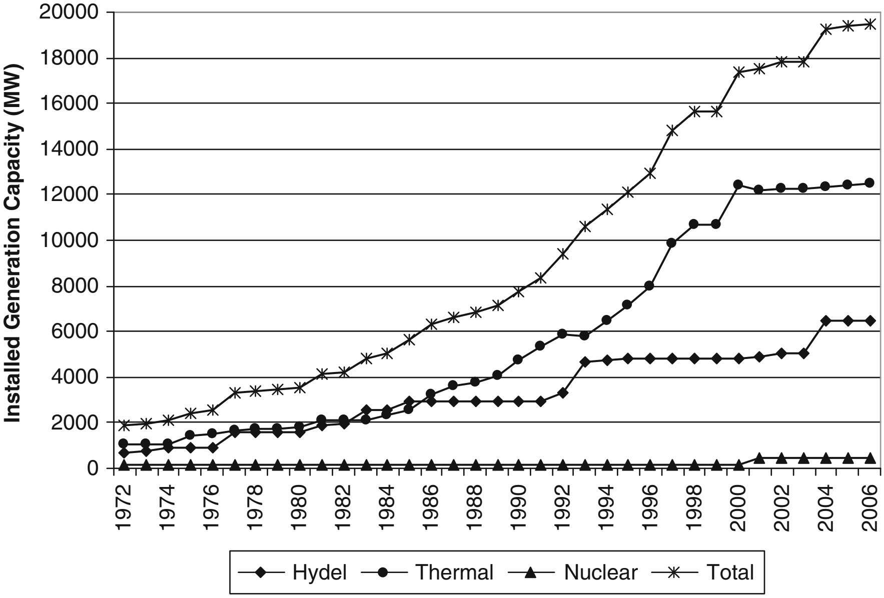

Fig. 1 Trend in installed generation capacity in Pakistan

3 History of Electricity Demand in Agricultural and Services Sector

Agricultural and services sector consumes about 18% of the total electricity consumption in Pakistan [4]. Figure 2 shows the history of electricity consumption in the country. This shows that the demand of electricity has increased rapidly from 1980 onwards and further increased at faster rate after the year 2001 [5, 6].

Agriculture demands great labor but very little skill; electricity minimizes the labor. Using electricity to operate plough, rollers, reapers, threshers, corn-grinders, wood-saws, and pumps will not only improve the performance of agricultural sector but also increase the share of agriculture in country's income. With electric pumps, it is possible to stimulate both density and average pumpage in areas where it is necessary to do so [11].

Electric tubewell is the major consumer of electricity in the agricultural sector of Pakistan. There were about 768,000 tubewells in operation in the year 2004; this number was 268,000 in the year 1990 [11]. This figure has reached to one million in the year 2009 [1]. Figure 3 shows the number of tubewells in Pakistan for the period 1986–2004. Electric tubewells are about 13% of total tubewell population and consuming about 17.8% of electricity produced in Pakistan [11]. The demand of electricity has reduced in the agricultural sector due to the government policies like farmers having to pay initial capital cost of the installation. This initial capital cost includes rest: 25,000 for the transformer and Rs. 10,000 for single pole from main line.

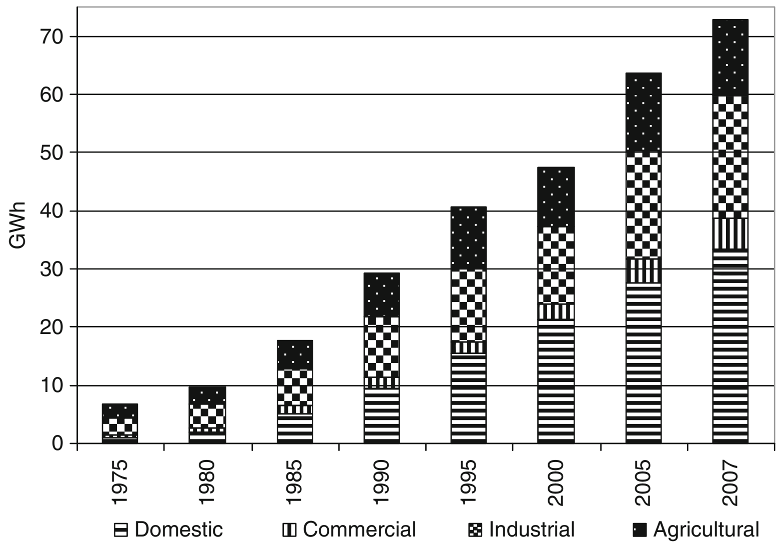

Fig. 2 Sector-wise electricity consumption in Pakistan

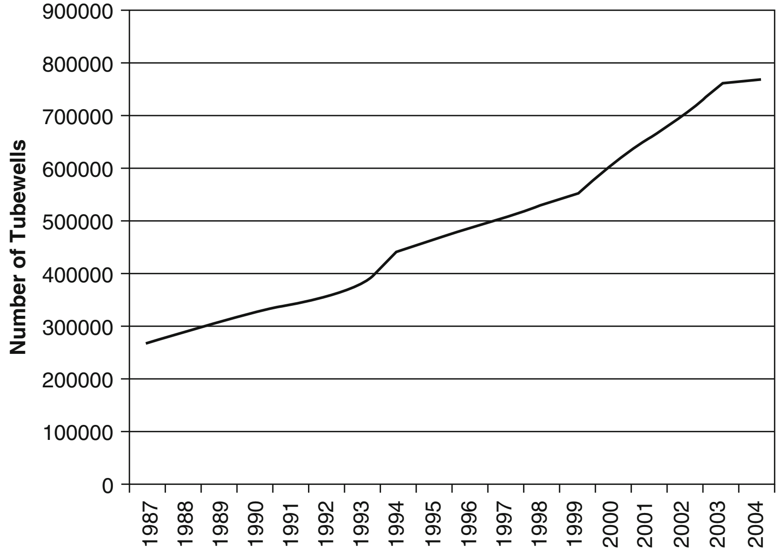

Fig. 3 Number of tubewells in Pakistan for period 1987–2004

For electric tubewell installation, the farmer has to bear the capital cost of drawing the cable from the line to the tubewell. Furthermore, load shedding is another issue, which may impact the farmer's irrigation application at right time, whereas in case of diesel tubewell there are no such problems. They prefer metered tariff because this tariff can be used on "need basis irrigation." But the farmer's preference is still toward diesel tubewells due to load shedding and costly connection for electric tubewell.

4 Formulation of Electricity Demand Model

The demand of electricity in certain sector is dependent on various factors such as GDP, population, electricity price, previous year's electricity demand, and the number of consumers. Econometric models for energy demand as function of national income have been used by many researchers [12–14]. An energy economic model was developed for forecasting the demand of electricity in the agricultural and services sector of Pakistan.

The energy demand using energy economic model may be expressed as

$$Y_i = k \cdot (G_i)^{\alpha} \cdot (T_i)^{\beta} \tag{1}$$

where Y_i is the energy demand for the year i, G_i is the GDP of the country for the year i, T_i is the socio-economic development factor for the year i, k is the constant, α is the elasticity of GDP, and β is the elasticity of the socio-economic development factor for year i.

Lagged variables (previous year's electricity consumption) have been used to improve the accuracy of predictions. Hence, such an econometric model can be developed for Pakistan to improve accuracy for the prediction of electricity demand in agricultural sector. In Modified Dynamic Energy Economic Model, electricity demand is a function of the previous year's electricity demand and the number of consumers.

The energy demand using MDEE Model may be expressed as

$$Y_i = k \cdot (Y_{i-1})^{\alpha} \cdot (G_i)^{\beta} \cdot (\tau_i)^{\gamma} \tag{2}$$

where k is the constant, α is the time response parameter, β is the elasticity of GDP per capita, γ is the elasticity of the time trend variable, and $\tau = 1, 2, 3 \ldots 32$ corresponding to 1974, 1975 … 2004.

The value of constant k and the parameters α, β, and γ are determined after taking "ln" on both sides.

$$\begin{aligned} \ln(Y_i) &= \ln(k) + \alpha \cdot \ln(Y_{i-1}) + \beta \cdot \ln(G_i) + \gamma \cdot \ln(\tau_i) \\ \overline{Y_i} &= \overline{k} + \alpha \cdot \overline{Y_{i-1}} + \beta \cdot \overline{G_i} + \gamma \cdot \overline{\tau_i} \end{aligned} \tag{3}$$

The proposed multiple linear regression Index model to forecast electricity consumption using GDP, price of electricity, and population is

$$Y = a + b_1 Y_{i-1} + b_2 G_i + b_3 EP_i + b_4 C_i + e \tag{4}$$

where Y_i is the energy demand for the year i, G_i is the GDP of the country for the year i, EP_i is the price of electricity, C_i is the number of consumers, a is the constant, b_1 is the elasticity of lagged value of electricity consumption, b_2 is the elasticity of GDP, b_3 is the elasticity of price of electricity, b_4 is the elasticity of the number of consumers in a given sector, and e is the error (disturbance term or white noise).

The unknown parameters b_1, b_2, b_3, and b_4 are determined by OLS principle using Mini-Tab 13.0 Version Statistical Software Package. Once the unknown parameters are determined, they are fitted into the Index Model.

Both models have been validated by analyzing the model coefficients and predicted values. Both models have been validated by comparing the estimated electricity demand with the past consumption, the values of Standard Error, R^2, t-statistics for each variable, F-statistic, coefficients/constants and their signs, and Durbin d- and h-statistics.

Table 1 gives the statistical analysis of the MDEE and Index model results; T values are given in the brackets.

The estimated electricity demand has been compared with the actual demand. Figure 4 shows that the MDEE model is more accurate as compared to Index model. Finally, MDEE model has be used to forecast the demand of electricity in the country.

Table 1 Statistical analysis of the MDEE and index model

Explanatory variable	MDEE model	Index model
Constant	−6.77 (−3.13)	−0.512 (−2.33)
Ec $_{(t-1)}$	0.6774 (5.49)	0.625 (5.7)
ln GDP	0.45 (3.03)	0.711 (2.9)
EP_i	–	0.01634 (−1.45)
R^2	98.7	97.9
DW d-statistic	1.62	1.45
DW h-statistic	1.5	1.94
f-statistic	1,095.97	438.98

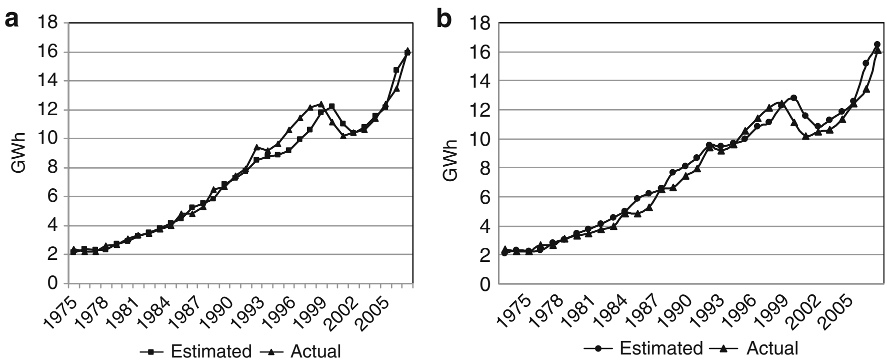

Fig. 4 Comparison of actual and estimated electricity demand using MDEE and Index model. (**a**) Using MDEE model. (**b**) Using Index model

Table 2 Total GDP (FC of 2000) for various scenarios

Year	GDP (million Rs.)		
	PGS	CGS	OGS
2007	4,846	4,846	4,846
2010	5,295	5,610	5,936
2015	6,139	7,160	8,326
2020	7,116	9,138	11,678
2025	8,250	11,663	16,380
2030	9,564	14,885	22,973

5 Scenario Development

During the last 32 years (1975–2007), Pakistan's economy has grown at an average growth rate of 4.93% per annum. However, due to high population growth rates, the per capita GDP has increased at only 2.56% per annum during the same period. During the years 2006–2007 and 2007–2008, Pakistan's economy grew at the rate of 5.8% and 6.8% per annum, respectively [1].

The official targets set by the Government of Pakistan (GOP) in Medium Term Development Framework (MTDF) [1] 2005–2010 envisage increase in GDP growth to 8.2% by the year 2010. The National Transmission and Dispatch Company (NTDC) in consultation with Pakistan Institute of Development Economics (PIDE) has projected the growth rates of Pakistan economy up to the year 2025. According to NTDC's study (medium scenario), the growth rates of national GDP for the durations 2005–2010 and 2010–2025 would be 5.8% and 6.3%, respectively [15].

Keeping in view the above-stated past trends, future targets, and projections of national GDP, three different scenarios have been assumed depicting possible economic growth and electricity demand in the country: Optimistic Growth Scenario (OGS), Conservative Growth Scenario (CGS), and Pessimistic Growth Scenario (PGS). The OGS scenario assumes that the economy will grow at 7%, while CGS scenario assumes that the economy of Pakistan will grow at 5%, and under PGS, the assumed GDP growth is 3%. Total GDP at constant factor cost of 1999–2000 for various scenarios is presented in Table 2.

6 Electricity Demand Forecast

The demand of electricity is projected to increase rapidly under all three scenarios. Under PGS scenario, the demand of electricity is projected to 82,400 GWh; under CGS scenario, 100,500 GWh in Agricultural and Others sector; and under OGS scenario, the demand of electricity is projected to 122,200 GWh.

Figure 5 shows the increase in annual total final electricity demand between 2007 and 2030 for all the three scenarios in the agricultural and others sector of Pakistan.

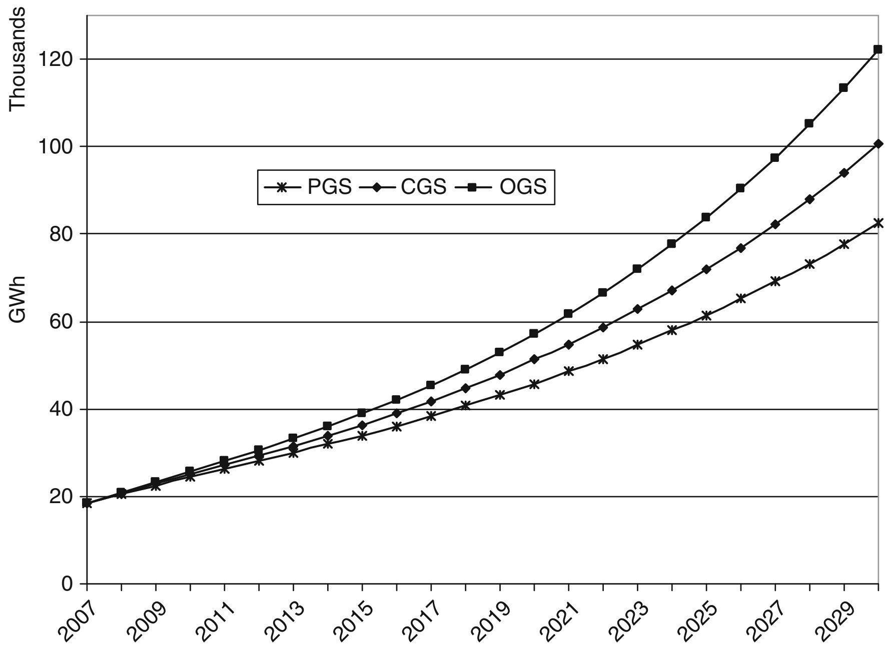

Fig. 5 Projections of electricity demand in Agricultural and Others sector

7 Results and Discussion

The demand of electricity has been forecasted in the agricultural and services sector under three different scenarios, which is almost 4.5–6 times of current demand in these sectors. The demand of electricity in all the sectors is projected to increase rapidly under all three scenarios. Under PGS scenario the demand of electricity is projected to 82,400 GWh; under CGS scenario, 100,500 GWh in Agricultural and Others sector; and under OGS scenario, the demand of electricity is projected to 122,200 GWh.

Agricultural sector holds a key role in the country's economy and an uninterrupted supply of electricity should be ensured to enhance the agriculture production and to overcome food shortage in the country. Change from flat to metered tariff has shown positive impact on the electricity utilization in agricultural sector.

To meet this demand, wind energy can be widely used for water pumping purpose in the potential areas, diesel generators for reducing the demand in the sector, and solar PV can be used for product refrigeration. There is also a need to improve the efficiency of the diesel pumps in Pakistan to improve the irrigation performance and reduce load on the electricity sector.

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Solar Drying Technology: Potentials and Developments

B.K. Bala and Serm Janjai

Abstract This chapter presents developments and potentials of solar drying technologies for drying fruits, vegetables, spices, medicinal plants, and fish. Experimental performances of different types of forced solar dryers such as solar tunnel dryer, improved version of solar tunnel dryer, roof-integrated solar dryer, and greenhouse-type solar dryers are addressed. Drying time in the solar dryers was significantly less than that required for natural sun drying and the products are quality products in terms of color and texture. Simulated performances of solar tunnel dryer, improved version of solar tunnel dryer, roof-integrated solar dryers, and greenhouse solar dryers are presented. The agreement between the simulated and experimental results is very good. A multilayer neural network approach was used to predict the performance of the solar tunnel dryer and the prediction of the performance of the dryer was found to be excellent after it was adequately trained.

Keywords Drying efficiency • Experimental and simulated results • Modeling • Neural network • Solar dryers

Nomenclature

C_p	Specific heat, kJ/kg °K
E	Solar radiation, W/m^2
G_a	Mass flow rate of air, kg/m^{2}s
H	Humidity ratio, kg/kg
K	Drying constant, min^{-1}

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L_g Latent heat of chili, kJ/kg
M Moisture content, % or ratio (db) or (wb)
M_e Equilibrium moisture content, % or ratio (db) or (wb)
M_0 Initial moisture content, % or ratio (db) or (wb)
T Temperature, °C
V Air velocity, m/s
B Depth of collector/dryer, m
h_c Convective heat transfer coefficient, W/m^2 °K
h_r Radiative heat transfer coefficient, W/m^2 °K
t Time, min
z Thickness, m

Greek

α Absorbance
ρ Density, kg/m^3
ρ Reflectance
τ Transmittance

Subscripts

a Air
am Ambient
c Collector
e Equilibrium moisture content
g Chili
l Liquid
L Long wave
p Absorber plate
s Sky
S Short wave
w Water
v Water vapor

1 Introduction

Solar drying can be considered as an elaboration of sun drying and it is an efficient system of utilizing solar energy [1–4]. The tropics and subtropics have abundant solar radiation. Hence the obvious option for drying would be the natural convection solar dryers. Many studies on natural convection solar drying of agricultural products have been reported [5–10]. These dryers have been widely tested in the tropical and subtropical countries. Considerable studies on simulation and optimization have also been reported [8, 9, 11]. The success achieved by indirect natural convection solar dryers has been limited, the drying rates achieved to date not having been very satisfactory [12]. Furthermore, natural convection dryers are not suitable for small-scale industrial production of dried fruits, vegetables, spices, fish and medicinal and herbal plants. These prompted researchers to develop forced convection solar dryers. These dryers are (1) solar tunnel drier [13], (2) indirect forced convection solar dryer [12], (3) greenhouse-type solar dryer [14], (4) roof-integrated solar dryer [15], and (5) solar assisted dryer [16]. Numerous tests in the different regions of the tropics and subtropics have shown that fruits, vegetables, cereals, grain, legumes, oil seeds, spices, fish and even meat can be dried properly in the solar tunnel dryer [13, 17–27].

The purpose of this chapter is to present the developments and potentials of solar drying technologies for drying fruits, vegetables, spices, medicinal plants, and fish and the performances of the solar dryers for drying of fruits, vegetables, spices, medicinal plants and fish and also to present simulated performances of solar tunnel dryer for drying of chili and pv-ventilated solar greenhouse dryer for drying of peeled longan, and neural network prediction of the performance of the solar tunnel dryer for drying of jackfruit and jackfruit leather.

2 Solar Drying Systems

Different types of solar dryers have been designed, developed, and tested in the different regions of the tropics and subtropics. The major two categories of the dryers are natural convection solar dryers and forced convection solar dryers. In the natural convection solar dryers, the airflow is established by buoyancy induced airflow, while in forced convection solar dryers the airflow is provided by using fan either operated by electricity/solar module or fossil fuel. Now the solar dryers designed, developed, and used in tropics and subtropics are discussed under two headings.

2.1 Natural Convection Solar Drying

Natural convection solar drying has advantages over forced convection solar drying in that it requires lower investment, though it is difficult to control drying temperature and the drying rate may be limited. Due to low cost and simple operation and maintenance, natural convection solar dryer appear to be the obvious option and popular choice for drying agricultural products. Natural convection solar dryer can be classified as (1) indirect natural convection solar dryer, (2) direct natural convection solar dryer, and (3) mixed-mode natural convection solar dryer.

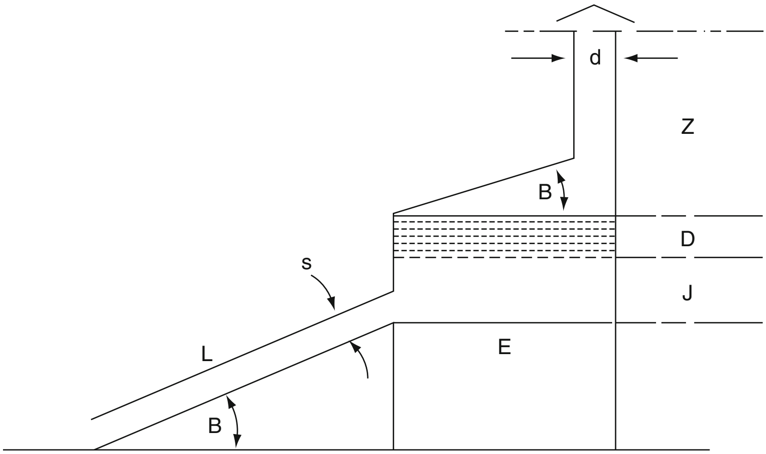

Fig. 1 Indirect natural convection solar dryer

Indirect natural convection solar dryer is the oldest type of solar dryer and it consists of a separate solar collector with a transparent cover on the top and a drying unit with an opaque cover on the top. These are connected in series (Fig. 1). In such a dryer, the crop is contained within a cabinet in a relatively thin bed, which completely spans the cabinet. Air, which is heated in a simple flat plate-type solar collector and then flows as a result of the buoyancy forces resulting from the temperature differences up through the crop bed, thereby producing the drying. The drying rates achieved to date with these dryers have not, generally, been very satisfactory. Oosthuizen [7] identified part of this failure due to the fact that the dryers have usually not really been matched to the design requirements. Oosthuizen [7] also discussed the use of a model in the selection of a dryer design that meets a particular set of requirements. Such indirect natural convection solar dryers appear to have wide application in many developing countries for the drying of crops such as rice and corn.

Many attempts to develop such indirect free or natural convective solar crop dryers have been made [5, 8, 9, 28, 29]. The basic concepts involved in modeling such dryers are discussed by Exell [6] and a computer model that appears to be capable of predicting the main characteristics of such dryers is described by Oosthuizen [7, 12]. Bala and Woods [8] reported a mathematical model to simulate the indirect natural convection solar drying of rough rice and Bala and Woods [9] also developed a technique for optimization of natural convection solar dryers.

Direct type solar dryer called cabinet-type solar dryer is essentially a solar hot box, in which the desired product can be dried on a small scale. It consists of a quadrilateral-shaped cabinet, trays for the product, and single-layered transparent plastic/glass at the top (Fig. 2). Solar radiation is transmitted through roof and absorbed on the blackened interior surfaces. Owing to the energy trapped, the internal temperature is increased. Holes are drilled through the base to permit fresh ventilating air entry into the cabinet. Outlet posts are located on the upper

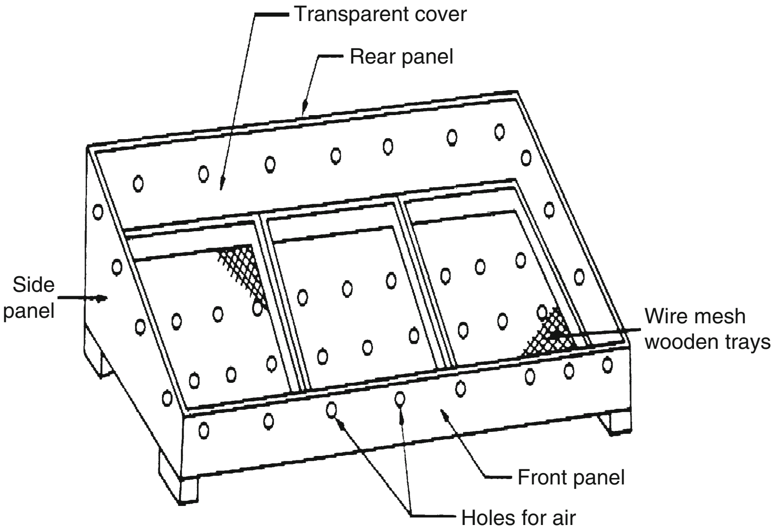

Fig. 2 Cabinet-type solar dryer

parts of the cabinet side and rear panels. As the temperature rises, warm air passes out of these upper apertures by natural convection, creating a partial vacuum and drawing fresh air up through the base. As a result, there is a continuous flow of air over the drying product, which is placed on perforated trays in the interior cabinet case. This dryer could be used to dry fruits, vegetables, soybean, mung bean, etc. The capacity of the drier was 30–50 kg per batch. It was concluded that the cabinet-type dryer may be useful for domestic applications for drying fruits and vegetables in developing countries [10].

An extensive study has been conducted on solar drying of agricultural products using cabinet/box-type and tent-type solar dryers [30–33]. Sodha et al. [30] developed an analytical model for predicting temperature and moisture content during drying of fruits in cabinet/box-type solar dryer.

The mixed-mode solar dryer consists of a separate solar collector and a drying unit, both having a transparent cover on the top. Solar radiation is received in the collector as well as in the dryer box. Exell and Kornsakoo [5] developed a simple mixed-mode solar dryer designed to provide the rice farmer in Southeast Asia with a cheap and simple but efficient method of drying in the wet season harvest. The dryer is composed of three main components as shown in Fig. 3, namely, the solar collector, the paddy box, and the chimney. The solar collector consists of a matt-black substance spread on the ground and provided with transparent top and side covers. The dryer was initially designed with a bed of burnt rice husk as the absorber and clear UV-stabilized polyethylene plastic sheet as transparent cover. However, these materials could be substituted with locally available materials such as charcoal, black plastic or black-painted metal sheets, and dark-colored pebbles.

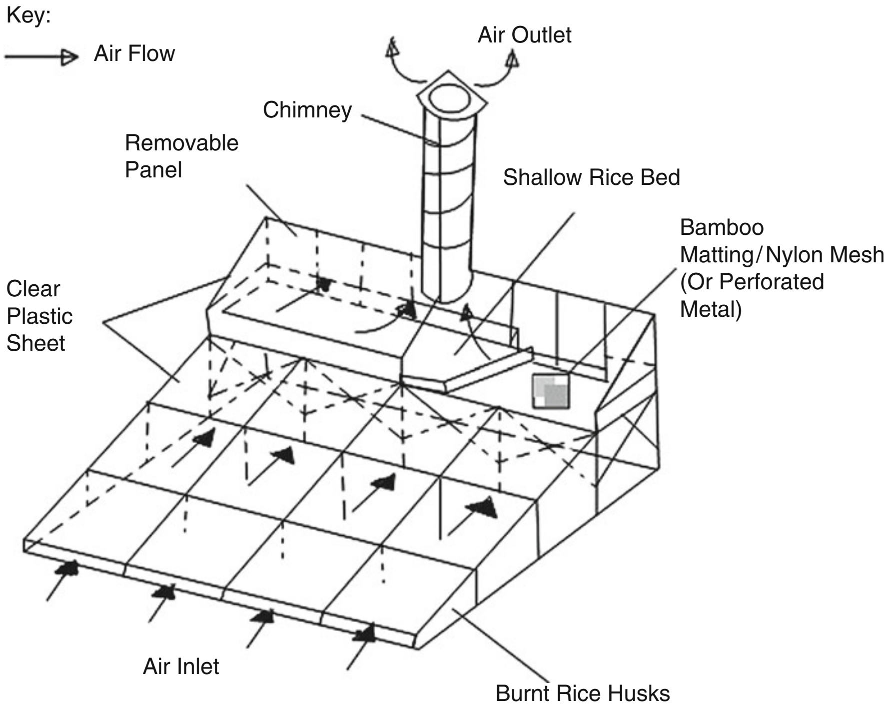

Fig. 3 AIT dryer

Zaman and Bala [3] at Bangladesh Agricultural University fabricated and tested three different categories of natural convection solar dryers such as (1) cabinet-type solar dryer, (2) mixed-mode solar dryer, and (3) AIT-type solar dryer to assess the drying performance of these dryers to provide the rice farmers with an appropriate and economic method of drying. Although the AIT dryer or its modification, and the mixed-mode dryer produced quality dried product, this dryer is not in use in Bangladesh and even in the tropics and subtropics.

Many studies have been made to develop mixed solar dryer [5, 11]. The basic concepts involved in modeling of such dryers are discussed by Simate [11] and the computer simulation model is combined with the cost of the drier materials and a search technique to find the optimal dimensions of such dryers. This model is based on the concept of optimal design of solar dryers developed by Bala and Woods [9].

Kenya Black Box Solar Dryer was developed by Eckert [34] and more than 90 dryers were tested during 1996–1997 as part of GTZ project. The size of the dryer is 2 m $\times$ 0.8 m and drying capacity 15–20 kg of fresh mangoes per day in the Kenyan climate, resulting in approximately 0.50 kg per day of dried product. Price of the drier is US \$340. The temperature reaches up to 40°C above ambient. The drier was

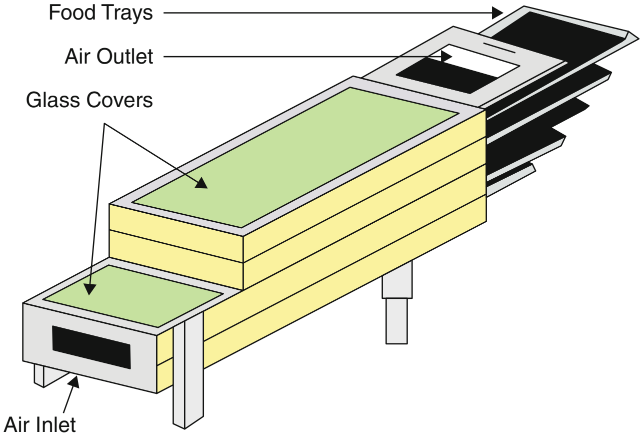

Fig. 4 Kenya black box solar dryer

pronounced technically reliable, economically viable, and socially acceptable by the Kenyan people. They concluded that black-box solar dryer can be appropriate for small-scale drying in areas with a climate conductive to solar drying with convection. Kenya black-box solar drier is shown in Fig. 4.

2.2 Forced Convection Solar Drying

The success achieved by the indirect natural convection solar dryer has been very limited due to low buoyancy induced air flow rate. Therefore, adding a small fan powered by a photovoltaic system to provide the required air flow will give drying rates much higher than those achieved by an indirect natural convection solar dryer. The required air flow can be supplied by using fan operated either by electricity/ solar module or fossil fuel. The pv-operated system has the advantage that it can be operated independent of electrical grid. Such dryers can be used to dry fruits, vegetables, spices, and even fish for small-scale industrial production of quality dried products. Such dryers can also be used to dry medicinal products such as medicinal plants sensitive to direct exposure to solar radiation at a small-scale production. Figure 5 shows arrangement of such a forced convection solar dryer.

3 PV-Ventilated Solar Drying Systems

Several versions of PV-ventilated forced convection solar dryers have been developed such as (1) solar tunnel dryer with plastic cover, (2) solar tunnel dryer with polycarbonate cover, (3) greenhouse solar dryer, and (4) roof-integrated solar dryer.

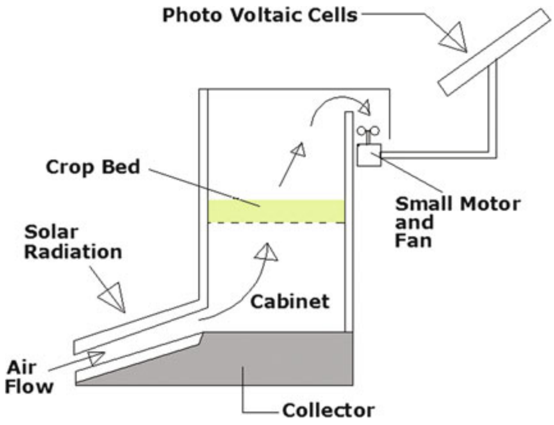

Fig. 5 Arrangement of an indirect forced convection solar dryer

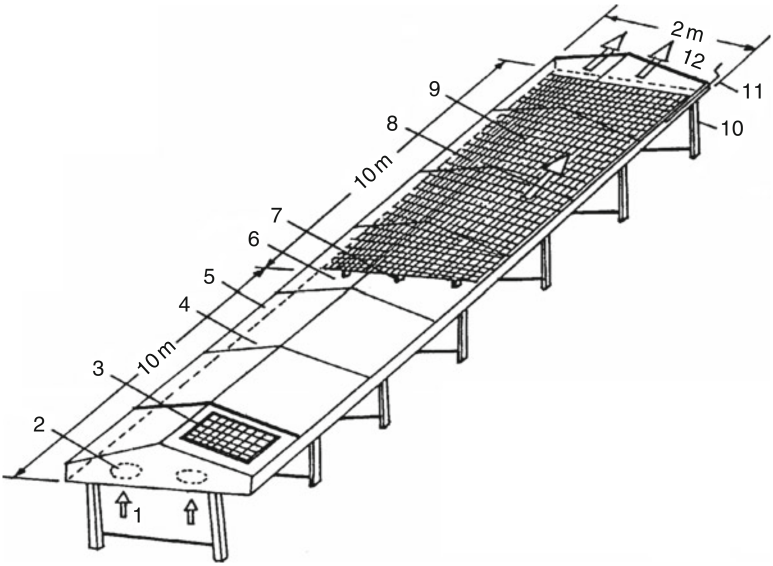

Fig. 6 Solar tunnel dryer

Mühlbauer and his associates at the Institute of Agricultural Engineering in Tropics and Subtropics, University of Hohenheim, Germany, developed a solar tunnel dryer. Solar tunnel consists of a flat plate air heating collector and a tunnel drying unit and a small fan to provide the required air flow over the product to be dried. These are connected in series as shown in Fig. 6. Solar tunnel dryer can be operated by one 40 W photovoltaic module independent of electrical grid. The collector and drying chamber were made of plain metal sheets and wooden frames in a number of small sections and were joined together in series. These sections can be dismantled easily for transportation from one place to another. Glass wool was used between the two metal sheets at the bottom of the dryer as an insulation material to reduce the heat loss from the bottom of drier. Collector size of the drier is 10 m × 2 m. The photovoltaic system has the advantage that temperature of the drying air could be automatically controlled by the solar radiation. Numerous tests in the different regions of the tropics and subtropics have shown that fruits, vegetables, cereals, legumes, oil seeds, spices, fish, and even meat can be properly dried in the solar tunnel dryer.

The design of the solar tunnel dryer has been further improved and tested by Janjai and Keawprasert [35] at Silpakorn University at Nakhon Pathom in Thailand. The dryer still consists of two parts, namely the solar collector part and the drying part, similar to the original version. Instead of using PE plastic sheet, the roof of the new design dryer is made of polycarbonate plates fixed with the side walls of the dryer. The plates have an inclination angle of 5° for the drainage of rain. As loading of products to be dried cannot be done from the top of the dryer, rectangular windows were made at the side wall of the drying part for loading and unloading products. Back insulator was made of high-density foam sandwitched between two galvanized metal sheets. A 15 W-solar cell module was used to power a DC fan for ventilating the dryer. The collector part and the drying part have the area of $1.2 \times 4\ m^2$ and $1.2 \times 5\ m^2$, respectively. The schematic diagram of this dryer is shown in Fig. 7.

A pv-ventilated greenhouse solar dryer was developed at Silpakorn University [36]. The dryer essentially consists of a parabolic shape greenhouse with a black concrete floor with an area of $5.5 \times 8.0\ m^2$ (Fig. 8). The parabolic cross-sectional shape helps to reduce the wind load in case of a tropical rain storms. The structure of the dryer is made of galvanized iron bars. The roof of the dryer is covered with polycarbonate plates. The products to be dried are placed in a thin layer on two

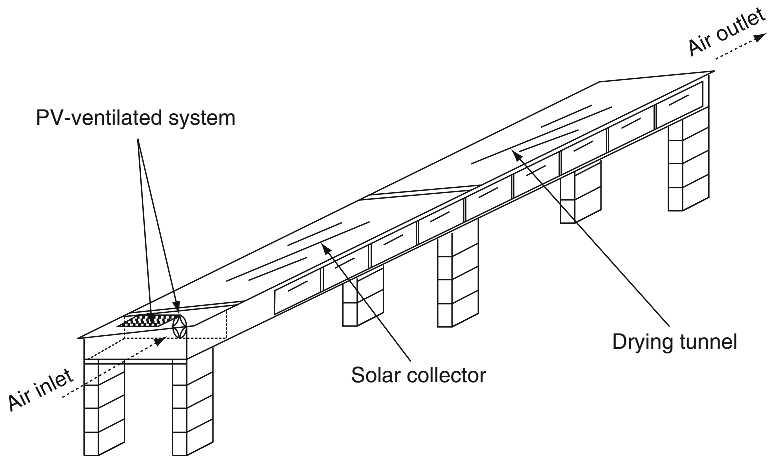

Fig. 7 Schematic diagram of the solar tunnel dryer with polycarbonate cover

Fig. 8 Greenhouse-type solar dryer with polycarbonate sheet

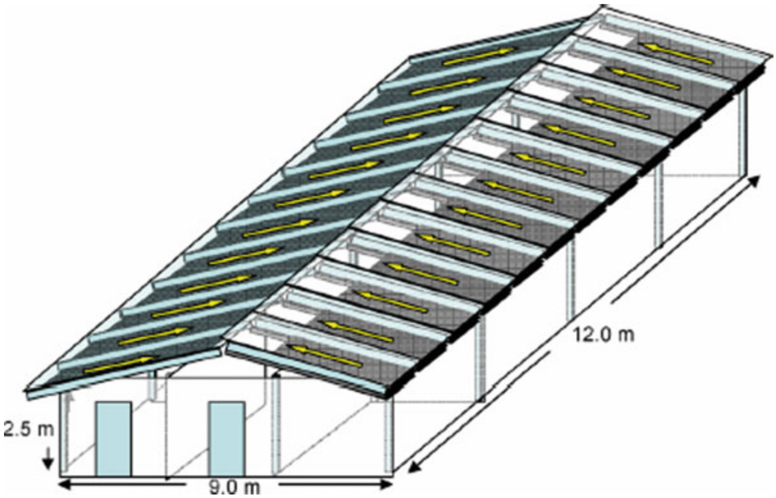

Fig. 9 Roof-integrated solar dryer [37]

arrays of trays. These arrays of trays are placed on single-level raised platforms with a passage at the middle for loading and unloading the products inside the dryer. Three fans powered by a solar cell module of 50 W were installed in the wall opposite to the air inlet to ventilate the dryer. With this PV model, the dryer can be used in the rural areas without access to electrical grids.

The roof-integrated solar dryer consists of a roof-integrated solar collector and a drying bin with an electric motor operated fan to provide the required air flow (Fig. 9) [37]. The roof-integrated collector consists of two arrays of collector: one facing the south and other facing the north. These arrays of collectors also serve as the roof of the building. The roof-integrated solar collector is essentially an insulated black-painted roof serving as an absorber, which is covered with polycarbonate plate. The drying bin is essentially a deep bed batch dryer. The bin is connected to the middle of the collector through a T-type air duct connection.

3.1 Experimental Studies

Large-scale field level studies were conducted at Bangladesh Agricultural University, Mymensingh, Bangladesh, and Silpakorn University at Nakhon Pathom, Thailand, to demonstrate the potentiality of the solar dryers for production of high-quality solar dried fruits, vegetables, spices, medicinal plants, and fish. Packages of technology for solar drying of fruits, vegetables, spices, medicinal plants, and fish have also been developed at Bangladesh Agricultural University, Mymensingh, Bangladesh.

3.2 Collector and Drying Efficiency

Collector efficiency is defined as the ratio of energy output of the collector to energy input to the collector. Solar energy input on the collector is computed as

$$IA_{\text{collector}} = 10^{-6} \times A_{\text{collector}} \int_0^t \text{Sr}(t)\,\text{d}t, \tag{1}$$

where

$IA_{\text{collector}}$ = Solar energy input on the collector, MJ

$\text{Sr}(t)$ = Solar radiation at time t, W/m^2

$A_{\text{collector}}$ = Collector area, m^2

t = time, s

and that of the solar module is computed as

$$IA_{\text{module}} = 10^{-6} \times A_{\text{module}} \int_0^t \text{Sr}(t)\,\text{d}t, \tag{2}$$

where

IA_{module} = Solar energy input on the solar module, MJ

A_{module} = Module area, m^2

The output of the collector in terms of energy is

$$\text{Output}_{\text{collector}} = 10^{-3} \int_0^t \dot{m}(t)\, C_{\text{pa}}(T_{\text{c}} - T_{\text{i}})\, \text{d}t, \tag{3}$$

where
$\text{Output}_{\text{collector}}$ = Collector output, MJ
$\dot{m}(t)$ = Airflow rate at time t, kg/s
C_{pa} = Specific heat of air, kJ/kg °C
T_{c} = Temperature at the collector outlet, °C
T_{i} = Temperature at the collector inlet, °C
Thus, collector efficiency is

$$\text{Collector efficiency} = \frac{\text{Output}_{\text{collector}}}{IA_{\text{collector}} + IA_{\text{module}}}. \tag{4}$$

The drying efficiency is defined as the ratio of energy output of the drying section to energy input to the drying section. Solar radiation input on the drying section is

$$IA_{\text{dryer}} = 10^{-6} \times A_{\text{dryer}} \int_0^t \text{Sr}(t)\, \text{d}t, \tag{5}$$

where
IA_{dryer} = Solar energy input on the dryer, MJ
A_{dryer} = Dryer area, m^2
The output of the dryer in terms of energy is

$$\text{Output}_{\text{dryer}} = 10^{-3} \times \text{mr} \times L_{\text{g}}. \tag{6}$$

$\text{Output}_{\text{dryer}}$ = Output of the dryer, MJ
mr = Moisture removed, kg
L_{g} = Latent heat of vaporization of moisture, kJ/kg
Thus, efficiency of the dryer is

$$\eta_{\text{drying}} = \frac{\text{Output}_{\text{dryer}}}{IA_{\text{dryer}} + \text{Output}_{\text{collector}}}. \tag{7}$$

The overall drying efficiency is defined as the ratio of energy output of the dryer to total energy input. Thus, overall efficiency of the system is

$$\eta_{\text{overall}} = \frac{\text{Output}_{\text{dryer}}}{IA_{\text{collector}} + IA_{\text{module}} + IA_{\text{dryer}}}. \tag{8}$$

4 Mathematical Modeling

Mathematical models are useful for predicting performance and optimal designs of solar drying systems. The fundamentals of heat and mass transfer during drying are given in Bala [1]. The details of heat and mass transfer during drying of chili in a solar tunnel dryer, roof-integrated solar dryer, and greenhouse solar dryer are given in Hossain [38] and Janjai et al. [36, 37], respectively. Mathematical modeling of solar drying using solar tunnel dryer is discussed below.

4.1 Analysis of Collector Performance

Considering an element, dx of collector at a distance x from the inlet (Fig. 10), the energy balances on the collector components give the following equations.

4.2 Energy Balances on the Plastic Cover

Energy balance on the cover gives the following equation:

$$h_{\mathrm{cam}}(T_{\mathrm{c}} - T_{\mathrm{am}}) + h_{\mathrm{ca}}(T_{\mathrm{c}} - T_{\mathrm{a}}) + h_{\mathrm{rcs}}(T_{\mathrm{c}} - T_{\mathrm{s}}) - h_{\mathrm{rpc}}(T_{\mathrm{p}} - T_{\mathrm{c}}) = \alpha_{\mathrm{cS}}(1 + \tau_{\mathrm{cS}}\rho_{\mathrm{pS}})E. \tag{9}$$

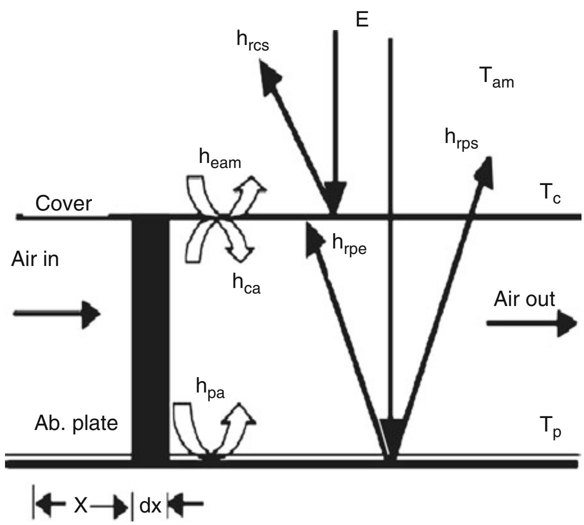

Fig. 10 Heat balances in the flat plate solar collector of depth, *b*

4.3 Energy Balances on the Absorber Plate

The following equation gives the energy balance on the absorber plate:

$$h_{pa}(T_p - T_a) + h_{rpc}(T_p - T_c) + h_{rps}(T_p - T_s) = \frac{\tau_{cS}\alpha_{pS}E}{1-(1-\alpha_{pS})\rho_{pS}}. \qquad (10)$$

4.4 Energy Balances on the Air Stream

The following equation gives the energy balances in the air inside the collector:

$$bG_aC_{pa}\frac{dT_a}{dx} = h_{pa}(T_p - T_a) + h_{ca}(T_c - T_a). \qquad (11)$$

4.5 Analysis of Solar Tunnel Dryer Performance

The following systems of equations are developed to describe the drying of a product in the solar tunnel dryer. Considering an element, dx of drying tunnel at a distance x from the inlet. The energy balances in the drier components are shown in Fig. 11.

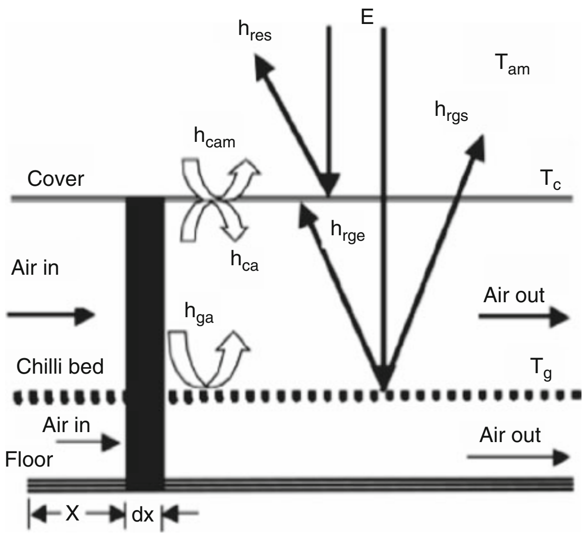

Fig. 11 Energy balances in the solar tunnel dryer of depth, *b*

4.6 Energy Balances on the Cover

Heat balance on plastic cover of drying tunnel is same as the cover of collector, and the temperature of plastic cover is

$$T_{\mathrm{c}} = \frac{h_{\mathrm{cam}}T_{\mathrm{am}} + h_{\mathrm{ca}}T_{\mathrm{a}} + h_{\mathrm{rcs}}T_{\mathrm{s}} + h_{\mathrm{rgc}}T_{\mathrm{g}} + \alpha_{\mathrm{cS}}(1 + \tau_{\mathrm{cS}}\rho_{\mathrm{gS}})E}{h_{\mathrm{cam}} + h_{\mathrm{ca}} + h_{\mathrm{rcs}} + h_{\mathrm{rgc}}}. \tag{12}$$

4.7 Energy Balances on the Product

The following energy balance equation is developed for the drying in the solar tunnel drier.

$$\frac{\partial T_{\mathrm{g}}}{\partial t} = -\frac{\left[-\rho_{\mathrm{g}}z_{\mathrm{g}}(C_{\mathrm{v}} - C_{\mathrm{l}})\frac{\partial M}{\partial t} + h_{\mathrm{ga}} + h_{\mathrm{rgc}} + h_{\mathrm{rgs}}\right]T_{\mathrm{g}}}{\rho_{\mathrm{g}}z_{\mathrm{g}}(C_{\mathrm{pg}} + C_{\mathrm{pw}}M)} + \frac{\left\{\frac{\alpha_{\mathrm{gS}}\tau_{\mathrm{cS}}}{1 - (1 - \alpha_{\mathrm{gS}})\rho_{\mathrm{gS}}}\right\}E + \rho_{\mathrm{g}}z_{\mathrm{g}}L_{\mathrm{g}}\frac{\partial M}{\partial t} + h_{\mathrm{ga}}T_{\mathrm{a}} + h_{\mathrm{rgc}}T_{\mathrm{c}} + h_{\mathrm{rgs}}T_{\mathrm{s}}}{\rho_{\mathrm{g}}z_{\mathrm{g}}(C_{\mathrm{pg}} + C_{\mathrm{pw}}M)}. \tag{13}$$

4.8 Energy Balances of the Air Stream

Change in enthalpy of air = heat transferred convectively to the product and heat supplied to air in the evaporated moisture.

$$\frac{\partial T_{\mathrm{a}}}{\partial x} = -\frac{(h_{\mathrm{ca}} + h_{\mathrm{ga}})T_{\mathrm{a}}}{\rho_{\mathrm{a}}z_{\mathrm{a}}V_{\mathrm{a}}(C_{\mathrm{pa}} + C_{\mathrm{pv}}H)} + \frac{h_{\mathrm{ca}}T_{\mathrm{c}} + h_{\mathrm{ga}}T_{\mathrm{g}}}{\rho_{\mathrm{a}}z_{\mathrm{a}}V_{\mathrm{a}}(C_{\mathrm{pa}} + C_{\mathrm{pv}}H)}. \tag{14}$$

4.9 Drying Rate Equation

The rate of change of moisture content of a thin-layer product inside the dryer can be expressed by an appropriate thin-layer drying equation. The Newton equation in differential form is

$$\frac{\mathrm{d}M}{\mathrm{d}t} = -K(M - M_{\mathrm{e}}). \tag{15}$$

4.10 Mass Balance Equation

The exchange of moisture between the product and the air inside the dryer is given by

Moisture lost by product = moisture gained by air.

$$\rho_{\mathrm{g}} \mathrm{d}x \left(-\frac{\partial M}{\partial t} \right) \mathrm{d}t = bG_{\mathrm{a}} \left(\frac{\partial H}{\partial x} \right) \mathrm{d}x \, \mathrm{d}t. \tag{16}$$

Equations (9)–(16) are solved using numerical techniques.

4.11 Neural Network Computing

The neurocomputing techniques are shaped after biological neural functions and structures. Thus, they are popularly known as artificial NNs. Similarly, as for their biological counterparts, the functions of artificial NNs are being developed not by programming them, but by exposing them to carefully selected data on which they can learn how to perform the required processing task. In such a modeling approach, there is no need to formulate an analytical description of the process. Instead, a black-box process model is constructed by interacting the network with representative samples of measurable quantities that characterize the process.

An independent multilayer ANN model of solar tunnel drier has been developed to represent the drying system of jackfruit bulb and jackfruit leather [39]. Network of both the model is four-layered and has a large number of simple processing elements, called neurons. The input layer of the model consists of seven neurons that correspond to the seven input variables, and the output layer has one neuron, which represents the final moisture content (FMC) in the model (Fig. 12).

A wide variety of training algorithms have been developed, each with its own strengths and weakness. The ANN drier models are trained by backpropagation

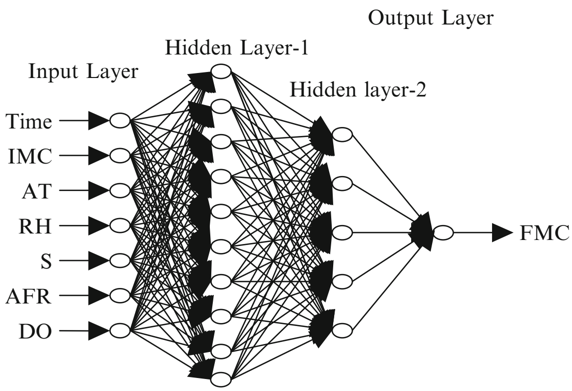

Fig. 12 The structure of the ANN solar tunnel dryer model for drying jackfruit bulb and jackfruit leather

algorithm so that application of a set of input would produce the desired set of output. After the end of training, simulations were done with the trained model for another set of data to check the accuracy of the training achieved. Further details are given in Bala et al. [39].

5 Results and Discussions

5.1 Experimental Results

Large-scale field level studies were conducted at both Bangladesh Agricultural University, Mymensingh, Bangladesh, and Silpakorn University at Nakhon Pathom, Thailand, to demonstrate the potentiality of the solar driers for production of high-quality solar dried fruits, vegetables, spices, medicinal plants, and fish. Some typical results for solar tunnel dryers, greenhouse-type solar dryer, and roof-integrated solar dryer are summarized below.

Figure 13 shows the variations of the ambient air temperature and relative humidity of a typical experimental run during solar drying of Bombay duck at Cox's Bazar in Bangladesh. The ambient relative humidity decreases with the increase in the ambient temperature. The second day of the experiment was bright in the morning and cloudy in the afternoon, which resulted in the sharp fall and rise in the relative humidity.

The patterns of temperature changes of the drying air at the collector outlet and airflow rate of a typical experimental run are shown in Fig. 14. The variation of the airflow rate helped to regulate the drying temperature. During high insolation

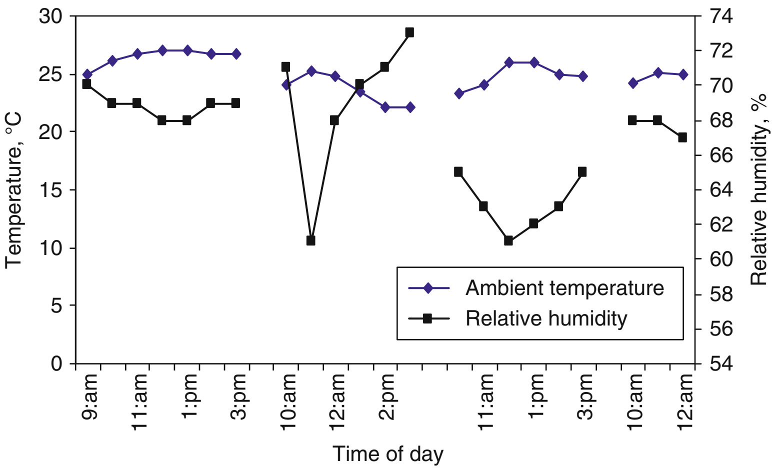

Fig. 13 Variations of ambient temperature and relative humidity with time of day during drying of Bombay duck

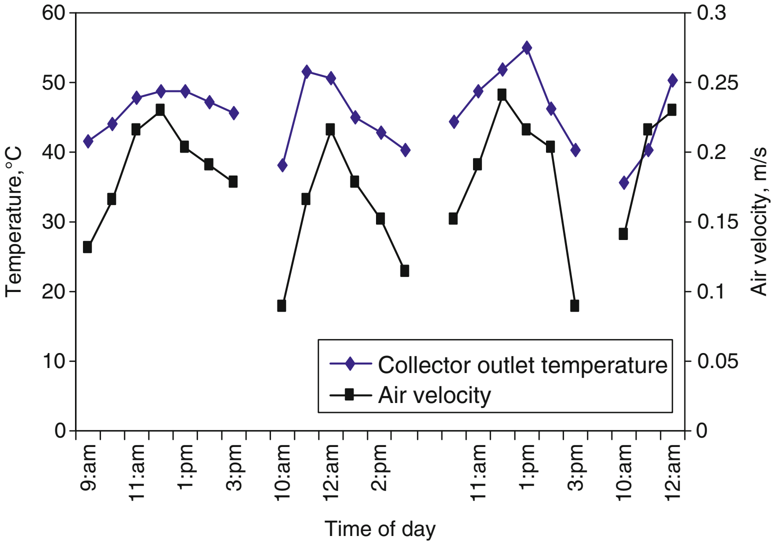

Fig. 14 Variations of collector outlet temperature and air flow rate with time of day during drying of Bombay duck

period more energy was received by the collector which was intended to increase the drying air temperature, but it was compensated by the increase of the air flow rate. While during low solar insolation period less energy was received by the collector and airflow rate was low. Hence, the decrease in temperature due to low solar insolation was compensated by the increase in temperature due to low airflow rate. This resulted in minimum variation of the drying air temperature throughout the drying period and saved the product from overheating/partial cooking due to excess temperature.

Figure 15 shows the variations of collector outlet temperatures with solar radiation. The equation relating collector outlet temperature (°C) and solar radiation (W/m^2) is given below:

$$\text{Collector outlet temperature} = 0.0282 \times \text{solar radiation} + 35.523 \quad r^2 = 0.30. \tag{17}$$

The coefficient of determination $r^2 = 0.30$ is highly significant at 1% level. Here, the intercept is significant, but the slope is insignificant and hence the collector outlet temperature changes within a close range.

Dried mango is an excellent snack food and has a demand for both national and international markets. Comparison of the moisture contents of mango in the solar tunnel drier with those obtained by the traditional method for a typical experimental run during drying at Chapai Nawabganj, Bangladesh, is shown in Fig. 16. The solar tunnel drying required 3 days to dry mango samples from 78.87% (wb) to 13.47% as compared to 78.87% to 22.48% in 3 days.

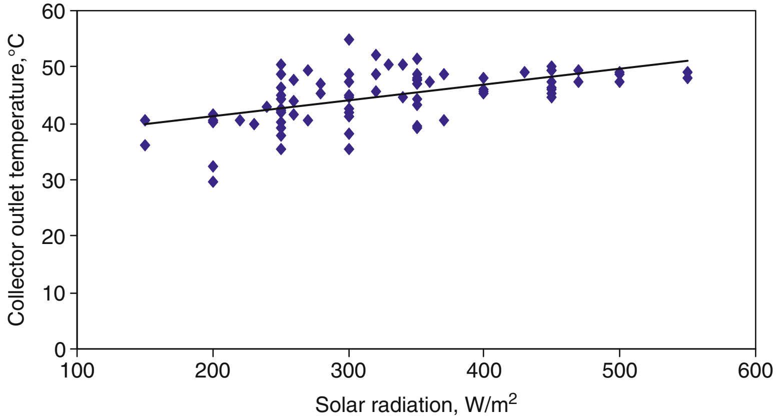

Fig. 15 Air temperature at the outlet of the collector as a function of solar radiation

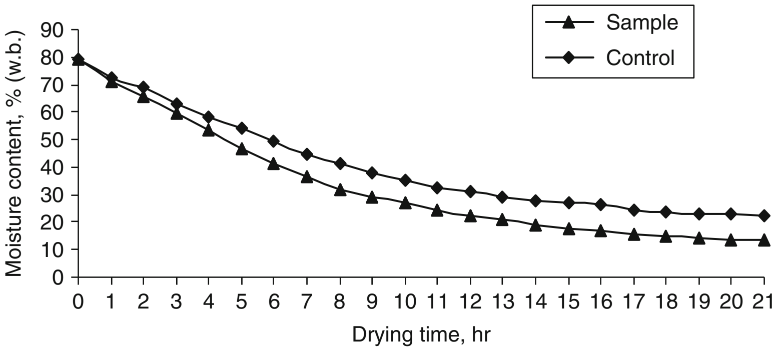

Fig. 16 Variations of moisture content with time during solar drying of mango

Jackfruit is a popular tropical fruit and it is the national fruit of Bangladesh. Dried jackfruit and jackfruit leather are now becoming popular in the tropics and subtropics. The typical drying curves of jackfruits dried in the improved solar dryer and those dried with natural sun drying at Nakhon Pathom, Thailand, are shown in Fig. 17. There was no difference of drying rate at different positions of solar tunnel dryer. For all experiments conducted, the drying time of jackfruits varied between 2 and 3 days compared to 4–5 days needed for sun drying, depending on the weather conditions.

Longan is one of the most economically important fruits in the northern Thailand. It is widely processed as a dried fruit for export to China and Taiwan. Comparison of the moisture contents of peeled longan inside the greenhouse dryer with those obtained by the traditional sun drying method for a typical experimental run conducted at Silpakorn University is shown in Fig. 18. The moisture contents of peeled longan at two locations at the same height inside the dryer reached to 12.60% (wb) from 81.00% (wb) in 24 h of drying in 3 days, while the moisture

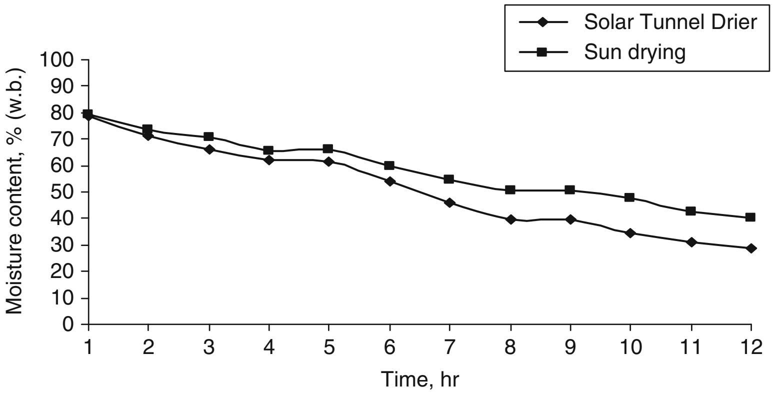

Fig. 17 Drying curves of jackfruit dried in the solar tunnel dryer and those dried with natural sun drying

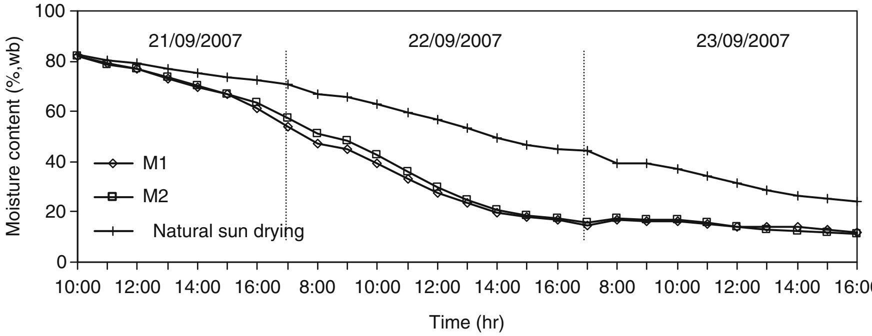

Fig. 18 Comparison of the moisture contents of peeled longan inside the greenhouse dryer with the traditional sun drying method

content of a similar sample in the traditional method after the same period of drying was 24.30% (wb).

Cabbage is a very popular vegetable in tropics and subtropics and produced at a large scale in winter. It is also a popular vegetable throughout the world. It is a perishable product and waste due to lack of proper preservation is very high. The dried vegetable is a tasty dish and has demand in both national and international markets. Comparison of the moisture contents of cabbage in the solar tunnel drier with those obtained by the traditional method for a typical experimental run during drying at Bangladesh Agricultural University at Mymensingh is shown in Fig. 19. The moisture content of cabbage reached from 95% to 10.81% in the solar tunnel drier and 95% to 24.20% in the traditional method.

Chili is an important spice and a potential cash crop in the world. It is dried for making powder and storage. Comparison of the moisture contents of chili inside the greenhouse dryer with those obtained by the traditional sun drying method for

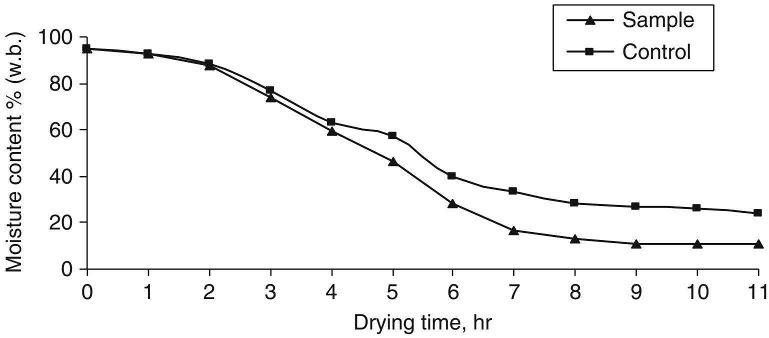

Fig. 19 Variations of moisture content with time for a typical experimental run during solar drying of cabbage

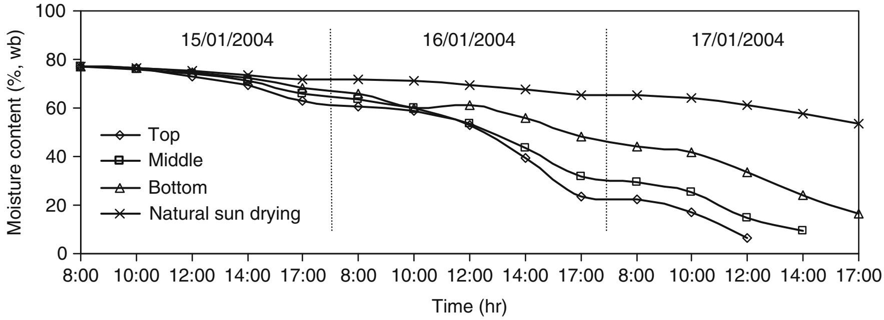

Fig. 20 Comparison of the moisture contents of chili inside the greenhouse dryer with the traditional sun drying method for a typical experimental run

a typical experimental run conducted in Thailand is shown in Fig. 20. The moisture contents of chili at three different locations starting from top to bottom inside the dryer are shown.

Ginger is a very popular spice in the tropics and subtropics and quality dried ginger has wide national and international market for export. The typical drying curves of ginger dried in the solar tunnel dryer and those dried with natural sun drying at Bangladesh Agricultural University, Mymensingh, are shown in Fig. 21. Ginger was dried to 9.7% from 89% in the solar tunnel drier as compared to 22.63% from 89% in the traditional method. There was no difference of drying rate at different positions of solar tunnel dryer.

Coffee is one of the most popular drinks all over the world. It is dried for roasting and storage. Figure 22 shows that the moisture content of coffee reached to 8.3% from 58.36% (wb) in 6 days of drying in the solar tunnel dryer, while it took 6 days to bring down the moisture content in a similar sample to 26.65% in traditional sun drying method.

In general, dry rosella flowers are used to make rosella juice by boiling these in water. It is a medicinal plant whose constituents are believed to help reduce high

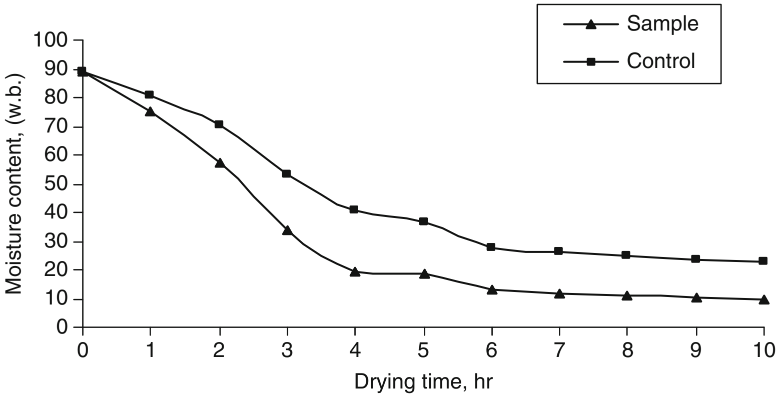

Fig. 21 Drying curves of ginger dried in the solar tunnel dryer and those dried with natural sun drying

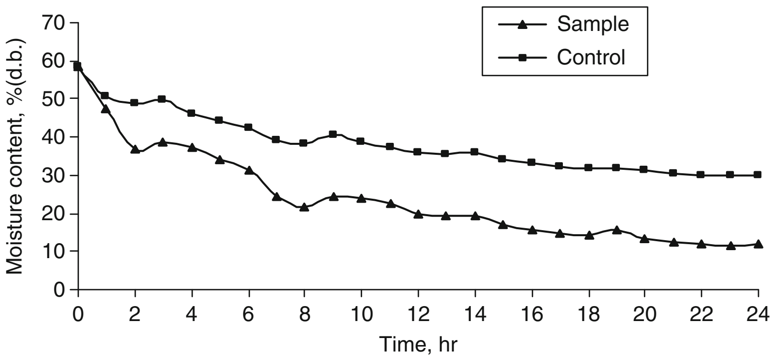

Fig. 22 Variation of moisture content with time of day for a typical experimental run during solar drying of coffee

blood pressure. Rosella flower was also dried in a roof-integrated solar dryer at Suan Phoeng, Thailand. For a typical clear sky weather condition, the moisture content of the rosella flower in the drying bin was reduced from an initial value of 85% (wb) to the final value of 17.2% (wb) within 3 days or with an effective drying time of approximately 24 solar hours, whereas the moisture content of the sun dried samples was reduced to 57.4% (wb) during the same drying period as shown in Fig. 23.

Basaka (*Adhatoda vasica* Nees.) is an important medicinal plant in the tropics and subtropics and it cures cough and breathing problem such as asthma. Quality dried basaka has wide national and international market for export. The typical drying curves of basaka dried in the dryer and those dried with natural sun drying at Bangladesh Agricultural Research Institute, Gazipur, are shown as Fig. 24. Blanched basaka was dried to 3% from 74% in 6 h in the hybrid solar drier as compared to 12.5% from 74% in the traditional method, while nonblanched basaka

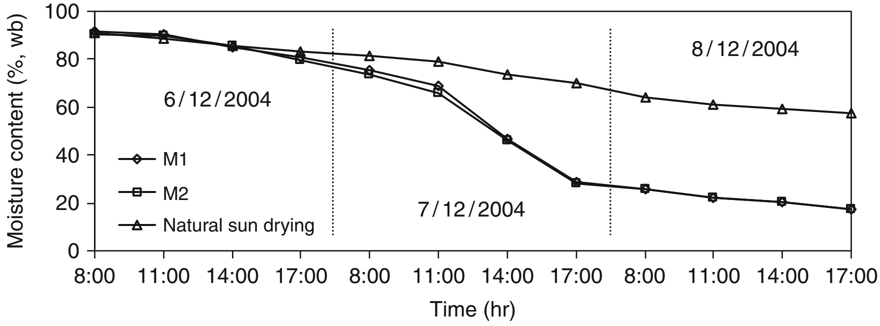

Fig. 23 Comparison of the moisture changes inside roof-integrated solar dryer and open sun drying during drying of rosella flower

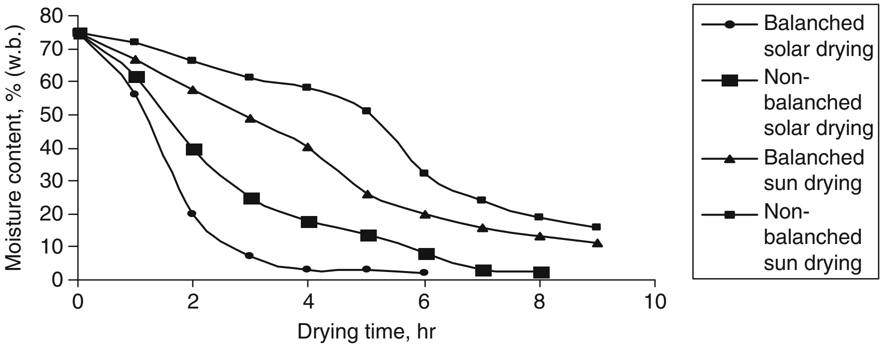

Fig. 24 Comparison of moisture changes inside hybrid solar dryer and open sun drying during drying of basaka leaves

was dried to 3% from 74% in 8 in the hybrid solar drier as compared to 16% from 74% in the traditional method. In solar dryer, it took 6 h to reduce moisture content of blanched leaves from 74 to 3% (wb), but for nonblanched samples it took 8 h to reduce similar moisture contents. There is a significant difference of drying rate between the blanched and nonblanched basaka as well as between the drying inside the hybrid solar dryer and open sun drying.

Solar tunnel drier has been widely tested in the fields in Bangladesh for drying of fish. The typical drying curves of fish dried in the solar tunnel dryer and those dried with natural sun drying at Cox's Bazar, Bangladesh, is shown in Fig. 25. Drying in the solar tunnel drier required 3 days to dry silver jew fish from 71.56% (wb) to 14.75% as compared to 71.56% to 23.63% in 3 days in traditional sun drying. There was no difference of drying rate at different positions of solar tunnel dryer.

Statistical analysis was conducted to assess whether there is any significant difference between solar drying and sun drying. Statistical analysis of solar drying data of Bombay duck of four experimental runs shows that although there is a highly significant difference in the experimental runs at 0% level, the difference

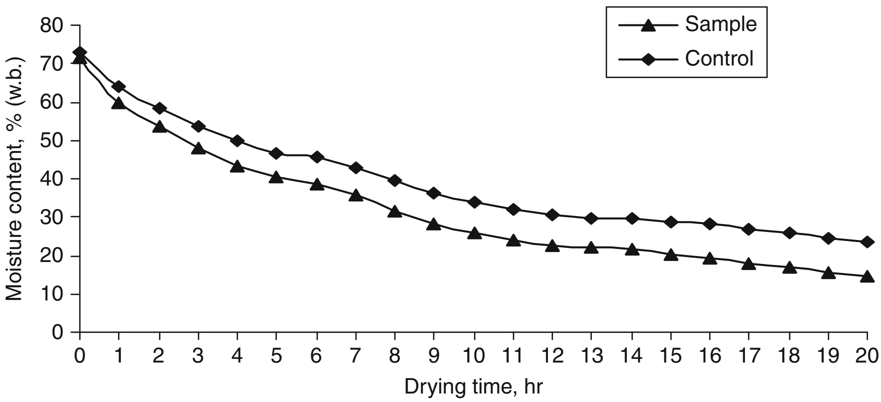

Fig. 25 Variations of moisture content with time for during solar drying of silver jew fish

Table 1 Analysis of variance of the solar drying data of four experimental runs

K value	Source	df	SS	MS	*F* value	Prob.
2	Treat A	3	323.382	107.79	32.12	0.00
4	Block B	1	165.690	165.69	49.37	0.00
6	AB	3	42.513	14.17	04.22	0.02
−7	Error	16	53.697	03.36		

Note: Block (Solar drying in the tunnel drier and sun drying) and Treatment (Experimental runs)

between the drying in the solar tunnel dryer and drying in the sun is also highly significant at 0% level (Table 1). This implies that drying in the solar tunnel dryer considerably reduces the drying time.

In all the cases, there was a considerable in reduction in drying time in solar drying. The solar dried products were high-quality dried products in terms of color, taste, and flavor.

5.2 Simulated Results

The mathematical model developed was validated against the experimental data of chili in Bangladesh. The simulated and observed air temperatures along the length of the dryer are shown in Fig. 26. The agreement is good.

Figure 27 shows a typical comparison between the predicted and experimental values of the temperatures at the outlet of the collector during drying of chili in a roof-integrated solar dryer at Silpakorn University. The agreement is good.

Figure 28 shows the experimental and simulated moisture content during solar drying of green chili in a solar tunnel dryer. Good agreement was found between the experimental and simulated moisture contents.

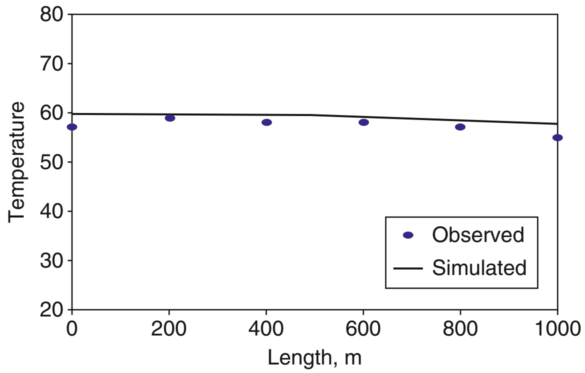

Fig. 26 Observed and simulated air temperature along the length of the dryer

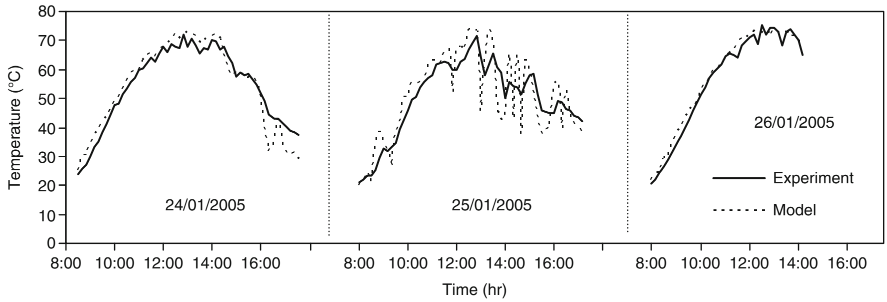

Fig. 27 Predicted and experimental values of the outlet temperature of the roof-integrated collector

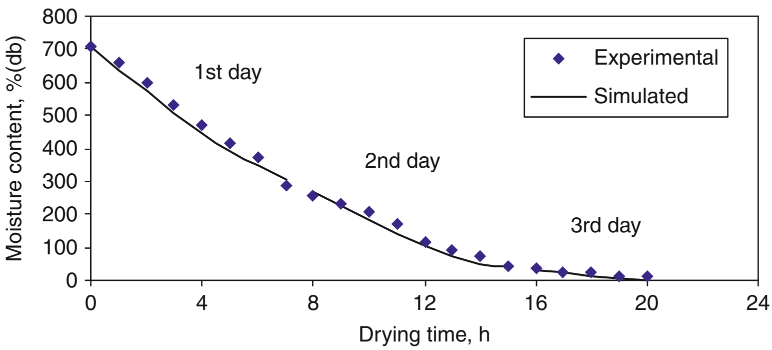

Fig. 28 Experimental and simulated moisture content during drying of green chili [38]

Figure 29 shows a comparison of the predicted and observed moisture contents of peeled longan inside a pv-ventilated greenhouse dryer and the model predicts the moisture content changes during drying well.

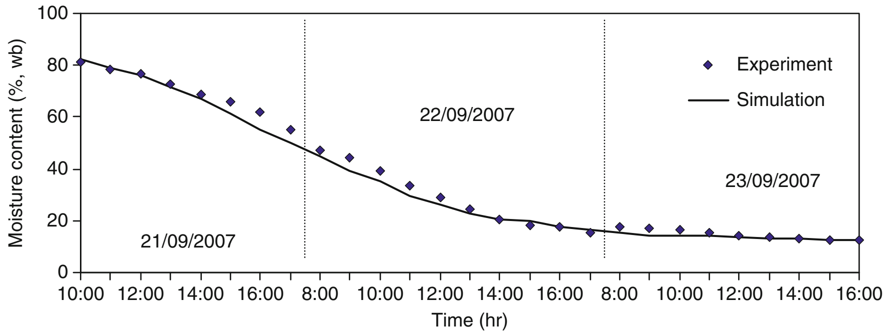

Fig. 29 Comparison of the simulated and observed moisture content during drying of peeled longan for a typical full-scale experimental run

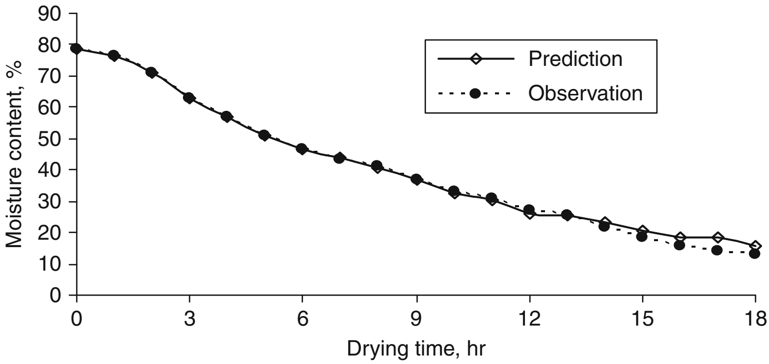

Fig. 30 Variation of predicted and observed moisture content of jackfruit leather with drying time

5.2.1 Neural Network Prediction

Comparison between the observed and neural network prediction of the performance of solar tunnel drier for drying of jackfruit leather is shown in Fig. 30. The agreement between the predicted and observed moisture contents is very good. Thus, if the model is adequately trained, it can appropriately represent the solar tunnel drying system very well.

5.2.2 Collector and Drying Efficiency

Table 2 shows collector efficiency, drying efficiency, and overall efficiency for a loading of 120 kg. The overall efficiency is within the range of 33–49%, while the overall efficiency for natural convection solar dryers is within the range of 12–18% [40]. This overall efficiency of the solar tunnel drier is due to the fact that the solar tunnel drier is a forced convection solar drier and the drying unit receives energy from both collector and incident radiation.

Table 2 Collector efficiency, drying efficiency and overall efficiency

Experimental run	Collector			Drier			Overall efficiency (%)
	Energy input (MJ)	Energy output (MJ)	Efficiency (%)	Energy input (MJ)	Energy output (MJ)	Efficiency (%)	
1	335.34	100.22	29.88	435.56	269.27	61.82	40.15
2	403.38	181.48	44.98	548.86	267.95	45.81	33.21
3	381.67	124.09	32.51	505.76	269.52	53.29	35.31
4	274.43	61.92	22.56	336.35	269.27	80.00	49.06
Average	348.71	116.93	32.48	456.63	269.00	60.23	39.43

Table 3 Computation of payback period of the solar tunnel dryer

Cost of drier	Tk 70,000
Salvage value	Tk 5,000
Expected life	15 years
Depreciation	Tk 4,333
Labor cost 70 × 6 × 30	Tk 12,600
Cost for sample preparation 50 × 2 × 24 × 6	Tk 14,400
Maintenance cost	Tk 1,000
Total operating cost	Tk 27,000
Cost of raw fish 24 × 120 × 10	Tk 28,800
Total cost	Tk 61,133
Total income 24 × 20 × 250	Tk 120,000
Net income	Tk 58,867

Note: One US Dollar = Taka 61.00

5.2.3 Economics of Solar Dryer

Solar dried products in the tropics and subtropics are sold at a price 2–3 times the price of the sun dried products. Since solar dried products are high-quality dried products of international standard, there is a demand for solar dried products in the international markets. The payback period of the solar tunnel dryer is 1–3 years depending on the location, product, and duration of operation of the dryer.

Table 3 shows that the payback period of the solar tunnel dryer for drying Bombay duck is almost 1 year, but the initial cost is very high. The dried product producers in the rural areas in Bangladesh should be provided with microcredit and extension of the microcredit approach of Grameen Bank should be adopted [41].

5.2.4 Potentials and Limitations

Field level tests demonstrated the potentialities for solar drying of grains such as rice and wheat using AIT dryer. But the quality is not reflected in the price. Hence, such dryers are not in use in the field.

Field level tests in Bangladesh and Thailand also have demonstrated the potentialities of solar tunnel dryer, improved solar tunnel dryer, greenhouse-type solar dryer, and roof-integrated solar dryer for production of quality dried fruits, vegetables, spices, medicinal plants, and fish.

Different products to be dried have different maximum permissible drying air temperatures. The drying air temperature for a product must not exceed the maximum permissible drying air temperature. In case of a solar tunnel dryer, the drying air temperature can be achieved by simply adjusting collector length (in solar tunnel dryer) or air flow rate by changing the number of fans in operation.

Solar dryers with UV-stabilized plastic cover require frequent replacement of the plastic cover. However, this problem can be overcome if solar drier with polycarbonate cover is used.

The photovoltaic system has the advantage that the temperature of the drying air is automatically controlled by the solar radiation.

In cloudy days, the pv-ventilated solar driers can be used for drying since it operates on diffuse solar radiation, but the drying rate is significantly reduced.

One major disadvantage of this drier is that it does not have any backup heating system. But in rainy days the pv-ventilated solar drier can be used if it is integrated with either a biomass furnace or oil or gas burner.

The year round operation of the pv-ventilated solar driers for production of different solar dried products would further reduce payback period and would justify the financial viability of the pv-ventilated solar driers as attractive and reliable alternative to the sun drying in the tropics and subtropics.

Solar tunnel driers are now in operation in different regions of the tropics and subtropics and the other types of pv-ventilated solar dryers designed by Janjai (Personal communication) are also in operation in the field in Thailand.

Since the drier is PV operated it can be used in the areas where there is no electric grid connection.

The photovoltaic driven solar drier must be optimized for efficient operation.

Finally, solar driers are environmentally sound.

6 Conclusions

Field level tests demonstrated that pv-ventilated solar dryers are appropriate for production of quality dried fruits, vegetables, spices, and fish.

In all the cases, the use of solar dryer leads to considerable reduction of drying time in comparison to sun drying and the quality of the product dried in the solar drier was of quality dried products as compared to sun dried products.

The solar dryer can be operated by a photovoltaic module independent of electrical grid.

The photovoltaic driven solar driers must be optimized for efficient operation.

Simulation models can be used to provide design data and for optimal design of solar dryers.

The neural network prediction of the model has been found very good and can be used to predict the potential of the dryer for different locations and can also be used in a predictive optimal control algorithm.

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A Promising Technology of Pressure into Power: A Case Study of Pressure into Power Approach in Gas Transmission Lines in Pakistan

Imran Nazir Unar, Suhail A. Soomro, Shaheen Aziz, Abdul Rehman Memon, and Khan M. Qureshi

Abstract Pakistan is gas rich but power poor country. Conventional approach is always directed toward power plants using fossil fuel. Some trials have also taken place demonstrating wind and other nontraditional energy source for generating electricity. A pragmatic and feasible unexploited resource is the potential energy from high-pressure natural gas. Currently, this energy is being wasted at gas pressure reducing stations in Pakistan. At present there are two integrated gas companies (transmission and distribution), i.e., Sui Southern Gas Company Limited (SNGPL) and Sui Northern Gas Pipelines Limited (SSGCL). The gas is transmitted through the transmission pipelines in the pressure ranges of 800–1,000 psig. The gas is distributed by reducing from the transmission pressure into distribution pressure up to a maximum level of 150 psig at the city gate stations normally called "sales metering station (SMS)." There are almost more than 200 SMSs in SNGPL and SSGCL.

This study highlights real possibilities to utilize the energy lost in gas reducing stations (SMSs) as a source of electrical power. The present study shows that with average pressure ratio (ratio of upstream to downstream pressure) of 10 and average gas flow of 35 MMSCFD from any gas metering station, more than 2 MWe power could be generated without consumption of any fuel.

Keywords Gas transmission • Pakistan • PIP • Power generation • Sustainability

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1 Introduction

Pakistan has unceasing power shortfall, which will persist for the next 20–30 years at least. It is therefore a national imperative to explore all available and potential sources of power; preferably with best thermal efficiency to contain the fossil fuel resources and minimize dependence on imported oil.

The primary fuel for power generation in Pakistan is natural gas or oil. Pakistan is among the most natural gas dependent economies of the world. Natural gas was first discovered in 1952 at Sui in Balochistan province which proved a most significant and largest gas reservoir. This major discovery at Sui followed a number of medium and small size gas fields in other parts of the country. One study showed that the so far discovered gas reserves are about 1.2 TCF of which 453 BCF have already been produced [1].

2 Sui Northern Gas and Sui Southern Gas Company

There are two public sector companies, Sui Northern Gas and Sui Southern Gas, which are responsible for transmission and distribution of gas in the north and the south of Pakistan, respectively. There is a well-developed gas transmission and distribution network consisting of more than 8,000 km of transmission lines and above 53,000 km of distribution lines [2]. The natural gas resource is a finite source of energy. Regular foreign exchange investment is needed to maintain and expand natural gas reserves. Similarly, oil prices are not constant and tend to fluctuate; usually upwards which also adds abnormal pressure to the foreign exchange availability.

In this chapter, a unique opportunity will be introduced for power production without the consumption of any fuel. It is not based on the usual solar, wind, or hydropower concepts, but utilizes the existing potential energy of the high-pressure natural gas transmission network in Pakistan as a source for electrical energy. The technology is called Pressure into Power (PIP) technology.

3 Exploration, Transmission, and Distribution Setup of Natural Gas in Pakistan

In Pakistan, the transmission and distribution of natural gas is being carried out by two integrated gas companies called SSGCL and SNGPL.

Figure 1 shows a brief model of the integrated gas company and all the major components are highlighted.

Natural gas field is explored by different exploration companies such as OGDCL, PPL, OMV, BHPB, MOL, PEL, PCPL, etc. After its exploration, raw gas is sent to

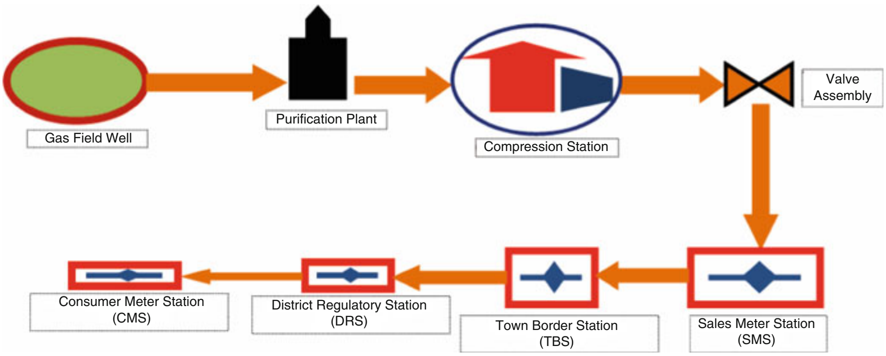

Fig. 1 General model of integrated gas company

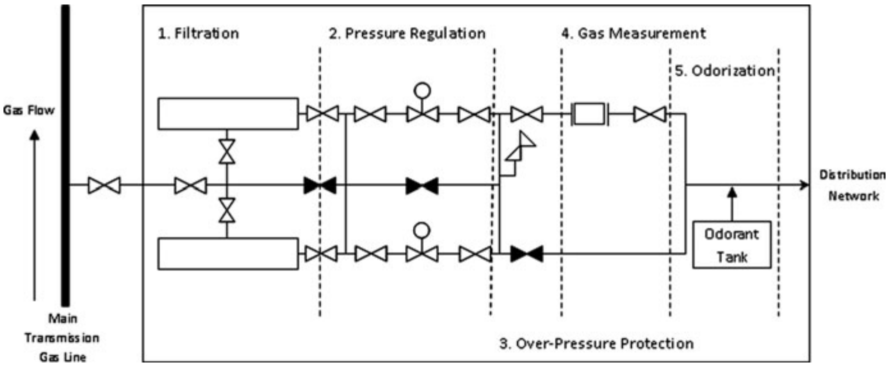

Fig. 2 An overview of a sales metering station (SMS)

purification plants. The purified natural gas is then handed over to the integrated gas company for its transmission and distribution.

The natural gas is first transmitted at high pressures of ranges 800–1,100 psig from purification facilities to the main cities or consumers. The high pressures (900–1,100 psig) are being maintained after long distances by the compression stations, installed after certain miles of length. At the gate of any city or town, the off-take is taken out and the natural gas is filtered (only for dust particles or condensate), pressure reduced (usually up to 275 psig normally), measured and distributed in the city or town [3]. The station for pressure reducing and measurement of natural gas is called "SMS." In the city the gas is further depressurized at Town Border Station (TBS) or at District Regulating Station (DRS), and finally it is injected in the consumer facilities after its measurement. The measurement facility is called Consumer Measurement Station (CMS).

Figure 2 shows a typical layout of SMS along with its different operational zones.

4 PIP: Power Production from Pressure Potential

Potential energy of natural gas is lowered through throttling. The gas-throttling process may be replaced by a gas expansion process in turbo expanders (TE) for the conversion of pressure of the natural gas into the mechanical energy of the rotation of TE impeller, which can be transmitted to a loading device, for example, an electric generator, compressor, or pump [4].

This precious potential energy can be used either for power generation to get revenue or used to save energy for various high volume natural gas consuming process industries [5].

Apart from no-fuel consumption, one another very important but maybe not so appreciated factor of this power production source is no harmful impact on environment. The power production efficiency is greater with natural gas expansion than conventional thermal power producing technology, with significant absence of polluting components through waste gas emission [5].

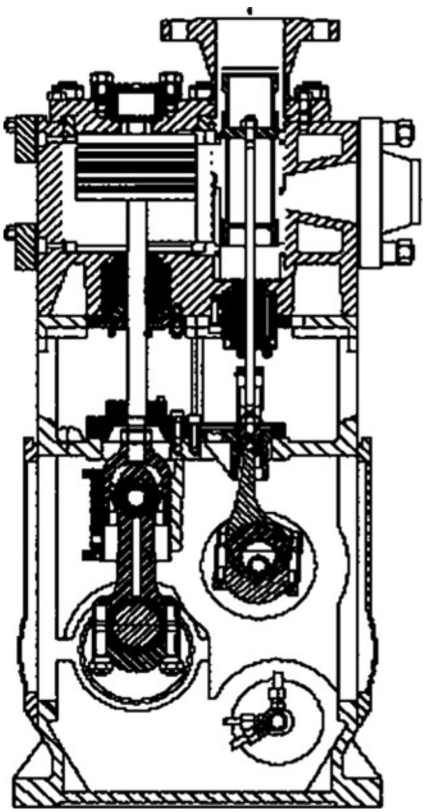

Fig. 3 Turbo expender by Dresser

In this power producing source, the pressure of natural gas produces power with no additional fuel burning and therefore does not require any additional natural gas for electricity production. The expansion engine or turbine lowers the pressure of gas which was introduced at high pressure and then injected in the gas network for its end use [5].

Turbines are generally rated from 150 kW to 2.5 MW for power production; however, several stages are required to reduce pressure, and one heavy pressure reduction valve could be replaced by an array of small turbine-generator modules [6].

Maddaloni and Rowe [7] proposed that high pressure natural gas can give electrical power with an exergetic efficiency approaching 75% with the assumption of maximum component operating efficiencies and a pressure ratio of 4:1. For this pressure ratio (4:1), a preheating system with 1 kg/sec of natural gas mass flow rate has the potential to produce over 140 kW of electrical power and with the same pressure ratio, a purification system could produce over 110 kW/(kg/s of natural gas) of electrical power [7]. The modeling results of an actual pressure reduction facility showed the electricity production was as high as 1,110 kW [7].

Several international companies developed the efficient gas expanders like Dresser Inc. [8]. The gas expansion engine is the heart of Dresser's PiP™ power generation solution (as shown in Fig. 3) connected to a generator. As per Dresser Inc., up to 1.5 MWe per unit can be harvested from their expansion engine acting as a pressure reducing gas regulator.

5 Case Study with Actual Facts and Figures in a City of Pakistan

Multan is a big and highly populated city of Pakistan and considered as central city of the country. Multan city is located in the province of Punjab, Pakistan and due to the rapid increase in industrialization for the last couple of years, it is in good ranking. The domestic and industrial natural gas requirements for Multan city has been fulfilled by the SNGPL Company. There are more than 40 gas regulating and metering stations (SMS) in Multan region operated by Transmission Department of SNGPL. Four SMSs were selected for their high gas volume flow rates as compared to others from Multan region where high pressure natural gas is reduced and metered from transmission gas lines to distribute the gas in the city and industries. The four SMSs were divided into two categories as domestic and industrial SMS. The monthly gas consumption record of selected four SMSs along with gas flow, inlet (high) pressure, outlet (low) pressure is given for the year 2007 in Tables 1 and 2 (for domestic load) and Tables 3 and 4 (for industrial load).

Table 1 Monthly inlet/outlet pressure and gas flow for the year 2007 of SMS-I Multan

Location	Month	Inlet high pressure (PSIG)	Outlet low pressure (PSIG)	Gas flow (MMSCF)
	January	873	85	1,079.886
	February	870	85	843.421
	March	870	86	774.689
	April	870	85	582.957
	May	870	84	557.893
	June	870	80	538.018
	July	870	75	573.963
	August	870	75	573.642
	September	871	75	594.606
	October	872	75	631.123
	November	870	80	638.703
SMS-I Multan	December	873	80	944.368

Table 2 Monthly inlet/outlet pressure and gas flow for the year 2007 of SMS-IV Multan

Location	Month	Inlet high pressure (PSIG)	Outlet low pressure (PSIG)	Gas flow (MMSCF)
	January	860	79	497.466
	February	865	80	430.497
	March	863	81	414.347
	April	860	80	352.023
	May	859	78	345.715
	June	860	74	341.546
	July	860	70	329.785
	August	862	69	328.284
	September	864	71	337.837
	October	861	70	368.928
	November	858	75	383.923
SMS-IV Multan	December	861	76	450.795

Table 3 Monthly inlet/outlet pressure and gas flow for the year 2007 of SMS-III Multan

Location	Month	Inlet high pressure (PSIG)	Outlet low pressure (PSIG)	Gas flow (MMSCF)
	January	876	660	1,049.272
	February	874	661	1,542.230
	March	875	662	1,736.659
	April	875	659	1,698.938
	May	873	664	1,736.481
	June	877	663	1,699.716
	July	875	660	1,667.608
	August	876	660	1,852.687
	September	870	662	1,803.249
	October	872	664	1,815.847
	November	874	662	1,726.413
SMS-III Multan	December	875	660	1,611.460

Table 4 Monthly inlet/outlet pressure and gas flow for the year 2007 of SMS-VI Multan

Location	Month	Inlet high pressure (PSIG)	Outlet low pressure (PSIG)	Gas flow (MMSCF)
	January	1,020	60	138.716
	February	1,031	61	142.401
	March	1,028	61	157.973
	April	1,030	62	154.986
	May	1,030	60	162.494
	June	1,034	59	167.360
	July	1,027	60	174.935
	August	1,030	62	177.098
	September	1,031	60	162.817
	October	1,028	61	164.503
	November	1,025	60	162.177
SMS-VI Multan	December	1,005	61	167.320

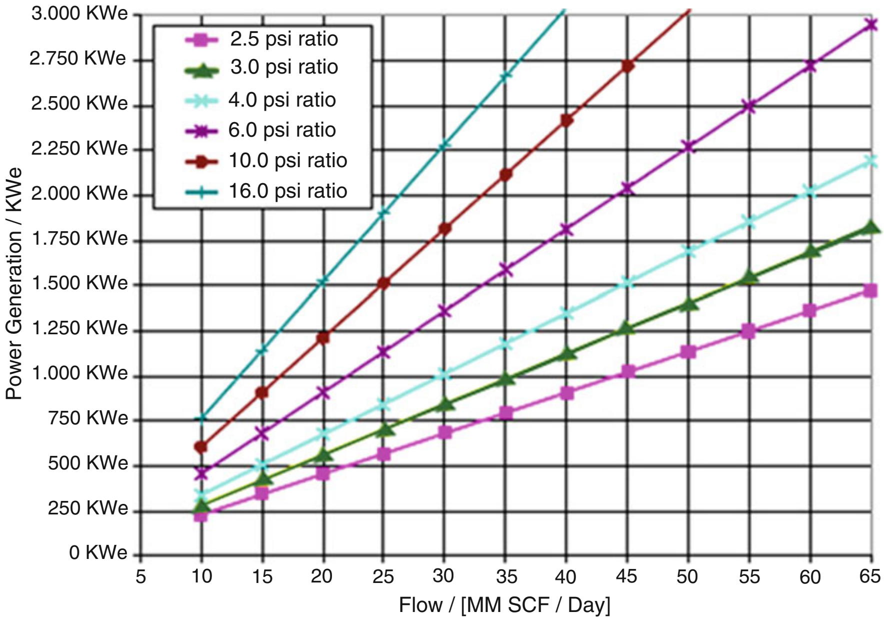

Fig. 4 Potential power generation vs. flow and pressure ratio

6 Results and Discussion

Dresser Inc. [8] gave one curve (Fig. 4) to estimate the power potential for any natural gas pressure regulating station (SMS) at different pressure reduction ratio and gas flow. For example, a gas expansion station with pressure ratio of 6.0 (ratio

Table 5 Monthly estimated power production from SMS-I Multan

Location	Month	Pressure ratio (high/low)	Gas flow/day (MMSCFD)	Estimated power production (kW)
	January	10.27	34.84	2,125
	February	10.24	30.12	1,800
	March	10.12	24.99	1,500
	April	10.24	19.43	1,195
	May	10.36	18	1,125
	June	10.88	17.93	1,150
	July	11.6	18.51	1,250
	August	11.6	18.5	1,250
	September	11.61	19.82	1,305
	October	11.63	20.36	1,305
	November	10.88	21.29	1,295
SMS-I Multan	December	10.91	30.46	1,875

Table 6 Monthly estimated power production from SMS-IV Multan

Location	Month	Pressure ratio (high/low)	Gas flow/day (MMSCFD)	Estimated power production (kW)
	January	10.89	16.05	992
	February	10.81	15.37	920
	March	10.65	13.37	805
	April	10.75	11.73	735
	May	11.01	11.15	705
	June	11.62	11.38	745
	July	12.29	10.64	745
	August	12.49	10.59	745
	September	12.17	11.26	745
	October	12.3	11.9	750
	November	11.44	12.8	780
SMS-IV Multan	December	11.33	14.54	925

Table 7 Monthly estimated power production from SMS-III Multan

Location	Month	Pressure ratio (high/low)	Gas flow/day (MMSCFD)	Estimated power production (kW)
	January	1.33	33.85	305
	February	1.32	55.08	675
	March	1.32	56.02	680
	April	1.33	56.63	695
	May	1.31	56.02	680
	June	1.32	56.66	695
	July	1.33	53.79	665
	August	1.33	59.76	835
	September	1.31	60.11	835
	October	1.31	58.58	830
	November	1.32	57.55	825
SMS-III Multan	December	1.33	51.98	645

of inlet high pressure over outlet low pressure) and gas flow rate of 25 million standard cubic feet per day (MMSCF/day), the potential power generation capability from this gas expansion station is about 1,125 kW.

Similarly utilizing the data given in Tables 1–4, monthly estimated power production was calculated using Fig. 4 and shown in Tables 5 and 6 (for domestic load) and Tables 7 and 8 (for industrial load).

It is seen from Tables 5–8 that the power production at various SMSs operated by the natural gas transmission company in Pakistan is feasible. The power production from domestic SMSs is higher than that of industrial because of high pressure

Table 8 Monthly estimated power production from SMS-VI Multan

Location	Month	Pressure ratio (high/low)	Gas flow/day (MMSCFD)	Estimated power production (kW)
	January	17	4.47	405
	February	16.9	5.09	535
	March	16.85	5.1	535
	April	16.61	5.17	535
	May	17.17	5.24	535
	June	17.53	5.58	565
	July	17.12	5.64	550
	August	16.61	5.71	550
	September	17.18	5.43	535
	October	16.85	5.31	535
	November	17.08	5.41	535
SMS-VI Multan	December	16.48	5.4	325

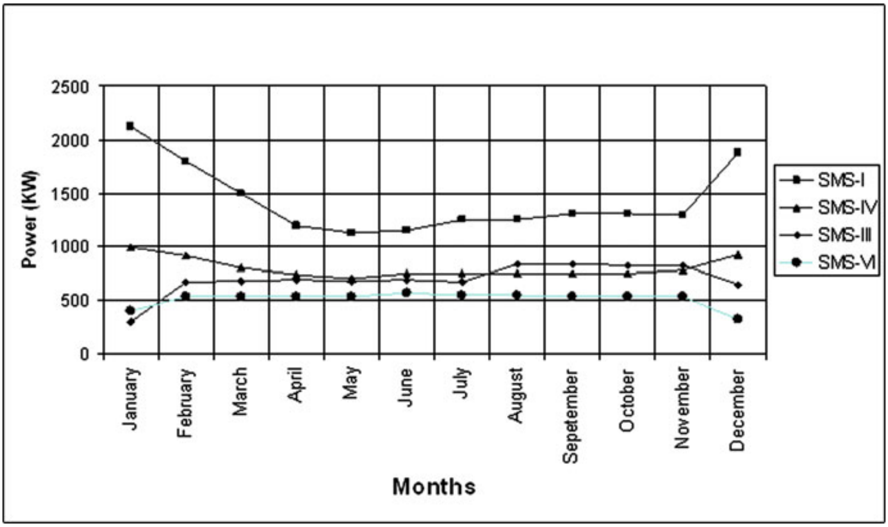

Fig. 5 Estimated power production through PIP technique at various SMSs for the year 2007

ratio. Though the gas consumption is higher at industrial SMSs as shown in Table 5 for SMS-III Multan but there is less power production due to a reduced amount of difference in pressures between input (high) and output (low). The monthly power production can be seen for all the mentioned SMSs in Fig. 5.

Figure 5 clearly shows that there is a seasonal effect in the power production as mentioned by Maddaloni et al. [9]. This is because of the gas consumption variations for summer and winter season at domestic SMSs but the industrial gas consumption is about constant throughout the year so gives a smooth profile of power production.

7 Conclusion

From this study following observations have been concluded:

1. The maximum estimated power generation at domestic SMS is about 2,125 kW with average pressure ratio (ratio of upstream pressure to downstream pressure) is about 10.27 and the average gas flow is about 34.84 MMSCFD.
2. Power production from the potential of pressure at SMS (or pressure let-down station) is an innovative method and quite feasible in Pakistan.
3. Pakistan is rich in the natural gas transmission system as two giant organizations are currently working, i.e., SNGPL and SSGCL and more than 200 SMSs (metering and pressure letdown stations) are installed throughout the Pakistan so there is a great potential to develop the system with feasible economical considerations.
4. As no fuel is consumed for power generation through PIP system, hence the economy of the country may increase for generation of maximum power by this system and less utilization of the conventional fuels (such as gasoline, diesel, natural gas, coal, etc.).
5. This power generation approach is an environment friendly system due to no emissions of green house gasses (such as CO_2) and air pollutants (such as NO_x and SO_x) as no fuel burning at all for power production in the system.
6. The forecast power that may produce from the SMS can be used for supplying electricity to the low populated towns or villages. This will decrease the demand for electricity from main national grid which may be used at highly populated cities.
7. The estimated power may be utilized for industrial purposes also.
8. There is a seasonal effect on the power production through PIP technology due to the gas consumption pattern variation in summer and winter season significantly.

Acknowledgments The data for different sales metering station were collected from the daily transmission reports of SNGPL.

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Technologies for Harnessing Tidal Power in Pakistan

Raza Haider Leghari, Mohammad Aslam Uqaili, and Khanji Harijan

Abstract Pakistan is facing a somber power crisis due to lessening of conventional energy sources of energy. There is a large gap between demand and supply of electricity, which is about 2.5–5 GW, registering a shortfall of more than 20%. Alertness of global warming and climate changes menacing the earth noticeably, we are all responsible to evade exploitation of fuel energy, particularly CO_2 emitting. The need for exploring alternative, environmental-friendly, and renewable energy resources has therefore become more foreseeable.

Tidal power is the clean and white energy technology, which is available at no fuel cost and minimal running cost. The coastline of Pakistan, which is about 1,045 km long with dominant features, is the best resource for harnessing tidal energy. The tidal energy resources present in the oceans are of much higher density and better reliability than any other renewable for the likely future. Though tidal power is predictable and available in the form of blocks of energy, it may not solve the energy crisis, but can decrease the reliance on fossil fuels. It can spread our energy resources and meet stringent greenhouse gas emission targets.

The chapter presents the assessment of tidal power harnessing technologies and selection of suitable technology for Pakistan. Despite the fact that tidal power has not yet been introduced in Pakistan compared to other renewable energy technologies, but in near future it may play a key role. The study concludes that the tidal stream power technology is the best technology for tidal pilot power plants in the coastal creeks of Pakistan.

Keywords Energy crisis • Environment friendly • Pakistan • Pilot projects • Renewable energy • Tidal power

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1 Introduction

Development of renewable energy in the world is only because of growth in electricity demand in the developing nations. Power generation using conventional energy sources does not meet the ground realities and the environmental policies. The renewable forms of energy are clean but unpredictable, so as to provide auxiliary electricity supply. Tidal energy is the one that is predictable in nature and more submissive to estimate. Though tidal current resources at a certain location fluctuate with recurring patterns, they are quite predictable, based on collective facts of tidal ranges, segments, and flow velocities [1]. Exploring the coastal resources for electricity production conveys highest returns to the society and makes an important involvement in the national targets for energy mix. Electrical energy is an imperative component to development and indicator for upgradation of the society. The development of the huge coastal resources in terms of tidal power generation can enhance the resource productivity of the system.

Pakistan lies in the string of underdeveloping countries, but is wealthy in the indigenous resources; ocean energy is one of them. The energy from the strong tidal currents can be converted into electrical form. There are two tidal bulges in a lunar day and this is caused because of the gravitational forces of moon, sun, and earth, and the resulting effect is regular movement and ups and downs of seawater. With no sufficient energy in working forms and at reasonable prices, there is a little hope for developments of improving the economies of a country and the living conditions of the people [2].

The determination of any energy source can be practical by the technology. It makes the jobs easier and acts as a driver for recent developments. There is a past history of tidal energy exploration before Christ, where the energy was used to grind the grains. In today’s world, demand of electrical energy has been increased but the resources are becoming limited, so again technology will prove to cope this crisis. Marine and tidal currents are a promising energy resource that has not yet been commercially developed. But there are several ongoing research and development projects for pilot considerations in Europe and America [3].

The energy from the ocean can be extracted in one of the two forms, ocean thermal and ocean mechanical energy. The technology for ocean mechanical energy is in progress and can be harnessed in two forms, potential and kinetic energy. The structure to harness the potential energy of moving tidal waters is based on a barrage system and for kinetic energy the current velocity of tides is utilized for conversion. The tidal power plant based on barrage system has high capital cost and long completion time. It is similar to hydropower station but with some enhanced feature, like the head required here is less than conventional hydro. Tidal barrages are built at estuaries, lagoons, and the beaches that influence high and low tides [4].

The tidal plant based on tidal stream technology utilizes the kinetic energy of moving tidal currents. This type of plant is easy to install with low capital cost as compared to tidal barrage system. As the kinetic energy in fluid flow is proportional to velocity cubed, the energy accessibility is extremely responsive to the velocity [5].

The tidal stream power plant works best at creeks, rocky shores, and narrow heads with high velocity tidal currents. The technology is gaining success as all the features are built in a single unit. This is one of the recent forms of technology to be developed, and research work for implementing the pilot projects has also been carried out. The technology has now been step forwarded from pilot projects to commercialization. The developers believe it is well on track to deliver encouraging results with the potential to supply electricity on large scale, at low cost, and environmental friendly [6].

According to the data collected from National Institute of Oceanography, Pakistan, the tidal velocities in the Indus deltaic region are in between 2.5 and 3.0 m/s. And the data from Pakistan navy hydrographic department shows the average figures of tidal range in coastal region are from 2.0 to 3.4 m [7]. The study of the technology in this work is focused on the tidal velocities and ranges available in the Pakistan coast.

2 Tidal Power Harnessing Technologies

Oceans cover more than two-thirds of the earth surface and have a large potential of energy. The energy from the mechanical occurrence of tides can be exploited in two ways: tidal barrage and tidal stream. The basic mechanical systems and electricity generation mechanism is explained.

2.1 Tidal Barrages

Tidal barrages utilize the potential energy of seawater to convert mechanical energy into electrical through tidal turbines. One of the advantages of tidal barrage power plant is its low head, as high required for hydropower plants. The barrage structure contains a sequence of turbines and sluice gates. These machines convert tidal flows into mechanical energy. The costal belt in Pakistan has several creeks and straits where the tidal flows inundate up to 80 km [8].

Indus deltaic region along Pakistan coast has several bays and lagoon that cover large sea areas. The saline deposits in these areas are copious than the open sea because of high rate of physical and chemical processes. If these parts of the coast are closed artificially, the physical change will create hydraulic head with greater level of water on the seaside. This natural head can be exploited for acquiring potential mechanical power. The natural made costal topography is a great asset for potential energy supply in the region and to overcome the energy reliance. The barrage structure is shown in Fig. 1.

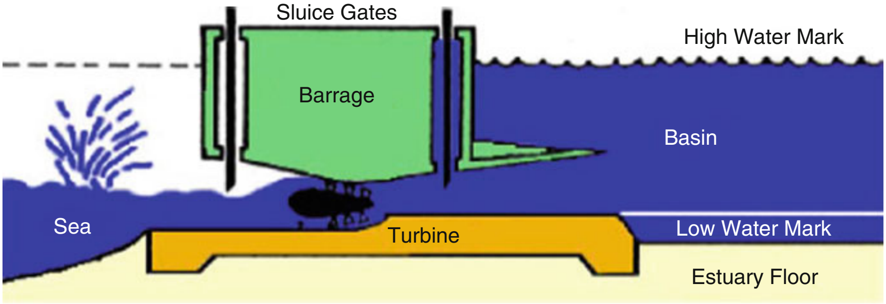

Fig. 1 Overview of tidal barrage system

2.2 Tidal Barrages Energy Generating System

The tidal regime in the coast of Pakistan is semidiurnal that has two high tides and two low tides every 24 h and 50 min. One tidal cycle completes by means of two tides of 6 h and 25 min duration each. The electricity generation from tidal barrage can be obtained in one of the two generating systems: one is ebb generation and the other is two-way generation.

Ebb generation: The tides are classified as ebb and flood, ebb tide is the seaward tidal flow from high water to low water. Flood tide is the landward tidal flow from low water to high water. In ebb generation, incoming tidal flow is stored in the reservoir and released back through sluice gates to drive the turbines.

Two-way generation: In two-way generation, the same procedure follows except the flood is also utilized for driving turbines.

2.3 Tidal Range

The prerequisite for tidal barrage power plants is the maximum tidal range in meters. The feasible tidal range is 5 m, but with the growth of new turbine technology this requirement appears not to be limited. The tidal range of 2–3 m could also be utilized for tidal power generation. The existing example is Kislaya Guba tidal power plant in Russia, which is operating since 1968 [9]. In Pakistan, the creek system lengthens more than an area of 170 km; the flow of ebb and flood tides in this region is extremely smart for tidal power generation. According to the data recorded by Pakistan Navy Hydrographic Department, the tidal range around these creeks is in between 2 and 4 m [10]. The technology now has been advanced and it can prove to be approving for this range.

2.4 Turbines Used for Barrage System

Bulb-type turbine: Bulb-shaped turbine that covert the potential tidal flow into mechanical and generator coupled into electrical. For maintenance purpose, seawater is stopped which breaks the continuity of supply. These turbines have possible loss of generation because of the structure (Fig. 2).

Rim-type turbine: The rim-type turbines contain generator that is escalated at right angles to the turbine blade. This design makes the admittance easier. These turbines are not appropriate for pumping; therefore it becomes hard to control the overall performance (Fig. 3).

Tubular-type turbine: The blades of these turbines are coupled to an extended shaft and adjusted at an angle so that the generator is sitting on top of the barrage. Severn tidal power plant in UK has projected tubular turbines for power generation (Fig. 4).

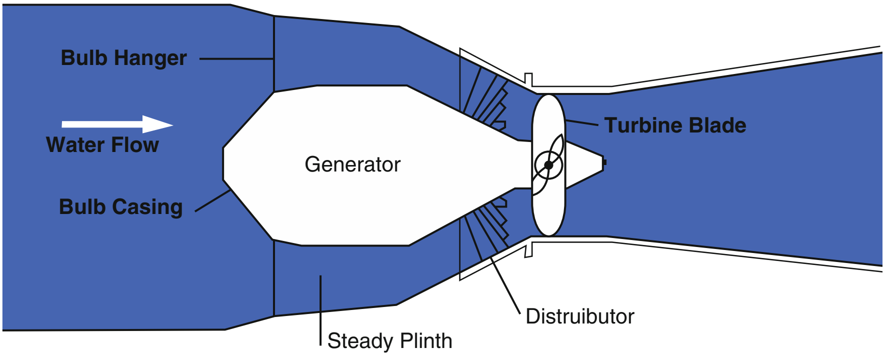

Fig. 2 *Bulb turbine*. Source: Australian CRC for Renewable Energy Ltd. (ACRE)

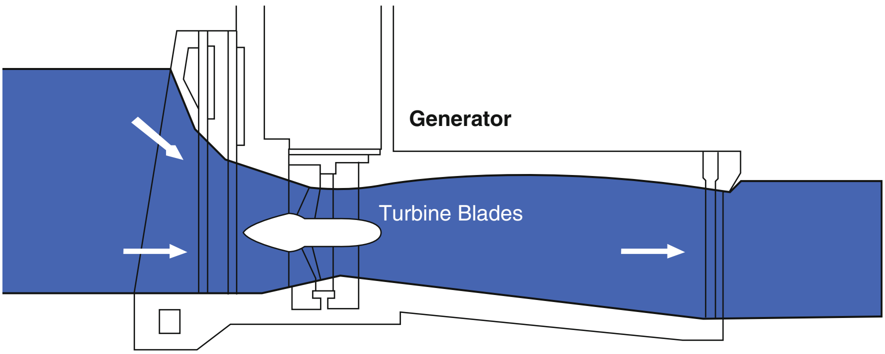

Fig. 3 *Rim turbine*. Source: ACRE

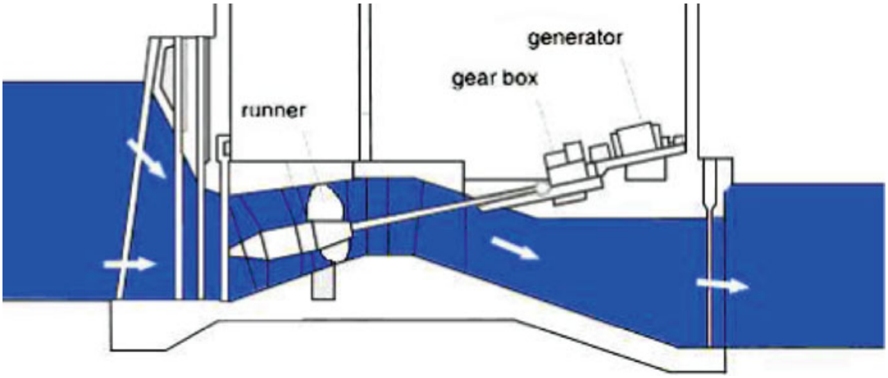

Fig. 4 *Tubular turbine*. Source: ACRE

3 Tidal Stream Technology

This technology is new and has been progressive in the last decade. Tidal stream technology explores the kinetic energy from moving seawater currents. This system is very much similar to wind energy technology. The coastal areas in Pakistan influence high tidal currents, which contain a lot of kinetic energy. This energy can be changed into electricity using underwater sea turbines. The Marine Current Turbines (MCT) are most packed together than wind turbines just because the density of seawater is 832 times larger than the air. This puts more stress on the turbine structure [11].

This technology is new at this stage, but the developers are trying to design efficient and larger turbines to utilize the maximum current velocity. The similarity to wind turbine technology has made the performance tasks easier and achievable. The underwater sea turbines are submerged into the tidal stream and are made free to move and line up themselves with varying flow direction. The energy available in the coastal waters is great in amounts, only the exploitation is required therefore the marine energy sector is presently the center of much educational and industrial research in the world.

3.1 Marine Current Devices

The utilization of the energy in a tidal flow requires the conversion of kinetic energy into mechanical system, which can then drive a generator. In association to tidal barrage system, these technologies have least cost and the time of installation and commissioning is also less. The process of installation is complex because everything happens in the sea. In tidal estuaries the stream is constant; therefore no yawing system is required to line up the turbine to the flow. These distinctive features have made the tidal stream technology successful and productive [12].

There are two companies that have been the world leader in the growth of tidal stream technology for extracting energy from tidal currents at small- and large-scale power generation:

- MCT, "SeaGen"
- Lunar Energy Device [Rotech Tidal Turbine (RTT)]

3.2 Marine Current Turbines

MCT are open flow waterpower switching devices that have twin open axial flow rotors (propeller type) mounted on "wings" either side of a mono pile protract structure, which is installed in the seabed. Rotors have full span pitch control and drive induction generators at variable speed through three stage gearboxes. The gearboxes and generators are submerged, therefore the casings of which are exposed openly to the fleeting seawater for competent cooling. An obvious and important feature of the technology is that the complete wing together with the rotors can be lifting up the pile above the water surface for maintenance. Blade pitch is rotated 1,800° at slack water to lodge bidirectional tides without necessitating a split yaw control mechanism [13]. The device is shown in Fig. 5.

3.3 Lunar Energy Device

Lunar energy or RTT take hold of an exclusive worldwide license to a single, pioneering technology concerned with generating renewable energy from tidal streams. It is a bidirectional horizontal axis turbine housed in a balanced venturi duct. The venturi draws the accessible ocean currents into the RTT in order to

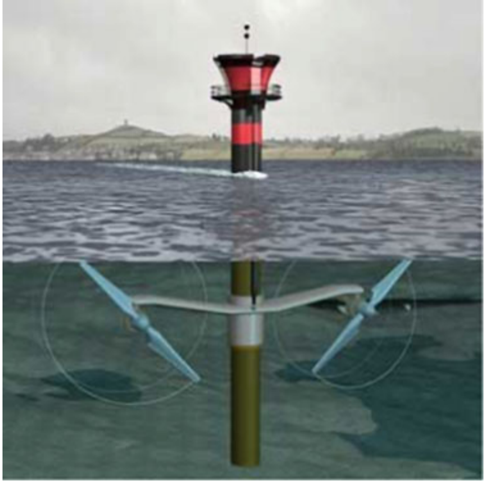

Fig. 5 Marine current turbine

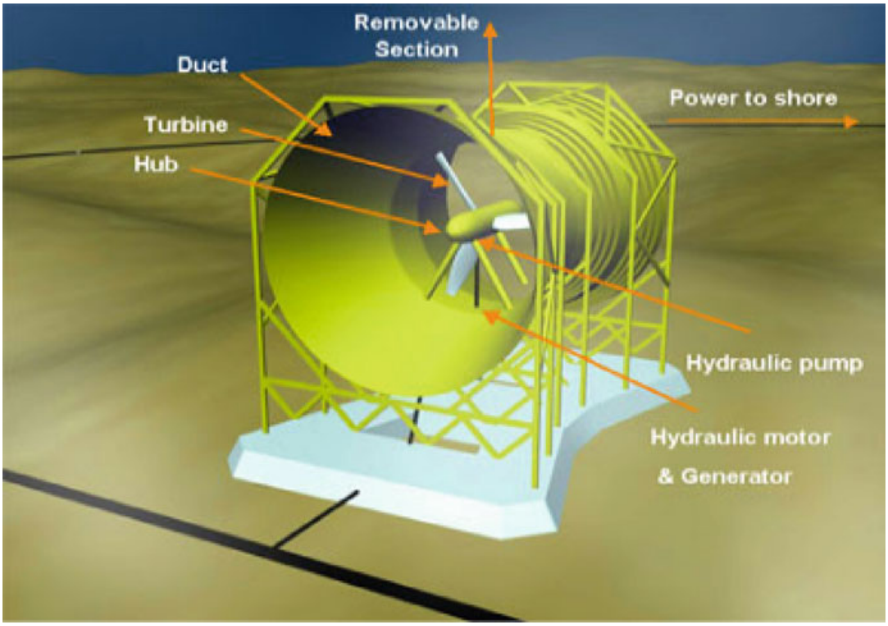

Fig. 6 Rotech tidal turbine

detain mechanical energy and convert it into electricity. The venturi duct eliminates the need for blade pitch control to make level the tidal flow so that it comes close to the turbine blades ensuring maximum extraction of the available energy [13]. The RTT is shown in Fig. 6.

4 Suitable Technology for Pakistan

The technology assessment for tidal power generation proves to be clean, green, predictable, and efficient. The detailed study of different power plant in the world shows that the energy in part can be contributed for base load electricity. The assessment and topography of Indus deltaic creeks prove to be suitable location for making use of tidal stream. The velocities around these areas are in between 2 and 3 m/s, and according to the manufacturers the required velocity for power generation is 2.4 m/s.

These machines have been effectively installed and giving maximum output. This is proved the basic physics of electricity generation from the moving tidal current and operation for both horizontal and vertical axis turbines. The company has now invented the large commercial turbine, having two rotors generating equivalent electricity. This twin rotor impression proved to be more power generation from single pile mechanism. This is going to decrease the cost and stay the rotors away from the pile for standard bidirectional function [14].

5 Conclusion

There are many dynamic factors following the growth in renewable energy technologies, which make it an attractive market to be in at the present time. Tidal energy is a particularly lively part of that market and is fast developing along lines that could one day make it momentous provider to energy generation not just in Pakistan, but worldwide. The investigation carried out for assessing technology indicates tidal stream technology to be a suitable option. The downside aspect is the limited supply that is according to the tidal cycles. The only factor affecting promotion of these technologies is the cost, but if we compare it to fossil fuels power generating plants then it will not be so expensive. We have to utilize these abundant, indigenous, and environmental friendly technologies for promoting the renewable energy sector in order to come in the row of developing nations.

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Utilizing Solar Thermal Energy in Textile Processing Units

Asad Mahmood and Khanji Harijan

Abstract This chapter presents the prospects of solar thermal energy utilization in the textile processing units in Pakistan. Various solar thermal technologies suitable for thermal energy production and their applications for different processes in the textile units are discussed. The chapter concludes that solar thermal energy utilization in the textile processing units could add a comfort to some extent to the textile industry of Pakistan.

Keywords Environmental pollution • Solar energy • Textile industry • Thermal energy • Water heating

1 Introduction

Pakistan is amongst the most prominent cotton producing countries in the world. The affluent availability of local cotton has led to a well-established textile sector in the country. The local textile industry has been the backbone of the country's economy. It contributes more than 60% to the total export earnings of the country, accounts for 46% of the total manufacturing, and provides employment to 38% of the manufacturing labor force. A large proportion of its cotton products go into export. Most of the Pakistan's textile trade is with the USA, EU, and the Middle East. The main textile exports include cotton cloth, cotton yarn, knitwear, tents, and canvas/tarpaulin, silk, and synthetic textile [1–2].

The textile processing units in Pakistan use fossil fuels for meeting their thermal energy needs. The fossil fuels have more than 85% share in the commercial energy supplies in the country. The indigenous reserves of the fossil fuels (oil and gas) are

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limited and the country is heavily dependent on the import of oil. In fossil fuel run textile units, toxic emissions into the air and ground water are the major environmental concerns. Pakistan textile industry is facing a tough challenge in the form of global environmental standards. To sustain its role in export markets, Pakistan has to comply with international environmental protocols [1].

To maintain a reasonable industrial growth, the country must have a sustainable energy supply. But the state of affairs in the field of energy reveals a disturbing picture. Persistent energy shortages loom dangerously as demand continues to outstrip supply. The situation becomes more alarming due to the fact that the continued burning of fossil fuels endangers the climate through such phenomena as global warming. It is imperative to explore alternative fuels, for process heat production for textile industry, that are not only free (or very cheap), but are environment friendly and available locally. Solar energy systems meet these criteria [1, 3–4].

Pakistan, Afghanistan, and parts of India have a very good overall solar-energy potential. The average daily insolation rate in these regions amounts to approximately 5.3 kWh/m^2 as shown in Fig. 1. Sandy Desert, Central Makran, Pothwar Plateau, Thal Desert, and Upper Sindh have been identified as the potential locations for the applications of solar energy in Pakistan. The solar radiation rate at these locations amounts to about 6.0 kWh/m^2. The sun shines between 8 and 8.5 h daily, or approximately 3,000 h/annum. The sunshine duration gives us an ideal foundation where we can harness the solar thermal energy to meet our process requirements [3–5]. This chapter presents the prospects of solar thermal energy utilization in the textile processing units in Pakistan.

Fig. 1 Solar radiation map of central Asia

Table 1 Applications of solar thermal energy

Category	Temperature (°C)	Solar collector type	Application
Low grade	Up to 85	Flat-plate collector	Water heating, space heating, and air drying
	80–120	Evacuated tube collector, compound parabolic concentrator	Process steam, hot water, desalination, and cooking
	100–350	Parabolic trough concentrator	Process heat and power generation
Medium grade	Above 500	Parabolic dish concentrator	For steam and power generation

2 Solar Thermal Technologies

The industrial processes usually require energy within a range of temperatures from 50 to 250°C. Active solar liquid- or air-heating systems can be used to deliver energy to these processes. Depending on the temperature range needed, different solar collector technologies and different concepts for their integration into the industrial heating system can be considered. Solar thermal technologies can be employed for a variety of applications in a wide temperature range (Table 1). The main component of a solar-heating system is the solar collector [6–9].

2.1 Flat-Plate Collector

The flat-plate collector (FPC) is the simplest form to transform solar energy into heat. FPC consists of (1) a selectively coated metallic tube (riser) and plate (fin) arrangement, called an absorber; (2) top glass cover; and (3) housing with back and side insulation (Fig. 2).

The black plate or fin absorbs solar radiation and transfers it to the water (or any other fluid) flowing in the tubes or risers. The risers are connected to a common header in the collector. The absorber plate is insulated on the backside, and the top is covered with glass to reduce heat loss. The absorbers are selectively coated so as to minimize heat losses due to remittance. These collectors are suitable for applications that require a maximum temperature of about 85°C.

2.2 Evacuated Tube Collector

The efficiency of FPCs is low at temperatures above 80–85°C, mainly because of excessive heat losses. One way of reducing these heat losses is to evacuate the space between absorber and glass cover. In evacuated tube collectors (ETCs), the absorber is housed in an evacuated cylindrical glass tube as shown in Fig. 3. As there

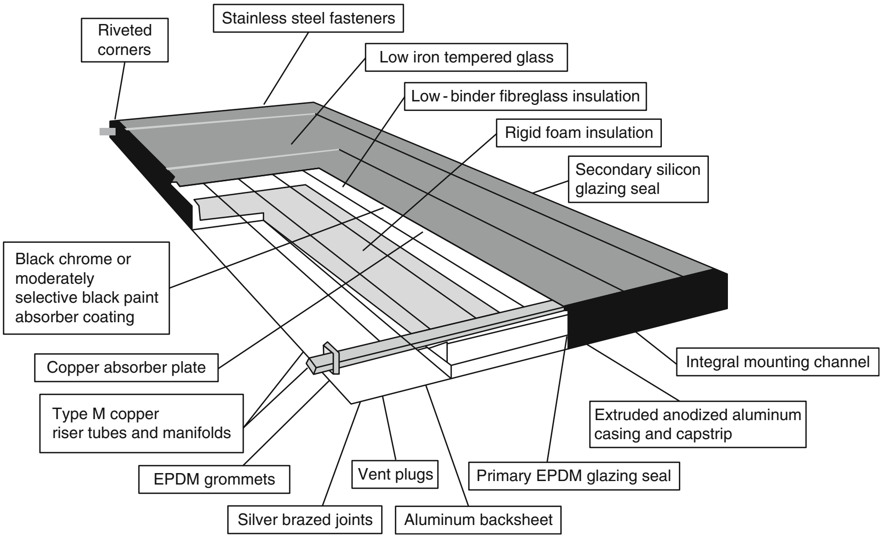

Fig. 2 Sectional view of a FPC

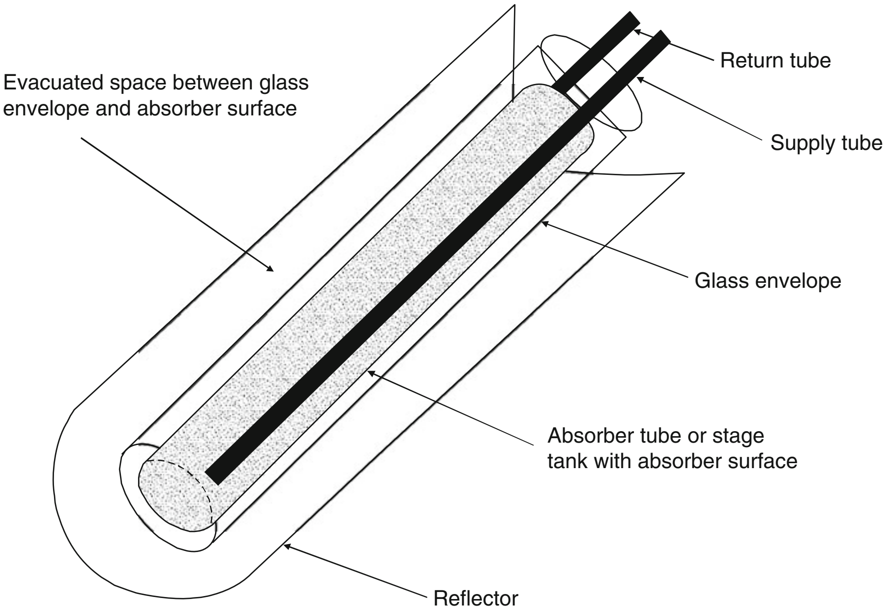

Fig. 3 Sectional view of an ETC

is no medium between the absorber and the cover, the heat losses are minimized. There are two ways in which heat can be extracted from ETC: by circulating thermic fluid directly through the tubes or by using heat pipes that transfer thermal energy to the fluid flowing in the header.

2.3 Compound Parabolic Concentrator Collector

Another way to reduce the heat losses of a solar collector is by reducing the area of absorber with respect to the collecting area, since the heat losses are proportional to the absorber area, and not to the collecting (aperture) area. This concentration can be obtained using reflectors that force the radiation incident within a certain angle into the collector aperture in direction to the absorber after one or more reflections. The wide acceptance angle of these collectors allows them to collect both diffuse and beam radiation (just like a FPC does), unlike parabolic trough/dish concentrators that require (a) beam radiation and (b) continuous tracking. Figure 4 shows a cross-sectional view of compound parabolic concentrator (CPC) collector.

2.4 Parabolic Trough Concentrator

The parabolic trough concentrator (Fig. 5) is essentially a trough lined with reflective material. The trough focuses the sunrays on a pipe located along its focal line. A heat-transfer fluid, typically high-temperature oil, is circulated through pipes, and the heated fluid is then pumped to a central power block where it exchanges its heat to generate steam. Number of such modules can be interconnected to deliver the desired load.

2.5 Parabolic Dish Concentrator

A parabolic dish concentrator is a point-focusing concentrator in the form of a dish that reflects solar radiation onto a receiver mounted at the focal point. The concentrator is mounted on a structure with a two-axis tracking mechanism. Figure 6 shows a schematic of parabolic dish concentrator.

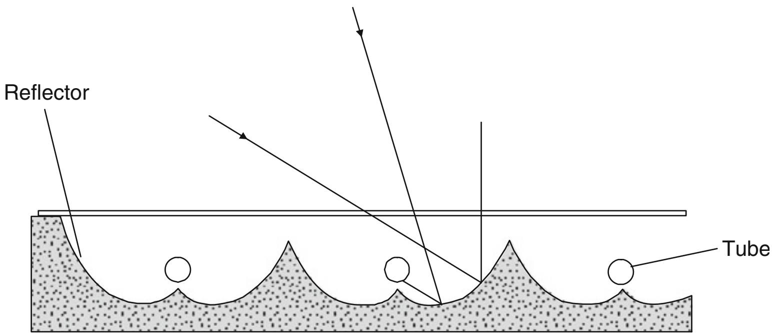

Fig. 4 Sectional view of a CPC collector

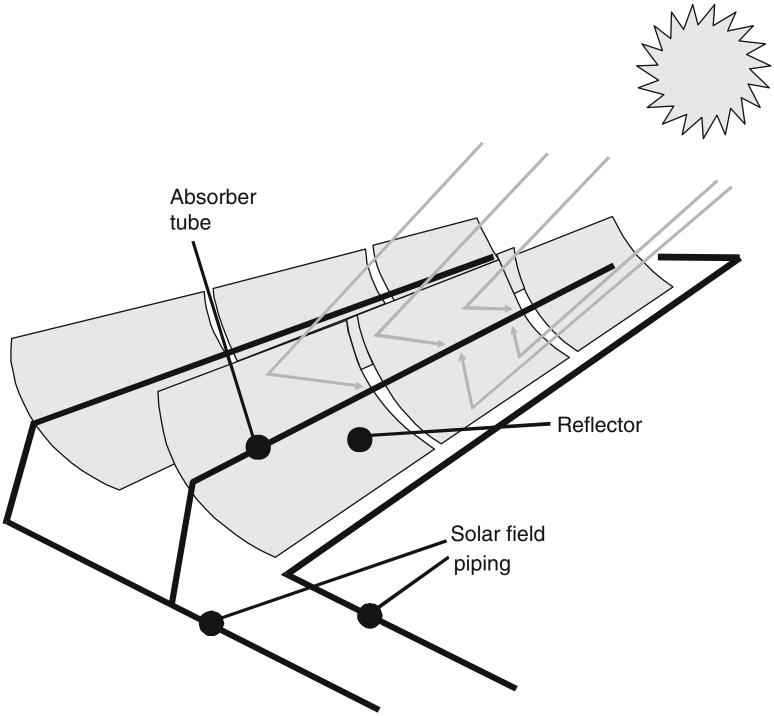

Fig. 5 Schematic of parabolic trough concentrators

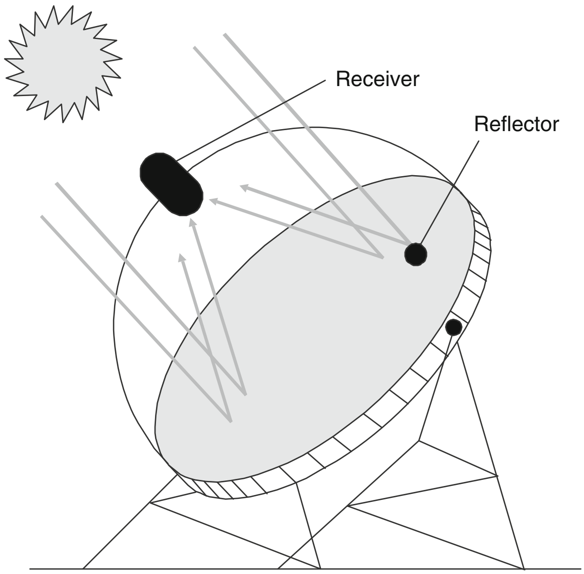

Fig. 6 Schematic of a parabolic dish concentrator

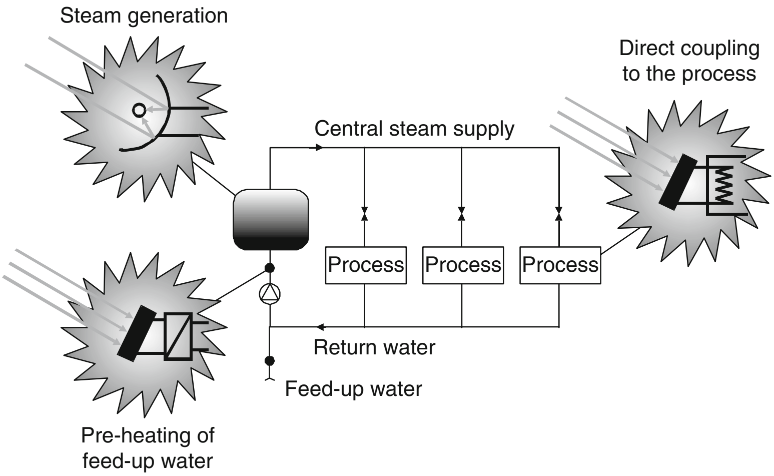

Fig. 7 Different ways of using solar energy for the process heating

3 Solar Thermal Systems for Industries

An industrial solar installation consists of a solar collector field through which water or air is circulated (primary circuit). A regulation system controls this circulation depending on the available solar radiation intensity. The collected solar energy can either be used directly or by means of a heat exchanger, for the heating of liquids or for steam generation as per the process needs.

The coupling of the solar system with the conventional heat-supply system can be done in several ways such as (1) direct coupling to a specific process, (2) preheating of boiler feed water, and (3) steam generation in the central system. Figure 7 shows these possibilities graphically.

The collector field requires a large tract of shadow-free space. In most cases, solar collectors may be accommodated on the terrace/roof using tailor-made structures. If spare ground space is available then some of the collectors could also be installed there [6–9].

4 Utilizing Solar Thermal Energy in Textile Industry

There are 22 major industries where boilers supply process heat either in the form of steam or hot air up to a temperature of 150°C. These include dairy, food processing, textiles, hotel, edible oil, chemical, marine chemicals, bulk drug, breweries, and distilleries [10]. Many of these industries also use hot water in the range of 70–90°C. The data was collected for different textile processes so that the importance of using the solar thermal technologies can be justified through the techno-economic analysis.

Table 2 Specific hot water requirements in textile unit

Process	Temperature requirement (°C)	Requirement (l/kg) of fabric
Sizing	90	2
Rope washing	50–60	10–17
Kier boil		
(a) Open	50–90	3–8
(b) Pressure	50–90	5–10
Continuous bleaching		
(a) Saturator	50–70	1–2
(b) Rope washing	50–60	10–15
(c) Open width washing	50–60	10–15
Cloth mercerizing	50–60	10–15
Yarn mercerizing	70	15
Jiggers		
(a) Desize/bleach	50–80	5–8
(b) Dyeing	40–90	18–20
Winches		
(a) Desize/bleach	50–80	45–60
(b) Dyeing	40–90	45–85
Package machine		
(a) Boil	50–90	10
(b) Dyeing	40–90	20–25
Beam dyeing		
(a) Scouring	50–80	30–40
(b) Dyeing	50–90	35
Jet dyeing	80–90	25–30
Continuous dyeing	40–90	22–25
Open width soaper	60–80	10
Water mangle	50–60	3
Starch padding	90	2

A typical textile mill processing about 1.0×10^5 m or 10,000 kg of cloth per day requires about 2×10^8 kcal of thermal energy. This is equivalent to about 20 MT (million tons) of oil or 50 MT of coal per day. Although process heat requirement spans a broad temperature range, almost 90% of heat is used at temperatures, which can be provided by solar energy (Table 2).

For the dyeing and printing sectors, medium range heat is needed, as given below.

Dyeing	125°C
Printing	140°C
Curing	140°C
Aging	100°C
Finishing	
For stenters	steam at 180°C
For calendar	steam at 100°C

Here, solar energy could be used in the following manner.

The hot water requirement for soaping, washing, boiler feed, dyeing machines, and low-temperature processes can be provided by selectively coated FPCs. Solar water heating is a potential candidate to replace the conventional energy sources in textile industry and can be an economical choice.

Solar concentrators such as ETCs and parabolic trough collectors could be used to provide low-pressure steam for starch preparation, heating, drying, and curing of processed or printed cloth. This can also be used for space heating and humidification. Solar air heaters may be used in the drying of yarn, processed, and finished cloth.

The use of solar thermal energy in textile processing units could reduce energy demand (of conventional sources) and still allow for continued economic growth. Besides, solar systems not only meet the energy needs, they also contribute to improvement in the environment, apart from ensuring the energy independence for the nation.

The use of solar thermal energy systems in textile processing units results in direct local and global environmental benefits. Emission reductions through small-capacity solar systems are in the range of 0.6–0.9 MT of CO_2/annum based on electricity savings, depending upon the resource mix. In the case of large commercial and industrial systems, emission reductions are in the range of 0.2–0.4 MT of CO_2/annum as they mainly replace the boiler fuel.

Nonetheless, their overall cost-effectiveness depends on optimized system designing and integration within the overall process. This is more so in case of solar systems, which do not replace the conventional systems but act as “add-on.” Also, the unavailability of adequate and appropriate open space may become a constraint even if everything else is favorable for a solar system.

5 Conclusion

To maintain a reasonable industrial growth, the country must have a sustainable energy supply. But the state of affairs in the field of energy reveals a disturbing picture. Persistent energy shortages loom dangerously as demand continues to outstrip supply. The situation becomes more alarming due to the fact that the continued burning of fossil fuels endangers the climate through such phenomena as global warming.

With accelerated industrial growth and spiraling energy costs, it is imperative to explore alternative fuels, for process heat production for textile industry, that are not only free (or very cheap), but are environment friendly and available locally. Solar systems meet these criteria. Devising such strategies could reduce energy demand (of conventional sources) and still allow for continued economic growth. Besides, solar systems not only meet the energy needs, they also contribute to improvement in the environment, apart from ensuring the energy independence for the nation.

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Wind Power Performance Improvements Using Artificial Neural Network Controller for DC–DC Converter

Mukhtiar Ahmed Mahar, Abdul Sattar Larik, Mohammad Rafiq Abro, Mohammad Aslam Uqaili, Mukhtiar Ali Unar, and Abdul Rasheed Shaikh

Abstract Pakistan is nowadays facing serious energy crises, especially in power sector due to increase in load demand. To bridge the gap between load demand and generation of electricity, the wind power is a cheapest indigenous solution.

Wind power these days is gaining popularity as a growing renewable energy source in the world because of its environmentally clean and safe usage. For generation of wind power, the trend is to install large wind farms either onshore or offshore. These wind farms consist of a large number of wind turbines. Onshore wind farms cover large areas of land but an interesting option is to build offshore wind farms because of higher average wind speeds at sea.

In wind power generation, power electronics converters are widely used because of their manifold advantage. DC–DC topologies are most commonly used in wind farms because of their high efficiency and compact size. A single-active bridge (SAB) converter being simple in topology has recently drawn attraction of many researchers. Such converter despite its simple design and number of attractive features produces oscillations. Therefore, it is imperative to design an appropriate controller to minimize the oscillations. The artificial neural network is proposed for the SAB converter and it is believed to handle oscillations.

Keywords Wind farms • DC–DC converters • Single-active bridge converter • Linear controller • Neural network control

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1 Introduction

Pakistan is a developing country and its growth in industrial, commercial and, as well as, in domestic sector has enhanced load so tremendously that the demand on power sector has been increased to such a level that the Pakistan is facing severe power shortage of 4,500 MW [1, 2]. It is an alarming situation of energy crisis in Pakistan. Because of this shortfall, load shedding is inevitable and the severe load shedding has badly affected the economic growth of the country.

The total installed power capacity of Pakistan is 19,572 MW. The main sources of power production are hydel, thermal, and nuclear energy. The details are given in Table 1 [1, 2]. The thermal energy is the main contributing source in power sector which utilizes the fossil fuels such as gas, furnace oil, coal, etc. The details of each fossil fuel are shown in Fig. 1. Unfortunately, Pakistan has limited fossil fuels and to import, particularly oil, is to overburden its economy further.

Fossil fuels supply over 80% of the world's energy needs and coal is the world's most abundant fossil fuel, more commonly found than oil, natural gas, and uranium fuel [3, 4]. The future availability of fossil fuels is shown in Fig. 2. Fossil fuels emit gases and create environmental pollution problems, such as global warming (green house effect), acid rain, and urban pollution [3].

Table 1 Installed power capacity in (MW) during 2008–2009

Type	Installed capacity	Percentage share in total capacity
Hydel (WAPDA)	6,595	34
Thermal (WAPDA)	4,900	
Thermal (KESC)	1,756	
Thermal (IPPs)	5,859	64
Nuclear	462	2
Total capacity	19,572	100

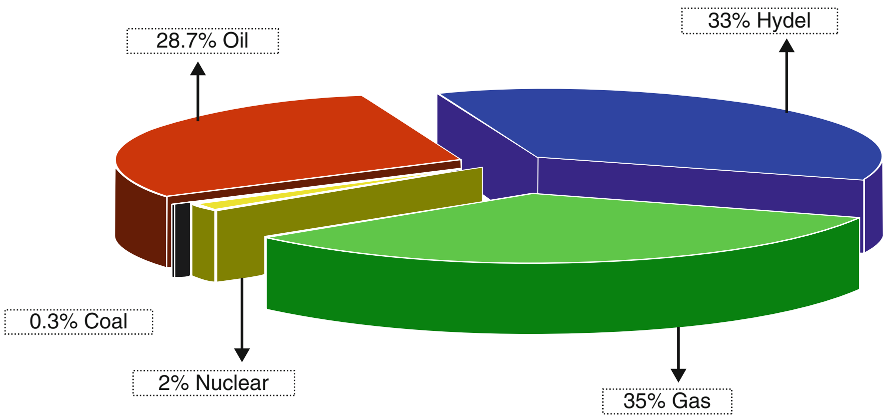

Fig. 1 Overview of generation pattern of power sector

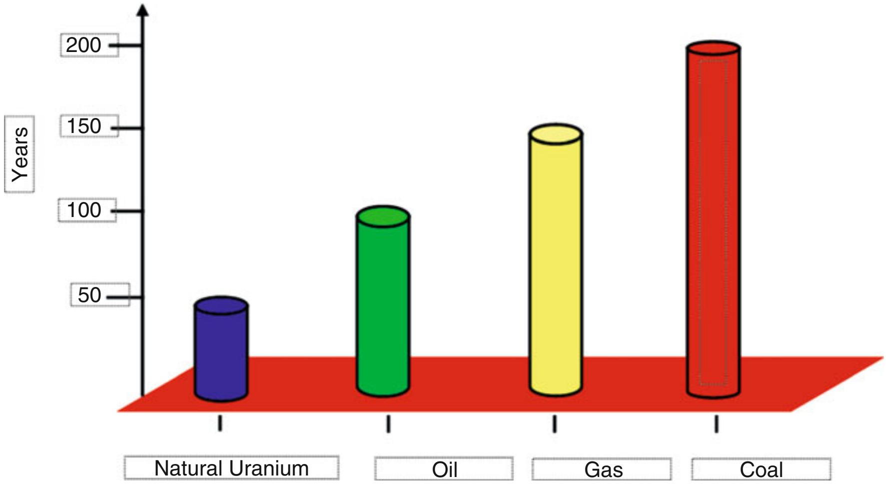

Fig. 2 Future availability of fossil fuels

In Pakistan so far about 883 million barrels crude oil reserves have been discovered of which 559 million barrels have already been produced [4]. Total coal resource potential of Pakistan is estimated to be around 185 billion tons, out of which about 175 billion tons are located in the Thar Desert, Sindh province, which is the 5th largest single coal field in the world [4]. However, much of Pakistan's coal has a low calorific value and a high ash and sulfur content, which limits its value [4].

Hydel power generation in Pakistan is 34% [1, 2]; however, this varies with seasons due to availability of water. Pakistan also generates 2% of electricity from nuclear power plants. Security and safety are the main issues of nuclear power plants [3].

Owing to increase in demand for electrical energy and environmental issues concerned with aforesaid power plants, Pakistan should look for some other energy sources which could be utilized for the production of electricity. Renewable energy sources such as wind and solar are the cheapest, environmentally clean, and safe sources but the main issue concerned with solar power is not yet significant as a source for the grid [5].

The wind energy utilized in windmills has been used to generate electrical energy since the 1980s, but commercial use of wind power started only in the early 1990s [6]. Many countries are expanding their dependency over wind energy for the production of electricity and this process is increasing exponentially year after year. With nearly 74,000 Mega Watts (MW) installed all over the world by the end of 2006 and the currently installed wind power capacity is nearly 69,000 MW [6].

Pakistan has a lot of wind resource in coastal areas and northern areas [1, 2]. The costal belt of Pakistan is about 1,046 km long. It consists of province of Sindh and coastal areas of Baluchistan. A wind corridor at Gharo-Keti Bandar, Sindh has been identified with an actual potential of 50,000 MW [1, 2]. The major part of electricity requirement can be met by installing wind turbines (WT) in this corridor. The first WT generator was installed in Pakistan in Jamphir, Sindh, in December, 2008 [7].

The offshore wind energy is the large-scale use of renewable energy. Wind farms located offshore are planned because of higher average wind speeds at sea and space limitations onshore. The offshore wind farms are placed more than 60 km from the shore; therefore, nowadays a high voltage direct current (HVDC) is an attractive transmission system [8, 9].

In order to obtain desired voltage level of HVDC transmission, DC–DC converters are a key component of wind farms. DC–DC converters convert a source of direct current from one voltage level to another. The WT are connected in different ways to a DC–DC converter to adjust the voltage level for transmission.

2 Layout of Wind Farm with DC–DC Converters

The different configurations of WT connected with DC–DC converters are available in the literature [9, 10]. In order to highlight the significance of DC–DC converters, a layout of wind farms is shown in Fig. 3. Each group of WT is

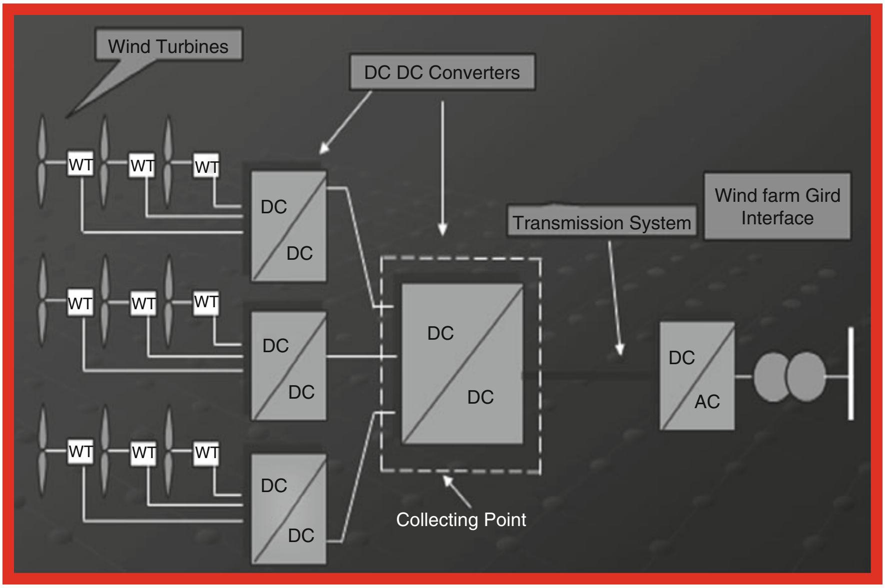

Fig. 3 Layout of DC wind farm [9]

connected with high power DC–DC converters. The main function of DC–DC converters is to adjust the voltage level of the output of WT. The DC–DC converters are then connected in parallel to a high power DC–DC converter which produces the voltage to a desired level of transmission. Different types of DC–DC converters have been used [9, 11], such as full-bridge converter using phase shift control, series parallel resonant converter, and single-active bridge (SAB) DC–DC converters. The soft switching of SAB topology is simple and also their controller design is equally easy as compared to other converters. Moreover, the SAB topology has less number of active and passive devices than other DC–DC topologies.

Therefore, there is a dire need to design a cost effective and reliable controller for the said converter topology to handle any nonlinear conditions in the system and to improve the reliable and efficient performance of the SAB converter.

3 Single-Active Bridge DC–DC Converter

The SAB DC–DC converter is a simple topology which consists of lower number of active and passive devices [12]. Such converter is a combination of a DC–AC converter followed by an AC–DC converter as shown in Fig. 4. The half-bridge inverter configuration is connected on primary side of the transformer while rectifier full wave bridge is employed on secondary side of the high frequency transformer.

In previous work, the dynamics of the SAB converter were controlled by using linear controller (proportional + integral) which has well-known limitation as pointed out by various researchers [12–15]. The major problem confronted with

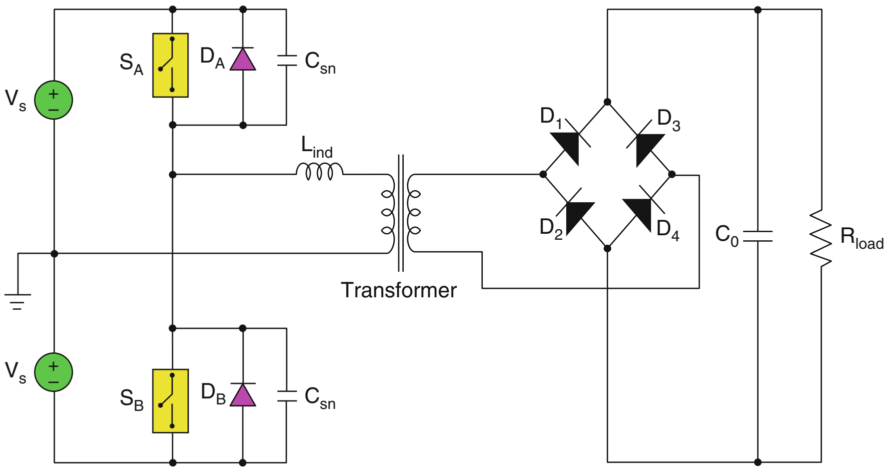

Fig. 4 Single active bridge DC–DC converter [12]

SAB converter when operated with PI controllers is that it generates oscillations in output voltage as well as inductor current. These oscillations create disturbances and degrade the performance of converter. Furthermore, disturbances generated due to the conventional techniques lead to the generation of abnormal harmonics which have deleterious effects on the system's network as well as affects badly the performance of the converter.

4 Artificial Neural Network Controller

The main purpose of this work is to design a controller for the SAB converter to control the high voltage ripples at the output of the converter at a particular mode of operation. In this chapter, the neural network controller is proposed for said converter and its advantages and justification in power electronic converters are also discussed.

Artificial neural network controller is an advanced controller particularly interesting due to its fast dynamic behavior and robustness. The neural network controllers are nonlinear controllers which enhance the system performance, increase system speed, and reduce the system complexity. They have also self-adapting capabilities that make them able to control nonlinearities, uncertainties, and parameter variations of the plant. The neural network enables parallel and distributed processes because of its parallel structure [15–19].

Artificial neural network controllers are now being extensively used in power electronic converters [15, 17–19]. A number of researchers are still devoting in the further development of control techniques for power electronics converters to improve its performance. Various researchers [17–19] used artificial neural network as a control technique for DC–DC converter.

In this work, Multilayer Feedforward Neural Network (FNN) is considered. Feed forward neural network is a multilayer network as shown in Fig. 5. It consists of an

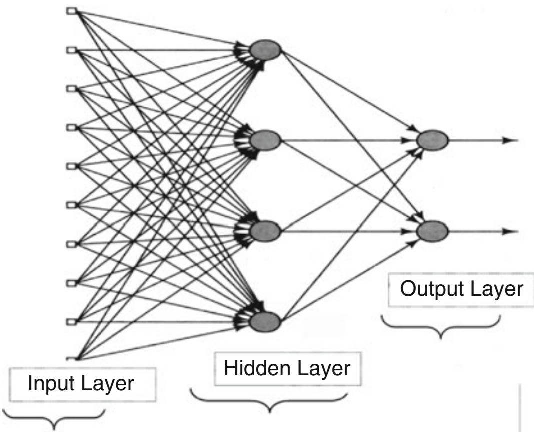

Fig. 5 Feed forward multilayer neural network

input layer, one or more hidden layers, and an output layer. The data sample is fed to the input layer. The hidden layer composed of one or more layers and as the name indicates these layers cannot be accessed from outside the network. The hidden layers enable the network to learn complex tasks by extracting progressively more meaningful features from the input patterns. The final layer is the output layer, which may contain one or more output neurons. This is the layer where the network decision, for a given input pattern, can be readout.

Multilayer FNN is the most popular architecture because it is easy to implement and allows supervising learning [16]. When a signal passes through the network, it always propagates in the forward direction from one layer to the next layer and not to the other neurons in the same or the previous layer. The number of hidden layers and the number of neurons in each layer are not fixed. Each layer may have a different number of neurons depending on the application. The developer will have to determine how many layers and how many neurons per layer should be selected for a particular application.

5 Simulation Results and Discussion

The simulation model of NNC for the SAB converter is shown in Fig. 6. The SAB converter is controlled with two separate neural network controllers which are designed for inner current loop and outer voltage loop. Such control structure is referred to as cascade control.

The performance of SAB converter with NNC is tested under steady state as well as dynamic regions. The simulated results of inductor current and output voltage of the SAB converter under steady state operation are shown in Fig. 7 which shows

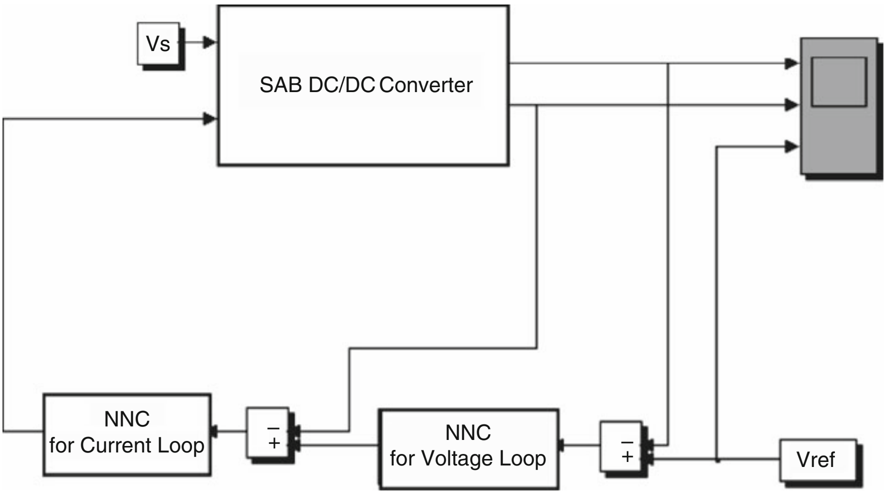

Fig. 6 Simulation model of the SAB converter with neural network controllers

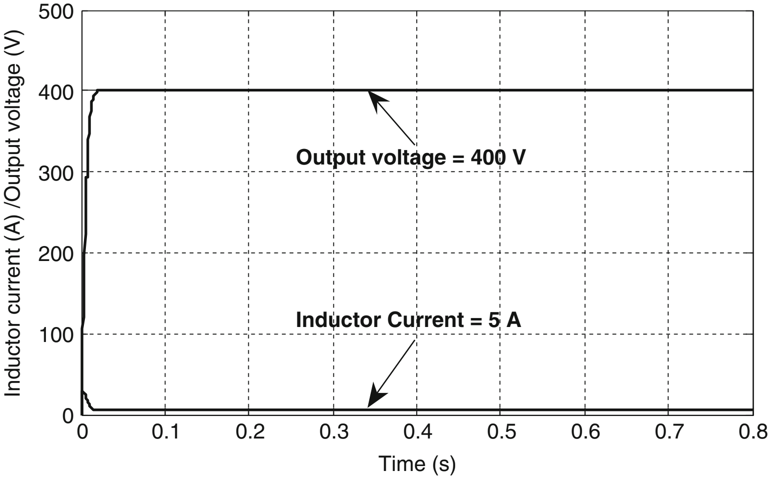

Fig. 7 Simulated waveforms of the SAB converter with NNC during Steady-state operation

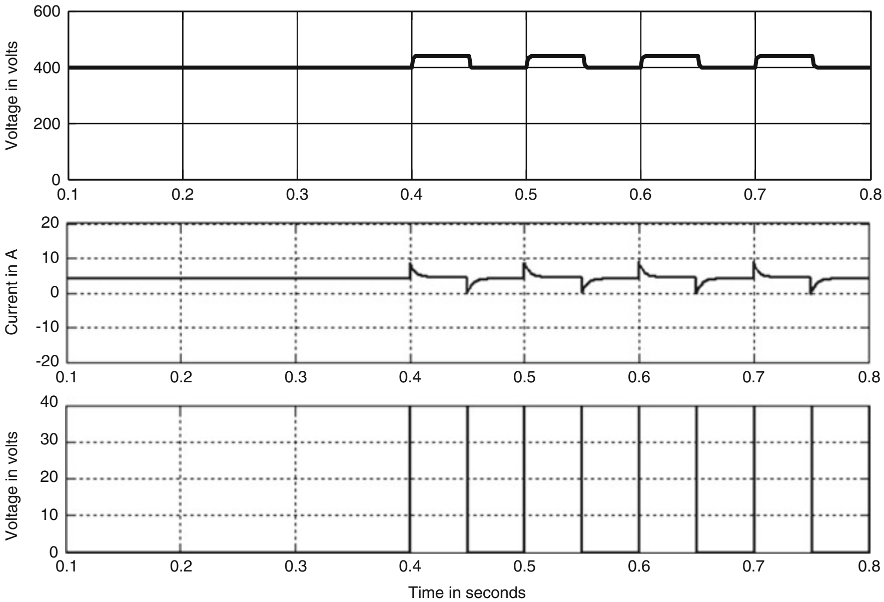

Fig. 8 Simulated waveforms of the SAB converter with NNC during reference voltage variation

both inductor current and output voltage are free from oscillations. During this operation, the output voltage as well as inductor current is maintained by the controllers at 400 volts and inductor current at 5 A, respectively.

The performance of SAB converter with NNC is also analyzed during dynamic operation by considering the reference voltage variations. Figure 8 shows the simulated waveforms of the reference variation with NNC controllers. The output voltage has no overshoot and smoothly increases up to the maximum value. The peak-to-peak value of inductor current is 13.385 A which is 8.115 A less than the PI controller as used in a previous work [19].

6 Conclusion

In this chapter, the energy crises situation and future scope of wind power in Pakistan is highlighted. The environmental issues of different power plants are also mentioned. The key positions of DC–DC converters in wind farms are highlighted. The shortfalls concerned with the SAB DC–DC converter are also mentioned. Due to pitfalls associated with conventional linear controllers as indicated in this chapter, an artificial neural network is proposed for the SAB converter. The neural network controller is an efficient tool for the SAB converter that have sufficiently damped the oscillations of the output voltage as well as of inductor current under nonlinear situations as compared to PI controllers as used in previous research.

The results obtained clearly reflect the robust performance of the SAB converter and the neural network controller is proved to be an advanced nonlinear controller having fast dynamic behavior which enhances the system performance.

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Practical Application of Solar Energy at Desert of Tharparkar, Pakistan

R.S. Abro, Mohammad Aslam Uqaili, Suresh Kumar, Khanji Harijan, and Muhammad Yaseen

Abstract Tharparkar is a backward district of Sindh, Pakistan. Most of the rural population of this district suffers from poverty and is deprived of very basic necessities of life such as drinking water and electricity. Demographic pattern was the main hurdle for rural electrification as the villages are scattered far apart in a random manner and a grid supplied electrical distribution was not technically feasible. Solar energy is one of the alternatives for rural electrification and other applications at desert of Tharparkar.

This chapter presents the practical applications of solar energy at desert of Tharparkar, Pakistan. Alternative Energy Development Board (AEDB) has successfully electrified 50 villages of Tharparkar district through about 168 kW of DC power. A solar refrigerator has also been installed at BHU of village Khensir taluka Chacharo to store vaccines for snake bites and other lifesaving drugs. Remarkable socioeconomic and sociocultural change has been visualized in the dark areas which has been brightened through solar energy.

Keywords Rural electrification • Socioeconomic development • Solar energy • Solar home systems • Solar refrigeration • Tharparkar

1 Introduction

Tharparkar district constitutes the extreme southeastern district of Sindh province. In the north it joins with Mirpur Khas and Umerkot districts. In the west it joins with Badin district and in the east with Rajasthan (India). In the south lies the marshy wasteland of Rann of Kutch. The area is dominated by vast land of undulating sand mountains and

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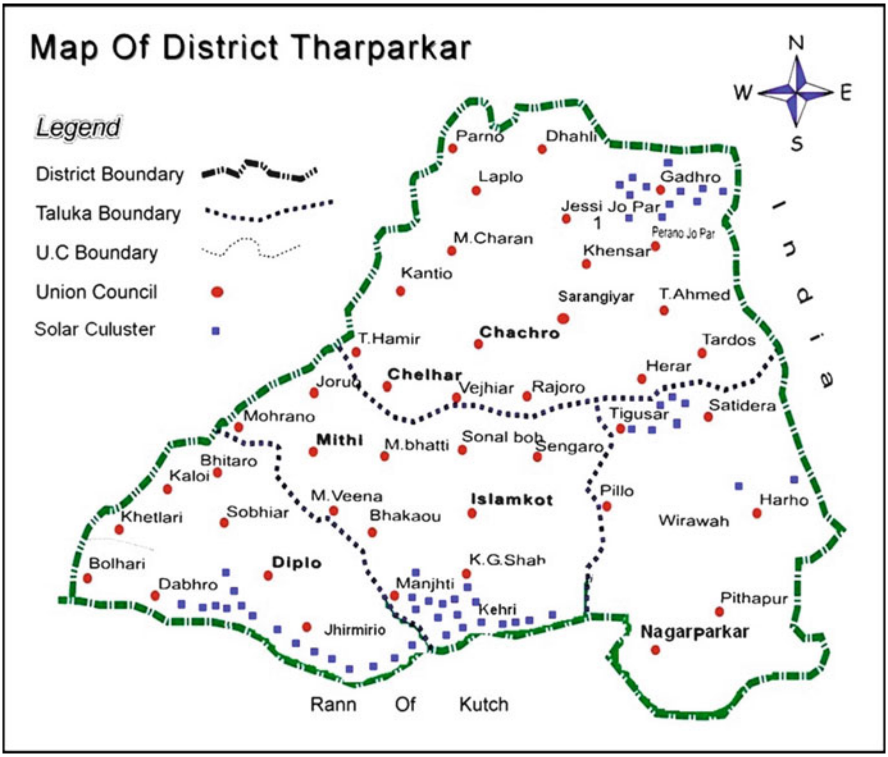

Fig. 1 Map of Tharparkar

equals 19,638 square kilometers. The population of the district is about 1.4 million and the majority lives in small clusters of rural areas. The district has four administrative blocks known as Talukas (Tehsil), namely, Diplo, Mithi, Chachro, and Nagarparkar as shown in Figure 1. Most of the rural population suffers from poverty and is deprived of very basic necessities of life such as drinking water and electricity. It is the demanding state of district that prompted the government to launch the "Roshan Pakistan" program with the solar photo-voltaic technologies in the rural area of Tharparkar [1–4].

2 Background

Tharparkar is a backward district of Sindh which has just started receiving the enlightened rays of modern civilization. Only a decade ago, distances of a few scores of kilometers were covered in days and when the Second World War vintage truck was brought in, they had to negotiate sand dunes and use PSP sheets where traction was not possible. By all definitions, life was primitive if not prehistoric. It started with the rise of sun and went into deep slumber with its setting [4–5].

2.1 Inadequate Supply of Energy – Basic Cause of Backwardness

The sub-civilized life pattern was always a cause of concern for Government, philanthropists and Non-Governmental Organizations and to begin with water and light were the basic areas of focus. Demographic pattern was the main hurdle for electricity as the villages are scattered far apart in a random manner and a grid supplied electrical distribution was not technically feasible. Technological constraints kept the environment in dark for an extended period of time [4–6].

2.2 Life Pattern

The darkness dictated the routine and the livelihood. Utilizing day light hours, men and women would go into the fields early in the morning, plough their fields, and come back home in the evening. They would fetch water from the villages and wells far away and too deep where the water is pulled up with camels or donkeys. To further improve their livelihood, they would resort to some patterns of cottage industries such as carpet weaving, sewing, embroidery, decorative clothes, and decorated quilts. With the indoctrination of philanthropic organizations and governmental intervention, the local population started the education of its children. The government set up primary and high schools in its villages. Nonetheless, all these activities had a short life, i.e., the day light hours [3–5].

2.3 Darkness: The Worst Social Impediment

The lack of light had its impact on all the social life. Ladies could hardly get together after sunset. Lantern burnt by kerosene was hardly a unifying torch for them.

Men would get together in the relatively more influential man Autaq and discuss their mutual problems. There is a wide segregation of human groups owing to this limited interaction which has widened into a great gulf between the communities. In Thar it is very common to have a village of not more than 100 homes divided into three communities not seeing eye to eye to each other. As a result, this isolation of communities has deprived the area from human synergy which is so important for progress of any kind [3–5].

2.4 Snake Bite and Scorpion: A Common Hazard

The present situation had its toll on the survivability of life. Pitch dark homes, villages, courtyards, and streets make venomous snakes invisible and roam freely. Most of the villages cannot preserve the antisnake bite serum owing to lack of refrigerating facilities. Terror and deaths from snake bites is a common and a menace for local population.

2.5 Government Dispensary, Basic Health Units, and Hospitals

There are 148 government dispensaries (GD) and Basic Health Units (BHU) in Tharparkar district. Most of BHU and GD are not storing the snake bite vaccines due to nonavailability of power and refrigerators [3, 7]. This office helps out the health department to install solar powered refrigerators.

Taluka	BHU	GD	Population
Mithi	9	27	333,006
Diplo	7	36	224,255
Nagarparkar	5	14	211,322
Chachro	9	19	493,691

2.6 Rural Electrification Project at Tharparkar

Eventually, the renewable energy has come to the rescue of Thar. AEDB launched projects for 3,000 homes in Taluka Mithi, Diplo, Chachro, and Nagarparkar.

The objective of the rural electrification project, designed and launched by AEDB, was to provide electric lighting, means of communication and clean drinking water facilities to the villages where it is technically and economically not feasible to extend gird connectivity. Under this project, 906 villages have been identified in province of Sindh. Out of those 906 villages, 100 villages of entire Sindh were supposed to be electrified through alternative energy resources by AEDB in phase I [8–9]. In this respect, it is blessing for Tharparkar district for having major portion of village electrification in single district.

There are other remote areas which are also not connected with national grid such as coastal belt of Badin, Thatta, the remote areas of Manchar Lake, entire Kohistan belt, and areas of "Achhro Thar" at Sangher. All these areas are also supposed to be provided reasonable proportion as those are also under the same condition.

Rural Electrification Project (REP) Mithi Office was established in June 2007 and is heavily engaged to electrify the backward areas of "Thar" desert through Solar Home Systems (SHS). By the grace of God, team of trained skilled manpower including engineers and other staff has successfully electrified 50 villages of Tharparkar district, shown in Figure 1, through about 168 KW of DC power. Figure 2 shows a SHS installed by AEDB in a village of Tharparkar. Remarkable socioeconomic and sociocultural change has been visualized in the dark areas of Tharparkar which have been brightened through solar energy [8, 10].

This project was started with effect from July 2007 and has to be completed in 31 months. In this respect, REP Mithi Office has rather completed this project before the time even with extended figures of the villages.

Fig. 2 A view of Solar Home System installed in Thar

REP Mithi office is also supporting People's Primary HealthCare Initiative (PPHI) to install solar refrigerators at BHU to store vaccines for snake bites and other lifesaving drugs. In this connection, this office has installed solar refrigerator at BHU of village Khensir taluka Chacharo. Installation and survey of other BHU is also in process.

Mithi office is also in process of exceeding this figure, in this respect we have requested several local and international donor agencies for funding towards this noble cause. In response to that, in March 2009 German Consul General came to visit to visualize the work done by AEDB, to justify their funding. The reports regarding this project were published in largest circulated newspapers. Status of some projects as recommended by parliamentarians and as directed by PM's secretariat are highlighted as under [8]:

1. Feasibility of Deh Tiko Baran as recommended by Sardar Nabeel Ahmed Khan Gabool MNA (NA-248) has been completed.
2. Feasibility of UC Moadan, Gadap Town as recommended by Mr. Sher Mohammad Baloch MNA (NA-258) has been completed.
3. Feasibility of solar street lighting system at Larkana has been completed.
4. Feasibility of Saidahoo – Achhro Thar as recommended by Mr. Ghulam Dastagir Rajar MNA is under process.

Besides rural electrification through SHS, AEDB is also working on solar water pumping and desalination. Because water is the basic need of human being and ground water, i.e., dug well and rainy ponds is only source of the almost whole populace of the district Tharparkar.

The Thari people, men and women are wasting most of time for fetching water through camels, donkeys, etc., for its livestock and its supply to homes. The Thar Desert is well known for its handicraft industry such as carpets. The embroidery work is the main production of handicraft industry of Tharparkar. Solar water pumping along with desalination will certainly help to improve their rate of production of handmade things so the economical condition of poor Thari peoples will also be improved.

The water in the Tharparkar is almost saline and causes serious disease, therefore application of solar technology is the only way to get instant rid of potable water and power to light their huts.

3 Conclusion

There are about 2,225 villages in Tharparkar district, out of which only in 100 villages the basic necessity the electric power has been provided and among these villages 50 villages were electrified through solar energy. The world has entered into the twenty-first century, but 2,125 villages of Tharparkar district are still in dark.

Keeping in view the power crises and related challenges, WAPDA may not electrify the villages of Tharparkar district in near future or up to year 2020, which are 20 km away from national grid. The instant solution to enlighten the pitch dark homes of "Thari" peoples is only through Solar PV (Solar Home System).

In light of the above discussion, it is recommended that the policy makers may emphasize the importance of renewable energy technologies and funds may be provided to AEDB for Rural Electrification at Tharparkar so that the far farther villages of remote areas of Tharparkar can be electrified.

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Ethanol Production from Molasses Using an Indigenous Strain of Thermotolerant *Kluyveromyces marxianus* Under Controlled Conditions

Shaheen Aziz, Hafeez ur Rehman Memon, Farman Ali Shah, M.I. Rajoka, and Suhail A. Soomro

Ethanol produced by a fermenting renewable crop such as sugarcane molasses is a very cheap source of alternative fuel. All the developed and some developing countries have taken up bioethanol as an alternative energy source. This situation arises because of the depletion of the fossil fuel reserves, rising costs, and environmental impacts. This study shows that a newly indigenous strain isolated as a mutant strain of thermotolerant *Kluyveromyces marxianus* M15 produced a maximum production of ethanol in 48 h. The kinetic parameters have been studied for cell growth, substrate consumption, and ethanol production for wild and mutant strains of *K. marxianus* M15. It has been observed that the wild strain was growing up to 55°C, while the mutant strain was growing up to 65°C. In this study, the mutant strain M15 was proved to be stronger than its parental culture due to its microbial activity. *K. marxianus* were grown in a 23-l fermentor (working volume 15 l) on different substrates, including glucose, sucrose, and molasses at concentrations of 10, 12, 15, and 17%. Total sugars were tested for their ability. M15 produced maximum ethanol of 72.5–75.2 g l^{-1} with concentration of 15%, and β-fructofuranosidase (F-Fase) at 72 and 48 h, respectively.

Keywords Ethanol • Fermentation • Kinetic parameters • *Kluyveromyces marxianus* sp. • Molasses • Thermal effects • Thermotolerant • Yeast

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1 Introduction

The yeast species *Kluyveromyces marxianus* have been isolated from a great variety of habitats, resulting in a high metabolic diversity and a substantial degree of intraspecific polymorphism. As a consequence, several different biotechnological applications have been investigated with this yeast: production of enzymes (β-galactosidase, β-glucosidase, inulinase, and polygalacturonases, among others), single-cell protein, aroma compounds, and ethanol [1]. About 99% of the ethanol produced in the USA is used to make "E10" or "gasohol," a mixture of 10% ethanol and 90% gasoline. Any gasoline-powered engine can use E10. E85 can be used only in specially made vehicles, a fuel that is 85% ethanol and 15% gasoline. The Government of Pakistan is also considering allowing adding ethanol E5 and E10 to gasoline in a bid to relieve the pressure on fossil fuel. Cellulose and hemicellulose are the major components of the plant biomass and can be degraded to glucose and pentoses by the action of a potent and cheap mixture of cellulolytic and xylanolytic enzymes, respectively [2].

Ethanol as a source of energy is produced mostly from a strain of yeast, i.e., *K. marxianus* and *Sacchromyces cerevisiae*. *K. marxianus* DMKU3-1042 was found to be most suitable strain for high-temperature growth and ethanol production at 45°C [3]. Strains of *K. marxianus* have attracted much attention because they can grow at higher temperature and produce ethanol comparable to that by *S. cerevisiae* at an industrial scale [4]. It is noteworthy for its high product formation rate, which would make it an attractive candidate for industrial ethanol production in summer when temperature goes to 45–50°C in temperate regions of the world.

In the current study, ethanol has been produced from a newly developed indigenous thermophilic mutant derivative (M15) of *K. marxianus*. The fermentation was carried out in a fully controlled bioreactor, at 65°C. The influence of temperatures on ethanol production can be quantified in a time course study to estimate maximum growth rate, and maximum specific product formation rate for understanding metabolic network and their regulation [5]. Application of such data permits engineers to optimize product yields, predict the hidden process regulatory mechanism, and calculate the energy requirements of a process in industrial bioreactors [6, 7].

2 Materials and Methods

2.1 Growth of Organism

A thermotolerant strain of *K. marxianus* D-67283 was collected from Shakkar Gunj Sugar Mills, Jhang, Faisalabad. The thermotolerant *K. marxianus* strain was growing very fast under optimized conditions, as shown in Fig. 1, and the strain was maintained on Sabouraud's agar plates and slants, as described earlier elsewhere [8].

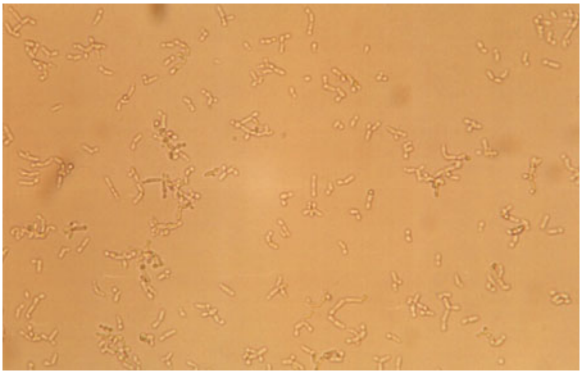

Fig. 1 Morphological observation of thermotolerant klyveromyces marxianus yeast

2.2 Chemicals and Growth Media

All chemicals were purchased from Sigma Chemical Co., Missouri, USA. *K. marxianus* was grown submerged in 250-ml conical flask containing 100 ml of yeast on Sabouraud's media. The media consists of yeast extract 0.5% (w/v), peptone 0.5% (w/v), NaCl 0.5% (w/v), and glucose 2% (w/v). The initial pH of the medium was adjusted to 5.5 with 1 M HCl. For other growth studies, the seed culture developed on glucose was used as inoculum and washed twice with sterile saline before use.

2.3 Isolation of Mutants

K. marxianus cells were cultured in yeast culture medium at 40°C for 24 h, centrifuged (5,000 × *g*, 15 min), and suspended in 50 ml of saline containing 0.02% yeast extract. The cells of 3.0 absorbance (at 610 nm) were dispensed equally in 30-ml McCartney vials. The cells were exposed to different doses of γ-ray in a Co-60 irradiator. The exposure of cell suspension ($\approx 3.0 \times 10^9$ cells ml^{-1}) to γ-irradiation of 1,200 Gy gave approximately a 3-log reduction in colony-forming units. The radiated cells were allowed to express in the presence of 120 g l^{-1} sucrose + 1.5% deoxyglucose (DG) medium at 65°C to isolate thermophilic and simultaneously derepressed mutants.

The serial dilutions of expressed cells were plated on sucrose-DG plates to obtain approximately 30 colonies per plate. The 50 selected colonies were subsequently replica-plated on sucrose + DG (1.5%, w/v) agar plates. The colonies were individually flooded with glucose oxidase reagent. The colonies surrounded by a pink halo were picked and screened by measuring diameter of pink halo around each colony. One mutant strain produced substantially higher ethanol at 65°C and was designated *K. marxianus* M15. The ethanol secretion was tested in the presence of increasing sugar concentration (10, 12, 15, and 17%, w/v).

2.4 Batch Culture Studies

For the culture studies, sugar cane molasses (100, 150 and 170 gl^{-1}), $(NH_4)_2SO_4$ 0.75%, peptone 0.5%, sodium chloride 0.5% and yeast extract 0.5% (pH 5.5) were used in a 23-l fermentor at 40 ± 0.2°C for both organisms. Inocula were prepared in 250 ml conical flasks containing 10 g glucose l^{-1} in above sterile medium (pH 5.5) by aseptically transferring cells from single colonies (five replicates) and grown at 45°C on an orbital shaker (150 rpm for 24 h). Concentration of the organism was adjusted to contain 2.24 g dry cells l^{-1}.

Fermentor studies were carried out in a microprocessor-controlled 23-l stainless steel fermentor (Biostat C5, Braun Biotechnology, Melsungen, Germany) (15 l working volume vessel) equipped with instruments and controllers for parameters such as agitation, temperature, pH, and dissolved oxygen, and fitted with a reflux cooler in the gas exhaust to minimize evaporation. The vessel was filled with a medium containing sugars (15% TRS) in molasses supplemented with an optimum concentration of $(NH_4)_2SO_4$ (75 g l^{-1}). The pH was adjusted to 5.5 (optimum) and the medium was steam-sterilized in situ for 30 min. The fermentor was inoculated with 10% (v/v) active inoculum. Aeration was carried out through a sparger at 15 l min^{-1} for 8 h to enhance biomass production before switching over to 3 l min^{-1}. This process lasted up to 40 h during which foaming was controlled by adding silicone oil as an antifoaming agent. Temperature-dependent formation of ethanol occurred along with minute quantities of acetic acid, succinic acid, and glycerol. The pH dropped due to the formation of acetic acid, so pH was controlled automatically at 5.5 using potassium hydroxide solution.

Cell growth was measured on dry cell mass basis after centrifugation of 100 ml sample (5,000 × *g* at 10°C for 10 min) and suspension in saline. Cell-free supernatant was used for determining ethanol and unfermented sugars. Total sugars in molasses were determined using a Brix hydrometer measuring specific gravity (Atago, ATC-1, Brix: 0–32%, Japan). Ethanol was determined gravimetrically through laboratory-scale distillation of fixed volume of fermented broth. Alternatively, glucose, sucrose, acetic acid, succinic acid, glycerol, and ethanol were analyzed by HPLC (Perkin Elmer, USA) using column HPX-87H (300 mm × 78 mm) (Bio, Richmond, California) maintained at 45°C in a column oven. Sulfuric acid (0.001 N) in HPLC-grade water was used as a mobile phase at 0.6 ml min^{-1}. The samples were detected by refractive index detector and quantified using Turbochron 4 software of Perkin Elmer, USA.

2.5 Determination of Kinetic Parameters

The kinetic parameters for batch fermentation were calculated as described previously, using empirical approach of the Arrhenius [9] to describe the relationship of temperature dependent on growth and product formation.

The value of μ, i.e., specific growth rate, s was calculated from plot of ln (X) vs. time. Various growth kinetics constants were determined by using the following formulae:

$$\text{Product yield coefficient with respect to cell mass } \left(Y_{\mathrm{p/x}}\right) = \mathrm{d}P/\mathrm{d}x$$

$$\text{Product yield coefficient with respect to substrate } \left(Y_{\mathrm{p/s}}\right) = \mathrm{d}P/\mathrm{d}s$$

$$\text{Specific rate of product formation } (q_{\mathrm{p}}) = \mu\, x\, Y_{\mathrm{p}}/x$$

Substrate utilization (q_s) = $\mu x/Yx/s$. For this purpose, specific rate of growth (μ) and product formation (q_p, g/g cells h) were used to calculate the demand of activation energy for cell growth and death, product formation, and product inactivation as described earlier [10].

3 Results and Discussion

Improvement of ethanol production by *K. marxianus* at 45 or 50°C by gamma ray mutagenesis was sought to isolate catabolite resistant and simultaneously ethanol hyper-producer mutant derivatives of *K. marxianus* with retention of β-fructofuranosidase activity [11]. Preliminarily, extensive studies were undertaken to optimize ethanol production by varying process conditions such as substrate type, pH of the medium, carbon source concentration, oxygen, flow rate, and nitrogen additives. The traditional classical method involved varying one parameter at a time by maintaining pre-optimized fermentation conditions for optimal production of ethanol in a 23-l fermentor in duplicate.

The mutant strains were selected on 1% deoxy-D-glucose, with addition of 9.5% ethanol as mentioned above. In the preliminary experiments, the selected mutant strains were tested for production of invertase using plate tests. The criteria for selection and production are based on the pink zones formed due to the formation of glucose by reaction of sucrose with invertase. The organism liberates invertase during growth, which reacts with sucrose to produce pink zones of glucose when tested with a glucose oxidase kit. The diameter of the pink zone is taken as an indicator of invertase secretion [12]. Plate test studies also indicated that a well-developed pink zone on sucrose agar plates appeared around 1,000 colonies in the case of mutant strains, and three variants with enhanced enzyme production abilities were selected. Semi-quantitative plate studies revealed that one derivative capable of producing the largest amount of β-fructofuranosidase with retention of ethanol production ability could be isolated and designated M15 for ethanol and enzyme production, as shown in Table 1.

Fermentation kinetic parameters for growth and substrate utilization at temperature range 20–65°C are shown in Table 2, and product formation kinetic parameters are shown in Table 3.

Table 1 Plate tests of β-fructofuranosidase (invertase) production by DG- and temperature-resistant mutant derivatives of *Kluyveromyces marxianus*

	Zone of pink color (mm) at different time periods (h)		
Mutants	24 h	48 h	72 h
M15	7	16	20
M21	6	14	18
M3	6	13	17

Table 2 Fermentation kinetic parameters of *K. marxianus* (W) and its mutant strain (M) for growth and substrate utilization using ammonium sulfate (0.75%), pH 5.5, added in molasses medium (15% sugars) at different temperatures under control conditions

Temperature (°C)	Strain	μ (h^{-1})	Q_x (g cells l^{-1} h^{-1})	$Y_{x/s}$ (g cells/g substrate)	Q_s (g l^{-1} h^{-1})	q_s (g g^{-1} h^{-1})	t_d (h)
	W	0.10^{fg}	0.780^{abcdef}	0.087^{abc}	1.85^{g}	1.149^{hi}	6.93^{d}
20	M	0.20^{de}	0.839^{abc}	0.090^{abc}	2.05^{g}	2.222^{defghi}	3.46^{fg}
	W	0.12^{f}	0.786^{abcde}	0.085^{abc}	1.86^{g}	1.412^{fghi}	5.78^{e}
25	M	0.24^{cd}	0.842^{abc}	0.094^{ab}	2.79^{def}	2.553^{def}	2.89^{gh}
	W	0.20^{de}	0.810^{abcd}	0.089^{abc}	2.61^{f}	2.247^{defghi}	3.46^{fg}
30	M	0.24^{cd}	0.889^{ab}	0.096^{ab}	3.88^{b}	2.500^{defg}	2.89^{gh}
	W	0.21^{cde}	0.812^{abcd}	0.094^{ab}	3.12^{cde}	2.230^{defghi}	3.30^{fg}
35	M	0.26^{bc}	0.890^{ab}	0.100^{ab}	4.11^{b}	2.600^{def}	2.66^{ghi}
	W	0.23^{cde}	0.814^{abcd}	0.098^{ab}	3.35^{c}	2.347^{defgh}	3.01^{fgh}
40	M	0.30^{b}	0.895^{a}	0.102^{ab}	4.76^{a}	2.941^{de}	2.31^{hi}
	W	0.18^{e}	0.799^{abcdef}	0.099^{ab}	1.33^{h}	2.001^{efghi}	2.48^{hi}
45	M	0.36^{a}	0.899^{a}	0.109^{a}	4.99^{a}	3.303^{d}	1.92^{i}
	W	0.10^{fg}	0.708^{def}	0.078^{abc}	1.26^{hi}	1.282^{ghi}	6.93^{d}
50	M	0.30^{b}	0.823^{abcd}	0.100^{ab}	3.98^{b}	3.001^{de}	2.88^{gh}
	W	0.08^{fgh}	0.67^{4f}	0.075^{abc}	0.83^{ij}	1.066^{i}	8.66^{c}
55	M	0.20^{de}	0.764^{bcdef}	0.087^{abc}	2.83^{cd}	2.298^{defghi}	3.46^{fg}
	W	0.06^{gh}	0.210^{g}	0.005^{de}	0.36^{jk}	12.00^{b}	11.55^{b}
60	M	0.19^{e}	0.723^{cdef}	0.054^{bcd}	2.67^{ef}	3.518^{d}	3.65^{fg}
	W	0.03^{h}	0.133^{g}	0.001^{e}	0.21^{k}	30.00^{a}	23.1^{a}
65	M	0.18^{e}	0.675^{ef}	0.039^{cde}	0.34^{k}	4.615^{c}	3.85^{f}
LSD values ($P \leq 0.05$)		0.05218	0.1278	0.521	0.4811	1.261	0.9436

Glucose, sucrose, and molasses were employed to study their effect on growth and production of ethanol from mutant 15 in a time course study, as shown in Tables 4 and 5. Effect of substrate concentration on kinetic parameters revealed that 15% sugars gave the highest values of all kinetic parameters except Q_P. The optimum ethanol production (75 g l^{-1}) was observed after 72 h of fermentation with media containing blackstrap molasses (15% total reducing sugars), optimal pH 5.5 at 40–45°C. The representative kinetics of product formation by the mutant culture from glucose, sucrose, and molasses medium (Fig. 2) indicated that the activity in the case of mutant derivative reached maximum values after 40 h of fermentation. Sucrose and molasses supported only 1.16- to 1.36-fold more synthesis of Ffase than that on glucose. Thus, Ffase biosynthesis in the mutant cells and induction level on glucose were comparable with those on sucrose and molasses, and glucose repression of enzyme synthesis was completely overcome by mutation.

Table 3 Fermentation kinetic parameters of *K. marxianus* (W) and its mutant strain (M) product formation using ammonium sulfate (0.75%), pH 5.5, added in molasses medium (15% sugars) at different temperatures under control condition

Temperature (°C)	Strain	Q_p (g l^{-1} h^{-1})	q_p (g g^{-1} h^{-1})	$Y_{p/s}$ (g cells/g substrate)	$Y_{p/x}$ (g/g cells)
	W	1.83^{i}	0.18^{j}	0.16^{g}	1.80^{hij}
20	M	3.83^{efg}	0.27^{hi}	0.26^{ef}	1.35^{j}
	W	2.83^{h}	0.27^{hi}	0.29^{def}	2.25^{gh}
25	M	4.18^{cde}	0.31^{ij}	0.38^{b}	1.29^{j}
	W	3.75^{efg}	0.35^{hi}	0.38^{bc}	1.75^{hij}
30	M	4.75^{abc}	0.39^{ghi}	0.48^{a}	1.62^{ij}
	W	4.05^{ef}	0.45^{fgh}	0.47^{a}	2.14^{hi}
35	M	5.18^{ab}	0.59^{ef}	0.51^{a}	2.27^{gh}
	W	4.90^{ab}	0.72^{de}	0.48^{a}	3.13^{ef}
40	M	5.20^{ab}	0.85^{c}	0.51^{a}	2.83^{fg}
	W	4.13^{cdef}	1.10^{ab}	0.26^{ef}	6.11^{c}
45	M	5.28^{a}	1.29^{a}	0.51^{a}	3.58^{de}
	W	3.50^{fg}	0.81^{cd}	0.13^{g}	7.10^{a}
50	M	4.57^{bcd}	1.12^{b}	0.33^{cd}	3.73^{d}
	W	3.35^{gh}	0.54^{fg}	0.118^{g}	6.75^{a}
55	M	4.05^{def}	0.80^{cd}	0.31^{de}	4.00^{d}
	W	0.13^{j}	0.00^{k}	0.053^{h}	0.00^{k}
60	M	3.31^{gh}	0.55^{fg}	0.29^{ef}	2.90^{f}
	W	0.12^{j}	0.00^{k}	0.012^{h}	0.00^{k}
65	M	3.30^{gh}	0.35^{hi}	0.24^{f}	2.00^{hi}
LSD values ($P \leq 0.05$)	0.6412	0.1566	0.052	0.5716	

Table 4 Fermentation kinetic parameters of *K. marxianus* (W) and its mutant strain (M) for growth and substrate utilization in the presence of different nitrogen sources

Nitrogen source	(%)	Strain	μ (h^{-1})	Q_x (g cells l^{-1} h^{-1})	$Y_{x/s}$ (g cells/ g substrate)	Q_s (g l^{-1} h^{-1})	q_s (g g^{-1} h^{-1})	t_d (h)
	0.5	W	0.24^{cdefg}	0.82^{abc}	0.085^{b}	4.81^{a}	2.82^{defg}	2.89^{cdef}
		M	0.30^{ab}	0.865^{ab}	0.090^{b}	4.92^{a}	3.33^{abc}	2.31^{gh}
	0.75	W	0.29^{bc}	0.83^{abc}	0.091^{b}	2.22^{c}	3.19^{abcd}	2.39^{fgh}
		M	0.35^{a}	0.89^{a}	0.098^{a}	5.01^{a}	3.62^{a}	1.98^{h}
	1.0	W	0.22^{fgh}	0.84^{abc}	0.088^{b}	4.51^{ab}	2.50^{gh}	3.15^{bcd}
$(NH_4)_2SO_4$		M	0.28^{bcd}	0.85^{ab}	0.090^{b}	4.72^{ab}	3.11^{bcd}	2.47^{h}
	2.65	W	0.23^{defgh}	0.81^{abc}	0.075^{b}	4.82^{a}	3.06^{cde}	3.01^{gh}
		M	0.29^{bc}	0.82^{abc}	0.080^{b}	4.91^{a}	3.57^{ab}	2.39^{fgh}
	3.9	W	0.24^{cdefg}	0.82^{abc}	0.081^{b}	4.75^{ab}	2.96^{cdefgh}	2.89^{cdef}
		M	0.30^{ab}	0.83^{abc}	0.088^{b}	4.95^{a}	3.41^{abc}	2.31^{gh}
Corn steep liquor	5.3	W	0.21^{fgh}	0.82^{abc}	0.085^{b}	4.63^{b}	2.47^{gh}	3.30^{abc}
		M	0.27^{bcde}	0.85^{abc}	0.089^{b}	4.81^{a}	3.03^{cdef}	2.56^{defg}
	0.22	W	0.20^{gh}	0.71^{c}	0.080^{b}	4.81^{a}	2.50^{gh}	3.46^{ab}
		M	0.26^{bcdef}	0.75^{bc}	0.088^{b}	4.91^{a}	2.60^{efgh}	2.66^{defg}
	0.34	W	0.21^{fgh}	0.72^{bc}	0.082^{b}	4.82^{a}	2.56^{fgh}	3.30^{abc}
		M	0.27^{bcde}	0.78^{abc}	0.090^{b}	4.93^{a}	3.00^{cdef}	2.56^{efg}
	0.45	W	0.18^{h}	0.73^{bc}	0.084^{b}	4.87^{a}	2.11^{h}	3.85^{a}
Urea		M	0.24^{cdefg}	0.79^{abc}	0.089^{b}	4.90^{a}	2.70^{defg}	2.89^{cdef}
LSD values ($P \leq 0.05$)	0.05237	0.1385	0.2283	1.196	0.4912	0.5664		

Each value is a mean of two experiments. ± stands for standard error between $n = 2$. Mean followed by different superscripts indicate that they are significantly different at $P \leq 0.05$ using MStat C software. All three nitrogen sources were used at equimolar nitrogen concentration basis as 0.11, 0.16, and 0.212%

Table 5 Fermentation kinetic parameters of *K. marxianus* (W) and its mutant strain (M) product formation in the presence of different nitrogen sources added in molasses medium (15% sugars) at pH 5.5 at 40°C

Nitrogen source (%)		Strain	Q_p ($g\ l^{-1}\ h^{-1}$)	q_p ($g\ g^{-1}\ h^{-1}$)	$Y_{p/s}$ (g/g substrate)	$Y_{x/s}$ (g/g cells)
	0.5	W	4.52^{bcd}	1.39^{efg}	0.44^{a}	5.80^{a}
		M	5.10^{ab}	1.84^{b}	0.49^{a}	6.12^{a}
	0.75	W	4.92^{bc}	1.70^{bcd}	0.47^{a}	5.85^{a}
		M	5.37^{a}	2.19^{a}	0.51^{a}	6.25^{a}
	1.0	W	4.60^{bcd}	1.26^{gh}	0.42^{a}	5.75^{ab}
$(NH_4)_2SO_4$		M	5.10^{ab}	1.70^{bcd}	0.48^{a}	6.10^{a}
	2.65	W	4.23^{cd}	1.32^{efgh}	0.42^{a}	5.75^{ab}
		M	4.42^{bcd}	1.70^{bcd}	0.48^{a}	5.85^{a}
	3.9	W	4.36^{cd}	1.40^{efg}	0.47^{a}	5.80^{a}
		M	4.50^{bcd}	1.76^{bc}	0.49^{a}	5.87^{a}
	5.3	W	4.52^{bcd}	1.14^{hi}	0.41^{a}	5.45^{d}
Corn steep liquor		M	4.72^{bcd}	1.56^{cde}	0.45^{a}	5.80^{a}
	0.22	W	4.31^{cd}	1.08^{hi}	0.41^{a}	5.40^{c}
		M	4.53^{bcd}	1.51^{def}	0.43^{a}	5.82^{a}
	0.34	W	4.44^{bcd}	0.93^{ij}	0.42^{a}	4.45^{d}
		M	4.61^{bcd}	1.31^{fgh}	0.44^{a}	4.85^{cd}
	0.45	W	4.50^{bcd}	0.82^{j}	0.45^{a}	4.55^{d}
Urea		M	4.65^{bcd}	1.18^{gh}	0.48^{a}	4.90^{bcd}
LSD values ($P \leq 0.05$)	0.7570	0.2456	0.05	0.8731		

Each value is a mean of two experiments. ± stands for standard error between $n = 2$. Mean followed by different superscripts are significantly different at $P \leq 0.05$ using MStat C software. All three nitrogen sources were used at equimolar nitrogen concentration basis as 0.11, 0.16, and 0.212%

The product yield of Ffase and specific product formation rate (q_p) by mutant are several fold higher than the reported values by other workers on *Aspergillus* spp., *S. cerevisiae*, and their mutants or some recombinants [13–17].

It was observed that maximum values of ethanol (75 g l^{-1}) were obtained with *I* vvm aeration rate for 8 h, followed by 0.25 vvm for another 32 h at 45°C with 250 rmp agitation speed in a 23-lfermentor using pH 5.5, following growth on 150 g TRS l^{-1}, though the organism could grow up to 65°C. While other researchers have also done work on *K. marxianus* [18–20], the yeast grew only up to 52°C.

Kinetic parameters showed that the effect of different temperatures and tested organisms on product formation parameters was found to be highly significant. The interactive effect of temperatures and organisms was also found to be highly significant on Q_p, $Y_{p/s}$, and $Y_{p/x}$. Fig. 2 shows the maximum production of ethanol obtained at 40˚C. Of sucrose 15%, molasses 12%, molasses 15%, and molasses 17% used for production of ethanol, Fig. 2 shows that higher production of ethanol was obtained at 15% molasses.

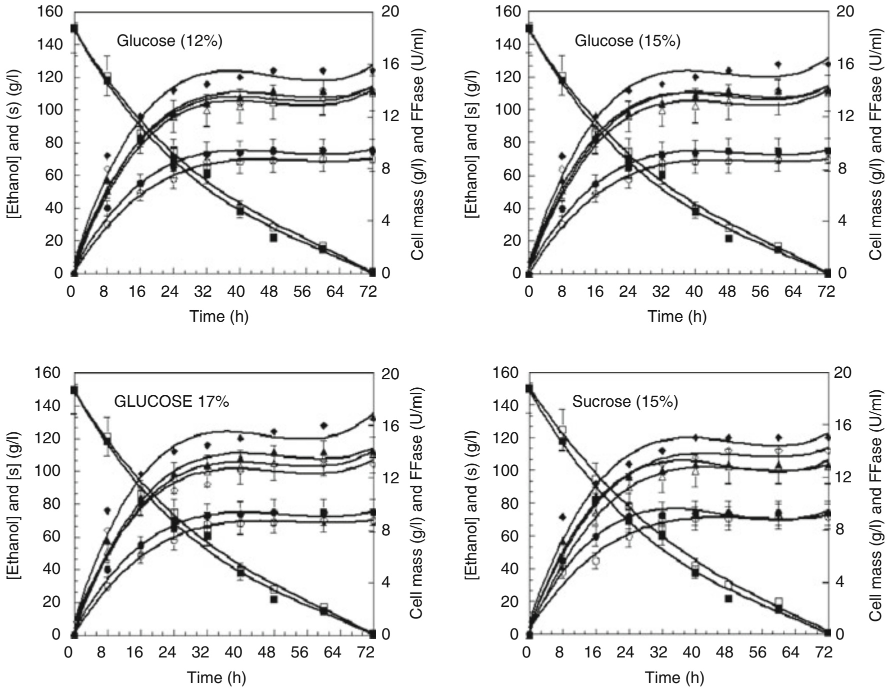

Fig. 2 Effect of different glucose and sucrose concentrations (glucose 12, 15, and 17%) and sucrose (15%) on ethanol formation (*circle*: W; *filled circle*: M), cell mass formed (*triangle*: W; *filled triangle*: M), Ffase (*diamond*: W; *filled diamond*: M) formation, and substrate present in fermentor (*square*: W; *filled square*: M) in batch culture at 40°C. Error bars show standard error between mean of $n = 3$ observations

3.1 Effect of Nitrogen Sources on Ethanol Production

Nitrogen sources such as ammonium sulfate, corn steep liquor (CSL), and urea were added to the growth medium to enhance growth and ethanol formation. All these sources were used at the appropriate rate to contain 0.11, 0.16, and 0.212% nitrogen in the growth medium. The results of growth kinetic parameters are presented in Tables 4 and 5, and show that the effect of different nitrogen sources on all growth parameters was found to be highly significant. Similarly, high significant difference was also found with tested organisms in all product formation except Q_s, Q_x and $Y_{x/s}$.

Ethanol production was found to be maximum with ammonium sulfate and minimum with CSL containing media. Cell mass production ($Y_{x/s}$) was found to be significantly higher in media containing CSL, whereas it was found to be significantly lower in media containing ammonium sulfate. Substrate consumption rate (Q_s) ranged between 1.34 and 2.29 g l^{-1} h^{-1}, which is recorded maximum in CSL and minimum in DAP. Parent and mutant strains of *K. marxianus* both showed maximum values with substrate supplemented with CSL. Specific consumption rate (q_s) was found to be greater in ammonium sulfate and lower in CSL supplemented medium. The values of q_s ranged between 0.95 and 1.05 g l^{-1} h^{-1}. The CSL supplemented medium showed significantly higher values of μ compared to the medium containing urea as nitrogen source.

3.2 Effect of Carbon Sources on Cell Mass and Ethanol Production

Different substrates such as glucose, sucrose, and molasses each at 10, 12, 15, and 17% total sugars were tested for their ability to support ethanol formation. Fermentation was carried out in a 23-l fermentor (working volume 15 l). The results reported are in the average of $n = 2$ experiments. The representative kinetics of product formation by the wild and mutant cultures from glucose, sucrose, and molasses (Fig. 2) indicated that alcohol concentration in both strains reached maximum values after 36 h. These curves also indicated that production of ethanol was apparently growth associated.

3.3 Effect on Growth Parameters

The results of kinetic parameters for substrate consumption, cell mass, and product formation are presented in Tables 6 and 7; highly significant difference was found between tested organisms (wild and mutant M15 of *K. marxianus*) in respect to cell mass formation rate (Q_x), growth yield coefficient ($Y_{x/s}$), and specific substrate consumption rate (Q_s), whereas nonsignificant results were recorded with specific substrate consumption rate (q_s) and specific growth rate (μ). Interactive effect of carbon sources $\times$ organisms was found to be highly significant with respect to all growth kinetic parameters.

The results of both wild (W) and mutant (M) strains of *K. marxianus* showed same optimum pH 5.5, but wild organism showed maximum specific growth rate at 40°C, while mutant organism showed maximum specific growth rate and ethanol formation rate at 45°C.

The optimal (maximum) ethanol production and β-fructofuranocidase formation under fermentation studies were carried out in a microprocessor-controlled 23-l stainless steel fermentor. For wild organism, temperature of 40°C, initial pH 5.5, molasses = 15% sugars, and nitrogen source ammonium sulfate (0.75%) were optimized. Most effective stirring speed in all experiments was 300 rpm and oxygen flow rate was 1.0 vvm for 8 h, followed by 0.1 vvm for 28–32 h. The mutant supported maximum ethanol and invertase at 45°C. Other optimized fermentation

Table 6 Fermentation kinetic parameters of *K. marxianus* (W) and its mutant strain (M) for growth and substrate utilization, using ammonium sulfate (0.75%), pH 5.5, in the presence of different carbon sources at 40°C

Carbon source (%)		Strain	μ (h^{-1})	Q_x (g cells l^{-1} h^{-1})	$Y_{x/s}$ (g cells/g substrate)	Q_s (g l^{-1} h^{-1})	q_s (g g^{-1} h^{-1})	t_d (h)
	10	W	0.22^{abc}	0.800^{a}	0.085^{a}	4.551^{a}	2.58^{abcd}	3.1^{bcd}
		M	0.23^{abc}	0.825^{a}	0.090^{a}	4.925^{a}	2.55^{abcd}	3.0^{bcd}
	12	W	0.23^{abc}	0.814^{a}	0.088^{a}	4.672^{a}	2.61^{abc}	3.0^{bcd}
		M	0.24^{ab}	0.850^{a}	0.092^{a}	4.954^{a}	2.60^{abc}	2.8^{cd}
	15	W	0.20^{abc}	0.875^{a}	0.095^{a}	4.712^{a}	2.10^{cde}	3.4^{abc}
		M	0.25^{a}	0.895^{a}	0.098^{a}	5.010^{a}	2.55^{abc}	2.7^{d}
	17	W	0.18^{c}	0.840^{a}	0.084^{a}	4.705^{a}	2.14^{de}	3.8^{a}
Glucose		M	0.24^{ab}	0.866^{a}	0.094^{a}	4.980^{a}	2.55^{abcd}	2.8^{cd}
	10	W	0.20^{abc}	0.755^{a}	0.077^{a}	4.340^{a}	2.59^{abcd}	3.4^{abc}
		M	0.21^{abc}	0.820^{a}	0.082^{a}	4.770^{a}	2.56^{bcde}	3.3^{abcd}
	12	W	0.22^{abc}	0.810^{a}	0.079^{a}	4.530^{b}	2.78^{abc}	3.1^{bcd}
		M	0.23^{abc}	0.831^{a}	0.087^{a}	4.805^{a}	2.64^{abc}	3.0^{bcd}
	15	W	0.23^{abc}	0.825^{a}	0.080^{a}	4.621^{a}	2.87^{a}	3.0^{bcd}
		M	0.24^{ab}	0.850^{a}	0.088^{a}	4.810^{a}	2.72^{a}	2.8^{cd}
	17	W	0.23^{abc}	0.816^{a}	0.082^{a}	4.692^{a}	2.80^{ab}	3.0^{bcd}
Sucrose		M	0.24^{ab}	0.840^{a}	0.089^{a}	4.820^{a}	2.69^{abc}	2.8^{cd}
	10	W	0.22^{abc}	0.799^{a}	0.083^{a}	4.550^{a}	2.65^{abc}	3.1^{bcd}
		M	0.23^{abc}	0.825^{a}	0.091^{a}	4.924^{a}	2.52^{abcd}	3.0^{bcd}
	12	W	0.21^{abc}	0.815^{a}	0.084^{a}	4.705^{a}	2.50^{cde}	3.3^{abcd}
		M	0.24^{ab}	0.852^{a}	0.092^{a}	4.970^{a}	2.60^{abc}	3.4^{abc}
	15	W	0.20^{abc}	0.841^{a}	0.085^{a}	4.707^{a}	2.35^{abc}	3.0^{bcd}
		M	0.24^{ab}	0.865^{a}	0.093^{a}	4.970^{a}	2.58^{abcd}	2.8^{cd}
	17	W	0.19^{bc}	0.838^{a}	0.080^{a}	4.710^{a}	2.37^{e}	3.6^{ab}
Molasses		M	0.24^{ab}	0.836^{a}	0.090^{a}	4.960^{a}	2.66^{abcd}	2.8^{cd}
LSD values ($P \leq 0.05$)	0.0519	0.0483	0.0519	0.975	0.415	0.511		

Each value is a mean of two experiments. ± stands for standard error between $n = 2$. Mean followed by different superscripts are significantly different at $P \leq 0.05$ using MStat C software. Carbon source concentrations were 10, 12, 15, and 17% (w/v). Ammonium sulfate (0.75%) was used as a nitrogen source

conditions as given above did not differ significantly and were maintained in all further experiments.

Among carbon sources tested, glucose caused catabolite repression of the wild organism, thereby limiting ethanol production, but the mutant organism was partially devoid of this phenomenon. Initial concentration of 15% was optimum for production of ethanol for the parental organism, but the mutant was significantly improved in this respect as molasses and ammonium sulfate were the best carbon and nitrogen sources.

The large-scale production may also be anticipated as economically feasible as the optimized carbon and nitrogen sources are cheap and found in abundance in agricultural countries like Pakistan that also support the industrial scale production.

Table 7 Fermentation kinetic parameters of *K. marxianus* (W) and its mutant M15 strain (M) for product formation from different carbon sources in yeast medium

Carbon source (%)		Strain	Q_p(g/l/h)	q_p(g/g/h)	$Y_{p/s}$(g/g substrate)	$Y_{p/x}$(g/g cells)
Glucose		W	4.52[bcdef]	1.20[cde]	0.46[a]	5.48[a]
	10	M	5.10[abcd]	1.33[abcde]	0.49[a]	5.82[a]
		W	4.82[bcde]	1.26[abcde]	0.50[a]	5.50[a]
	12	M	5.27[ab]	1.38[abcd]	0.51[a]	5.75[a]
		W	4.84[bcde]	1.34[abcde]	0.45[a]	5.80[a]
	15	M	5.79[a]	1.56[a]	0.51[a]	6.25[a]
		W	3.50[g]	1.39[abcd]	0.41[a]	5.60[a]
	17	M	4.79[bcde]	1.53[ab]	0.51[a]	6.14[a]
Sucrose		W	4.20[efg]	1.09[e]	0.44[a]	5.45[a]
	10	M	4.80[bcde]	1.15[de]	0.48[a]	5.50[a]
		W	4.35[def]	1.24[cde]	0.48[a]	5.65[a]
	12	M	4.85[bcd]	1.29[abcde]	0.49[a]	5.65[a]
		W	4.43[def]	1.31[abcde]	0.45[a]	5.72[a]
	15	M	4.95[bcd]	1.38[abcde]	0.50[a]	5.75[a]
		W	4.00[fg]	1.29[abcde]	0.41[a]	5.65[a]
	17	M	4.40[def]	1.39[abcde]	0.50[a]	5.82[a]
Molasses		W	4.50[def]	1.21[cde]	0.47[a]	5.52[a]
	10	M	5.05[abcd]	1.31[abcde]	0.48[a]	5.72[a]
		W	4.70[bcdef]	1.26[abcde]	0.45[a]	5.52[a]
	12	M	5.24[abcd]	1.45[abcd]	0.51[a]	6.05[a]
		W	4.00[bcde]	1.28[abcde]	0.40[a]	5.58[a]
	15	M	5.20[abc]	1.47[abc]	0.49[a]	6.15[a]
		W	4.50[cdef]	1.21[abcde]	0.47[a]	5.52[a]
	17	M	4.65[bcdef]	1.45[e]	0.51[a]	6.05[a]
LSD values ($P \leq 0.05$)			0.7612	0.3200	0.050	0.9066

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Fluidization in Cold Flow Circulating Fluidized Bed System

Ahsanullah Soomro, Saleem Raza Samo, and Ahmed Hussain

Abstract Fluidized bed combustion (FBC) system is widely regarded as one of the most promising techniques for burning low-grade fuels and also to reduce the emission of atmospheric pollutants such as SO_2 and NO_x released during the combustion. The performance of a circulating fluidized bed (CFB) boiler is influenced by the mixing of gas and particles. A high mixing rate contributes to an effective distribution of reactants, whereas insufficient mixing can lead to hydrocarbon emissions. Therefore, an adequate understanding of the mixing behavior is important to ensure a high combustion efficiency and emission control. In this work, the cold flow CFB system containing rectangular cross section (150 $\times$ 300 mm) riser having a height of 2.1 m was fabricated in the Department of Energy and Environment Engineering, Quaid-e-Awam University of Engineering, Science and Technology, to study the fluidization of fuel particle and air at various flow rates. The riser exit has also been made of Plexiglas, which is useful in studying the end effects in rectangular cross section geometry. While conducting experiment, it was found that the pressure in the riser section increased as primary air flow rate was increased, and also the rate of circulation of solid particles increased.

Keywords Design of cold flow CFB • Fluidization • Fluidization regimes • Result and discussion

1 Introduction

FBC is probably the most important practical development in combustion technology since the successful operation of large-scale pulverized-fuel furnaces in the early 1920s. In FBC chamber, fuel is intruded and combusted like a hot turbulent bed

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composed of ash, inert particles (sand), and/or sulfur sorbent. Rapid flow of upward moving air suspends fuel and bed particles in a fluidized manner during combustion. Fuel is continuously added to a fluidized bed of noncombustible particles (sand). Steady combustion takes place at red heat. In normal circumstances, the bed consists almost entirely of hot bed material which may be sand, ash, or material which reacts with potential pollutants in the low-grade fuel [1].

The hostile environment of coal combustion makes measurements challenging in circulating fluidized bed (CFB) power plants. Even essential flow variables such as overall solid fluxes are seldom recorded. In contrast, cold facilities can produce detailed hydrodynamic data. However, because the density and viscosity of cold gases are markedly different than that of typical combustion products, the hydrodynamics of cold units may not be relevant to CFB combustors (CFBCs) [2].

CFBs are a relatively new method of forcing chemical reactions to occur in chemical and petroleum industries. Compared with conventional fluidized beds, CFB have many advantages including better interfacial contacting and reduced back mixing [3].

1.1 Fluidization

Fluidization is a process in which solids are caused to behave like a fluid by blowing gas or liquid upward through the solid-filled reactor. Fluidization is widely used in commercial operations; the applications can be roughly divided into two categories, i.e.

- Physical operations, such as transportation, heating, absorption, mixing of fine powder, etc.
- Chemical operations, such as reactions of gases on solid catalysts and reactions of solids with gases, etc. (http://dissertations.ub.rug.nl/FILES/faculties/science/2004/c.dechsiri/c2.pdf).

1.2 Fluidization Regimes

When the solid/hard particles are moving, the fluidized bed behaves differently as velocity, gas, and solid properties are varied. It has become apparent that there are many regimes of fluidization, as shown in Fig. 1. When the velocity of a gas passing through a bed of solid particles is increased continually, a few vibrate, but still within the same height as the bed at rest. This is called a fixed bed. With increasing gas velocity, a point is reached where the drag force imparted by the upward moving gas equals the weight of the particles, and the voidage of the bed increases slightly: this is the onset of fluidization and is called minimum fluidization with a corresponding minimum fluidization velocity, Umf. By raising the gas flow further,

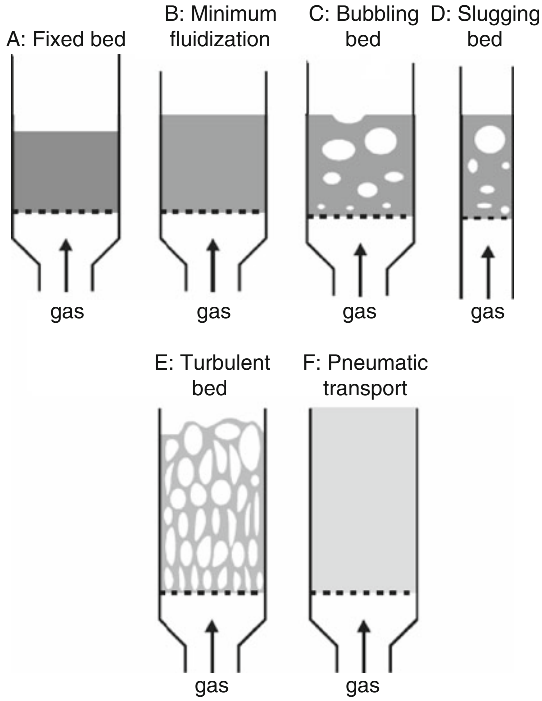

Fig. 1 Schematic representations of fluidized beds in different regimes

the formation of bubbles sets in. At this stage, a bubbling bed occurs as shown in Fig. 1. As the velocity is rising further still, the bubbles in a bubbling bed will combine and grow as they rise. If the ratio of the height to the diameter of the bed is high enough, the size of bubbles may become almost the same as diameter of the bed. This is called slugging. If the particles are fluidized at a high enough gas flow rate, the velocity exceeds the terminal velocity of the particles. The upper surface of the bed disappears and, instead of bubbles, one observes a turbulent motion of solid clusters and voids of gas of various sizes and shapes. Beds under these conditions are called turbulent beds as shown in Fig. 1e. With further increases of gas velocity, eventually the fluidized bed becomes an entrained bed in which we have disperse, dilute, or lean phase fluidized bed, which amounts to pneumatic transport of solids (http://dissertations.ub.rug.nl/FILES/faculties/science/2004/c.dechsiri/c2.pdf).

2 Prospectus of CFB in Pakistan

Total coal reserves of Pakistan are estimated to be around 185 billion tones, out of which about 175 billion reserves are located in Thar Desert, Sindh Province, which is the fifth largest single coalfield in the world. The coal reserves appear to be quite extensive and could potentially enable the generation of thousands of MW of electrical power. The use of this vast quality of indigenous fuel could provide a low-cost alternative to imported fuel with added security of local supply and control. Already, a power plant of 150 MW capacity using Lakhra Coal has been put in operation in Sindh province with the technical assistance of Chinese engineers, but due to unavailability of skilled manpower in the field of fluidized bed technology, the plant managements face difficulties in the operation of the plant. The CFB technology, which exhibits several advantages over conventional fluidized bed, has so far not entered into the energy sector of Pakistan. Operation of CFBC has confirmed many advantages over the conventional FB which include fuel flexibility, low NO_x and SO_x emissions, and higher turndown ratio [4].

3 Material and Methods

The CFB under investigation is a cold flow circulating fluidized bed (CFCFR), meaning that there is no combustion component in the process. But can be used to study the fluidization of various solids, e.g., saw dust, rice husk, and sand, riser inlet and exit effects, gas, and solid flows between the riser and downcomer, secondary air injections to control the solid inflow, solid and gas distribution, and solid distribution in the bottom zone, to observe the denser/dilute phase coexistence in the axial voidage profile, and to see the variable solid refluxing from the riser top due to L-connector design.

The CFB test rig consists of an air supply device, a distributor of mild steel, a see-through riser column of Plexiglas, primary and secondary cyclones of stainless steel, and a solid feeding system. The typical arrangement of the CFB test rig and the design features are represented in Fig. 2.

3.1 Riser Section of CFB

The riser is the most important section of the CFB because this is the section where most chemical reactions take place. The riser section of the CFB test rig consists of three parts: a plenum, a distributor, and tall column or riser. In order to have visual observation, the riser column was made of Plexiglas to observe the particle fluidization behavior and perform digital imaging. The design of the components is shown in Fig. 3.

The air supply box serves as a header, allowing primary air access to the distributor section. Its main function combined with the distributor is to supply homogenous fluidizing air to the riser. They were fabricated from mild steel having a smooth finish so that it offers minimum resistance to air flow. Since the degree of homogeneity of the fluidizing gas directly affects the solids distribution in the riser section. Therefore particular care have been taken in the design distribution to address the issue. Generally, the homogeneity increases by decreasing the hole size and increasing the hole density. However, this may result in large pressure drop which requires more energy consumption for pumping the gas [5].

Distributor's designs which were used for experimentation are as follows.

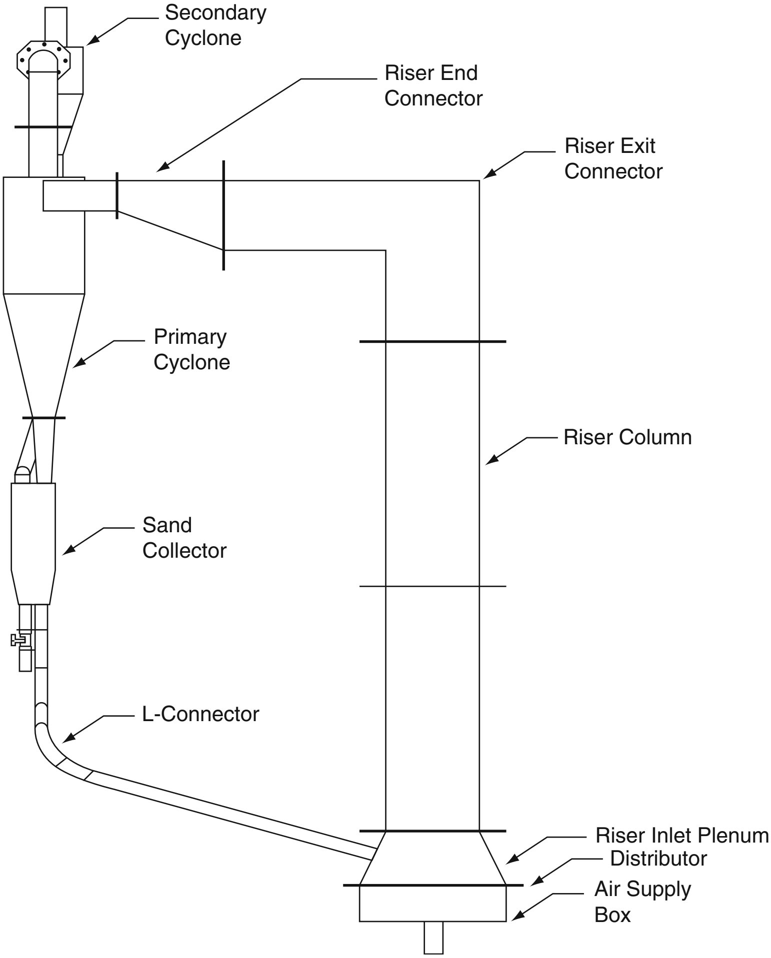

Fig. 2 Schematic diagram of CFB test rig

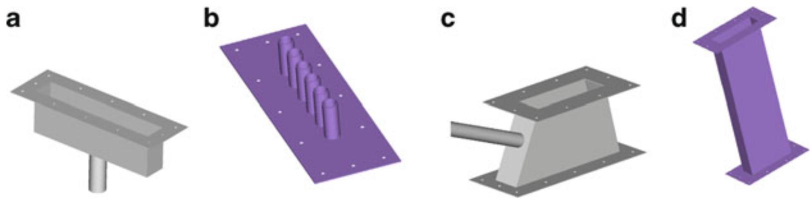

Fig. 3 Parts of riser column: (**a**) air supply box, (**b**) distributor, (**c**) riser inlet plenum, and (**d**) riser column

3.2 Bubble Cap Type Distributor

The bubble cap type distributor is shown in Fig. 4. It has 12 bubble caps of internal diameter of 10 mm. The bubble caps were arranged in such a way that they can supply homogenous supply of fluidized air. The air can be supplied through 2 mm holes in each bubble cap. The distributor was fabricated of stainless steel. The fabricated bubble cap distributor is shown in Fig. 4.

A CFB for industrial use often has a vertical riser of square cross section to convey the upward cocurrent flow of gas and solids. A square or rectangular cross section is common for CFBCs. In our design, we have incorporated a rectangular cross section (150 $\times$ 300 mm) riser having a height of 2.1 m. The riser exit has also been made of Plexiglas, which is useful in studying the end effects in rectangular cross section geometry. The whole CFB design was made modular and was connected to one another using flanges and nut bolts. This modular design offered easy design modification needed for future experimental variations. The typical modular arrangement is shown in Fig. 5.

The riser end connector or outlet bend is basically "L" shaped as shown in Fig. 6. It served the usual purpose of turning the gas solid flow through 90° so that the flow enters the primary cyclone, which in turn separates the solids from the gas. It is very important to observe the fluidization behavior in the riser exit, which is mostly affected by flow separation and erosion problems.

3.3 Gas–Solid Separating System

Cyclones are the main gas–solid separation equipment in the fluidization technology. Although the separating theory appears in voluminous literature, its design still depends on empirical equations due to many unknown parameter.

Fig. 4 Photograph of bubble cap type distributor

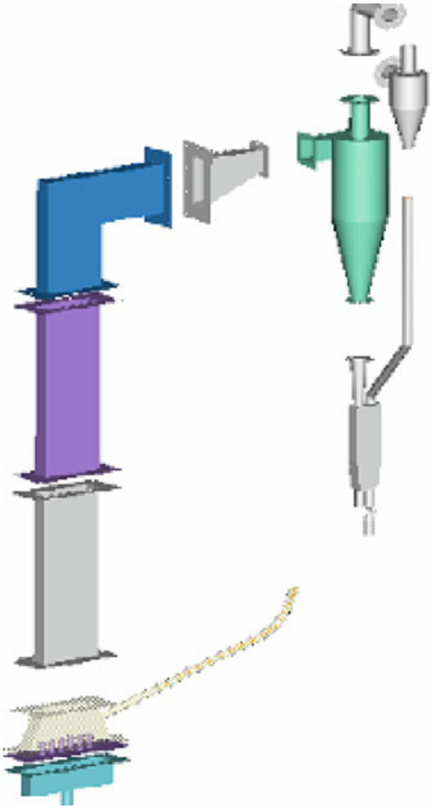

Fig. 5 Modular arrangement of CFB test rig

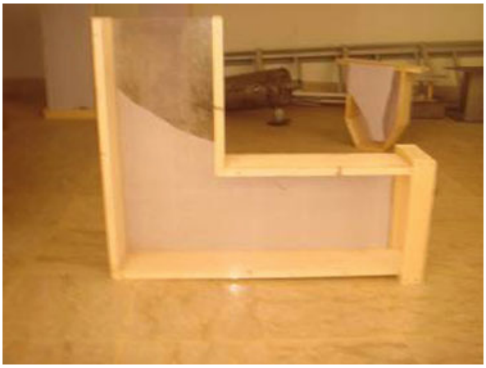

Fig. 6 Right angled riser exit section

The primary cyclone and secondary cyclones were fabricated of mild steel. This was done mainly to avoid any corrosion problem in the long-term use of equipment in future. The cyclones that were fabricated are shown in Fig. 7.

Fig. 7 Photograph of primary and secondary cyclones

Fig. 8 Sand collector in solid feeding system

The solid particles are collected in a collector and they are introduced in the riser section by the use of "L" valve. The solid particles are introduced into the riser using secondary flow injection from a compressor. The solid feeding system is shown in Fig. 8.

3.4 Air Supply System

The capacity of the blower is 3.50 m^3/min at the pressure of 150 mbar. The blower is capable of supplying constant, smooth air supply for the fluidization experiment. The Crelec H-29 brand blower used for the fluidizing experiments has a power of 1.5 kW and a maximum flow rate of 3.5 m^3/min.

3.5 Pressure Measurement in the Riser Section

The axial voidage distribution in CFB is an important parameter to determine. It is also a measure of pressure drop along the CFB, and it is related to solid hold up within the riser. The axial voidage profile of the riser column can be determined by measuring the axial differential pressure profile [5].

A multitube manometer was used to measure the axial pressure at various pressure tappings provided in the riser section and the L-connector. The number of tappings available in the riser section is seven. The pressure taps were made air tight by using sealing material. All the pressure taps are fed to multitube manometer tubes. The pressure tap through the riser wall had a copper tube inserted into it. The locations of the pressure measuring taps in the riser section were at the height of 0.3, 0.6, 1.02, 1.52, 1.85, 2.25, and 2.45 m, which were measured from base of the distributor. Typical arrangement of the pressure measuring system in the CFB rig is shown in Fig. 9 and Fig. 10 shows the laboratory scale of CFB rig.

4 Results and Discussion

It is important to understand the characteristic of the inlet design because this is the area where strong momentum interaction of gas–solid flow occurs. The behavior of gas and solid in bed was influenced by the upward air flow which was captured using digital camera to identify the flow pattern in the riser. The fluidization image from the experiments for sand particles is shown in Fig. 11.

Visual observations of the flow in the riser exit revealed that dunes of significant size were formed in the riser exit connector. It is due to the fact that solids in the horizontal connector have settled under gravity, which means that the remainder of the suspension is accelerated. This also highlights the phenomena of flow separations and is shown in Fig. 12.

4.1 Effect of Air Distributors

The distributors have a strong influence on the fluidization behavior inside the riser. In this study, we have used the bubble cap type distributor to see the effect of primary air distribution inside the riser. Sand particles were used as fluidizing particles. In order to observe the fluidization behavior inside the distributor section, a certain amount of powder was introduced into the riser section. The primary air could be adjusted using the bypass valve for fluidizing air. In the start of the experiment, the primary air from the blower was adjusted to a minimum. For observing the fluidization behavior in different distributor designs, the riser connector was fabricated of

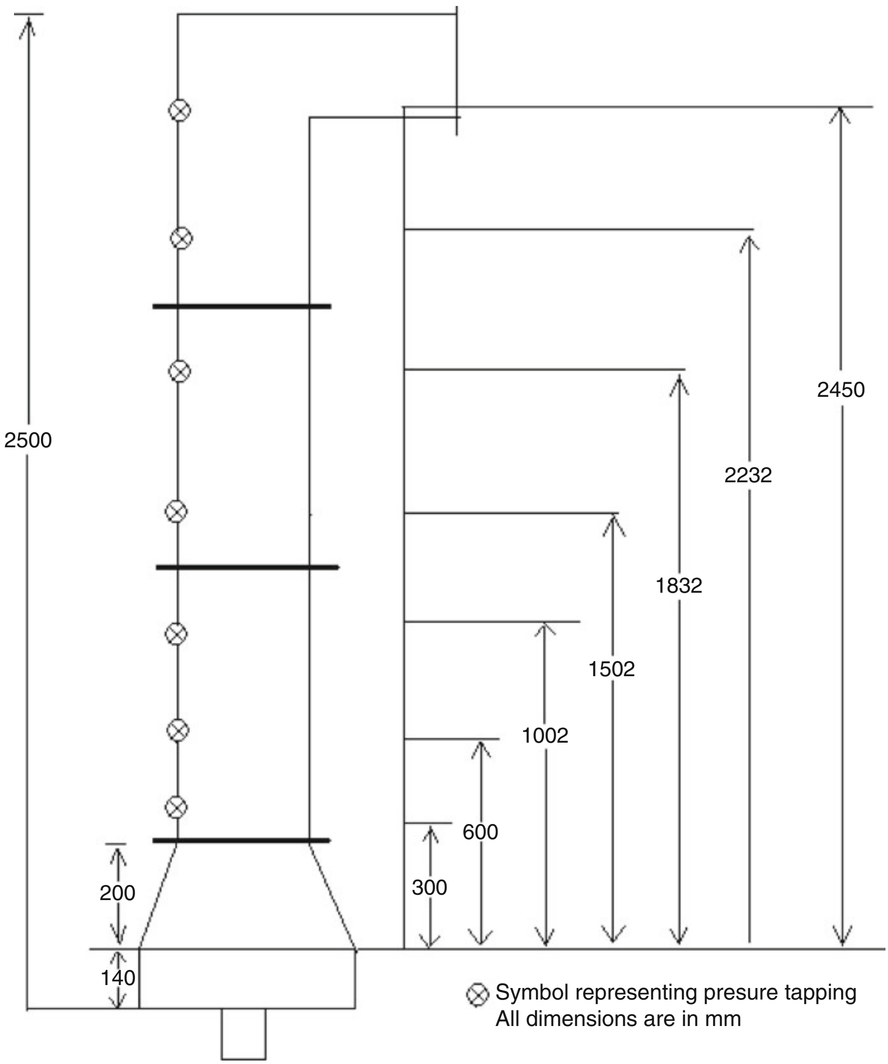

Fig. 9 Pressure tap arrangement in the CFCFB test rig

Plexiglas, which can offer visual observations and digital imaging of the fluidization phenomena. While conducting experiment, we have found that the pressure in the riser section increases as primary air flow rate is increased.

These experiments have also provided an understanding of the bubble behavior in the distributor section. Bubble growth was observed as they rose through the bed. Mostly, the larger bubbles rose more quickly than the smaller ones. It was observed that they overtook the smaller bubbles and coalesced with them. The higher the fluidizing velocity, the larger and more the bubbles, because most of the excess gas

Fig. 10 A photograph of laboratory-scale CFB test rig

Fig. 11 Fluidization behavior for sand particles

flows as bubbles. The rising bubbles drew a streak of particles after them and carry some particles in their wake. This mechanism has led to the solid circulation in the riser section.

The circulation of the solid is dependent on the flow rate of the primary. The faster these supplied air velocities, the better fluidization becomes. The pressure of

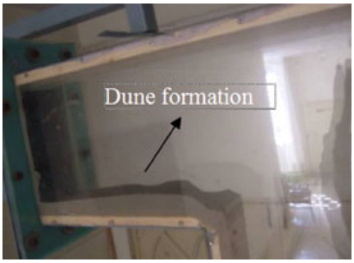

Fig. 12 Dune formation in the riser exit

Fig. 13 Fluidization of sand particles at different flow rate

Primary flow (m^3/sec)	Digital image
0.0091	
0.0076	
0.0052	
0.004	
0.002	

fluidization gas tends to be dropped when it flows upward along the riser section. On the top of the distributor plate, the air pressure is higher which pushes the solid upward.

4.2 *Effects of Air Flow Rate*

While changing the air flow rate, we have found that increasing the air flow rate causes the better fluidization and better circulation of solid as shown in Fig. 13. The air flow rates were measured with the help of ultrasonic flow meter.

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Assessment of Land-Based Pollution Sources in the Mediterranean Sea Along Gaza Coast – Palestine

Hossam Adel Zaqoot, Taysir Saleem Hujair, Abdul Khalique Ansari, and Shaukat Hayat Khan

Abstract The Gaza coastal area is experiencing a rapid growth of its population and economy, which is increasing stress and causes serious threats on the coastal and marine environment. This work is concerned with the assessment of land-based pollution sources in the Mediterranean Sea along Gaza coast. These sources are untreated wastewater discharges directly into sea, industrial effluents, recreational activities, agricultural activities, solid waste, and runoff pollution. During this study all available data were collected from Environment Quality Authority, Palestinian Authority, Ministry of Health, Environmental research published papers, reports, and nongovernmental organizations. In the present study, it was observed that the lack of operational and inefficient wastewater treatment plants makes the wastewater to be considered as the major source of pollution in the coastal and marine environment of Gaza. Based on the recent information, available reports and literatures, the land-based pollutants by sewage disposal constitute the greatest threat to coastal and marine ecosystems and to public health in Gaza. In addition, the Gaza treatment plant capacity is about 42,000 m^3/day and it receives about 60,000 m^3/day and the amount of 15,000 m^3/day dumped directly to the sea as raw sewage. Previous studies showed that the amount of pollutant discharges through sewage disposal such as BOD, nitrogen, and phosphorus may be considered the most significant pollutant threat to the coastal waters by causing high nutrient levels and even eutrophication near sewage outfalls and also causes long-term adverse impacts on the ecology of marine environment. The worst marine waters pollution is found to be in the central area of the Gaza Strip, where untreated effluent from Gaza City is discharged. This study provides an assessment of the land-based pollution sources and will act as a database for future investigations and in developing a management plan to control marine pollution along the Gaza coast.

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Keywords Gaza coast • Land based sources • Mediterranean Sea • Pollution

1 Introduction

Several million tons of pollutants are being discharged into the Mediterranean Sea every year from industrial activities of the 19 industrial countries surrounding the Mediterranean region [1]. Intense human activities in areas surrounding enclosed and semiclosed seas such as the Mediterranean Sea always produce in the long term several environmental impacts in the form of coastal and marine degradation [2]. Land-based marine pollution sources are the most serious environmental issue in the Mediterranean Sea accounting for about 80% of the pollution. The Gaza coastal and marine environment is facing large and serious threats from land-based pollution sources. The small Gaza Strip is one of the most densely populated areas in the world counting nearly 1.4 million inhabitants [3]. The limited land resources, physical isolation of the Gaza areas, and the lack of environmental management plans have caused many environmental issues. These issues lead to pollution of the coastal environment, deterioration of natural resources, and reduction of fish populations [4]. Beaches of the Gaza Strip have potential for beach tourism for the local population and foreign tourists [5]. A major problem, however, is the pollution of the seawater and beaches, which pose a major health risk for swimmers and aquatic life. About one third of the population is served by a collection sewage system. The rest of the populations rely on latrines connected to unsealed vaults. Gray water is disposed of via narrow surface channels, which in turn discharge their content into the seawater. Vacuum tankers are used to remove solid seepage from latrines and discharge it on the soil surfaces, which are very close to seashore. This may increase the pollution level in the coastal waters of Gaza. Another major problem that increases the health risks from using seawater for recreation is the limitation of treatment facilities and the method of effluent disposal. The sewage is either discharged near to the sea shore or a few meters offshore. This brings bathers into close contact with contaminated water, which clearly is a public health hazard. Due to the political circumstances, war, and siege in Gaza that resulted in strict travel limitations imposed on Palestinians, as well as the limited recreational areas, almost all of infrastructure installations that have been planned to be constructed along the beach in recent years to encourage tourism activities in the area have been postponed. Unplanned infrastructure development is a part of the general pattern of population growth and urban expansion. Human growth and mismanagement of these events has almost always been a major cause of pollution of the surrounding areas, which in this particular situation include the only recreational site in Gaza. In principle, land-based pollution sources assessment is a comprehensive tool to promote environmental priorities as well as a desired pattern of physical, economic, and sociocultural development in Gaza [6]. This study provides a preliminary assessment of the main land-based sources causing pollution along Gaza coast and may act as a database for future investigations and would help environmentalists and decision makers to develop a proper management plan to reduce the pollution level along Gaza coastal waters.

2 Data and Methodology

2.1 Study Area

The Gaza coastline which is part of the Mediterranean Sea is selected as a study area. Gaza coastline is 42 km long, between 6 and 12 km wide, and covers an area of 365 km^2. It is situated in the south part of Palestine and southeast of the Mediterranean Sea. The coastal zone of Gaza can be defined as the land side area of the coast covering an area of about 74 km^2, and roughly consists of the beach and the coastal sand dunes next to the Mediterranean Sea [4].

2.2 Data Collection

The data collected during this study is not consolidated by any institution or organization and is often not easily available when needed by any researcher for assessment purpose. Therefore, there is a need to develop a suitable information system that coordinates the activities of all institutions and related stakeholders so as to provide a good informative data that will help researchers during their research works. In the present work, all the data and documents were collected from different institutions, organizations, and some other NGOs as well as publications and reports that are available in websites.

3 Land-Based Pollution Sources

Human activities including urbanization in coastal areas, pollution from wastewater, tourism industry, agricultural pollutants, industrial pollution, influence of fisheries, and solid wastes exert pressures on marine and coastal environment. All these are land-based sources that cause pollution along the coastal waters of Gaza. The major land-based pollution sources along Gaza coastal environment are discussed as below.

3.1 Wastewater Pollution

Most of the wastewater is discharged untreated or partially treated along Gaza coast. There are more than 20 individual sewage drains, ending either on the beach or a short distance away in the surf zone. High percentage of the wastewater that is generated in Gaza City is currently discharged without treatment into the sea (50,000 m^3/day). About 40% of the wastewater that is generated in Gaza is currently discharged into the Mediterranean Sea; a minor part infiltrates into the soil and contaminates the groundwater [7]. The percentage of population served by sewerage systems is about 60%. The insufficient number of sewage treatment plants in operation, combined with poor operating conditions of available treatment plants, and the present disposal practices are likely to have an adverse effect on the quality of seawater [8]. The discharge of sewage into seawater can cause public health problems either from contact with polluted waters or from consumption of contaminated fish or shellfish. The discharge of untreated sewage effluents also produces long-term adverse impacts on the ecology of sensitive coastal ecosystems due to the contribution of nutrients and other chemical pollutants. In addition, pollution due to inadequate sewage disposal causes nutrient enrichment around population centers, and high nutrient levels and even eutrophication near sewage outfalls. Increased nutrients pollution level promotes algal and bacterial growth, degradation of sea grass, decreased fisheries production, and leads to human health risks [4].

3.1.1 Existing Wastewater Treatment Plants in Gaza

The main two operating treatment plants in Gaza Strip are Beit Lahia Wastewater Treatment Plant (WWTP) in the northern area, and Gaza WWTP in the center of Gaza City. The effluent of the treatment plants and Wadi Gaza are mostly discharged into the Mediterranean Sea. The total annual wastewater generated in the area is estimated at about more than 40 MCM, from which 22 MCM are disposed into the sewers and 18 MCM into cesspits or pit latrines. Due to the low water consumption in the Gaza Strip, the generated wastewater is with a high level of BOD while the average value is about 560 mg/l [9]. Figure 1 shows the wastewater outfall along the Gaza shoreline that contributes more pollution load in the coastal waters. The main three WWTPs are functioning in Gaza Strip are discussed as follows.

Gaza WWTP

Gaza WWTP was originally constructed in 1977 and in 1999 the plant was expanded to a capacity of 32,000 m^3/day. The current flow to the plant is about 42,000 m^3/day [8]. Nevertheless the plant is still receiving more wastewater than it has the capacity to treat, so most of the effluent is discharged to the Mediterranean Sea. The system comprises two sedimentation ponds, one anaerobic pond, two trickling filters, one aerated lagoon, disinfecting chamber, eight sludge drying beds, and a pond for holding sludge. The effluent BOD is 30 mg/l, TSS is lower than

Fig. 1 Wastewater outfall along Gaza coast

30 mg/l and KJ-N is lower than 50 mg/l. 10,000 CM/day of the effluent is infiltrated through two infiltration basins in agricultural area to the east of the plant [9].

Beit-Lahia WWTP

The Beit-Lahia treatment plant has been in operation since 1973. Due to the rapid population growth and the lack of funds to rehabilitate the plant, the sewage influent has been constantly overflowing the designed capacity. The amount of the sewage influent is approximately 8,000–10,000 m^3/day, and less than 30% of the influent is currently being treated. The existing wastewater plant was designed as a lagoon system with polishing ponds, without any treatment facility. The plant is located 1.5 km east of Beit-Lahia town in the northern part of Gaza. It serves the town of Jabalia as well as nearby refugee camps and the communities of Beit-Lahia and Beit-Hanun. The plant has no pretreatment facilities and a peak flow capacity of 5,000 m^3/day. At present, about 12,000 m^3 passes through it each day. The treatment plant is located in a closed depression without a natural outlet to sea, although the distance to the coast is only 4.5 km. The original design of the WWTP included four effluent ponds that would recharge the aquifer or evaporate. However, as time passed the high volume of effluent overflow has formed a lake covering 40 hectare. This has become a significant pollutant of the aquifer and a major environmental health problem for the population surrounding the lake. As a result of the existence of the lake, 14 groundwater wells are no longer used. A new WWTP for the Northern Governorate is planned at another location some 5 km away from the existing plant. The new plant's capacity is designed to provide treatment for 40,100 m^3 of water each day. The groundwater wells in Beit-Lahia are especially prone to pollution from the WWTP, since they are located only 240–300 m away.

Rafah WWTP

The Rafah WWTP was designed for a capacity of 1,800 m^3/day. At present, the plant is considered overloaded by receiving more than 4,000 m^3/day. The plant includes inlet microscreen 0.4 mm, one aerated pond, volume 31,200 m^3 fitted with surface aerators and horizontal mixers, one chlorination channel for disinfection (not in operation), and one pumping station containing two pumps to discharge the effluent to the sea. The aerators of the plant are only operated daytime and not on a 24 hours basis [9]. Figure 2 and Table 1 illustrate the load of pollutant discharges from different areas of the Gaza Strip to the sea during the year 2000–2001 (Table 1).

Shomar et al. [7] during the period of 2001 and 2002 has carried a research work in the wastewater of Gaza chemistry and management approach and showed the performance of the two main treatment plants. The results of his study are shown in

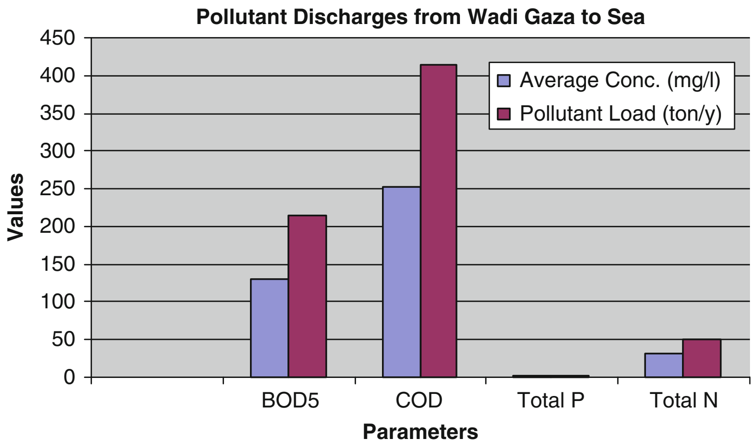

Fig. 2 Pollutant discharges from Wadi Gaza to the sea, 2000/2001

Table 1 Pollutant discharges from wastewater to the sea, 2000/2001

Location	Flow to the sea (m^3/day)	BOD5 (mg/l)	COD (mg/l)	Total P (mg/l)	Total N (mg/l)
Gaza WWTP effluent	32,000	33.3	98	5.4	50
Rafah WWTP effluent	4,200	269.3	652.2	4.5	93.1
Deir El-Balah	3,000	589	1,165	5	100
Pollutants load from Gaza WWTP (ton/year)		389.94	1,147.58	63.23	585.50
Pollutant load from Rafah WWTP (ton/year)		414.72	1,004.39	6.93	143.37
Pollutant load from Deir El-Balah (ton/year)		644.96	1,275.68	5.48	109.50
Total pollutants load (ton/year)		1,449.62	3,427.65	75.64	838.37

Table 2 Performance of WWTPs in the Gaza Strip (4–19 July 2001)

Parameters	Beit Lahia WWTP influent	Beit Lahia WWTP effluent	Removal (%)	Gaza WWTP influent	Gaza WWTP effluent	Removal (%)
pH	7.04	4.43	−6	7.5	7.7	−3
Temperature (°C)	22.3	22.3	0	25.5	26	−2
Settleable solids SS (Ml/l)	6	0.1	98	9	0.1	99
Total dissolved solids (TDS) (mg/l)	895	1,007	−13	1,470	1,536	−4
Total suspended solids (TSS) (mg/l)	1,288	1,024	20	440	20	95
Chloride (mg/l)	270	250	–	555	480	–
Fluoride (mg/l)	0.6	0.6	0	1.2	1.4	–
Sulfate (mg/l)	242	250	–	314	320	–
Total P (mg/l)	15	6	60	23	9	61
Total N (mg/l)	17	6	65	19	7	63
NO_2 (mg/l)	63	16	75	71	20	72
NH_4–N (mg/l)	64.4	61.4	5	62	60	3
COD (mg O_2/l)	884	108	88	940	89	91
BOD5 (mg O_2/l)	420	35	92	520	25	95

Adopted from Shomar et al. [7]

Table 3 Average concentration of heavy metals in Beit Lahia WWTP

Parameters	LD*	Inf 2000	Eff 2000	Inf 2001	Eff 2001	Inf 2002	Eff 2002
Ag (μg/l)	0.5	0.7	0.6	NM	NM	7.3	1.3
Al (μg/l)	25	73	39	NM	NM	138	44
As (μg/l)	5	5.6	5.1	0.7	0.6	5.5	5.4
Cd (μg/l)	0.5	<0.5	0.8	0.1	<0.5	<0.5	1.3
Co (μg/l)	0.3	0.3	0.8	NM	NM	0.6	0.8
Cr (μg/l)	2.5	38.9	7.6	25.3	2.9	25.2	8.4
Cu (μg/l)	1	6.0	6.7	2.5	2.7	8.5	5.1
Fe (μg/l)	15	373	114	344	76	356	347
Mn (μg/l)	1	120	96	116	47	142	139
Ni (μg/l)	0.5	21.9	11.8	NM	NM	13.1	12.1
Pb (μg/l)	2.5	2.6	<2.5	2.9	<2.5	2.7	<2.5
Zn (μg/l)	10	120	35	105	29	87	59

Adopted from Shomar et al. [7] *NM* not measured, *LD** limit of detection

Tables 3 and 4. The conclusion of his study results showed that the major ions of Cl, F, NO_3, SO_4, Na, Ca, Mg, and K in wastewater were similar to their values in the groundwater of the area of each treatment plant. Also the study showed that the major indicating parameters (BOD5, COD, and TSS) were removed to the maximum and all tested heavy metals in the effluent complied with different standards. The wastewater effluent had good characteristics close to the guidelines and standards of many developed countries, and in general the results revealed that there was no significant difference between the performances of the two treatment plants in terms of heavy metal removal [7].

Table 4 Average concentration of heavy metals in Gaza WWTP

Parameters	LD*	Inf 2000	Eff 2000	Inf 2001	Eff 2001	Inf 2002	Eff 2002
Ag (μg/l)	0.5	0.8	0.8	NM	NM	0.7	1.0
Al (μg/l)	25	71	61	NM	NM	89	278
As (μg/l)	5	6.6	7.0	0.4	1.1	7.8	8.4
Cd (μg/l)	0.5	0.5	<0.5	0.1	0.1	0.5	<0.5
Co (μg/l)	0.3	0.4	0.7	NM	NM	0.5	0.9
Cr (μg/l)	2.5	11.3	4.8	7.0	2.6	11.3	5.9
Cu (μg/l)	1	7.0	7.0	4.3	3.2	6.9	7.5
Fe (μg/l)	15	137	132	163	121	198	202
Mn (μg/l)	1	76	68	303	103	70	52
Ni (μg/l)	0.5	5.5	6.8	NM	NM	5.4	7.1
Pb (μg/l)	2.5	2.6	2.6	2.5	<2.5	3.3	<2.5
Zn (μg/l)	10	75	54	61	41	92	56

Adopted from Shomar et al. [7] *NM* not measured, *LD** limit of detection

3.2 Coastal Activities

Gaza shoreline is destroyed by new infrastructures, marinas, and urban expansion, and by the increase in population (with its need for wastewater and waste disposal), as well as stress and the pressure on water resources. Outstanding habitats, like dunes, are degraded. The Mediterranean basin provides a physical illustration of the problem of overloading and this appears to be a core issue of sustainable development of tourism and recreational areas. Tourism has positive environmental effects, i.e., tourist demands for a quality environment, especially for clean bathing water, are a powerful tool for improving water purification facilities and solid waste disposal in popular areas. The impacts of the tourist industry on the coastal and marine resources of Gaza result from all the subsectors of the industry, primarily the construction and operation of facilities. In the future with the expected developments in the coastal area and with the anticipated pressure from the recreational and tourism activities, the amount of pollutants reaching the sea, especially those of solid waste and wastewater, may increase [4] and [9].

3.3 Agricultural Pollution

In the Gaza Strip, there are more than 125 different types of pesticides being used annually, mainly organochlorinated, organophosphated, carbamates, and pyrethroids. Most of these pesticides are used to protect the main crop products (citrus, vegetables, fruits, and flowers) from pests and fungi [10]. The insecticides and rodenticides are also used in towns and cities to control household insects and pests. The most common used application methods are spraying with liquid formulations, dusting with powders, and injection with gas. Spraying methods are used to apply more than 70% of the pesticides. Methyl bromide, considered to be the most dangerous fumigants, used to be applied directly to the soil. Currently, nitrogen fertilizers (commonly nitrate or ammonium compounds) and phosphorus fertilizers as well as potassium fertilizers are used in large quantities in most agricultural activities in the Gaza Strip. All phosphorus and nitrogen and potassium fertilizers are applied to the soil before plantation to prepare and enrich the soil for seed grow up. The remaining quantity of these compounds is added to the plant during grow up campaigned with water to compensate the plant uptake of the nutrients. More than 900 metric tons of formulated pesticides are used annually in Gaza Strip. Nevertheless, several dangerous agricultural pesticides that are restricted, and banned in most developed countries are still allowed to enter the Gaza Strip and widely used. Generally, the extent and intensity of agriculture in Gaza produce high annual rates of fertilizers application (28,157 tons/year). Nitrogen fertilizers used in agriculture make up 70% of the nitrate load in the Gaza underground water resources, since nitrogen fertilizers constitute 43% of the fertilizers use. More than 200,000 m^3 of organic fertilizers are used annually in the Gaza Strip, 85% of these quantities are imported from other countries, and the other quantities are produced locally from the animal farms [9]. The organic fertilizers which are in use at Gaza are not monitored to meet with the international standards. Pesticides and fertilizers reach the coastal and marine environment via rivers, atmospheric transport and runoff during heavy rain seasons. The main point source is Wadi Gaza, which is considered the only surface water in the Gaza Strip. Figure 3 shows the estimated amount of pesticides and fertilizers used in Gaza during the period 2000–2001.

The Wadi crosses heavy agricultural areas in both Israel and the Gaza Strip, and during heavy rainfall and flooding seasons, it carries the agricultural chemical pesticides and fertilizers residues and finally discharged into the sea. The severity of pesticides and fertilizers runoff is influenced by the slop or grade of an area, the

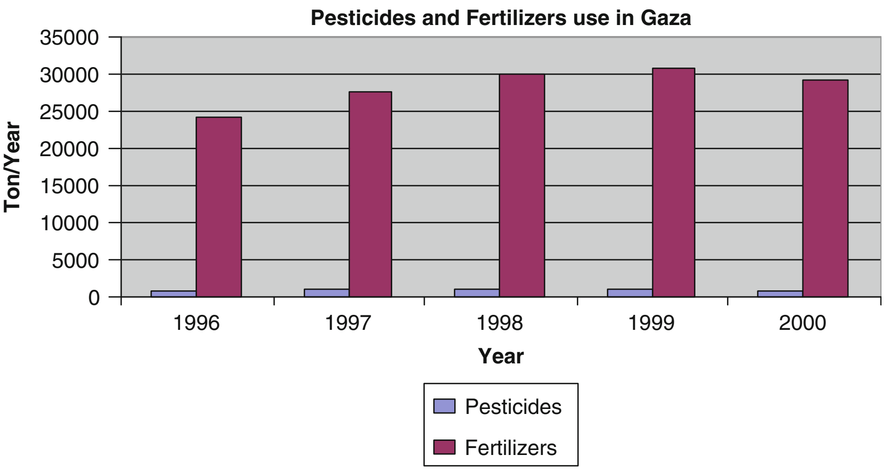

Fig. 3 Pesticides and fertilizers used in Gaza during 1996–2000

errodiability, texture, moisture content of the soil, and the amount and time of rainfall and irrigation. Runoff can also occur if pesticide is applied to a saturated soil, resulting from heavy rainfall and over-irrigation. Pesticides and fertilizers in the marine environment may affect living organisms through contamination of seafood. This may become a public health problem. It has been estimated that 90% of the used pesticides in agricultural activities do not reach the targeted species. Pesticides are highly toxic and tend to accumulate in the coastal and marine biota, making pesticide contamination a serious concern. The negative effects of pesticides and fertilizers in the marine and coastal environments include changes in several community structures, such as the increase in algae and sponges, and the damage of sea-grass beds and other aquatic vegetation from herbicides. Marine organisms may be affected either directly, as the pesticide and fertilizers moves through the food chain and accumulate in the biota, or by loss or alteration of their habitat. These negative impacts will lead to a decrease in the fisheries production.

3.4 Industrial Pollution

The main polluting industries in the Gaza Strip include the pharmaceutical industry, cosmetics industry, galvanic factory, textile dyeing, jeans washing factories, car washing workshops, electroplating, painting, soft drinks factories, ice cream factories, and detergent factories. Most of these industries are located in the area that has the best fresh groundwater. Most of the factories in the Gaza Strip discharge their wastewater without proper treatment or even without any treatment to the municipal sewerage system or surrounding dunes. Furthermore, the solid waste, which may include hazardous waste, is badly managed and is dumped without separation in the municipal landfills or open areas. Also the gaseous emissions from some industries are not monitored, and no treatment is used which endanger the public health of the workers and the people living close proximity to these industries. The description of the industrial pollution contributions along Gaza coastal waters is given as below.

3.4.1 Industrial Wastewater

At present a significant portion of the industrial wastewater generated in the Gaza Strip is similar to domestic wastewater. This is because most of industries in the Gaza Strip are small-scale industries and several industries such as garment manufacturing, plastic, paper manufacturing, print shops, glass, wood, leather, asphalt, petrol stations, and refrigeration do not use water as a raw material in the production process, but only for domestic purposes. These industries constitute with about 60% of the total number of the industrial establishments in the Gaza Strip and absorb the highest number of employees. Table 5 presents the wastewater estimation of the main polluting industries in Gaza Governorates.

Table 5 Annual wastewater production of selected main polluting industries

Type of industry	Wastewater quantity (m^3/year)
Textile dyeing	30,000
Jeans washing	55,000
Car washing	22,500
Photo processing*	54
Electroplating	2,500

Table 6 Heavy metals in the effluents of ten industries in Gaza (μg/l), year of 2000

Industry	Fe	Zn	Cu	Mn	As	Pb	Cr	Cd
Pharmaceutical industry	97	259	2.68	40	0.92	<2.5	<2.5	<0.5
Cosmetics industry	127	109	4.262	45	0.36	4.1	5.52	<0.5
Jeans washing	775	1,369	500	124	1.2	6.61	16.43	<0.5
Electroplating factory	5,450	29,500	4,000	219	3.58	102	15,859	70.15
Galvanic factory	2,900	3,096	14.95	26	2.36	10.3	797	9.40
Detergent factory	1,619	1,730	1	71	7.77	110	1,073	8.65
Cloth washing factory	277	503	500	57	1.9	6.52	50.65	<0.5
Ice cream factory	222	251	100	26	1.44	<2.5	50.95	0.86
Soft drinks factory	825	143	400	64	1.34	4.25	22.32	<0.5
Car washing workshops	1,308	212	100	75	2.12	27.3	23.13	<0.5

Adopted from Shomar et al. [7]

Lab analyses of the effluents from some industries in the Gaza Strip showed that it contains some heavy metals with concentrations exceeding the permissible limits. In addition, it has a high COD/BOD ratio which indicates that these contaminants are hardly biodegradable [11]. Besides the above pollutants some industrial wastewater streams are highly colored which may increase the pollution level. Most of the industrial effluents used to be discharged without treatment to the sewer system and ends up at the WWTPs and then to the coastal waters along Gaza coast. Although the quantities of the industrial wastewater compared with the inflow to these treatment plants are considerably low and the dilution factor is very high, its accumulation impact on the coastal waters quality and aquatic life may be of concern. The information about the industrial wastewater quality and its impact on the Mediterranean Sea is rather little or unavailable. This raises the need to implement some mitigation and preventive measures to control these effluents into seawater according to the permissible standards and regulations [9]. From the field surveys, it was observed that the industrial wastewater was disposed to the municipal sewage system when the latter was present, or to septic tanks constructed for each industry, or directly to the surrounding areas which are in some cases Wadies. Treatment processes were almost absent, and in the best case they were very simple, represented in sediment tanks. There was no regular inspection, and in case such inspection present there were no scientific rules regarding the discharge standards or quality control. Tables 6 and 7 show the heavy metals in the effluent of several industries located in Gaza. The results of 2001 for the same industries were similar to the results of 2000. The treatment plants are able to absorb all amounts of pollutants and the final effluent is considered clean for agriculture and other reuse applications [7].

Table 7 Heavy metals in the effluents of industries in Gaza (μg/l), year of 2002

Industry	Ag	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Detergent	2.79	925	31	0.7	2.2	103.5	174	645	12	27	10.7	269
Plastics industry	<0.5	920	5	<0.5	0.3	6.9	10	395	22	2	17.2	53
Galvanic	21.55	104	8	<0.5	3.4	71.5	385	565	3	5	<2.5	10,200
Jeans washing	8.9	59	5	0.6	0.8	7.6	39	380	111	5	<2.5	940
Pharmaceutical	1	313	14	0.8	3.5	102.5	54	3,200	221	22	53.0	605
Cosmetics	0.5	33	8	<0.5	0.5	11.4	11	379	42	5	<2.5	426
Cloth washing	1.755	38	10	<0.5	0.5	34.1	25	281	32	13	<2.5	102
Paintings	<0.5	1,440	15	0.5	2.2	8.7	51	585	45	6	453	173
Soft drinks	2.05	466	14	0.8	1	27.3	32	1,330	21	14	84.5	63
Electroplating	0.94	143	<5	0.7	3.6	48,050	1,585	1,270	80	74	7	1,085

Adopted from Shomar et al. [7]

3.4.2 Industrial Solid Waste

Data on the industrial solid waste quantities and composition is limited. Generally, there is no separation of the hazardous waste. It is collected with other waste and dumped in the municipal landfills or in the open areas. Recently, the Ministry of Industry carried out a field survey of the industries in the Gaza Strip, but the data has not been analyzed yet. According to this survey, more than 15,526 tons/year of solid waste is generated from the industries in the the Gaza Strip. At the Gaza Industrial Estate, there was special agreement with the municipality of Gaza to collect the solid and hazardous waste from the individual industries and to transfer it to Gaza landfill. Special arrangement will be developed for collection, transportation of the hazardous waste and disposal in the hazardous waste cell at Gaza landfill. At present large quantities of the industrial solid waste is randomly dumped near the shoreline due to the crucial current political situation in Gaza Strip since the last decade. There is no updated information with respect to the quantity, quality, and the impacts of these contaminants on the Mediterranean Sea.

3.5 Domestic Solid Waste

Solid waste amounts are increasing in the Mediterranean area. This increase is coupled with deficient collection systems and inadequate disposal practices. In addition to this, disposal of solid wastes from ships and other offshore sources and other coastal activities cause negative impacts to the coastal areas of the Mediterranean region.

Solid waste in Gaza generally consists of household waste, building debris, agricultural waste, industrial waste, medical waste, and car workshops. Solid waste generation rates range from 0.35 to 1.0 kg per capita. The total amount of solid waste generated in Gaza Governorates varies between 600 and 650 tons/day in the cities and villages .In the refugee camps it ranges from 250 to 270 tons/day. It is estimated that more than 65% of the household solid waste consists of organic material, while sand is the second major component of 23% of the waste [12]. The recreational activities on Gaza beach are potentially jeopardized with the quality of seawater. This pollution affects the tourism activities in the area due to major health risks for swimmers and marine life. In absence of the environmental standards, roles, and legislations, the beach is used as a dumpsite for municipal solid waste and construction debris. Garbage is dumped randomly from the near urbanized areas close to the beach. Also, industrial waste used to be dumped near the coast of Gaza. Other sources of pollution on the beach of Gaza are: washing animals in the sea, lack of containers, lack of toilets, and absence of litter bins. One of the biggest problems regarding beach pollution in Gaza is the problem of construction debris that the harbor authority used for a long time to dump in the sea to build the fishery harbor. This practice actually added huge amount of debris into the sea. Another dangerous phenomenon that takes place from time to time is the illegal disposal of some hazardous chemicals in the sea. In the last few years, many barrels of hazardous chemicals have been found near the sea [6].

3.6 Fishing Activities

The marine part of Gaza is the area along the coast that stretches upto 20 nautical miles offshore. This marine area has been divided into three Maritime Activity Zones, named K, L, and M. In Gaza, there are approximately 2,500 fishermen. In addition, 1,200 Palestinians have jobs related to fishing, such as the manufacture and maintenance of boats, nets, and some other activities. As reported in 2002, there were 727 vessels involved for a total of 2,305 fishermen. These vessels being used for fishing along Gaza coastal waters are unmotorized hasaka, that is, a small vessel with a closed deck that is handled by oars on the deck and has a length of about 3 m. A motorized hasaka is a relatively small vessel, with a length of 5.5–8 m. A flouka is also a small vessel with an open deck and has a length of 5–8 m. The launch vessels are bigger, ranging from 8 to maximum 14 m length. Trawlers are large vessels, between 16 and 27 m in length [4]. Most of the high-value fishes are the demersal species that are the main exports to foreign markets, whereas the pelagic landings are consumed locally providing an important source of protein in the diet of the inhabitants. Obviously the fish landings show fluctuations during this period as a consequence of the political situation. According to Palestinian official sources, the total fish production sharply decreased from the year of 2000 till present. The main threats to marine biodiversity in Gaza are environmental pollution and habitat destruction. It is fair to say that there are no pristine areas left in Gaza, all habitats have been impacted upon. The sand from the dune ecosystems is heavily mined by the construction industry. The sea turtles have been hunted to near extinction and their nesting beaches (in the north) suffer greatly from sand mining and pollution. In such a restricted area, there is great potential for overfishing. In addition, a large portion of the catch is juvenile, fine mesh nets are used, and chemical poison used for fishing. Thus the potential of overfishing is real and it is recommended to be monitored regularly.

3.7 Oil Pollution

Oil pollution in the coastal environment can have serious environmental consequences that may range from damage to marine life as well as to destruction of beaches [13]. The oil pollution in Gaza coastal waters does not come from major accidents, but from sewer outfalls, ship bilges, and possibly oil tanker operations near Ashkelon Harbor that is located in Israel. But most of these types of spills are small, and consequently lead to a diffuse and chronic oil spillage that forms a threat to marine ecology. A second type of oil pollution is major oil spill accident. The chance of such an accident in Gaza waters is small but oil tankers are nearby, off the coast of Ashkelon or entering and leaving the Suez Canal. In 1999, NOAA has been presented Environmental Sensitivity Index maps on oil pollution for the coastal zone along Gaza in the Mediterranean Sea [14].

4 Conclusion

This work has concentrated on the assessment of land-based pollution sources along the Gaza coast; these sources include wastewater, industrial effluents, recreational activities, agricultural pollutants, solid waste, fishing activities, and oil pollution. The coastal area in Gaza has a rapid growth of population and economy, which evidently increases the stress in the coastal and marine environment. The lack of operational efficiency of the WWTPs makes the wastewater to be considered as the most polluting of land-based pollution sources in the coastal and marine environment of Gaza. Based on the current assessment, the land-based pollutants by sewage disposal constitute the greatest threat to the coastal and marine ecosystems and to public health in Gaza. The amount of pollutants discharged through sewage disposal such as BOD, Nitrogen, and Phosphorus may be considered the most significant pollutant threats to the coastal waters by causing high nutrient levels and even eutrophication near sewage outfalls and also causing long-term adverse impacts on the ecology of marine environment. Therefore, it is widely acknowledged that the pollution on the coastal and marine environment must be controlled by improving the wastewater sewage collection system and treatment facilities performance. On the other hand, future emissions of pollutants should be prevented by implementing laws and convections related to the Mediterranean Sea region on possible effluents and preventing the pollution to come from its main sources. The agricultural activities that contribute to marine pollution are pesticides, fertilizers, and lack of awareness. However, the contribution of the industrial sector to the pollution of the Mediterranean Sea is relatively small as compared with other sources, for example, domestic wastewater. This study provides an assessment of the main land-based pollution sources along Gaza coast and may act as database for future investigations and developing management plan to control marine pollution along Gaza coastal waters. Further improvement can be made to upgrade this assessment and data of land-based pollution sources. This can be done by conducting more survey and research in the coastal waters and marine environment of Gaza.

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Impact of Sewage Water on Quality of Fullali Canal Water, Hyderabad, Sindh, Pakistan

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Abstract Untreated sewage of Hyderabad city is the key source of increasing pollution through discharge of sewage water into Phuleli canal causing contamination and hazards to the health of local people and irrigation system. This canal provides water to a population of more than two million of three major districts in lower Sindh along Akram Wah. Sewage water from Fullali canal was sampled from different station points and analyzed for pH, electrical conductivity (EC), total dissolved solid (TDS) residues, chlorides, hardness, alkalinity, dissolved oxygen (DO), and different cations like sodium (Na), calcium (Ca), magnesium (Mg), and potassium (K) to observe the effect of municipal discharge upon the quality of water used for irrigation purpose and also for drinking purpose. A significant number of samples showed elevated concentration of salts along the Phuleli canal which reached up to maximum values at three sampling stations.

This canal water contaminated with pathogens and harmful toxic chemicals from effluents is hazardous to both the ecosystem and all life forms whose survival depends on it.

Keywords Contamination • Irrigation • Municipal discharge • Sewage

1 Introduction

Kotri Barrage was constructed in 1955 with a design discharge capacity of 875,000 cusecs to irrigate through lined channels, Fullali, Pinyari, and Kalari canals. Fullali canal takes off from the left bank of the River Indus at Kotri Barrage and passes through Hyderabad city to provide water for irrigation to Hyderabad and Badin districts. The population of Hyderabad city is 1.5 million (1998) and it is the second

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most populated city in Sindh province. As the city is expanding and developing with the addition of population, industrial activities, and agricultural practices and other infrastructures, large volumes of organic and inorganic substances from industrial effluents containing oil, greases, and municipal wastes are discharged into the nonperennial Fullali canal. The canal originates from the left bank of River Indus from Ghulam Muhammad Barrage and has a discharge capacity of 14,350 cusecs, with a total cultivable commanded area (CCA) of 929,358 acres. Although there are a large number of points from where the sewage water from both the sides is added to the Fullali canal, the following are the main locations from where the sewage water is added: (1) Cantonment sewage water sampling station, (2) surface drain near Kali mori, (3) drain near old power house, and (4) Darya Khan Panhwar.

Water is vital to health, well-being, food security, and socioeconomic development of mankind. The presence of contaminants in natural freshwater continues to be one of the most important environmental issues in many areas of the world. Many of the earth's major rivers are polluted due to population growth, agricultural activities, urbanization, and industrialization. Particularly in developing countries, an estimated 1.3 billion persons living in low-income countries do not have access to safe drinking water [1, 2]. The Indus River, Pakistan, is one of the world's 1argest rivers in terms of drainage basin area (970,000 km^2). It mainly supplies water for drinking purposes in towns and for agricultural activity in countryside along its entire route, and is an important source of livelihood for millions of people. The Indus River is the single most important natural resource in Pakistan, and is one of the world's largest rivers in terms of drainage area and river discharge [3, 4]. 1t originates from the northern mountainous region, is flanked by agricultural areas and industrial estates of varied types, and finally enters the Arabian Sea. Much of its flow originates in the mountains of the Karakoram and Himalayas.

The Indus basin irrigation system in Pakistan is the largest integrated irrigation system in the world, and irrigates an area of about 16 million ha. The total length of the canals, main canal branches, and distributaries is about 57,000 km. The system has 88,600 outlets for the irrigation of service areas: a total of 17 barrages and canal diversion works, 42 major canals, 6,000 km of minor canals, 600 km of link canals, and 78,000 watercourses. The length of the farm channels and watercourses is about 1.6 million km [5–8]. Presently, 90% of the bathwater containing pollutants in high concentrations fall into the Indus River and its tributaries, and river water pollution has consistently increased with industrialization and urbanization. It is the source of much of the country's irrigation water and electric energy [9]. The major concerns regarding performance of irrigated agriculture in Pakistan are low crop yields and low water use efficiency [10].

A number of studies have been carried out to examine the water quality of Fullali canal, sewage water added to Fullali canal, and the effect of sewage water added to Fullali canal while it passes through Hyderabad city [11–15]. This report examines the quality of water used for irrigation purposes from Fullali canal while it passes through Hyderabad city as per WHO standards [16, 17].

2 Materials and Methods

2.1 Description of the Investigated Area

Four sampling points were selected at different distances starting from Ghulam Muhammad Barrage to Bihari Colony Bridge, i.e., 20 km away from the initial point (Table 1).

Samples of surface water from Fullali canal were collected in polyethylene containers capable of taking up to 1 L of water. Each bottle was rinsed with 1 M HCl and several times with deionized water before sample collection. The samples were transported immediately to the laboratory, until analyzed by standard methods. pH, temperature, conductivity, and TDS measurements were done on-site using an Orion 420 A pH meter for pH measurements and Jenway conductivity/TDS meter for electrical conductivity, temperature, and TDS measurements. All other parameters were determined within 2 days of sample collection. Atomic absorption spectrometer (Varion AA 20) was employed for the determination of metals in the water. Standard calibration curves were obtained by analyzing standards prepared by serial dilution of 1,000 ppm stock solutions. Duplicate determinations were made. After every ten determinations, blank and standard curves were checked to obtain reproducible results. The analysis was carried out in triplicate ($n = 3$), with a delay time of 3 s and an integration time of 3 s.

Many samples were collected from pumping stations before and after the discharge of sewage water into Fullali canal. The samples were collected on the same day (Table 2).

The sampling time and temperature (water and air) were noted at the sampling site. The collected water was transferred to Wrinkler bottle at the sampling site, and some excess water was allowed to flow to remove air bubbles. Manganese sulfate (2 ml, 36%, w/v) and alkali sodium iodide – sodium azide (2 ml) were added. The bottle was stoppered, mixed thoroughly, and finally sealed. The determination of dissolved oxygen was carried out in the laboratory on the same day [2].

The residues were determined as reported. The total residue was obtained by weighing the material left after evaporation of a well-mixed sample (50 ml) and drying the residue at 105°C. Both filterable and nonfilterable residues were determined by filtering 100 ml on a glass fiber filter (47 mm, 0.47 μm) (Gelman sciences, Australia), and the filtrate was dried and weighed. Similarly, the filtrate was evaporated, dried at 105°C, and weighed. Each of the residues was heated, dried at 105°C, and weighed. Each of the residues would be heated at 550±50°C for 2 h in a muffle furnace (Phoenix, Alpha, Sheffield). The loss in weight corresponded to volatile residues and the remaining to fixed residues. The samples were analyzed for alkalinity and hardness by titrating with standard silver nitrate (0.01M), hydrochloric acid (0.01M), and ethylenediaminetetra acetic acid sodium salt (EDTA) (0.01M) [1].

Table 1 Analysis of samples that were collected in July 2007

Parameters	Sample 0	Sample A				Sample B				Sample C			
		1	2	3	4	1	2	3	4	1	2	3	4
Time of collection (p.m.)	3:45	4:00	4:15	5:00	5:25	3:50	4:30	6:00	6:15	4:05	4:45	6:25	6:30
Temp. air (°C)	40	36	35	36	32	34	38	30	32	36	30	29	32
Temp. H_2O (°C)	38	34	33	34	32	35	35	33	32	34	33	33	2
pH	8.35	7.28	7.80	7.89	6.89	6.99	7.25	6.93	7.25	8.01	7.35	7.47	7.10
Conductance (mS/cm)	424×10^3	460×10^3	420×10^3	423×10^3	551×10^3	$1{,}312\times10^3$	527×10^3	$1{,}947\times10^3$	378×10^3	422×10^3	513×10^3	462×10^3	$1{,}569\times10^3$
Salinity (%)	0.2	0.2	0.2	0.2	0.3	0.6	0.2	0.1	0.2	0.2	0.2	0.2	0.8
TDS (mg/L)	197	218	199	200	265	634	249	955	1,920	200	244	218	765
Total residue	144	24	216	18	16	22	42	26	18	16	18	16	22
Volatile residue	6	10	4	6	12	14	16	4	14	10	6	12	8
Fixed residue	142	14	12	12	4	8	26	22	4	6	12	4	20
Chlorides	0.35	11.34	0.53	0.53	0.71	1.42	1.1	1.59	4.1	0.89	0.71	0.53	2.13
Hardness	125	375	125	200	250	175	225	200	400	125	125	250	225
Alkalinity	180	240	180	160	560	240	580	640	640	160	260	180	360
DO (mg/L)	17.5	10	14.4	13.5	7.0	Nil	Nil	Nil	Nil	15.6	16.2	10.5	7.9
Atomic absorption													
K (mg/L)	0.0	0.3	0.4	0.1	0.1	0.6	1.1	1.5	2.2	0.2	0.2	0.1	0.8
Na (mg/L)	2.0	3.0	2.0	2.0	2.0	9.0	6.0	9.0	2.0	3.0	4.0	4.0	9.0
Ca (mg/L)	2.2	2.5	1.7	1.7	2.8	2.5	1.4	2.4	3.9	1.6	2.1	1.9	3.2
Mg (mg/L)	19.0	22.0	20.0	20.0	23.0	48.0	28.0	44.0	112	21.0	18.0	23.0	25.0

0 = Sample from near bridge at the regulator of Fullali canal, 1 = Jacob tank Cantonment board waste, 2 = ;Kali Mori open drain, 3 = Open drain near old power house, 4 = Darya Khan Panhwar Pumping Station, A = Municipal waste or industrial effluents, B = Water which is used after municipal waste or industrial effluents are added and through lifts are used for agricultural purposes, C = Fullali canal quality 2 km from the addition of each municipal waste or industrial effluents

Table 2 Average quantity of wastewater and the percentage contribution of wastewater from different stations discharged into Fullali

Waste station	Average quantity discharged (m/day)	Percentage of contribution of the total discharged
Jacob tank Cantonment board waste	13,944±1,397	6.18
Kali Mori open drain	56,376±2,232	25
Open drain near old power house	42,323.44±3,229.82	18.76
Darya Khan Panhwar pumping station	96,441±4,151	42.75
Site area pumping station near Nara Jail	13,500±1,963.4	5.98
Other sources	3,000±855	1.33
Total	225,584.44	100

Reproduced from [12]

3 Results and Discussion

Water is the major contributing factor for life and for salinity development and management. The poor chemical condition of untreated industrial water and wastewater in Fullali canal is notified whenever they are in excess of the quality standards of receiving surface water, especially during quick flow periods. The temperature of the canal varies with climate and the season, and its measurement is useful to indicate the trend of various chemical, biochemical, and biological activities. The rise in temperature leads to faster chemical and biochemical reactions. The growth and death of microorganisms and kinetics of biochemical oxygen demand are also regulated to some extent by water temperature. Temperature may also affect some other characteristics of water such as dissolution of gases, pH, and conductivity. For example, neutral to alkaline pH is the general characteristic of flowing water. Generally, pH is higher during winter and lower during monsoon and summer. pH is elevated with an increase in phytoplankton population.

Conductivity of canal water is mainly associated with the dissolved material. The use of poor-quality water causes problems of salinity, permeability, and phytotoxicity to common agricultural crops (Table 3).

Calcium is an essential plant nutrient, and water high in calcium or magnesium is considered hard and is not desirable for domestic water supplies; however, hard water is considered good for irrigation. Calcium helps keep soil in good physical condition, which favors good water penetration and easy tilling. Magnesium is another essential plant nutrient and normally occurs at about half the concentration of calcium.

Water high in sodium is considered “soft” and is generally undesirable for irrigation.

Unfavorable conditions are likely to develop when the concentration of sodium exceeds that of calcium plus magnesium. When clay particles adsorb sodium, they tend to disperse and create “slick spots.” Sodium-affected soils take water slowly;

Table 3 WHO Standards for drinking water quality

Physical characteristics	
Color	Colorless
Odor	Odorless
Taste	Tasteless
pH	6.5–8.5
Electrical conductivity	900 10^6s/cm EPA PAK
Dissolved oxygen	6.5–8.5 ppm
TDS salts	500–1,000 ppm
Chemicals	
Chlorides	250 ppm
Calcium	100 ppm
Magnesium	30 ppm

form dry, hard clods that melt when wetted; and tend to seal the soil surface, leaving a slick appearance. Sodium not only affects the soil structure, but may also have a toxic effect on plants. Potassium is an essential plant nutrient commonly found in good supply irrigation water. Potassium is a minor element in irrigation waters and consequently, its determination is no longer a routine part of irrigation water analysis.

4 Conclusion

In the designed study, the presence of pollutants from hazardous industry is noticeable and may affect the individuality of a habitat plus aquatic life such as fish, plants, and local people who survive on Fullali canal water. Continuous and direct addition of untreated water to the Fullali canal would make water no more fit either for irrigation or for drinking purpose in long time. Hence, the construction of a treatment plant before the effluents are added to the canal is suggested.

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Environmental Impact of Untreated Effluents from Sugar Industry: A Case Study

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Abstract Sugar industry, being the major consumer of water, discharges its effluents into the outside environment mostly as untreated. However, besides knowing about the pollution strength of these effluents, knowledge about the mode of disposal of these effluents into the surroundings is also crucial. Thus, an intensive investigation was carried out to know the disposal patterns adopted by three selected sugar mills, namely, Habib Sugar Mills, Nawabshah, Matiari Sugar Mills, Matiari, and Fauji Sugar Mills, Tando Mohammad Khan, along with the obvious problems people were facing as a result. The study concluded that the disposal of untreated effluents into the surroundings had a negative impact on the resources such as land and water (both surface and ground) in particular and on the health of people and their livestock in general.

Keywords Disposal and pollution • Impacts of effluents • Sugar mills • Waste water

1 Introduction

There are over 30 sugar units in Sindh out of over 70 in the country. Sugar manufacturing plants use large amounts of water in their process of sugar manufacture [1,2]. At the same time, the industry is a large generator of wastewater/effluent [3], which is mostly disposed of by the mills untreated in the outside environment. The disposal of untreated wastewater from sugar mills is the cause of multiple environmental problems [4–6]. To know the approach adopted by the sugar mills to dispense with the effluents, three sugar mills were made the focus of this study, namely, Habib Sugar Mills (HSM), Nawabshah, Matiari Sugar Mills (MSM),

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Matiari, and Fauji Sugar Mills, Tando Mohammad Khan (FTMK), in addition to the impacts posed by the effluents when discharged untreated into the surroundings. Laboratory-scale experiments were performed [7,8] to develop a procedure for biological treatment of recalcitrant anaerobic industrial effluent (from ethanol and citric acid production) using first the microalga *Chlorella vulgaris* followed by the macrophyte *Lemna minuscule*.

This chapter reviews the suitability and the status of development of anaerobic reactors for the digestion of selected organic effluents from sugar and distillery, pulp and paper, slaughterhouse, and dairy units. In addition, modifications in the existing reactor designs for improving the efficiency of digestion have also been suggested [9].

An upflow anaerobic sludge bed (UASB) pilot plant of 2.83 m capacity was operated for 526 days to assess the treatability of cane sugar mill wastewater, at an HRT of 5.5 h, and average organic loading rate of 13 kg COD/m/day, giving a COD reduction of 75–80% [10]. The average methane gas recovery was 0.22 m CH/kg COD removed at an average temperature of 34°C. The biomass grew in the form of granules with excellent settling properties and a high methanogenic activity of 0.56 kg COD-CH/kg VSS/day. In the research carried out [11], it was found that pseudo-first-order kinetics described the anaerobic digestion of sugar mill wastewater using laboratory-scale fixed bed reactors. A pseudo-first-order equation described the relationship of COD removal rate with the effluent COD. The values of the maximum COD removal rate and saturation constant were found to be 3.02 g COD/1 day and 0.34 g COD/1, respectively; UASB wastewater (pre-) treatment systems represent a proven sustainable technology for a wide range of very different industrial effluents [12], including those containing toxic/inhibitory compounds. The process is also feasible for treatment of domestic wastewater with temperatures as low as 14–16°C and likely even lower. Compared to conventional aerobic treatment systems, the anaerobic treatment process merely offers advantages.

In this work [13,14], thermal extraction was used to quantify extracellular polymers (ECP) in granules from anaerobic upflow reactors.

1.1 Current Status of Disposal Criterion Adopted by the Sugar Mills

Every industry has its own mechanism to deal with the effluent that it generates. This holds true for sugar mills as well, which discharge their effluents according to their own set of methodology. The mode of disposal of wastewater by the sugar mills in question is discussed separately hereunder.

1.2 HSM, Nawabshah

The factory is a private limited company located in Nawabshah at about 125 km from Hyderabad. The cane crushing capacity of the plant is about 7,500 ton/day [12]. The millers discharge their effluents through a network of long cylinders, which then transfer this wastewater into the ponds or lagoons built outside the plant premises at a distance of 1.5–2 km from the mills. The survey of these lagoons yielded that there were at least 14 lagoons, constructed in a haphazard way over an area of 1.5–2 acres, having an average depth of 8–10 ft, where the industry stagnates its effluents for a period of 7–8 months.

The schematic presentation of disposal method of the effluent as practiced by HSM, Nawabshah, is given in Fig. 1.

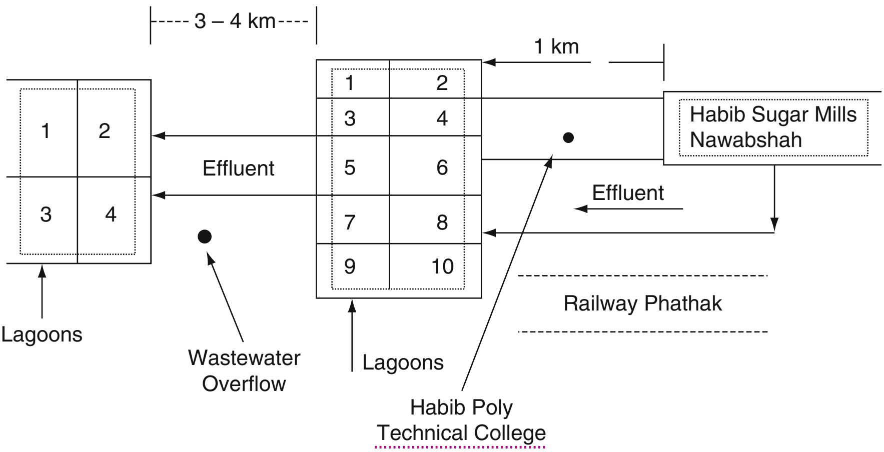

Fig. 1 Effluent disposal way of HSM, Nawabshah, MSM, Matiari

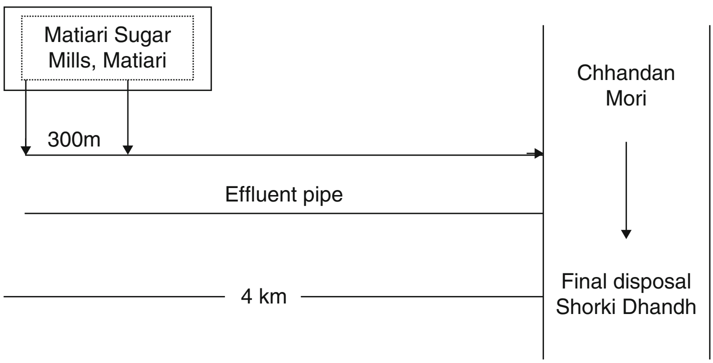

Fig. 2 The effluent discharge way of MSM, Matiari

The MSM is located at a distance of 6 km from Matiari town and about 35 km from Hyderabad. The sugar mills dispose of their effluent untreated through two large size concrete-made drains. After carrying the effluent for about 300 m from the mills, the effluent of both the drains runs or enters into a big underground cylindrical pipe, which then carries the effluent for final disposal into a canal called Chandan Mori, just 3–4 km away from the mills. This canal is 25–28 ft wide and 8–10 km long having a depth of 2–3 ft.

Figure 2 is a schematic presentation of the disposal method of the mills.

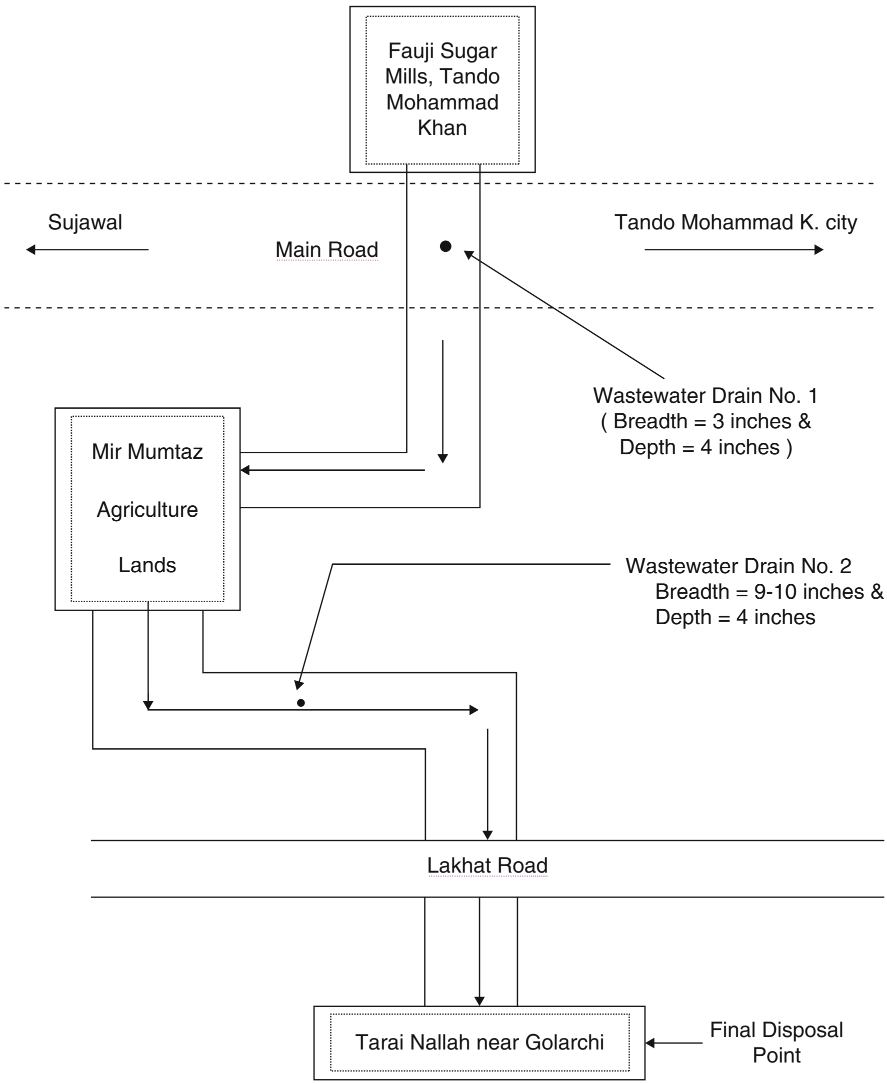

Fig. 3 Effluent disposal way of Fauji Sugar Mills, Tando Mohammad Khan

1.3 Fauji Sugar Mills, Tando Mohammad Khan

Fauji Sugar Mills is almost surrounded now by the city of Tando Mohammad Khan (TMK). The wastewater of the mills is neither discharged to the ponds nor thrown away into any canal. Rather, it is disposed via a storm wastewater drain, which passes between the Mir Mumtaz agricultural lands. This drain then takes a big shape and bifurcates the Lakhat Road and finally settles down in Tarai Nallah in Tarai Village near Golarchi.

The schematic presentation of the effluent disposal by the mills is shown in Fig. 3.

2 Investigation and Field Survey

In order to know the magnitude of problems caused by the disposal of wastewater into the surrounding environment, people in the vicinity of sugar mills were asked certain questions. The specimen of the questionnaire is shown as under.

3 Results and Discussion

Sugar mills discharge their wastewaters untreated, which can adversely affect its receiving source, be it groundwater, surface water, or any given agricultural land and may impose in the long run many health risks on the local community. Major impacts as observed during environmental surveys of the three sugar mills are concerned with odors from settled untreated wastewaters, contamination of groundwater sources, soil erosion, and sludge dumping.

In case of Fauji Sugar Mills, TMK, it was noticed that the effluents were being discharged outside through Mir Mumtaz agricultural lands, which had rendered a portion of soil, parallel to the effluent drain, infertile or barren. The effects were apparent up to 50 m giving a blackish look to the soil.

While in case of HSM, Nawabshah, the aftereffects of untreated wastewater disposal included contamination of groundwater resources, especially near the wastewater ponds. This was validated when a sample of groundwater was collected from the railway crossing hand pump situated 500–700 m from the wastewater ponds. This hand pump was actually not in use for the last 2 years, and the people abandoned its use.

However, somehow I got the sample from it for its analysis in the laboratory for common physical and chemical water quality parameters such as its color, odor, turbidity, dissolved oxygen (DO), and pH. The results showed zero level of the existence of DO, pH being on the acidic side, in addition to undesirable changes in the physical state of the sample with respect to its color, odor, and turbidity. It is more than likely that the seepage or percolation of the factory's effluents may have caused this water to turn from sweet water to poison.

Initially, the management of HSM thought it safe to dispose of the effluent in this way, but as time went by (roughly 40 years), effects or aftereffects of this practice started to transpire in the form of groundwater contamination, which even made the city of Nawabshah familiar owing to the foul smell emanating from these ponds.

MSM, Matiari, disposes of its wastewater via a network of cylinders for its final settlement in the canal known as Chandan Mori, which is a source of very pungent odor. Besides, the stagnant mills' wastewater is a breeding ground for mosquitoes and other fliers.

The sugar mill effluents contaminate the groundwater by seeping through the soil from unlined ponds, drains, and lagoons or from dumps and spills as in the case of HSM. Unlike surface water pollution, groundwater contamination does not occur overnight or within a short passage of time, which means it takes many years to contaminate the quality of groundwater, because the mechanism of contamination is not direct and too slow as well. Similarly, it may take a long time to cleanse itself, as it moves only slowly and is out of contact with the air [13].

The children of the area were also seen splashing around in the stinking wastewaters of HSM, along with the cattle for a dip in the ponds. The effect this has on their health is perhaps the most worrisome aspect of the situation. Apparently, no effort is being made to warn the people against the dangers of using the pond water that is said to be technically unfit even for irrigation.

When asked from a local Dermatologist he said that since the wastewater of the ponds was highly organic in nature, therefore, children in this case were susceptible to skin diseases like darkening of skin and rashness, besides attracting many insects and flies toward their sugary skins.

The survey questionnaire (Table 1) shows that around 20 people were interviewed in each immediate industrial locality. On average, over 50% people were of the opinion that the sugar mills' wastewater posed a direct or indirect effect on their health and on the livestock. The same number of people also complained of the odor nuisance caused by the stagnant wastewater in the ponds, as well as contamination of groundwater sources nearby the ponds.

Table 1 Public opinion on impacts of sugar mills effluents

Name of industry Area/locality						
		Level of impacts				
Name of person and age	Profession	Human health (%)	Livestock (%)	Agricultural lands (%)	Odor problem (%)	Surface water or groundwater (%)
		$A = 45$	$B = 45$	$C = 35$	$B = 55$	$A = 50$
		$B = 55$	$D = 25$	$D = 45$	$D = 25$	$B = 50$

A = High/severe; B = Mild; C = Less; D = No problem

4 Conclusions

It was concluded from the environmental survey that people living in the vicinity of the selected sugar mills were being affected by the discharge of untreated sugar mills wastewater. In case of HSM, the wastewater ponds built outside the plant premises at a distance of 2 km from the mills were the source of pungent and unpleasant odor that is bound to increase with time. In addition, it has now transpired through this study that the groundwater source in the immediate vicinity of ponds has been affected severely to the extent that it is no longer in use for any given purpose.

In case of MSM, the final effluent was being thrown into a large open canal, which was a source of breeding ground for mosquitoes, flies, and insects causing problems to the health of people.

While Fauji Sugar Mills final effluent was being drained outside the mills passing through the cropping area, the immediate portion of the soil was impacted resulting in the soil being left infertile and uncultivable with blackish color.

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Environmental Impacts of KPT Commercial Office Building, Karachi

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Abstract Urban Development especially the construction of high-rise buildings in Pakistan is encouraged by investors; therefore the need of the hour is Environmentally Sustainable Urban Development. This chapter outlines the environmental impacts of Karachi port trust's commercial office building during construction and operational phases. The analysis is based on screening, scoping, prediction and evaluation. The purpose of this research paper was to test the hypothesis that high-rise buildings have negative environmental impacts during construction and operation. For this purpose, the KPT tower complex, proposed high-rise building of Pakistan which has 78 stories, was selected. This was achieved by critical study of site, literature review, secondary data from different sources and with special contribution of Pakistan upper and atmospheric research commission regarding the data about ambient air quality monitoring, and shadow analysis of the building.

The adverse impacts which have been identified while analyzing the proposed KPT tower complex are construction waste water, construction waste, health and safety of the workers, marine and ecological impacts (Mangroves), waste water discharge, solid waste generation and disposal, energy consumption and traffic flow and the positive impacts are identified as generation of employment.

The research concludes that the proposed building may pose negative as well as positive impacts. Further study regarding the evaluation of EIA system in Pakistan and the review of status of implementation of EMP in EIA reports of buildings has been suggested.

Keywords Environmental impact assessment • Evaluation • KPT Commercial office building • Prediction • Scoping • Screening • Sustainable Urban development

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1 Introduction

The main factors for the construction of tall buildings are increase in global population and the increasing rate of urbanization. Globally, cities are being challenged to accommodate more people at higher densities and to relax pressure on finite resources, including arable land. The result is intensification of our cities, both in plan and in height [1].

The concept of sustainable city is basically related with the improvement of environmental degradation. In major cities, buildings are significant for the economic and social development as well as being environmentally sustainable. “A sustainable city is regarded as which satisfies the needs of the inhabitants without damaging the natural as well as built environment in future”. The concept of sustainable city lies in the sustainability of the economic, social and environmental sectors. Buildings are regarded as a significant part of sustainable city development. The sustainability of cities lies in the sustainability of the buildings. In the cities buildings are not only the major contributors of environmental degradation but are also important in sustaining the city economy. The environmental performance of cities lies in secondary priority while economic and social sectors are on the top priorities; therefore the environmental improvement should be given a top priority in the sustainability of cities [2] .

Tall buildings play a positive role in the development of major cities. Tall buildings can be a symbol of economic identity and iconic structure of global positioning [3].

No doubt that construction industry plays a vital role in the enhancement of quality of life and also for meeting the needs of the society, but on other hand, construction is also a major contributor to the environmental problems; therefore the responsibility for ensuring construction activities with respect to the environmental policies needs to be clarified and sustainable environmental approaches be implemented by reducting waste [4]. No doubt that construction has environmental disturbances but it has also positive impacts on the urban environment [5].

Construction of a single reason to disturb the environment from excessive use of global resources, the construction and building operations in the pollution of natural environment and cultural landscape [6].

Due to global warming, experts estimate that up to 60% of global cut, it is necessary to reduce global warming and is the best option for reducing the environmental building and construction work is called the largest source of indirect global production. In this regard, the sustainability of the environment lies in the sustainability of tall buildings and it must therefore be viewed that the buildings are an integral part of a city’s sustainable growth. Appropriate measures should be taken to conserve water and reduce waste and recycle materials during the building construction process [7].

As compared to all infrastructure developments, tall buildings are likely to have great impact on the environment. One of the positive aspects is that tall buildings may generate a wide range of different employment opportunities, particularly offices but also hotels and leisure facilities.

Tall buildings may have a greater level of impact on their surroundings, e.g., the residential and business communities may be affected by overshadowing, overlooking and other amenity considerations such as environmental effects, sunlight and light, energy efficiency, waste reduction, water consumption and waste water discharge [8].

In the assessment of the environmental sustainability of buildings, a number of technological, ecological and socio-cultural factors are considered. However, in general the following factors are considered: emissions to air, greenhouse gas production, releases to water, contamination of land, waste management and use of non-renewable and renewable natural resources [9].

The built environment is recognized as being the largest single contributor to climate change, with the creation, running and maintenance of buildings estimated to account for 50% of all energy usage and more than 50% of all climate change emissions globally [10].

The contribution that commercial buildings in urban areas can make towards environmental sustainability is rarely exploited to its full potential [11].

The Environmental Impact Assessment (EIA) of Urban Development/Construction projects is the process of identifying, predicting, evaluating and mitigating the biophysical, social and other relevant environmental effects of development proposals or projects prior to taking major decisions and making commitments [12].

EIA can be broadly defined as the systematic identification and evaluation of the potential impacts (effects) of proposed projects. It helps to identify the possible environmental effects of the proposed project, proposes measures to mitigate adverse effects and predicts whether there will be significant adverse environmental effects, even after the mitigation is implemented [13].

1.1 Issue of Concern

According to Pakistan environmental protection act (PEPA-1997), it is mandatory to submit EIA and NOC from the environmental protection agency before the commencement of urban development projects. In Pakistan, few technical studies such as Mubarak Centre Lahore and Centaur's Building Islamabad have been conducted but from an academic point of view not a single study has been done regarding the environmental and social impact assessment of the construction and operation of proposed high-rise buildings.

1.2 Hypothesis

The hypothesis of the research is that high-rise building has negative impact on the natural as well built environment. To test the hypothesis, the proposed KPT commercial office building located along the Mai Kollachi expressway has been selected.

2 Limitations of the Research

The boundaries for environmental and social impacts analysis are limited to the baseline line study of the area. The duration of field visits was very short and was used only for preliminary data collection. The best environmental assessment requires field visits in all four seasons; therefore the secondary data provided by Pakistan Upper and Atmospheric Research Commission (SUPARCO) have been used for impact evaluation and prediction of the impacts especially of the air, noise, wind and shadow analysis of the building. The issues highlighted are based on the preliminary field visits data, literature review and secondary data by SUPARCO. The study of site alternatives and assessment of design parameters of the building in terms of architecture, structure, mechanics and electricals are beyond the scope of research.

3 Objective of Research

The objective of this research is screening, scoping, prediction and evaluation of the environmental impacts of construction and operation of the building.

4 Research Methodology

The methodology to achieve the desired objective is given below. The objective is achieved through site visits, data collection, literature review and secondary data by Pakistan Upper and Atmospheric Research Commission. For screening EIA/IEE regulations, 2000 of Pakistan Environmental Protection Act 1997 has been referred and for scoping of the impacts, the Leopold Matrix method has been used. For the prediction of impacts, qualitative assessment based on the site visits, literature survey and secondary data provided by Pakistan Upper and Atmospheric Research Commission has been adopted especially of ambient air and noise quality monitoring, and wind and shadow analysis of the KPT commercial office building. Evaluation of the impacts is based on the NEQS guidelines and Leopold Matrix method in which evaluated boxes have been created. The evaluation of the impacts is based on the time of occurrence, duration of impacts, probability of occurrence, remedial measures, magnitude/importance and risk.

5 Project Description and Baseline Study of the Area

5.1 Project Description

The proposed KPT commercial office tower/building will contain commercial as well as residential blocks with facilities such as parking, landscaping, etc. The project development will include site formation works and construction of infrastructure including building structure, drains, sewers and utilities, and landscape areas. The site selected for the project is 35.8 acres of reclaimed land acquired by KPT for the development. The main building would be 78 stories. Baseline of the site: the climate of the site is moderate. The china creek is already polluted due to the drainage of industrial and commercial wastes. The ambient air quality of the site is below the limits of stated united environmental protection regulations. Site contains mangroves. There is no cultural and archaeological site of national and international importance located in the proposed area of the project.

5.2 Analysis Screening

According to the SCHEDULE II of the Pakistan Environmental Protection Agency (review of IEE and EIA) regulations, 2000, Large-scale urban development and tourism development projects with total cost more than Rs. 50 million require EIA. The total cost of this project is estimated to be about 20 billion.

5.2.1 Scoping

The impacts which are screened are given in Table 1.

6 Prediction

Prediction involves the identification of potential change in the indicators of environment receptors (Table 2).

Table 1 Scoping of the environmental impacts

Activity	Environmental impacts
Site selection phase	Ecological impact (Mangroves)
	Soil erosion
	Air emissions
	Vibration and noise
	Traffic flow
	Water demand
	Construction waste water
	Construction waste
	Socio-economic impact
Construction phase	Workers health and safety issues
	Solid waste
	Water demand
	Waste water discharge
	Energy consumption
	Traffic volume
	Visual impacts
	Shadow impacts
Operational stage	Socio-economic impacts

6.1 Evaluation

Evaluation of predictive change of an impact is analyzed on the basis of scoring and weighted method in which evaluated box is created following Leopold Matrix guidelines. Each evaluated impact is defined as follows (Tables 3 and 4):

- Time of occurrence Probability
- Benefit Magnitude Risk Secondary impacts
- Duration Remedial measures

7 Findings

During construction of the building, the impacts on soil, traffic flow and water demand will be negative, minor but not significant. On the other side, the impacts of vibration and noise, air quality, construction waste water, construction waste, ecology and marine environment will be negative and significant. The socio-economic impacts will be positive.

During the operation of the building, the impacts of solid waste, water demand, waste water discharge, energy consumption and traffic flow and emissions will be negative, major and significant. On the other hand, the impacts of shadow will be negative, minor but not significant. The visual impacts of the site and socio-economic impacts will be positive and major.

Table 2 Prediction of the environmental impacts

Environmental indicators	Change	Impact due to project action	Occurrence
Physical environmental indicators			
Soil	Alteration of soil structure	Soil erosion Contamination of soil	Occurred
Water	Water consumption and waste water	Shortage of water/water demand Waste water generation	Occurred
Energy	Energy consumption	Electricity consumption/load shedding in the vicinity	Occurred
Air quality	Alteration in the air quality	Dust and air emissions	Occurred
Noise and vibration	Increase in noise level	Noise	Occurred
Ecology	Cutting of mangroves	Loss of habitat	
Traffic flow	Increase in traffic volume	Traffic congestion specially during peak hours	Occurred
Construction waste	Generation of construction waste water, storage of flammable materials	Hindrances in traffic flow Fire occurrences	Occurred
Solid waste	Generation of solid waste during operation	Soil contamination, health impact	Occurred
Waste water discharge	Contamination of the water	Threat to marine environment	Occurred
Visual impacts	Aesthetic views	Positive	Occurred
Shadow	Blockage of sun light	Energy consumption	May occur
Occupational health and safety	It may lead to death or minor or major injuries, fire and emergencies	Health and safety issues	Occurred
Socio-environmental indicators			
Cultural, archeological and ethnic occurred	No effect	Destruction of architectural, historical and cultural structures	Not
Socio-economic	Positive effect	Employment to locals	Occurred

8 Conclusion

The paper concludes with the main findings of environmental impacts. In this research study, all the aspects of construction and operation of KPT Tower complex project have been critically assessed. Keeping in view the baseline study of the site, literature reviewed, site visits and personal observation it has been concluded that the site which has been selected for the KPT tower is suitable because it is near commercial business district and has aesthetic views. From the environmental assessment point of view, it has been concluded that the proposed building may pose negative impacts in terms of waste water discharge, construction waste, energy consumption, solid waste generation and disposal and impact on ecological and marine environment of the china creek. KPT has already made provision for waste water treatment plan and other environmental pollution control measures for

Table 3 Evaluation of environmental impacts criteria

Characteristic evaluated	Classification	Symbol
	Major	5–4
	Moderate	3–2
	Minor	1
Importance	Unable to determine	?
	Certain	C
	Probable	P
	Unlikely	U
Probability	Not known	?
	Immediate	I
	Delayed	D
	Long-term	L
Time of occurrence	Not known	?
	Transient	T
	Short	S
	Permanent	F
Duration	Not known	?
	Positive	+
	Negative	–
Benefit	Not known	?
	Planned	Y
	Not planned	N
Remedial measures	Not known	?
Risk	Potential hazard	!
Secondary impacts	Will give rise to	*
	Is a result of	"

the construction and operation of the building; therefore if mitigation measures and environmental management plan be designed and implemented, this project will be in national interest in terms of employment generation and office accommodation and thus the revenue generated from business activities.

9 Recommendations/Need of Further Research in This Area

As the EIA system of Pakistan lacks the implementation and effectiveness particularly to urban development projects (high-rise buildings), further study has been suggested in the evaluation of EIA system of Pakistan in which comparative study of EIA systems of different countries should be carried.

Study about the sectoral guidelines for the construction and operation of high-rise buildings has been suggested because the system lacks the sectoral guidelines particular to high-rise building.

For the implementation and effectiveness of the EIA reports, the study of review of the status of implementation of environmental management plan in EIA Reports of building has been suggested.

Table 4 Evaluation boxes of environmental impacts

Environmental component	Environmental impact	Evaluation box of environmental impact
During construction of commercial office tower		
Soil	Soil erosion Contamination of soil	I C -3 S
Air quality	Dust and vehicular emissions	I C ! -5* S Y
Vibration and noise	Noise	I C ! -5* S Y
Traffic flow	Traffic congestion specially during peak hours	I C ! -5* S Y
Water demand	Water shortage/consumption	I p -3 S Y
Construction waste water	Health and safety of workers at site	I C ! -5* S Y

(continued)

Table 4 (continued)

Environmental component	Environmental impact	Evaluation box of environmental impact
Construction waste	Disturbance for workers Fire occurrence Hindrances for traffic flow	**I** **C** **!** **-5*** **S** **Y**
Health and safety	Accidents Fire occurrences and emergency	**I** **C** **-3** **F** **Y**
Ecology and marine environment	Cutting of mangroves Threat to marine ecosystem	**I** **C** **-5** **F** **Y**
Socio-economic	Jobs	**I** **C** **+5*** **L** **?**
During operation of commercial office tower		
Solid waste	Soil contamination Health impact	**L** **C** **!** **-5*** **F** **Y**
Water demand	Water consumption/shortage	**L** **C** **-5*** **F** **Y**

(continued)

Table 4 (continued)

Environmental component	Environmental impact	Evaluation box of environmental impact
Waste water	Impact on ecology and marine environment	L C ! -5* F Y
Energy consumption	Power consumption/load shedding	L C -5 ? Y
Visual impacts	Aesthetic views Land mark of city	L C +4 F ?
Shadow	Electricity consumption Effect on plants	L P -1 S ?
Social and economic	Social interaction between people employment	L C +5 F Y
Traffic volume and emissions	Traffic congestion emissions	I C -5 F Y

(continued)

Table 4 (continued)

Environmental component	Environmental impact	Evaluation box of environmental impact
Fire occurences and emergencies	Chances of fire occurrences Emergencies in terms of disasters	I P -3 F Y

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Catalytic Effect of BL and BL+Ca Mixed Catalyst on Sulfur-Containing Gasses of Pakistani Lignite Chars

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Abstract The catalytic effect of different catalysts, i.e., 3% Ca, 5% Na–BL, and 3% Ca+5% Na–BL catalysts, on relative amount of harmful sulfur-containing gasses have been investigated qualitatively by thermogravimetry in steam gasification under temperature of 700–900°C at ambient pressure for two Pakistani Lakhra and Thar lignite chars. The hazardous pollutants such as SO_2 and H_2S produced by char and black liquor (BL) itself in steam gasification are captured by the existence of Ca mixed with BL to form $CaSO_3$ and CaS on char matrix and successfully assist in the completion of the desulfurization process, but this action is more effective at temperatures less than 900ºC.

Keywords Catalytic effect • Desulfurization • Lignite chars • Steam gasification • Sulfur gasses

1 Introduction

Pakistan is abundant in natural coal reserves, has vast resources in all four provinces [1], and has emerged as one of the leading country – seventh in the list of top 20 countries of the world, after the discovery of huge lignite coal resources in Sindh [2].

Both Thar (THR) and Lakhra (LKH) coals contain low ash content but high moisture, volatility, and sulfur [1]; due to these characteristics, special techniques are required with regard to mining, power generation, and gasification studies. The high moisture content can continuously reduce the efficiency of power generation and increase the boiler loading and coal feed rate. The high volatility can produce

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more methane and coal tar that require primarily to be utilized before further conversion, while the presence of ash is responsible for slugging and fouling problem in the conventional boiler. Besides, the high sulfur content is a regular threat to the environment. Therefore, it is our need to minimize these hazardous pollutants and improve the concept of green engineering.

As pointed by our previous studies [3–6], in anthracite gasification, the black liquor (BL) contained a plenty of alkali metal, lignin, and degradation compound, and the Ca^{+2} ion in $CaCO_3$ reacted with COOH group in coal to ion exchange calcium, which can be mixed as a perfect catalyst in coal gasification.

Therefore, in this investigation, the catalytic action of BL, Ca, and BL+Ca alkali mixed catalyst concentrations on a qualitative amount of harmful pollutant, such as sulfur-containing gasses, is examined.

2 Experimental

2.1 Apparatus

The flow scheme of experimental apparatus is shown in Fig. 1.

The gasification experiments are carried out by NETZSCH thermal analyzer STA 409, associated with mass spectrometer QMS 403 Aeolos, water vapor furnace (T_{max} = 1,250°C), steam evaporator DV_2MK, compact rotary van pump PK 4D, gas control device, system controller TASC 414/4, and computer installed with NETZSCH and Aeolos software [5,6]. The mass spectrometer basically consists of ion separation in rod system of quadrupole in which ions are separated by

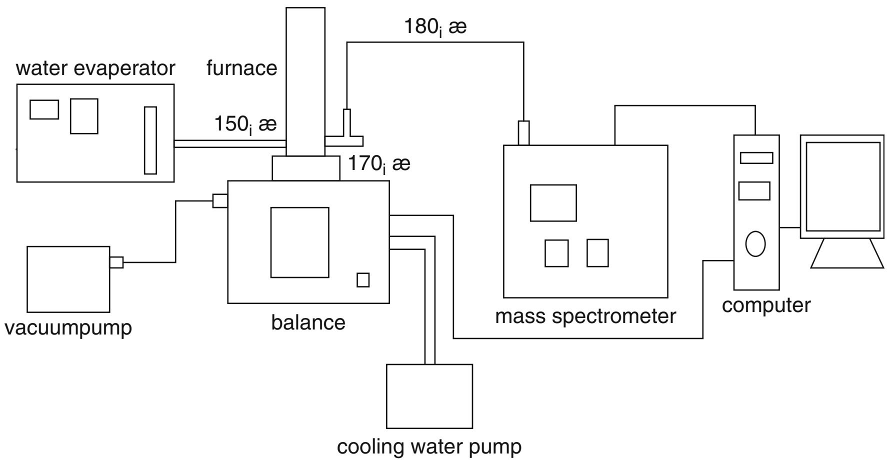

Fig. 1 The flow scheme of experimental apparatus

mass/charge ratio in the rod system and electrically detected by various types of detectors as Faraday cup, continuous and discrete dynode secondary electron multipliers (C-SEM and SEM). The steam inside the evaporator DV_2MK is kept at 160°C and then introduced into the furnace through the heat preservation tube (150°C). To avoid steam condensation, the heat preservation is also set at the inlet, inside, and outlet of the furnace.

2.2 Sample Preparation

2.2.1 Material

Two kinds of Pakistani THR and LKH lignite are mainly used. Their proximate and ultimate analysis is given in Table 1. Prior to sample preparation, char is prepared by using fixed bed. Then these chars are pulverized with particle size 0–0.154 mm (<100 mesh). The component percents of above chars are listed in Table 1.

The BL from wood pulp, provided by the Naping Paper Mill, Fujian, China, was used as the catalyst and the Na content in BL is 2.073 wt%, measured directly by a flame photometer using an equipment model HG-3, 2400318, made by Beijing measuring instrument plant in China. The calcium as a $CaCO_3$ (99.0% purity, Xi Long Chemical Plant, Shantou, Guangdong Province) powder, ground and sieved with 0–0.154 mm diameter (<100 mesh), was used to make the mixed catalyst. The preparation of mixed BL+Ca catalyst was already reported in the previous paper [5,6].

2.2.2 Impregnation of Catalyst

The 5%, 8% Na–BL loading and 3% Ca in the char sample are the weight ratio of Na amount only from the additive BL and of Ca amount occupied in $CaCO_3$ to the raw char, respectively. The mixed catalysts 3% Ca+5% Na–BL were, respectively, loaded into 100 g raw char, and these mixed char samples with a uniform

Table 1 Proximate and ultimate analysis of Pakistani LKH and THR lignite and char

	Proximate analysis				Ultimate analysis				
Coal type	M_{ad}%	A_{ad}%	V_{ad}%	FC_{ad}%	$S_{t,ad}$%	H_{ad}%	C_{ad}%	N_{ad}%	O_{ad}%
LKH lignite	10.24	14.66	44.54	30.56	5.15	3.07	52.44	0.85	13.6
THR lignite	8.5	19.37	48.52	23.66	4.02	2.94	49.93	0.98	14.31
LKH lignite char	6.07	28.19	4.82	60.92	5.62	1.71	54.77	0.89	2.75
THR lignite char	3.88	36.25	6.18	53.69	3.46	1.36	51.78	0.74	2.53

$O_{ad}\% = 100 - A_{ad}\% - S_{t,ad}\% - C_{ad}\% - H_{ad}\% - N_{ad}\% - M_{ad}\%$

impregnation were dried at 110°C for 24 h, then ground and sieved to 0–0.154 mm diameter, and stored in desiccators for use in experiments.

2.3 Experimental Procedure

All connections of NETZCH thermal analyzer were opened and purged first with argon gas 50 ml/min for 1.5 h. About 50 mg char sample was placed in the Al_2O_3 crucible and inserted into TG sample carrier, and then the furnace was closed. Both inlet and outlet of the furnace were first closed to produce vacuum in the furnace by vacuum pump for releasing any adsorptive gas and then opened; the same operating procedure was repeated again. The temperature in the furnace was risen at 20°C/min to the required value and kept constant, and then the steam gasification reaction was started for about 60 min. During steam gasification, the TGA and mass profiles were continuously monitored by a computer using the NETZCH and Aeolos software. In all cases of BL, Ca, and BL+Ca catalysts, the weight changes of char sample and ion current of sulfur-containing gasses were measured under 700, 750, 800, 850, and 900°C at ambient pressure, at a steam flow rate of 4 g/h at ambient pressure.

3 Results and Discussions

3.1 Effect of Catalyst on Sulfur-Containing Gasses

As we know, using BL as catalyst in the gasification process, some sulfur gasses, such as hydrogen sulfide (H_2S) and carbonyl sulfide (COS), and traces of organic gasses, such as CH_3SH, $(CH_3)_2S$, and $(CH_3)_2S_2$, can be produced from BL, which often infract the environmental regulations [7]. In order to achieve the emission control regulation of sulfur gasses, the mixed catalyst of $CaCO_3$+BL is employed in char gasification, in which $CaCO_3$ is captured as an amount of sulfur-containing gasses [8]. Therefore, during THR and LKH char gasification with 5% Na–BL and 5% Na–BL+Ca catalysts, some sulfur-containing gasses such as SO_2 and H_2S are qualitatively measured by the amount of ion intensities of evolved gasses using a mass spectrometer connected to a thermal analyzer. The relative changes in ion current intensities of SO_2 and H_2S with catalyst concentrations and temperature are listed in Table 2.

For more clearly and visually understanding the variation tendency of ion current vs temp of SO_2 and H_2S in gasification process, the relationship between ion current (IC) of sulfur-containing gasses and temperature are, respectively, illustrated in Fig. 2a–d for SO_2 and Fig. 2e–h for H_2S, in which each plot corresponds to with out catalyst, 3% Ca, 5% Na–BL and 8% (5% Na–BL+3% Ca) catalyst.

Table 2 Effect of catalyst on sulfur-containing gasses at 700–900°C

		Catalyst loading (wt%)							
		None		3% Ca		5% BL		5% BL+3% Ca	
Coal	Temp (°C)	SO_2 (IC/A)	H_2S (IC/A)	SO_2 (IC/A)	H_2S (IC/A)	SO_2 (IC/A)	H_2S (IC/A)	SO_2 (IC/A)	H_2S (IC/A)
LKH	700	16.3×10^{-12}	9.2×10^{-12}	16.8×10^{-12}	3×10^{-12}	4.9×10^{-12}	5.3×10^{-12}	5.5×10^{-12}	10.6×10^{-12}
THR		19.8×10^{-12}	9.5×10^{-12}	11.9×10^{-12}	2.6×10^{-12}	12.4×10^{-12}	4.1×10^{-12}	6.9×10^{-12}	4.3×10^{-12}
LKH	750	18.1×10^{-12}	17.6×10^{-12}	15.9×10^{-12}	3.4×10^{-12}	7.9×10^{-12}	104×10^{-12}	10.9×10^{-12}	16.5×10^{-12}
THR		20.2×10^{-12}	12.4×10^{-12}	12.4×10^{-12}	3.5×10^{-12}	15.3×10^{-12}	4.0×10^{-12}	6.8×10^{-12}	3.7×10^{-12}
LKH	800	21×10^{-12}	19.0×10^{-12}	15.6×10^{-12}	3.2×10^{-12}	10.7×10^{-12}	12.6×10^{-12}	14.6×10^{-12}	19×10^{-12}
THR		20.3×10^{-12}	13.7×10^{-12}	10.1×10^{-12}	3×10^{-12}	16.8×10^{-12}	2.9×10^{-12}	18.2×10^{-12}	5.0×10^{-12}
LKH	850	14.5×10^{-12}	34×10^{-12}	28×10^{-12}	4.4×10^{-12}	13.1×10^{-12}	24.4×10^{-12}	20×10^{-12}	22.7×10^{-12}
THR		16.6×10^{-12}	23.9×10^{-12}	12.4×10^{-12}	3×10^{-12}	9.9×10^{-12}	11.9×10^{-12}	26.4×10^{-12}	18.2×10^{-12}
LKH	900	172×10^{-12}	33.7×10^{-12}	15.6×10^{-12}	3.4×10^{-12}	22.8×10^{-12}	244.5×10^{-12}	17.3×10^{-12}	60.0×10^{-12}
THR		22.2×10^{-12}	65.1×10^{-12}	19.4×10^{-12}	36.5×10^{-12}	14.0×10^{-12}	36.5×10^{-12}	22.8×10^{-12}	84.9×10^{-12}

LKH Lakhra, *THR* Thar, *IC* ion current, *A* ampere

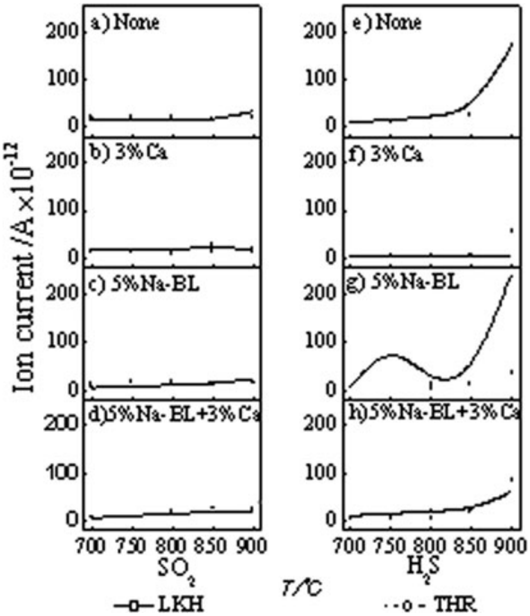

Fig. 2 Effect of catalyst concentration and temperature on ion current of SO_2 and H_2S for LKH and THR chars

At 3% Ca catalyst, the IC of SO_2 and H_2S in Fig. 2b and f appears to be a little less than that at none-catalyst in Fig 2a and e. At 5% Na–BL in case of LKH char only, H_2S has higher IC values, with a jump increase at 900ºC, while SO_2 has lower values as indicated in Fig 2g and c. On the contrary, for THR char, both SO_2 and H_2S exhibit less IC values than that from the pure char. In the case of 5% Na–BL +3% Ca, as illustrated in Fig. 2d and h, both SO_2 and H_2S emission are reduced and captured by the existence of Ca content or well-dispersed Ca inside char matrix and this action is more effective especially at 900 degree centigrade. Normally $CaCO_3$ undergo decomposing reaction to CaO at 825 degree centigrade and then CaO as a capture sulfur medium will continuously react with SO_2 and H_2S, produced in gasification [9] to form $CaSO_3$(s) and CaS(s) to complete the desulfurization process. As a typical example, the mass curves of SO_2 and H_2S, produced in the gasification of LKH and THR chars using both 5% Na–BL and 8% (5% Na–BL+3% Ca) catalysts at the temperature range of 700–900°C, are represented individually in Figs. 3a–e and 4a–e. They clearly designate that in the gasification of chars, BL produces more sulfur-containing gasses, especially at a higher temperature of 900°C, but by adding some $CaCO_3$ to the BL catalyst, emission of these harmful sulfur gasses is greatly reduced. The above observations reveal that an effective desulfurization action can also be achieved by adding a certain quantity of $CaCO_3$ into a catalyst in gasification, but the better operating temperature should be less than 900°C.

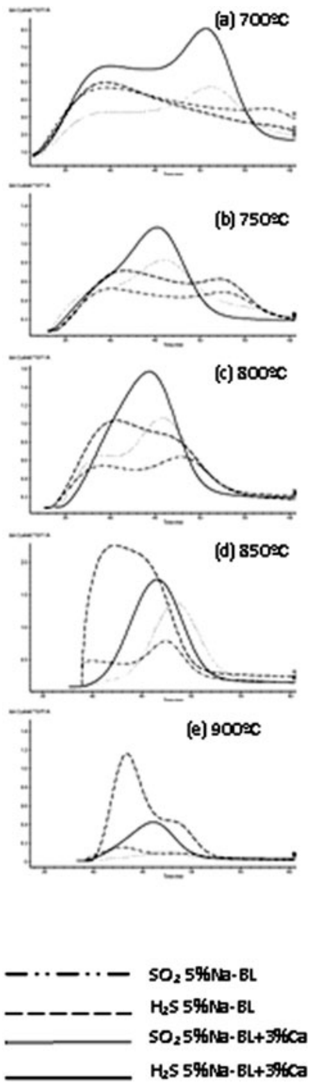

Fig. 3 MS curves for SO_2 and H_2S in the range of 700–900°C for LKH char

4 Conclusion

Sulfur gasses such as SO_2 and H_2S produced by char and BL catalyst itself in steam gasification can be captured by the existence of Ca content mixed with BL or well-dispersed Ca inside char matrix to form $CaSO_3$ and CaS and to complete the desulfurization process, but this action is more effective especially at less than 900°C.

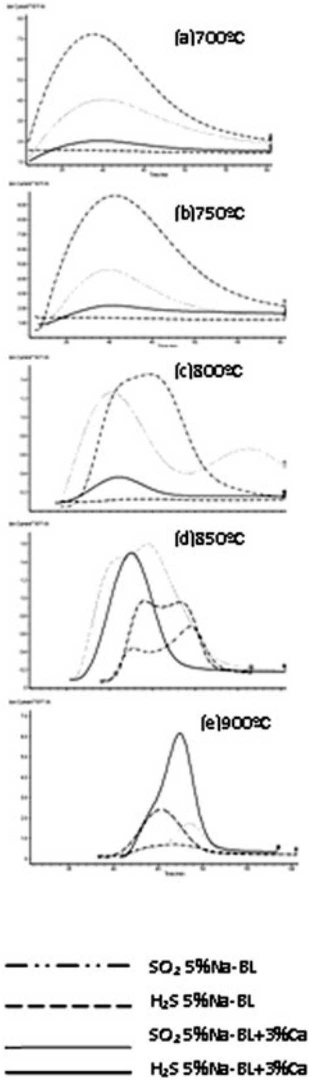

Fig. 4 MS curves for SO_2 and H_2S in the range of 700–900°C for THR char

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Improved Sustainability of Cotton Sulfur Dyeing by Pad-Ox Processes

Awais Khatri, Abdul Salam, Fahmina Absarullah, and Rafia Anwar

Abstract Sulfur dyeing of cotton textiles is widely practiced in textile industry for producing inexpensive black, navy, brown, olive, and green shades in medium to heavy depths. As a part of sulfur dyeing process, intensive rinsing is carried out to remove unfixed dyes after dyeing. The unfixed dyes produce high sulfide content and hence undesirable levels of oxygen demands to the effluent. Clariant Ltd. introduced eco-sustainable processes for sulfur dyeing, generally known as pad-ox, using Diresul RDT sulfur dyes. This chapter presents a study on comparing effluent quality, ultimate color yield and colorfastness, and cost of pad-ox dyeing methods with the conventional pad-steam dyeing. The study showed that the pad-ox processes produce reduced oxygen demands of effluent with higher color yield and acceptable colorfastness. Interestingly, a review on water and energy consumption showed that pad-ox dyeings are cheaper than the conventional dyeing.

Keywords Cotton • Pad-ox processes • Sulfur dyeing • Sustainable

1 Introduction

Sulfur dyes are the most economical dyes ever introduced for cellulosics, especially cotton textiles. They are widely used in the textile industry for dyeing cotton to produce inexpensive black, navy, brown, olive, and green shades in medium to heavy depths [1–4]. However, intensive rinsing is required for removing unfixed dyes after dyeing to achieve acceptable colorfastness. The rinsing generates large amount of drainage water with high sulfide content, which creates undesirable levels of oxygen demands to the dyeing effluent [2, 3, 5–7].

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Sulfur dyes are chemically reduced using sodium sulfide or sodium hydrosulfite to produce their soluble leuco form before application. Immediately after application of leuco dyes via aqueous medium, the substrate is subjected to oxidation using a mild oxidant such as sodium perborate. Thus, the dyes are converted to their original insoluble form and trapped within the fiber polymer of the substrate [2–4, 8]. The conventional reduction and oxidation processes create sustainability problem to the effluent. The ecological alternatives to the reduction and oxidation processes have been well reported [8–10]. The ecology in terms of sulfide content and economy in terms of the amount of water and energy consumption remained major concerns in sulfur dyeing of cotton.

Clariant Ltd. [11, 12] introduced pad-ox processes as the eco-sustainable and economic way of sulfur dyeing of cotton. The new processes propose 100% fixation of the dyes to substrate; hence, no dye is drained in rinsing. This work was undertaken in collaboration with Clariant Pakistan Ltd. to present practical advantages of continuous pad-ox dyeing methods over conventional pad-steam dyeing. Three ways of new dyeing technique, pad-ox, pad-dry-ox, and pad-steam-ox, were studied against pad-steam dyeing.

2 Experimental

2.1 Materials

A mill scoured, bleached, and mercerized cotton woven fabric (250 g/m^2, twill) was used for all dyeings.

Diresul RDT sulfur dyes (Clariant), Brown RDT-GS, Navy RDT-GF, and Black RDT were used. The Clariant dyeing auxiliaries were Reducer RDT, Penetrant EHA, Landiquest 1097N, Diresul Oxidant BRI, Indosol E-50, Leveler F, and Sirrix AK. The sodium hydroxide, sodium hydrosulfite, sodium carbonate, sodium sulfate, and acetic acid were analytical grade.

2.2 Methods

Clariant-recommended methods were adopted. All fabrics were dyed to a heavy color depth of 120 g/l. Concentrations of dyeing auxiliaries are given in Table 1.

2.2.1 Pad-Steam Dyeing

Fabric samples were padded in dyeing solution (70% liquor pick-up, ambient temperature, Rapid P-B1 horizontal padder), steamed (wet-temperature of 101–102°C,

Table 1 Concentrations of dyeing auxiliaries

	Concentration (g/l)			
Auxiliaries	Pad-steam	Pad-ox	Pad-dry-ox	Pad-steam-ox
Padding solution				
Reducer RDT	25	15	15	15
Sodium hydroxide 50%	20	15	15	15
Penetrant EH	2	3	3	6
Landiquest1097N	–	3	3	3
Sirrix AK liquid	2	–	–	–
Sodium hydrosulfite	2	–	–	–
Oxidation solution				
Diresul oxidant BRI	6	25	25	25
Acetic acid 80%	4	25	25	25
Indosol E-50	–	23	23	23
Leveler F	–	5	5	5
Sodium sulfate	–	30	30	30
Soaping solution				
Sirrix AK liquid	2	–	–	–
Sodium carbonate	2	–	–	–

Table 2 Initial rinsing conditions after steaming

	Black		Brown and navy	
Rinsing steps	Temperature (°C)	Time (s)	Temperature (°C)	Time (s)
1	50	60	40	60
2	60	60	50	60
3	70	60	60	60

100% moisture, 60 s, Rapid H-TS-3 laboratory steamer), rinsed as per Table 2, oxidized (70°C, 60 s), rinsed (60°C, 180 s), soaped (90°C, 180 s), rinsed (60°C, 180 s), hydro-extracted (Haier HWS60-40 spin dryer), and finally dried (ambient air). Rinsings, oxidation, and soaping were carried out on a Rapid HT dyeing machine.

2.2.2 Pad-Ox Dyeing

Fabric samples were padded (60°C), subjected to ambient airing (60 s), oxidized (75°C, pH of 4–4.5, 60 s), rinsed (75°C, 180 s), hydro-extracted, and finally dried (ambient air).

2.2.3 Pad-Dry-Ox Dyeing

Fabric samples were padded (60°C), dried (100°C, 60 s, Thermostatic GZX-GF-101 drying box), oxidized (75°C, pH of 4–4.5, 60 s), rinsed (75°C, 180 s), hydro-extracted, and finally dried (ambient air).

2.2.4 Pad-Steam-Ox Dyeing

Fabric samples were padded (60°C), steamed (wet-temperature of 101–102°C, 100% moisture, 60 s), oxidized (75°C, pH of 4–4.5, 60 s), rinsed (75°C, 180 s), hydro-extracted, and finally dried (ambient air).

2.3 Measurements and Analysis

2.3.1 Color Yield

Color yield (K/S) is used as a measure of the amount of dye fixed on colored textiles. K/S value is determined from surface reflectance (R) of the substrate as $K/S = (1 - R)2/2R$. It was determined using a Datacolor 600 spectrophotometer.

2.3.2 Colorfastness Testing

Dyed and printed textiles tend to fade in color during use because of color loss by rubbing, washing/laundering, and/or exposure to light. The fading is tested by standard colorfastness tests, the results of which reflect the quality of colored textile material. The dyed fabric samples dyed were tested for colorfastness to rubbing (ISO 105-X12), to washing (ISO 105-C03), and to light (ISO 105-B02). In order to compare colorfastness properties, color of samples dyed by new processes was matched to that of the conventionally dyed samples.

2.3.3 Effluent Testing

Chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are widely used parameters for testing sustainability of the effluent water. Draining water was collected during washing-off of fabrics dyed with Diresul Black RDT and tested for COD (HACH) and BOD (HACH).

3 Results and Discussion

The ecology and economy are key advantages offered by pad-ox sulfur dyeing techniques. The new processes produce no dye in the effluent, thus reducing the ecological threat. In addition, the new processes have only one short rinsing instead of three thorough rinsings, thus reducing a lot of water and energy consumption [11, 12]. The results obtained for comparative color yield, colorfastness, and effluent quality are discussed in the following sections. A review on water and energy consumption is also presented.

3.1 Color Yield

Figure 1 shows that the pad-ox processes produced higher color yields than pad-steam process. This should be expected since the new processes are claimed to provide 100% dye fixation to the substrate. Pad-ox process gave a significant increase in color yield that was even better than other new processes.

3.2 Colorfastness

As given in Table 3, pad-ox and pad-dry-ox produced less rubbing fastness than pad-steam. This may be because fabric is subjected to dry air after padding, which results in poorer rubbing fastness [2, 3]. Pad-steam-ox produced similar rubbing

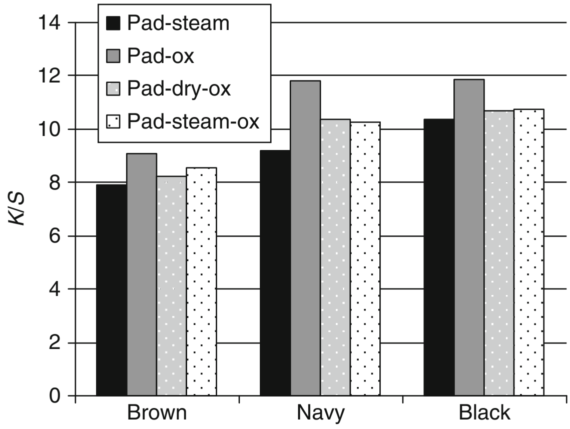

Fig. 1 Color yields obtained by pad-steam and new processes

Table 3 Colorfastness results (gray scale rating for colorfastness to rubbing and washing; Br = brown, N = navy, Bl = black)

	Colorfastness to rubbing						Colorfastness to washing						Colorfastness to light		
	Dry			Wet			Color change			Staining			Blue wool ref.		
Process	Br	N	Bl	Br	N	Bl	Br	N	Bl	Br	N	Bl	Br	N	Bl
Pad-steam	4.5	4.5	4	3.5	3.5	2.5	4	4.5	4	4.5	4.5	4	7	6	6.5
Pad-ox	4.5	4	3.5	2	2	1.5	4.5	4	4.5	4.5	4	4.5	6	6	7
Pad-dry-ox	4	3.5	4.5	3	2.5	3	4.5	4.5	4.5	4.5	4.5	4.5	7	7.5	7.5
Pad-steam-ox	4.5	4.5	4.5	3	3.5	3	4.5	4	4.5	5	5	4.5	7	6	7

Table 4 Effluent testing results

Process	COD (ppm)	BOD (ppm)
Pad-steam	134	63
Pad-ox	114	53
Pad-dry-ox	108	48
Pad-steam-ox	119	51

fastness to pad-steam. Colorfastness to washing and to light produced by the new processes is generally similar to that produced by pad-steam process. In fact, pad-dry-ox and pad-steam-ox produced slightly better washing and light fastness.

3.3 Effluent Quality

Effluent testing results for black are given in Table 4. Note the new processes provide a 10–18% reduction in COD and 15–23% in BOD. The pad-dry-ox gave better reduction in oxygen demands among the three new processes. These are encouraging results for ecological benefit and may be for economic benefit in terms of costs of effluent purification or load-based penalties on more polluted effluent.

The new processes still produce certain levels of COD and BOD. This is because of the use of conventional reduction and oxidation chemicals. A considerable reduction in the level of oxygen demands may be expected by utilizing ecology alternatives for reduction and oxidation treatments in pad-ox processes [8–10].

The color yield, colorfastness, and effluent quality conclusions could be useful for the selection of a new process having known the need of a customer or the end use.

3.4 Water and Energy Consumption

Water consumption has a considerable influence on the economy of any process. Two rinsings and soaping steps are eliminated in the new processes if compared with pad-steam process. Therefore, the new processes save around 90% of the amount of water consumed in conventional dyeing [11, 12]. Further, the energy consumption in terms of power and steam is minimized. The cost on soaping chemicals is also saved. The pad-ox is cheaper than pad-dry-ox and pad-steam-ox because drying and steaming consume a significant amount of energy.

4 Conclusions

The new pad-ox processes for dyeing cotton with sulfur dyes are effective for reducing effluent load and the cost. The processes produced higher color yields and acceptable colorfastness. Pad-ox processes generally resulted around 15–23%

reduction in oxygen demands of the effluent. The reduced effluent load, around 90% reduction in the amount of water use, considerable reduction in the amount of energy consumption, and not using soaping chemicals offer a great cost and sustainability advantage to dye-houses. Further, it is expected that more reduction in the effluent load can be obtained if pad-ox processes are carried out using eco-sustainable chemicals for reduction and oxidation treatments.

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Industrial Effluent Treatment by Photocatalytic Degradation of Sodium Dodecylbenzensulfonate (DBS)

Mukhtar Ul-Hassan, A. Jabbar Chaudhary, Suhail A. Soomro, and Shaheen Aziz

Abstract Surfactants in the environment are a prerequisite for the sustainable development of human health and ecosystems. Surfactants are important in daily life in households as well as in industrial cleansing processes. It is important to have a detailed knowledge about their lifetime in the environment, their biodegradability in wastewater treatment plants and in natural waters, and their ecotoxicity.

Most of the issues on environmental acceptability focus on the effects on the environment associated with the use and disposal of these surfactants. These effects are taken into account by a risk assessment. The first step in a risk assessment is to estimate the concentrations of surfactants in the environmental compartment of interest, such as wastewater treatment plant effluents, surface waters, sediments, and soils. This estimate is generated either by actual measurement or by prediction via modeling. The measured or predicted concentrations are then compared to the concentrations of surfactant known to be toxic to organisms living in these environmental compartments.

There are many situations where industry is producing both heavy metals ions and organic pollutants. Successful treatment of effluents of this type to achieve legislative compliance will depend on whether the heavy metals effect the process of degradation of the organic species and whether the presence of organic molecules hinder the process of removal of heavy metals. Degradation of cationic surfactant was studied with a photolytic cell system. Compressed air was used as oxidant and the temperature was maintained at 25–30°C. Effects of UV source, hydrogen peroxide (H_2O_2), and titanium dioxide (TiO_2) on sodium dodecylbenzensulfonate (DBS) were recorded. High-performance liquid chromatography (HPLC) and infrared spectroscopy (IR) were used to analyze the rate of degradation of $C_{24}H_{39}NaO_5$.

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Keywords Catalysts • Hydrogen peroxide (H_2O_2) • Photolytic cell • Rate of reaction • Sodium dodecylbenzensulfonate (DBS) • Titanium dioxide (TiO_2)

1 Introduction

Surfactants (surface-active agents) can be anionic, amphoteric, polymeric, and nonionic. They are held in industries such as agrochemical, mining, and oil field. Surfactants have a hydrophilic head, which attaches to water, and a hydrophobic part of the molecule that avoids water. The hydrophobic part of the molecule is also free to attach to grease, fat, or oil on the surface.

Heterogeneous photocatalysis is a well-known technology used to solve the problem of water pollution [1, 2]. Even in the nuclear industry, during decontamination of protective clothing and contaminated materials, detergents are employed to bring down the level of radioactive contamination to within safe limits. However, the surfactant present in these wastes interferes in the chemical treatment process, reducing the decontamination [3]. Although surfactants have been studied in complex water soil systems [3, 4], the effects are not well understood. Different methods have been used to destroy and reduce the levels of organic pollutants including treatment with activate sludge [5], clinical oxidation [6], biological oxidation [7], thermal degradation [8], ozonization [9], and photooxidation with ultraviolet radiation [8].

The present experiments were conducted using surfactants as a model on account of the possible contamination of the environment by surfactants arising from the widespread use of soaps and detergents [9] of low biodegradability [10], and the inhibiting effect on the biodegradation of some other pollutants [11, 12]. The surfactant used was sodium dodecylbenzensulfonate (DBS). It has a molecular weight of 430.6 and has abbreviations such as NAC.

2 Experimental

The photolytic cell system used (Fig. 1) consists of a UV probe (1) surrounded by a reaction chamber (5). Compressed air was used as the oxidant in the photolysis and is supplied through the inlet (2) and exits through the outlet (3). The temperature in the system was measured by thermometer (4) and the reaction chamber was maintained at 25–30°C by a water cooling jacket (6), which surrounded the UV probe.

The effects of UV source, hydrogen peroxide (H_2O_2), and titanium dioxide (TiO_2) on the degradation of $C_{24}H_{39}NaO_5$ were studied. The effect of the UV source on the degradation of $C_{24}H_{39}NaO_5$ was examined using a 150- and 400-W UV probes.

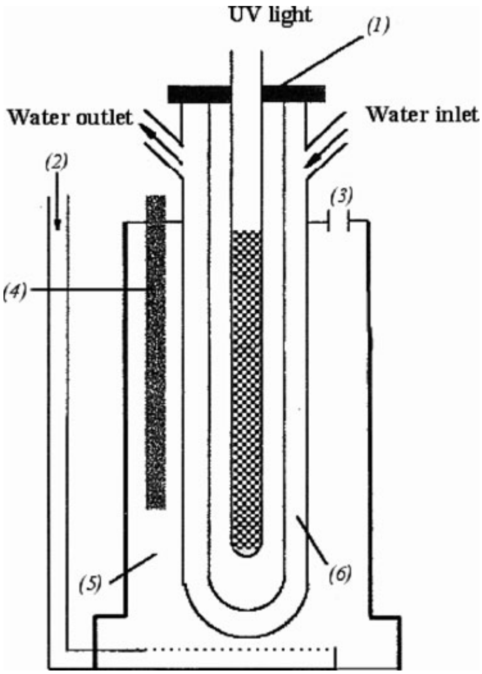

Fig. 1 Schematic illustration of the photolytic cell system. (1) UV probe, (2) inlet, (3) outlet, (4) thermometer, (5) reaction chamber, and (6) cooling jacket

DBS (50 ppm) and H_2O_2 (5 cm^3 dm^{-3}) were prepared. The same procedure was applied with the concentration of H_2O_2 (10 cm^3 dm^{-3}). The degradation was followed by using another catalyst, namely TiO_2, and as in H_2O_2, the same procedure and method was applied. The analysis of DBS was carried out by using high-performance liquid chromatography (HPLC) and infrared spectroscopy (IR).

3 Results and Discussion

3.1 Effect of UV Source on the Degradation of Sodium Dodecylbenzensulfonate

The effects of UV sources on the degradation of DBS were analyzed by using 50 ppm sample in photocatalytic cell. Lamps with 150 and 400 W were used in photocatalytic cell and the sample was withdrawn at 2, 4, 6, and 8 h time interval. It was observed that, using 150 W lamp, degradation percentage increased from 6.5 to 31.5% at 2, 4, 6, and 8 h time interval, whereas, using 400 W lamp, the degradation is better than using 150 W lamp. It was observed that the degradation % increases from 9 to 59.1% at the same time intervals used for 150 W lamp as shown in Table 1.

Table 1 Effect of UV source

	Degradation of DBS (%)	
Time (h)	150 W lamp	400 W lamp
2	6.5	9
4	11.7	19.6
6	20.3	43.9
8	31.5	59.1

Table 2 Degradation of DBS with catalyst H_2O_2

	Degradation of DBS (%) using H_2O_2		
Time (h)	No catalyst	H_2O_2 (5 cm^3 dm^{-3})	H_2O_2 (10 cm^3 dm^{-3})
0	0	0	0
2	9	18.6	23.9
4	19.6	38.3	48.8
6	43.9	61.4	73.7
8	59.1	81.5	98.6

Table 3 Degradation of DBS with catalyst TiO_2

	Degradation of DBS (%) using TiO_2		
Time (h)	No catalyst	TiO_2 (1 g dm^{-3})	TiO_2 (2 g dm^{-3})
0	0	0	0
2	9	30.4	42.9
4	19.6	48.3	56.8
6	43.9	68.4	75.7
8	59.1	81.5	94.6

Table 4 Effect of hydrogen peroxide (H_2O_2) on the degradation of $C_{24}H_{39}NaO_5$ and the rate of reaction

	Degradation of DBS (%)		
Time (h)	No catalyst ln (C_t/C_o)	H_2O_2 (5 cm^3 dm^{-3}) ln (C_t/C_o)	H_2O_2 (10 cm^3 dm^{-3}) ln (C_t/C_o)
0	0	0	0
2	−0.1	−0.21	−0.28
4	−0.22	−0.49	−0.68
6	−0.58	−0.97	−1.37
8	−0.91	−1.74	−6.2

3.2 *Photolytic Oxidation of Sodium Dodecylbenzesulfonate*

The next set of experiments was based on the degradation of DBS with different types of catalysts and concentrations. By addition of H_2O_2 as an oxidant and TiO_2 as a heterogeneous catalyst, the results showed that there is an increase in degradation percentage (Tables 2 and 3).

Experiment with H_2O_2 on DBS was determined by adding different volumes (5 and 10 cm^3 dm^{-3}) of H_2O_2 solution to a solution containing the same initial concentration of DBS (Table 4). The addition of 5 cm^3 dm^{-3} of H_2O_2 increased the extent of degradation of DBS from 18.6 to 81.5% at 2, 4, 6, and 8 h time intervals. Further increases the concentration of H_2O_2 (10 cm^3 dm^{-3}) increases even more, i.e., 23.9–98.6% (Fig. 2).

Heterogeneous photocatalysis using semiconductor particles of TiO_2 on the degradation of DBS was determined by adding different volumes (1 and 2 g dm^{-3}) of TiO_2 to a solution containing the same initial concentration of DBS (Table 5). The results show that the addition of 1 g dm^{-3} of TiO_2 increases the initial degradation of DBS from 30.4 to 81.5% (Fig. 3). DBS further improved degradation, if 2 g is used the degradation increases from 42.9 to 94.6%.

3.3 *The Effect of DBS in the Presence of Catalysts and the Rate of Reaction*

The change in the concentration of DBS with time was followed, and the results in Figs. 4 and 5 show the changes in rate of reaction. The addition of various catalysts shows the increase in rate of reaction.

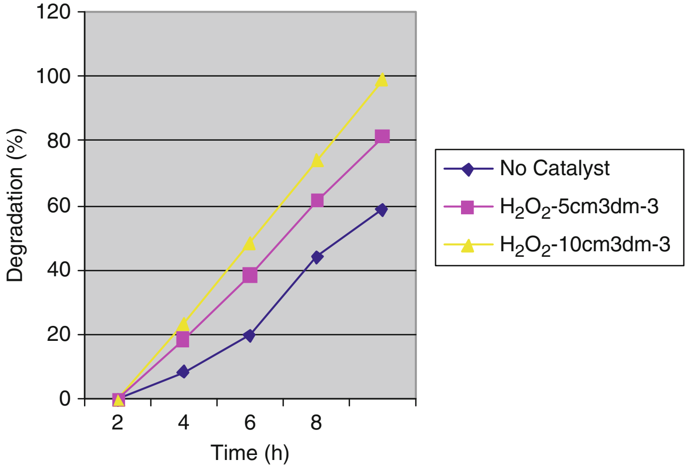

Fig. 2 Degradation of sodium dodecylbenzensulfonate (DBS) with hydrogen peroxide (H_2O_2)

Table 5 Degradation of sodium dodecylbenzensulfonate (DBS) with catalyst TiO_2

	Degradation of DBS (%)		
Time (h)	No catalyst ln (C_t/C_o)	TiO_2 (1 g dm^{-3}) ln (C_t/C_o)	TiO_2 (2 g dm^{-3}) ln (C_t/C_o)
0	0	0	0
2	−0.1	−0.18	−0.26
4	−0.22	−0.46	−0.64
6	−0.58	−0.91	−1.26
8	−0.91	−1.63	−3.16

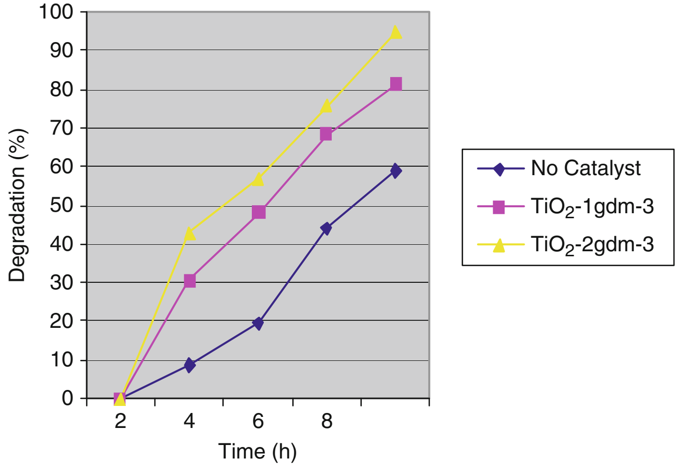

Fig. 3 Degradation of sodium dodecylbenzensulfonate (DBS) with titanium dioxide (TiO_2)

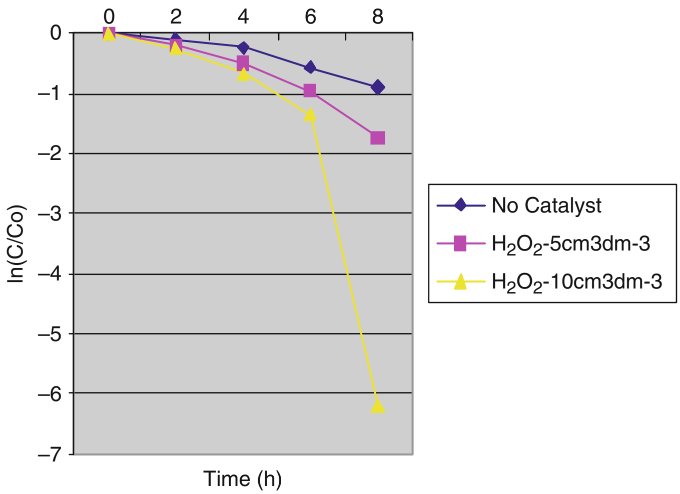

Fig. 4 Degradation of sodium dodecylbenzensulfonate (DBS) with hydrogen peroxide (H_2O_2)

4 Conclusion

It can be concluded that the photocatalytic system can be used for the degradation of organic pollutants. The rate of degradation of DBS varies according to the type and volume of a catalyst compared to the absence of catalyst. The level of degradation on DBS was recorded with varying levels of H_2O_2 and TiO_2.

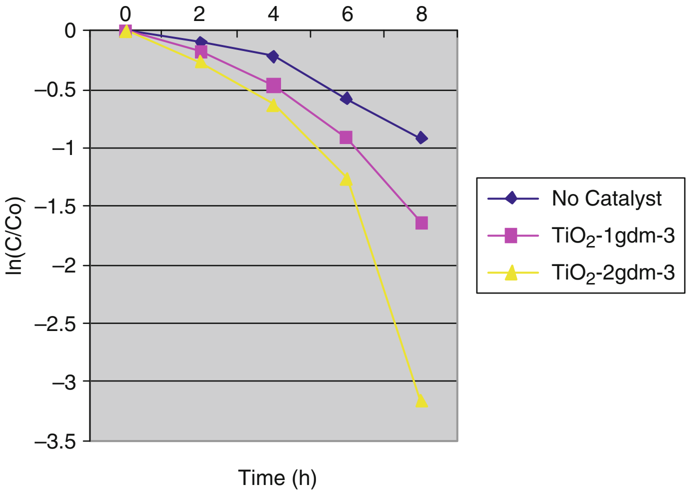

Fig. 5 Degradation of sodium dodecylbenzensulfonate (DBS) with titanium dioxide (TiO_2)

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Municipal Solid Waste Management: Options for Its Treatment and Energy Recovery

Suhail A. Soomro, Hafeez ur Rehman Memon, Mohammad Aslam Uqaili, and Shaheen Aziz

Abstract The amount of municipal solid waste (MSW) generation varies with the population, seasonal variation, and also with the localities of the cities. Different treatment methods are available for the treatment of MSW. These methods also depend upon the composition of MSW and the facilities available in that particular locality. The most commonly used treatment methods include land filling, composting, and incineration.

In this study, estimates were worked out for the amount of MSW generated in seven large cities (Karachi, Lahore, Faisalabad, Hyderabad, Multan, Peshawar, and Quetta) of Pakistan during the period 1998–2008. Based on the available data, estimations have also been made by extrapolation for the next decade.

The population of selected cites is in millions and is increasing rapidly every year. These cities generate huge quantities of MSW daily; however, these wastes are not managed properly. Populations beyond control and poor management of MSW have further been the reasons of environmental pollution and spread of disastrous diseases in these localities.

Incineration technology has been focused as it involves the combustion of organic materials and/or substances. Studies further revealed that incineration reduces the volume of MSW to 95%. From the current statistics, the electricity/power potential of Karachi (204.3 MWh), Lahore (140.6 MWh), Faisalabad (37.3 MWh), Hyderabad (22.6 MWh), Multan (23.6 MWh), Peshawar (17 MWh), and Quetta (9.54 MWh) had been worked out. The studies suggest that by adopting incineration technology for MSW management, the volume of MSW can be reduced substantially in addition to power generation, which will lessen the burden on other sources.

Keywords Energy recovery • Incineration • MSW • Treatment

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1 Background

Municipal solid waste (MSW) includes mainly household waste (domestic waste) and commercial wastes (generated from shops). These wastes are generally in solid or semisolid form. It can be classified as biodegradable waste that includes food and kitchen waste, green waste, and paper (can also be recycled); recyclable material: paper, glass, bottles, cans, metals, certain plastics, etc.; inert waste: construction and demolition waste, dirt, rocks, and debris; composite wastes: waste clothing, Tetra Packs, and waste plastics such as toys; domestic hazardous waste (also called “household hazardous waste”); and toxic waste: medication, e-waste, paints, chemicals, light bulbs, fluorescent tubes, spray cans, fertilizer and pesticide containers, batteries, and shoe polish.

Solid waste management deals with the way resources are used as well as with end-of-life deposition of materials in the waste stream. It includes ways to collect, recycle, transport, and dispose of MSW that affect cost. Today, solid waste management involves technologies that are more energy efficient and protective of human health and the environment. The amount of solid waste continues to increase annually. In general, most common disposal methods pollute land, water, or air to some degree. Consequently, management of solid waste presents an increasingly acute problem. The waste management system emphasizes on “not to treating waste unnecessarily” this motive approaches to adopt other means by which we can minimize the need of waste treatment by recycling or reuse of waste material.

“Recovery” and “Recycling” are often used interchangeably. Both terms mean that an item is used in some way instead of discarded as trash. Recovery lessens the amount of garbage requiring disposal, thus saving resources in terms of landfill space and conserving the energy that would be used for incineration. Recovery also reduces environmental pollution and chemicals that cause water pollution, generates jobs, and conserves water. Source reduction, also identified as waste prevention, is a front-end approach by changing the way products are made and used in contrary to move away from the traditional “end-of-the-pipe” waste management approach used in the past. MSW burning can generate energy while reducing the volume of waste by up to 95%, an environmental benefit (Table 1 and Fig. 1).

Ash disposal and the air polluting emissions from MSW plant combustion operations are the primary environmental impact control issues. Unfortunately, in Pakistan and other developing countries, the MSW is not properly treated before disposal. Even, land filling is not practiced. The local government disposes MSW as open dumps that not only cause environmental pollution but also inflict diseases to humans. The objective of this study is to collect the data of MSW generated in Pakistan, its composition, and report on incinerator for the treatment of MSW of Pakistan (Fig. 2).

There are a number of treatment methods available for the waste treatment. The treatment method also depends upon the composition of MSW in addition to the facilities available. The first target of MSW treatment is the reduction of volume and weight. The treatment methods that are generally used all over the world are

Table 1 Population of major cities of Pakistan (million)

Year	1998	2000	2005	2010	2015	2018
Karachi	9.26	10.2	13.1	16.9	22.6	26.9
Lahore	5.06	5.52	7.03	8.86	11.2	13.2
Hyderabad	1.15	1.26	1.56	2.01	2.60	3.05
Faisalabad	1.97	2.12	2.47	3.04	4.04	4.80
Peshawar	0.98	1.05	1.30	1.64	2.05	2.34
Quetta	0.56	0.61	0.74	0.92	1.18	1.37
Multan	1.18	1.30	1.66	2.11	2.70	3.20

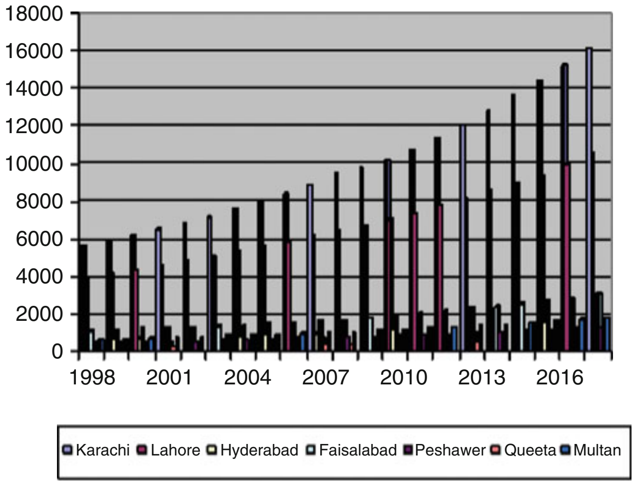

Fig. 1 MSW generation in major cities of Pakistan (ton/day)

land filling, composting, incineration, etc. Land disposal comprises landfills, land application, and underground injection into deep wells. Generally, land filling is the most widely used method. Landfills are areas allocated specifically for garbage dumping. Composting is the method of treating MSW by aerobic decomposition of biodegradable organic matter. The decomposition is performed primarily by facultative and obligate aerobic bacteria, yeasts, and fungi.

Incineration is an MSW treatment technology that involves the combustion of organic materials and/or substances. Incineration is the most effective method for volume and weight reduction of MSW. Incineration and other high temperature waste treatment systems. In combustion of solid organic waste, the temperature ranges from 1,200 to 1,500°C. Energy generation and volume reduction are the two major advantages of the method and are helpful in meeting the power requirements of urban area. Emission must be controlled during incineration as being very important factor. Incineration of waste materials converts the waste into incinerator bottom ash, flue gases, particulates, and heat, which can in turn be used to generate electric power. The flue gases are treated before being dispersed in the atmosphere.

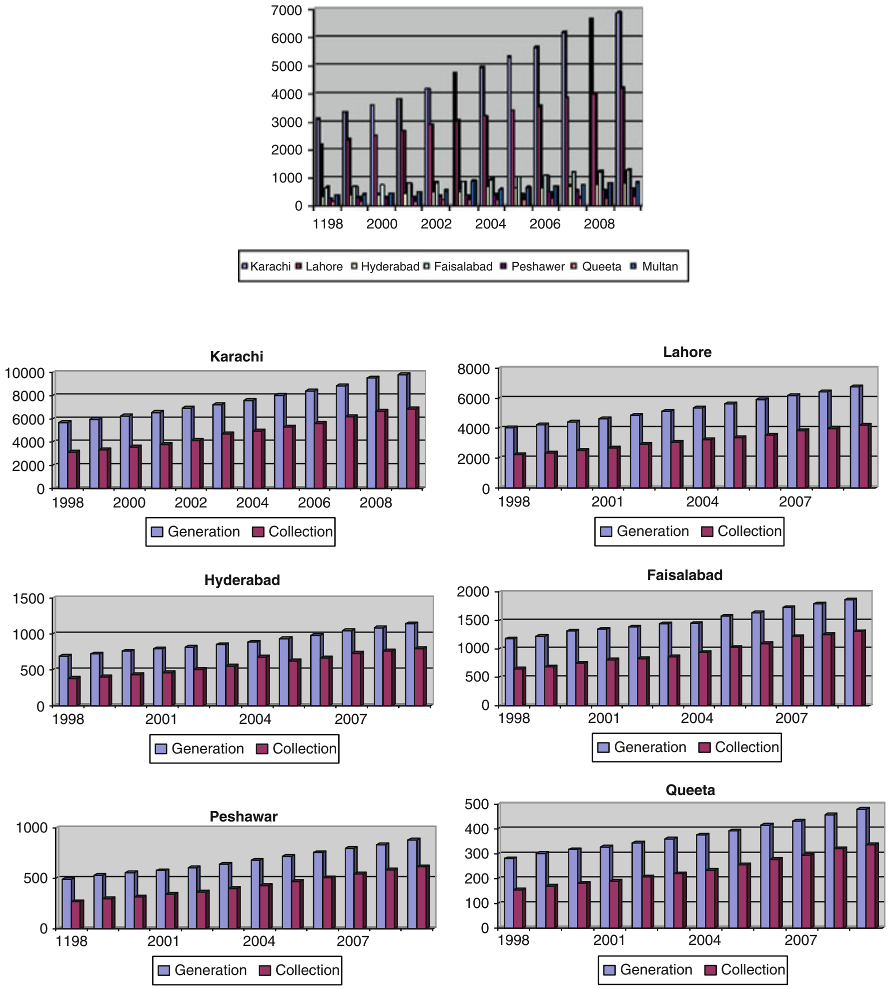

Fig. 2 Generation and collection city wise

Incineration with energy recovery is one of several waste-to-energy (WTE) technologies such as gasification, plasma arc gasification, pyrolysis, and anaerobic digestion that had been used worldwide.

2 Pakistan Status

Pakistan occupies an area of 796,096 km^2 and has a population of 162,419,946 according to 2005 Census (EPA-Pakistan). Nearly 65% people live in rural areas, while 35% in urban areas. As a result of global urbanization, there is a tremendous increase in the volumes of solid waste. According to estimates about 1.3 billion metric tons of MSW was generated globally in 1990. At present, the yearly generation of solid waste equals to 1.6 billion metric tons. A considerable amount of money goes in the management of such huge volumes of solid waste. Asian countries alone were spending nearly US$25 billion on solid waste management annually in the early 1990s; this amount is likely to be doubled by 2025.

Currently, MSW in Pakistan is not being carried out in a proper manner. The collection, transportation, and disposal or dumping is unscientific and even facilities are not according to the size of the cities. The environmental and sanitary conditions have become worse and if not improved will still deteriorate in years to come. This has given rise to severe health problems in the country especially in the highly populated areas. The situation therefore demands a rapid and long-term solution of solid waste management. These aspects may include rate of urbanization, pattern and density of urban areas, physical planning and control of development, physical composition of waste, density of waste, temperature and precipitation, scavenger's activity for recyclable separation, and the capacity, adequacy, and limitations of respective municipalities to manage the solid waste, i.e., storage, collection, transportation, and disposal. The cities under study are growing at a rate ranging between 4 and 8%, which is much higher than the overall growth rate of Pakistan. Major cities are estimated to double their population in next 10 years. These cities are generating high amounts of solid waste which is increasing day by day.

The average rate of waste generation from all types of municipal controlled areas varies from 1.896 to 4.29 kg/house/day in a few major cities. It shows a trend of waste generation where an increase has been recorded in accordance with city's population besides its social and economic development. In Pakistan, solid waste is mainly collected by municipalities and waste collection efficiencies range from 0% in low-income rural areas to 90% in high-income areas of large cities. Collection rate of solid waste by respective municipalities ranges now in urban area from 75 to 80% of the total waste generated. Crude open dumping is the most common practice throughout all the cities and dump sites are commonly set to fire to reduce the volume of accumulating waste, thus adding to the air pollution caused by the uncovered dumped waste itself.

3 Result and Discussion

There is no proper management of MSW in Pakistan. All the wastes are openly dumped near residential areas. The population is increasing very rapidly; people from rural areas migrate to urban areas in search of better facilities, so the rate of MSW generation is also increasing day by day. Due to which the disposal problem of MSW has become very serious because it covers large land area as well as it causes many dangerous diseases and also polluted environment. Due to the burning of MSW in open environment, the rate of air pollution is also increased.

The management should take positive steps for proper management of MSW. Due to increase in the population, we are also facing very huge problem of energy requirement. The reservoir of oil and gas decreases so there is a need for other resources of energy generation.

Nowadays, many developed countries use the technology of incineration by which they produce large amount of energy as well as reduce the volume and weight of MSW. In incineration process, the MSW burns in an incinerator that produces large amount of heat energy and the heat energy is converted to the valuable amount of electrical energy. MSW incineration is an advanced waste treatment technology and the cost to implement, operate, and maintain this technology is high. A significant amount of foreign currency must be available for the initial procurement of equipment and spares and for replenishing stocks of spares and for expatriate expert plant overhauls later. The investments in an MSW plant depend to a great extent on the required form of energy output. The least expensive plants are those equipped with hot water boilers only. Production of steam and electricity makes the investments in mechanical plant and civil works much higher (about 40%). The operating costs are also higher for electricity producing facilities. If government takes positive steps through incineration currently, electricity/power in Karachi (204.3 MWh), Lahore (140.6 MWh), Faisalabad (37.3 MWh), Hyderabad (22.6 MWh), Multan (23.6 MWh), Peshawar (17 MWh), and Quetta (9.54 MWh) could be generated from this waste. It is estimated that the generation of MSW would increase in next 10 years up to 60% from current estimation. It is also estimated that in 2018 through incineration process power generation would be achieved in Karachi (336.37 MWh), Lahore (220.1 MWh), Faisalabad (65 MWh), Hyderabad (28.7 MWh), Multan (40.02 MWh), Peshawar (29.52 MWh), and Quetta (16.5 MWh) from this waste.

4 Conclusion

In this research paper, an attempt has been made to provide a description about MSW generation, collection, and treatment technology in Pakistan. All the MSW is dumped in open areas and there is no proper method to handle the MSW. There are large amounts of MSW generated in Pakistan and the amount of MSW increases day by day. The MSW Pakistan can be handled in a proper manner by using the technique of incineration. Though the cost of incineration technology is high as compared to other technologies of MSW treatment, the volume of MSW using this technology is reduced substantially in addition to electricity generation.

The amount of MSW generated in Pakistan is approximately 60,000 tons/day. By using the advance novel technique of incineration, we can produce 1,250 MWh of electricity. If the incineration technology for MSW treatment is adopted, we can easily reduce the amount of MSW to 95% that pollutes the environment. Additionally, we can generate electricity to minimize our energy crises.

The amount of waste generated increases day by day as the population increases. It is suggested that the local governments must emphasize on building proper landfill sites to protect the environment. To supplement the land filling facilities, incineration technology must be taken into consideration for the future needs of waste disposal and treatment.

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Hospital Waste Generation and Management: A Case Study of Hospitals in Karachi, Pakistan

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Abstract The management and treatment of hospital solid waste are one of the major concerns all over the world, in specific in developing countries, because of its infectious nature in general. In developed countries, this type of waste is properly treated using technology and the disposed, but in developing countries, the problems still exist because of multidimensional limitations. One of the major limitations is the availability of baseline date for waste generation, classification, and analysis. The hospitals are generally not concerned about all these data. The major reason is the lack of monitoring of stack holders, i.e., local government, EPA, etc., in addition to lack of awareness in the community.

The current study focuses on the collection of waste from major hospitals in Karachi. The research team collected data from the various wards of the selected hospitals. It was found that the medical and gynecology wards are the largest waste producers because of the number of bed. The civil hospital was the largest waste producer. The amount of kilograms per bed is in the range of 2.228–6.800.

Keywords Hospital waste • Infectious waste • Solid waste • Waste generation

1 Introduction

Generally, the wastes generated from hospital and clinics are categorized as non-hazardous wastes and hazardous wastes.

The sources of nonhazardous wastes from hospitals are kitchen wastes, office materials, workshop residuals, and patient-processing activities in wards which do

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not handle infectious diseases, i.e., first aid packaging, used disposable bed liners and diapers, disposable masks, pharmaceutical packaging, etc. After source segregation of recyclables, disposal is typically by sanitary landfill.

Potentially hazardous wastes from hospitals and clinics that have a pathogenic, chemical, explosive, or radioactive nature are called "medical wastes" [1, 2]. Medical wastes include the following:

- Pathological wastes (i.e., body parts, aborted fetus, tissue and body fluids from surgery, and dead, infected laboratory animals)
- Infectious waste (i.e., surgical dressings and bandages, infected laboratory beddings, infectious cultures and stocks from laboratories, and all wastes from patients in isolation wards handling infectious diseases)
- Sharps (i.e., needles, syringes, used instruments, and broken glass)
- Pharmaceutical wastes (i.e., soiled or out-of-date pharmaceutical products)
- Chemical wastes (i.e., spent solvents, disinfectants, pesticides, and diagnostic chemicals)
- Aerosols (i.e., aerosol containers or gas canisters which may explode if incinerated or punctured)
- Radioactive wastes (i.e., sealed sources in instruments, and open sources used in in vitro diagnosis or nuclear medical therapy)
- Sludges from any on-site wastewater treatment facilities may be potentially hazardous

Pathological wastes should be destroyed [3–5] by incineration under high heat, i.e., over 900°C, with an afterburner temperature at over 800°C, although some countries require burial of human pathological wastes at official cemeteries for religious reasons. To reach these temperatures and have adequate afterburning and pollution control typically require the development of a regional medical waste facility. Smaller individual hospital or clinic incinerators may not be able to reach these temperatures and afterburning retention periods. Volatilized metals (such as arsenic, mercury, and lead), dioxins, and furans could result from inadequate burning temperatures and retention periods.

Other procedures [6–9] to consider may include chemical disinfection or sterilization (i.e., irradiation, microwave, autoclave, or hydroclave) followed by secure landfill disposal of residuals. In some cases, following complete disinfection, some wastes may be recycled. For example, sometimes thick plastics, such as intravenous bags and tubs, and syringes, are disinfected and subjected to recycling by specialized contractors.

Pharmaceutical wastes require destruction and secure land disposal, or return to the manufacturer for destruction through chemical or incineration methods.

Chemical wastes [10, 11] need to be source-segregated according to their recycling potential and compatibility, and those which are nonrecyclable may require stabilization, neutralization, encapsulation, or incineration.

Hospital wastewater treatment sludges require treatment (i.e., anaerobic digestion, composting, incineration, etc.) that raises temperatures to levels that destroy pathogenic microorganisms.

The overall quantity of wastes generated in hospitals varies according to the income level of the country. For developing countries, the data base is limited, but it appears that the following range of quantities is likely:

- General waste which is not contaminated and can be handled with general municipal refuse: 1.0–2.0 kg/bed/day.
- Contaminated medical waste which needs special management and is considered potentially hazardous: 0.2–0.8 kg/bed/day.

Low-income countries [3, 4, 9] would tend to generate medical wastes on the low end of this range, while middle-income countries would tend to generate medical wastes on the upper end of this range.

Improperly managed medical wastes pose a risk to the personnel who are handling these wastes, including custodial personnel and waste collectors, and to those providing disposal or picking through the wastes for recyclables. There is the danger that syringes will be recovered from transfer depots and disposal sites by waste pickers for recycling (i.e., by drug users). Contaminated containers for collection of medical wastes are not usually dedicated to only one site, but are circulated throughout cities: each skip truck brings an empty container to the hospital or clinic and removes the full one while it covers its daily collection route for general refuse.

Incineration is generally considered the preferred technology for some, if not all, medical wastes. Infected tissue, body parts, and laboratory animal carcasses are generally recommended to be incinerated. On-site incinerators operating on a batch basis or regional incinerators operating on a continuous basis are considered as appropriate technology. Because of the cost of meeting stringent air pollution control emission standards, many high-income countries are taking steps to steam-sterilize, irradiate, chemically disinfect, or gas/vapor sterilize some of the medical wastes.

One hospital incinerator [12–14] with a capacity of 0.75 ton/h, operating on a continuous feed, could cost from US$0.5–1.0 million to implement. Air pollution control systems, if added to meet 1995 USA standards, could cost another $0.5–1.0 million to implement. Incinerators that operate on a batch basis are typically dedicated to one hospital, as their capacity is limited to less than 1 ton/day. Regional incinerators would typically be designed to operate on a continuous feed basis.

Hospital waste treatment/destruction facilities could be implemented through one or more design, build, own, and operate (DBOO) or design, build, operate, and transfer (DBOT) concession agreements of 10–15 years' duration. Or, the government could implement the facilities and arrange for service contracts of 2–5 years for operation and maintenance. Each hospital would be required to pay tipping fees, which fully cover the costs of investment, debt service, and operation. As part of the privatization agreement, the company providing the treatment/destruction services could also be awarded the task of providing collection of the wastes from each hospital and maintaining a manifest system to track the waste from source to ultimate disposal.

Secured sanitary landfill is generally considered the preferred technology for medical wastes which do not require incineration or disinfection, such as packaging materials and general kitchen wastes. Nevertheless, special measures to fence and control access to the area of landfilling for medical wastes are essential. No waste picking should be allowed in the secured area. Also, the machinery for compacting refuse should not come in direct contact with the waste. Instead, the waste should be dumped into a trench and a adequate layer of soil dumped over the waste. Only thereafter is it recommendable that the machinery work over the soil-covered waste to compact it and grade the surface so that infiltration of rainwater is minimized.

2 Technologies of Infectious Waste Treatment

The purpose of treating infectious waste is to change its biological character so as to reduce or eliminate its potential for causing disease.

Facilities involved with the treatment of infectious waste should establish standard operating procedure for each treatment process. Standardization of procedures should include establishing acceptable operating limits which take into account all factors that may affect the treatment process.

The techniques that are generally used are steam sterilization, thermal inactivation, gas/vapor sterilization, chemical disinfection, sterilization by radiation, and incineration.

Steam sterilization of infectious waste utilizes saturated steam within a pressure vessel, known as steam sterilizers, autoclave, or retort, at temperatures sufficient to kill infectious agents present in the waste.

The principal factors that should be considered when treating infectious waste by steam sterilization are as follows:

- Type of waste
- Packing and containers
- Volume of the waste load and its configuration in the treatment chamber

Thermal inactivation includes treatment methods that utilize heat transfer to provide a condition that reduces the presence of infectious agents in waste. Generally, this method is used for treating larger volumes of infectious waste (such as in industrial applications). Different thermal inactivation techniques are used for the treatment of solid infectious waste.

Dry heat treatment may be applied to solid infectious waste. In this technique, the waste is heated in an oven which is usually operated by electricity. Dry heat is a less efficient treatment agent than steam and, therefore, higher temperature or longer treatment cycles are necessary. A typical cycle for dry heat sterilization is treatment at 320–380°F for 2–4 h.

The extensive time and energy requirement of thermal inactivation precludes the common use of this technique for the treatment of solid infectious waste.

Gas/vapor sterilization is an option that may be used for treating certain infectious waste. In this method, the sterilizing agent is a gaseous or vaporized chemical. The two most commonly used chemicals are ethylene oxide and formaldehyde. There is substantial evidence that these chemicals are probable human carcinogens, and caution must be exercised when they are used. Therefore, when the use of gas/vapor sterilization is considered, the relative hazard of the treatment itself should be weighed against the benefits resulting from the treatment.

Chemical treatment is most appropriate for liquid wastes; however, it can also be used for treating solid infectious waste.

In order to use chemical treatment effectively, the following factors should be considered:

- Type of microorganism
- Degree of contamination
- Amount of pertinacious material present
- Concentration and quantity of disinfectant
- Contact time
- Other relevant factors, e.g., temperature, pH, mixing requirement, and biology of microorganism
- The disposal of chemically treated waste should be in accordance with the local requirements

An emerging technology for treating infectious waste involves the use of ionizing radiation. Experience being gained from radiation of medical supplies, medical components, food, and other consumer products is providing a basis for the development of practical applications for the treatment of infectious waste.

The advantages of ionizing radiation sterilization for treatment of infectious waste relative to that of other available treatment methods include the following:

- Nominal electricity requirements
- No steam requirement
- No residual heat in treated waste
- Performance of the system

The principal disadvantages of a radiation sterilization facility are as follows:

- High capital cost
- Requirement for highly trained operating and support personnel
- Large space requirement
- Problem of ultimate disposal of the decayed radiation source

When properly used and monitored, ionizing radiation may provide an effective method of treating infectious waste.

Incineration is a process that converts combustible materials into noncombustible residue or ash. The product gasses are vented to the atmosphere through the incinerator stack, while the treated residue may be disposed of in a sanitary landfill. Incineration provides the advantages of greatly reducing the mass and volume of the waste, often by more than 95%, which, in turn, substantially reduces transport and disposal cost.

Incineration can be a suitable treatment technique for all types of infectious waste. Incineration is especially advantageous with pathological waste and contaminated sharps because it renders body parts unrecognizable and sharps unusable. Incinerators that are properly designed, maintained, and operated are effective in killing organisms that are present in infectious waste. However, if the incinerator is not operating properly, viable pathogenic organisms can be released to the environment in stack emission, residue ash, or waste water.

The principal factors that should be considered when incinerating infectious waste are as follows:

- Variation in waste composition
- Waste feed rate
- Combustion temperature

The absence of regulations that apply to hospital incinerators [13, 14] does not relieve a hospital of its responsibility for meeting the criteria for proper incineration of infectious waste. Therefore, hospitals and other facilities treating infectious waste by this method should ensure that the waste is being properly incinerated.

2.1 Type of Infectious Waste and Appropriate Treatment Techniques

Types of wastes	Techniques
Isolation	Steam sterilization, incineration
Cultures and stocks of infectious agents	Steam sterilization, incineration
Human blood and allied	Steam sterilization
Products	Incineration, chemical disinfection, discharge to sanitary sewers
Pathological wastes	Steam sterilization, incineration, handling by mortician
Contaminated animal carcasses	Steam sterilization
Body parts and bedding	Incineration
Bedding	Incineration

Secondary treatment if required should be followed by incineration.

3 The Current Study

In order to properly treat and manage the hazardous infectious hospital waste and evaluate the cost of treatment, authenticated data of waste generation should be available so that a proper treatment facility may be either designed indigenously or imported from other countries. Unfortunately, the base line data are not available. The current study of collecting the hospital waste generated from the hospital of Karachi is part of the project that is focused on designing an indigenous incinerator. The work was jointly carried out by PCSIR laboratories, Karachi, and Mehran University of Engineering and Technology, Jamshoro.

4 Methodology

Six hospitals in Karachi were selected for the study. The hospitals that had been selected to collect the amount of infectious hospital waste are Jinnah Postgraduate Medical Center (JPMC), Civil Hospital, Abbasi Shaheed Hospital, Liaquat National Hospital, and Agha Khan Hospital. In order to have a clearer picture, infectious hospital wastes were collected from different wards of the selected hospitals. A number of studies have been carried out in different countries on hospital waste management, globally.

5 Results and Discussion

A complete survey of JPMC hospital solid waste has been carried out and is presented in Table 1. A total of 26 wards/units have been surveyed during this study. Dust bins with plastic bags were provided in each unit and after 24 h, the waste was collected and weighed.

The load in kilograms per bed per day has been calculated and presented in Table 1.

The total solid waste load of each ward/unit of JPMC is given in Table 1. The total waste generated per day is 1,697 kg and the number of beds was 1,110.

A comparative statement (showing solid waste generated) has been prepared for JPMC, Civil Hospital, Abbasi Shaheed Hospital, and Liaquat National Hospitals of Karachi, and is presented in Table 2.

Table 3 shows the comparison data of wards, bed strength, and waste generated per day and per bed for JPMC, Civil Hospital, Abbasi Shaheed Hospital, and Liaquat National Hospitals, Karachi. The quantity of waste generated per bed from Agha Khan and Civil Hospitals is higher than that of other hospitals. The reasons for higher waste generation in Agha Khan Hospital are the use of proper dressing and other treatment material on large scale and the maintenance of hygienic condition. However, in Civil Hospital, due to the low standard of the hospital, the waste is being generated by visitors and patients, and by the hospital staff.

The status of hospital waste management is also studied. It is shown in Table 4 that the hospitals use different incineration systems for waste treatment along with the cost of the incineration system.

Table 1 Hospital solid waste from wards of JPMC, Karachi

S.no.	Name of ward/department	Beds	Wastes (kg/day)
1.	Medical ward	200	264
2.	Gynecology and obstetrics unit	150	267
3.	Surgical unit	130	152
4.	Ophthalmology unit	100	46
5.	Orthopedic unit	80	124
6.	Neurosurgery unit	50	46
7.	Radiotherapy unit	50	45
8.	Thoracic surgery unit	40	36
9.	Special ward	40	43
10.	Plastic surgery	40	66
11.	Intensive care unit	35	46
12.	ENT unit	35	65
13.	Cardiology unit	35	28
14.	Neurology unit	30	69
15.	Psychiatry unit	30	20
16.	Nephrology	30	97
17.	Casualty department	20	66
18.	Dermatology unit	15	16
19.	Operation theaters	–	60
20.	Clinical pathology	–	40
21.	Blood bank	–	1
22.	Kitchen	–	54
23.	Rehabilitation department	–	35
24.	Radiology unit	–	6
25.	Dental department	–	4
26.	Atomic energy center	–	1
Total		1,110	1,697

Table 2 Ward-wise generation rate in Karachi hospitals (kg/bed/day)

S.no.	Wards	Civil	Jinnah	Abbasi	Liaquat
1.	Medical	2.228	1.320	2.860	1.280
2.	Surgical	3.346	1.170	1.575	1.500
3.	Gynecology and obstetrics	3.819	1.780	3.250	1.670
4.	Orthopedics	3.442	1.560	1.920	1.080
5.	Cardiac	3.490	0.800	1.580	1.610
6.	ICU	5.500	1.310	2.500	1.560
7.	Neurology	2.600	2.730	1.220	–
8.	Urology	3.520	–	–	–
9.	ENT	3.400	2.320	1.470	–
10.	Eye	2.700	0.430	1.180	–
11.	Pediatric	3.096	–	1.380	1.360
12.	Nephrology	–	3.250	1.200	–
13.	Plastic surgery	3.710	1.670	–	–
14.	Skin	3.500	0.810	–	–
15.	Burns	6.800	–	1.910	–
16.	Accidental	–	1.560	–	–
17.	Psychiatry	2.750	0.680	–	–
Average		3.470	1.520 kg/bed/day	2.030	1.280

Table 3 Waste generation rate of Karachi hospitals

Hospitals rate	Wards	Bed strength	Waste (kg/day)	Generation (kg/bed)
Civil	25	1,342	4,952	3.470
Jinnah	24	1,110	1,697	1.520
Abbasi	20	579	1,484	2.030
Liaquat	21	556	907	1.280
Agha Khan	15	432	2,215	5.130
Total	115	4,019	11,255	2.680

Table 4 Comparative statement of incinerators

S.no.	Name of hospitals	Capacity (kg/h)	Local/imported	Cost (Rs. in millions)	Current status
1.	Jinnah	450	Indigenous	1.0	
2.	Agha Khan Hospital	750	Imported (England)	3.2	
3.	Liaquat National Hospital	200	Imported (American)	2.0	

The cost effectiveness has been studied and presented in Table 4. The costs of two imported incinerators installed at Agha Khan and Liaquat National Hospitals, Karachi, have been compared. It can be observed from Table 4 that the cost of an indigenous incinerator also saves the foreign exchange component. An indigenous incinerator for the treatment of infectious solid hospital waste may be designed.

With the development of an indigenous incinerator, the following advantages can be achieved:

1. Local technology skill will develop and with the passage of time, now models can be developed comparatively at less cost.
2. Employment can be generated in this field.
3. Foreign exchange can be saved and more foreign exchange can be earned by exporting our incinerators.
4. Most of the hospitals can be offered to install this indigenous incinerator.
5. Hospital waste management problem can be solved.
6. Clean and safe environment can be provided to patients and visitors in the hospitals.

6 Conclusions

The following conclusions have been made:

- The hospital authorities are unconcerned about the spreading menace of infectious waste.
- There are no arrangements for segregation of waste by type, their proper temporary storage, transportation, and ultimate disposal either by the hospital staff or by the municipal authorities.

- The hospital staff in general and the sanitary staff in particular are unaware of the hazards posed by the infectious waste.
- Patients in the hospital are always at the risk of hazards of the infectious waste.
- No prior treatment is given to the waste before disposal.
- Most of the infectious waste finds its way in the city sewerage system.
- Due to the above-mentioned facts, hospitals have become a source of spreading contagious disease.
- It is dangerous to leave solid waste with municipal waste, or at any open space.
- Incineration is a suitable method for the disposal of infectious waste because it reduces mass and volume, and completely destroys the hazardous waste.
- It is a must to incinerate infectious hospital solid waste for avoiding any environmental or health hazards.
- An incinerator (controlled-air incinerator) has been indigenously designed, fabricated, and installed at JPMC, Karachi, for treatment of hospital solid waste. This incinerator is the first of its kind in Pakistan for the treatment of hospital solid waste.

It is recommended that every hospital should have a proper solid waste management system which includes segregation of solid waste at source, proper storage, transportation, and incineration of infectious solid waste within the hospital premises. Indigenously fabricated controlled-air incinerators are recommended as they are cost effective (at least 50% less in comparison to the imported incinerator) and environmentally safe. Hospital staff should be provided solid waste management training for proper handling and disposal of the solid waste. Public awareness program should be arranged for hospital solid waste management.

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Modeling of Solid Waste Management Systems

B.K. Bala

Abstract Present solid waste management system in Dhaka city is reviewed, and the constraints and shortfalls are discussed. Solid wastes are categorized as recyclable and nonrecyclable. A limited portion of the organic solid wastes is composted and the major share is open dumped. Recently, a scientifically engineered landfill has been constructed by Dhaka City Corporation.

Recent efforts on modeling of solid waste management systems are critically reviewed and a system dynamics model of solid waste management is presented to simulate population, solid waste generation and composite index, electricity generation from the incineration of solid waste, engineer landfill and fertilizers from composting. Environmental performance for open dumping, scientific landfills, incineration and composting of solid wastes using life cycle assessment model is also evaluated.

Simulated results show that solid waste generation, collection capacity and electricity generation potential from the incineration of the solid waste increase with time. Population, uncleared waste, untreated waste and composite index are projected to increase with time for Dhaka city. Simulated results also show that increasing the budget for collection capacity alone does not improve environmental quality. This model can be used as a computer laboratory for solid waste management policy analysis.

Keywords Composting • Incineration • Landfill • Life cycle assessment • Modeling • Open dumping • Simulation • Solid wastes

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1 Introduction

Solid waste crisis is emerging in Bangladesh and the majority of the cities are severely affected. The disposal problem is more serious for Dhaka city, the capital of Bangladesh. Population of Dhaka was 5.284 million in 2001 and it is projected to be 6.7 million in 2010 and 7.7 million in 2015 [1]. The population of Dhaka city is 5.7 million and per capita solid waste generation is estimated to be 0.56 kg/day. Daily solid waste generations from different sources are 1,950 tons/day from domestic sources, 1,050 tons/day from business sources and 200 tons/day from street sources [1]. Solid waste generation of Dhaka Metropolitan area in 1998 was 3,944 tons/day and 4,750 tons/day in 2000. Solid waste generation in Dhaka city is increasing rapidly with rapidly growing population and GDP and Japan International Cooperation Agency (JICA) [2] predicted solid waste generation to increase from 3,200 tons/day in 2004 to 4,634 tons/day in 2015. Sufian and Bala [3] predicted the waste generation in Dhaka city to increase from 1.027 million tons in 1995 to 4.257 million tons in 2025.

Of the total waste produced, nearly 20% is used for recovery and recycling and about 37% remains scattered laying around on roadsides, open spaces or in drains. The remaining 43% of the wastes are deposited together in the same primary depots from where about 45% is finally disposed of either by the DCC or Community-Based Organizations (CBOs) in the open landfill sites at Matuail near Jatrabari, Beribadh in Mirpur and in Uttara.

The major sources of solid wastes in Dhaka city are residences, streets, market places, commercial establishment and hospitals. The JICA study shows 63% (2,120 tons/day) of the total waste (3,340) is from residential sources while another project of the Dhaka City Corporation (DCC) estimated that it is 49.08%. Other sources, for example, commercial and industrial waste volume is not specified clearly in JICA's "Clean Dhaka Master Plan" study but according to DCC and some other recent studies, commercial waste generation is no less than 20% of the total. The sources and their contributions are shown in Table 1. The density of solid waste depends on its organic and inorganic contents and the density value of solid waste in the Dhaka city is 600 kg/m^3. Dhaka city Corporation is responsible for collecting and disposal of solid wastes in Dhaka city. Solid wastes are collected from street corners, dumping grounds, concrete and steel bins while some recyclable solids are collected on payment from the houses.

In Bangladesh, analysis of the compositions of the urban solid waste is not generally carried out on a regular basis by the municipalities. The typical

Table 1 Sources and contributions of solid waste from different sources

Types of solid waste	Quantity
Domestic	40–60
Commercial	5–20
Street sweeping	20–30
Combustible	20–30
Noncombustible	30–40
Moisture	45–50

compositions of solid waste by weight of Dhaka city analyzed by several sources are shown in Table 2. On an average, constituents are 18% inorganic matter and 82% organic matter [4].

Heating values of solid wastes depend on the types of wastes and moisture contents of the wastes. Themelis et al. [5] reported that the heating values of the

Table 2 Compositions of solid waste of Dhaka

Constituent	Reported by Khan [4] Residential (weight %)	Industrial (weight %)	Reported by Alam [6] (Weight %)
Plastic	1.74	1.48	2.3
Paper	5.68	7.22	10.0
Glass	6.38	10.22	1.4
Metal			0.5
Textile	1.83	1.59	–
Food stuff and kitchen	84.37	79.49	–
Food waste	–	–	18.0
Wood/grass	–	–	2.1
Ash/soil	–	–	40.0
Other	–	–	25.0
Total	100.00	100.00	99.3

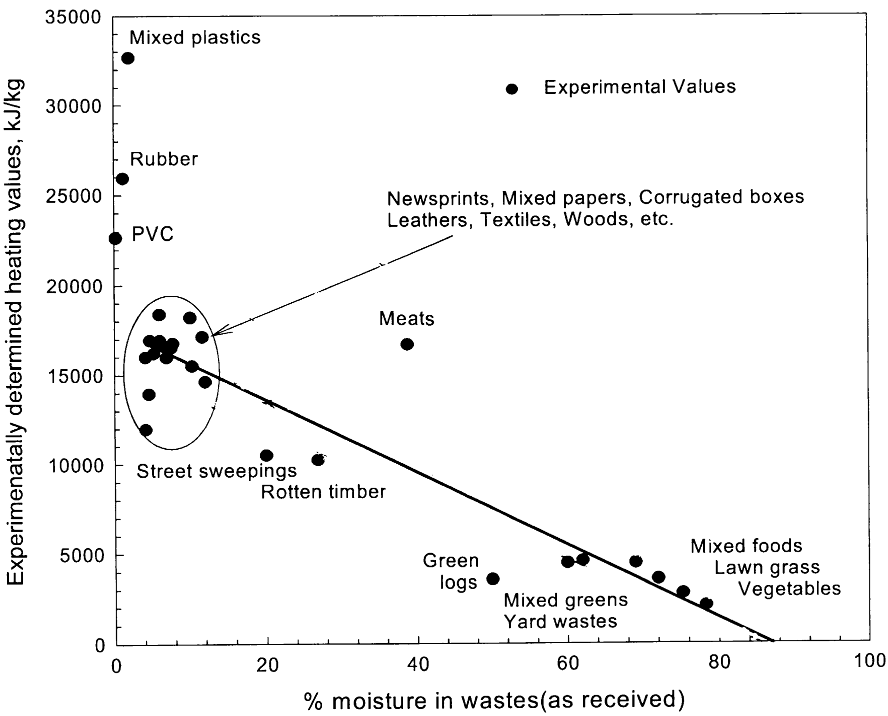

Fig. 1 Variation of heating values of different types of solid wastes with moisture contents [5]

different types of wastes decrease the increase of moisture contents. Figure 1 shows the variation of the heating values of different types of solid wastes based on Themelis et al. [5]. The heating values of residential, industrial and commercial wastes are 9.20, 5.67 and 6.94 MJ/kg and the corresponding percentages of the wastes by weight are 44.2, 14.7 and 17.7%, respectively, with street sweeping of 23.4% [6]. Since street is not in consideration, the new percentages of wastes in the above sectors are 57.70, 19.19 and 23.11%, respectively. Based on these data the calorific value of the solid waste generated in Dhaka city is estimated to be 8.0 MJ/kg.

The disposal method is open dumping in an unhygienic manner. Recently the open dump at Matuail has been converted into sanitary landfill. A portion of recyclable solid waste of Dhaka city is used in recycling industries (plastics, paper, glass, metals, etc.), but this amount is very small and undertaken informally. A major part of the solid waste of the DCC remains uncollected. This uncollected waste mostly remains in bins, temporary roadside depots and open spaces or street sides, causing a number of problems:

- Uncollected waste occupies huge spaces of the city streets causing traffic congestion.
- Uncollected waste in temporary depots often gets burned that reduces air quality.
- Aerosols and dusts can spread microbes from uncollected and decomposing wastes.
- Waste that is disposed of here and there and not collected properly can cause severe aesthetic nuisance in terms of smell and appearance.
- Uncollected waste may produce dirty water that mixes up with nearby water bodies and degrade water quality.
- Uncollected waste creates discomfort to pedestrians, particularly children and aged people.

The DCC is still quite unable to keep up its utility services due to its budget constraints and lack of other resources. The conservancy tax revenue of the DCC is lower than its expenditure, which is the main reason behind inadequate solid waste collection and management. It was found that the DCC spent 476 million taka in 2002–2003 for solid waste management, while the conservancy tax revenue was only 146 million taka. Expenditure on SWM has increased in last few years but the gap between expenditure and tax revenue remained high. The DCC is also unable to collect and dispose of all solid wastes due to the rapid increase in population and waste every day. On the other hand, many transport vehicles and equipments are not used daily, which also results in the low level of waste collection. The DCC, however, engaged a large number of NGOs, CBOs and private companies for municipal solid waste collection, disposal and recycling activities.

Three types of solid waste management systems exist: (1) formal system, (2) community initiative and (3) informal system. In the formal system, solid wastes are collected and dumped in the outskirts of the city. In the community initiative, solid wastes are collected from the houses and subjected to composting while in the informal system recycling, solids are collected by informal labour forces [7].

Traditional labor intensive methods are used for solid waste management in Dhaka city. Waste is simply collected from the designated communal dustbins and demountable containers, transported by open 1.5–5 ton capacity trucks, demountable containers, tractors and trailers and disposed of in a crude unsanitary method nearby low-lying areas of the city. Collection system is inadequate and involves four or five times of handling of a particular waste before it is finally disposed of at an open dumping site. The waste collection system relies on communal containers located along the road sides. Collection coverage of waste is inefficient and as a result 35–50% of waste remains uncollected in the city. Approximately 120,000 people are involved in recycling and almost 50% of the inorganic fraction is recycled [7].

Many of the households and even individuals do not dispose of their waste properly in bins or roadside containers. On the other hand, none of the municipal waste workers or even community workers take safety measures while performing their duty. In Bangladesh, collection, segregation, transportation and disposal of solid wastes are unscientific. Uncontrolled dumping of wastes on the outskirts of towns and cities has created overflowing landfills, which have environmental impacts in the form of pollution to soil, groundwater and air, and also contribute to global warming. In the absence of formalized solid waste management practices, recycling in the form of composting has emerged only as an informal sector.

DCC currently disposes of about 44% of the total generated waste (3,340 tons/day) at three landfill sites located at Matuail (20 ha), Beri Bund (2 ha) and Uttara (1 ha). Matuail is the only official site owned by DCC and the daily total disposal on wet season average is 1,400 tons/day. Matuail receives 65% of the total disposal volume, Beri Bund and Uttara receive 30% and 5%, respectively. All these landfill sites are open, with no gas collection system or leachate treatment technology. The Beri Bund landfill is very close to the Buriganga River. Matuail, the major landfill site, is located within 1 km of residential areas (e.g. Jatrabari, Jurain). Most of the abandoned landfill sites are also close to residential areas.

Recycling industry raises a total of 436 tons/day of material recovery. The amount recovered is the reduction of waste to be managed by DCC. Composting contributes very little to the waste reduction although the compostable waste has the largest portion among generated wastes.

The major constraints of solid waste management in Bangladesh are: (1) lack of finance and insufficient tax collection, (2) lack of manpower and infrastructure, (3) lack of access to municipal solid waste service, (4) shortage of suitable land for final disposal of solid waste, (5) lack of proper institutional setup, (6) lack of awareness, (7) lack of partnership, (8) incomplete and insufficient waste collection, (9) lack of proper handling rules and standard and (10) absence of national policy to encourage recycling [7].

Waste Concern is a national NGO working on solid waste management issues in about 20 cities and towns of Bangladesh, especially Dhaka and Khulna. They have initiated recycling and reusing of solid waste in Dhaka city. Waste Concern owns four compost plants with a total capacity of about 15 tons/day. These plants are located in Mirpur, Baily Road, Green Road and Dhalpur areas of the city. Another

NGO in Kalabagan started helping in SWM of Dhaka city. They collect waste from the households and dispose of them into the municipal depots. However, door-to-door collection rate of solid waste needs to be increased; otherwise the city environment and quality of life will be degrading further.

In order to improve solid waste management system in Dhaka city, the following issues should be addressed: (1) promotion of recycling/composting/electricity from solid waste, (2) promotion of participatory action, (3) promotion of source separation of waste, (4) tax incentive for use and production of recycled product and (5) promotion of more waste-related projects [7].

- It is clear that due to limited resources and organizational capacity, it is difficult for DCC to ensure efficient and appropriate delivery of solid waste collection and disposal services to the entire city population. Therefore, DCC is encouraging community-based organizations and local NGOs to organize and carryout community waste management programs (mainly house to house collection and disposal at roadside bins).
- Moreover, as the capacity of landfill area is coming to a saturation point in the near future, the separation of solid waste at source will divert a major portion of organic waste for composting and some materials for recycling, thereby relieving the pressure on the landfill. In the meantime, DCC can concentrate on formulating policies for overall solid waste management, which requires substantial funding and legislation.

Here two important alternatives are: (1) electricity generation from solid waste and (2) production of compost from composting of the solid waste and these are summarized below:

A growing number of other cities including in Bangladesh are facing the problem of solid waste disposal. Bangladesh will not be able to find space for further dumping raw municipal solid wastes because of the lack of space for new landfills. Some municipal authorities are already facing great difficulties to appropriate landfill sites for municipal solid wastes. Municipal solid waste incineration can play important role in municipal solid wastes management.

Yongfeng [8] reported that municipal solid waste incineration has recently emerged as the method of choice for the primary treatment of municipal solid wastes in many cities in China. There were 67 incineration plants in operation in China in 2005 with a total daily capacity of approximately 33,010 tons. This was about 12.9% of all municipal solid wastes. In China almost all of the municipal solid waste incineration plants are designed to dispose of municipal solid wastes and produce electricity. In addition, the heating value of municipal solid waste was 6.060 MJ/kg. However, the problem of low heating has been solved by improving the stoker design and prolonging the storage to increase the lower heating value [8]. The Chinese experiences of solid waste incineration with low heating value similar to Bangladesh suggest the potentials of municipal solid waste incineration for disposal and electricity generation in Bangladesh.

Alam and Bole [6] analyzed the electrical energy recovery potential from urban solid waste of Dhaka city and its economic feasibility and emphasized that

1.28 million tons of municipal waste generated in the Dhaka city could be used to produce about 72 MW of electricity. If it is not economically viable in the context of only electricity production, it is of importance if optimum energy utilization and environmental implications are considered. Recently Sufian and Bala [9] applied system dynamics for modeling electrical energy recovery from urban solid waste.

The solid waste has a heating value of 6.0 MJ/kg, about one-third of the heating value of coal, but unlike coal it has very low sulphur content. The electrical energy from heat energy recovery from an incineration plant involves the burning of solid wastes at high (815–980°C) temperatures [10]. If incineration is to become an economical method for solid waste disposal, useful material and energy must be recovered by the process. Heat can be recovered by putting a waste heat boiler or some other heat recovery device on an existing solid waste incinerator. The heat so recovered can be utilized for generating electricity or for space heating purpose.

Zubrugg et al. [11] reported a study based on the experiences of *Waste Concern*, a NGO with a community-based decentralized composting project in Mirpur, Dhaka, Bangladesh. Organic waste was converted into waste using a labor intensive aerobic and mesophilic composting procedure. This case study is a success story of decentralized collection and composting scheme. The case of Mirpur shows that composting can be a good alternative to conventional solid waste management options, reducing the amount of waste to be transported and dumped by producing a valuable raw material for fertilizers. Zubrugg et al. [12] reported a study on community and private initiatives in the Indian cities of Bangalore, Chennai, Pune and Mumbai for decentralized composting of urban wastes and summarized the key issues and overall deficiencies.

Organic wastes can be converted into compost using labor intensive and a simple thermophile composting procedure [11]. Figure 2 shows flow chart of the composting process. The prestored organic waste is mixed with additives and piled around a triangular aerator/rack made of bamboo, which allows a better air circulation inside pile. The total composting process lasts for 53 days, which can be described by a thermophilic phase (27 days, 40–70°C) and a mesophilic phase (26 days, 20–40°C). During the first phase, the compost piles are turned frequently to regulate their temperature and ensure an equal decomposition level throughout the pile. The turning process, together with the observed temperature curve, indicates that the pile is well hygienized and pathogenic organisms and weed seeds do not survive. As the pile temperature drops to ambient temperature, the material is left to mature without turning or watering. The material changes its color into dark brown, which is a sign of mature compost. The mature compost is then screened and packed into bags.

Several studies have been reported on life cycle assessment of municipal solid waste management systems [13–15]. Consonni et al. [13, 14] examined environmental impacts and economics of the various strategies using life cycle assessment starting from heat and mass balances. Velumani and Meenakshi [15] reported life cycle inventory analysis for three different municipal solid waste management scenarios: (1) open landfill, (2) generation, collection, transportation and sanitary land filling and (3) generation, collection, transportation, segregation, incineration,

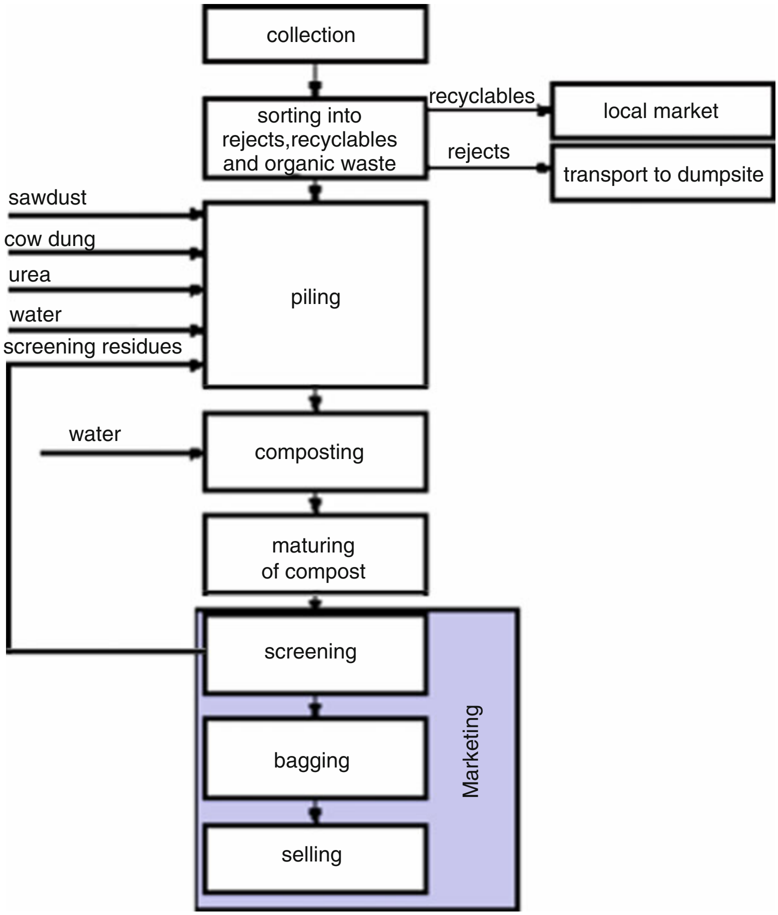

Fig. 2 Flow chart of composting process

recycling and sanitary land filling for Coimbatore city, India to aid the decision makers and planners for integrated management of solid waste management for sustainable development.

Life Cycle Assessment (LCA) is a methodology for examining environmental impacts associated with a product, process or service "from cradle to grave" from the production of raw materials to ultimate disposal of wastes. LCA is used in this study as a quantitative tool for environmental impact assessment. The full assessment includes the entire life cycle of solid waste production, segregation, collection, composting, scientific landfill and incineration for electricity generation. The interrelationships of the components of LCA are shown in Fig. 3. Four basic steps of LCA assessment are:

Goal and scope definition, which includes the preliminary assumptions about the aim of the study, the functional unit and boundaries of the system.

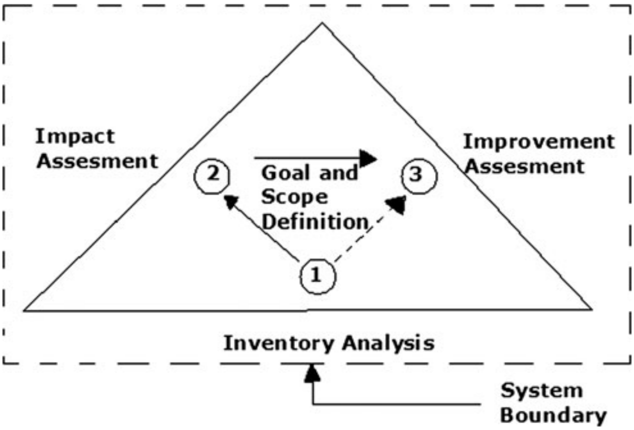

Fig. 3 Inter-relationship of the components of LCA system

Life Cycle Inventory (LCI), which focuses on the quantification of mass and energy fluxes.

Life Cycle Impact Assessment (LCIA), where the environmental impact of the activity is assessed by means of impact indicators.

Life Cycle Improvement Assessment, which aims at evaluating possible changes or modifications of the system that can reduce its environmental impact.

The objective of the goal and definition stage is to specify the purpose and the scope of the study. By purpose it means the reason for carrying out the LCA. Specifying the scope of the study implies defining the context in which the assessment is being made, i.e., defining the system and its boundary and specifying the functional unit. The activities undertaken to do this usually are:

– Problem specification,
– Scope defining and
– Functional unit.

The functional unit used in the scenarios has been defined as the amount of municipal solid waste generated at Dhaka city. The system boundaries selected for the life cycle of solid waste were defined as the moment when material ceases to have value, becoming waste and when waste becomes inert landfill material or is converted to air and/or water emissions or regains some value.

Many studies have been reported on strategies to achieve municipal solid waste management [16–18]. Linear programming, mixed integer programming, input–output analysis, expert system and system dynamics have been applied to aid decision makers in planning and management of solid waste management systems [19–26]. Waste analysis software tool is also becoming available [27].

Banar et al. [28] used life cycle assessment methodology to determine the optimum municipal solid waste management strategy for Eskisehir, Turkey and also used SimaPro7 libraries to obtain background data for the life cycle inventory.

Ozeler et al. [29] developed and compared different solid waste management scenarios for the solid waste management system of Ankara, Turkey to find the most feasible solid waste management system using life cycle assessment methodology and the life cycle inventory was carried out by IWM Model-1.

Dyson and Chang [30] emphasized the capability of system dynamics for prediction of solid waste generation and Sufian and Bala [3, 9] and Bala and Sufian [31] successfully applied system dynamics to model and analyze the policy options of solid waste management system. In this study, this model has been further developed and composting and life cycle assessment have also been included.

2 System Dynamics Modeling of Urban Solid Waste Management System

Planning of Urban Solid Waste Management (USWM) has to address several interdependent issues such as public health, the environment, compost from solid waste, electricity generation potential from the incineration of the urban solid waste generated, present and future costs to society, and also environmental impacts. The USWM is a complex, dynamic and multi-faceted system depending not only on available technology but also upon economic and social factors. Experimentation with an actually existing urban solid waste management system containing economic, social, technological, environmental and political elements may be expensive and time consuming or totally unrealistic. By simulating an USWM by a computer model, one can conduct a series of experiments. Computer models clearly are of great value to understand the dynamics of such complex systems [32]. Owing to the intrinsically complex nature of USWM problems, it is advantageous to implement USWM policy options only after careful modeling analyses. Forrester's system dynamics methodology provides a foundation for constructing computer models to do what the human mind cannot do, i.e., rationally analyze the structure, the interactions and mode of behavior of complex socio-economic, technological and environmental systems [33]. Hence, the system dynamics approach is the most appropriate technique to handle these types of complex problems. A detailed description of the methodology is given in Forrester [34] and Bala [32, 34].

System dynamics methodology is based on the feedback concept of control theory and the feedback loops simulate dynamic behavior [32, 33]. Two basic building blocks in system dynamics studies are stock or level and flow or rate. Stock variables (symbolized by rectangles) are state variables and stocks represent accumulation in the system. Flow variables (symbolized by valves) are the rate of change in the stock variables and flows represent the activities and decision function in the system. Converters (represented by circles) are intermediate variables used for miscellaneous calculations. Finally, the connectors (represented by simple arrows) represent cause and effect links within the model structure [32]. Based on the feedback concept of system dynamics, the causal loop diagrams were drawn and the state variables (stock and flow) were identified. Stocks represent integral difference equations and these equations were solved using Runge Kutta third-order method. The flow diagram of the model was constructed using icon operated stock and flow symbols of STELLA software. The STELLA flow diagram of the urban solid waste management system is shown in Fig. 4. The equations for such a formulation are given in Sufian [35].

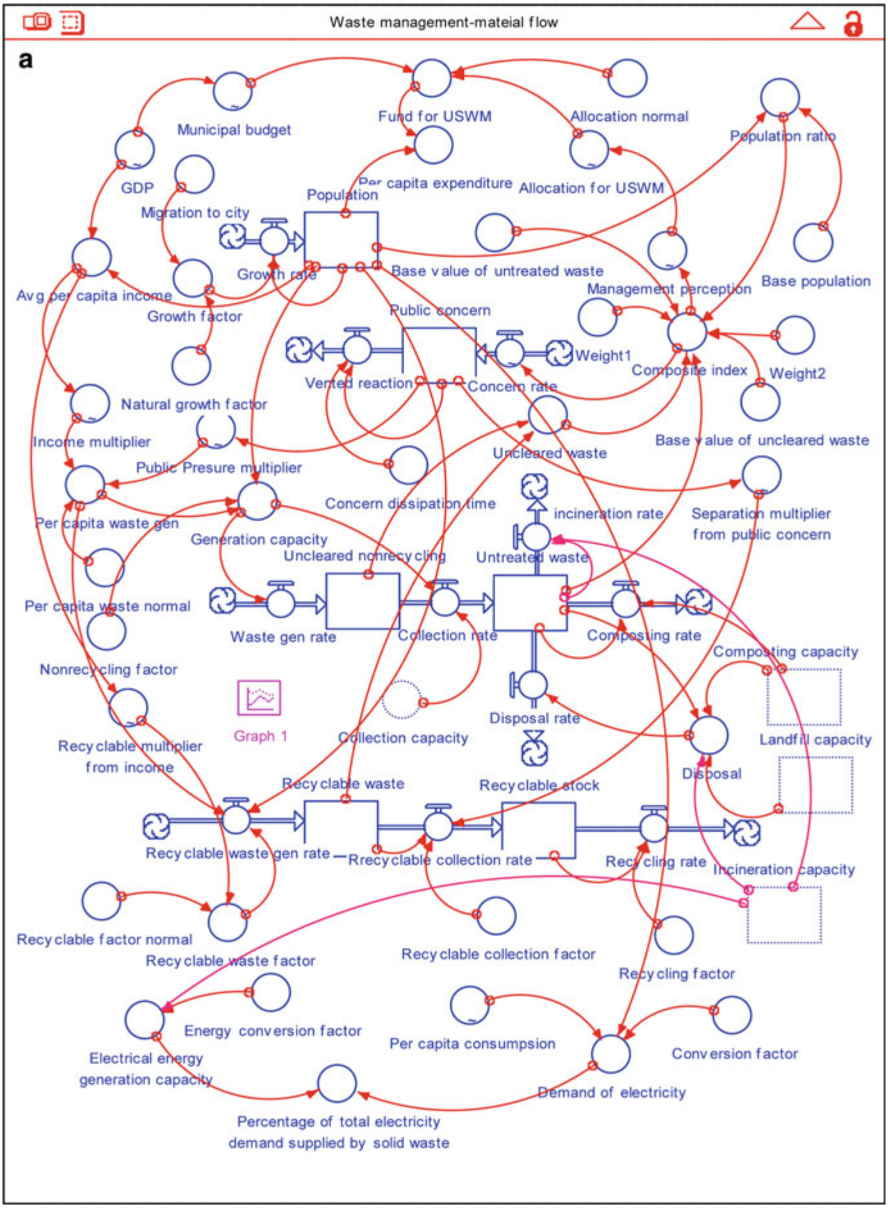

Fig. 4 (**a**) STELLA flow diagram of solid waste management system – material flow

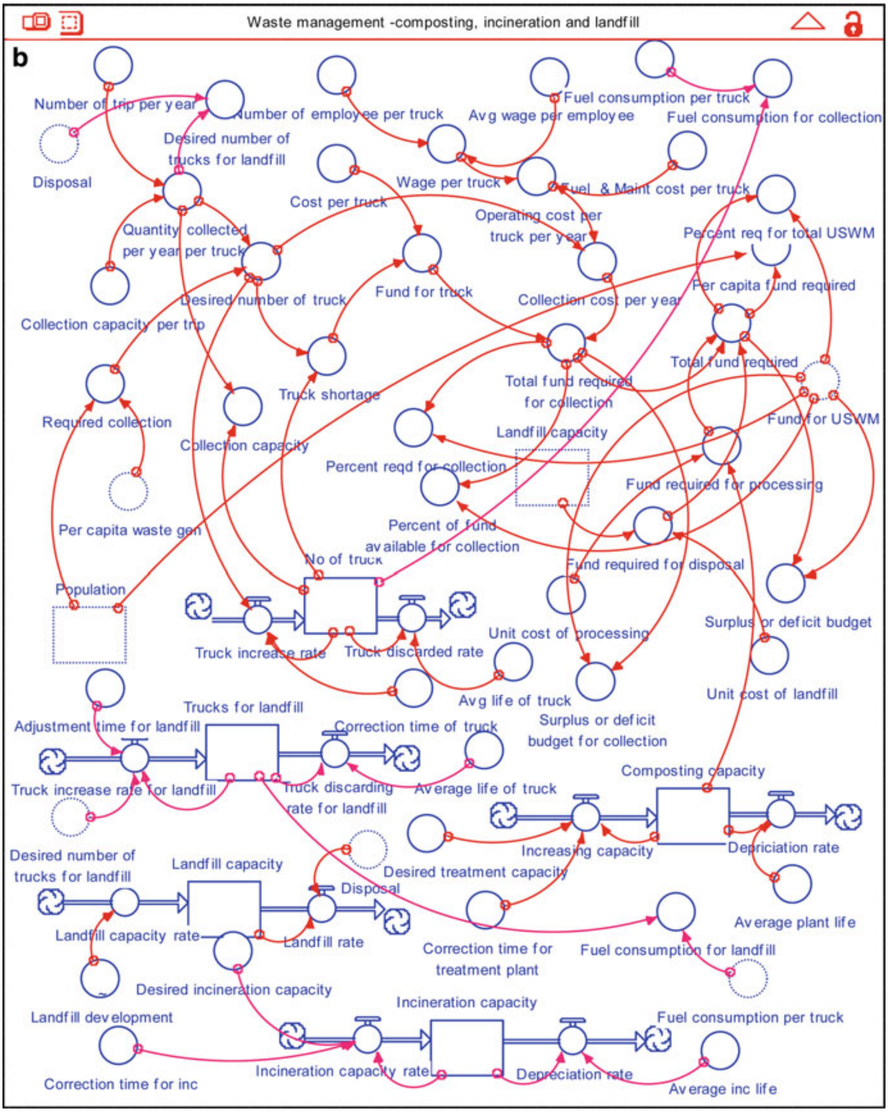

Fig. 4 (**b**) STELLA flow diagram of solid waste management system – composting, incineration and landfill

The model described here is a theoretical framework for examining urban solid waste generation and its management system in Dhaka City. Although a landfill has been constructed at Matuail and the Dhaka city corporation does not have any electricity generation plant fuelled by urban solid waste, electrical energy generation potential from urban solid waste at Dhaka city and the controlled disposal of a

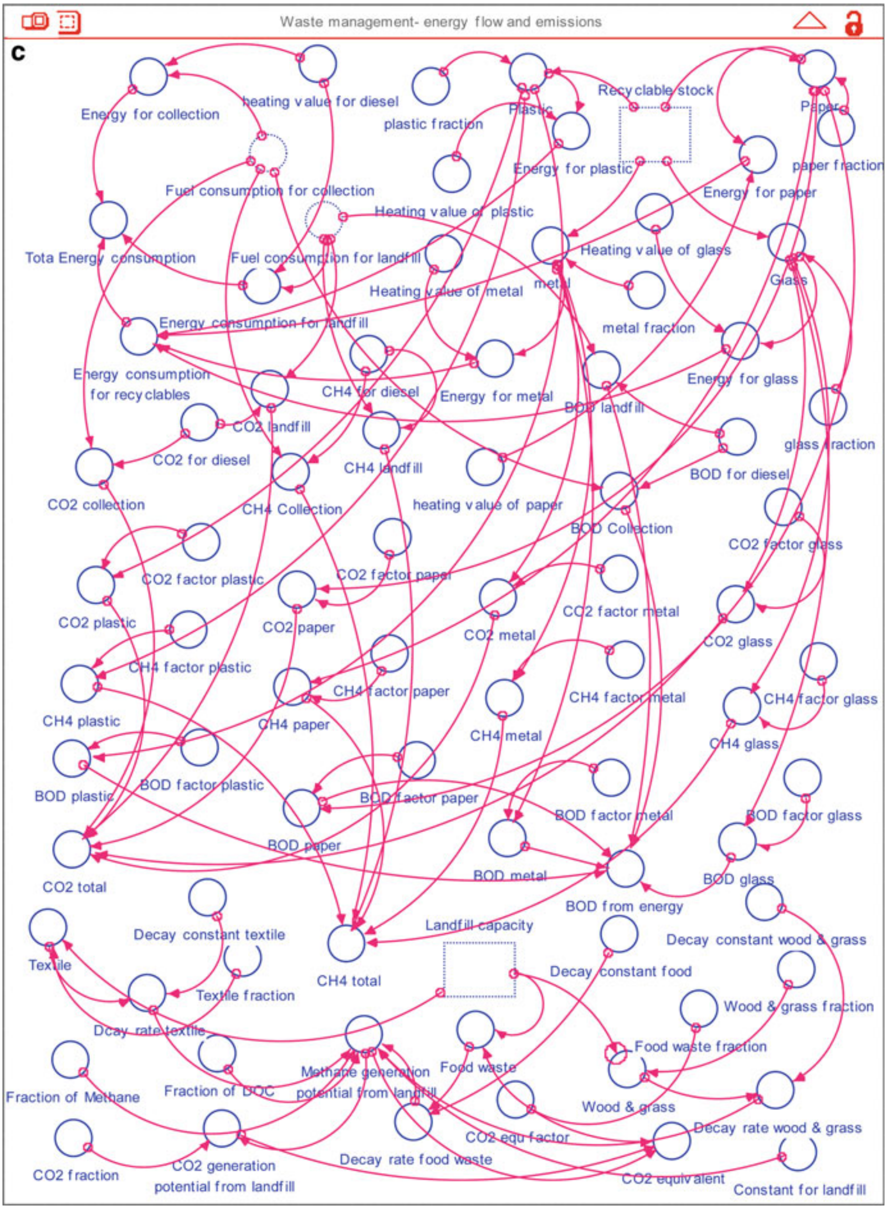

Fig. 4 (**c**) STELLA flow diagram of solid waste management system – energy flow and emissions

portion of collected wastes as landfill, and treatment of waste (incineration, composting, etc.) are included in this model.

The model predicts scenarios which include generation, segregation, collection, transportation, composting, sanitary landfill, incineration of municipal solid wastes

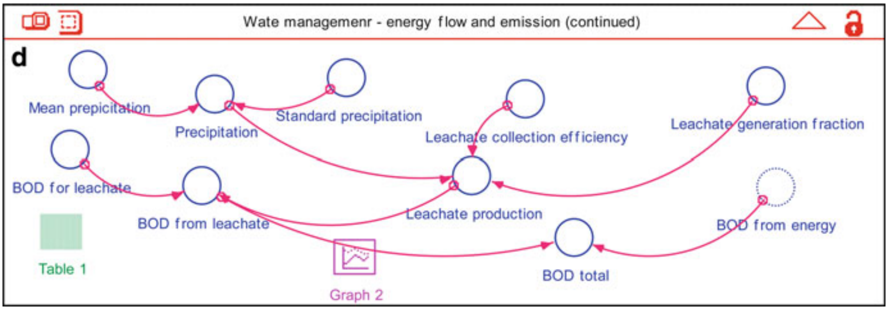

Fig. 4 (**d**) STELLA flow diagram of solid waste management systems – energy flow and emissions (continued)

and environmental impacts. Municipal solid wastes are separated into recyclable wastes and non-recyclable wastes. A fraction of organic solid wastes from the municipal solid wastes is used for composting and the remaining portion of the nonrecyclable wastes is used for sanitary landfill and incineration. In sanitary landfill, wastes are spread and compacted by mechanical compactors and energy inputs and emissions are calculated. Energy inputs and outputs, and emissions during incineration are also computed. In addition, the organic fertilizers available from composting are estimated.

There is a large gap between the waste generation and management system which results in environmental pollution. Both the uncollected waste and unhygienic disposal of waste create environmental pollution, which gives rise to increased public annoyance and anger and hence public concern develops to reduce waste generation and source separation of recyclable waste. But, waste generation increases with increased population and GDP as well as per-capita income. Hence, the electrical energy generation potential from the urban solid waste also increases. On the other hand, composite index shows the lack of waste collection (uncleared waste). A higher composite index increases management perception which increases fund allocation for solid waste management. The composite index is defined as:

$$\text{Composite Index} = (w_1 \times \text{UNCL} + w_2 \times \text{UNTR}) \times \text{POPR} \tag{1}$$

where

w_1, w_2 = weighting factor ($w_1 = 0.5$ and $w_2 = 0.5$)
UNCL = the ratio of uncleared waste at any point of time to the base value,
UNTR = the ratio of the untreated waste at any point of time to the base value and
POPR = the ratio of the population at any point of time to the base value.

A higher value of composite index indicates a progressive deterioration in health and environmental quality.

Life Cycle Assessment (LCA) of municipal solid waste management of the Dhaka city is also included in this model. The scope of life cycle assessment is to account for all possible environmental impacts "from cradle to grave", i.e., along the whole sequence of actions required to bring about and later terminate a given product or activity. Life cycle assessment of municipal solid wastes starts just at the moment when it is put into the waste bin and ends when it is disposed. Life cycle assessment assesses the use of resources and releases of emissions to air, water, land and the generation of useful products from the wastes. This is done here by compiling an inventory of relevant inputs and outputs of the system, evaluating the potential impacts of those inputs and outputs in relation to the objectives of the study. To evaluate the global warming potential properly, CO_2 emissions are broken down into a fraction originated by fossil carbon (plastics, rubber or fossil fuel) and a renewable fraction originated from biogenic materials (paper, wood or organic fractions). Figure 4a–d shows the STELLA flow diagram of a system dynamics model used to analyze the planning for USWM of the Dhaka City.

3 Results and Discussion

The authors considered various ways of validating a system dynamics model, such as comparing the model results with historical data, checking whether the model generates plausible behavior and checking the quality of parameter values. Some of the parameters have been derived from studies in other areas and some were the results of expert guesswork. To judge the plausibility of the model, the behavior of the key variables in the base run were examined by the authors.

Computer projections of population, solid waste generation, uncleared waste and untreated waste for Dhaka City are shown in Fig. 5. Dhaka City had a population of 4.375 million in 1995 and is approaching 12.082 million by 2025. The population growth rate of the city is higher than the average value of the whole country. This might be due to the fact that for job opportunities or other attractive factors there is a rapid population inflow into the city. More population means more waste, and more waste means more resources needed for waste management. The waste generation increases from 1.027 million tonnes in 1995 to 4.257 million tonnes in 2025. An estimate of waste generation is crucially important for collection services and disposal facilities. It is clear from the figure that uncleared waste increases from 519,681 tonnes in 1995 to 33.183e+006 tonnes in 2025, and untreated waste increases from 376,321 tonnes in 1995 to 11.65e+006 tonnes in 2025. The uncleared waste of Dhaka city is increasing with time because of an inadequate collection capacity to transport the wastes to the dumpsites. Untreated waste is also increasing with time due to the lack of treatment facilities.

Figure 6 shows simulated incineration capacity, composting capacity, landfill capacity, electrical energy generation potential and composite index for a time

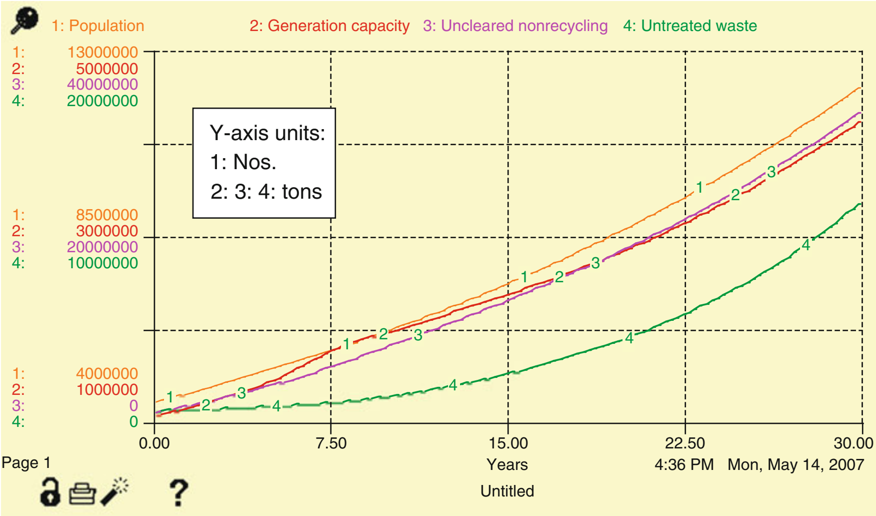

Fig. 5 Population, solid waste generation, uncleared waste and untreated waste of Dhaka city for a time horizon of 30 years

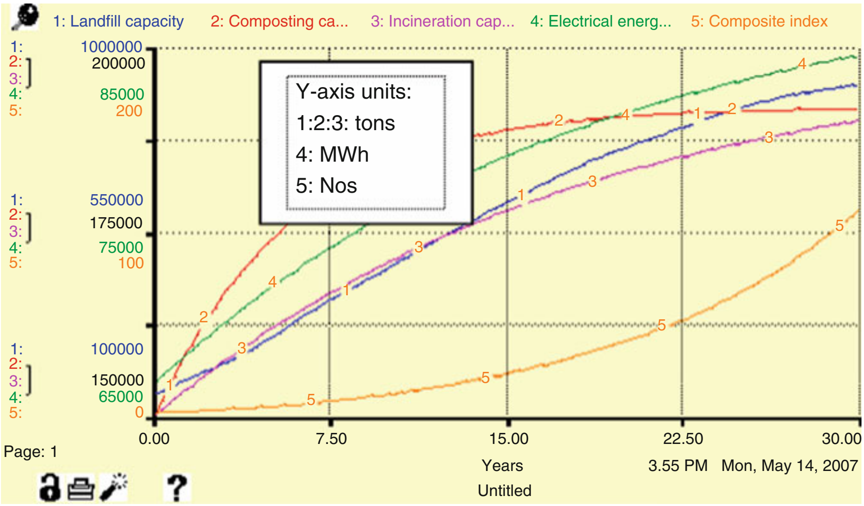

Fig. 6 Simulated landfill capacity, composting capacity, incineration capacity, electricity generation potential from solid waste and composite index for a time horizon of 30 years

horizon of 30 years. For a policy of introduction of incineration plant, composting and sanitary landfill, landfill capacity increases from 150,000 tonnes in 1995 to 907,729 tonnes in 2025; incineration capacity increases from 150,00 tonnes in 1995 to 0.190e+006 tonnes in 2025 and the corresponding electrical energy generation capacity increases from 66,750 MWh in 1995 to 84,556 MWh in 2025, and the composting plant capacity increases up to 15 years and then it becomes almost constant. The electrical energy recovery from urban solid waste generation of Dhaka City can supply a significant portion of the consumption requirement of electrical energy of the city. Hence adoption of the policy for electricity from urban solid waste of Dhaka City should be dictated by the economy of adoption of the technology of electricity generation from the solid waste and environmental implications. The composite index increases from 0.86 in 1995 to 101.47 in 2025. The rapid increase in composite index with time means that the quality of the environment is deteriorating rapidly with time. In the early period (0–7.5 years), composite index is very low with a very small growth rate while in the later period it increases very rapidly. The rapid increase in composite index with time means that the quality of the environment is deteriorating rapidly with time. Thus, solid waste management system is sustainable in the short run and becomes unsustainable in the long run.

Figure 7 shows the simulated total funds required for collection, landfill and treatment, total fund required and fund for USWM for a time horizon of 30 years. The simulated total fund required for collection, total fund required and fund for USWM are increasing with time. Fund required for collection increases from Tk 3.46e+008 in 1995 to Tk 14.15e+008 in 2025 as the generation of solid waste increases. The fund required for disposal also increases from Tk 7.50e+007 in 1995 to Tk 45.38e+007 in 2025. The fund required for waste treatment is increasing up to 15 years. After 15 years, the fund required for treatment is more or less constant at a value of Tk 5.70e+007. This is because of the fact that the capacity utilization of the treatment plant is fulfilled. Fund required for landfill is also increasing until towards

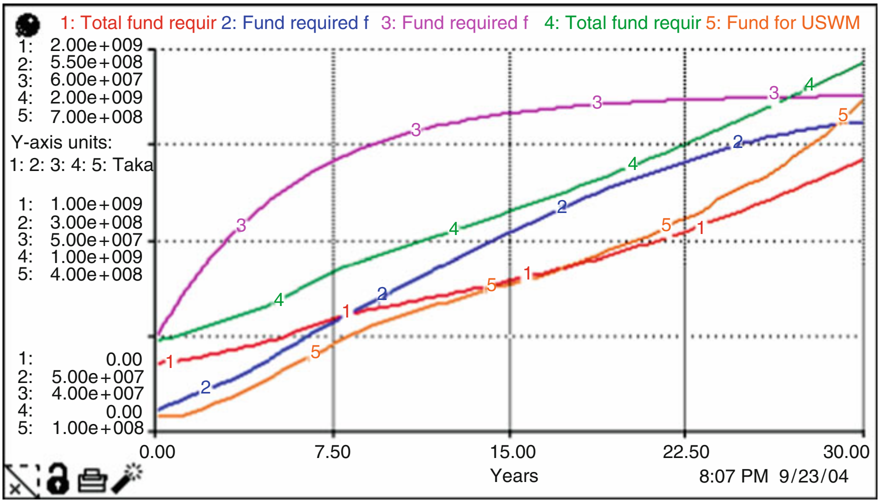

Fig. 7 Simulated total fund required for collection, fund required for disposal, fund required for processing, total fund required and fund for USWM for a time horizon of 30 years (1 US $ = Taka 70.00)

the end of the simulated period. These are due to the fact that treatment capacity and landfill capacity are approaching the proposed desired treatment capacity and proposed desired landfill capacity respectively. Logically, the total fund required increases from Tk 4.660e+008 in 1995 to Tk 19.27e+008 in 2005, and the total fund required for solid waste management increases from Tk 1.18e+008 in 1995 to Tk 6.16e+008 in 2005. Thus, increased funds are needed for both collection and solid waste management.

Figure 8 shows the simulated desired number of trucks, number of trucks used, surplus or deficit total budget, surplus or deficit budget for collection and percent of fund available for collection for a time horizon of 30 years. The desired number of trucks increases from 575 in 1995 to 2,384 in 2025, whereas the number of trucks used increases from 230 in 1995 to 1,148 in 2025. There is always a gap between the desired number of trucks and number of trucks used. Thus, the collection service at Dhaka city is deteriorating rather than improving. Moreover, the transportation of the waste to the dumpsite is not properly managed. Wastes are seen flying from the trucks during transport. Since the population and wastes generated are increasing with time, the desired number of trucks is also increasing. The number of trucks never equals the desired number of trucks, because the policy was to reduce the shortage in number of trucks which is dynamic. This indicates that more funds are required to mitigate the shortage of trucks and to meet the collection cost. The patterns of the change of deficit of the budget and the budget for collection decrease with time but the percent of fund available for collection increases from almost 34% in 1995 to 39% in 2000 and then gradually to 43.5%

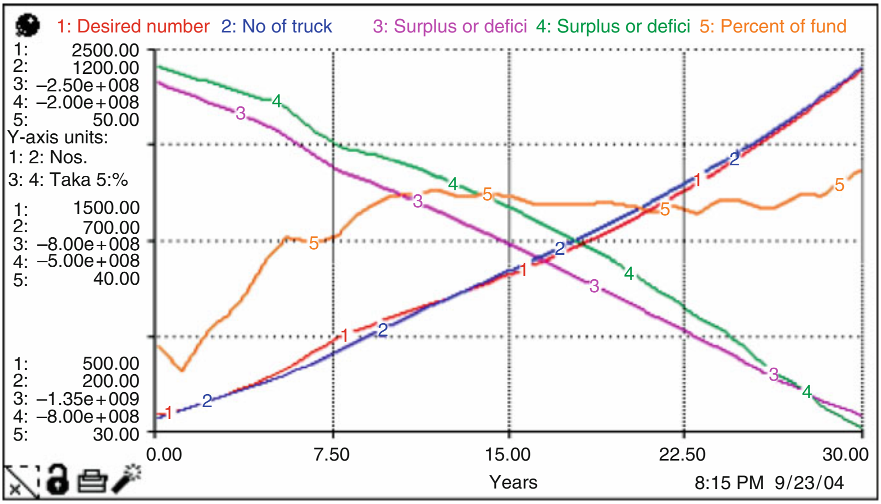

Fig. 8 Simulated desired number of trucks, number of trucks used, surplus or deficit budget, surplus or deficit budget for collection and percent of fund available for collection for a time horizon of 30 years

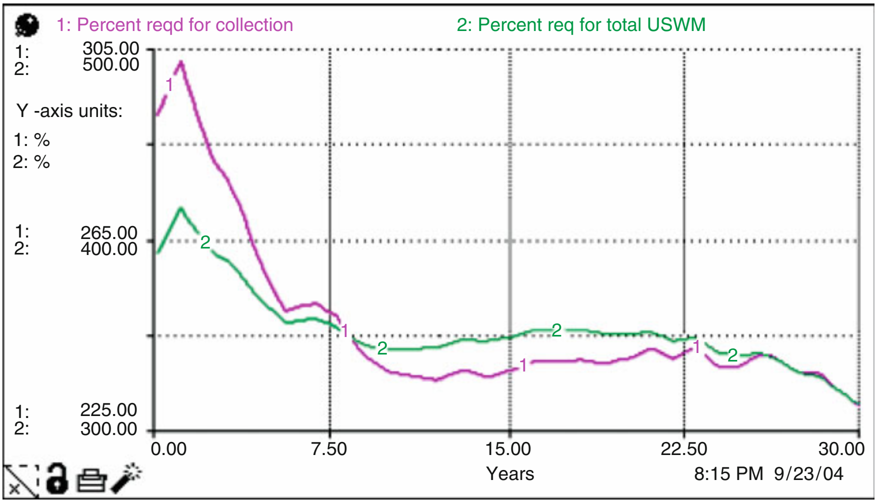

Fig. 9 Simulated percent of fund increased required for only total waste collection and total USWM for a time horizon of 30 years

in 2005 and then almost remains constant. Thus, there is high shortage of fund for collection particularly for trucks for collection.

Figure 9 shows the simulated percent of fund increase required for only total waste collection and total USWM for a time horizon of 30 years. Initially the required budget for collection is 291%. The budget requirement for collection decreases from 291% to 254% sharply within 5 years, then it gradually decreases to a constant value of 238% within 10 years and it continues up to 25 years. After 25 years, it decreases gradually. But for total urban solid waste management, the required budget for total waste management is 415%. Then, the budget requirement decreases gradually from 415% to an almost constant value of 340% within 10 years. The initial jumps of the budgets for total waste collection and total urban solid waste management are due to the introduction of treatment plant and landfills for solid waste disposal.

Figure 10 shows simulated composts, i.e., nitrogen, potassium and phosphorus, and composite index. Composts available from solid waste increase from 0.150e+006 tonnes in 1995 to 0.191e+006 tonnes in 2025. Nitrogen, potassium and phosphorus increase from 3,600 tonnes in 1995 to 4,602 tonnes in 2025, from 2,550 tonnes in 1995 to 3,260 tonnes in 2025 and from 1,800 tonnes in 1995 to 2,301 tonnes in 2025 and follow the production pattern of the composts. There is a significant contribution of organic fertilizers from the compost from composting of solid waste. This compost is a good quality organic fertilizer for garden vegetables and other crops and it is approved by Bangladesh Agricultural Research Council (BARC).

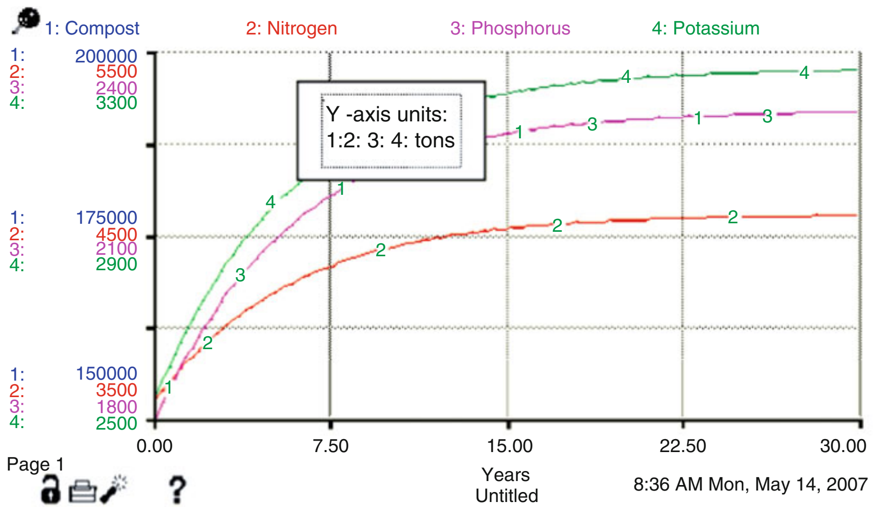

Fig. 10 Simulated compost, nitrogen, phosphorus and potassium for a time horizon of 30 years

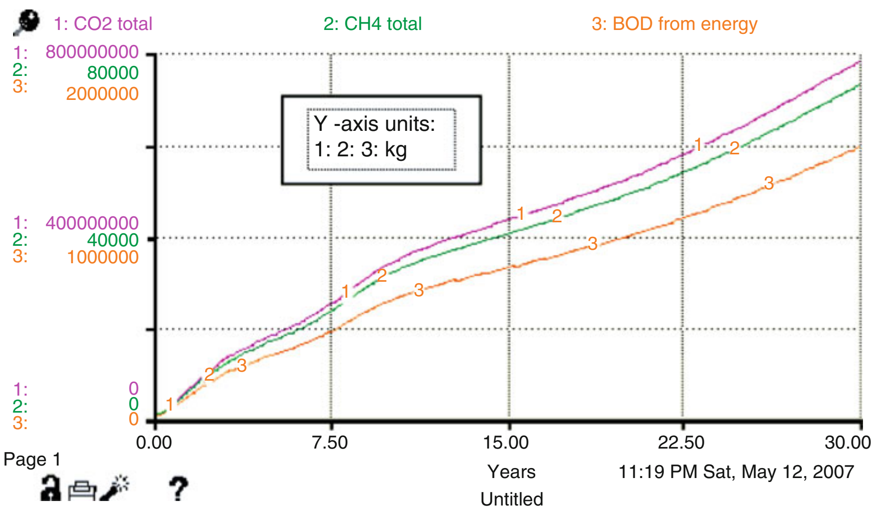

Fig. 11 Simulated CO_2 total, CH_4 total and BOD from energy for a time horizon of 30 years

Figure 11 shows simulated CO_2 total, CH_4 and BOD from energy. Simulated CO_2 total increases from 5.153e+006 kg in 1995 to 78.112e+007 kg in 2025. CH_4 total increases from 412 kg in 1995 to 72,884 kg in 2005 and BOD from energy increases from 8,136 kg in 1995 to 1.48e+006 kg in 2025. The increase of these emissions with time is due to the increase in solid waste generated. However, the intensity of production of these emissions is moderately low due to the proposed introduction of the composting, incineration plant and sanitary landfill.

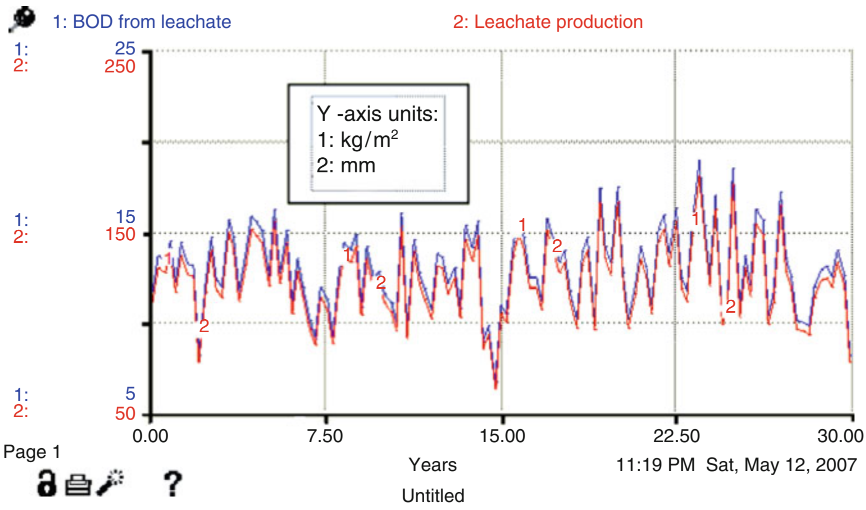

Fig. 12 Simulated leachate production (mm) and BOD (kg/m^2) from leachate for a time horizon of 30 years

Figure 12 shows the simulated leachate production and BOD from leachate for a time horizon of 30 years. The simulated leachate production shows fluctuations which are mainly due to the fluctuation in the annual rainfall. BOD from leachate follows the pattern of leachate production. However, BOD from leachate lies between 100 and 150 mm.

In order to obtain insight into the effect of the alternative policy options, the following two policy options are considered:

Policy 1: Increasing the collection capacity and assessing its impact on uncleared waste, untreated waste, no. of trucks and composite index.

Policy 2: Increasing collection capacity, treatment capacity and landfill capacity and assessing its impact on uncleared waste, untreated waste, number of trucks and composite index.

Policy 1: Figure 13 shows the simulated uncleared waste, untreated waste, number of trucks and composite index for increase in collection capacity for a time horizon of 30 years. From the figure it is observed that if we increase the collection capacity by doubling truck increase rate, the uncleared waste decreases and untreated waste increases, but the composite index remains unchanged as compared with the base scenarios discussed earlier. This means that increasing collection capacity alone does not improve the environmental quality because composite index is the indicator of environmental quality.

Policy 2: Figure 14 shows the simulated uncleared waste, untreated waste, number of trucks used and composite index with increase in collection capacity, treatment capacity and landfill capacity for a time horizon of 30 years. From Fig. 10, it is observed that if we increase collection capacity, treatment capacity and landfill capacity by doubling the truck increase rate, treatment capacity increase

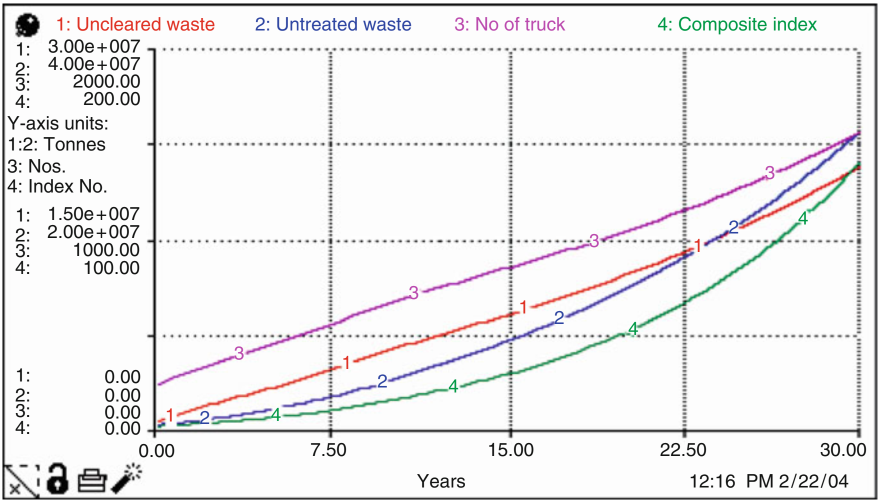

Fig. 13 Simulated uncleared waste, untreated waste, number of trucks and composite index with increase in collection capacity for a time horizon of 30 years

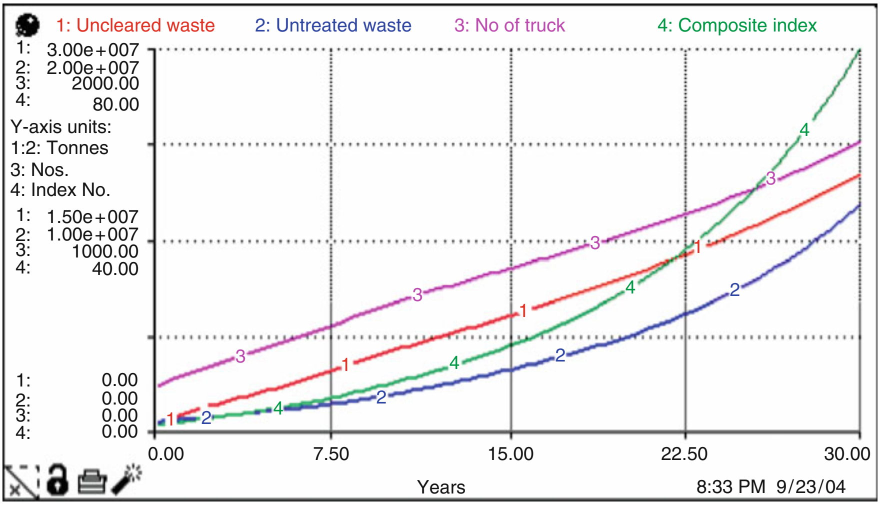

Fig. 14 Simulated uncleared waste, untreated waste, number of trucks and composite index with increased collection capacity, treatment capacity and landfill capacity for a time horizon of 30 years

rate and landfill capacity increase rate, respectively, the uncleared waste decreases in a similar fashion as in Policy 1; but, untreated waste and the composite index also decrease as compared to Policy 1. Increased composite index is a sign of environmental quality deterioration and decreased composite index is a sign of environmental quality improvement. This implies that the increased budget allocation for both clearing and treating the wastes is essential for improving the environmental quality of Dhaka city.

Energy from the waste as well as from the incineration reduces greenhouse gas emission. An analysis of CO_2 equivalent emission per kWh of electricity produced by energy from waste showed that global warming potential of emission from waste is less than coal, fuel and even natural gas.

Finally, in the short run, the proposed policy is for sustainable development. But in the long run, it appears to be a dream unless population control within the carrying capacity of the city is achieved and the treatment plants with energy and material recovery are realized.

4 Conclusions

Population, solid waste generation and electrical energy generation possibility from the solid waste for Dhaka City are increasing with time. The electrical energy recovery from urban solid waste generation of Dhaka City can supply a significant portion of the consumption requirement of electrical energy of the city. Adoption of the policy for electricity from urban solid waste should be dictated by the economy of adoption of the technology of electricity generation from the waste and environmental implications. A potential for organic fertilizers for composting of solid waste exists and this compost is a good quality organic fertilizer for garden vegetables. A policy of introduction of incineration, composting and sanitary landfill is assessed. The intensity of production of the emissions is moderately low due to the proposed introduction of the composting, incineration plant and sanitary landfill. The proposed system is sustainable in short run but becomes unsustainable in the long run. Finally, this model can be used as a tool to assess and design policy options.

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Econtrol Dyeing Process: An Ecological and Economical Approach

Shamshad Ali, Zeeshan Khatri, and Khan Muhammad Brohi

Abstract Ecology and economy are among the most used catch words of our time, and their significance is of the greatest possible importance for the survival of textile industry. Econtrol dyeing process was introduced by Dystar and Monforts in ITMA in 1995 to provide the textile dyer with a dyeing system that would produce a simple, rapid, and economical, continuous dyeing method for cellulosic fibers with minimal chemical usage. The most significant and unique feature of this process is that it does not use a separate fixation step, i.e., steaming, curing, or dwell time, which is essential and associated with the conventional reactive dyeing methods in practice. It can be used to dye all ranges of shades that can be obtained with reactive dyes through various dyeing processes on all cellulosic fibers such as cotton, viscose, tencel, and linen. This paper represents a review of the economical and ecological merits offered by this process in comparison with other continuous dyeing methods. The example of Afroze Textile Mills Limited, Karachi, Pakistan, is provided as a case study which is running this process successfully since last 5 years.

Keywords Continuous dyeing • Conventional reactive dyeing • Economical continuous dyeing • Econtrol dyeing

1 Introduction

To understand the emergence of the Econtrol process and its success, the following points are to be considered by the dye houses.

1. The number of shades to be dyed has risen steadily with higher fastness specifications.
2. Environmental regulations have become more stringent.

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3. Batch sizes have declined dramatically.
4. Delivery times are reduced [1].

Traditionally, four dyeing processes have been employed to dye cotton and viscose with reactive dyes by continuous method (Fig. 1). They are as follows:

1. Cold pad-batch.
2. Pad-dry Thermofix.
3. Pad steam.
4. Pad-dry chemical pad-steam [2].

The characteristic features of the mentioned continuous reactive dyeing processes for cellulosic fibers are given in Table 1.

The selection of dyeing process depends upon many factors, most importantly the cost of the process. Most of the processes use high temperature (100–160°C) and hazardous chemicals (urea, sodium silicate, and salt) in order to achieve maximum yield.

The limitations of these dyeing processes are listed in Table 2.

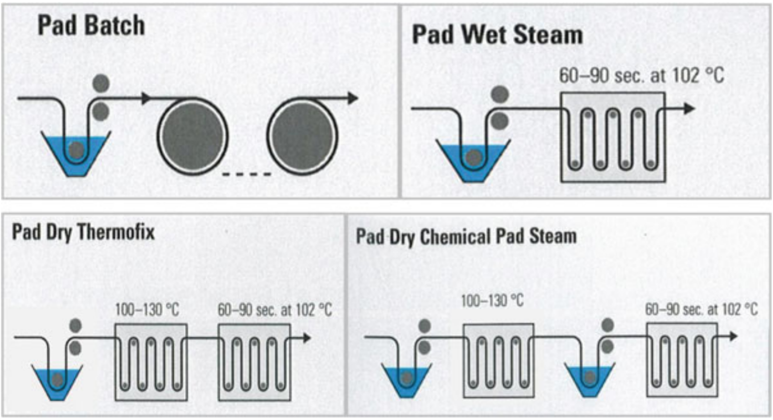

Fig. 1 Most common dyeing methods for cellulosic fibers

Table 1 Characteristic features of continuous reactive dyeing processes [3]

Processes	Drying	Fixation (°C)	Fixation medium
Pad-batch	–	20–35	Padding liquor
Pad-wet steam	–	102	Steam 100%
Pad Thermofix	110–130°C	160	Air
Pad-dry chemical pad-steam	110–130°C	102	Steam 100%

Table 2 Limitations of most common dyeing processes [3]

Dyeing process	Drawbacks
Pad-batch	High fixation time, bath stability
Pad-dry Thermofix	Low light fastness, damage of elastan, yellowing
Pad-wet steam	Limited yield, tailing
Pad-dry chemical pad-steam	Special machine necessary, high energy demand

2 Econtrol Dyeing Process

The Econtrol process was developed jointly by Dystar and Monforts. It is one of the few real inventions in process development and machinery in recent years. It comprises just three steps: Application of the dyes through padding, drying in moist condition, and washing off [4], as shown in Fig. 2.

The dyeing range is a simple arrangement shown in Fig. 3. The range is started with a lead fabric, which brings water into the installation through the wetting arrangement in order to establish the chamber climate. The jet temperature is 120°C. After a short time, the bath containing the dye liquor is raised and the fabric is impregnated with dyestuff. When the dye goods reach the wetting arrangement, this is turned away. A measuring device controls and regulates the steam content of the atmosphere in the hotflue. The goods dwell for 2 min in the hotflue and the reactive dyestuff is fixed to the fiber with a high yield [2, 5]. Owing to the mild fixation climate in the machine compared to that in other common dyeing processes, soft fabric handle is obtained. Econtrol is the registered trade mark of Dystar.

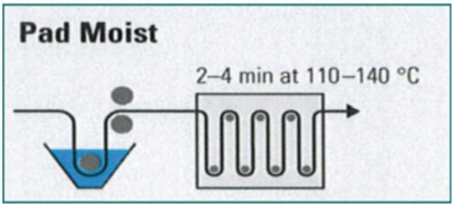

Fig. 2 Econtrol continuous dyeing method for cellulosic fibers

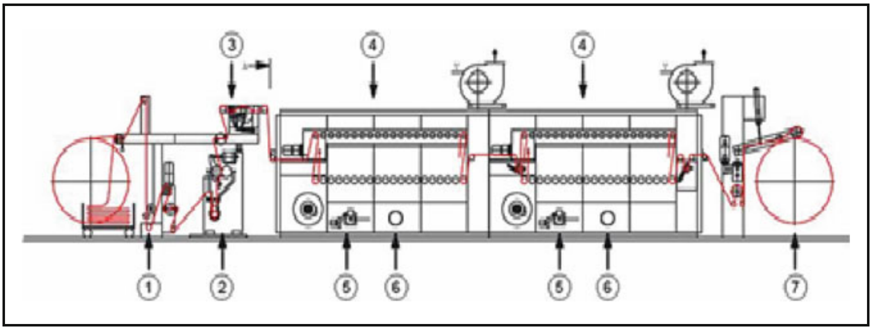

Fig. 3 Econtrol process steps. (1) Feeding section, (2) pad mangle, (3) wetting unit, (4) Thermex hotflue, (5) measuring and control unit (chamber atmosphere), (6) steam injection unit, (7) outlet section

2.1 Role of Humidity

It is worth mentioning here that fixation of reactive dyes is impossible in normal drying conditions. During drying, the temperature of the moist good is far lower than the surrounding temperature. The fabric temperature depends on the humidity of the air used to dry it [1].

If humidity is 25% and the air temperature is 120°C, the temperature on the surface of the goods is around 68°C. If humidity is increased to 30%, the temperature on the goods is around 71°C (see Fig. 4). The Econtrol process uses this physical fact to fix the reactive dye during drying. Three key variables, time, temperature, and humidity, are used to ensure accurate control of the dyeing process in the Thermex Hotflue. The goods should spend about 2–3 min in the chambers [1, 2]. The presence of humidity in the fixation chamber assists in the diffusion of dyes inside the fabrics with compact weave structure.

2.2 The Process Edge

The process is developed to achieve optimum results in the shortest possible time. The fewer the variables affecting the dyeing process, the higher the probability of achieving this goal. Tolksdorf reported 25 variables in pad-dry chemical pad-steam process that can adversely affect the dyeing process. By contrast, Econtrol process has 15 dyeing process variables (40% reduced). This is owing to the fact that the

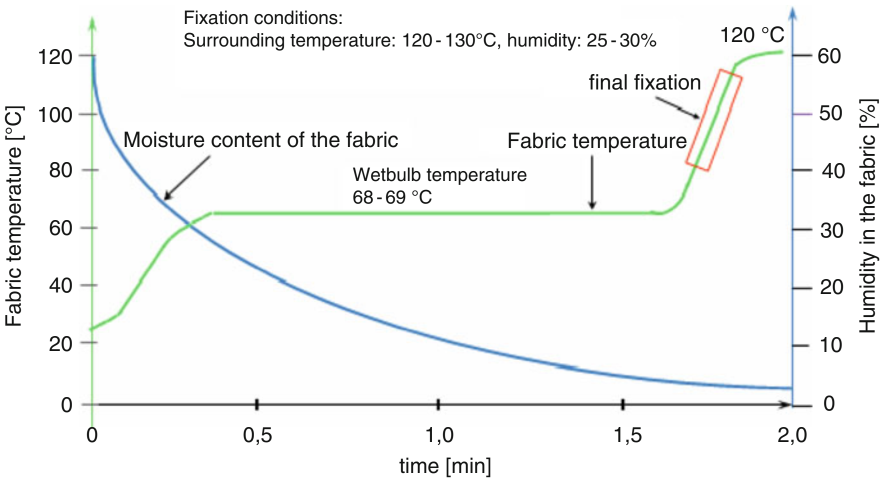

Fig. 4 Econtrol – material temperature and humidity of the goods [6]

Econtrol process does not use a separate fixation step, which is, curing, steaming, or batching [1].

Likewise, improved light fastness rating is obtained because there is no urea present in the recipe, and the absence of salt is helpful in the washing-off process [2]. Similarly, 35% less time will be needed for Econtrol process in lab matching when compared against the pad-dry chemical pad-steam process [1].

Figure 5 shows the amount of various chemicals used by different dyeing processes in the dyeing of ten million meters of fabric.

It is interesting to note here that the most environment-friendly process is often also the most economical. Econtrol is a relevant example to quote. By eliminating the need of curing/steaming stage, huge amount of energy can be saved [1].

Similarly, there is no need to go for harsh chemicals such as salt, urea, and sodium silicate. It would eventually extend the life of the dyeing machine. Moreover, since they do not have to wash out, they cannot contaminate effluent or exhaust air. Econtrol process is, therefore, both economical and eco-friendly. This process can be used for fabrics weighing 70–500 g/m^2.

Depending upon the working conditions in production plants, Table 3 presents the summary of average depth of shade obtained from dyeing processes.

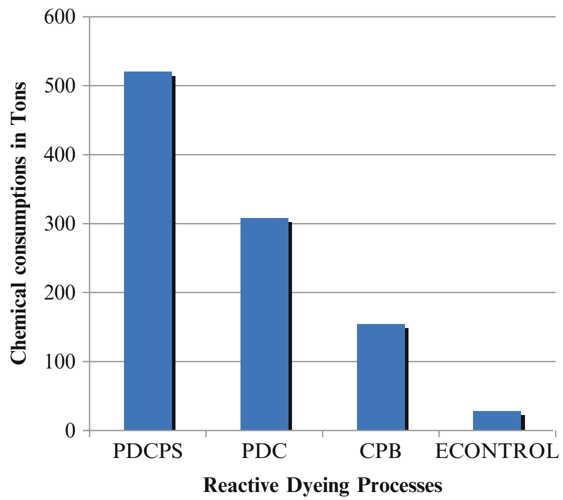

Fig. 5 Chemical consumptions in continuous dyeing

Table 3 Depth of shade (yield) of different dyeing processes [3]

Dyeing process	Yield (%)
Pad moist[a]	100 (as a standard)
Pad-batch	95
Pad-dry Thermofix	95
Pad-wet steam	85
Pad-dry chemical pad-steam	105

[a]The Econtrol process offered by Clariant

3 Industrial Production: A Case Study

In Pakistan, Afroze Textile Mills Limited situated in Karachi is the leading dye house that is running the Econtrol process successfully since the last 5 years. The data taken from their production unit are listed in Tables 4 and 5.

Medium or highly substantive reactive dyes are selected for the dyeing process. The dyeing recipe employed there with success is in the range of 40–100 g/L. The Drimarene CL (Clariant) and Remazol RGB (Dystar) dyestuffs are used there.

There are three chambers in the Thermex Hotflue (Monforts) at Afroze Textile Mills Limited; each chamber has a cloth content of 32 m length.

The bulk production is achieving 25% greater depth of shade from Econtrol process than pad-dry cure process by using the same amount of dyestuff. In comparison with cold pad-batch process, they are getting similar fastness ratings except light fastness, 1–2 rating less. The Econtrol process has replaced the pad-dry cure process and the pad-dry chemical pad-steam process done for 100% cotton fabric with reactive dyes in Afroze Textile Mills Ltd., Karachi, Pakistan.

4 Ecological Benefits

The Econtrol process simultaneously offers the following ecological benefit:

The combined reduction in the quantities of chemicals (urea, salt, and sodium silicate), and dyes from the recipe, also the water used for washing-off process, greatly cuts down the effluent load discharged from the dye house to the environment [2].

Table 4 Padding recipe used for Econtrol process in Afroze Textile Mills Limited

Reactive dyes	Quantity (g/L)
Soda ash	20
Caustic soda 48°Be	10
Mild oxidizing agent	6
Antimigrating agent	10

Table 5 Process conditions used for Econtrol process in Afroze Textile Mills Limited

Parameters	Range
Padding temperature	25°C
Drying/fixation temperature	140°C
Drying/fixation time	2 min
Humidity	25–30% volume
Steam regulation	50%
Exhaust air damper	30%
Speed of machine	50 m/min

5 Economical Benefits

The Econtrol process offers the following significant economic advantages:

Lower chemical cost, this is owing to the elimination of the usage of various chemicals and auxiliaries that include urea, salt, and sodium silicate, and are considered essential for the reactive dyeing process.

Lower dyes cost, this is due to the higher fixation yield, that is, less dye would be required to obtain the required depth of shade on the fabric.

Lower water cost, as a result of greater fiber–polymer reaction, the hydrolysis of dyes will be lower and hence, the washing-off process would definitely utilize less volume of water.

Lower energy cost, in consequence of the exclusion of the thermofixation step during the continuous dyeing process on the Thermex Hotflue, reduced thermal energy would be needed for the fiber–polymer reaction to take place.

The process also has a logistical benefit: As the fabric is in dry state at the end of the Econtrol process, they do not have to be washed off immediately and can be stored. Now it can be said that the new dyeing technology is more economical despite its somewhat higher investment cost (hotflue plus accessories) [2].

6 Conclusions

The key issue that will concern the continuous dyer in the future would be the search for the dyeing process which must be simple to use for ranges of shade, and can provide the dyer the economy, even when dyeing small batches, and rapid color change, as the duration of the fashion trend is on fall worldwide, plus it should be reliable, due to excellent reproducibility, and without any harm to the environment. The continuous dyeing on Thermosol machine would continue to deliver all these features in the shape of economical and ecological dyeing process, that is, Econtrol.

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Cold Pad Batch Dyeing: Eco-friendly Dye Application on Cotton

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Abstract Over the last few decades, the environmental impact of dyes and processes has become an increasingly large part of the dyer's task. In recent years, the "default" choice is reactive dyes because of their generally good fastness to wet treatments and good range/brightness of shades. In seeking to achieve eco-friendly responsibility in dye application, there is no single solution since there is no single definition of what is green or environmentally responsible. Environmental responsibility is best achieved in cold pad batch application since little or no electrolyte is required, dye fixation is at ambient temperature, and fixation is high. This chapter represents general methodology of cold pad batch dyeing (CPB) of cotton fabric with reactive dyes and gives approach to eco-friendliness of this process.

Keywords Bath stability • Cotton dyeing • CPB • Eco-friendly dyeing • Energy efficient • Environmental responsible dyeing • Reactive dyeing

1 Introduction

Cold pad batch dyeing dates back, soon after the introduction of reactive dyes in 1956. Over the decades, several innovative changes have taken place in the process from the point of view of the dyestuff selection and chemicals used for the process. Pad batch dyeing is a cold method used for dyeing cellulosics (mainly low-percent cotton and polyester/cotton blends) that can achieve large reductions in pollution, energy requirements, and costs.

The basic technique is to saturate the prepared fabric with premixed dye liquor (Table 1) and pass it through a padder, which forces the dyestuff inside the fabric

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Table 1 Dyeing recipe for cold pad batch

Dyes and auxiliaries	Quantity
Reactive dye	*x* g/l
Antimigrating agent	1 g/l
Wetting agent	2 g/l
Caustic soda 36°Bé	15–33 ml/l
Sodium silicate 38°Bé	70 ml/l
Soda ash	10–20 g/l

for greater penetration while removing the excess dye solution. The fabric is then stored, or batched, on rolls or in boxes for 4–12 h. Typically, the batches are covered with a plastic film to prevent carbon dioxide absorption and water evaporation. While in batching, the dyestuff reacts with and penetrates the fabric, resulting in even, consistent color. After the reaction is completed, the fabric is washed [1]. The dyeing ecology is also discussed [2].

2 Materials and Methods

2.1 Fabric Requirement

Pad batch dyeing can be used on wovens or knits in many constructions. Certain tubular knit styles may develop edge marks at the fold, but new methods in development will reduce this problem in heavyweight styles [3].

2.2 Dyeing Equipment

The equipment needed for pad batch dyeing includes a padding unit; a batcher or material handling system; a dye/alkali mixing device (dosing pump); A-frames, storage racks, and storage boxes; and a washing off device (beam, beck, continuous). Figure 1 demonstrates the line diagram of CPB. The simplicity and flexibility of the system allow for use of available equipment-becks, beams, and continuous equipment for washing [4]. Pad batch dyeing requires a low capital investment and offers overall cost savings in dyes, chemicals, labor, water, and other areas.

2.3 Dyestuff Selection

Dye quality is more consistent. Compared with rope dyeing, pad batch dyeing can attain more even color absorbency, greater colorfastness, and much lower

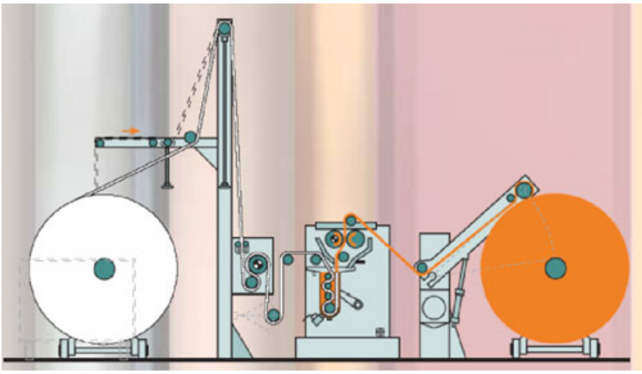

Fig. 1 CPB dyeing equipment

defect levels (when the fabric is correctly prepared). High-reactivity dyes used in pad batch dyeing have rapid fixation and stability, resulting in shade reliability and repeatability. With high-reactivity dyes, cleanup is easy and frequent shade changes present little problem. Pad batch dyeing requires highly reactive "cold dyeing" fiber reactive dyes. The list of dyes that have gained prominence and published [5].

Rinsing processes have been most studied for reactive dyes [6, 7]. The rinsing process is most efficient when the dye has a high fixation and low substantivity. These two seemingly antagonistic requirements (and hence environmental responsibility) are best achieved in cold pad batch application [8]. In other application methods, "low salt" dyes have been developed [9, 10], as have dyes with high fixation, often via the use of two or more reactive groups of the same (homo-) or different (heterobifunctional) types. Convincing reasons can be cited in favor of any of the major reactive systems in pad batch application [11].

Highly reactive dyes can be fixed in shorter times at lower pH and are often easier to wash off; low-reactivity ranges offer higher stability in the padding liquor and mixed bifunctional systems give highly efficient fixation and excellent fastness performance. Detailed recommendations have been provided for systems of all kinds of reactive dyes [12].

3 General Considerations

Pad batch dyeing offers several advantages than conventional dyeing processes. No salt or chemical specialty agents are needed. Eliminating these chemicals reduces waste as well as chemical and wastewater treatment costs. More efficient use of dye leaves less color in the wastewater and reduces water and energy consumption. The dye fixation of 92–97% is achieved in cold pad batch dyeing in comparison to 42–80% exhaust dyeing at 10:1 liquor to good ratio [2].

3.1 Bath Stability

Separately prepared dye and alkali solutions are cooled to pad liquor temperature and sent to the padder via a mixing device. A mixture ratio of 4 parts of dye solution and auxiliaries to 1 part of alkali solution has provided good results in practice. Other mixture ratios are also possible.

By increasing the amount of sodium silicate to 100 ml/l, the bath stability with a high amount of dye can be increased, but this is not recommended due to the impairment of the washing off properties [13].

3.2 Alkali Buffer System

Figure 2 shows the required amount of NaOH 36°Bé with 50 ml/l of sodium silicate 38°Bé for each concentration of Drimaren CL/HF dye [14].

Figure 3 shows the required amount of NaOH 36°Bé with 10 g/l of soda ash for each concentration of Drimaren CL/HF dye [14].

The fixation with soda ash/caustic is rapid and easy to wash off. In addition, external influences such as CO_2 and other acid components in the air are excluded. Ciba (now Hundsman) has demonstrated three different methods, silicate/NaOH, soda ash/NaOH, and soda ash/NaOH (with bicarbonate as an impurity). Figure 4 shows continuous decrease in pH as the batching time increases in case of bicarbonate impurity.

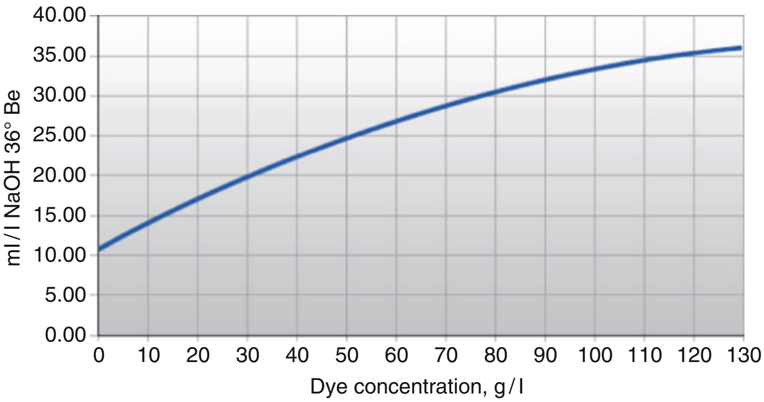

Fig. 2 50 ml/l Sodium silicate 38°Bé + ml/l NaOH 36°Bé (depending on dye concentration)

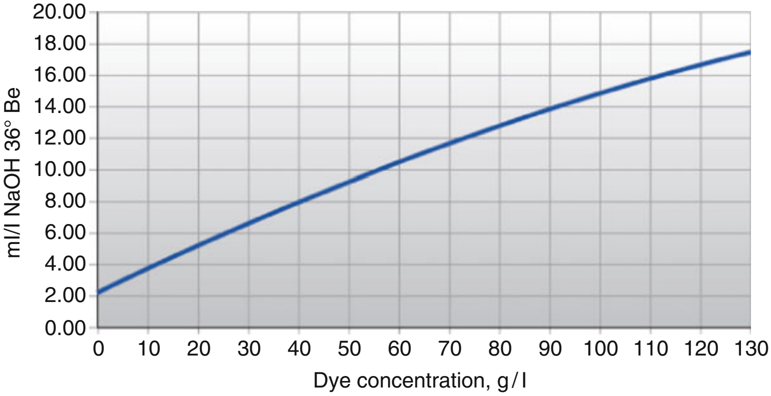

Fig. 3 10 g/l Soda ash + ml/l NaOH 36°Bé (depending on dye concentration)

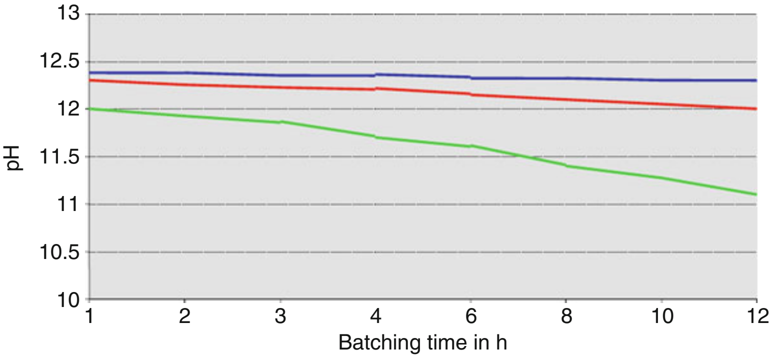

Fig. 4 Silicate/NaOH (1), soda ash/NaOH (2), and soda ash/NaOH (with bicarbonate as an impurity) (3)

3.3 Batching Time

Once the fabric is padded through the dye solution, the fabric is then allowed to rotate for 8–24 h depending on the dye reactivity. Higher the dye reactivity, shorter will be the dwell time. The fabric is wrapped in plastic sheeting to prevent drying out and exposure to air. The drying out problem, which causes migration of dyes resulting in edge marks, must be avoided.

3.3.1 Carbonation

Reaction between carbon dioxide (from air) and caustic soda is shown below:

$$2NaOH + CO_2 + H_2O \rightarrow Na_2CO_3 + H_2O$$

Table 2 Ideal conditions for pad batch dyeing

Complete change of dye liquor in the trough every 2–3 min
Padder pressure should be around 60–80%
Smallest possible trough volume
Fabric absorbency at moderate to high
Ambient trough temperature
Kuester padder and Bicoflex, to achieve profiles of linear pressure across the fabric width

The quality of commercial soda ash is also very important, as it can contain high amounts of sodium bicarbonate. The presence of sodium bicarbonate results in a second reaction:

$$NaHCO_3 + NaOH \rightarrow Na_2CO_3 + H_2O$$

3.3.2 Changing pH During Batching

As mentioned in the above equation, the formation of soda ash from soda bicarbonate leads to a decrease in pH and too slow dye fixation, resulting in edge marks. The problem is particularly acute when the alkali does not constitute a buffered system.

Radiofrequency energy has also been evaluated to increase the rate of fixation in pad batch dyeing trials with sulphatoethylsulphone, bis(aminonicotinotriazine) and aminochlorotriazine–vinylsulphone dyes [15]. The dwell time required was reduced from several hours to about 15 min by heating the impregnated fabric in the radiofrequency field.

3.4 Tailing Problem

One-dip one-nip is preferred to multi-dip multi-nip. Dye affinity also influences; use of less substantive dyes can overcome tailing problem. Ideal conditions are given in Table 2 to overcome this problem. Detailed recommendations are provided for dyeing fabric (RFD) [16].

4 Conclusions

CPB dyeing can cope with two issues: prolonged batching and bath stability. We conclude simply that the batching time can be minimized by selection of medium to high-reactivity dyes, while the bath stability can be controlled through good selection of alkali buffer system. CBP having modest investment layout, fabric simply required to pad in the dye liquor and batched for certain hours and is suitable for small and fairly large batches. Very simple working conditions, limited man-power requirements, low-energy consumption since heat is not required for dye fixation, and low water consumption than exhaust dyeing are the advantages of CBP. Good penetration and level dyeing with good reproducibility, achieving high level of dye fixations that lowers the effluent load, makes CPB eco-friendly in many aspects in present times.

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Environmental Policies for New Road Network of Pakistan to Control Air Emissions

Khan Muhammad Brohi, Mohammad Aslam Uqaili, and Rasool Bux Mahar

Abstract Most of the developing countries face a lack of infrastructure facilities and the road transport network is one of them. In this chapter, first Strategic Environmental Assessment (SEA) is carried out for proper combination of policies for economic and environmental impacts of air emissions. Second, for the estimation of economic and environmental impacts of this project, a multiregional Computable General Equilibrium (CGE) model is proposed. Third, impacts of the new road network that connects south and northwest of Pakistan are analyzed using CGE model. It is found that construction of this project is going to change the industrial structure, especially in production of manufacturing sector, and it will also change the Equivalent Variation (EV). It is also observed that most of the economic and environmental impacts of air emissions appeared in northwest part of Pakistan. Finally, the combination of policies for desired economic and environmental impacts of air emissions in project is proposed

Keywords Air emission policy • Decision making • Economic and environmental impact of air emissions • In road transport sector • Multiregional CGE model • Pakistan

1 Introduction

Most of the developing countries face a lack of infrastructure facilities and road transport network is one of them. During the last few decades, many developing countries in Asia have experienced a high rate of economic growth, and Pakistan is also one of them. However, Pakistan will confront a lot of problems. One of the

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crucial problems is road transport, and it is necessary to improve the road transport network in accordance with the rapid economic growth.

Road communication plays a vital role in the transportation system of Pakistan. At present the railways and road transport traffic load ratio is 12:88. It clearly indicates the need for massive investment in road infrastructure to take up this extra load of road transport. The geographical location of major cities in Pakistan is shown in Fig. 1. Karachi, which is the port city, located in south, is the biggest city with a population of 15.5 million (which comprises approximately 10% of the Pakistan's population). It is the only commercial seaport, which handles all imports and exports of the country but rest of the major cities are widely dispersed. Hence, the establishment of a long-distance road transport network system is important, especially to connect inland cities, such as Lahore, Rawalpindi, Islamabad, and Peshawar with the port. Hence, a new road network is proposed from Karachi to Peshawar (south to northwest of Pakistan) with a total length of 1,786 km, which comprises four lanes. The proposed road network is shown in Fig. 2.

In the first stage of this research, the Strategic Environmental Assessment (SEA) has been carried out for proper combination of policies for economic and environmental impacts. SEA has been investigated for road network project of Pakistan and presented in this study. Due to the correlation of economic and environmental strategies, their impacts on this project are analyzed. For this purpose, a multiregional Computable General Equilibrium (CGE) model is used as an analytical tool. In this analysis, CGE model is proposed for SEA. The proposed new road network, which will connect south and northwest of Pakistan, is analyzed and discussed using CGE model with its economic environmental impact. Finally, the

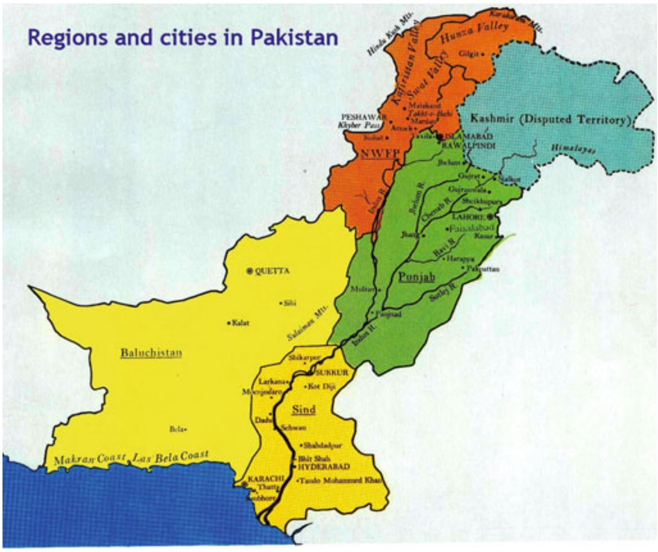

Fig. 1 Regions and cities in Pakistan

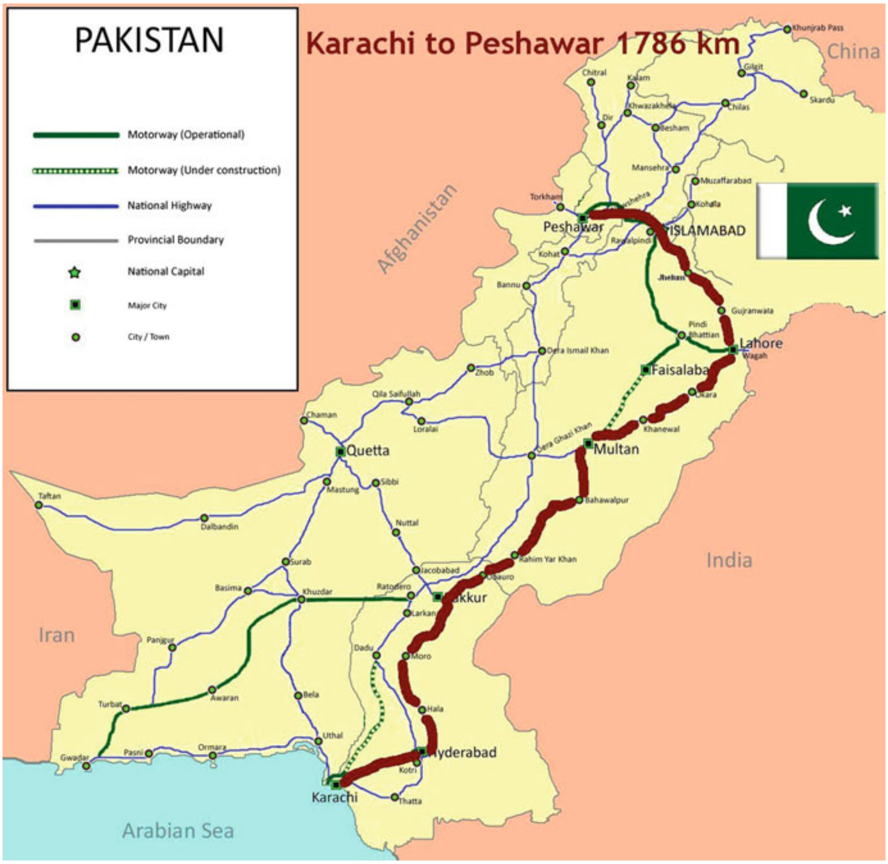

Fig. 2 Karachi to Peshawar 1,786 km

combination of policy measures for maintaining and controlling economic and environmental impacts is discussed in detail.

2 SEA in Road Transport Network Project of Pakistan

The environmental assessment is carried out by using SEA, which is in fact a broader vision of well-known Environmental Impact Assessment (EIA) strategy. SEA is generally used for assessing impacts related to sustainability issues (e.g., use of natural resources, greenhouse effects, and biodiversity), global and country level effects, whereas EIA focuses on more regional impacts [1–5].

In transport sector, environmental assessment is used to evaluate the economic and environmental implications of a number of projects. These assessment techniques enable the decision makers to choose the best alternatives. Figure 3 shows the sequence of actions and assessments within a tiered planning system. This figure

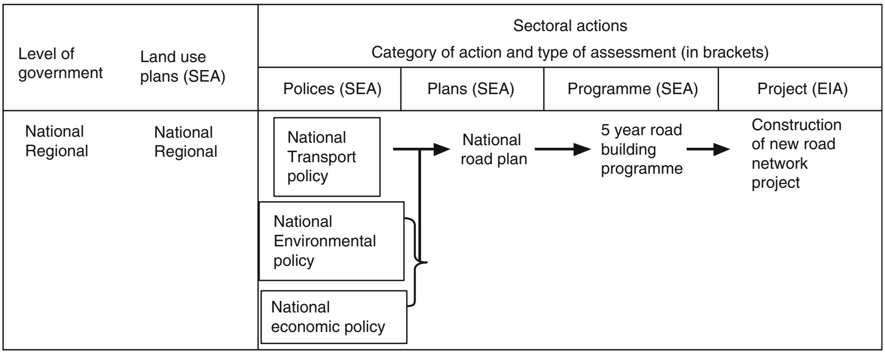

Fig. 3 Sequence of actions within a tiered planning and assessment system

also shows the organization of government and land use plan for Pakistan on national and regional level. The flow of policy making for environmental and economic on national level is also shown in Fig. 3. This road network project is planned to complete in 5 years from Karachi to Peshawar.

3 Present Situation of Policies in Pakistan

Like most developing countries, Pakistan is facing serious environmental problems. Rapid expansion in industrial production and urbanization have led to increased levels of wastewater pollution, solid waste, and vehicle emissions that have resulted in serious health and social problems in many areas of the country. In response to environmental concerns, the Government of Pakistan prepared its National Conservation Strategy (NCS) in March 1992. It was a 10-year investment plan for addressing environmental issues. Following early success in implementing the NCS, however, progress now appears to be faltering because of several major factors. First, not enough attention has been given to government policies that provide incentives for individuals to pollute the environment and exploit natural resources in unsustainable manner. The NCS focused on investment projects but did not suggest specific policies for creating economic incentives. Second, institutions set up for managing the environment, such as the Environmental Protection Agencies, appear to be weak and incapable of implementing an appropriate environmental strategy. This institutional failure is largely the result of the lack of technical expertise within the institutions, which was recognized by the NCS. Third, the goals set by the NSC may have been over ambitious given technical, economic, and institutional constraints that Pakistan faces. Finally, many attributed slow progress to a lack of political commitment to sustainable environmental improvement.

4 SEA is Proposed for New Road Network Project in Pakistan

Examine current state of implementation of policy decisions on economic and environmental impact in Pakistan, suggest SEA in this project. SEA has three key products: decision-making tool, analytical methodologies, and strategy recommendation. The most important is how to implement these decision-making policies and also the authority for the implementation of the policies. Our contribution is to make proper decision body related with the present situation of Pakistan. Since different countries have different problems, the implementation of policies will also be different. The image of contribution for decision-making body in SEA for policy making in road network project of Pakistan is shown in Fig. 4 [3, 5].

Figure 4 shows the main authorities, which are responsible for decision making of policies and implementation. These are:

1. Government of Pakistan for financing and implementation
2. Technical persons from environment and highway department, from national and regional level in order to get details regarding economic and environmental impacts
3. World Bank and Asian Development Bank are the second big donor or financing authorities and they must check the progress of project step by step and then release the installments for project
4. Public representation or political influence persons should be included for motivating and convincing the impacts of this project positively
5. Technical advisor from academic institution for training programs is also needed

The specific targets of policies for this project are mentioned in the following paragraphs.

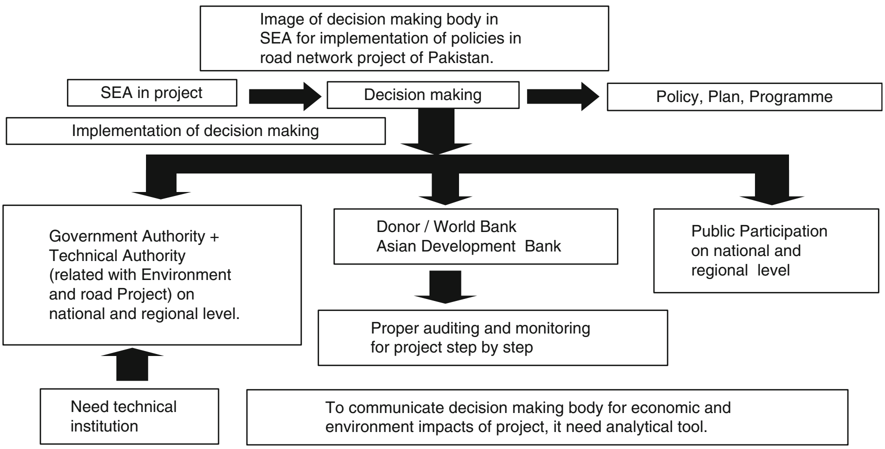

Fig. 4 Image of policy making road network of Pakistan

5 Model for Analysis

Construction of new road network is a national project for Pakistan. Although this project is having many impacts in different directions, from a personal level to national level, in this research, major impacts like economic and environmental aspects are discussed. To investigate the economic impacts, factors such as industrial structure of production, price of labor, rental price of land, income level are considered. The environmental impacts are studied by considering pollutants such as CO_2, SPM, SO_2, NO_2. SEA is basically a framework and needs different analytical tools within this framework. Cost-benefit analysis and impact of these analytical tools used box SEA framework, are based on the application of that particular sector. The concept of decision-making body in SEA is discussed in the previous part of this chapter. There are a lot of methods to analyze these two impacts, but the main problem is the availability of analytical data. In developing countries like Pakistan, problems like lack of sufficient data for the analysis are also there. To consider data problems, our proposal is to introduce CGE model as an analytical tool in SEA for proper decision making on combination of policy for economic and environmental impacts. Due to the efficiency of CGE model to rebuild in the case of possible problems in the economic model, it is adopted here in SEA.

6 Multiregional CGE Model for Pakistan

CGE has been used to address a wide range of policy issues such as development strategy. CGE analysis has been the most popular approach in applied economics till date. It is also important to mention here that CGE model is useful for short-term policy making, i.e., for 2–3 years. Mostly developing countries have short-term policy plan, due to the political influence problems. Originally, a lot of CGE models have been used for forecasting economic growth of developing countries, where there are not sufficient data for development of econometric models. But they were all single regional models, which cannot be used for transport network planning or regional development planning. To support these planning, we proposed a multiregional CGE model for road network project of Pakistan. In Japan, some multiregional CGE models have been developed, which have been used for impact analysis of transport network improvements, and this is used as reference for developing a multi-CGE model for Pakistan. It is supposed that after the improvement in road network, firms and households will change their purchase pattern. Such changes in demand will cause other changes, for example, change of production pattern and change of demand factor. In this study, a multiregional CGE model for Pakistan is proposed, which has theoretical basis on a Japanese multiregional CGE model [6]. And using this CGE model, it is intended to analyze regional impacts of road network improvement in Pakistan. Details of explanation for CGE model analysis, dataset for model, and measurement of economic benefits can be found in references [7, 8].

7 Economic Impacts of New Road Network Project

Figures 5 and 6 show the simulation results of construction of new road network from Karachi to Lahore (case 1) and from Karachi to Peshawar (case 2), respectively.

8 Impact on Transport Cost (T/C)

Figure 7 shows the economic impacts of road network on transport cost for two cases, where figures (a) and (b) describe the percentage of cost reduction occurred for case 1 and 2, respectively. For case 1, the maximum percentage of transport cost (T/C) decreased to 38.5% from Sindh to Punjab and then to 29.0% from Sindh to

Fig. 5 Road network Karachi to Lahore case 1

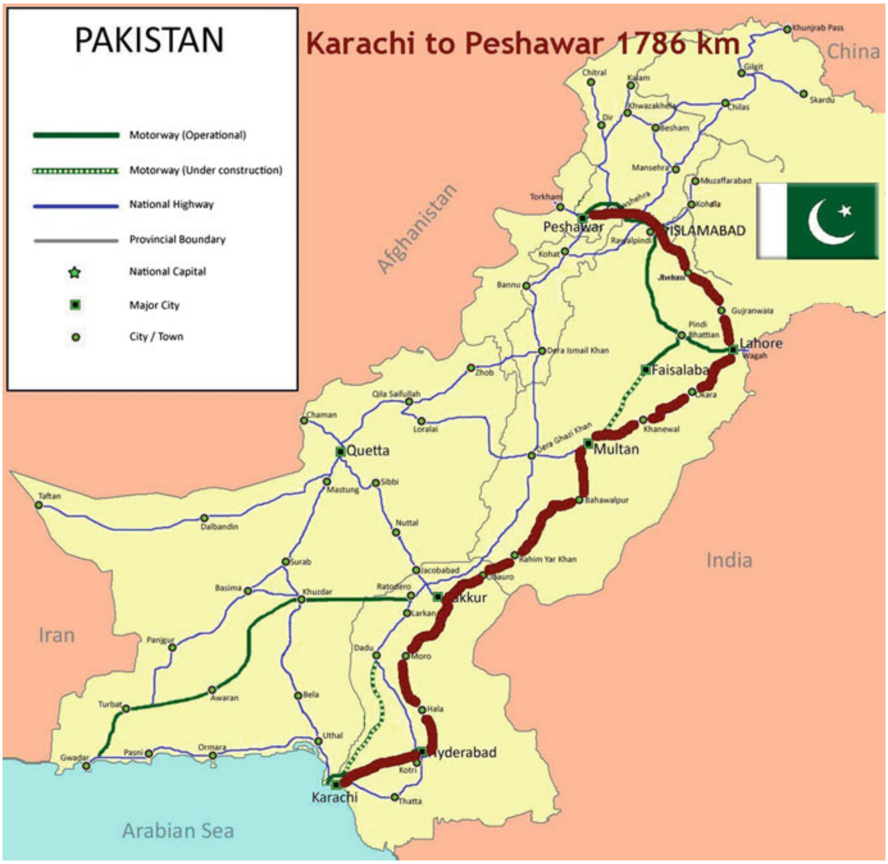

Fig. 6 Road network Karachi to Peshawar case 2

Sindh, whereas for the case 2, transport cost decreased to 41.4% from Sindh to Punjab and then to 29.2% from Sindh to NWFP. These values show that projects have higher percentage of cost reduction in Punjab and NWFP regions. When transport cost decreased due to construction of new road network project, the demand of goods on regional and international level will increase. It is directly going to effect the production, which eventually effects the rental price of land and labor cost, producer's, and consumer's cost.

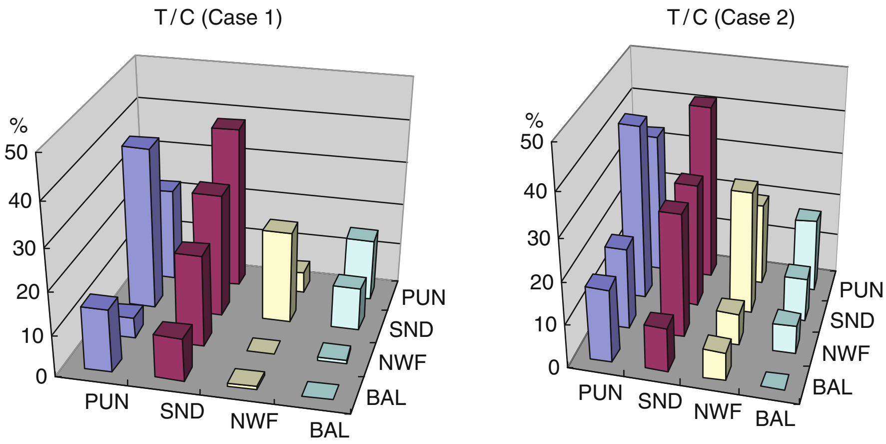

Fig. 7 Impact of transport cost

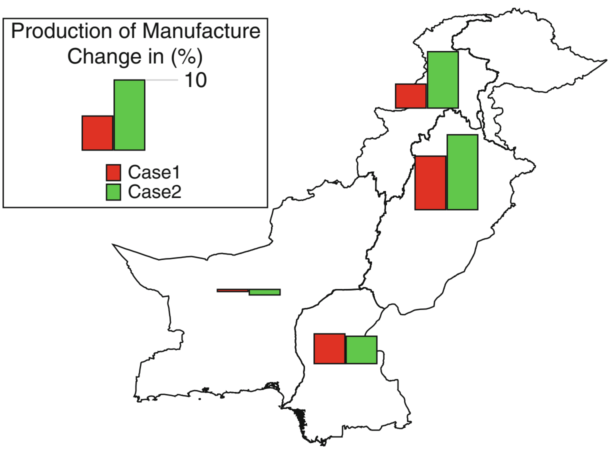

Fig. 8 Production of manufacturing sector

9 Impact on Production Sectors

Figure 8 shows the impact on production of manufacturing sector after the improvement in road network; for case 1, an increase of 7.7% ($35,780 million) in Punjab and 4.3% ($16,730 million) in NWFP is observed, whereas for case 2 these values are increased by 10.7% ($49,710 million) and 8.1% ($37,630 million) for Punjab and NWFP, respectively. Figure 9 shows the impact on production of construction sector after the improvement in road network. For case 1, it is increased by 4.8%

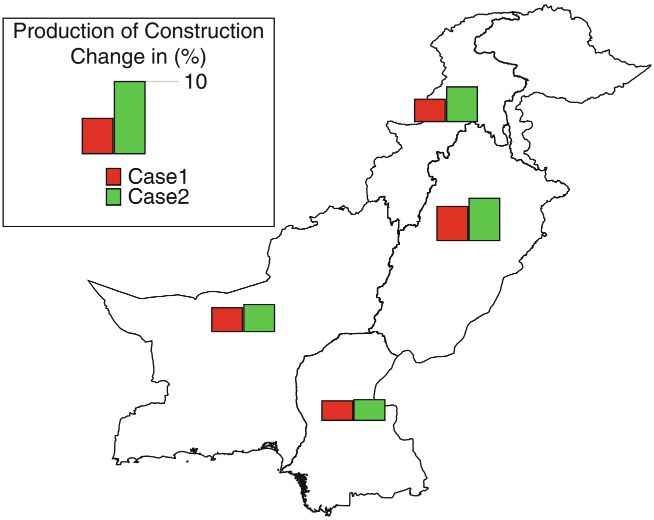

Fig. 9 Production of construction sector

($3,190 million) in Punjab and 3.3% ($2,190 million) in NWFP, and for case 2 these values are 5.9% ($3,920 million) and 4.9% ($3,260 million) for Punjab and NWFP, respectively. These values show that maximum impact occurred in Punjab and NWFP regions. One can see from figures that the maximum economic benefits are found in case 2 as compares with case 1.

10 Environmental Impacts of New Road Network

10.1 Estimation of Air Emission Produced from Road Network Project

From economic analysis, it is clear that after construction of proposed new road network, the transport cost will reduce considerably which results in an increase in production. This will in turn increases the road transport, which will result in the increase in different types of emissions. Figure 10a shows the amount of CO_2 emission, (b) Small Particulate Matter (SPM) emission, (c) SO_2 emission, and (d) NO_2 emission produced by road transport sector. There is no big difference between case 1 and 2 emissions. Hence, it shows that case 2 is more appropriate than case 1; after getting these emission results, government can make some policies for controlling emissions. An environmental policy aimed at significantly reducing pollution emissions may have great effects on prices, quantities, and the structure of the economy.

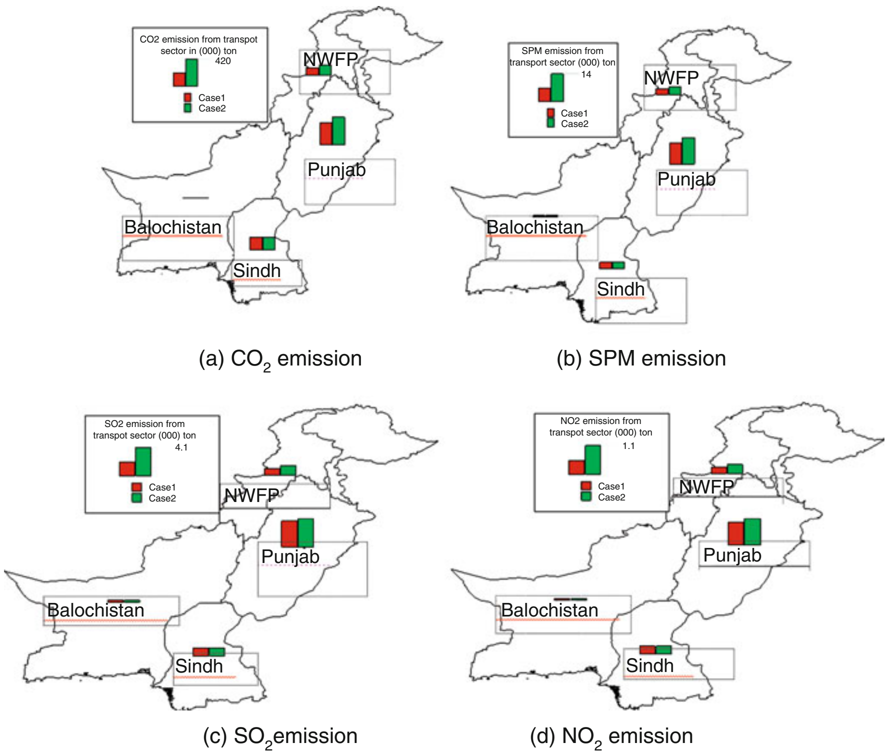

Fig. 10 Emission from road transport sector

11 Specified Policies and Their Effects on Environment and Economic Growth

SEA has three key products: decision-making tool, analytical methodologies, and strategy recommendation. In decision-making tool, main concern is combination of policies, which are explained in the previous part of this chapter. There are a number of policies, but all cannot be implemented. The policies, which are chosen in this research, are presented in Fig. 11. This figure reflects that some of the policies are affecting environment directly and economic growth of Pakistan indirectly.

Most of the policies are related to road transport sector. The following are the specified policies: (1) Introducing compressible natural gas (CNG) in all types of vehicles. Using CNG will reduce emission from 20 to 22% for petrol and 20 to 25% for diesel fuel vehicles. (2) Imposing ban on vehicles that are more than 25 years old which makes more than 30–35% of the vehicles in Pakistan. (3) Proper checking of fuel efficiency because quality of fuel is the big problem in developing countries. (4) Introducing fuel tax. (5) Introducing green tax. (6) Introducing proper highway

Policy Area	Specified Policies	Outcome	
		Economic	Environmental
Road transport sector policies	(1) Introduce Compressible Natural Gas (CNG) in vehicles (2) Bane for 25 years old vehicles (3) Improvement of fuel efficiency (4) Fuel tax (5) Green tax (6) Proper highway charge system	Less expenditure on health Increase revenue of Pakistan	Reduce some % of CO2, SPM, SO2, and NO2 emissions

Fig. 11 Specified policy and their effects on environment and economic growth

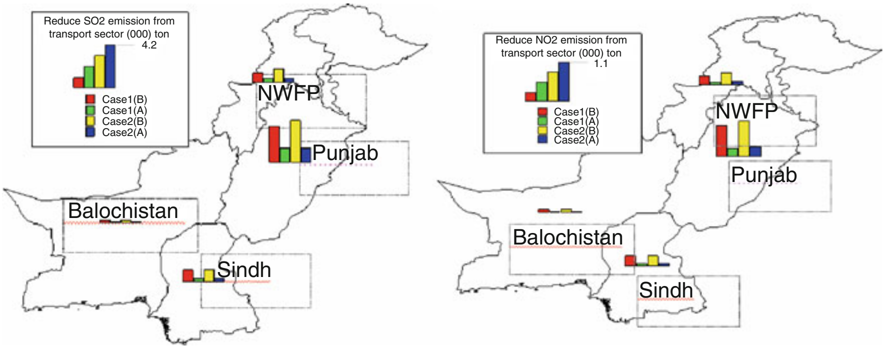

Fig. 12 Reduced emissions from vehicles after combination of policy

toll system. These charges, however, will increase the revenue of the country. After introducing these specified policies, the analytical results show that emission from road transport sector can be reduced to about 30–32%. From economic point of view, it increases the revenue of the Government of Pakistan and also reduces the public health expenditure. Figures 10 and 12 show the result of analysis after reduction of emission from vehicles.

12 Conclusions

In this study, a multiregional CGE model has been proposed in SEA project to analyze the economic and environmental impacts of air emissions of new road network, which will connect the major but dispersed inland cities in northwest part of Pakistan with the port city of Karachi.

After building a new road network project, manufacturing, production of the Punjab, North West Frontier Province and will be increased in case 1 and 2. Calculation of environmental impacts of air emissions, especially for CO_2 emission from road transport sector in Punjab is 0.34–0.42 million tons but after combination of polices it will be reduced to 0.118–0.147 million tons. For NWFP, the emission of CO_2 is 0.118–0.163 million tons but after the combination of polices it will be 0.041–0.057 million tons for case 1 and 2, respectively.

It was found that case 2 was more feasible than case 1 for Pakistan as it clear the air emission results. Hence, it is clear that decision making for combination of policies in SEA framework is important.

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Indigenous Knowledge: The Way to Sustainable Development – Community Participation in Environmental Issues

Tauseef Lateef

Abstract The "top-down" intervention approaches to development have been highly critiqued in the recent past by many academics, leading to a growing interest in *Indigenous Knowledge*. The way to sustainable development and usage of the remaining natural resources are now increasingly being sought and utilized with the consent and understanding of *Indigenous People's Knowledge* around the world – with little or no damage to the natural world. Scientists and development practitioners have realized that in order to have sustainability within development projects, the knowledge of the local people cannot be ignored.

The indigenous people of the world, whom earlier the colonists and later the big pharmaceutical and multinational oil corporations (MNCs) of the West considered *savages* and a hindrance to development, are now increasingly being acknowledged and considered a key resource in maximizing the enhancement of knowledge because of their understanding of the natural flora and fauna as well as the environment at large.

This chapter with the help of secondary data looks at the emergence and importance of indigenous knowledge. It also highlights with the help of examples that the future of sustainable development is indeed hinged upon the recognition and adoption of indigenous knowledge and its practices, in many, if not all, current development projects.

The author defines indigenous knowledge as

> a wealth of accumulated knowledge of the people(s), acquired through generations of practical experience, perfected by trial and error, and innovatively best adapted for local conditions.

Keywords Anthropology • Development • Ethnography • Indigenous Knowledge • Natural Resources • Sustainable Development • Underdevelopment

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1 Development or Underdevelopment

For millennia, people have lived in this world without considering themselves as *Developed* or *Underdeveloped* [4]. The term was officially used by Harry Truman on January 20, 1949. He shared his concept of *Fair deal* for the world. This notion supplied the impetus to render the world dichotomous, i.e., the *Third World* and *First World*. Economic policies were drafted on the basis of this doctrine and two thirds of the world was seen as primitive and poverty ridden and hence an impediment to development [1, 5, 6, 9, 18].

The basic premise was that all countries have to pass through stages of economic growth in a linear way and that countries in the West have to play an important role in making this transition possible [10]. The development policies of the past thus have been that of a *top-down* technical fix for the problems facing the Third World. The *knowledge* of the people and their *indigenous way of life* was considered a hindrance in the development process [5, 10, 11].

Development was not only seen in terms of economic change that had to be brought into a society, but it was far more complex because it involved changing the whole society from *Traditional* to *Modern*. It involves the process of modernization in which the *traditional values*, *institutions*, and *indigenous way of life* had to be replaced by a more *rational*, *scientific*, and *efficient way of life*, or as Hobart puts it, all traditional people were considered "savage, decadent or merely pagan and unenlightened" [17]. They required law and order, Western forms of effective government, or Christianity, and civilization, so that these "savage people," incapable of making progress themselves, could be helped by the West through the process of development [4]. Various development agencies thus emerged by the end of World War II: the World Bank (WB), IMF, UN, FAO, etc. All had implicit policies that followed the modernization and dependency theories. These theories, which were mostly economic and change-based, did not consider the human and cultural aspects and therefore failed apparently [6].

The failure of the theories that were mostly economic and top-down in practice, started a change in the thinking of the development practitioners, and in the early 1970s, the process of development was reevaluated. Development agencies, particularly the World Bank and the United Nations, started promoting and integrating rural development into their realm of focus and looked for a more comprehensive view to development that included focusing on the *very poor* and taking into account the *social and cultural aspect* in development programs. This shift opened new opportunities for anthropologists when development agencies like USAID mandated social soundness analysis (SSA) and knowledge, attitude, and practices (KAP) studies to be conducted for all of their projects [4]. Anthropology with its "ethnographically grounded methodology" [8] had something to offer to both the study of development and its practice. This change in strategy got anthropologists involved in great numbers into the process of development – and this time in history can be considered as the starting point of *Development*

Anthropology or the birth of *Contemporary Importance to Indigenous Knowledge* [4, 6, 8].[1]

2 Definitions of Indigenous Knowledge

To pinpoint and identify one single definition and term it as the definition of indigenous knowledge is very difficult. Many have tried to define it, but none provides a conclusive definition because IK is a budding field of inquiry, containing multiple meanings, and is still evolving [9, 18].

> Indigenous knowledge is the local knowledge – knowledge that is unique to a given culture or society. IK contrasts with the international knowledge system generated by universities, research institutions, and private firms. It is the basis for local-level decision making in agriculture, health care, food preparation, education, natural resource management, and a host of other activities in rural communities. [12, 21]
>
> Indigenous knowledge is the knowledge that people in a given community has developed over time, and continues to develop. It is based on experience, often tested over centuries of use, adapted to local culture and environment, dynamic, and changing.[2]
>
> [IK] an ancient, communal, holistic and spiritual knowledge that encompasses every aspect of human existence.[3]

To clearly understand indigenous knowledge and its various practices and how it can best be used for a sustainable future, it is also important to see and understand what we mean by *Sustainable Development*, the term having replaced *Development*, since the latter failed to produce significant results in improving the state of the world. Let us examine some definitions of sustainable development.

3 Definitions of Sustainable Development

> Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[4]

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[1]For further details of the involvement of anthropologists within development, see http://www.cultureandpublication.org/conference/a_and_d_anthropologyanddevelopment.html, Accessed 2 Aug 2004.

[2]Source: IIRR (1996) Recording and using indigenous knowledge: a manual. Also see http://www.worldbank.org/afr/ik/index.html, Accessed 4 June 2004.

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[4]Source: "Caring for the Earth" (IUCN, UNEP, and WWF 1991) the World Commission on Environment and Development (WCED) as cited in Ulluwishewa (1993), Website reference: http://www.nuffic.nl/ciran/ikdm.html, Accessed 19 Aug 2004.

> Development which meets the needs of the present without compromising the ability of future generations to meet their own needs. Some people also believe that the concept of sustainable development should include preserving the environment for other species as well as for people.[5]

A review of both the definitions of "indigenous knowledge" and that of "sustainable development" highlights certain similarities. Both consider the importance of natural resources as assets and use them in a way that maintains a sustained balance for present needs as well as for future generations. The ethos of "scared balance" is reflective, as people learn more and more through the wisdom of their ancestors and adapt and alter their perspective by making modifications in their current practices – but in accordance to local conditions so that no harm is made to the natural balance of the environment. Some indigenous communities consider themselves a part or an extension of "nature" itself, and this includes all living as well as nonliving things. Their knowledge and practice take special care of the biodiversity so that no resource is overutilized. In order to keep this balance intact, certain practices become a crucial part of their belief system, e.g., limiting off certain forest gardens by believing it to be a part of the spiritual world; or practices such as the sacredness of cows in India. These practices are seen as ways to keep the balance in place. However, without this ethos and practices derived thereof, survival would be difficult.

4 Historical Evolution of Indigenous Knowledge

The shift in the development paradigm and the involvement of anthropologists with development in the mid-1970s and the early 1980s triggered the birth of "contemporary attention to indigenous knowledge" [14].

Malinowski is referred to as the father of British anthropology and social scientists, such as Brokensha, Warren, Brush, Chambers, Richards, Wamalwa, Werner, Boster, and Alcorn, can be classified as the forefathers of *Contemporary Indigenous Knowledge*.

The pioneering work of these academics and especially that of Brokensha in his book, *Indigenous Knowledge Systems and Development*, is considered the most comprehensive canon of its time, expounding indigenous knowledge in detail. The book was widely appreciated and was used in both academic and development circles. Examining various indigenous practices and local knowledge of traditional people, the book reasons how the world of development can learn and use them [1–3, 11, 12, 15, 16].

The beginning of indigenous knowledge has been divided into two strands according to Sillitoe: one was concerned with academic, and the other, development. The involvement of anthropologists was initially focused toward the

[5]Website reference: http://www.met.gov.sb/learn/glossaryoz.htm, Accessed 19 Aug 2004.

development side of IK as suggested by the nature of research carried out in the 1980s [11]. The main reason behind their work was to show how “indigenous knowledge” could best contribute to the world of development. The argument was based upon a new approach and way of thinking, “development from below” [3]. These studies became the basis for the change in the thinking of the development practitioners through evidences like:

“Indigenous agricultural revolution” by [19].

“Rural development: putting the last first” by [15].

“Farmer first: farmer innovation and agriculture research” edited by [15]. This book is touted as championing what [20] calls the “paradigm shift” in agricultural science. It highlights local people’s knowledge – “indigenous technical knowledge” (ITK) – as evidenced by the adaptive nature of farmers, especially those living in difficult terrain areas where farming is more difficult than normal and the farmers learn from experimentation and innovation. “Farmer First” promotes for a different kind of agriculture research ethos and methods that is opposite to the popular “transfer of technology” (TOT) being created in research stations and transferred to the Third World countries to adopt [3]. The raison d’être for the book is to make a case for putting the farmer first and before the research institutes in question. There is a lot to be learned from these resourceful farmers and this can only be achieved through a shift in the thinking of the institutions and through linking formal Research and Development with an informal one [3, 15].

5 Documenting and Dissemination

The role of IK as a collaborator in the resource building process for sustainable solutions has been advocated by many, and it is argued that this wisdom of traditional knowledge can be put together with scientific knowledge to achieve what has not been achieved so far. This future sustainability can be achieved by documenting this untapped resource that is rapidly diminishing. The advocates argue that once IK is documented systematically, it would be possible to compare and contrast it with existing and prevailing global knowledge, also termed as *Western Scientific Knowledge* [11, 12, 14].

Agrawal calls this process “scientization” of indigenous knowledge and an ex situ conservation of IK. This is a three-stage process where first a cultural meaning or ritual associated with certain herbal remedy gets detached. Agrawal calls this “particularization.” The process whereby the only aspect that is utilized is the one proven and validated by science is termed “validation.” And lastly, when the entire practice has gone through these processes, Agrawal dubs it “generalization.” She highlights that documentation of indigenous knowledge should not only limit the growth of it to this point, but, more importantly, this should be a step toward getting more empowerment to the marginalized through lobbying and advocating for resource allocation for the betterment of indigenous people [1, 13].

Warren, Rajaserakaran, Slikkerveer, Brokensha, and many more are ardent advocates for international centers for global dissemination of indigenous knowledge. Many organizations now have comprehensive online databases, while others even have training manuals. More and more material is being published, and more websites are emerging, highlighting the importance of IK [12]. Some of these are in collaboration with the "big" development agencies and institutions, while others are a result of local initiatives by indigenous people themselves. Eyzaguirre calls this a "Global recognition of indigenous knowledge: is this the latest phase of 'globalization'?" This notion is agreed with widely and advocated by a large number of academics, all of who believe that the future of development and practices that are sustainable is through the recognition of indigenous knowledge and that its dissemination is of profound importance [1, 12, 14].

> Given enough time, everything that is old will become new again. Conway (1997) as cited in [7]

Indigenous knowledge has finally been recognized as can be gaged from the importance it has gained in the last few years. However, this raises another issue: that of protection of this knowledge and the people who possess it. The indigenous people from colonial times to present have been a victim of excessive exploitation. Their territories and dwelling places were earlier invaded by colonists and more recently by the governments of various countries. These indigenous people are currently in minority, and their native lands have been turned into national parks and governments have given rights to use their land for oil and gas exploration. The first issue that emerges has to do with the rights of indigenous peoples. And to analyze what rights indigenous people have – or do not have, we first have to know who indigenous people are and they are defined by various organizations [9].

It was from the knowledge of indigenous Maya Indians that the world learned of a tree called *heve*, which grows in the province of Esmeraldasin Amazon. Heve trees secrete a white milky fluid that hardens on contact with air. The Maya Indians call this resin "cauchu" meaning the from the "tree-that-weeps" – it became the raw material for rubber and allowed companies such as Macintosh, Hancock, Goodyear, Michelin, and Dunlop to make rubber tires, for example, that brought a revolution in the automobile industry.

The tree Azadirachta Indica, also known as the *Neem Tree*, furnished different kinds of raw material from its various parts. It leaves, for example, are used to protect stored grains from insects (particularly moths) as it has been used as a natural pesticide by rural farmers in India for centuries.

These knowledgeable farmers domesticated most of the crops, such as cotton, wheat, rice, and millet, as well as animals that are now the prime target for extensive research for world food needs [9].

6 Conclusion

This chapter addresses the importance of indigenous knowledge and how it can be used as a resource for a sustainable future. Despite having gained attention, indigenous knowledge still has a long way to go in being recognized as a key partner for sustainable future developments. Dialogs among the many stakeholders need to take place in order to understand the different issues faced by each. It seems indigenous knowledge has started to travel in the right direction, as recognized and emphasized in the Human Development Report of 2004, which stated the need to promote an atmosphere where growth of cultural identities can take place so that respect and understanding of each other can occur in a better and positive way. Thus, it can be said that the future of indigenous knowledge as a collaborator and partner for sustainable development is hinged critically upon development practitioners paying close attention to these resource-rich farmers and tackling the issues of indigenous peoples in a systematic manner, keeping in mind the needs and rights of the people.

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New Stationary Phase Material for GC Separation of Organic Compounds

A.J. Laghari, Zeenat M. Ali, L.A. Zardari, and M.Y. Khuhawar

Abstract In the past few decades, shape selectivity has drawn a great deal of attention from chromatographers. The chemistry and characteristics of bonded stationary phases such as phase type, length of bonded phase, surface coverage, and silica surface material have an effect on the shape selectivity of the columns. The new packing procedure provided columns with reasonable efficiencies, with high stability. It has several advantages and is constructed of inexpensive, commercially available materials. This new material allows GC analysis to be conducted in any laboratory environment capable of supporting conventional packed column GC and imposes no additional consumable costs.

The column has been successfully tested and compared for qualitative as well as quantitative analysis with different correlation of thermodynamic quantities (ΔH°, ΔS°, and ΔG°) versus bonded phase densities and shelf life and robustness of the prepared packed column. The effects of temperature and residual silanol groups are sources of difficulty in elucidation of the mobile phase role in selectivity and retention for GC measurements.

The separation occurs by the partitioning of the sample components between two phases. The gas chromatography of volatile organic compounds is superior with regard to the precision and accuracy.

Gas chromatography is extensively used for the separation of complex organic mixtures using both packed and capillary columns. Continuous research work is being carried out in order to improve the separation capabilities of the columns for complex mixtures.

The literature survey shows that attempts have been made to modify the stationary phase in gas chromatographic columns with addition of inorganic electrolytes or with coordinatively unsaturated metal chelates. As tetradentate Schiff bases are excellent complexing reagents, they form highly stable metal chelates. Therefore,

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it is considered to examine copper(II) chelate of substituted tetradentate Schiff base as mixed stationary phases together with OV-1 (3%). The proposed stationary phase has not been reported earlier. The obtained results are compared with the well-known GC stationary phase OV-1 (3%). An increase in capacity factor, theoretical plates, and resolution between alcohols, aromatics, and ketones has been observed on mixed stationary phases and compared to OV-1 stationary phase, using same analytical conditions.

Keywords GC Stationary phases • Metal chelates • Packed columns

1 Introduction

Gas chromatography is extensively used for the separation of complex organic mixtures using both packed and capillary columns. Continuous research work is being carried out in order to improve the separation capabilities of the columns for complex mixtures. A number of attempts have been made to modify the bonded stationary phase in gas chromatographic packed columns with addition of inorganic electrolytes or with coordinatively unsaturated metal chelates.

Burkle et al. [1] used nickel(II) bis(trifluoroacetyl) IR camphorate in squalane and nickel(II) bis(α-heptafluorobutyl)terpeneketonates in squalane as bonded phase.

Maslowska and Bazylak [2–4] reported copper(II) and nickel(II) chelates of tetradentate Schiff bases as stationary phases individually or together with squalane for the complex mixtures of pyridine derivatives.

Wasiak [5] reported triphenyl phosphine complexes of rhodium(I) and ruthenium(II) as modifiers in gas solid chromatography.

Maslowska and Bazylak [6] reported the separation of some alkanes and alcohol mixtures by gas chromatography using packed column of tetradentate Schiff base nickel(II) complex.

Wasiak and Szezepaniak [7] reported study of high temperature treated chemically bonded metallophenyl siloxane by complexation gas chromatography.

Polanuer et al. [8] reported the determination of polar compounds in aqueous solution by sorbents modified with potassium fluoride crystal hydrate.

Wasiak [9–11] examined chemically bonded copper(II)–nickel(II) chelates as selective complexing sorbents for gas chromatography. The columns were chemically bonded to β-diketone chelates with silica.

Wasiak [12] reported the modified chemically bonded chelates as complexing sorbents with *N*-benzoylthiourea group for gas chromatography.

Wasiak et al. [13] reported the stationary phase containing copper(II) and palladium(II) salts bonded to β-diketone groups on the surface of silica particles.

Wasiak [14] reported the specific interaction of ketones, ethers, and nitromethanes with *N*-benzoylthiourea. The copper(II) complex was chemically bonded to silica supports.

Wasiak and Ryokowska [15] reported chromatographic column packing containing Ni(II) and Co(II) acetylacetone and hexafluoroacetylacetone bonded to silica surface in order to interact specifically with ethers and thioethers.

Wasiak and Ryokowska [16] examined the chemically bonded chelates as selective complexing sorbents in gas chromatography. The silica surface was modified with Co(II) and Ni(II) complexes of acetylacetone and hexafluoroacetylacetone.

Wasiak and Urbaniak [17] synthesized the column packing by bonding aminosilane with SiO_2 surface and then bonding with Cu(II) using the complexation properties of amino group.

Maslowska and Bazylak [18] reported tetradentate ketoamine nickel complexes as the electron acceptor stationary phases in gas chromatography.

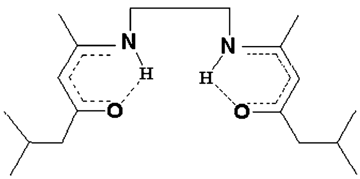
Recently from this laboratory of Dr. M.A. Kazi Institute of Chemistry [19,20], copper(II) and nickel(II) and palladium(II) chelates of some β-diketones have been used as mixed stationary phases with OV-101 and OV-1 for GC separation of organic compounds.

2 Present Work

The present work examined the possibility of copper(II) chelate of tetradentate Schiff base, bis(isovalerylacetone)ethylenediimine, individually and together with OV-1 as bonded phase for GC separation of organic compounds. This work was also intended to increase the organic portion of the ligands, for better shielding of metal ions (Fig. 1).

3 Instruments

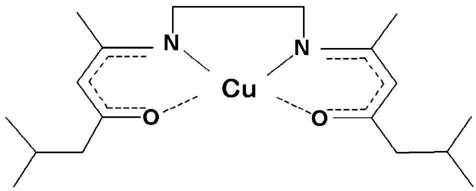
Shimazdu GC-9A (Japan) gas chromatograph with flame ionization detection (FID) and Data Apex software CSW-17 for recording chromatograms was used to carry out the project.



bis(Isovaleryacetone)ethylenediimine (H_2IVA_2en)

Fig. 1 Sturcture of Schiff Base; Bis(isovalerylacetone) ethylenediimine

Fig. 2 Sturcture of Schiff Base Metal Chelate; bis (isovalerylacetone) ethylenediimine copper(II)



COPPER(II)COMPLEX OF H_2IVA_2en

4 Experimental

The reagent H_2IVA_2en and its copper(II) complex were prepared as reported [21]. The reagent H_2IVA_2en was prepared by heating isovaleryacetone and ethylenediamine together at 70°C in the ratio of 2:1 in methanol. The melting point reported and observed was 112–114°C. The copper(II) chelate was prepared by warming together the reagent H_2IVA_2en and copper(II) acetate in methanolic solution at 60–70°C. The melting point of metal chelate reported and observed was 143–145°C (Fig. 2).

5 Preparation of Stationary Phases

5.1 OV-1 (3%) as a Single Stationary Phase

Exactly 0.3 g of OV-1 (BDH, UK) was dissolved in 15 ml of chloroform, and 10.00 g of Chromosorb G/NAW (60–80 mesh size) was added. After thorough mixing, the solvent was evaporated at 60°C on rotavapor (BUCHI, Switzerland), under reduced pressure.

Metal chelate (5%) + OV-1 (3%) as a mixed stationary phase.

Exactly weighed 0.5 g of copper(II) chelate of H_2IVA_2en in a beaker was dissolved in 15 ml of chloroform, and 0.3 g of OV-1 dissolved separately in chloroform was added. In the mixed solvent, 10.00 g of Chromosorb G/NAW (60–80 mesh size) was added. After complete mixing, the solvent was evaporated at 60°C on rotavapor under reduced pressure.

5.2 Column Packing

In the present work, glass columns (2 m × 3 mm ID) were used. As these columns contained residual caustic materials, they were thoroughly cleaned with diluted acids.

The objective in packing the column is to fill it as tightly as possible without fracturing or deforming the particles. A wad of quartz wool was placed partially into the detector end of the column and excess wool was bent back around the outside of column. Rubber tubing was connected to the column. This method ensured that the quartz wool was not pulled out of the column during filling. A funnel was connected to the detector end of the column. The other end of the column was connected to a vacuum pump through rubber tubing. The packing material (bonded phase) was added slowly while vacuum was applied at the other end. During the entire filling operation, the column was agitated so that the packing may settle down evenly. When the column was filled, the quartz wool was placed at the column end and vacuum source was disconnected.

5.3 Conditioning of Column

The procedure used here was as followed [14]. The carrier gas (pure nitrogen) inlet of the column was properly connected to the injection port and its outlet left unconnected (Fig. 3). The nitrogen as carrier gas was allowed to flow at the rate of 50 ml/min. The temperature of the column oven was increased by programming with the upper limit of temperature (125–150°C). At this temperature, the column was left for 24 h. The outlet end of the column was connected to the detector (FID). Before proceeding for analytical studies of the samples, around 40–50 injections with 10 μl Hamilton syringe (USA) of benzene, toluene, and xylene were made at temperatures below 100°C, with carrier gas flow rate of 15 ml/min. This was followed by several injections of analytes.

Fig. 3 Columns containing stationary phases are installed in GC

6 Results

After glass packed column conditioning and optimization, standard organic samples were run on the glass column (2 m × 3 mm ID) with set conditions and FID detection system, containing mixed stationary bonded phase [5% $H_2IVA_2enCu(II)$ + 3% OV-1 on Chromosorb G/NAW (60–80 mesh size)] in order to make sure that responses are steady and easy to understand. The 5% Schiff base metal chelate was selected after a series of packed columns containing 1–8% Schiff base metal chelate materials, but the column containing 5% proved good for optimum results. Obtained results were compared with well-known GC bonded phase 3% OV-1. It was observed that the glass column containing mixed stationary bonded phase gave better results than the column with 3% OV-1 bonded phase. Isothermal elution was carried out for all the compounds. The parameters such as retention time, capacity factor, peak asymmetry, theoretical plates, and resolution factors (Rs.) were calculated on the computer with CSW-17 software. Saturated long chain hydrocarbons C_6–C_{10} were used onto each of the column and logarithm of the adjusted retention time was plotted against the carbon number × 100. Linear correlations were obtained from five calibrators. The curves were used to calculate Kovats retention indices (RI). It was observed that RI values for aromatic hydrocarbons, alcohols, aldehydes, ketones, and heteroaromatics increased on mixed stationary bonded phase of 5% IVA_2enCu + 3% OV-1 as compared to that of 3% OV-1 under the same operating conditions (Fig. 4a, b). The chromatograms of mixed organic compounds with aromatics and ketones such as (1) 2-butanone, (2) benzene, (3) 3-methyl-2-butanone, (4) 4-methyl-2-pentanone, (5) pyridine, (6) mesityl oxide, (7) 2-picoline, (8) 2,6-lutidine, (9) 3-picoline, (10) nonane, (11) 2-pyridinecarboxaldehyde, and (12) mesitylene are better resolved on the new mixed stationary bonded phase than the traditional bonded phase in the column.

Separation of organic compounds (1) 2-butanone, (2) benzene, (3) 3-methyl-2-butanone, (4) 4-methyl-2-pentanone,(5) pyridine, (6) mesityl oxide, (7) 2-picoline, (8) 2,6-lutidine, (9) 3-picoline, (10) nonane, (11) 2-pyridinecarboxaldehyde, and (12) mesitylene.

6.1 Conditions

Packed glass column (2 m × 3 mm ID). Isothermal temperature 70°C. N_2 flow rate 12 ml/min. FID detection system.

During this work, 46 organic compounds were examined and analyzed for the prepared stationary phase ranging from normal alkanes, nitrocompounds, alcohols, aromatics, heteroaromatics, ketones, ethers, aldehydes, and esters (Table 1). However, alcohols on the higher end like 1-heptanol and 2-octanol which were overlapped on single stationary phase are completely separated and resolved on

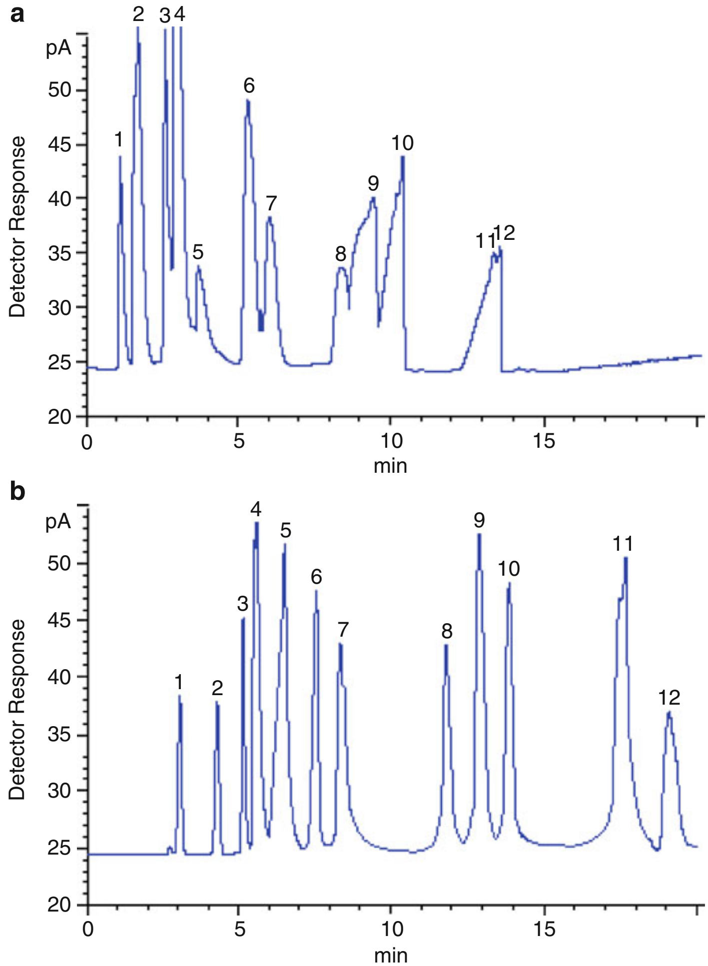


Fig. 4 (**a**) OV-1 (3%) as a single stationary phase and (**b**) Cu(II)IVA$_2$en + OV-1 (3%) as a mixed stationary phase

the mixed stationary phase of metal chelate, and so is the case with the separation of 2-pyridinecarboxaldehyde and mesitylene (1,3,5-trimethyl benzene) using same operating conditions for the two columns. A comparative study has been done to justify the usefulness of the prepared new packed column of mixed stationary phase containing 5% CuIVA$_2$en + 3% OV-1 with that of single stationary phase containing only 3% OV-1 (Table 2).

Table 1 Examined compounds

S. no.	Name of compound	S. no.	Name of compound
1	Hexane	24	Aniline
2	Heptane	25	Piperidine (hexahydropyridine)
3	Octane	26	Methanol
4	Nonane	27	2-Propanol
5	Decane	28	1-Propanol
6	Acetonitrile (cyanomethane)	29	2-Butanol
7	Nitromethane	30	*tert*-Butanol (2-methyl-2-propanol)
8	1,2-Dichloroethane	31	Isoamyl alcohol (3-methyl-1-butanol)
9	2,2-Dimethoxypropane	32	1-Pentanol
10	2-Nitropropane	33	1-Hexanol
11	Dioxane	34	1-Heptanol
12	Benzene	35	2-Octanol
13	Toluene	36	Crotyl alcohol (2-butenol)
14	*o*-Xylene	37	2-Butanone
15	Mesitylene (1,3,5-trimethyl benzene)	38	3-Methyl-2-butanone
16	*o*-Toluidine (2-aminotoluene)	39	3,3-Dimethyl-2-butanone
17	2-Nitrotoluene	40	4-Methyl-2-pentanone
18	2-Pyridinecarboxaldehyde	41	Mesityl oxide (4-methyl-3-penten-2-one)
19	Pyridine	42	Cyclohexanone
20	α-Picoline (2-methyl-pyridine)	43	Benzaldehyde
21	γ-Picoline (4-Methyl-pyridine)	44	Diethyl ether
22	2,6-Lutidine	45	Propyl propanoate
23	β-Picoline (3-methyl-pyridine)	46	Ethyl trifluoroacetate

Table 2 Comparative study of column performance efficiency

Column	Kovats index (RI)	Capacity factor (k)	Resolution (R)	Theoretical plates (N)
$CuIVA_2en$ (5%) + OV-1 (3%)	521–1,152	12.87–120.00	0.795–6.580	452–2,983
OV-1 (3%)	510–1,140	10.07–70.67	0.479–3.970	140–1,780

7 Conclusion

- New stationary phase material for packed column gas chromatography, bis (isovalerylacetone)ethylenediimine copper(II) (5%) together with OV-1 (3%), has been examined for the separation of organic compounds.
- An increase in capacity factor, theoretical plates, and resolution between alcohols, aromatics, and ketones has been observed using new bonded phase as compared to 3% OV-1 stationary phase, under same analytical conditions.
- The better chromatography using copper chelate as new stationary phase may be due to gas phase donor–acceptor coordination between organic compounds and copper chelate.

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Value-Added Product Recovery from Banana Plant Waste: A Sustainable Way for Development

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Abstract Pakistan being an agriculture country is enriched with abundance of biomass residues from agricultural crops such as wheat straw, rice husk, bagasse, banana plant, etc. that may be used for resources recovery. The banana plant is one of the potential cellulosic material like cotton crop, wood, etc., obtained from agricultural land. Development in the area of bio-conversion offers a cheap and safe method of not only disposal of agricultural residues but may also be used for the production of product, like, ethanol. Ethanol production from cellulosic material is a two stage process. Initially, the cellulosic material is converted to reducing sugar by acid hydrolysis or enzymatic hydrolysis and afterward, production of ethanol by fermentation process. The current work focuses on the optimization of acid hydrolysis and fermentation using *Sacchromyces cerevisiae* yeast.

In the current study, process conditions for acid hydrolysis, i.e., particle size, reaction time, shaking speed, temperature and concentration of acid were studied in addition to fermentation process optimization.

In acid hydrolysis, samples of various particle sizes, i.e., 26, 28, 30, 40, 50, and 100 μm, were used. It was found that reduction in particle size enhances the conversion of reducing sugars from banana plant. The optimized conditions for hydrolysis were found to be shaking time 2 h, temperature 80°C, shaking intensity 90 rpm, and solid–liquid ratio 50 g in 300 ml of H_2SO_4. With 100-μm particle size, optimum yield of Brix (*reducing sugar*) was obtained (21–24% per 300 ml). pH was adjusted in the range of 4.5–5.2.

For the production of ethanol, aerobic fermentation was carried out using *S. cerevisiae* yeast species. The fermentation reaction was carried out in a 300-ml conical flask. Optimum yield was obtained at 31°C, residence time 8 h, and when shaken at 80 rpm.

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Keywords Banana • Recovery • *Sacchromyces cerevisiae* yeast species • Sustainable development • Value added • Waste

1 Introduction

Historically, ethanol has been used by humans as the intoxicating ingredient in alcoholic beverages. The presence of dried residues of alcohol on 9,000-year-old pottery found in China implies that alcoholic beverages were used even among Neolithic people. Ethanol isolation as a pure compound was first achieved by the Persian alchemist Muhammad Ibn Zakarīıya Rāzi (Rhazes, 865–925). Geber (Jabir ibn Hayyan) and Al-Kindi (Alkindus) also contributed to the development of distillation techniques. In 1796, Johann Tobias Lowitz obtained pure ethanol using activated charcoal. Later on, Antoine Lavoisier described ethanol as a compound of carbon, hydrogen, and oxygen, and in 1808, the formula of ethanol was determined by Nicolas-Théodore de Saussure. Archibald Scott Couper published the structural formula of ethanol 50 years later, placing ethanol among the first compounds whose chemical structure had been determined.

Synthetically, ethanol was first prepared in 1827 by Henry Hennel in Great Britain and S.G. Sérullas in France. Michael Faraday, in 1828, prepared ethanol by acid-catalyzed hydration of ethylene, a process that is used today for industrial ethanol synthesis.

In the USA, ethanol was used as lamp fuel as early as 1840, but a tax levied on industrial alcohol during the Civil War made this use uneconomical.

Photosynthesis is the most efficient method for harnessing solar energy for biomass production. The global production of lignocellulosic (LC) material from the land is about 120–150 billion ton dry matter/annum, some 302 billion ton oil equivalent (TOE) or more than four times the world's yearly total energy consumption [1]. In Pakistan, LC materials are the most important components of renewable biomass and contributed 17.7 million ton oil equivalent (MTOE)/annum fuel wood, animal waste, cotton sticks, and other crop residues in 2002–2003 against the anticipated demand of 83.7 MTOE. During the recent decades, Pakistan has experienced fairly good economic growth, but the country is still at a low level of economic development. In the coming decades, Pakistan needs large inputs of energy in order to sustain the pace of its economic development. Presently, 68% of primary energy needs of the country are met by commercial fuels (oil, natural gas, coal, and hydro- and nuclear power) and 32% by traditional fuels (fuel wood, crop residues, and animal wastes). Since Pakistan is a resource-deficient country, it has to rely on imports to cover about one-third of her primary energy demands [1].

Grasses; trimmings of lawns; other agriculture wastes; and industrial, domestic, food, and urban solid wastes are currently overproduced (over 43 million ton/year [2]) but underutilized. Recycling these wastes would not only aid in pollution abatement but can also serve as a vital source of energy and food for the future. The use of wastes for methane or ethanol production will reduce overall cost and make the process economically viable. Different researchers have extracted ethanol from rice husk, wheat straw, and sugarcane bagasse. Pineapple, banana fruit, and waste paper have also been used.

The removal of lead or toxic aromatics used in gasoline as octane boosters has provided new application and markets for alcohol to enhance octane rating and provide an alternative liquid fuel. Ethyl alcohol is gaining increased acceptability as fuel as it burns clean and can be quite easily blended with gasoline. The cost of molasses is increasing rapidly and distillers are concerned by the price hike. Other attractive alternative is the readily available LC biomass banana plant, which has a considerable promise as a raw material for liquid fuels and certain petrochemical intermediates, as this is renewable. Utility of cellulose in LC biomass is tremendously enhanced if it is first hydrolyzed to glucose and other soluble sugars that can be used for fermentation of alcohol or other products. For production of ethanol from LC biomass, one of the designed processes is enzyme/acid hydrolysis, followed by fermentation to ethanol.

Cellulosic feedstock is composed of the hemicellulose lignin. Lignin acts as a binding material to all other components. It is also responsible for providing the rigidity to a cellulosic feedstock. Actually, cellulose is a polymer of a series of β-D-glucopyranose and is a chief constituent of the feedstock. Hemicellulose, like cellulose, is a polysaccharide that is less complex and easy to hydrolyse.

Sugar present in the cellulose is mostly glucose. However, hemicellulose is a mixture of different types of sugars. It consists of C_6 (glucose, mannose, and galactose) and C5 (xylose, arabinose, and rhamnose) sugars. Glucose, mannose, and xylose constitute about 95–97% of the total sugars.

2 Experimental Work and Methodology

The banana waste was initially crushed in the hammer mill. The crushed sample was then separated into different particle size by sieve analysis. The samples of various particle sizes were used to convert the cellulosic banana plant material to reducing sugar by acid hydrolysis. The reducing sugars obtained from banana plant were used for the production of ethanol using *Sacchromyces cerevisiae* yeast species.

2.1 Acid Hydrolysis

Fifty grams of sample of different particle size was taken for acid hydrolysis. The sample was placed in a 1,000-ml conical flask. The separator funnel was filled with 437 ml of distilled water and 10, 20, 30, and 40% of sulfuric acid and set to get 300 ml/acid. A temperature of 70–80°C and a shaking speed of 90 rpm were maintained in Lab-Thermo shaker TS-40XY. A volume of 300 ml of acid was added for 1 and 2 h. After hydrolysis, pH was adjusted between 4.9 and 5.2 by adding NaOH drop wise. Separation of NaOH solution from solid residues was carried out by simple filtration. The solution was cooled to room temperature and stored in a sample bottle. The solid residue was stored in a 100-ml conical flask.

2.2 Fermentation Process

Batch culture experiments were carried out in 250 ml conical flasks with a working volume of 100 ml under aerobic conditions in a water shaking bath. Fermentation was performed at pH 5.0 for 8 h at 30°C. The top of the conical flask was plugged with cotton so that carbon dioxide can escape from the top of the flask and also to avoid contamination.

The sample was continuously shaken in the shaking bath to maintain aerobic conditions and to avoid foaming on the upper surface of the flask. Formation of yeast layer over the surface of the solution which hinders oxygen supply may also be avoided. Excess time was maintained for complete conversion of glucose to ethanol.

Centrifugation separation technique was used to separate the biomass (*S. cerevisiae* yeast) at 25°C at 3,000 rpm for 20 min (Centrifuge Kokusan H-103 series). The biomass was treated with saline water after washing. The cell mass was dried at room temperature for 12 h.

Separation of ethanol was carried out by distillation process in a vacuum evaporator at 78°C under isolated condition as the product is highly volatile.

2.3 Quantitative and Qualitative Analysis

Gas chromatography and spectrometer were used to analyze the reducing sugar and ethanol concentrations. Gas chromatography is a technique that can be used to separate volatile organic compounds. A gas chromatograph consists of a flowing mobile phase, an injector port, a separation column containing the stationary phase, a detector, and a data recorder. The organic compounds are separated due to differences in the column.

The following operating conditions were chosen to obtain the final results.

- Equipment ID: GC-6890
- Company name: Agilent Technology (HP) with FID detection system
- Column used: Network GC (Capillary GC)
- Capillary column DB-1701
- 30 min length, 0.25 mm internal diameter
- Film thickness 0.32 μm (14% cyanopropyl silane liquid)
- Carrier gas: N_2 gas (mobile phase) 2 ml/min
- FID: H_2 gas 40 ml/min
- Air 450 ml/min
- N_2 as make-up gas 45 ml/min

3 Results and Discussion

In the present work, banana waste has been utilized for the preparation of ethanol. Initially, banana waste is converted into reducing sugar by acid hydrolysis and later on converted to fermentable sugars. The sugar is then used for the production of ethanol by fermentation process, using yeast.

3.1 Acid Hydrolysis for Sugar Recovery

The type of sugar product recovered depends on the rate of two reactions when cellulosic materials are treated with dilute acid:

Banana waste cellulose + H_2SO_4 K1 reducing sugar (glucose)
Glucose + yeast K2 ethanol + CO_2

Acid hydrolysis of banana waste was conducted by using different mesh size/particle size such as 26 meshes (708 µm), 28 meshes (595 µm), 30 meshes (546 µm), 40 meshes (352 µm), 50 meshes (298 µm), 60 meshes (250 µm), and 100 meshes (149 µm), as shown in Table 1.

Different concentrations of sulfuric acid 10, 20, 30, 40, and 50% per 437 ml of distilled water were used. To 50 g of the sieved banana sample, 300 ml of H_2S0_4 was added and shaken in the Lab-Thermo shaker No(TS-40XV) at 90 rpm and 70°C for 1 h. Sugar recovery was checked by using digital refractometer model ATAGO (DBX-55).

3.2 Effect of Particle Size

The effect of particle size on % sugar recovery is reported in Fig. 1. Different particle size of 26 mesh (708 µm), 28 mesh (595 µm), 30 mesh (546 µm), 40 mesh (352 µm), 50 mesh (298 µm), 60 mesh (250 µm), and 100 mesh (149 µm) were used

Table 1 Acid hydrolysis of banana waste

			Brix % after hydrolysis with H_2SO_4 at various concentrations				
S.no.	Particle size in mesh	Mass in g	10% Brix	20% Brix	30% Brix	40% Brix	50% Brix
1.	26	50	13	15	14	13	12
2.	28	50	13	15	14	12	12
3.	30	50	13	16	15	12	12
4.	40	50	14	16	15	13	13
5.	50	50	14	17	16	14	13
6.	60	50	15	19	16	14	13
7.	100	50	15	19	19	15	14

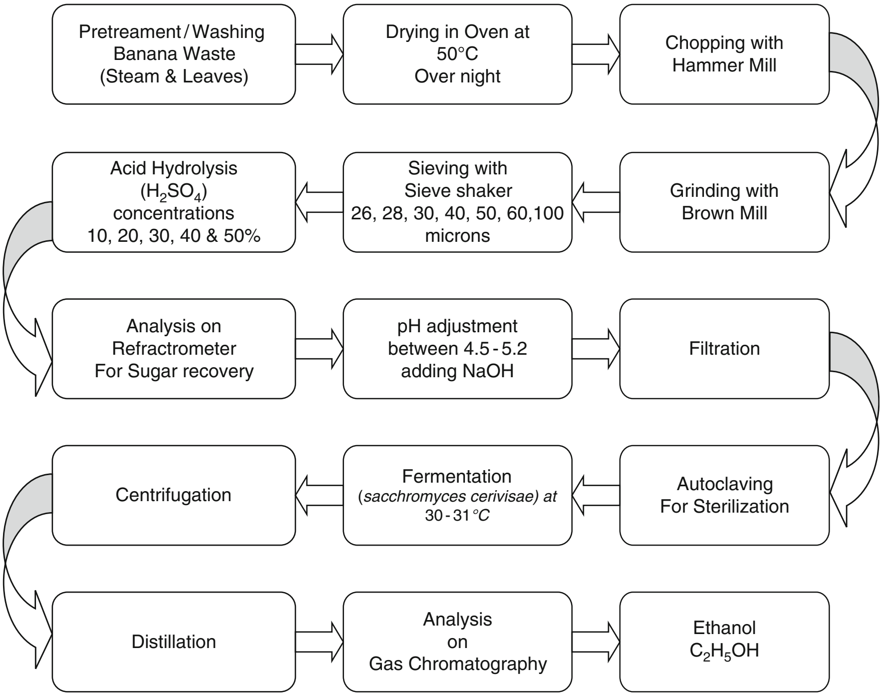

Fig. 1 Flow diagram for the production ethanol from banana waste

to observe the effect on % sugar recovery. It was found that at highest sugar recovery, 19% was achieved when a sample of 149-μm size was used. Fine particle size of biomass reduces the crystallinity of the biomass and hence gives better results when it is hydrolyzed (Jin and Chen 2006). It also helps in terms of glucose recovery and energy saving (Hideno et al. 2009).

3.3 *Effect of Temperature*

Temperature is an important parameter during the hydrolysis process. The effect of temperature on % sugar recovery is reported in Fig. 2. Hydrolysis of 50 g of banana waste of 149 μm size was conducted at different temperatures, 60, 70, 80, 90, and 100°C, to optimize the temperature. Degradation of sugar is not possible at low temperature, i.e., 60–80°C, as observed in Fig. 2. Maximum sugar recovery of 24% was achieved at 90°C. According to previous studies, it was also reported that low temperature is not favorable for the degradation of sugar. Wood was hydrolyzed at 237°C to achieve a maximum sugar recovery of 50% (Ayhan Demirbas 2003).

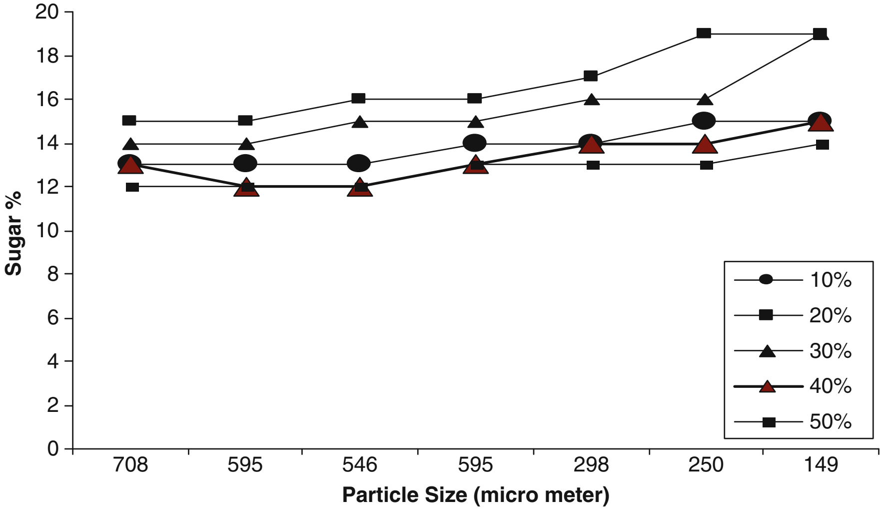

Fig. 2 Effect of particle size on % sugar recovery

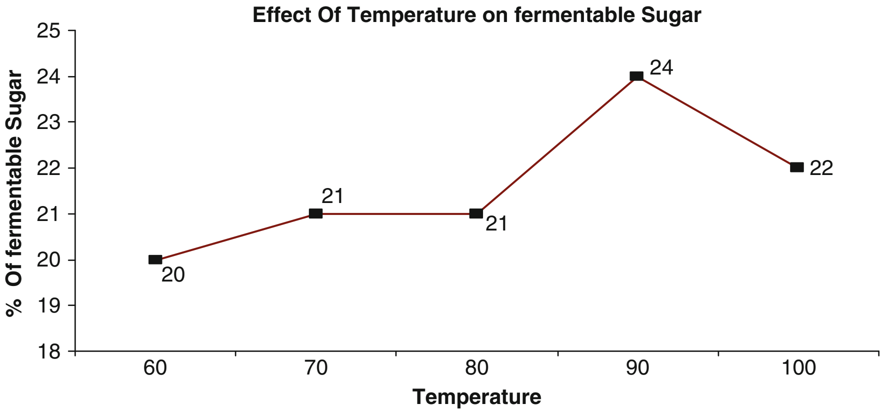

Fig. 3 Effect of temperature on % sugar recovery

3.4 Effect of Acid Concentration on Sugar Recovery

The effect of acid concentration on % sugar recovery is reported in Fig. 3. Fifty grams of banana waste of 149 μm size was hydrolyzed by using different concentrations of H_2SO_4, 10, 20, 40, and 50%. The sample was shaken in the thermo shaker at 90 rpm and heated at 90°C for 1 h. It was found that 20% of acid concentration revealed 24% sugar conversion. It was also observed that by increasing acid concentration from 10 to 20%, the sugar recovery also increased. Using higher acid concentration will also affect the degradation of sugar conversion (Ayhan Demirbas 2003).

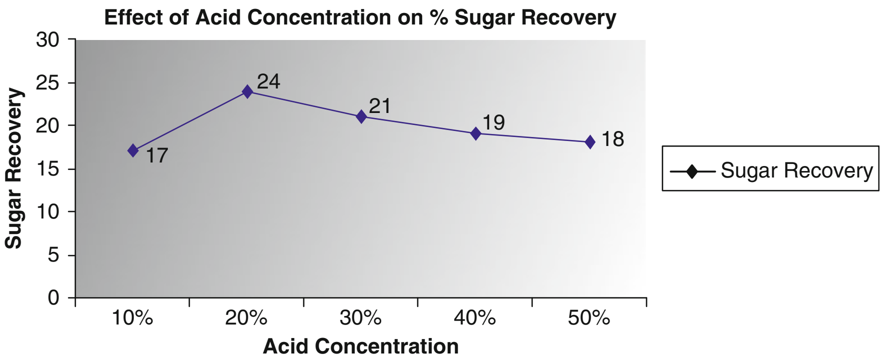

Fig. 4 Effect of acid concentration on % sugar recovery

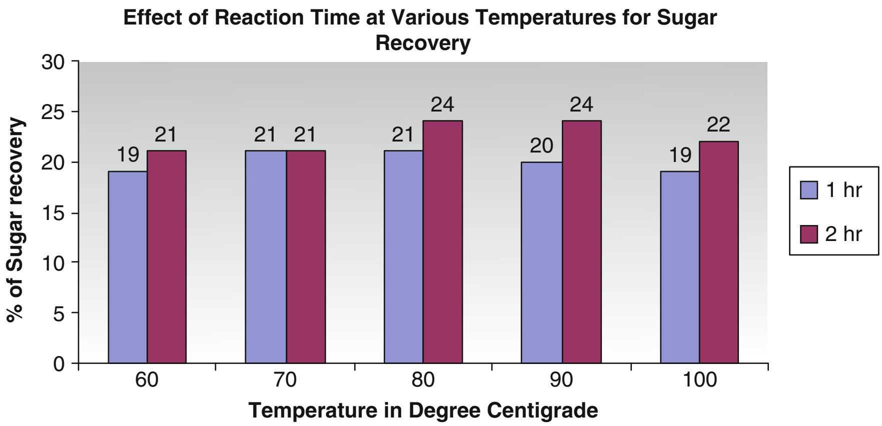

Fig. 5 The effect of reaction time on % sugar recovery

3.5 Effect of Reaction Time

Acid hydrolysis was carried at 1 and 2 h to analyze the effect of time on % sugar recovery, as shown in Fig. 4. Fifty grams of banana waste of 149 μm size was hydrolyzed using 20% H_2SO_4 and shaken at 90 rpm. The results showed that maximum sugar recovery of 24% was achieved at both 80 and 90°C in 2-h reaction time. It was reported that 2-h reaction time is the best for maximum sugar recovery, when compared to that in previous work which was 240 min, i.e., 4 h (Yen et al. 1982) (Fig. 5).

3.6 Fermentation

After hydrolysis, fermentation was conducted to convert the fermentable sugar into ethanol. To the hydrolyzed sample in the conical flask, 3 g of yeast (*S. cerevisiae*)

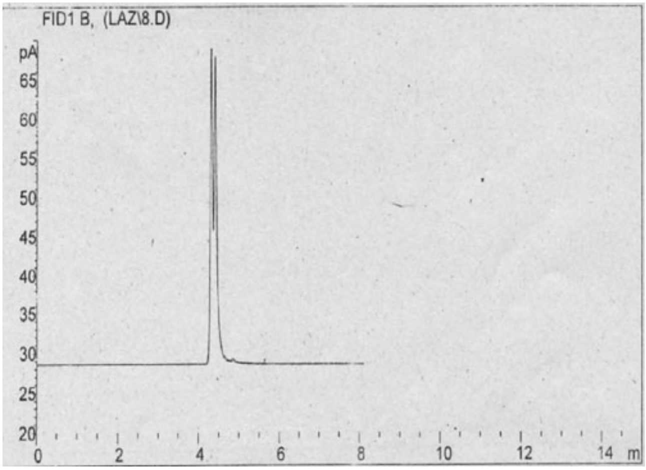

Fig. 6 Ethanol produced at 20% acid concentration

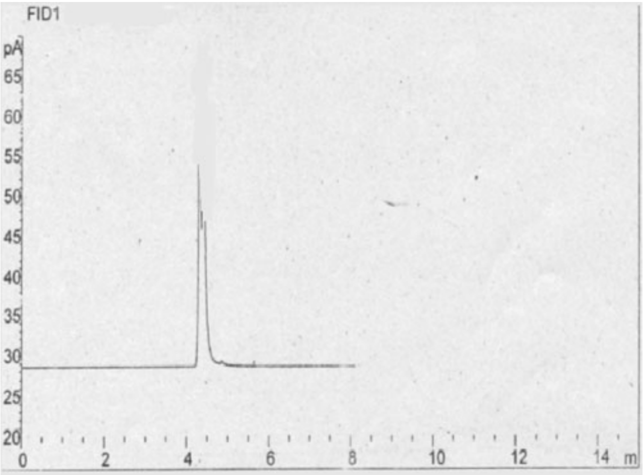

Fig. 7 Ethanol produced at 50% acid concentration

and 10 g of urea were added. The flask was plugged with cotton at the neck to prevent overflow of sample and closed tightly to maintain anaerobic environment for the conversion of reducing sugar to ethanol. The sample was shaken in the thermo shaker for 8 h at 117 rpm. Temperature was adjusted to 30–31°C. The following results were obtained.

In Fig. 6, the peak shows that at 20% acid concentration, 595.85 μl ethanol was produced. Highest volume of ethanol was achieved in a sample containing 24% sugar.

In Fig. 7, the peaks show decrease in ethanol (100 μl) in the sample containing 50% acid concentration. This volume of ethanol is gradually decreased than that in

Table 2 Ethanol production from hydrolyzed samples

S.no.	% of H_2SO_4	Recovery of sugar (mg/ml)	Ethanol produced (μl)
1.	10	18	89.00
2.	20	24	595.85
3.	30	22	165.60
4.	40	21	120.33
5.	50	19	100.00

the previous result at 40% acid concentration. Using higher acid concentration may harm the cellulose and burn it, thereby decreasing the sugar recovery, which is not beneficial.

In Table 2, hydrolysis of samples at different acid concentrations and ethanol recovery are reported. The result showed that the sample hydrolyzed using 20% H_2SO_4 produced the highest volume of ethanol, 595.85 μl. This quantity 0.59585 l/kg is compared with that of the previous research work, in which ethanol extracted from banana fruit was 0.091 l/kg, banana pulp 0.082 l/kg, and banana peel 0.006 l/kg (Hammond et al. 1999). If we calculate this amount of ethanol produced from 1 ton of banana cellulose, it comes around 12.8 l of ethanol/ton. This result is close to commercial ethanol yield around the world, which is 13 l of ethanol/ton of cellulose.

4 Conclusions

- The results of gas chromatograph showed that sample containing the highest sugar recovery of 24% reported the highest volume of ethanol 595.84 μl.
- The optimized conditions for acid hydrolysis were 20% at 80°C for 2-h reaction time.
- It was also found that a smaller particle size of 149 μm increases the sugar recovery.
- Pakistan is an agricultural country enriched with agriculture products producing abundant quantities of agricultural waste such as banana waste, rice husk, wheat straw, cotton waste, and saw dust. These cellulosic materials may be used to produce ethanol, thereby providing solution to current energy crises in Pakistan.
- The use of ethanol in automobile can enhance the octane rating by 10% by blending ethanol in gasoline from 91 to 98. In this way, higher octane number of ethanol may give higher compression ratio and decreases air pollutants.
- The potential benefits of production of ethanol include its ability to compete with petroleum prices to reduce hazardous emission, to create jobs in new areas, and to enhance farmer's income.
- Further improvements in acid hydrolysis method can be achieved if the amount of acid used can be reduced without affecting the sugar yield.
- Method for recovery of acid after hydrolysis is the most important area in which acid can be recovered by solvent extraction method.

- Study can be done on azeotropic distillation which can produce from 98 to 99% grade ethanol.
- Greenhouse gas emissions can be reduced by using bio-resource for ethanol production in order to meet the present energy crises.

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