POLLUTION CONTROL AND RESOURCE RECOVERY: INDUSTRIAL CONSTRUCTION AND DEMOLITION WASTES

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PREFACE

Construction and demolition (C&D) waste is one of the largest components of solid wastes generated from municipal activities. Large-scale urbanization and building construction have been playing an essential role in the Chinese arena, which will also lead to a large volume of C&D wastes generated in the next several decades.

Hazardous components such as heavy metals and persistent organic pollutants exist in C&D wastes during the demolishment of chemical industry (electroplating factory), metallurgical industry (zinc smelting plant, steel plant), light industry, processing enterprises, pesticide industry, and fire/explosion disaster sites. Once they become C&D waste and the concentrations of hazardous substances exceed a certain value, they will be the source of contamination. In one hand, such contaminated wastes may bring potential environmental risks to the atmospheric and subsurface system, volatilizing into the air, accumulating in topsoil, and contaminating groundwater when disposed of in unprotected landfills or randomly stacked over time. On the other hand, for the very small fraction (approximately 5%) of C&D waste that flow into the renewable building material industry, scarcely any environmentally benign processes have been utilized because only the physical properties of the products are focused on.

The pollution source of industrial C&D waste can be very complex. Even within the same industry, the pollution characteristics between different processes vary significantly. The contamination caused by the leakage of agents and catalysts from the equipment has made the situation even worse. The current study on the pollution control and clean reuse for these wastes is very limited. No specific treatment methods can be referred, and they are disposed and reused in the same way as ordinary C&D waste. The ordinary C&D waste can be safe for reuse due to its non-toxicity. However, the industrial C&D waste contaminated by heavy metals, organic pollutants, or those generated in earthquakes and explosion accidents should be treated properly before reuse.

In this book, pollution control and resource reuse for industrial C&D wastes contaminated by heavy metals, organic pollutants, and those generated in earthquakes and explosion accidents has been fully described. The current situation of C&D waste management is introduced first. The representative sampling methods and equipment, pretreatment and analysis, generation and pollution characteristics of hazardous C&D waste, migration potential and patterns of pollutants during random stacking and landfilling, pollution controlling methods, environmental risk assessment, reuse technologies, recycled products treatment, and policy and management approaches are also included. The whole process of "source identification—classified separation and enrichment—site monitoring and evaluation—heavy metal stabilization and solidification—organic matter degradation—dust controlling—clean and high value utilization of recycled aggregate—reuse and risk assessment—management and policy support" have been practiced and given. Several engineering projects with annual handling capacity of 30,000 and 1,000,000 t C&D waste are introduced in detail. The readers include solid waste engineers, managers, technicians and maintenance staff, recycling coordinators and government officials, undergraduates and graduates, and researchers.

SUMMARY

Hazardous components such as heavy metals and persistent organic pollutants exist in construction and demolition (C&D) waste during the demolishment of chemical, metallurgical, light, processing, and pesticide industry along with fire/explosion disaster sites. In this book, current management situation, sampling technologies, pretreatment and analysis, generation and pollution characteristics of hazardous C&D waste, migration potential and patterns of pollutants, pollution controlling methods, environmental risk assessment, reuse technologies, policy and management approaches, and several engineering projects with annual handling capacity of 300,00 t and 1,000,000 t C&D waste are introduced in detail with the purpose of drawing attention to the pollution control of C&D waste prior to recycling and providing proper alternatives for engineers to address the C&D waste issues faced.

ABBREVIATIONS

ABS Absorption factor
AF Waste to skin adherence factor
ANC Acid neutralizing capacity
AT Averaging time
BCR Community Bureau of Reference
BHC Benzene hexachloride
BW Body weight
C&D waste Construction and demolition waste
CA Citric acid
CCME Canadian Council of Ministers of the Environment
CEPA Chinese Environmental Protection Administration
CESQG Conditionally exempt small quantity generators
CI Chemical industry
CRG Contaminated recycled gravel
CTC Carbon tetrachloride
DDD Dichloro-diphenyl-dichloroethane
DDT Dichloro-diphenyl-trichloroethane
EC Electric conductivity
ED Exposure duration
EF Exposure frequency
EPA Environmental protection agency
$\mathrm{ET}_{\mathrm{(ind)}}$ Proportion of the daily exposure time indoor
$\mathrm{ET}_{\mathrm{(out)}}$ Proportion of the daily exposure time outdoor
EU European Union
F1 Acid extractable fraction
F2 Reducible fraction
F3 Oxidizable fraction
F4 Residual fraction
FT-IR Fourier transforms infrared spectra
GC-MS Gas Chromatography-Mass Spectrometer
HAs Humic acids
HCB Hexachlorobenzene
HPLC High performance liquid chromatography
ICDW Industrial construction and demolition waste
ICP Inductive coupled plasma
ICP-OES Inductively coupled plasma-optical emission spectrometry
INH Inhaled amount of air by an adult
IR Inhalation rate of waste
IR_{f} Ingestion rate of food
IRG Initial recycled gravel
IR_{w} Ingestion rate of underground water
LI Light industry
MEP Multistage extraction procedure

MI Metallurgical industry
NA Not available
NDRC National Development and Reform Commission
OPPs Organophosphorus pesticides
PAHs Polycyclic aromatic hydrocarbons
PC Power consumption
PCA Principal component analysis
PCB Polychlorinated biphenyl
PI Pesticide industry
PIAF Retention ratio of inhalable waste particles in body
POPs Persistent organic pollutants
PPs Pyrethroid pesticides
RAC Risk assessment code
RBCA Risk-based corrective action
RC Recycled aggregates
RCRA The resource conservation and recovery act
RfD Reference dose
RfD_d Dermal chronic RfD
RfD_i Inhalation chronic RfD
RfD_o Oral chronic RfD
RS Residential aggregates
RSD Relative standard deviation
SA Skin surface area available for contact
SEM Scanning electron microscopy
SFd Dermal slope factor
SF_i Inhalation slope factor
SF_o Oral slope factor
SPE Solid Phase extraction
SPLP Synthetic precipitation leaching procedure
TCLP Toxicity characteristic leaching procedure
TDS Total dissolved solids
TPH Total petroleum hydrocarbon
TSP Total suspended particulate content in air
TVHM The threshold values of heavy metals
$TVHM^{e3}$ The threshold values of heavy metals Level-III
VOCs Volatile organic compounds
WFD Waste Framework Directive
XPS X-ray photoelectron spectroscopy
XRD X-ray diffraction
XRF X-ray fluorescence
ZHE Zero headspace extractors

LIST OF ENVIRONMENTAL CRITERIA AND STANDARDS INVOLVED

"Canadian environmental quality guidelines" (CEQGs)
"Code for design of building fire protection" (GB 50016-2014)
"Code for seismic design of buildings" (GB50011-2010)
"Discharge standard of pollutants for municipal wastewater" (GB18918-2002)
"Environmental quality for soils" (GB15168-1995)
"Environmental quality risk assessment criteria for soil at manufacturing facilities" (HJ-T 25-1999)
"Environmental quality standard for surface water" (GB3838-2002)
"Evaluation standard for green building" (GB/T 50378-2014)
"Load code for the design of building structures" (GB50009-2012)
"Identification standards for hazardous wastes-Identification for leaching toxicity" (GB 5085.3-2007)
"Industrial Construction Anticorrosion Design" (GB 50046-2008)
"Industrial solid waste sampling and preparation technical specifications" (HJ/T 20-1998)
"Integrated wastewater discharge standards" (GB8978-1996)
"Multistage extraction procedure" (EPA 1320)
"Solid waste-Extraction procedure for leaching toxicity-Acetic acid buffer solution method" (HJ/T-300)
"Solid waste-extraction procedure for leaching toxicity-sulphuric acid & nitric acid method" (HJ/T-299)
"Standard for pollution control on the security landfill site for hazardous wastes" (GB 18598-2001)
"Standard of soil quality assessment for exhibition sites" (HJ 350-2007)
"Standard Test Method for Leaching Solid Material in a Column Apparatus" (ASTMD 4874-95-2001)
"Standards for drinking water quality" (GB5749-2006)
"Synthetic precipitation leaching procedure" (EPA 1312)
"Technical guidelines for construction of highway road bases" (JTJ034-2000)
"Toxicity characteristic leaching procedure" (EPA 1311)

CHAPTER ONE

General Introduction of Construction and Demolition Waste

1.1 DEFINITION, SOURCE, AND CLASSIFICATION

Construction and demolition (C&D) waste has become an enormous part of municipal solid wastes since 1990s due to rapid urbanization and industrialization process. There is not much criteria for C&D waste management in China, which have led to its explicit definition and coverage. It is traditionally recognized that C&D waste is the debris generated during the construction, renovation, and demolition of buildings, roads, and bridges, such as concrete, wood, metals, glass, and salvaged building components. "Regulations on municipal construction waste and engineering sludge (Revised version)" established by the Ministry of Construction in 2003 issued a wider definition of C&D waste in which the sludge, muck, and mud were also included.

C&D waste can be classified into five categories depending on its source: (1) Land excavation waste, which refers to the waste generated during the process of land excavation, including topsoil and deep soil. (2) Road excavation waste, which can be divided into concrete and asphalt road waste, including waste concrete block, asphalt, concrete blocks, etc. (3) Building demolition waste, including stone, concrete, sediment, wood, mortar, roofing scrap, steel, and metal, etc. (4) Construction waste, which is generated during construction and renovation projects, including discarded bricks, concrete, stone, mortar, wood, plastic, glass, etc. (5) Building materials waste, which mainly refers to the waste generated during the production process of building materials.

C&D waste can also be classified according to its recycling. Its recycling represents the recovery of useful energy and substances from construction waste through material recycling, material exchange, energy conversion, and other management or technical ways.

Except for the C&D waste derived from civilian buildings, industrial C&D waste and the subsequent hazardous substances should not be ignored.

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This means C&D waste can be classified into two groups: common C&D waste and hazardous C&D waste. The hazardous C&D waste contains pollutants or other poisonous substances which exceed their legal limits. A large proportion of hazardous C&D waste comes from the industrial workshops, which is namely industrial C&D waste. It possesses the characteristics of both hazardous waste and C&D waste, reflecting in its massive production and high environment risk. Strict treatment should be employed before the hazardous C&D waste is disposed or reused.

1.2 COMPONENTS AND CHARACTERISTICS OF HAZARDOUS INDUSTRIAL CONSTRUCTION AND DEMOLITION WASTE

Common C&D waste may pose lasting harms on the environment and ecology. Sediment, rubble, and other inert construction waste do not seem to cause much adverse environmental impact due to their inertness. But various kinds of organic acid will be emitted if they are piled without any pretreatment. The resultant leachate can also contain heavy metals that will contaminate the underground water, soil, and air.

C&D waste mentioned in this book varies from ordinary waste in its industrialized source and hazardous characteristics that occupy a large proportion of industrial C&D waste as discussed earlier. The main pollutants can be classified as heavy metals and persistent organic pollutants. Industrial C&D waste like lead-based paint, fluorescent lamps, asphalt (pavement and roof), wood preservative, and asbestos are all hazardous C&D waste, mainly from the chemical industry (electroplating factory), metallurgy (zinc smelting plants), light industry, and pesticide enterprises. The complex contamination may result from equipment maintenance and leakage, pipeline leak, as well as flotation agents, catalysts, preservatives, and other pollutants.

In chemical, metallurgy, thermal, light and other industrial enterprises, heavy metals, sulfates, organic matter (such as polycyclic aromatic hydrocarbons), and other toxic substances inevitably leak and spill on the wall or ground in the process lines, in which the contaminants will be leached by rain and thus transferred to the surrounding soil and water environment. Knowledge and executive management of industrial C&D waste are lacking in most countries nowadays, resulting in the ineffective disposal and regulation, which has largely retarded the sustainable development.

1.3 ESTIMATION OF CONSTRUCTION AND DEMOLITION WASTE PRODUCTION

In general the C&D waste production is added by construction, demolition, and renovation waste amount. The detailed estimation methods are introduced below.

1. The production of construction waste can be estimated in three ways. (1) Calculation based on the construction area. Commonly, 30 m^2 construction waste is generated within a 1000 m^2 construction area. For brick and frame structure, 500–600 t construction waste is generated in a 10,000 m^2 construction area. (2) Calculation based on the material consumption. Commonly, it is reasonable to estimate the production amount of C&D waste according to the material consumption. C&D waste proportion of the materials consumed is listed in Table 1.1 (3) Calculation based on the urban population output ratio. Related statistics show that the reasonable output ratio is 100 kg C&D waste production for each person annually.
2. The demolition waste of old buildings. No exact statistics is available due to the relatively complex characteristic of such waste. It can be estimated using the empirical coefficient method and the construction budget estimation method. (1) Empirical coefficient method. According to the Japanese residential completion report in 1999, 1.86 t of demolition waste is generated per square meter of demolition area. In China, the value is 1.35. The coefficient is usually affected by a variety of factors. (2) Construction budget estimation method. This method is generally used as a reference model due to the uncertainty of construction materials characteristics.

Table 1.1 Proportion of Construction and Demolition Waste in Total Materials Consumed

Main Components of C&D Waste	Proportion of the Materials Consumed (%)
Brick	3–12
Mortar	5–15
Concrete	1–4
Pile head	5–15
Roof material	3–8
Steel	2–8
Wood	5–10

3. Renovation waste. Since the public buildings involve large construction area and complex renovation process, as well as multiple material usage, which are different from residential building, these two kinds of buildings should be separated in the estimate of C&D waste production. According to the renovation waste generation standard of Luoyang, China, for building area of more than 160 m^2 the renovation waste can be calculated as 0.15 t/m^2, otherwise, it is 0.1 t/m^2.

Besides, another C&D waste yield estimation model is based on five different engineering projects, including building construction projects, road and municipal construction projects, material production projects, demolition projects, and renovation projects. Estimation formula and waste yield coefficients are listed in Table 1.2.

1.4 MANAGEMENT SITUATION OF CONSTRUCTION AND DEMOLITION WASTE IN CHINA AND DEVELOPING COUNTRIES

With the economic development and industrial restructuring, a number of real estate projects have been established and developed in China since 1990s. Meanwhile, there are many industrial plants either being removed or converted, thereby generating a huge amount of C&D waste. The [2011] No. 2919 paper issued by National Development and Reform Commission (NDRC) published the "'12th five-year' guidance of comprehensive resources utilization" and the "bulk solid waste utilization plan," in which the ten key demonstration projects were defined, including the construction waste projects. Several megatons of C&D waste recycling bases and equipment manufacturing projects were to be established. Forty million tons of annual utilization capacity was expected to increase. The comprehensive utilization ratio of municipal C&D waste was tentatively expected to rise to 50%.

Unfortunately the planned recycling projects for C&D waste have not been well implemented, and most projects were actually cut or terminated due to the lack of collection system and relatively high cost compared with the primary sources. The main existing management problems that have led to the ineffective disposal and reuse of C&D waste in China are listed below.

1. Deficient standards and regulations

Compared with developed countries, relevant regulations and standards started late in China, the existing regulations are more limited in their coverage and with blind spots in management. Many regulations published such as "Law

Table 1.2 Estimation Formula and Waste Yield Coefficients of Different Engineering Projects

Types	Estimation Formula	Waste Yield Coefficients	
Building construction	Main construction waste amount = Construction area × waste yield coefficient	$0.05\ t/m^2$	Brick and concrete
		$0.03\ t/m^2$	Concrete
	Foundation excavation construction waste amount = (excavation − backfill) × waste yield coefficient	$1.6\ t/m^3$	
Road and municipal construction	Waste amount = (excavation − backfill) × waste yield coefficient	$1.6\ t/m^3$	
Material production	Material production waste amount = total mass of materials × waste yield coefficient	0.02	
Demolition	House demolition waste amount = demolition area × waste yield coefficient	$0.8\ t/m^2$	Brick and wood
		$0.9\ t/m^2$	Brick and concrete
		$1\ t/m^2$	Concrete
		$0.2\ t/m^2$	Steel
	Structure demolition waste amount = demolition volume × waste yield coefficient	$1.9\ t/m^3$	
Renovation	Public architectural demolition waste amount = total cost × waste yield coefficient	2 t/10,000 Yuan	Office building
		3 t/10,000 Yuan	Commercial building
	Residential building demolition waste amount = building area × waste yield coefficient	$0.1\ t/m^2$	Less than $160\ m^2$
		$0.15\ t/m^2$	More than $160\ m^2$

of the People's Republic of China on the prevention and control of environmental pollution by solid waste" and "Rules for the implementation of the administration regulations of city appearance and environment sanitation" have put forward specific demands for the dumping, transportation, transit, backfilling, consumptive use, and other disposal activities of C&D waste. However, the pollution control for industrial C&D waste and its management is not involved. No relevant regulations and technologies are available.

2. Unreasonable supervision mode and unclear management responsibilities

The national Solid Waste and Chemicals Management Center and 31 province-level solid waste management centers have been set. But C&D waste is not involved. On the macro level the collection, transportation, disposal, and utilization of C&D waste are managed by the local construction and urban management departments. However, the contaminated C&D waste has not been effectively supervised and regulated by the environmental protection department. As a result the hazardous waste mixed in C&D waste is sent into regular disposal and reuse systems, which will cause severe environmental pollution with the migration of pollutants.

3. Inadequate understanding of environmental risks and lack of control measures

Organic matters and heavy metals in contaminated C&D waste are migrated into soil and aquatic systems with rain and will cause harm to the aquatic organisms and human health. Therefore a comprehensive and systematic inventory of contaminated C&D waste pollutants by industry, pollution control and generation list are necessary to be established for the setting and amendment of pollution control standards and regulations by the relevant departments.

1.5 CURRENT DEVELOPMENT OF CONSTRUCTION AND DEMOLITION WASTE WORLDWIDE

Utilization ratio of C&D waste in the EU exceeds 50% while that in South Korea and Japan reaches 97%. A lot of work in the circular economic legislation has been established, including a series of laws, regulations, and policies in the reuse, recycling, and reduction of C&D waste. These laws, regulations, and policies have made it clear the responsibilities and obligations related to the main responsibility in the treatment of C&D waste and have even made the plan targets of the recovery, promoting its minimization and recycling. Relevant legal and regulatory systems of C&D waste worldwide are shown in Tables 1.3 and 1.4.

Table 1.3 Relevant Laws and Regulations Worldwide for Construction and Demolition Waste

Countries	Laws and Regulations	Main Contents
Germany	"Regulation on the disposal of commercial wastes and certain building and demolition wastes," "Act on Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal," etc.	The waste generators or owners are obliged to recycle and reuse, and it should be preferential treatment of waste. Classification is necessary.
Britain	"Sustainable development in the construction industry," "Waste Strategy," etc.	Zero landfill of C&D waste is targeted till 2020.
United States	"The Superfund law," "Solid waste disposal," etc.	Source reduction should be carried out in some manufacturing companies. Some other regulations are also put forward.
Japan	"Waste Management Act," "Law for Promotion of utilization of recycled resources," "Construction material recycling law," etc.	Responsibility on classified demolition and reuse is clearly regulated. Recycling of concrete and other C&D waste and their treatment methods are also ruled.
Singapore	"The Singapore green Plan 2012," etc.	Waste reduction is included in the criteria system. C&D waste recycling is included in the Green Mark certification.

Table 1.4 Relevant Regulatory Systems Worldwide for Construction and Demolition Waste

Countries	Regulatory Systems	Main Contents
Germany	Charge system	Charge for the storage of untreated C&D waste. Fine for the random dumping of C&D waste
Britain	Tax system	Tax on dumping, landfilling, and incineration of C&D waste
United States	Advocacy by government while self-regulation by enterprises	Based on government-led control methods, improved by the market stimulus policies. The mode of advocacy by government while self-regulation by enterprises is to be established.
Japan	Whole process management	Whole process management is carried out in the generation, collection, disposal, and recycling of C&D waste
Singapore	Tax management, franchising, acceptance inspection, etc.	Levy a landfill tax on C&D waste. Franchise license is issued for C&D waste treatment business. Disposal of C&D waste is included in the criteria index of the project.

1.5.1 United States

C&D waste is divided into three categories in the United States. Firstly, inert or nonhazardous waste, secondly, hazardous wastes, and thirdly, waste containing dangerous ingredients. Most of C&D waste is harmless, which belongs to the first category. According to "The Resource Conservation and Recovery Act, RCRA," this kind of waste is not under the jurisdiction of the EPA, while it is managed by the state or local government. However, the second category, hazardous C&D waste, of which its generation, storage, transport, and disposal is under EPA regulation. Since most waste in the C&D waste landfill is inert the federal government does not require that those landfills should be equipped with the same environmental protection measures as municipal solid waste landfills. Research shows that regulations of C&D waste in different states are not consistent, antiseepage landfill is required in 23 states, groundwater monitoring is demanded in 27 states, while laws about the C&D waste recycling have been established in 17 states.

The Resource Conservation and Recovery Act, RCRA was published in the United States early in 1967, generator status is determined on a monthly basis, most C&D waste is considered nonhazardous solid wastes. The federal Hazardous and Solid Waste Amendments (HSWA) are the 1984 amendments to RCRA that focus on waste reduction and phasing out land disposal of hazardous waste as well as corrective action for its releases. Conditionally exempt small quantity generators (CESQG) is defined as those generated 100 kg or less per month of hazardous waste, or 1 kg or less per month of acutely hazardous waste. CESQG waste can be disposed of in solid waste landfills (40 CFR Parts 258). If C&D debris is sent to municipal solid waste landfills or landfills that accept CESQG waste, those landfills must still meet federal regulations set forth in RCRA, Subtitle D.

According to statistics the annual C&D waste generation in the United States is about 325 million tons, accounting for 25—40% of the total waste, most of which eventually enter the municipal waste landfill or C&D waste landfill. Governments are also actively exploring ways to reduce the land occupation by increasing the recycling rate of C&D waste. In California, for example, the government has made the minimum recovery requirements of the construction companies. In Florida, C&D waste is separated through manual sorting; the remaining residue is then landfilled.

1.5.2 European Union

There is a comprehensive and detailed classification and coding of C&D waste in EU, in which it is divided into eight categories. (1) Concrete, bricks, tiles, and ceramics (1701). (2) Wood, glass, and plastic (1702). (3) Bitumen, tar, and asphalt (1703). (4) Metal and alloy (1704). (5) Soil (including excavated soil from contaminated sites), stones, and dredging waste (1705). (6) Insulation materials and asbestos-containing construction materials (1706). (7) Gypsum building materials (1708). (8) Other C&D waste (1709), including those containing mercury, PCB, and other hazardous materials. The different types of wastes in the list are fully defined by the six-digit code for the waste and the respective two-digit and four-digit chapter headings.

Waste Framework Directive, WFD, 2008 sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling, and recovery. It includes a new recycling and recovery target to be achieved by 2020: 70% preparing for reuse, recycling, and other recovery of C&D waste.

Overall the European C&D waste management policies and standards can mainly be divided into five categories. (1) The waste policy framework, a national policy with "Waste Framework Directive" as its basis. (2) The provisions of the landfill, for example, the restrictions on landfills in Flanders (Belgium) effectively improved the recycling rate of C&D waste. (3) C&D waste policy. A C&D waste implementation plan was exerted in Flanders in 1995. As a country with the earliest C&D waste policies the recovery rate of C&D waste in Belgium already reached 85% in 2000. (4) Standards for recycled products. In addition to national mandatory standards, there are also some recommended industry standards such as the C&D waste recycled products quality assurance guideline issued by the German Federal Building Materials Recycling Association. (5) Standards for the places where C&D waste is generated, mainly for the management in building construction sites and demolition processes. There are two parts about the regulations of the C&D waste in the standards set by German Sustainable Building Council.

According to Eurostat data, C&D waste generation reached 819 million tons in the European Union in 2012, accounting for about 25—30% of the total waste, of which the average recovery rate was 25%. The recovery rate is above 80% in Netherlands, Belgium, Germany, and Denmark, while that is less than 5% in Spain, Portugal, and Greece, which is related to the management situation in each country. In Germany the most common method of waste management is called "controlled demolition". Plans should be developed before demolition, which must include the concept of controlled demolition and waste recycling, treatment, etc. Contaminated materials must be removed first, and then the useful parts such as doors and windows, heating systems, etc. Sorting system was added in the demolition site (in accordance with brick, concrete, wood, etc.).

1.5.3 Japan

C&D waste in Japan is classified into concrete blocks, wood, asphalt, building sludge, and mixed building waste. Among these, the mixed waste refers to the bricks, paper, wood, plastics, plasterboard, glass, metals, etc., which are discharged during the construction projects. C&D waste is treated by specialized enterprise, including rough and fine sorting, first large wood chunks and packaging cartons are manually sorted, and then other waste is further subdivided by mechanical assembly line. The nonrecyclable residues are either landfilled or incinerated according to their flammability.

Emissions of C&D waste in Japan are about 80 million tons, and the resource utilization exceeded 75% in 2000. It is a large decrease compared with the 100 million tons of emission in 1990s. The progress in waste minimization and resource is closely related to the encouragement in source reduction and recycling. In addition the research and applied technology also play an active role. The source reduction is focused and applied in the project planning and design phase, by developing, manufacturing, and widely using the building materials in which the generation of scraps could be controlled. In C&D waste recycling the waste concrete is manufactured into renewable gravel, recycled concretes, and recycled graded gravel, etc. through the crushing, screening, cleaning, and particle size adjustment process, which can be used for road paving. The wood chips made of waste wood can be used as wood panels, raw material for compost, and fuel. The building sludge is used for backfilling after being pressed and stabilized.

1.6 GENERAL PROCESSES OF DISPOSAL AND RECYCLING FOR CONSTRUCTION AND DEMOLITION WASTE

The term C&D waste treatment encompasses all alternatives that facilitate transport, storage, reuse, or final disposal processes. Traditional disposal and recycling are the two pathways of C&D waste treatment nowadays, including backfilling, stacking, landfilling, sea reclamation, and road pavement. No sorting or source separation is needed, and very coarse and simple crushing process can meet the requirements of these ways of disposal. Recycling commonly includes the manufacturing of various products which aims at turning C&D waste to regenerated resources. An overview of various alternatives for treatment and disposal is presented in Fig. 1.1.

General process for disposal and recycling of C&D waste includes pretreatment, crushing and sorting, classified storage, and deep processing, a typical flow sheet of these process is demonstrated in Figs. 1.2–1.5.

The C&D waste coming out of the feeder is sent into the jaw crusher for primarily crushing. Generally particle size is controlled less than 80 mm to meet the requirement of the iron removal and sorting. The iron remover and manual sorting platform aim at separating reinforcement bars or large blocks.

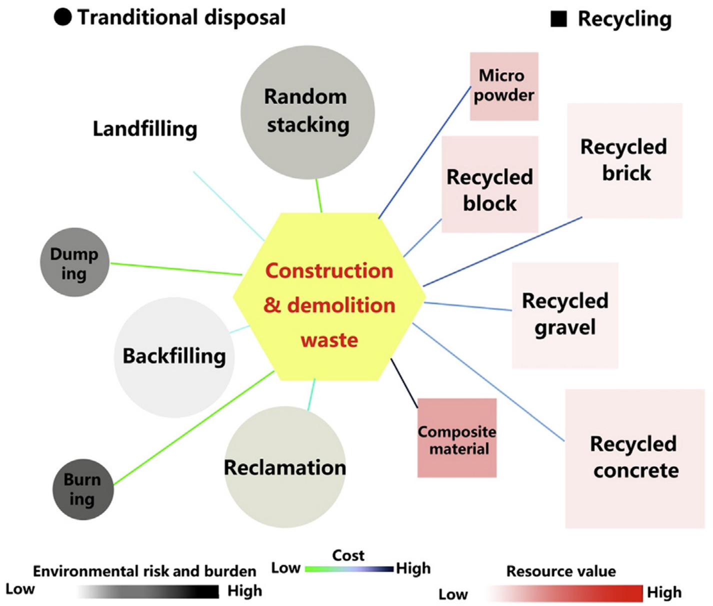

Figure 1.1 Treatment and disposal routes of construction and demolition waste.

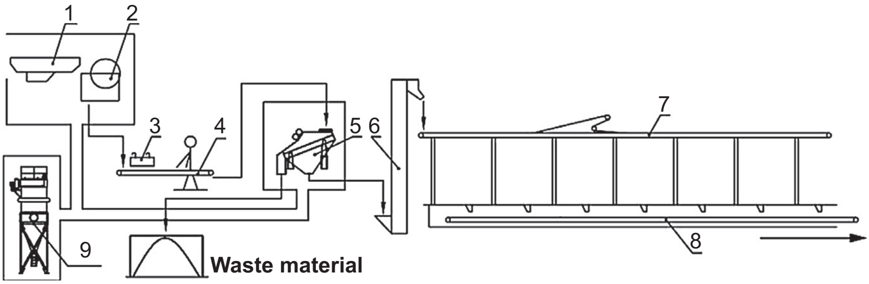

Figure 1.2 General pretreat process for disposal of construction and demolition waste, 1-feeder, 2-jaw crusher, 3-iron removal platform, 4-manual sorting platform, 5-straight vibrating screen, 6-bucket elevator, 7-stacker, 8-conveyor belt, 9-dust catcher.

The C&D waste is then sent into the impact crusher for secondary crushing. The secondary crushing operation is then combined with the vibrating screen aiming at the fine crushing of waste and dividing them into different scales. Wind sorting machines are used to separate the light materials such as plastic and wood.

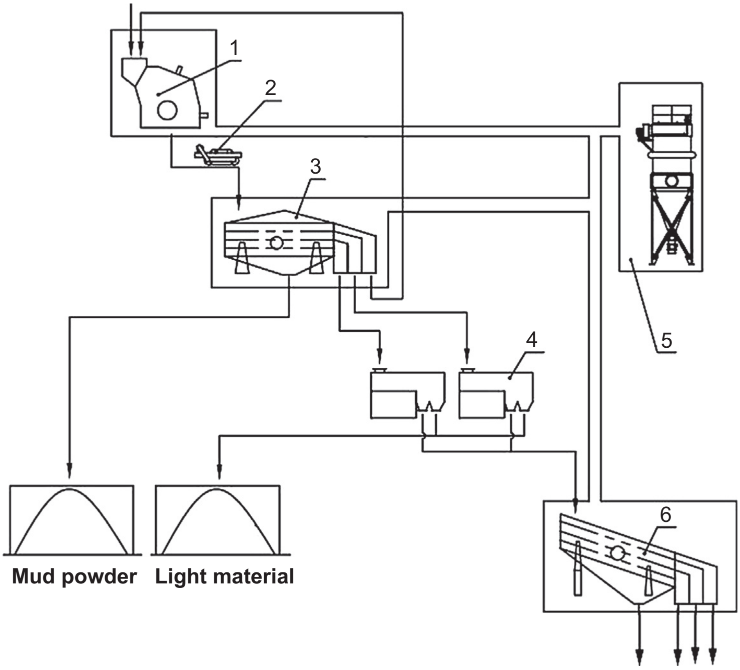

Figure 1.3 General crushing and sorting process for disposal of construction and demolition waste, 1-impact crusher, 2-iron remover, 3-straight vibrating mud remover, 4-whirl tube sorting machine, 5-dust catcher, 6-circular vibrating screen.

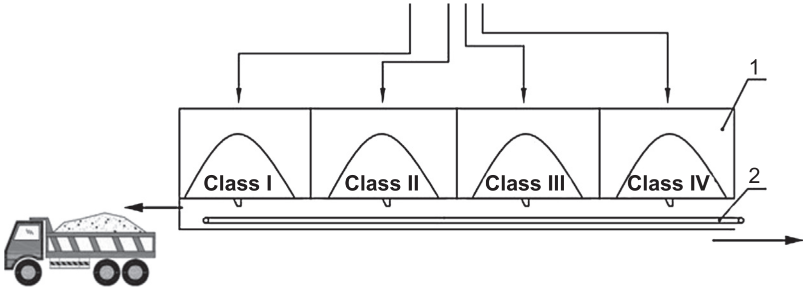

Figure 1.4 General classified storage process for disposal of construction and demolition waste, 1-storage warehouse for semifinished products, 2-conveyor belt.

The materials in classified storage section are semifinished products which are divided into several classes (usually four: 0–5 mm, 5–15 mm, 15–22 mm, and 22–31.5 mm). The function of storage warehouse is to continuously feed for the combined grinding and load for sale of semifinished products.

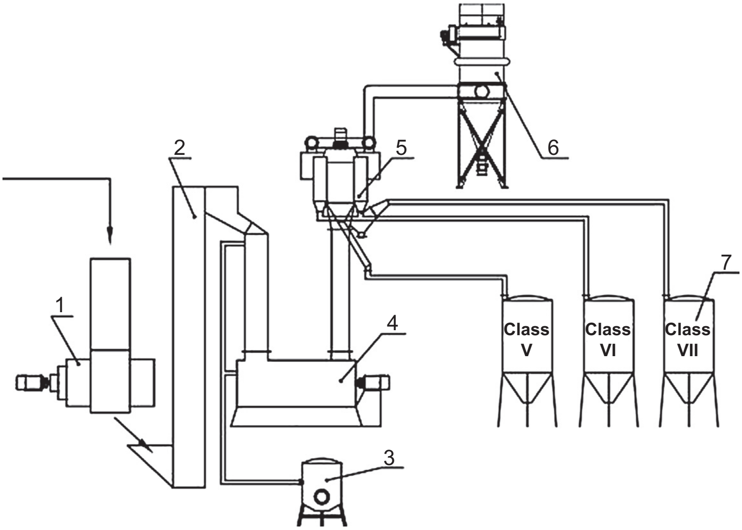

Figure 1.5 General deep processing for disposal of construction and demolition waste, 1-high pressure rolling machine, 2-bucket elevator, 3-boiling furnace, 4- whirlcone conical grinder with dryers, 5-combined powder separator, 6-dust catcher, 7-storage tank.

The materials with a high quality have already been sorted and removed of mud, impurities, and iron. They are first transported into the roll press for tertiary crushing and grinded to particles. The ground materials are classified into several classes (usually three: 0–0.08 mm, 0.08–0.16 mm, and 0.16–2.36 mm) and are collected in the tanks respectively.

CHAPTER TWO

Sampling Techniques and Equipment for Construction and Demolition Waste

2.1 REPRESENTATIVE SAMPLING TECHNIQUES FOR CONSTRUCTION AND DEMOLITION WASTE

2.1.1 In Situ Identification and Lab Analysis of Existing Pollutants

2.1.1.1 Identification for Heavy Metal Contaminated Industrial Construction and Demolition Waste

The scope and depth of the heavy metal contamination in the manufacturing and building structures involved in the processes with heavy metals is determined by pollutant identification methods before demolition or renovation. Heavy metals can penetrate into 2 cm of industrial construction and demolition (C&D) waste from the surface and cause severe contamination when the waste is exposed to heavy metals in solution. In industrial workshops, especially in older factories where the lack or failure of protection measures exist, the contamination may penetrate under 2 cm of industrial C&D waste. Identification methods are listed as follows.

1. In situ identification

   Site investigation should be performed before demolition or renovation of the factories by obtaining knowledge of the plant layout and making the monitoring plans. Various types of portable instruments for sample analysis and identification can be used, such as a handheld X-ray fluorescence (XRF) analyzer. According to archeometry laboratory, XRF spectrometry is an elemental analysis technique with broad application in science, research, and industry. XRF is based on the principle that individual atoms, when excited by an external energy source, emit X-ray photons of a characteristic energy or wavelength. By counting the number of photons of each energy emitted from a sample, the elements present may be identified and quantitated. This technique has already been widely used in quick analysis of environmental pollution survey of poisonous and harmful substances. A portable XRF analyzer can be used as preliminary on-site pollution identification equipment.

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2. Laboratory analysis

When there is no requisite for in situ identification, on-site sampling—laboratory analysis approach should be adopted as a supplement contamination identification method. Laboratory analysis includes full quantitative analysis and leaching toxicity analysis. Full quantitative analysis can be performed by microwave digestion—Inductive Coupled Plasma (ICP), mixed acid digestion—ICP detection, or XRF tests. For the leaching toxicity analysis, there are both EPA method and People's Republic of China environmental protection industry standard, using sulfuric acid and nitric acid as agents.

a. Identification limits of pollutants

Requirements for the contents of heavy metals in cement are listed in Table 2.1.

The heavy metals in building materials which eventually become C&D waste might increase through the deposition—adsorption of dust. The concentrations of heavy metals in uncontaminated C&D waste are listed in Table 2.2.

The final disposal environment of C&D waste has a great relevance to the soil environment. Therefore environmental quality standards for soil are also referred to Table 2.3.

Based on the data above the C&D waste can be divided into three categories, firstly, ordinary waste, uncontaminated by heavy metals, recycling is allowed; secondly, waste slightly polluted by heavy metals, a simple treatment is needed before being landfilled or utilized; thirdly, hazardous waste, strict treatment must be performed before being landfilled or utilized. The classification and pollution concentration regulation is listed in Table 2.4.

b. Leaching toxicity

Values presented in "Identification standards for hazardous wastes - Identification for leaching toxicity" (GB 5085.3—2007) are listed in

Table 2.1 Requirements for Heavy Metals Contents in Cement

Elements	Cement Clinker (mg/kg)	Cement (P.I) (mg/kg)
Zn	500	—
Cu	100	—
Pb	100	—
Cd	1.5	1.5
Cr	150	—
Ni	100	—

Table 2.2 Concentrations of Heavy Metals in Uncontaminated Construction and Demolition Waste

Zn (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Ni (mg/kg)
107	77	18	—	107	⋆
95	42	25	0.5	44	19
228	35	43	—	90	28
290 ± 381	50 ± 60	92 ± 111	2.0 ± 1.7	21 ± 13	76 ± 62
409	208	⋆	⋆	⋆	⋆
59	15	11	2.6	20	11
70	15	25	0.3	104	25
52.3 ± 0.7	9.82 ± 0.7	6.6 ± 0.19	2.75 ± 0.14	87.8 ± 9.0	6.39 ± 0.19

⋆, Not being determined; —, undetected.

Table 2.3 Environmental Quality Standards for Soil

Elements	Level I (Natural Background)	Level II (pH > 7.5)	Level III (pH > 6.5)
Zn (mg/kg)	100	300	500
Cu (mg/kg)	35	100 (farmland), 200 (orchard)	400
Pb (mg/kg)	35	350	500
Cd (mg/kg)	0.20	0.6	1.0
Cr (mg/kg)	90	350 (paddy field), 250 (dry land)	400 (paddy field), 300 (dry land)
Ni (mg/kg)	40	60	200

Table 2.4 Classification of Construction and Demolition Waste Contaminated by Heavy Metals

Elements	Ordinary Waste (mg/kg)	Waste Slightly Contaminated by Heavy Metals (mg/kg)	Hazardous Waste (mg/kg)
Zn	≤500	500—5000	≥5000
Cu	≤250	250—2500	≥2500
Pb	≤350	350—3500	≥3500
Cd	≤3	3—30	≥30
Cr	≤300	300—3000	≥3000
Ni	≤100	100—1000	≥1000

Table 2.5. The C&D waste in which contents of any metal exceed the values is defined as hazardous C&D waste with leaching toxicity. Necessary treatment must be performed before being landfilled or utilized. Otherwise, it must be sent to the hazardous waste landfills.

Table 2.5 Standard Values for Leaching Toxicity Identification

Number	Hazardous Substances	Limited Contents of the Pollutants in Leachate (mg/L)
1	Cu	100
2	Zn	100
3	Cd	1
4	Pb	5
5	Cr	15
6	Cr (VI)	5
7	Ni	5

2.1.1.2 Identification for Industrial Construction and Demolition Waste With Organic Contaminants

The scope and depth of the organic contamination in the manufacturing and building structures involved with organic pollutants is determined by pollutant identification methods before demolition or renovation. Organic matters may penetrate into 1.5 cm of industrial C&D waste from the surface when the waste is exposed to organic matters. In industrial workshops, especially in older factories where the lack or failure of protection measures exist, the contamination may penetrate under 3—3.5 cm of industrial C&D waste.

On-site sampling—laboratory analysis approach should be adopted as major contamination identification means for organic pollutants. Full quantitative analysis can be performed using Gas Chromatography-Mass Spectrometer.

As for typical structural construction materials such as cement, gypsum, concrete, etc., no or very low organic pollutants contain in their raw materials, additives, and production processes. However, the building and furnishing materials containing paint, as well as man-made composite panels, insulation board, and other civil construction materials, may have a content of volatile organic compounds, and their requirements are listed in Table 2.6.

The final disposal surroundings of C&D waste have a great relevance to the soil environment. Therefore environmental quality standards for soil are also referred to. Environmental quality risk assessment criteria for soil at manufacturing facilities (HJ-T 25-1999) have made a criterion for the contents of the organic pollutants, which is for the environmental risk assessment of the soil system within the industrial manufacturing activities. In this criterion the "Soil (direct contact)" is for the protection for workers with direct contact by touching or intaking pollutants during the industrial manufacturing activities, where as the "Soil (migrate to underground

Table 2.6 Limited Values for the Organic Pollutants

Items	Water-Based Exterior Wall Paint	Water-Based Exterior Wall Putty	Water-Based Interior Wall Paint	Water-Based Interior Wall Putty
VOC content	150 g/L	15 g/kg	120 g/L	15 g/kg
Sum of benzene, toluene, ethylbenzene, and xylene (mg/kg)	—		300	
Free formaldehyde content (mg/kg)	100		100	
Sum of glycol ethers and ether esters (%)	0.03		—	

water)" is in case that pollutants would cause harm to the drinking water underground through the migration. The values are listed in Table 2.7.

Standard of soil quality assessment for exhibition sites (HJ 350-2007) divides the soil environmental quality into two grades (A and B), where grade A is the target quality of soil system, representing the pollution level of uncontaminated soil. Grade B stands for the action value for remediation. This means remediation must be carried out if the monitoring value exceeds that in grade B. Both grade A and B are listed in Table 2.8. In addition, the Canadian environmental quality guidelines published by Canadian Council of Ministers of the Environment (CCME) are also listed in Table 2.8 as a reference.

As it can be seen from Table 2.7, "Soil (direct contact)" is more suitable for the industrial C&D waste within service or before demolition, where as "Soil (migrate to underground water)" is more suitable for the randomly stacked, transferred, or landfilled industrial C&D waste after being demolished without disposal. Characterizations of organic pollutants in some industrial C&D waste, their leaching toxicity, and environmental pollution risk assessment will be introduced in subsequent chapters.

Based on the data above, C&D waste can be divided into three categories in terms of organic pollution. Firstly, ordinary waste, uncontaminated by organic pollutants, can be recycled directly. Secondly, for waste slightly contaminated by organic pollutants, a simple treatment is needed before being landfilled or utilized. Thirdly, for hazardous waste, strict treatment is required before being landfilled or utilized. The classification and the pollution concentration regulation are listed in Table 2.9.

Table 2.7 Values for Environmental Quality Risk Assessment for Soil at Manufacturing Facilities (mg/kg)

Number	Item	Soil (Direct Contact)	Soil (Migrate to Underground Water)
1	Chloromethane	10,900	1170
2	Chloroethane	100,000	117,000
3	Dichloromethane	6340	684
4	1,1-Dichloroethane	272,000	29,300
5	1,2-Dichloroethane	522	56
6	1,1,1-Trichloroethane	95,100	10,300
7	1,1,2-Trichloroethane	834	90
8	Carbon tetrachloride (CTC)	366	40
9	1,2-Dibromoethane	0.6	0.1
10	Dibromo-tetrachloroethane	566	61
11	Hexane	163,000	17,600
12	1,4-Dioxane	4320	466
13	Vinyl chloride	25	2.7
14	Vinylidene chloride	79	8.6
15	*Cis*-1,2-dichloroethylene	27,200	2930
16	*Trans*-1,2-dichloroethylene	54,300	5680
17	Trichlorethylene	4320	466
18	Tetrachlorethylene	914	99
19	Hexachlorocyclopentadiene	26,500	NA
20	Styrene	543,000	NA
21	Benzene	1640	177
22	Toluene	543,000	NA
23	Ethylbenzene	272,000	NA
24	Xylene	1,000,000	586,000

25	1,2,4-Trimethylbenzene	136,000	14,700
26	Mesitylene	136,000	14,700
27	Nitrobenzene	1890	147
28	2,4-Dinitrotoluene	98	7.5
29	Chlorobenzene	54,300	5860
30	1,2-Dichlorobenzene	341,000	NA
31	1,3-Dichlorobenzene	337,000	26,100
32	1,4-Dichlorobenzene	2760	214
33	1,2,4-Trichlorobenzene	37,900	2930
34	Pentachlorobenzene	3030	234
35	Hexabromobenzene	7580	586
36	Cumene	109,000	11,700
37	Sec-butylbenzene	27,200	2930
38	Phenol	1,000,000	176,000
39	2-Cresol	189,000	14,700
40	3-Cresol	189,000	14,700
41	4-Cresol	18,900	1470
42	2,4-Xylenol	75,800	5860
43	2,6-Xylenol	2270	176
44	3,4-Xylenol	3790	293
45	2-Chlorophenol	18,900	1470
46	2,4-Dichlorophenol	11,400	879
47	Butanol	272,000	29,300
48	Ethylene glycol	1,000,000	586,000
49	Ethyl acetate	1,000,000	264,000
50	Bis (2-chloroethyl) ether	60	4.7
51	2-Butanone	1,000,000	11,700

(*Continued*)

Table 2.7 Values for Environmental Quality Risk Assessment for Soil at Manufacturing Facilities (mg/kg)—cont'd

Number	Item	Soil (Direct Contact)	Soil (Migrate to Underground Water)
52	2-Hexanone	109,000	11,700
53	4-Methyl-2-pentanone	21,700	23,400
54	O-toluidine	349	27
55	3-3′-dichlorobenzidine	147	11
56	Acenaphthene	227,000	NA
57	Fluorene	152,000	NA
58	Naphthalene	152,000	NA
59	Pyrene	114,000	NA
60	Chrysene	9080	NA
61	Fluoranthene	152,000	NA
62	Benzo (a) anthracene	91	NA
63	Benzo (a) pyrene	9.1	NA
64	Benzo (b) fluoranthene	91	NA
65	Benzo (k) fluoranthene	908	NA
66	Dibenzo (a, h) anthracene	9.1	NA
67	Dibenzofuran	15,200	1170
68	Indeno (1,2,3-cd) pyrene	91	NA
69	Dibutyl phthalate	379,000	NA
70	Octyl phthalate	75,800	NA
71	Dibutyl phthalate, benzyl ester	758,000	NA
72	Bis (2-ethylhexyl) phthalate	4740	NA
73	4,4-Dichloro-Diphenyl-Trichloroethane (DDT)	195	NA
74	γ-Benzene hexachloride (BHC)	51	4.0

Table 2.8 Standard Limits for Soil Environmental Quality (mg/kg)

		Exhibition Land Level		Canadian Environmental Quality Guidelines	
Number	**Item**	**A**	**B**	**Residential**	**Industrial**
VOCs					
1	Vinylidene chloride	0.1	8	5	50
2	Dichloromethane	2	210	5	50
3	1,2-Dichloroethylene	0.2	1000	5	50
4	1,1-Dichloroethane	3	1000	5	50
5	Chloroform	2	28		
6	1,2-Dichloroethane	0.8	24	5	50
7	1,1,1-Trichloroethane	3	1000	5	50
8	CTC	0.2	4	5	50
9	Benzene	0.2	13		
10	1,2-Dichloropropane	6.4	43		
11	Trichlorethylene	12	54	0.01	0.01
12	Bromochloromethane	10	92		
13	1,1,2-Trichloroethane	2	100	5	50
14	Toluene	26	520		
15	Dibromochloromethane	7.6	68		
16	Tetrachlorethylene	4	6	0.2	0.6
17	1,1,1,2-Tetrachloroethane	95	310		
18	Chlorobenzene	6	680	1	10
19	Ethylbenzene	10	230		
20	Xylene	5	160		
21	Bromoform	81	370		
22	Styrene	20	97	5	50
23	1,1,2,2-Tetrachloroethane	3.2	29	5	50
24	1,2,3-Trichloropropane	1.5	29		
Semi VOCs					
25	Mesitylene	19	180		
26	1,2,4-Trimethylbenzene	22	210		
27	1,3-Dichlorobenzene	68	240	1	10
28	1,4-Dichlorobenzene	27	240	1	10
29	1,2-Dichlorobenzene	150	370	1	10
30	1,2,4-Trichlorobenzene	68	1200	2	10
31	Naphthalene	54	530		
32	Hexachlorobutadiene	1	21		
33	Aniline	5.8	56		
34	2-Chlorophenol	39	1000		
35	Bis (2-chloroisopropyl) ether	2300	10,000		
36	N-nitroso-di-n-propylamine	0.33	0.66		
37	Hexachlorethane	6	100		
38	4-Methyl phenol	39	1000		
39	Nitrobenzene	3.9	100		

(*Continued*)

Table 2.8 Standard Limits for Soil Environmental Quality (mg/kg)—cont'd

		Exhibition Land Level		Canadian Environmental Quality Guidelines	
Number	**Item**	**A**	**B**	**Residential**	**Industrial**
40	2-Nitro-phenol	63	1600		
41	2,4-Dimethyl phenol	160	4100		
42	2,4-Dichlorophenol	23	610	0.5	5
43	N-nitrosodiphenylamine	130	600		
44	Hexachlorobenzene	0.66	2	2	10
45	Benzidine	0.1	0.9		
46	Philippines	2300	61,000		
47	Anthracene	2300	10,000	2.5	32
48	Carbazole	32	290		
49	Di-n-butyl phthalate	100	100		
50	Fluoranthene	310	8200	50	180
51	Pyrene	230	6100		
52	Benzo (a) anthracene	0.9	4		
53	3,3-Dichloro-benzidine	1.4	6		
54	Chrysene	9	40		
55	Bis (2-ethylhexyl) phthalate	46	210		
56	4-Chloroaniline	31	820		
57	Hexachlorobutadiene	1	21		
58	2-Methyl naphthalene	160	4100		
59	2,4,6-Trichlorophenol	62	270	0.5	5
60	2,4,5-Trichlorophenol	58	520		
61	2,4-Dinitrotoluene	1	4		
62	2-Chloro-naphthalene	630	16,000		
63	2,4-Dinitrophenol	16	410		
64	Fluorene	210	8200		
65	4,6-Dinitro-2-cresol	0.8	20		
66	Benzo (b) fluoranthene	0.9	4		
67	Benzo (k) fluoranthene	0.9	4		
68	Benzo (a) pyrene	0.3	0.66	20	72
69	Indeno (1,2,3-c, d) pyrene	0.9	4		
70	Dibenzo (a, h) anthracene	0.33	0.66		
71	Benzo (g, h, i) pyrene	230	6100		
Pesticides, Polychlorinated biphenyl (PCB), etc.					
72	Total petroleum hydrocarbon (TPH)	1000	—		
73	PCBs	0.2	1	1.3	33
74	BHC	1	—		
75	DDT	1	—	0.7	12
76	Aldrin	0.04	0.17		
77	Dieldrin	0.04	0.18		
78	Endrin	2.3	61		

Table 2.9 Classification of Construction and Demolition Waste Contaminated by Organic Pollutants

Pollutants	Ordinary Waste (mg/kg)	Waste Slightly Contaminated by Organic Pollutants (mg/kg)	Hazardous Waste (mg/kg)
Total VOCs	≤ 200	200–8000	≥ 8000
TPH	≤ 20	20–800	≥ 800
Organochlorine pesticides (total)	≤ 1	1–250	≥ 250
Organophosphorus pesticides (total)	≤ 15	15–500	≥ 500
Polycyclic aromatic hydrocarbons (total)	≤ 10	10–200	≥ 200
PCBs	≤ 0.1	0.1–250	≥ 250

2.1.2 Sampling Techniques for Industrial Construction Waste Before Demolition

1. Preparation
   Sampling background survey is required. Before the collection work is carried out the production years and processes should be investigated, and site investigation should be performed, including the nearby workshops and their management regulation. The characteristics of processes and layout of manufacturing facilities should also be collected. Building workshop unit, age, management, building workshop production process, features, equipment layout, quantity, building workshop environmental pollution, monitoring and analysis of historical data, etc., are the essential information and should be mastered.
2. Setup of sampling spots
   Upon the sufficient background information from background survey, sampling spots on the application of statistical techniques can be thus set. The layout of sampling spots should base on the following principles.
   a. It should be a priority to set sampling locations near the floor and wall next to the operating equipment and discharge pipes. In a well-ventilated open environment (large workshop) the sampling locations should not be located more than 10 meters away from the work area outside.
   b. The dangerous places for the personnel should be avoided.
   c. Places where damage of the structural stability of the building might be caused should be avoided.
   d. Distribution of sampling points should be even, generally using the "diagonal sampling pattern" or "grid-square sampling pattern."

Three to five points are set on one side of the wall or on the ground, and the samples are evenly mixed. The sampling range on the floor and wall surface should be based on the specific contamination distribution. For point pollution sources the sampling range should at least cover a circular area with a radius of 1.5 m. For line pollution sources, it should be in the range of a rectangle located in the center, leaving 1.5 meters on both sides.

   e. For gaseous pollutants, due to its well-distributed characteristics, sampling locations are not restricted by the regulations above. If there are smoke discharge pipes the preferred sampling location should be the wall and ground materials near the outlet of the pipe.

3. Sampling methods

Wood pieces, glass, clay, and plastics should be sorted out before sampling. For C&D waste in piles or particle (including gravel, broken bricks, powder, etc.), CJ313-2009-T garbage sampling and analytical methods can be referred to. For C&D waste in other shapes (block, flat, or slim), it should be crushed down before sampling.

4. Sampling procedures

Due to the specific features of C&D waste sampling the staff members involved should wear safety helmets and masks while dust removal equipment should be turned on.

   a. Make surveys and research on the internal structure of workshops, as well as on the distribution of manufacturing equipment.
   b. Determine the sampling area and make a division of it.
   c. Use scraping devices and cut along boundary line on the sampling surface.
   d. Scrap and strike on the samples cut down to make it fall evenly on the receiving device.
   e. Collect the samples and place them in containers.
   f. Determine the sampling area and use drills for the subsurface sampling.
   g. Collect and classify the cylindrical samples drilled in different depths.
   h. For each sampling, take at least three parallel samples.
   i. Make a record of the sampling person, place, time, weather, and the surrounding geological conditions.

2.1.3 Sampling of Industrial Demolition Waste

In principle, industrial solid waste sampling and preparation technical specifications (HJ/T 20-1998, in Chinese) can be consulted for reference of the sampling methods for industrial C&D waste after demolition. It is recommended to make adjustment in practical sampling based on the specific industrial backgrounds and their types. A feasible sampling method is listed in detail as follows.

1. Sampling techniques

For industrial C&D waste from metallurgy and electroplating industries, there is no close relationship between its pollution characteristics and the types and backgrounds, simple random sampling or stratified sampling is recommended after being centralizedly collected.

For industrial C&D waste from pesticide and chemical industries the pollutants may be complex due to the diversity of the decay time or hydrophibility. If the waste is stacked in cluster, classified collection should be carried out in small range. It is recommended that industrial C&D waste within a radius of 0.5—1 m is collected together, and the pollution source is divided into POPs, semi-VOCs, and VOCs.

For POPs the pollution is characterized by hydrophobicity and long residence. The diversity of different manufacturing sections has the greatest impact on the pollution characteristics while it is less affected by terrain, weather conditions, or other external environments. The division of different sampling regions based on the manufacturing backgrounds should be laid stress on. For each region, simple random sampling can be used.

For semi-VOCs contaminated industrial C&D waste the pollution is characterized by relatively poor hydrophilicity and uncertain residue time. The pollution characteristics are largely affected by a variety of conditions. Sampling procedures tend to be more complex, its representation is not as good as the former. It is recommended that the sampling is subdivided into three categories, industrial C&D waste from single section, mixed industrial C&D waste from different sections, and other industrial C&D waste. Also the sampling should be classified according to the geographical environments, into stacking center area, marginal area, water-nearby areas, etc. For each region, sampling is carried out in depths and random sampling method is used for each layer.

For VOCs contaminated industrial C&D waste the pollution characteristic is largely affected by the environment. It is recommended that samples are collected by drilling machines and classified by different depths. If necessary, gas and water samples can be collected as a reference.

2.1.4 Construction and Demolition Waste Generated in Earthquakes

Local landfill cannot efficiently solve the problem caused by C&D waste during earthquakes. It is impossible to have a large enough area of land to implement “local landfill.” Besides, “local landfill” can lead to soil and

Table 2.10 Components of the Construction and Demolition Waste Produced During Earthquakes

Components	Frame Structure	Brick and Concrete Structure	Components	Frame Structure	Brick and Concrete Structure
Concrete	30%	10%	Metal	5%	2%
Stone	20	10	Plastic	0.61%	1.13%
Clay	10%	15%	Wood	7.46%	10.95%
Brick	50%	70%	Organic matter	1.30	3.05
Sand	8%	5%	Waste ceramics	1%	1%
Glass	0.20	0.56	Others	0.11	0.27

groundwater contamination. Based on the research on the C&D waste produced in earthquakes from Dujiangyan and Shifang City in China the components of the C&D waste are listed in Table 2.10.

Sampling and collection process for C&D waste produced during earthquakes is determined as follows.

1. Classified stacking and collection

   Classified stacking and collection is carried out based on brick and concrete structure and reinforced concrete structure.

2. Classified treatment

   Clay aggregate is produced from C&D waste of brick and concrete structure through regeneration process. The process is crushing → iron removal → sorting → crushing → screening → classified treatment.

   Concrete aggregate is produced from C&D waste of reinforced concrete structure through regeneration process. The process is crushing → iron removal → sorting → crushing → screening → classified treatment.

   Mixed recycled aggregate is produced from low-quality mixed C&D waste. The process is crushing → iron removal → sorting → crushing → screening → classified treatment.

2.2 SAMPLING TOOLS AND EQUIPMENT

2.2.1 Typical Tools Used in Waste Sampling in a Workshop

Typical sampling tools for industrial C&D waste are listed in Table 2.11.

Table 2.11 Typical Sampling Tools for industrial Construction and Demolition Waste

Tools and Equipment	Notes
Sampling zoning tools	Mark the sampling regions for scraping
Scrape tools	Cut and scrap the sampling surface, including scrapers, disc cutters, chisels, etc.
Drilling tools	Drill holes on the subsurface, including drilling samplers, coring samplers, etc.
Receiving devices for the scraped waste	
Dust removal systems	Collect and remove the ash and particulate matters generated during sampling
Other tools	Hammers, drills, scissors, shelves, etc.
Auxiliary tools	Lighting equipment, power equipment, helmets, masks, sampling platform, tape, etc.

2.2.2 Remote Sampling Devices for Granular Waste

Based on the practical sampling experience, taking into consideration the highly volatile organic pollutants in closed workshops, a set of remote sampling devices for solid particles used in hazardous environments is devised. The set of devices includes a sample-receiving tube, liquid inlet port, Venturi tube, pump, and solid—liquid separation device. The Venturi tube is composed of the interconnected front tube, constricted part, throat, diffuse part, and rear tube. The end of sample-receiving device is connected with the throat of Venturi tube. The outlet of the centrifugal pump is connected with the front tube of Venturi tube. The rear tube of Venturi tube is connected with the solid—liquid separation device, the other side of which is connected with the inlet of the centrifugal pump. The main principle of this set of device is by use of the negative pressure produced in Venturi throat, solid particles are aspirated into the receiving tube. The solvent is used to dissolve the organic or inorganic pollutants/components in industrial C&D waste. The set of devices is simple to operate, easy to carry, and can effectively reduce the loss of the object. Besides, they have the advantage of long operating distance and safety. It can be used especially for toxic and hazardous organic contaminated samples within the workshop. The diagram of this device is demonstrated in Fig. 2.1, Figs 2.2 and 2.3.

This set of devices has ever been used as a remote sampler for industrial C&D waste particles near an outlet vent of a chemical laboratory, where organic and acid gases are continuously emitted. According to the experiment, 99.9% of particles smaller than 5 mm in radius were aspirated on a

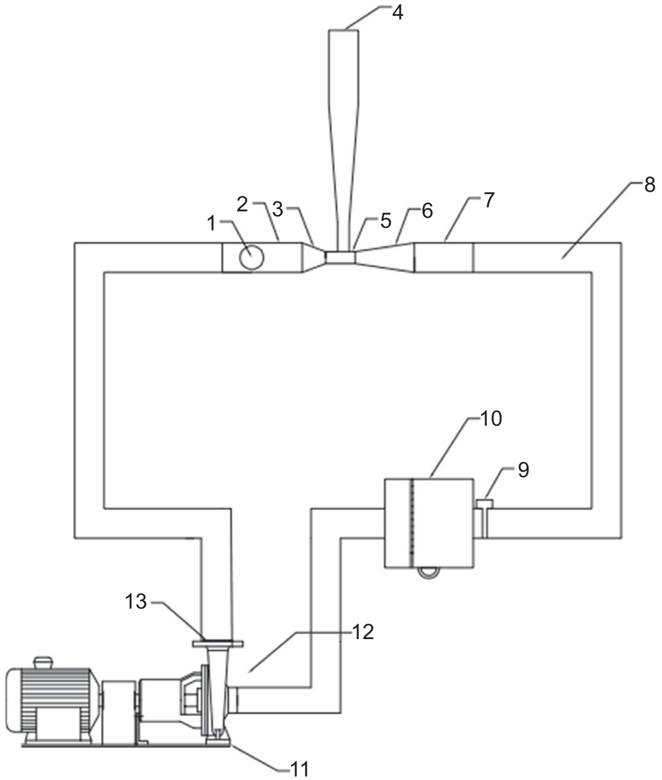

Figure 2.1 A schematic view of the Venturi tube sampling device. *1*, Liquid inlet; *2*, front tube of Venturi; *3*, constricted part of Venturi; *4*, sample-receiving tube; *5*, Venturi throat; *6*, diffusion tube of Venturi; *7*, rear tube of Venturi; *8*, connecting tube; *9*, valve (closed when backwashing); *10*, the solid—liquid separator; *11*, circulation pump; *12*, inlet of the circulation pump (change to outlet when backwashing); *13*, outlet of circulation pump (change to inlet when backwashing).

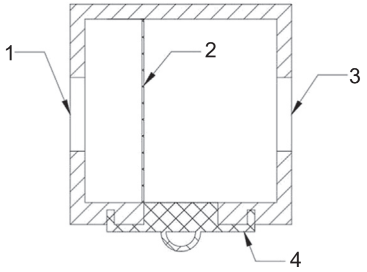

Figure 2.2 A schematic view of the enlarged solid—liquid separation device. *1*, connection part between the solid—liquid separator and the circulating pump; *2*, *3*, connection part between the solid—liquid separator and the Venturi; *4*, plug.

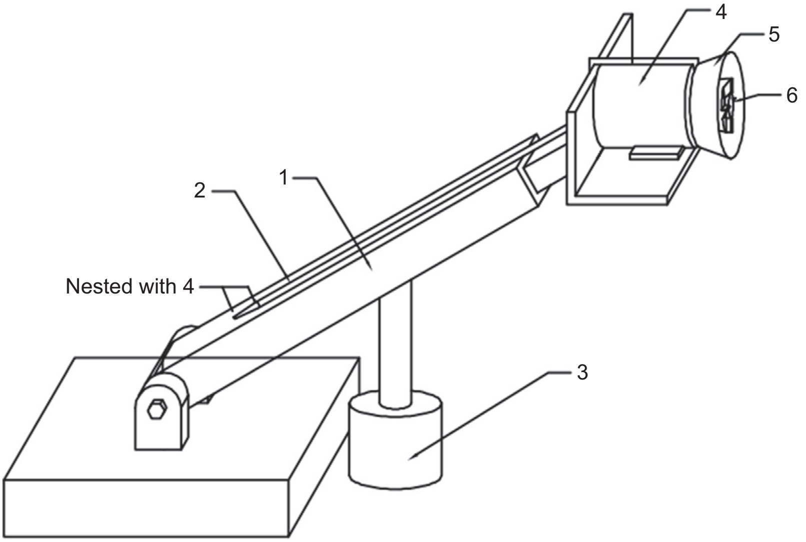

Figure 2.3 Installation of the Venturi tube sampling devices. *1-2*, telescopic boom; *3*, lifting jack; *4*, electric motor; *5*, cover; *6*, knife.

height of 3.4 m. While changing the sampling distance by moving the portable sampling device, it was proved that the absorption rate reached 99% within a height range of 0—10 m.

2.2.3 Stripping and Classification Machine for Construction and Demolition Waste

The set of devices discussed above are suitable for the sampling of particular industrial C&D waste. However, most industrial C&D waste in workshop before or after being demolished is in large blocks. In this case, a set of stripping and classification machine for industrial C&D waste with multiple functions including cutting, scraping, aspiration, dust removal, collection, and crushing is introduced in this section, as described below.

1. An absorber
   The absorption surface is capable of absorbing industrial C&D waste (such as walls, floors, etc.) and hold in a suitable place.
2. A scrapping device
   It is able to clamp and scrap the surface of industrial C&D waste with the movement of the absorber.
3. A cutting device
   This section is able to cut and knock down the surface or subsurface of industrial C&D waste laterally and vertically.

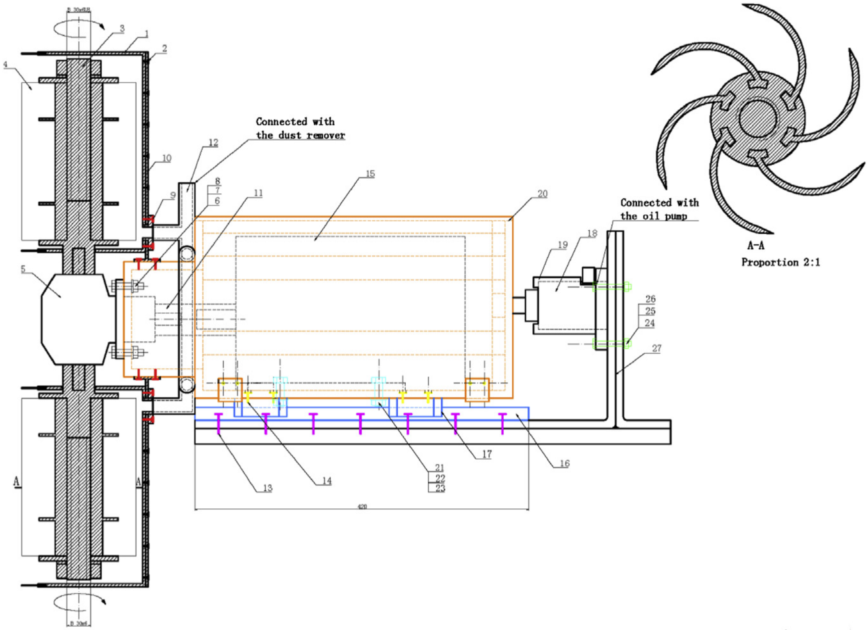

Figure 2.4 Stripping and classification machine for industrial construction and demolition waste.

Table 2.12 Main Technical Indicators for Stripping and Classification Machine for Industrial Construction and Demolition Waste

Number	Indicators	Scale
1	Diamond chips (mm)	φ350 ∗ 40 ∗ 2.4
2	Maximum cutting area (m)	3 × 2
3	Cutting forms	Duel knives cutting
4	Cutting speeds (m/s)	40–50
5	Longitudinal feed speed (mm/s)	0.1–1
6	Speed motor (kw)	5.5
7	Dust capacity (m^3/h)	3000–5000
8	Equipment air leakage rate (%)	2
9	Inlet size (mm)	1200 × 1500
10	Feeding size (mm)	1000
11	Range of outlet (mm)	150–300
12	Crushing processing capacity (t/h)	120–180
13	Motor power (kw)	140
14	Weight (t)	80

4. Several receiving boards

   They are used to temporarily receive the falling industrial C&D waste and transfer to the next section, thus reducing the loss and environmental risk during the process.
5. A dust removal device

   This section is used to absorb and collect the dust and hazardous gas produced during the sampling.
6. A crushing device

   This section is made up of the crushing cavity, jaw, the motor, and the inlet/outlet port and used to crush the industrial C&D waste stripped down into pieces for collection and transportation.

The device is shown in detail in Fig. 2.4, while the main technical indicators for stripping and classification machine for industrial C&D waste is listed in Table 2.12.

CHAPTER THREE

Pretreatment and Analysis Methods of Heavy Metals and Organic Pollutants Existing in Construction and Demolition Waste

3.1 PRETREATMENT AND ANALYSIS METHODS OF HEAVY METALS

3.1.1 Pretreatment Procedures and Equipment

3.1.1.1 Crushing

About 100 g heavy metal contaminated construction and demolition (C&D) waste is weighed and preliminarily crushed by a jaw crusher. Then the crushed C&D waste is mixed well and reduced by quartering twice. After that, the sample is dried at 100°C for 1 h. An electromagnetic crusher is used as a fine crushing for about 4–6 min. Crushed sample is placed in a polypropylene screw-cap plastic bottles for storage.

3.1.1.2 Digestion and Analysis of Total Amount of Heavy Metals

Teflon crucibles used for digestion should be soaked in 1:1 nitric acid for 12 h, wash with distilled water, and dry for later use. Volumetric flasks should be soaked in 1:1 nitric acid for 12 h and washed with distilled water.

Before digestion, 0.1000–0.3000 g of C&D waste powder is accurately weighed and evenly spread on the bottom of Teflon crucibles. Then they are placed in oven and dried for 2 h at 120°C together till constant weight. Aqua regia (18 mL) (hydrochloric acid:nitric acid = 3:1) is added, and 2 mL 40% hydrofluoric acid is added 10 min later. The crucibles with lids on are placed on an electric heating plate at 180°C and heated till the solid waste is dissolved. Then, 30 mL deionized water is added and the heating should be continuously maintained till the solution is vaporized to 2–3 mL. Transfer the liquid to a 25 mL plastic volumetric flask after it is cooled down, in which the volumetric flask should be washed with 1% nitric acid solution

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Table 3.1 Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) Emission Spectrum Wavelengths of the Elements

Elements	Wavelengths	Elements	Wavelengths	Elements	Wavelengths
Al	308.215	Cd	226.502	Fe	259.940
Sb	206.833	Ca	317.933	Pb	220.353
As	193.696	Cr	267.716	Mg	279.079
Ba	455.403	Co	228.616	Mn	257.610
Be	313.042	Cu	324.754	Mo	202.030
Ni	231.604	Se	196.026	Na	588.995
Tl	190.864	V	292.402	Zn	213.856

three times. Add deionized water to a certain volume and filter through 0.22 μm membrane. Place the solution at 4°C for analysis.

3.1.2 Analysis of Heavy Metals

Inductively coupled plasma-optical emission spectrometry (ICP-OES) is used for the qualitative and quantitative analysis of heavy metals. Emission spectrum wavelengths of the elements in ICP-OES are listed in Table 3.1, and the recovery rate of heavy metals is listed in Table 3.2.

3.1.3 Analysis of Mercury

The DMA-80 Mercury Analyzer is used for direct mercury analysis. C&D waste powder (0.1000—0.5000 g) is accurately weighed and placed in the nickel sample boat (boat is preburned for 20—30 min at 500°C). The drying temperature is set to 150°C, drying time 30 s, the decomposition temperature 850°C, and the decomposition time 200 s.

3.1.4 European Communities Bureau of Reference (BCR) Morphological Analysis of Construction and Demolition Waste

All the samples for morphological analysis should be less than 125 μm in size and are thoroughly freeze-dried.

3.1.4.1 Acid Extractable Fraction

C&D waste powder (0.5000 g) is accurately weighed and placed in 100 mL centrifuge tubes, in which 40 mL 0.11 mol/L HAc solution is spiked. The tubes are sealed and shaken at 25°C for 16 h. Then the residue is isolated by being centrifuged at 3000 rpm for 20 min. The supernatant is carefully transferred into a polyethylene container, sealed, and stored at 4°C. Distilled water (20 mL) is then added to the residue and shaken together for about

Table 3.2 Recovery Rate of Heavy Metals Using Pretreatment Procedures Developed

Elements	Cr (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Background value	166.107	30.050	5.695	46.566
Spiked amount 1	259	252	284	270
Measured value 1	420.888	272.420	273.396	300.028
Recovery rate 1	98.37%	96.18%	94.26%	93.87%
Spiked amount 2	259	257	287	275
Measured value 2	424.229	272.951	270.874	305.418
Recovery rate 2	99.66%	94.51%	92.40%	94.13%

15 min. Finally, they are centrifuged at 3000 rpm for 20 min and no solid residue should be discarded.

3.1.4.2 Reducible Fraction

A solution of 40 mL 0.5 mol/L fresh $NH_2OH \cdot HCl$ (Hydroxylamine hydrochloride) is added to the residue in a centrifuge tube produced in the first step, thoroughly shaken to suspension. The tube is sealed and shaken at 25°C for 16 h. Residue is isolated from the extract by being centrifuged at 3000 rpm for 20 min. Carefully transfer the supernatant into a polyethylene container, seal, and store at 4°C. Add 20 mL of distilled water to the residue. Centrifuge at 3000 rpm for 20 min after 15 min's shake. The supernatant is placed still and no solid residue should be discarded.

3.1.4.3 Oxidisable Fraction

A 10 mL solution of 30% H_2O_2 (Hydrogen Peroxide) is carefully added to the residue produced in the second step in a centrifuge tube. The mixture is digested at room temperature and occasionally shaken by hand. Continue to digest for 1 h under water bath at 85 ± 2°C and occasionally shaken by hand within the first 0.5 h. Take the lid away and let the solution vaporize to 1 mL. Then 10 mL 30% H_2O_2 is added and heated for 1 h. The volume of the remaining solution should be about 1 mL and should not be completely dried. A solution of 50 mL 1 mol/L NH_4Ac is added after it is cooled down and is shaken for 16 h at 25°C. The residue is isolated by being centrifuged at 3000 rpm for 20 min. The supernatant is carefully transferred into a polyethylene container, sealed, and stored at 4°C. Distilled water (20 mL) is added to the residue and shaken for about 15 min. Then the mixture is centrifuged at 3000 rpm for 20 min. The supernatant is placed still and no solid residue should be discarded.

3.1.4.4 Residual Fraction

Transfer the residue in the centrifuge tube into 100 mL Teflon crucibles. Sufficiently wash the centrifuge tube with 15 mL nitric acid and transfer all the solution to the crucibles. Spike 5 mL hydrochloric acid and 5 mL hydrofluoric acid into the Teflon crucible, and heat on the electric heating plate at 180°C until 2–5 mL of liquid is left. Another 25 mL deionized water is then added and the heating continues until the mixture is vaporized to about 2 mL. Transfer of liquid into 25 mL plastic flask after it is cooled down. The volume is increased with deionized water and filter through the 0.22 μm membrane in the 10 mL round bottom plastic centrifuge tube. Store at 4°C for analysis.

Concentrations of the heavy metals in all extract are analyzed using ICP-OES.

3.1.5 Analysis of Heavy Metals Leaching Toxicity in Waste

Most existing studies make environmental risk assessment based on the leaching amount and leaching rate in leaching experiments. Existing leaching methods for soil or solid waste are typically toxicity characteristic leaching procedure (TCLP) and synthetic precipitation leaching procedure (SPLP). There is no standard method for assessment of leaching toxicity for heavy metals in C&D waste. The leachate of C&D waste is strongly alkaline, and it is controversial that which method for C&D waste leaching is the most suitable. Comparisons of SPLP, TCLP, and leaching guidelines of maximum effective amount of inorganic components (EA NEN 7371) are carried out.

The three leaching methods of C&D waste are introduced as follows. For more detailed information, refer to the EPA methods. As for SPLP, 20 g of sample is added to 400 mL solution (pH 4.2) consisting of a mixture of 60/40% (wt) sulfuric acid and nitric acid and deionized water. As for TCLP, 20 g sample is added to 400 mL solution ($pH = 2.88$), of which the liquid to solid ratio is 20:1. The mixture is shaken at 25°C for 18 ± 2 h. As for EA NEN 7371, the leaching process is composed of two batches, namely "pH 7.0 ± 0.5" batch and "pH 4.0 ± 0.5" batch, the liquid to solid ratio is 50 L/kg. Samples (4 g) are added in 200 mL HNO_3 1N-deionized water extract. The two batches are mixed in equal amounts before analysis.

Results of the leaching experiments for TCLP, SPLP, and EA NEN 7371 are demonstrated in Fig. 3.1. The leaching rate of TCLP and SPLP was relatively low, in which that of TCLP was less than 1.5%. The leaching rate of Pb and Cd of SPLP was 0.02% and 0.009%, respectively. Most of the

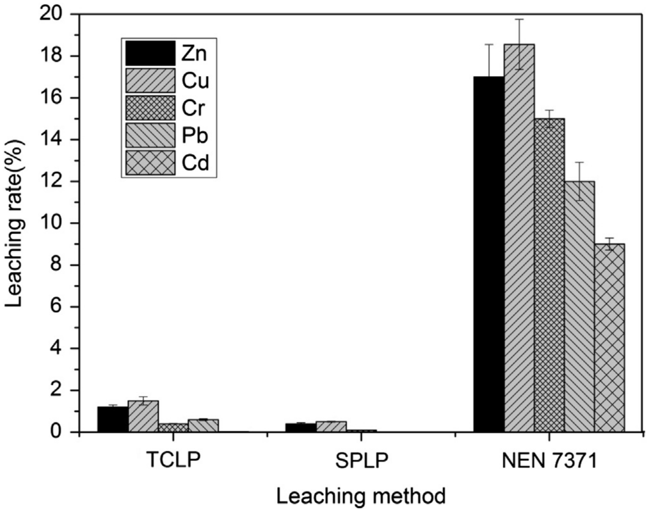

Figure 3.1 Leaching rates of heavy metals of contaminated recycled construction and demolition (C&D) waste by different leaching methods.

leaching rate of heavy metals was less than 0.5%. However, the leaching rate of EA NEN 7371 was higher than that of TCLP and SPLP, which was 9% higher. Among all the metals, the leaching rate of Cu was the highest, which was about 18.6%.

Methods TCLP and SPLP are both intended to simulate the leaching of solid waste under certain conditions. For example, TCLP aims to simulate the conditions in sanitary landfill, while SPLP simulates the acid rain conditions. However, C&D waste, as a type of alkaline material, the extracting agents may quickly turn from neutral to alkaline (Fig. 3.2). The leaching of heavy metals is relatively small in amount.

Method EA NEN 7371 is used to test the maximum amount in leaching process. By continuously adding acid solution, the pH is able to remain stable (the first stage of pH was about 7, the second stage of pH is about 4), the long-term leaching procedure under acid rain or other adverse environmental conditions are simulated. According to the results, method EA NEN 7371 was more suitable for leaching assessment of heavy metals of C&D waste.

3.1.6 X-Ray Powder Diffraction and X-Ray Photoelectron Spectroscopy Analysis

X-ray diffraction (XRD) analysis is mainly used to determine the mineral crystals of C&D waste samples and for the qualitative analysis of the

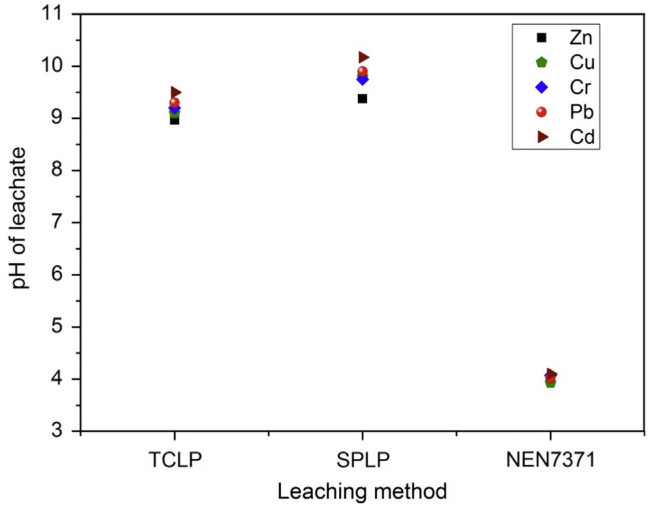

Figure 3.2 pH values of contaminated recycled C&D waste leachate by different methods.

composition of major pollutants. The samples were dried in an oven at 60°C, ground with a mortar, gone through a 320 mesh sieve and reserved for testing. The test conditions were set to be Cu-Ka XRD source, accelerating voltage 40 kV, acceleration currency 40 mA, scan step 0.02 degrees, scan rate 0.01 s/step, and scan range 10–90 degrees. The XRD pattern was analyzed using MDI Jade 5.0.

X-ray photoelectron spectroscopy is mainly used for the analysis of the chemical speciation of heavy metals. For the organic pollutants contaminated C&D waste, wash with acetone and then ethanol, and dry at 105°C in an oven. The detection conditions are monochromatic Al Ka (hv = 1486.6 eV), power 150 W, and the beam spot 500 μm.

3.2 ANALYSIS OF ORGANIC POLLUTANTS AND CYANIDES

The pretreatment method is demonstrated in Fig. 3.3.

3.2.1 Sample Preparation and Storage

Organic contaminated C&D waste (100 g) is weighed and placed in a dark place to dry naturally. Crush and screen large blocks to particles of size less than 1 mm. Mix all the waste and divide by quartering and dividing. Place the collected waste in a brown glass bottle and store at 2°C in freezers.

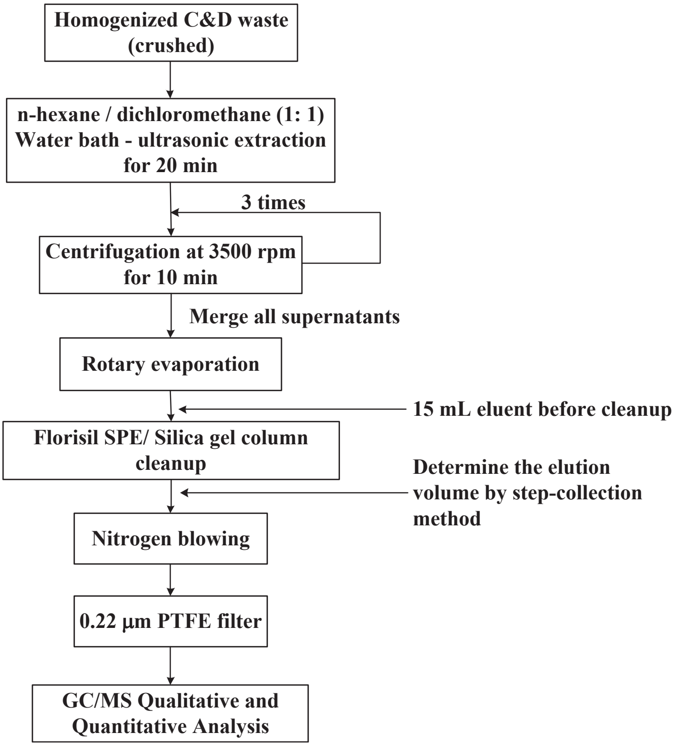

Figure 3.3 Pretreatment of organic matters in C&D waste.

3.2.2 Extraction Procedures of Organic Pollutants

3.2.2.1 Soxhlet Extraction

Accurately weigh 1.0000–2.0000 g sample and place in a Soxhlet tube. Transfer 1 mL 100 ppm terphenyl-d10 (used as standard substances to monitor the errors during the entire process). The extraction is performed on automatic Soxhlet extractor (Foss, Sweden) or similar devices in a solvent system of hexane, dichloromethane, and acetone mixture 1:1:1 (v/v/v). Set the heating plate temperature to 80°C, extraction time to 90 min, and elution time to 150 min. After extraction, transfer the extract solution to a 250 mL egg-shaped bottle that has been washed twice by the extraction agent.

3.2.2.2 Ultrasonic Extraction

Accurately weigh 1.0000–2.0000 g sample and place in a 30 mL glass centrifuge tube. Transfer 1 mL 100 ppm terphenyl-d10 (used as standard substances to monitor the errors during the entire process). The extraction is performed in a solvent system of hexane, dichloromethane, and acetone mixture 1:1:1 (v/v/v). The volume of the solvent is 20 mL. The extraction is carried out in water bath at 40°C for 20 min with ultrasonic treating. Take out the tubes every 5 min to make a concussion. After the ultrasonic extraction, the tubes are centrifuged at 3500 rpm for 10 min. Transfer the supernatant into a 250 mL eggplant shaped bottle. The whole centrifugation process is performed three times and the supernatant is merged for later pretreatment.

3.2.3 Cleanup Methods of Organic Pollutants

Both self-filled columns and commercial SPE columns are acceptable. For commercial Solid Phase Extraction (SPE) columns, the amount of eluent is different. Before cleanup, 10 mL eluent is flown through the column and 5 mL is discarded. The amount of eluent during the cleanup process is determined as 2 mL 100 mg/L standard of the target pollutant is added through the column. The eluent is collected once every 5 min and sent for analysis. Keep adding eluent until the concentration of the pollutant in eluent is less than 0.5 mg/L. The total amount of eluent added should be the amount used during the cleanup process.

Concentrate the eluent to 2—3 mL by a rotary evaporator and transfer it into a 10 mL glass flask after it is cooled down to room temperature. Wash with 2 mL dichloromethane (HPLC grade) twice and transfer into the volumetric flask. The diluted solution is filtered through 0.22 μm membrane, stored at 2°C in refrigerated cabinets, and should be analyzed within a week.

3.2.4 Qualitative and Quantitative Analysis Using GC—MS

Standard 30 m × 0.25 mm × 0.25 μm quartz columns are used. For unknown substances the test conditions are set as follows:

Injection volume 1 μL (splitless)
Inlet temperature 300°C
Column flow 1.0 mL/min
Column temperature program 50°C (4 min) $\xrightarrow{10^\circ\mathrm{C/min}}$ 300°C (2 min)
Solvent delay 4 min
MS interface temperature 280°C
Ion source temperature 230°C
Scan mode
Acquisition time 5—30 min
Interval 0.2 s
Mass range 35—500 amu

3.2.5 Effects of Pollutants, Procedures, and Types of Waste on Recovery Rate

Standards of 10 μg PAHs were spiked into different C&D waste respectively. To remove all the possibly existing target substances, the waste was placed in an oven for one night and was cooled down before experiment. The recovery study was performed under the same experimental conditions. Results showed that the recovery rate of all 13 PAHs compounds, 8 organochlorine pesticides, and 6 kinds of organophosphorus pesticide was above 80%, in which the recovery of PAHs was 82.2–110.5%, with an average of 97.6% (ion chromatograms shown in Figs. 3.4–3.6). The linear equations and recovery rate of PAHs are respectively listed in Tables 3.3 and 3.4. Those of organochlorine and organophosphorus pesticides are respectively listed in Tables 3.5–3.8. Comparison of the effects on the recovery rate between ultrasonic extraction and centrifugation is listed in Table 3.9.

3.2.6 Comparison of Organic Pollutants Leaching Systems in Waste

Few studies focus on the leaching method and system of organic pollutants. Current standards for the leaching of soil or solid organic waste are mainly EPA 1311: TCLP, EPA 1312: SPLP, EPA 1320: Multiple extraction procedure (MEP), ASTMD 4874-95 (2001): leaching standard for the methods

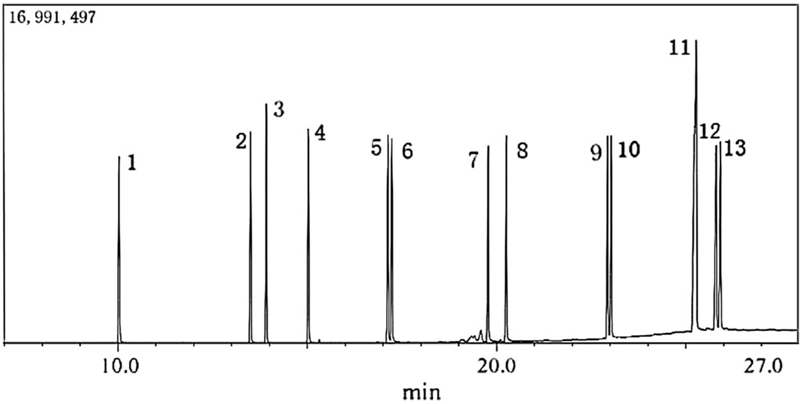

Figure 3.4 Selected ion chromatogram of 13 kinds of PAHs, 1: naphthalene, 2: acenaphthylene, 3: acenaphthene, 4: fluorene, 5: philippines, 6: anthracene, 7: fluoranthene, 8: pyrene, 9: benzo (a) anthracene, 10: Chrysene, 11: benzo (j) fluoranthene, 12: benzo (e) pyrene, 13: benzo (b) fluoranthene.

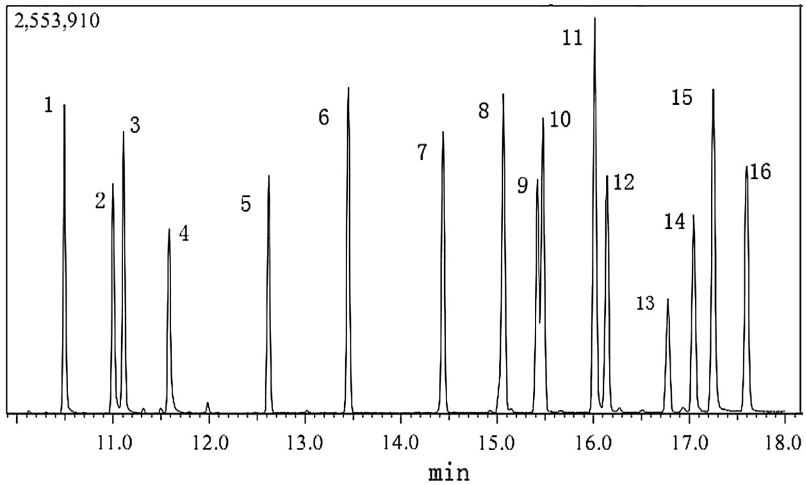

Figure 3.5 Selected ion chromatogram of 16 kinds of organochlorine pesticides, 1: α-BHC, 2: β-BHC, 3: γ-BHC, 4: δ- BHC, 5: heptachlor, 6: aldrin, 7: heptachlor epoxide, 8: alpha-chlordane, 9: α-endosulfan, 10: g-chlordane, 11: p, p′-DDE, 12: dieldrin, 13: endrin, 14: β-endosulfan, 15: p, p′-DDD, 16: endrin aldehyde.

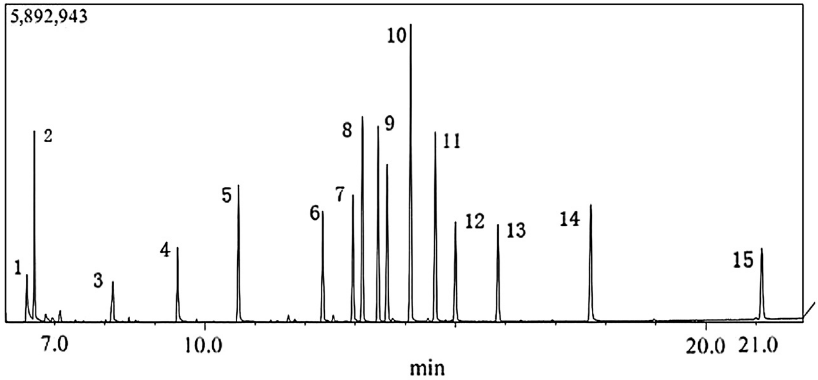

Figure 3.6 Selected ion chromatogram of 15 kinds of organophosphorus pesticides, 1: methamidophos, 2: dichlorvos, 3: acephate, 4: omethoate, 5: dimethoate, 6: methyl parathion, 7: fenitrothion, 8: malathion, 9: chlorpyrifos, 10: isofenphos, 11: quinoline parathion, 12: methidathion, 13: profenofos, 14: triazophos, 15: phosalone.

of solid material in extraction column, HJ/T-299: solid waste-extraction procedure for leaching toxicity-sulfuric acid and nitric acid method, HJ/T-300: solid waste-extraction procedure for leaching toxicity-acetic acid buffer solution method.

Table 3.3 Linear Equations of PAHs

PAH Compounds	Linear Equation	Correlation Coefficient (r^2)
Naphthalene	$Y = 344252.6X + 61{,}372.85$	0.999
Acenaphthylene	$Y = 364833.0X - 2431.71$	0.999
Acenaphthene	$Y = 224115.2X + 23{,}550.33$	0.999
Fluorene	$Y = 229156.0X + 14{,}289.26$	0.999
Philippines	$Y = 304781.9X - 56225.69$	0.999
Anthracene	$Y = 314714.0X - 6642.137$	0.999
Fluoranthene	$Y = 297199.2X - 50260.11$	0.999
Pyrene	$Y = 308713.9X - 37698.35$	0.999
Benzo (a) anthracene	$Y = 315484.6X - 68977.27$	0.999
Chrysene	$Y = 280700.4X - 19883.67$	0.999
Benzo (j) fluoranthene	$Y = 1008871X - 857512.5$	0.996
Benzo (e) pyrene	$Y = 339905.1X - 117072.8$	0.999
Benzo (b) fluoranthene	$Y = 332644.7X - 118412.5$	0.999

Leaching procedures of nonvolatile organic matters is different from that of volatile/semivolatile organic compounds. The concentrations of the nonvolatile organic compounds in the industrial C&D waste (ICDW) samples are relatively low, that is because these pollutants mainly exist in sediments and soil. The leaching analysis for the nonvolatile organic compounds was performed on the laboratory simulated waste. Leaching analysis for some semivolatile organic compounds (pesticides, etc.) were performed on both simulated waste and actual ICDW sampled in manufacturing workshops.

The leachate of C&D waste is strongly alkaline, and it is controversial that which method for C&D waste leaching is the most suitable. Comparisons of several methods were thus carried out. According to TCLP, 20 g sample was added to 400 mL glacial acetic acid extract ($pH = 2.88$), liquid to solid ratio 20:1. The mixture was placed in zero headspace extractors (ZHE) and remained sealed. After being shaken for 18 ± 2 h at $23 \pm 2°C$, they were immediately transferred to bottles and stored at 4°C. As for SPLP leaching procedure, 20 g sample was added to 400 mL reagent water, liquid to solid ratio was 20:1. The mixture was placed in ZHE and remained sealed. After being shaken for 18 ± 2 h at $23 \pm 2°C$, they were immediately transferred to bottles and stored at 4°C.

EPA 1320 multiple extraction procedure (MEP) is used for the simulation of the leaching of solid waste in landfills by repeated acid rain performed in a laboratory. It is based on a multistage leaching procedure in which

Table 3.4 Linear Equations of Organochlorine and Organophosphorus Pesticides

Organochlorine Pesticides	Linear Equation	Correlation Coefficient (r^2)
α-BHC	$Y = 34,033.43X - 24,155.71$	0.999
β-BHC	$Y = 25,967.56X - 27,355.61$	0.999
γ-BHC	$Y = 30,459.44X - 30,257.88$	0.998
δ-BHC	$Y = 23,885.48X - 24,948.29$	0.998
Heptachlor	$Y = 33,777.93X - 51,555.13$	0.996
Aldrin	$Y = 35,726.32X - 11,326.21$	0.999
Heptachlor epoxide	$Y = 91,620.03X - 203555.6$	0.992
Alpha-chlordane	$Y = 51,015.09X - 30,007.13$	0.999
α-endosulfan	$Y = 8184.575X - 4879.458$	0.999
g-chlordane	$Y = 42,952.38X - 25,870.58$	0.999
p, p′-DDE	$Y = 80,295.6X - 46,789.88$	0.999
Dieldrin	$Y = 53,798.97X - 26,454.83$	0.999
Endrin	$Y = 9007.179X - 16,218.3$	0.993
β-endosulfan	$Y = 8457.927X - 3125.333$	0.999
p, p′-DDD	$Y = 117322.3X - 68,120.21$	0.999
Endrin aldehyde	$Y = 33,098.95X - 13,654.04$	0.999
Methamidophos	$Y = 36,623.77X - 68,744.6$	0.990
Dichlorvos	$Y = 82,853.12X + 84,489.87$	0.995
Acephate	$Y = 29,415.64X - 103262.3$	0.980
Omethoate	$Y = 28,196.24X - 72,080.68$	0.992
Dimethoate	$Y = 55,533.4X - 40,480.57$	0.995
Methyl parathion	$Y = 31,743.3X - 26,974.12$	0.994
Fenitrothion	$Y = 30,806.13X - 14,619.52$	0.998
Malathion	$Y = 37,820.45X + 21,803.44$	0.999
Chlorpyrifos	$Y = 23,493.01X + 21,260.87$	0.997
Isofenphos	$Y = 109251.1X + 66,102.36$	0.999
Quinalphos	$Y = 45,221.74X + 31,872.76$	0.999
Methidathion	$Y = 59,955.24X - 52,266.77$	0.995
Profenofos	$Y = 15,438.38X + 13,124.61$	0.997
Triazophos	$Y = 32,548.34X - 3435.692$	0.999
Phosalone	$Y = 25,273.91X - 35,419.62$	0.992

nine repeated times are required for the maximum leaching rate. The first stage is TCLP leaching procedure, whereas the rest are SPLP leaching procedures.

The leaching results of organic matters in different methods are shown in Fig. 3.7. There was a large variation in the leaching amounts among different pollutants. Effects of different leaching agent on the leaching amount can be ordered as the glacial acetic acid–sodium hydroxide $\geq$ water $>$ sulfuric acid–nitric acid. Glacial acetic acid–sodium hydroxide system had an

Table 3.5 Recovery Rate of PAHs in Different Types of Construction and Demolition (C&D) Waste

PAHs	Gypsum Board	Brick	Concrete	Clay	Wall
Naphthalene	86.5	82.2	89.7	86.1	94.8
Acenaphthylene	90.5	98.9	82.4	105.2	99.6
Acenaphthene	92.1	100.3	85.8	107.1	100.9
Fluorene	90.4	101.8	88.5	109.6	103.3
Philippines	91.4	106.2	88.8	109.1	109.2
Anthracene	91.7	101.2	85.8	106.3	101.8
Fluoranthene	92.3	103.9	93.0	109.6	109.2
Pyrene	90.3	104.0	88.0	108.3	105.3
Benzo (a) anthracene	89.5	100.8	91.0	110.5	101.7
Chrysene	90.6	102.3	91.7	109.1	105.3
Benzo (j) fluoranthene	90.4	99.8	89.1	100.1	100.5
Benzo (e) pyrene	84.8	99.1	103.0	104.9	99.3
Benzo (b) fluoranthene	84.3	97.4	102.1	106.4	101.0

Table 3.6 Recovery Rate of PAHs in C&D Waste of Different Sizes

	Size (Diameter)			
PAHs	>2 mm	1–2 mm	0.45–1 mm (Particle)	<0.45 mm (Powder)
Naphthalene	87.5	81.0	89.4	85.7
Acenaphthylene	95.2	100.8	94.8	101.8
Acenaphthene	100.6	99.7	97.0	104.2
Fluorene	102.2	101.0	98.2	102.2
Philippines	100.7	102.3	95.5	100.1
Anthracene	101.6	96.9	101.3	84.6
Fluoranthene	101.9	101.3	93.8	92.5
Pyrene	99.7	99.7	91.3	87.7

Table 3.7 Recovery Rate of Organochlorine Pesticides in C&D Waste of Different Sizes

	Size (diameter)			
Organochlorine Pesticides	>2 mm	1–2 mm	0.45–1 mm (Particle)	<0.45 mm (Powder)
α-BHC	93.0	84.1	91.4	92.9
Aldrin	99.5	98.5	99.4	99.4
α-chlordane	86.5	87.2	89.8	88.9
α-endosulfan	90.5	98.4	97.2	97.2
g-chlordane	93.4	90.4	90.2	89.3
p, p′-DDE	106.4	112.2	108.7	108.7
Dieldrin	88.7	98.4	93.0	92.1
β-endosulfan	97.0	89.1	106.3	87.6

Table 3.8 Recovery Rate of Organophosphorus Pesticides in C&D Waste of Different Sizes

	Size (Diameter)			
Organophosphorus Pesticides	**>2 mm**	**1–2 mm**	**0.45–1 mm (Particle)**	**<0.45 mm (Powder)**
Dimethoate	95.8	86.5	81.9	88.8
Malathion	94.2	97.2	91.8	84.5
Chlorpyrifos	90.5	102.5	89.9	93.5
Quinalphos	94.9	93.2	92.2	84.0
Methidathion	100.9	102.3	92.5	93.8
Triazophos	103.1	98.4	91.7	97.6

Table 3.9 Comparison of the Effects on the Recovery Rate Between Ultrasonic Extraction and Centrifugation

Compound	Ultrasonic Extraction (%)	Centrifugation (%)
Naphthalene	99.0	1.0
Acenaphthylene	97.4	2.6
Acenaphthene	98.2	1.8
Fluorene	97.9	2.1
Philippines	95.8	4.2
Anthracene	97.3	2.7
Fluoranthene	96.2	3.8
Pyrene	96.4	3.6
Benzo (a) anthracene	95.8	4.2
Chrysene	97.1	2.9
Benzo (j) fluoranthene	86.1	13.9
Benzo (e) pyrene	93.1	6.9
Benzo (b) fluoranthene	91.5	8.5

approximately 10–25% more in leaching amount than sulfuric acid–nitric acid. The leaching of intermediates was relatively stable and had not varied with the leaching agents.

For volatile organic compounds, the leaching amount performed in ZHE vessels did not turn out to be more than that performed in ordinary PTFE bottles. Leaching amount of phorate was larger in clay–brick system than those in other systems. In dry brick system, even though the total amount of pollutant was extremely high, the leaching amount was only 10% of those in other systems. It seemed that phorate might have a strong combination with bricks in a dry environment. The leaching amount of ICDW performed in mortar and rock system was both larger than that in

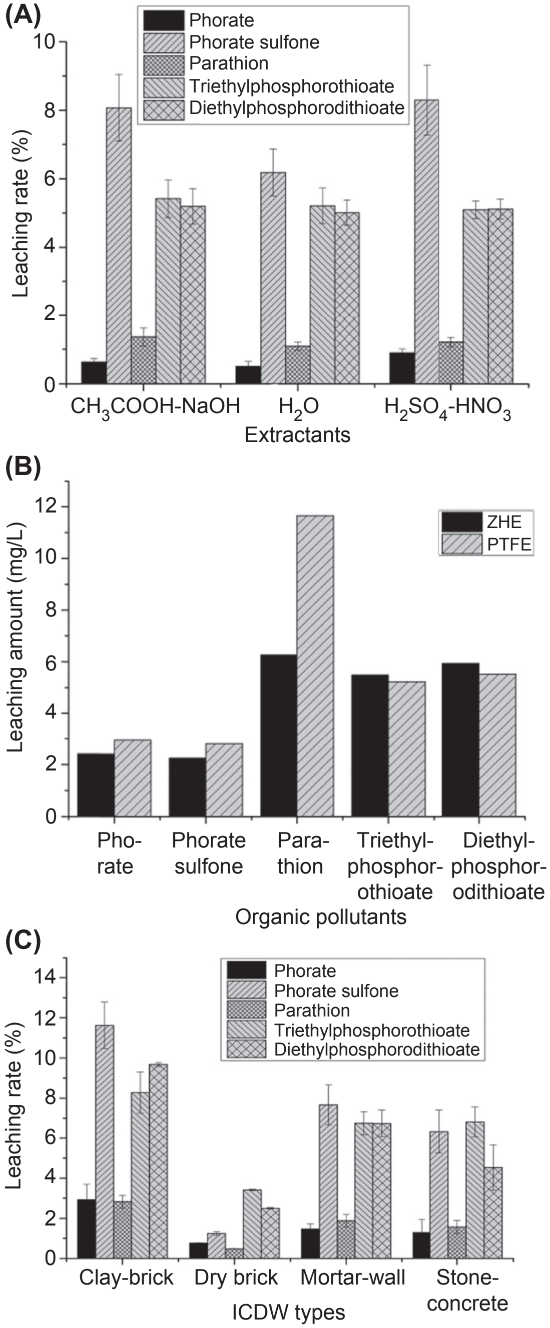

Figure 3.7 Leaching of organic pollutants in different leaching agent ((A): different extractants, (B): different pollutants, (C): different types of waste).

brick system. But for two intermediates and other organophosphorus pesticides, the rock system had the largest leaching amount.

Despite the content of heavy metals ranged between 50 and 1000 mg/kg, no metals were detected in the leachate. Results showed that the leaching rate of heavy metals in multicontaminated ICDW was relatively low.

CHAPTER FOUR

Pollution Characteristics of Industrial Construction and Demolition Waste

4.1 MERCURY AND ITS DISTRIBUTION IN CONSTRUCTION AND DEMOLITION WASTE

Different types of industrial construction and demolition (C&D) wastes in various places were collected and analyzed in detail. The coverage of investigation is shown in Table 4.1.

4.1.1 Distribution Characteristics of Mercury

Mercury contents of C&D waste from five different sources varied much overall, in which the maximum amount of 1542.83 μg/kg was 178.5 times the minimum amount of 6.46 μg/kg. The average amount of 164.97 μg/kg was 1.1 times the value of soil natural background limit of 150 μg/kg, taking Chinese standard of environmental quality for soils (GB15168-1995) as a comparison. It was indicated that the average mercury content of C&D waste in chemical industry (CI) was the highest among all. The waste with higher mercury contents in CI were, respectively, listed as follows, with the wall sample where cranes were used from a chemical plant in Wuxi (1215.47 μg/kg), concrete blocks from the wall of processing workshop (1542.83 μg/kg), concrete blocks from copper plating workshop of a electroplating factory in Shenzhen (1141.69 μg/kg), and bricks from a nickel plating workshop (1028.43 μg/kg). The average amount of mercury content in metallurgical industry (MI) C&D waste was 61.37 μg/kg, and the average amount of a zinc smelting factory in Yunnan (180.84 μg/kg) > a steel mill in Nanjing (93.69 μg/kg) > a steel mill in Shanghai (50.37 μg/kg) > firebrick in Baogang (21.34 μg/kg). The overall content was not high, and except for a zinc smelting factory in Yunnan, mercury content of the other waste was below first-level standard threshold (150 μg/kg) of soil. The maximum value of mercury content in metallurgical C&D waste present in the inner wall of the chimney from a steel mill was 620.52 μg/kg. Besides, the scraping from the outer wall of chimney (178.04 μg/kg) was far higher than other sampling points (<80 μg/kg).

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Table 4.1 Brief Description of the Samples Involved in This Section

Type	Name	Environment
Chemical industry	Chemical industry	Wall, coatings in workshops
	Electroplating factory	Workshops
	Paint factory	Wall, floor in workshops
	Glaze Technology Co., Ltd.	Wall, floor in workshops
	Incineration plant for hazardous waste	Wall, floor in workshops
Metallurgical industry	Zinc smelting plant	Electrolysis, cleaning workshops
	Abandoned steel mill	Boiler workshops
	Steel plant	Walls in workshops
	Steel plant	Boiler workshops
Light industry	Rubber factory	Workshops
	Light industry base	Walls in workshops
Pesticide industry	Pesticide manufacturing plant	Warehouses, workshops
Fire/explosion	Fire and explosion scene	Floor waste
Residential aggregates	University canteen	Bricks, wall
	Temporary dump sites	Bricks, wall
Recycled aggregates	Building materials company	Concrete, clay
	Earthquake C&D waste	Coarse and fine aggregate

C&D, construction and demolition.

Mercury pollution of the steel mills mainly appeared in the chimney, which might be associated with the use of high mercury-content coal.

The main reason why CI and MI contributed to high mercury content was that, in the industries such as electroplating factory, mercury-containing raw materials were used in the production process and some dripped on the floor or wall in the operation process. Pipeline aging and leakage of corrosive liquid caused damages of metope and ground, thus creating mercury-containing C&D waste through adsorption and entrainment. Material stock workshop, filling workshop, production workshop, demolition and maintenance, etc., also caused a mixed accumulation of much mercury-contained waste with general C&D waste. Furthermore, iron and steel industries needed to burn a lot of coal, and mercury escaped into the flue gas with coal combustion, resulting in generation of Hg-polluted wastes.

The average mercury content of C&D waste in light industry (LI) was 112.16 μg/kg, with the highest content of 506.44 μg/kg present in the insulation sandwich of wall rubber, compared with 75.97 μg/kg in living

Figure 4.1 Real appearance of sampling point in a zinc smelting factory in Yunnan.

quarters, 78.90 μg/kg in the regeneration product, and 46.67 μg/kg in the renovation wastes of a college canteen. The highest mercury content was nearly 100 times the lowest in CI or metallurgy industry, which had something to do with the use of raw materials and processing. Most Hg presenting in C&D wastes should come from the raw materials used in the production processes. The appearance of sampling spots is shown in Fig. 4.1.

4.1.2 Single Factor Evaluation of Mercury Pollution

There is no relevant standard about heavy metal contents yet in building materials industry, so the secondary standard for soil was adopted as the environmental safety threshold for reference. Five different sources were analyzed using single factor index evaluation method of mercury pollution for the level of C&D waste pollution, and its computation formula was as follows: $P = C/S$, where P is the mercury pollution index of C&D waste, C is the real average mercury contents of C&D waste (μg/kg), and S is the secondary standard threshold for soil mercury evaluation. The secondary standard was a limit to guarantee agricultural production and keep human body healthy, and $S = 300$ μg/kg if referring to the secondary standard of environmental quality standard for soils (GB15168-1995). $p < 1$ was no contamination, $1 \leq p < 2$ was mild contamination, $2 \leq p < 3$ was moderate pollution, $p > 3$ was heavy pollution. Single factor evaluation results of mercury pollution degree of C&D waste are shown in Table 4.2.

Referring to environmental quality standard for soils (GB15168-1995), the first-level standard is 150 μg/kg, the second-level standard 300 μg/kg, and the third-level standard 1500 μg/kg. Results of the single factor evaluation showed that mercury pollution of C&D waste in CI was more serious than others, and the average content of mercury was up to 669.27 μg/kg.

Table 4.2 Statistical Characteristics of Mercury Contents of C&D Wastes From Different Sources

Industry	Sampling Number	Maximum (μg/kg)	Minimum (μg/kg)	Mean (μg/kg)	Standard Deviation	Contamination Index
CI	10	1542.83	16.88	669.27	525.77	2.23
MI	38	620.52	6.84	61.37	110.91	0.20
LI	6	506.44	6.46	112.16	194.51	0.37
RS	5	156.73	24.59	75.97	50.95	0.25
RC	4	179.11	23.52	78.90	70.57	0.26
Total	63	1542.83	6.46	164.97	316.09	0.55

C&D, construction and demolition; *CI*, chemical industry; *LI*, light industry; *MI*, metallurgical industry; *RC*, recycled aggregates; *RS*, residential aggregates.

Mercury content of seven samples were over secondary standard threshold of mercury for soils, and one sample was more than third standard threshold of mercury for soils, contamination index was 2.23, i.e., moderate pollution, whereas mercury pollution index of C&D waste from other four sources was less than 1. One sample of MI and LI separately was more than the second-level standard threshold of mercury for soils, and mercury contents of recycled aggregates (RC) and residential wastes were less than secondary standard threshold of mercury for soils.

4.2 CHARACTERIZATION OF CU/ZN/PB/CR/CD/NI IN INDUSTRIAL C&D WASTE

Sixty three C&D waste samples from different sources have been collected. The concentration analysis and risk assessments have also been carried out.

4.2.1 Total Concentrations of Heavy Metals in C&D Waste

The total heavy metal concentrations of C&D waste samples are summarized in Table 4.3. The threshold values of heavy metals (TVHMs) of the environmental quality standard for soils in China are also shown. In this standard, Level-I value is the upper limit for soil environmental background, Level-II is the upper limit to guarantee agriculture and human health, Level-III is the threshold value to maintain regular growth in plants. Cd was not detected in most of the samples. The average contents of Pb, Cd, and Ni were lower than the TVHM^{e3} (Level-III), whereas Cu, Zn, and Cr are 1–4 times higher. However, the maximum of each element was far above the TVHM^{e3} (Level-III).

Table 4.3 Total Heavy Metal Concentrations in C&D Waste Samples From Five Sources

	Heavy Metal (mg/kg)					
Sample	**Cu**	**Zn**	**Pb**	**Cr**	**Cd**	**Ni**
CI	6310 ± 18,700[a] (296%)[b]	911 ± 969 (106%)	82 ± 129 (159%)	943 ± 912 (97%)	2.24 ± 0.22 (10%)	573 ± 843 (147%)
MI	204 ± 602 (296%)	3340 ± 5710 (171%)	201 ± 318 (158%)	232 ± 222 (95%)	6.3 ± 4.8 (76%)	54.2 ± 49.4 (91%)
LI	50.7 ± 35.2 (69%)	128 ± 53 (41%)	20.5 ± 9.2 (45%)	95.5 ± 67.5 (71%)	1.18 ± 1.01 (86%)	31.9 ± 29.7 (93%)
RS	35.9 ± 9.3 (26%)	704 ± 289 (41%)	23.7 ± 8.3 (35%)	95.0 ± 91.3 (96%)	ND[c]	18.0 ± 11.0 (61%)
RC	24.6 ± 2.9 (12%)	906 ± 538 (59%)	23.3 ± 3.8 (16%)	70.7 ± 12.8 (18%)	ND	21.3 ± 1.8 (8.6%)
Average	1130 ± 7490	2280 ± 4520	141 ± 265	311 ± 406	5.28 ± 4.67	131 ± 380
Max	59,400	49,300	1260	7510	15.4	2870
Min	4.43	17.7	ND	10.1	ND	5.29
De/An[d]	63/63	63/63	59/63	63/63	14/63	63/63
TVHM[e]	35	100	35	90	0.2	40
TVHM[f]	100	250	300	200	0.6	60
TVHM[g]	400	500	500	300	1	200

C&D, construction and demolition; *CI*, chemical industry; *LI*, light industry; *MI*, metallurgical industry; *RC*, recycled aggregates; *RS*, residential aggregates; *TVHM*, threshold value of heavy metals of the environmental quality standard for soils in China (CEPA, GB 15618-1995).

[a] Results are expressed as mean ± standard deviation.

[b] Coefficient of variation.

[c] Not detected.

[d] Number detected/Number analyzed.

[e] The first-level standard (Level-I).

[f] The second-level standard (Level-II).

[g] The third-level standard (Level-III).

To visualize the evaluation of each heavy metal, six graphs are presented in Fig. 4.2. The severely contaminated samples were mainly contained in the CI and MI categories. Generally, low degrees of the heavy metal contents were present in the LI, residential aggregates (RS), and RC samples. In the case of Zn, three of five RS samples and three of four RC samples exceeded the TVHM^{e3} (Level-III), with mean concentrations up to 704 and 906 mg/kg, respectively; simultaneously, low concentration existed in the LI samples, with 128 mg/kg on average. This phenomenon might be caused by the slathering of the walls and furniture with zinc-rich paint during interior renovation.

Considerable hazard was posed in various workplaces of CI and MI according to Fig. 4.2. For almost every graph, no significant differences were found between LI, RS, and RC, but the dots representing CI and MI protruded obviously from the others. For Cu, the most seriously polluted sample was CI8 (59,400 mg/kg) from a copper electroplating workshop, which exceeded the TVHM^{e3} (Level-III) by 150 times. CI10 (3190 mg/kg) from a nickel plating workshop came from the same plant. Other seriously polluted samples included MI1 and MI2 from the electrolysis workshop and clean workshop, respectively, in the zinc smelting plant (Fig. 4.2A).

For Zn, about half of the CI samples and one-third of the MI samples exceeded the TVHM^{e3} (Level-III). In MI, the most polluted sample was MI1 (49,300 mg/kg) from a zinc smelting electrolysis workshop, and it was more than 100 times higher than the TVHM^{e3} (Level-III). The severely polluted samples mainly came from the two MI plants, the zinc smelting plant and a Shanghai steel plant (Fig. 4.2B).

For Pb, almost all the LI, RS, and RC samples were below the TVHM^{e1} (Level-I), and all the CI samples were lower than the TVHM^{e3} (Level-III). Most of the MI samples met the TVHM^{e3} (Level-III) except MI2 (879 mg/kg) from a cleaning workshop in the zinc smelting plant, MI20 (766 mg/kg) and MI24 (1260 mg/kg) from a Shanghai steel plant, and MI29 (1050 mg/kg) from another Shanghai steel plant (Fig. 4.2C).

The Cr concentrations of the LI, RS, and RC samples were all below the TVHM^{e3} (Level-III). Among the CI samples, CI5 (701 mg/kg) from the CI corporation, CI9 (7510 mg/kg) from a chrome plating workshop in the electroplating factory, and CI10 (306 mg/kg) from a nickel plating workshop in the same plant exceeded the TVHM^{e3} (Level-III). Among the MI samples, almost all the severely contaminated ones came from Shanghai steel plants (Fig. 4.2D).

Cd was not detected in the majority of the samples. There were 11 samples exceeding the TVHM^{e3} (Level-III), among which 9 samples were from MI. MI1-2 were from Electrolysis & Clean workshop in zinc smelting plant,

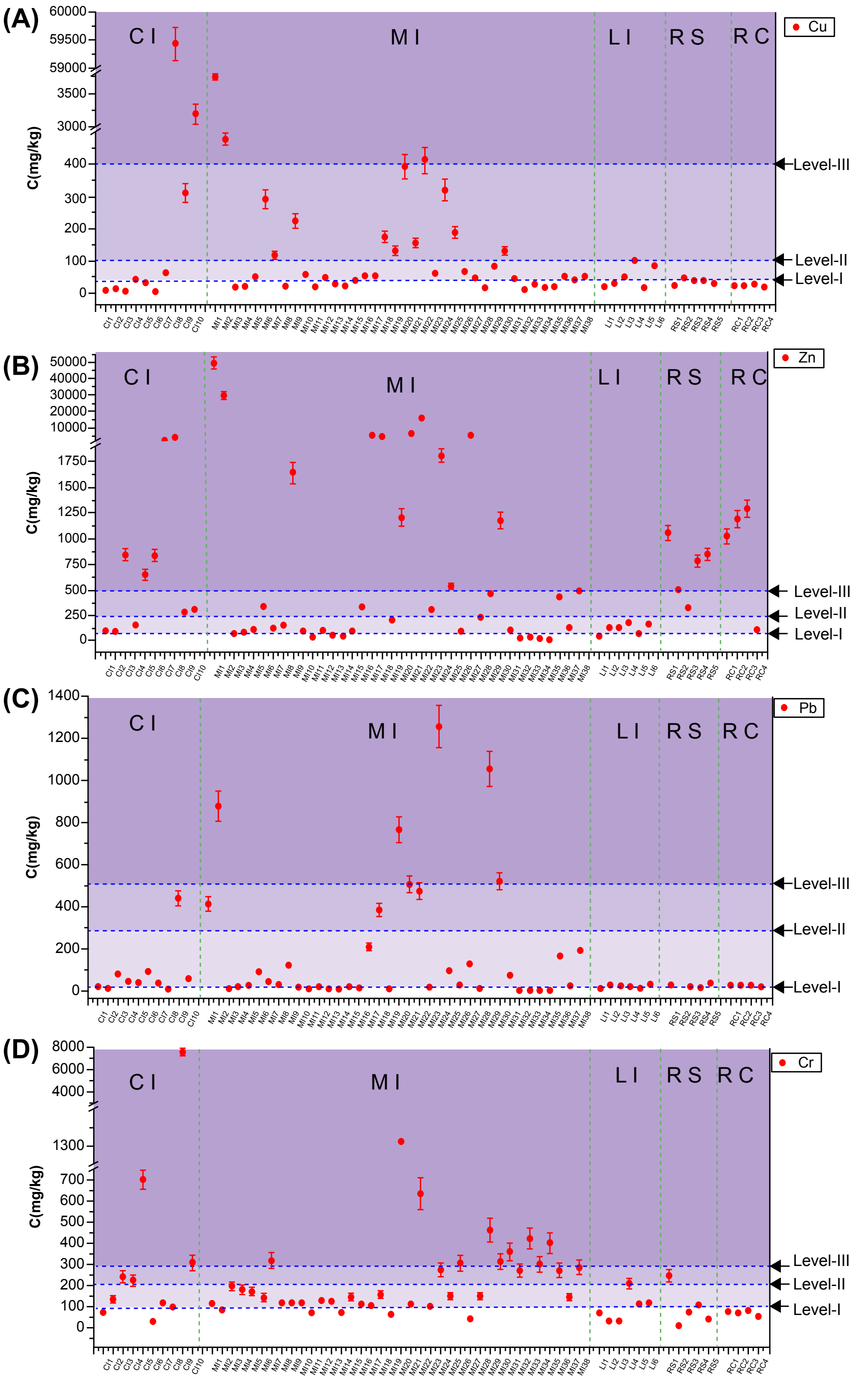

Figure 4.2 Concentrations of Cu (A), Zn (B), Pb (C), Cr (D), Cd (E), and Ni (F) in construction and demolition waste from five sources in China (n = 63). *CI*, chemical industry; Level-I, the first-level standard; Level-II, the second-level standard; Level-III, the third-level standard [environmental quality standard for soils in China (CEPA, GB 15618-1995)]; *LI*, light industry; *MI*, metallurgical industry; *RC*, recycled aggregates; *RS*, residential aggregates.

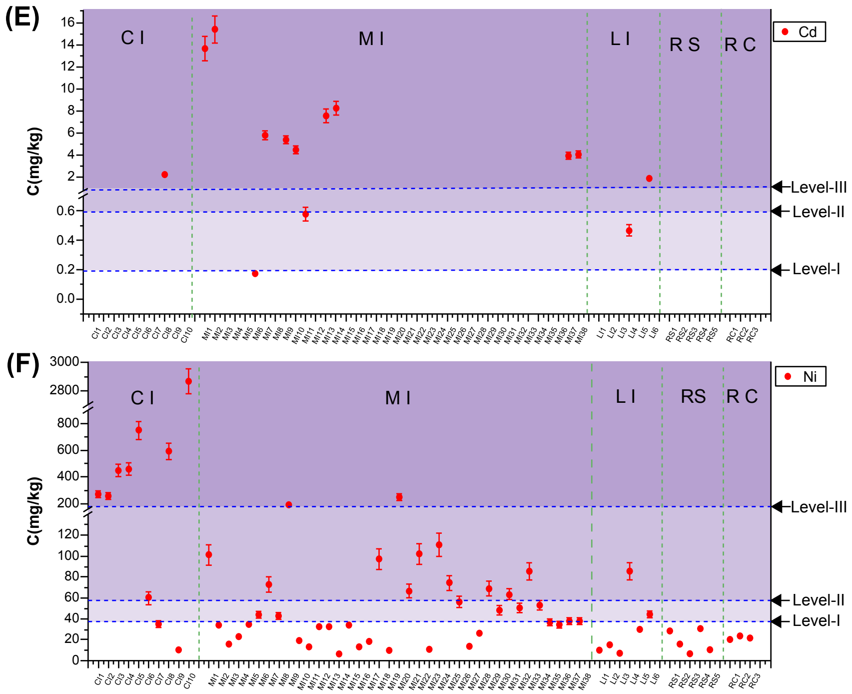

Figure 4.2 **(*continued*).**

and MI7, MI9-10, and MI13 were collected from chimney and boiler workshop in the abandoned steel mill. MI14 was from Shanghai steel plant. MI37-38 was collected from the boiler workshop in steel plants. The other two samples surpassing Level-III were CI8 from electroplating factory and LI6 from LI bases (Table 4.3 and Fig. 4.2E).

The mean concentration of Ni in the CI samples (573 mg/kg) was much higher than those of MI, LI, RS, and RC (54.2, 31.8, 18.0, and 21.3 mg/kg, respectively). Almost all the CI samples were higher than the TVHM^{e3} (Level-III), of which there is a maximum of 2870 mg/kg in CI10 from a nickel plating workshop in the electroplating factory. Five of six samples from the CI corporation posed a high risk (Fig. 4.2F).

4.2.2 X-Ray Fluorescence Analysis of Heavy Metals in C&D Waste

Due to the large number of samples, the six most polluted samples were selected as representative for X-ray fluorescence (XRF) analysis of heavy metals in C&D wastes, among which four samples (CI7—CI10) came

Table 4.4 Main Mineral Constituent of C&D Waste Samples According to the Xrf Analysis Presented as % W/W Content of Mineral Oxides

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O
CI-7	60.491	18.865	7.638	1.398	1.122	2.521	1.321
CI-8	30.162	4.563	1.528	0.712	14.039	0.701	0.074
CI-9	48.307	6.521	1.745	0.456	15.091	1.047	0.601
CI-10	49.552	7.137	1.678	0.389	11.107	2.191	0.858
MI-1	2.985	1.865	0.981	0.219	1.878	1.993	76.451
MI-2	2.359	1.227	2.385	0.133	1.184	2.142	73.901

Electroplating factory samples (CI-7, galvanizing workshop; CI-8, copper plating workshop; CI-9, chrome plating workshop; CI-10, nickel plating workshop), zinc smelter samples (MI-1, electrolysis workshop; MI-2, cleaning workshop).

from electroplating plants, and the other two (MI1-MI2) came from the zinc smelter plants (Table 4.4).

XRF was performed to investigate the chemical elemental composition. The details are shown in Table 4.4. As can be seen, electroplating factory C&D waste samples CI7—CI10 were mainly SiO_2 (30.2—60.5%), Al_2O_3 (4.6—18.9%), and CaO (1.1—15.1%), which were common composition in bricks, suggesting relatively slight corrosion. In contrast, zinc smelting plant samples MI1-2 were mainly Na_2O (73.9—76.5%). The high content of sodium meant that severe corrosion could have occurred in these floor bricks and also indicated frequent contact with sodium salts.

4.2.3 X-Ray Diffraction Analysis of Heavy Metals in C&D Waste

The crystalline phases of the six samples were analyzed by X-ray diffraction (Fig. 4.3). The main mineralogical compositions of the four CI samples were common brick compositions like quartz, silicon oxide, gypsum, and a small amount of berlinite, which was in good correspondence to the XRF results. Although the concentration of Pb was under THVM Level-II according to the Inductive Coupled Plasma results, lead arsenate, a highly toxic substance extensively used as an insecticide, was present in samples CI7 and CI8 in small quantities. There was also another toxic substance, potassium chromium oxide, in CI8. According to the figure, the Cr concentration in CI8 was the lowest among CI7—CI10, however, the chromium crystallization was not detected in the other three samples. This meant large quantities of Cr appeared to be noncrystal forms existing in the samples.

Obviously, much more complex patterns in MI samples were posed as the result of deposition and erosion on the workshop floor in zinc smelter

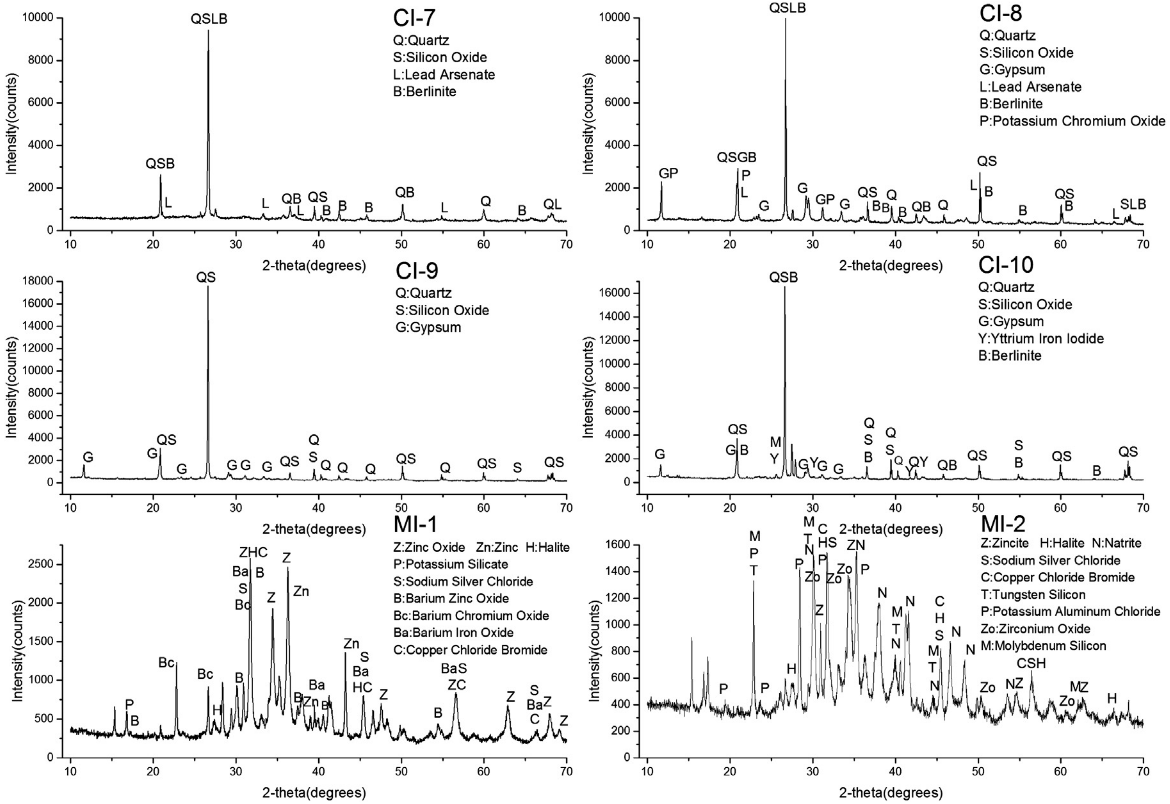

Figure 4.3 X-ray diffraction of six most polluted construction and demolition waste samples from the electroplating factory and zinc smelter in China. Electroplating factory samples (CI-7, galvanizing workshop; CI-8, copper plating workshop; CI-9, chrome plating workshop; CI-10, nickel plating workshop). Zinc smelter samples (MI-1, electrolysis workshop; MI-2, cleaning workshop).

plants. Combined with the XRF results, it can be found that above 70% (w/w) of them were mainly composed of sodium salts such as sodium silver chloride, halite, and nitrite. Moreover, peaks of copper chloride bromide were obvious. In view of the easy solubility of such toxic substances, it may pose a high danger as the high concentration of Cu (476—3740 mg/kg). A series of zinc-bearing minerals, such as zinc, zinc oxide, barium zinc oxide, and zincite, showed the extremely serious contamination in line with the total concentrations of Zn. The crystalline phases of chromium were identified in both MI1 and MI2. As carriers of heavy metals, the mineral phases especially for zinc and copper minerals were easily mobilized under acid condition, which meant a potential risk in natural environment.

4.2.4 Chemical Speciation of Heavy Metals in C&D Waste

The potential mobility, bioavailability, and toxicity of heavy metals in C&D waste are not only associated with their total concentration levels but also their chemical speciations. To evaluate bioavailability and environmental risk more accurately, a modified European Communities Bureau of Reference (BCR) sequential extraction was utilized. The results are shown in Table 4.5 and Fig. 4.4. The acid soluble/exchangeable fraction (F1) presented high bioavailability of the metals; meanwhile, metals associated with the reducible fraction (F2) could remain available under anoxic conditions. The oxidizable fraction (F3) was easily mobilized and transformed into F1 or F2 in oxidizing conditions. The residual fraction (F4) might hold metals within the crystal structure of its constituents and was identified as a stable fraction.

A verification of the results of the BCR sequential extraction procedure was performed by comparing the sum of the four fractions (F1, F2, F3, and F4) with the total digestion concentrations of heavy metals from the HNO_3 digestion procedure. The detailed calculation was expressed as follows:

$$\text{Recovery }(\%) = (\text{F1} + \text{F2} + \text{F3} + \text{F4})/\text{Total digestion} \times 100\%$$

The recovery rates are listed in Table 4.5 and were in good agreement with the total heavy metal concentrations, with satisfactory recovery rates ranging from 89.7% to 111%. This indicated that this modified BCR sequential extraction method was reliable.

Proportions of each chemical fraction are presented in Fig. 4.4. For the CI7 sample from the galvanizing workshop, Cu, Pb, Cr, and Ni mainly existed in the residual fraction, whereas their total concentrations were all under TVHM-II. But the acid extractable fraction of Pb contained the toxic substance lead arsenate. Zn mainly existed in the acid extractable

Table 4.5 Content Distributions of Each Fraction of Heavy Metals in Construction and Demolition Waste Samples (mg/kg)

Sample	Element	F1	F2	F3	F4	∑F	Total[a]	Recovery (%)[b]	RAC (%)[c]
CI-7	As	ND[d]	ND	ND	29.66 ± 2.21	29.66 ± 2.48	30.80 ± 2.75	96.29	ND
	Fe	550.76 ± 35. 56	619.08 ± 45.24	137.23 ± 12.27	17,448.72 ± 1310.83	18,755.77 ± 1648.63	17,945.38 ± 1361.5	104.52	2.94
	Mn	16.43 ± 1.15	4.50 ± 0.29	ND	875.40 ± 72.28	896.33 ± 72.64	878.69 ± 71.96	102.01	1.83
CI-8	As	ND	76.83 ± 6.36	30.17 ± 2.37	29.41 ± 2.74	136.42 ± 11.34	132.50 ± 12.23	102.96	ND
	Fe	364.15 ± 28.14	5993.08 ± 464.29	707.79 ± 67.39	3883.30 ± 261.97	10,948.31 ± 998.92	12,278.84 ± 1196.4	89.16	3.33
	Mn	51.48 ± 4.06	30.65 ± 2.91	2.73 ± 0.19	89.49 ± 7.29	174.35 ± 14.59	167.46 ± 14.64	104.11	29.53
CI-9	As	ND	ND	ND	18.81 ± 1.65	18.81 ± 1.65	18.84 ± 1.56	99.86	ND
	Fe	451.19 ± 32.16	4881.86 ± 354.29	864.36 ± 76.10	5370.45 ± 478.93	11,567.86 ± 1030.29	10,847.08 ± 988.33	106.64	3.90
	Mn	15.88 ± 1.06	91.18 ± 8.38	15.99 ± 1.43	166.28 ± 14.21	289.34 ± 23.68	292.23 ± 22.79	99.01	5.49
CI-10	As	ND	ND	ND	17.46 ± 1.42	17.46 ± 1.42	17.21 ± 1.38	101.50	ND
	Fe	1654.47 ± 117.25	4951.48 ± 378.35	421.76 ± 31.38	4767.28 ± 387.41	11,794.99 ± 931.29	11,098.99 ± 878.94	106.27	14.03
	Mn	136.50 ± 10.03	101.40 ± 9.32	0.74 ± 0.05	163.22 ± 14.01	401.85 ± 34.72	423.93 ± 41.34	94.79	33.97
MI-1	As	4.61 ± 0.26	29.30 ± 2.39	53.07 ± 4.93	63.38 ± 5.32	150.36 ± 13.97	155.09 ± 12.19	96.95	3.06
	Fe	31.57 ± 2.37	584.19 ± 32.91	595.30 ± 46.09	3696.13 ± 268.36	4907.18 ± 489.78	5288.42 ± 469.35	92.79	0.64
	Mn	46.58 ± 3.96	76.57 ± 5.97	38.70 ± 2.72	46.65 ± 3.96	208.50 ± 18.93	214.04 ± 19.17	97.41	22.34
MI-2	As	33.33 ± 2.12	34.99 ± 2.87	0.58 ± 0.07	138.75 ± 12.27	207.65 ± 16.26	232.31 ± 21.82	89.39	16.05
	Fe	65.97 ± 4.09	727.70 ± 36.47	395.31 ± 29.26	9696.55 ± 876.21	10,885.53 ± 983.02	11,962.41 ± 864.38	91.00	0.61
	Mn	ND	62.50 ± 4.27	13.75 ± 1.25	81.04 ± 6.09	157.28 ± 12.33	166.17 ± 15.19	94.65	ND

Electroplating factory samples (CI-7, galvanizing workshop; CI-8, copper plating workshop; CI-9, chrome plating workshop; CI-10, nickel plating workshop), F1, acid extractable fraction; F2, reducible fraction; F3, oxidizable fraction; F4, residual fraction, zinc smelter samples (MI-1, electrolysis workshop; MI-2, cleaning workshop).

[a] Total digestion concentration.

[b] Recovery = (F1 + F2 + F3 + F4)/Total digestion×100%.

[c] Risk assessment code (RAC) = F1/ΣF × 100%.

[d] Not detected.

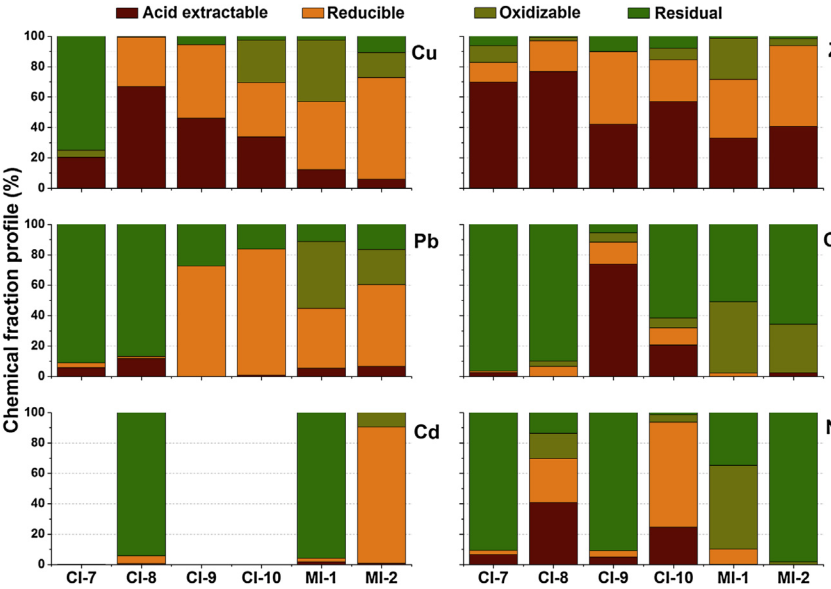

Figure 4.4 Chemical fraction profiles of Cu, Zn, Pb, Cr, Cd, and Ni in the six most polluted construction and demolition waste samples from the electroplating factory and zinc smelter in China. Electroplating factory samples (CI-7, galvanizing workshop; CI-8, copper plating workshop; CI-9, chrome plating workshop; CI-10, nickel plating workshop). Zinc smelter samples (MI-1, electrolysis workshop; MI-2, cleaning workshop).

fraction. The mobility fraction of Zn [(F1 + F2 + F3)/Total] in the CI7 sample was over 93%, with a very high total concentration of 2120 mg/kg.

In the CI8 sample, the mobility fractions of Cu and Zn were both over 99%, and that of Ni was over 86%. The concentrations of Cu, Zn, and Ni far surpassed TVHM-III. Pb, Cr, and Cd mainly existed in the residual fraction, but small quantities of lead arsenate and potassium chromium oxide existed in the mobility fraction.

The proportions of the mobility fractions of Cu, Zn, and Cr in the CI9 sample were 94.4, 89.9, and 94.3%, respectively. The total concentrations of Cu and Zn were below TVHM-II; however, the concentration was extremely high for Cr (7510 mg/kg), and mainly existed in the acid extractable fraction. As no chromium crystallization was detected, Cr could be existing in amorphous forms in this sample. Pb mainly existed in the reducible fraction, and Ni mainly existed in the residual fraction. Both their total concentrations were below TVHM-II.

The proportions of the mobility fractions of Cu, Zn, Pb, and Ni in the CI10 sample were all over 83%, with total concentration of Cu and Ni surpassing TVHM-III. Although Cr surpassed TVHM-III, it mainly existed in the residual fraction.

The proportions of the mobility fractions of Cu, Zn, and Pb in the MI-1 sample were all over 88%, with concentrations of Cu and Zn above TVHM-III and Pb above TVHM-II. Large quantities of Cu existed as copper halide and most of the Zn appeared to be zinc, zinc oxide, barium zinc oxide, and zincite. Cr and Ni mainly existed in the residual and oxidizable fractions. But there is barium chromate in the mobility fraction. Although the total concentration was high above TVHM-III, Cd mainly existed in the residual fraction and was over 95%.

In the MI-2 sample, the proportions of the mobility fractions of Cu, Zn, Pb, and Cd were over 83%, and all of them exceeded TVHM-III. Cu mainly existed in the reducible and oxidizable fractions as copper halide. Cd mainly existed in the reducible fraction and was over 89.5%. Cr and Ni mainly existed in the residual fraction and were over 65%; both were below TVHM-I.

The higher the proportion of heavy metals in the mobility fraction, the greater the potential for transfer ability will be exerted. These results suggested that Zn, Cu, Pb, and Ni had higher transfer ability and reflected that most heavy metals bound loosely with minerals in the form of mobility fractions. Therefore it was difficult to ensure the stabilities of these heavy metals by means of only a simple landfill or random stacking.

In another study, No. 1—4 samples were C&D waste from chemical industry and No. 5—6 were from metallurgical industry, No. 7 was the reference sample simulated in the laboratory. Speciation analysis of Cr, Cu, Ni, Pb, and Zn is listed in Table 4.6.

The acid extractable fraction, reducible fraction, and oxidizable fraction of Zn and Cu in C&D waste in Zn, Cu workshops from an electroplating factory and the electrolysis and cleaning section of zinc manufacturing factory were high in amount, whereas the residual fraction was low. The Zn and Cu in C&D waste in Zn, Cu workshops from an electroplating factory had strong mobility and would cause high environmental risks.

4.2.5 Risk Assessment Code of Heavy Metals in Most Polluted Waste

Compared with other chemical fractions, it is much easier for the acid extractable fraction to transform and migrate into the environment. Hence, the risk assessment code (RAC) is defined as the proportion of acid extractable elements in the total species distribution (%F1 for BCR), which is used

Table 4.6 Speciation Analysis of Heavy Metals in Construction and Demolition Waste

Sample	Speciation	Zn (mg/kg)	Cu (mg/kg)	Cr (mg/kg)	Ni (mg/kg)	Pb (mg/kg)
1. Zn workshop from an electroplating factory	Acid extractable fraction	1568.57	14.15	—	—	—
	Reducible fraction	289.79	—	—	—	—
	Oxidizable fraction	313.10	3.99	—	—	—
	Residual fraction	13.79	5.24	12.44	3.75	3.63
	Total	2185.26	23.38	12.44	3.75	3.63
2. Cu workshop from an electroplating factory	Acid extractable fraction	3014.30	31,720.20	—	255.17	—
	Reducible fraction	799.28	15,473.30	6.11	180.49	—
	Oxidizable fraction	112.68	356.12	4.29	129.67	—
	Residual fraction	2.84	3.52	8.46	8.54	0.69
	Total	3929.10	47,553.14	18.87	573.87	0.69
3. Cr workshop from an electroplating factory	Acid extractable fraction	133.42	155.57	5424.78	—	—
	Reducible fraction	151.38	164.02	1064.09	—	46.28
	Oxidizable fraction	1.33	—	565.11	—	—
	Residual fraction	3.20	1.90	40.93	1.023	1.74
	Total	289.33	321.49	7094.91	1.023	48.02
4. Ni workshop from an electroplating factory	Acid extractable fraction	192.72	983.35	70.08	648.16	—
	Reducible fraction	93.61	1047.95	38.63	1818.15	52.65
	Oxidizable fraction	31.64	1019.50	28.30	164.01	—
	Residual fraction	2.74	7.74	21.01	3.85	1.07
	Total	320.71	3058.54	158.02	2634.17	53.72
5. Electrolysis section in a zinc factory	Acid extractable fraction	17,133.68	290.02	—	—	21.24
	Reducible fraction	20,194.2	1063.25	1.67	6.57	156.98
	Oxidizable fraction	17,588.25	1200.81	44.41	44.71	218.20
	Residual fraction	79.35	6.45	4.04	2.25	4.54
	Total	54,995.48	2560.53	50.12	53.53	400.96

(*Continued*)

Table 4.6 Speciation Analysis of Heavy Metals in Construction and Demolition Waste—cont'd

Sample	Speciation	Zn (mg/kg)	Cu (mg/kg)	Cr (mg/kg)	Ni (mg/kg)	Pb (mg/kg)
6. Cleaning section in a zinc factory	Acid extractable fraction	13,353.54	28.34	—	—	53.98
	Reducible fraction	17,563.98	317.78	—	—	451.95
	Oxidizable fraction	1842.60	97.62	12.57	—	244.23
	Residual fraction	53.89	5.11	1.93	0.61	13.79
	Total	32,814.01	448.85	14.50	0.61	763.95
7. Laboratory simulation	Acid extractable fraction	103.03	514.07	242.69	—	501.58
	Reducible fraction	12.53	55.53	162.26	—	131.96
	Oxidizable fraction	13.62	—	343.45	—	—
	Residual fraction	4.85	2.53	27.06	1.77	0.78
	Total	134.03	572.13	775.46	1.77	634.32

—, undetected.

to evaluate the environmental risk levels of metals in the ecosystem. A proportion of 1−10% reflects a low risk, 11−30% a medium risk, 31−50% a high risk, and above 50% poses a very high risk and is considered dangerous. The RAC values are presented in Table 4.5. Specific results and evaluation criteria are shown in Fig. 4.5.

According to the RAC classification, the results presented in Fig. 4.5 suggested that Cd presented a low risk in almost all samples. Pb presented a medium risk in the CI8 sample and a low risk in the remaining samples. Ni, Cr, and Cu had different potential risks in different samples. Ni presented a high risk in the CI-8 sample, Cr a very high risk in the CI-9 sample, Cu a high risk in the CI-9 and CI-10 samples and a very high risk in the CI-8 sample. Meanwhile, Zn presented the highest potential risk overall. It presented a high risk in the CI-9, MI-1, and MI-2 samples and a very high risk in the CI-7, CI-8, and CI-10 samples. The environmental risk based on the average RAC in all samples was roughly sequenced as: Zn > Cu > Cr > Ni > Pb > Cd. The results indicated that much more attention should be paid to Zn, Cu, Cr, and Ni in C&D waste.

Issues such as increasing C&D waste disposal costs and the recycling potential of the many components in the C&D waste stream have resulted in the evolution of the recycling of C&D waste into a growing industry in

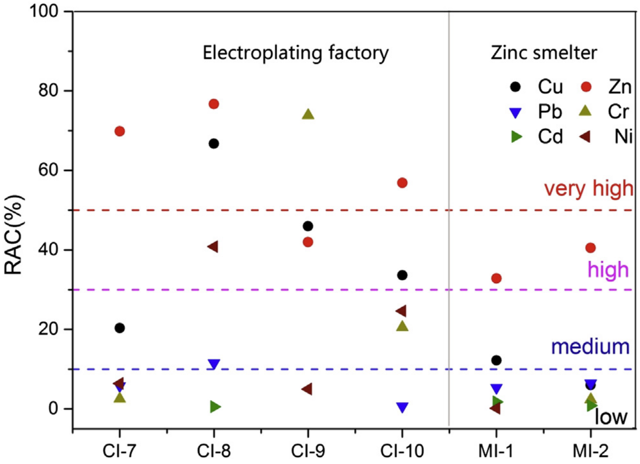

Figure 4.5 Risk assessment code (RAC) of Cu, Zn, Pb, Cr, Cd, and Ni in the six most polluted construction and demolition waste samples from the electroplating factory and zinc smelter in China. Electroplating factory samples (CI-7, galvanizing workshop; CI-8, copper plating workshop; CI-9, chrome plating workshop; CI-10, nickel plating workshop). Zinc smelter samples (MI-1, electrolysis workshop; MI-2, cleaning workshop).

China in recent years. In China, residential C&D wastes are the main raw material for recycled products because there are generally considered not to be environmental hazards. The recycling process of C&D waste includes three main steps: screening, drying, and crushing. Drying under 500°C can help remove organic pollutants, but incapable for heavy metal pollution. The third-level standard limit values (CEPA, GB 15618-1995) were exceeded for zinc in residential C&D waste, which may come from pigments, paints, lacquers, manganese batteries, and wood preservative coatings, and hence the removal of surface materials is necessary before recycling.

The contents of heavy metals at a chemical group were not as serious as other CI and MI plants, with only a relatively high risk of zinc and nickel. The company used to produce hydrochloric acid, caustic soda, zinc oxide, synthesis resins, pesticide, emulsifier, etc. By contrast, the three steel plants were extremely vulnerable to zinc, lead, chromium, and cadmium pollution. It was found that the presence of zinc, lead, and cadmium was mainly from steel-smelting activities. The lead pollution was mainly from the floor surface of the processing plant and transport workshop, probably due to the splash of lead-based gasoline during the transport process. The high concentrations of these chromium and cadmium hazardous compounds were found principally in the chimney affected directly by coal-burning flue gas. Thus it needed selective deconstruction for chimneys and workshop floors during building demolition to allow the wastes to be recycled.

The highest environmental risks of these pollutants were found to be present in the electroplating factories (galvanizing, copper plating, chrome plating, and nickel plating workshops) and zinc smelting plants (electrolysis and clean workshops). Zinc, copper, chromium, and nickel mainly existed in the mobility fraction, and lead and cadmium mainly existed in the residual fraction. It was proved that pH was the most relevant factor in the leaching methods of C&D waste due to its strong control of the heavy metals released. The frequent incidences of acid rain in China suggest that these pollutants can generate high potential mobility risks and ecological hazards in the case of a deposit in an unlined landfill or random stacking and recycling. Thus environmentally friendly processes, such as elution or immobilization, are required to remediate these contaminated C&D waste.

The samples from the zinc smelting plant and electroplating factory, in which the copper and zinc contents reached up to 5% of the total weight, could be a new resource to extract metals. Now there were two methods, thermal and hydrometallurgical methods, to recover the heavy metals from the solid phase. The combination of alkaline–acidic leaching enhanced the removal of Zn, Cr, and Ni, whereas thermal treatment can destroy persistent organic compounds and remove easily volatile heavy metals, such as Pb, Cd, and Cu.

4.3 LEACHING TOXICITY OF C&D WASTE FROM DIFFERENT SOURCES

Results of the leaching experiment are shown in Table 4.7 and Fig. 4.6. In general, the leaching toxicity of C&D waste from chemical and metallurgical industries was the highest, followed by residual C&D waste, whereas that of C&D waste from LI and RC was the lowest. Different heavy metals showed different leaching tendency. The metals easiest to be leached was Zn (22 of 62 samples) and Cu (21 of 62 samples), then it was Ni (12 of 62 samples) and Cr (9 of 62 samples), whereas Cd (2 of 62 samples) was the hardest to be leached.

4.4 CHARACTERISTICS OF ORGANIC POLLUTANTS IN MULTICONTAMINATED INDUSTRIAL C&D WASTE

Transfer of pollutants in industrial C&D waste exists between the atmosphere, water, and soil system. Industrial C&D waste from pesticide manufacturing plants pose an extreme threat to the environment due to the multiple contaminations (organic and inorganic pollutants). Meanwhile, it has been several decades since the production of a series of highly toxic pesticides like phorate (cynamid-3911) was banned. These plants have to be abandoned and have not been demolished until recently to meet the demand for urbanization and industrialization, with a huge amount of hazardous industrial C&D waste produced. Despite severe pollution, industrial C&D waste has not been listed as the focus of government administration due to its miscellaneous generation source and immature source separation technology.

Heavy metals broadly existed in the C&D waste of chemical and metallurgical factory. Floor wastes endured the most serious pollution of copper, lead, zinc, and chromium, whose maximum concentration reached 59,400, 1260, 49,300 and 7510 mg/kg, respectively. Among organic pollutants in soil and water around chemical factories, Persistent Organic Pollutants (typically polycyclic aromatic hydrocarbons (PAHs), Polychlorinated biphenyl, and organochlorine pesticide), pyrethroids, and organophosphorus residues attached to soil by means of absorption. Multiple contaminations of

Table 4.7 Leaching Toxicity of Heavy Metals in C&D Waste From Different Industries

	Heavy metal (mg/L)						
Sample	**Cu**	**Zn**	**Pb**	**Cr**	**Cd**	**Ni**	**As**
CI	0.48 ± 1.31[a] (273%)[b]	0.82 ± 1.81 (221%)	ND[c]	45.54 ± 142.16 (312%)	ND	0.18 ± 0.57 (317%)	0.01 ± 0.03 (300%)
MI	0.16 ± 0.30 (188%)	3.15 ± 6.34 (201%)	0.34 ± 1.56 (459%)	0.01 ± 0.04 (400%)	0.02 ± 0.11 (550%)	0.07 ± 0.18 (257%)	0.11 ± 0.53 (482%)
LI	ND	ND	ND	ND	ND	ND	ND
RS	ND	ND	ND	0.07 ± 0.15 (214%)	ND	ND	0.01 ± 0.03 (300%)
RC	ND	ND	ND	ND	ND	ND	ND
Average	0.17 ± 0.57	1.97 ± 5.06	0.2 ± 1.19	7.36 ± 57.15	0.01 ± 0.09	0.08 ± 0.28	0.07 ± 0.41
Max	4.19	27.84	9.18	450.10	0.67	1.80	3.09
Min	ND	ND	ND	ND	ND	ND	ND
De/An[d]	22/62	23/62	6/62	9/62	2/62	13/62	5/62
Standards for drinking water quality[e]	1.0	1.0	0.01	0.05	0.005	0.02	0.05
Environmental quality standards for surface water (Level-III)[f]	1.0	1.0	0.05	0.05	0.005	–	0.05
Integrated wastewater discharge standard[g]	2.0	5.0	1.0	1.5	0.1	1.0	0.5
Standard for pollution control on the security landfill site for hazardous wastes[h]	75	75	5	12	0.5	15	2.5
Identification standards for hazardous wastes[i]	100	100	5	15	1	5	5

C&D, construction and demolition; *CI*, chemical industry; *LI*, light industry; *MI*, metallurgical industry; *RC*, recycled aggregates; *RS*, residential aggregates.

[a] average ± SD

[b] coefficient of variation

[c] undetected

[d] samples detected of pollutants/total samples

[e] Standards for drinking water quality (GB5749-2006)

[f] Environmental quality standards for surface water (Level-III) (GB 3838-2002)

[g] Integrated wastewater discharge standard (China GB 8978-1996)

[h] Standard for pollution control on the security landfill site for hazardous wastes (China GB 18598-2001)

[i] Identification standards for hazardous wastes (China GB 5085.3-2007)

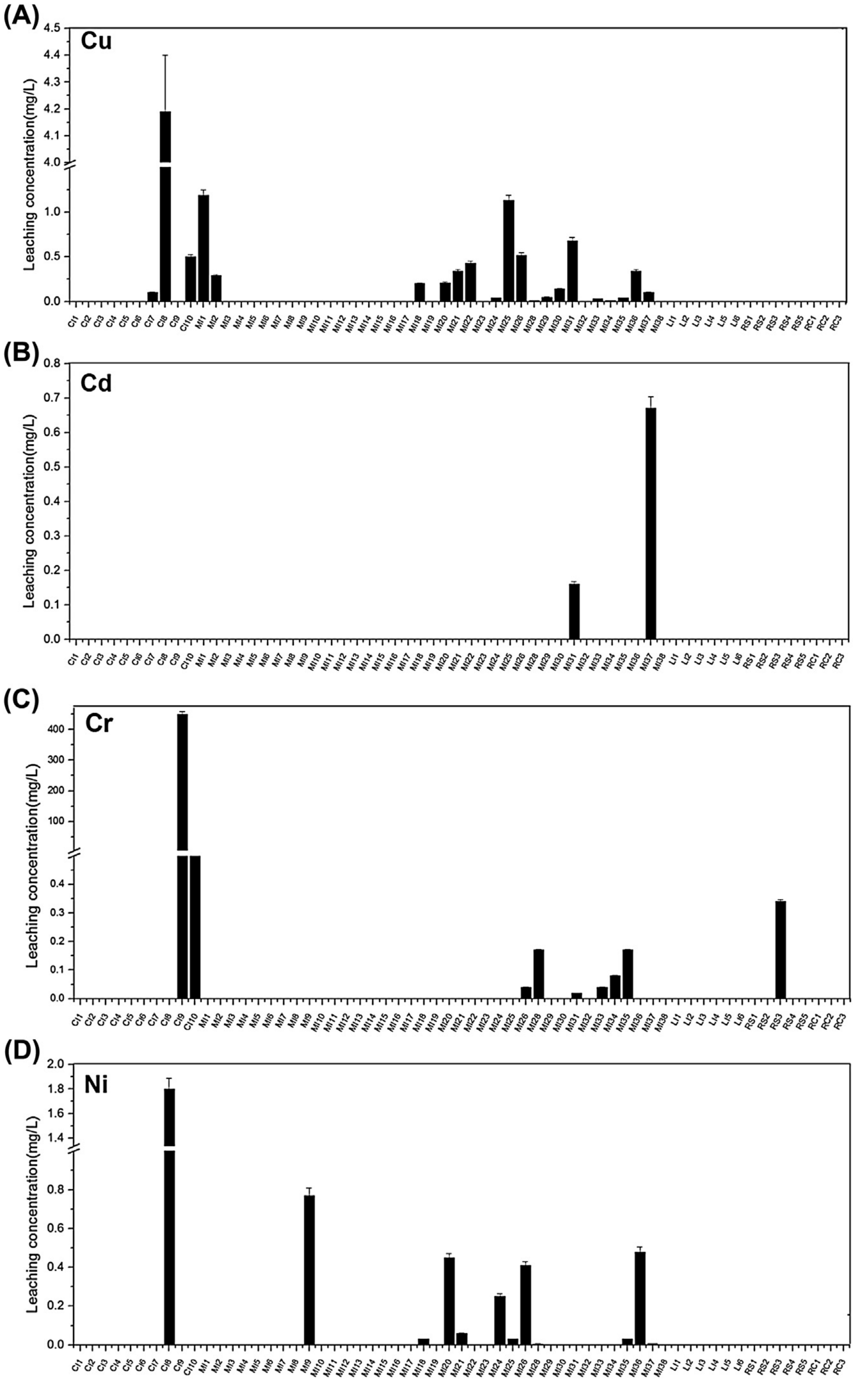

Figure 4.6 Concentrations of heavy metals in construction and demolition waste leachate from different sources. (A) Cu, (B) Cd, (C) Cr, (D) Ni, (E) As, (F) Pb, (G) Zn.

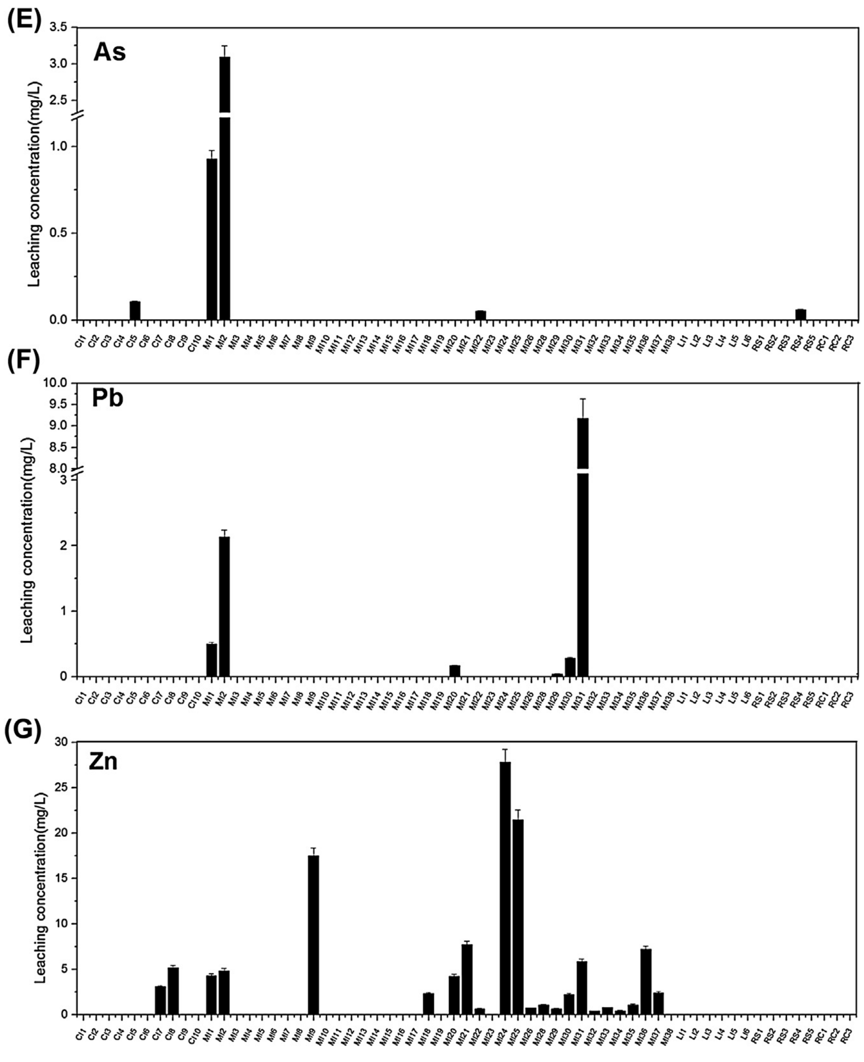

Figure 4.6 (*continued*).

cadmium, lead, and pesticide existed in several fertilizers and insecticides, which may be under risk of exposure in some workplaces. PAHs and PCBs had been found in C&D waste. This section demonstrates the systematic pollution characteristics of heavy metals and organic pesticide in industrial C&D waste of an abandoned pesticide manufacturing plant. Industrial C&D waste had been taken from different spots throughout the factory and 20 of them were analyzed. Qualification and quantification of heavy metals and organic pollutants in industrial C&D waste were obtained. This section elucidated characterization of industrial C&D waste in pesticide manufacturing plant thus providing a basic reference of source determination, separation, and management for industrial C&D waste.

4.4.1 PAH Existence and Its Distribution

Main specific pollutants including oil, PAHs, pesticides, and the intermediates existed in industrial C&D waste of pesticide manufacturing plants, mostly concentrating in particle and powder waste. The most severely contaminated industrial C&D waste were those around the tanks, of which the potential risk was the leakage through the cracks on the tank surface. Its production process should be focused on while the establishment of management and disposal of industrial C&D waste was performed. In situ reduction or source separation should be carried out.

Polycyclic aromatic hydrocarbons (PAHs) are primarily generated during industrial processes including the processing, burning, or use of organic matters. The scattering, spilling, or volatilization of chemical materials or pesticides would be a great pollution risk in the industrial C&D waste and soil systems.

It was found that PAHs and pyrethroids as well as their intermediates could be detected in C&D waste in some chemical and pesticide factories, among which 13 kinds of PAHs were detected. Deltamethrin and cypermethrin were found in a few samples. The highest concentration of cypermethrin was 53 mg/kg. Intermediates such as permethric acid ethyl ester were found in various samples. Distribution of PAHs in industrial C&D waste is listed in Table 4.8.

In C&D waste with a better ventilation condition, the degree of contamination by organic pollutants was relatively lower, including the wall waste of large open workshops and warehouses, or the external wall surface of the workshops. Moderate contamination existed in the surface plates of the raw materials and solvent transferring pipelines and the nearby ground waste. The degree of contamination was affected by the pipeline corrosion, weather conditions, and the specific process. There could be obvious pollution risks in the coatings and ground waste of enclosed workshops and warehouses. The pollution conditions were relatively complex in these regions, as gaseous, liquid, and solid-phase contaminants could coexist with absorption, permeation, diffusion, etc. The most seriously contaminated areas were the waste container, wrapping materials of tanks, and the ground waste nearby. These wastes contained huge amounts of pollutants and were no doubt hazardous wastes, which were not yet clearly defined and classified.

Table 4.8 Distribution of Polycyclic Aromatic Hydrocarbons (PAHs) in Industrial Construction and Demolition Waste, mg/kg

PAHs	Waste 1	Waste 2	Waste 3	Waste 4	Waste 5	Waste 6
Naphthalene	0.08	0.07	—	0.71	0.01	0
Acenaphthylene	0.04	0.13	0.02	—	0.03	0.14
Acenaphthene	—	—	—	—	—	0.04
Fluorene	0.08	0.18	0.13	—	0.05	0.53
Philippines	0.82	2.38	1.26	13.29	0.91	5.25
Anthracene	0.08	0.25	—	12.76	0.10	0.74
Fluoranthene	0.68	3.08	0.74	3.55	0.70	10.26
Pyrene	—	1.91	—	—	—	7.57
Benzo(a)anthracene	0.36	0.863	0.36	0.34	0.43	3.72
Chrysene	3.25	1.67	0.32	0.14	0.41	5.43
Benzo(j)fluoranthene	1.34	1.43	1.20	—	1.17	2.35
Benzo(e)pyrene	2.09	0.59	0.54	0.56	0.62	4.74
Benzo(b)fluoranthene	0.68	0.52	0.52	0.98	0.58	4.70

Therefore the disposal of organic pollutants-contaminated C&D waste should be based on the industrial manufacturing process. C&D waste with high pollution risks should be determined at first and source reduction should be carried out.

4.4.2 Existence of Volatile Organic Compounds in Industrial Waste From Pesticide Manufacturing Plants

Volatile organic compounds (VOCs) (not including pesticides) were detected in C&D waste from pesticide manufacturing plants and smelting plants. The results are shown in Table 4.9. Only those with high concentrations are listed.

Seventeen kinds of VOC pollutants were detected, but the concentrations were not high. The highest amount of C29-C36 was 513 mg/kg, whereas that of 1,2-dichloroethane was 64.2 mg/kg, which made them the two most severe pollutants. Except for the PAHs and pesticides, the risk of organic pollutants was low and specific disposal was not necessary.

4.4.3 A Comprehensive Study on Characterization of Organophosphorus Pesticides-Contaminated Waste

C&D wastes characterized in this section were obtained in an abandoned pesticide manufacturing plant in north China. Geological conditions and processing line of this plant are introduced as follows. Products of this plant mainly consisted of organophosphorus and pyrethroid pesticide. The

Table 4.9 Existence of Volatile Organic Compounds (VOCs) in Industrial Construction and Demolition Waste

VOCs	Unit	Detection Limit	Waste 1	Waste 2	Waste 3	Waste 4
Total Petroleum Hydrocarbon						
C6-C9	mg/kg	0.5	–	–	85.2	–
C10-C14		10	16	–	44	15
C15-C28		20	276	53	477	451
C29-C36		20	130	55	451	513
Substitutes						
Toluene-d8	mg/kg	–	97	98	98	96
4-Bromo-fluorobenzene		–	96	99	88	98
Dichlorofluoromethane		–	116	113	111	118
p-Terphenyld14		–	120	92	100	73
Monocyclic Aromatic Hydrocarbons						
Benzene	mg/kg	0.05	–	–	0.39	–
Toluene		0.05	–	–	0.07	–
p-Xylene		0.05	0.13	–		
o-Xylene		0.05	0.08	–		
Chlorinated Aliphatic Hydrocarbons						
1,1-Dichloroethane	mg/kg	0.05	–	–	0.34	–
1,2-Dichloroethane		0.05	–	0.13	64.2	0.08
1,1,2-Trichloroethane		0.05	–	–	0.39	–
Halogenated Aromatic Hydrocarbons						
Chlorobenzene	mg/kg	0.05	–	–	3.06	–
Dichlorotoluene		0.05	–	–	0.23	–

sampling map along with a simplified version of the general layout in which the sample was drawn is given in Fig. 4.7. The general layout only reserved the main workshops, fields, and other buildings relative to sampling, some buildings were shifted together. C&D waste from different workshops, warehouses, and other buildings throughout the plant were collected.

Although it was a decade since this plant was abandoned, extreme odor pervaded most parts of the plant. C&D waste from the workshops, facilities, tanks, and tubes was randomly discarded in residue. This was mainly because manufacture of phorate was banned along with the severe deficit around 2004. Two burning tanks were located in the east of the sampling range, which were used for the incineration of polluted substances. The concrete,

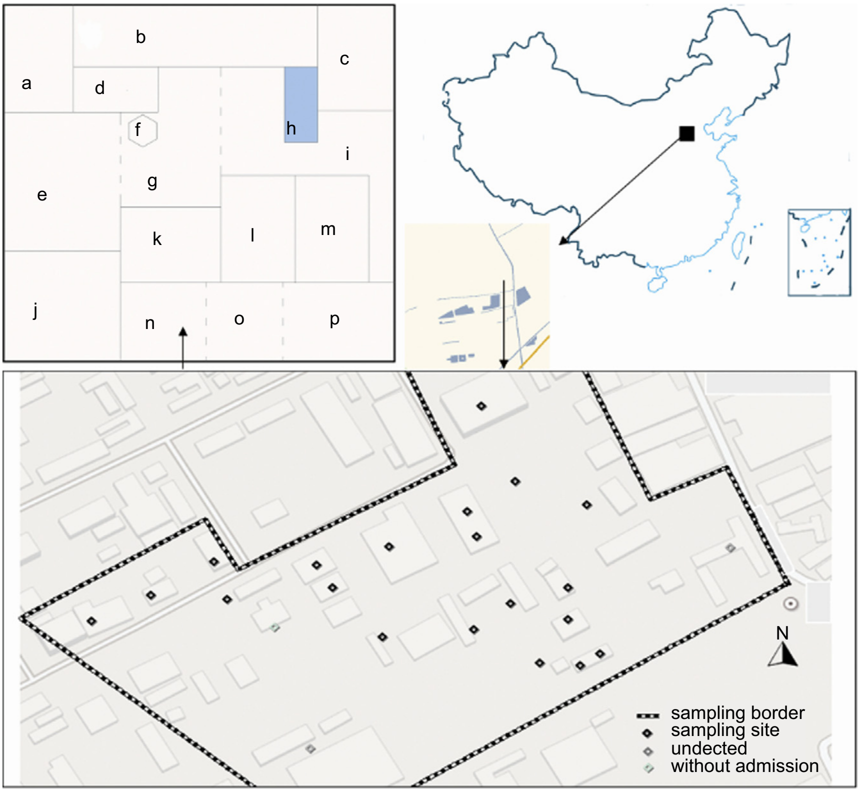

Figure 4.7 Sampling information. (*Bottom*) Dot map of actual sampling. (*Top left*) Simplified layout of the plant: (A) burning tank, (B) enclosed centralized stacking field of polluted construction and demolition waste, (C) sewage treatment facility, (D) neutralization process, (E) random stacking field, (F) tank, (G) stacking field with tanks, (H) small pool, (I) cultivation pool under demolition, (J) open warehouse, (K) enclosed workshop I, (L) enclosed workshop II, (M) enclosed workshop III, (N) open workshop I, (O) open workshop II, (P) open workshop III.

bricks wrapped around the towel and pond, and the solution were collected in neutralization process. A relatively small stacking field with tanks spread in disorder vertically connected the neutralization process and a much larger open field with piles of C&D waste randomly discarded in stack. An open warehouse made of wood was located at the end of the field. Three parallel enclosed workshops lay in the central district of the sampling map. A long field with three open workshops and several tanks was located a block away from the three workshops. A small pool had been generated naturally due to rainfall not far from the workshops. A large, round cultivation pond was under demolition. C&D waste and gas sample at the external edge of this field were obtained.

A total of 32 different types of C&D waste were collected, among which bricks were collected as major components of C&D waste, along with floated coating, concrete, rocks, detritus, and wood, in which 20 were detected as containing pollutants and are listed in Table 4.10. A trowel and chisel were used for the detachment of C&D waste from the external surface of the wall, floor, and tank. Each sampling was conducted in triplicate and the samples were stored in dark, and pretreated 7 days after sampling.

A detailed mean concentration (±standard deviation) of organic pollutants is listed in Table 4.11. Six kinds of pesticide intermediates were detected, among which dichlorovinyl ethyl chrysanthemate, for instance, existing in most wastes, could not be quantified due to lack of standards or products. Eleven organophosphorus pesticides and their metabolites were determined. One kind of pyrethroids, namely, cypermethrin, was also obtained.

Results showed that a large amount of pesticide intermediate compounds existed in most C&D waste. Existence of O,O′-diethyl dithiophosphate component was astonishing as the maximum concentration reached 18,749 mg/kg with an average of 3254 mg/kg. As for organophosphorus pesticides, phorate had the highest concentration in almost all the C&D waste with an average of 16,868 mg/kg. The peak of concentration of phorate reached an absolutely high level of 82,327 mg/kg. Four more C&D waste contained more than 10,000 mg/kg phorate, with a concentration of 73,057, 69,734, 20,207, and 76,196 mg/kg, respectively. Concentration of parathion was 6521 mg/kg in average, and the highest was 67,807 mg/kg. Results showed that parathion was also a severe pollutant in this plant. Fluxes of terbufos, ethion, and sulfotep were 0–1933, 0–585.2, and 0–383.9 mg/kg with a mean concentration of 170.0, 53.3, and 80.8 mg/kg, respectively. Two C&D wastes containing chlorpyrifos seemed to be polluted severely, with a concentration of 1431 and 1919 mg/kg, respectively. Phorate sulfone, a common metabolite of phorate, had an average and maximum concentration of 111.3 and 3163 mg/kg, respectively. Cypermethrin, a kind of pyrethroid pesticide, did not exist in most C&D wastes, but the maximum content was extremely high (2865 mg/kg). Accumulation of each pesticide component among different C&D wastes is demonstrated in Fig. 4.8.

Concentration data were log-transformed in this figure to reduce the influence of extremely high components like phorate. Results showed that

Table 4.10 Sources and Brief Properties of Construction and Demolition Waste

Item	Material	Location	Property	Odor
WS-1	Coatings	Workshop	Flat block	Extreme
WS-2	Coatings	Workshop	Flat block (larger)	Extreme
WS-3	Concrete, coatings	Workshop	Flat block	Mild
WS-4	Concrete	Workshop	Flat block	Mild
BK-1	Brick	Centralized stack field	Block	Strong
BK-2	Brick	Centralized stack field	Block	Strong
BK-3	Brick	Random stack field	Large block (wrapped by clay)	Strong
BK-4	Brick	Workshop, stack	Large block	Extreme
BK-5	Brick	Workshop, stack	Large block	Mild
BK-6	Brick	Workshop, stack	Large block	Strong
BK-7	Brick, detritus	Random stack field	Block	Mild
BK-8	Brick, detritus	Near pool	Block	Strong
WD-1	Wood	Warehouse	Large block	Mild
DS-1	Detritus	Random stack field	Small block, loose	None
DS-2	Concrete, brick, detritus	Workshop	Block	Strong
DS-3	Detritus, concrete	Random stack field	Small block	Mild
DS-4	Detritus	Neutralization department	Block, brittle	None
DS-5	Concrete, brick	Absorption tank	Moist, solid	None
DS-6	Detritus	Workshop, stack	Block	Strong
GT-1	Detritus, stone	Tank	Moist, hard block	Strong

GT-1 contained the most organic pollutants, whereas WS-4 contained the least. Mass concentration of organic pollutants did not absolutely correspond to the types of pollutants contained, indicating that complex and extreme pollution existed in most C&D wastes.

4.4.4 Existence of Organophosphorus Pesticides in C&D Waste From Exterior Plant

The existence of organophosphorus pesticides in C&D waste outside the plant and their concentrations are listed in Table 4.12.

Evidently, new organophosphorus pollutants were found in C&D waste outside the plant, including cyanthoate, synergistic phosphorus, and dichlorvos. The concentration of dichlorvos reached up to 1000 mg/kg, which was no doubt serious contamination.

Table 4.11 Mean (±Standard Deviation) Concentration of Pesticide Pollutants (mg/kg) in Construction and Demolition Waste From the Pesticide Manufacturing Plant

	Organophosphorus Pesticide										Pyrethroid
Samples	**O,O,O-Triethyl Phosphorothioate**	**O,O′-Diethyl Dithiophosphate**	**Phorate**	**Parathion**	**Terbufos**	**Ethion**	**Chlorpyrifos**	**Sulfotep**	**Cholrmephos**	**Phorate Sulfone**	**Cypermethrin**
WS-1	32.4 ± 1.6	163.2 ± 28.7	*1221 ± 92*	46.5 ± 33.4	5.7 ± 0.5	7.3 ± 0.4	Undetected (UD)	0.7 ± 1.3	UD	20.3 ± 1.0	UD
WS-2	574.1 ± 35.9	*2578 ± 156*	*1886 ± 139*	966.4 ± 86.9	349.2 ± 17.8	13.9 ± 1.4	UD	UD	UD	17.2 ± 0.3	UD
WS-3	424.3 ± 53.5	*5705 ± 150*	***73,057 ± 23,819***	***35,098 ± 2403***	UD	120.9 ± 4.2	UD	383.3 ± 42.5	UD	UD	139.3 ± 35.4
WS-4	7.2 ± 0.7	47.1 ± 4.4	386.5 ± 44.9	21.8 ± 1.9	4.6 ± 0.1	UD	UD	UD	UD	UD	UD
BK-1	215.0 ± 10.4	*3053 ± 187*	***69,734 ± 1718***	153.1 ± 36.7	37.9 ± 0.8	88.0 ± 1.5	*1431 ± 111*	154.2 ± 9.2	UD	71.6 ± 4.7	169.8 ± 64.9
BK-2	489.5 ± 47.0	*4515 ± 435*	***82,327 ± 10,457***	UD	UD	197.2 ± 81.7	*1919 ± 486*	178.6 ± 20.8	UD	171.3 ± 19.2	385.0 ± 142.2
BK-3	*2764 ± 713*	***11,699 ± 2548***	***20,207 ± 4368***	*8544 ± 2442*	*1933 ± 359*	UD	UD	374.4 ± 56.3	UD	UD	UD
BK-4	0.6 ± 0.6	*4126 ± 2287*	790.4 ± 371.1	***67,807 ± 39,114***	448.4 ± 251.2	UD	UD	265.6 ± 153.3	UD	UD	UD
BK-5	10.0 ± 1.5	200.3 ± 17.0	112.9 ± 5.8	105.6 ± 21.7	8.7 ± 0.3	UD	UD	4.3 ± 0.4	UD	UD	UD
BK-6	26.8 ± 18.6	380.7 ± 164.6	*1102 ± 729*	233.0 ± 47.6	42.9 ± 18.2	UD	UD	8.4 ± 3.2	UD	UD	UD
BK-7	377.3 ± 36.9	***18,749 ± 3315***	*2582 ± 422*	***12,003 ± 4413***	UD	20.5 ± 0.4	UD	173.5 ± 27.9	UD	UD	UD
BK-8	8.9 ± 7.2	668.1 ± 344.4	261.9 ± 28.6	*3849 ± 2163*	6.1 ± 4.7	UD	UD	25.5 ± 26.7	UD	UD	UD
WD-1	64.7 ± 9.9	237.7 ± 27.2	352.5 ± 169.8	106.7 ± 50.8	23.5 ± 2.8	UD	UD	UD	UD	UD	UD
DS-1	162.3 ± 9.2	438.5 ± 41.7	734.6 ± 30.5	462.5 ± 78.6	60.9 ± 5.9	7.8 ± 1.0	UD	10.3 ± 0.8	UD	16.5 ± 0.2	29.5 ± 14.7
DS-2	16.3 ± 6.2	153.7 ± 14.3	890.0 ± 70.7	50.3 ± 1.7	15.2 ± 0.1	UD	UD	UD	UD	54.7 ± 1.1	2865 ± 251
DS-3	UD	166.4 ± 7.9	152.1 ± 13.3	64.5 ± 9.0	18.1 ± 8.1	UD	UD	UD	UD	UD	UD
DS-4	176.5 ± 29.6	379.8 ± 49.4	380.5 ± 49.2	69.7 ± 25.1	16.9 ± 1.4	UD	UD	UD	UD	UD	UD
DS-5	0.8 ± 1.4	116.9 ± 4.7	514.4 ± 56.2	118.1 ± 7.2	22.5 ± 0.8	UD	UD	3.4 ± 3.0	UD	UD	UD
DS-6	82.3 ± 8.4	886.9 ± 51.4	*4473 ± 211*	158.7 ± 14.4	17.9 ± 0.8	25.0 ± 2.4	UD	3.6 ± 3.1	UD	UD	UD
GT-1	336.7 ± 78.6	***10,834 ± 3084***	***76,196 ± 15,701***	575.3 ± 581.1	387.5 ± 9.8	584.6 ± 32.1	UD	108.4 ± 39.2	579.4 ± 134.2	*1875 ± 1133*	UD
Average	288.5	*3254*	***16,868***	*6521*	170.0	53.3	167.5	80.8	29.0	111.3	179.4
Maximum	2764	***18,749***	***82,327***	***67,807***	1933	585.2	1919	383.9	692.1	*3163*	3155
Minimum	UD	47.1	112.9	UD	UD	UD	UD	UD	UD	UD	UD

Concentrations ≥1000 mg/kg are shown in italic, ≥10,000 mg/kg are shown in bold italic.

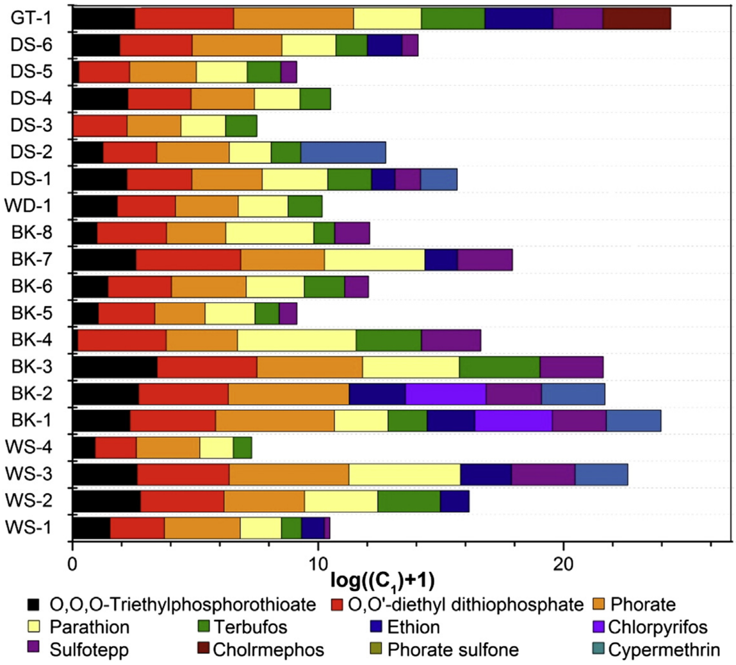

Figure 4.8 Log-transformed concentrations of organic pollutants in different samples.

4.4.5 Distribution and Possible Sources of Organic Pollutants Based on Practical and Statistical Analysis

Distribution of some typical organic pollutants was demonstrated in a spatial sampling map (Fig. 4.9). Three worst contaminated C&D wastes were obtained in the centralized stacking field of polluted C&D waste (BK-2), abandoned tank (GT-1), and enclosed workshop II (WS-3), respectively. C&D waste in the centralized stacking field reflected the most severely polluted C&D waste across the plant. Numerous tanks were discarded in the stack randomly, which were not washed off thoroughly before abandoning based on this section. WS-3 was taken from a packaging workshop. The bad contamination suggested that during package line, which was highly complex in process objects or machines, spilling or leakage of intermediates and products existed despite the wrapped around protection sleeve. BK-4, which was derived from where sulfur, industrial materials, and C&D waste was mixed, was highly contaminated. Muddy industrial materials, bricks, and concrete were stacked or compacted for years to form stratiform steady blocks hard to separate.

Table 4.12 Existence of Organic Pesticides in Construction and Demolition (C&D) Waste From the Exterior Plant (mg/kg)

Organic Pollutants	C&D Waste 1	C&D Waste 2	C&D Waste 3	C&D Waste 4
Parathion	<0.01	<0.01	<0.01	<0.01
Terbufos	<0.01	4.17	2.39	<0.01
Phorate	82.3	<0.01	<0.01	54.8
Phorate sulfone	<0.01	<0.01	<0.01	<0.01
Phorate sulfoxide	<0.005	<0.005	<0.005	<0.005
Cyanthoate	<0.01	<0.01	0.04	0.25
Sulfotep	<0.01	0.54	0.75	<0.01
Ethion	<0.01	<0.01	<0.01	<0.01
Fenthion	<0.005	<0.005	<0.005	<0.005
Synergistic phosphorus	9.17	17.22	10.59	34.17
Dichlorvos	1074	839	947	1059
Triethyl phosphorothioate	<0.01	<0.01	<0.01	<0.01

The two C&D wastes containing 10,000—50,000 mg/kg pollutants were both derived from the open stacking field, indicating that despite being exposed to sun and rain for decades, C&D waste still posed a tremendous risk to the environment. The low background organic content of C&D waste led to very slight absorption of organic pollutants. Nevertheless, Organophosphorus pesticides(OPPs) permeated into the surface of C&D waste and formed a relatively stable phase with time.

The slightest contamination level appeared in C&D waste from neutralization process (DS-4, DS-5), pool bank (BK-8), cultivation pool (DS-3), open warehouse (WD-1), and enclosed workshop III (DS-2,WS-4), respectively, most of which were reasonable. Neutralization process was mainly used for the addition of alkali to maintain the pH of incineration gas. OPPs in C&D waste immersed under water were largely dissolved into the pool when the surface fluctuated. The concentration of phorate in the water sample from the pool was 2.57 mg/L, five times that of the limit in the industrial effluent level III (GB8978-1996) (Fig. 4.10). The open warehouse was slightly contaminated, which can be resulted from the strict management and enclosed packaging and sealing of products. The low concentration of pesticide in DS-3 around the cultivation pool was an exception because it was merely on the external part as no admission was accessed under demolition. Based on the gas obtained (Fig. 4.10), this place was severely contaminated (Table 4.13).

Intermediates, mainly O,O'-diethyl dithiophosphate, shared most distribution features with phorate in C&D waste. Pesticide intermediates were

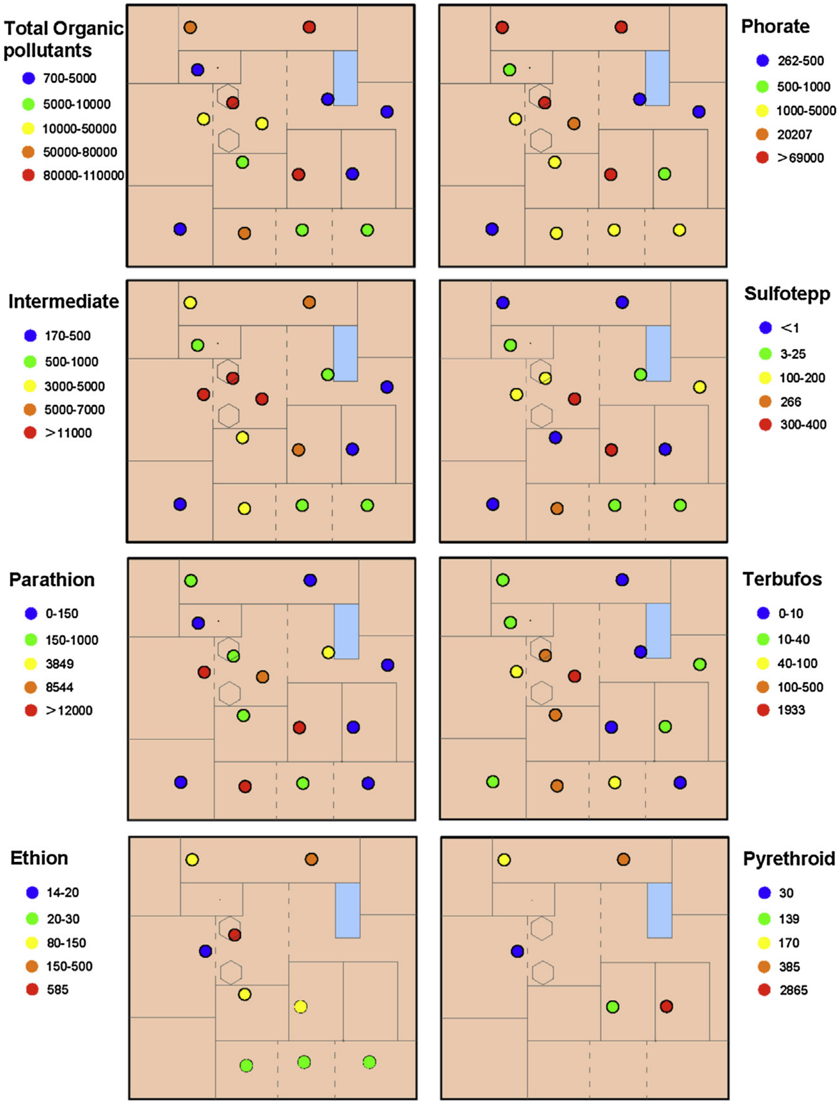

Figure 4.9 Spatial distribution of some typical organic pollutants throughout pesticide manufacturing plant.

not disposed of appropriately, which was due to the lack of knowledge or management of intermediates, whereas phorate was well recognized for its high toxicity. Actually, O,O'-diethyl dithiophosphate was highly corrosive and highly soluble in water. Pearson correlations were calculated for each pollutant to analyze its possible source, which are listed in Table 4.14.

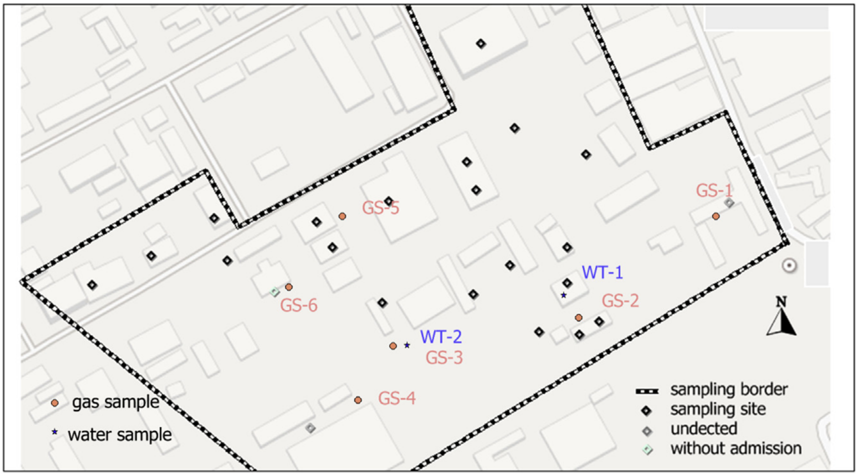

Figure 4.10 Sampling information including gaseous and water samples.

Table 4.13 Concentration of Phorate in Gaseous and Water Samples

	Gas Sample (μg/m³)						Water Sample (mg/L)	
Samples	**GS-1**	**GS-2**	**GS-3**	**GS-4**	**GS-5**	**GS-6**	**WT-1**	**WT-2**
Phorate	UD	1.07	0.25	UD	0.41	3.65	UD	2.57 ± 0.74

UD, undetected.

The two intermediates correlated well with each other ($r^2 = 0.29$, $p = .015$) as they were close in structure and usage. The remarkable difference of treatment and regulation between phorate and intermediate largely reduced their correlation in concentration ($r^2 = 0.11$, $p = .161$), although they were similarly used. Parathion was another severe pollutant that was not under strict regulation either. Furthermore, the low level of parathion in tanks was likely due to its distinguishing mixture or loading process. Correlation analysis showed no strong correlation of parathion concentration with other pesticides ($r^2 < 0.14$, $p > .81$).

The concentration of phorate sulfone had a strong correlation with phorate ($r^2 = 0.34$, $p = .007$), as it was metabolized from phorate. The maximum content of phorate sulfone, labeled as highly dangerous, in GT-1 was 3163 mg/kg; it was also detected elsewhere. A high concentration (71.3 mg/kg) in BK-2 suggested that a methodical execution of phorate disposal might largely decrease the risk of phorate sulfone. Transition from phorate to phorate sulfone was partly related to microbial activity and chemical oxidation. DS-2 was probably in close contact with microbes in soil

Table 4.14 Pearson Correlations (r) and the Associated *p* Values for Organic Pollutants

	O,O,O-Triethyl Phosphorothioate	O,O′-Diethyl Dithiophosphate	Phorate	Parathion	Terbufos	Ethion	Chlorpyrifos	Sulfotep	Cholrmephos	Phorate Sulfone
O,O′-Diethyl dithiophosphate	**0.535**									
	0.015									
Phorate	0.106	0.326								
	0.658	0.161								
Parathion	−0.096	0.064	−0.078							
	0.686	0.789	0.745							
Terbufos	***0.928***	**0.447**	−0.031	0.155						
	0.000	0.048	0.896	0.513						
Ethion	0.048	0.399	***0.793***	−0.089	0.049					
	0.840	0.081	0.000	0.709	0.839					
Chlorpyrifos	0.046	0.043	**0.457**	−0.083	−0.119	0.243				
	0.846	0.858	0.043	0.729	0.618	0.302				
Sulfotep	***0.627***	***0.642***	**0.472**	0.370	***0.566***	0.218	0.220			
	0.003	0.002	0.036	0.108	0.009	0.355	0.351			
Cholrmephos	0.019	0.354	**0.536**	−0.057	0.117	***0.925***	−0.076	0.043		
	0.938	0.125	0.015	0.812	0.623	0.000	0.751	0.856		
Phorate sulfone	0.021	0.354	***0.585***	−0.068	0.103	***0.950***	0.014	0.056	***0.995***	
	0.930	0.126	0.007	0.776	0.664	0.000	0.953	0.816	0.000	
Cypermethrin	−0.094	−0.134	0.000	−0.070	−0.105	−0.051	0.060	−0.100	−0.066	−0.032
	0.693	0.574	0.999	0.770	0.660	0.832	0.801	0.676	0.782	0.892

Significant at $p \leq .05$ is shown in bold and significant at $p \leq .01$ is shown in bold italic.

compared with brick wall wastes, which accelerated the metabolization of phorate.

Enclosed workshop III was a former cypermethrin workshop. Cypermethrin contained no phosphorus so the processing line ought to be different. That led to the unusually high content of pyrethroid pesticide (PPs) but low content of OPPs pollutants. This was also reflected by the irrelevance between cypermethrin and OPPs. Packaging in enclosed workshop II involved PPs along with OPP products, resulting in PP residue. Meanwhile, the demolition or other activities transferred a small part of PP-polluted C&D waste from the workshop onto open fields, mixed with other randomly stacked C&D waste. A larger part was centralizedly collected in an enclosed field. However, most part of the PP-polluted C&D waste could not be effectively recognized and remained in the residue.

4.4.6 Factors Affecting Concentration of Pollutants Among C&D Waste

Concentrations of organic and metal pollutants in C&D waste of different exposure conditions, locations, materials, and with different odor levels were analyzed. As shown in Fig. 4.11, C&D waste abandoned in an enclosed place underwent a heavier contamination. Exception occurring in some C&D waste suggested that some organophosphorus pesticides like parathion might not be so vulnerable under exposure. C&D waste abandoned in stack field had a slightly higher concentration of OPPs than that in workshop, which indicated that environmental pollution risk was not constrained in workshops, but scattered throughout the plant if C&D waste was not properly disposed.

Distribution of OPPs in different types of C&D wastes (brick, wood, etc.) is introduced in this section. Based on Fig. 4.11, most pollutants existed in rocks. Extreme contamination occurred in bricks and coatings, which were the main components of walls. Detritus, representative of ground C&D waste, was not severely polluted relatively due to accelerated degradation by microbes attached to soil with detritus. Meanwhile, the much larger organic content of soil than C&D waste might cause the absorption of OPPs. Contrary to the OPPs, heavy metals tended to accumulate in detritus, whereas those in bricks and coatings were not especially high. The odor emitted from OPP-contaminated C&D waste could partly tell the pollution level. C&D waste without odor was most slightly polluted in Fig. 4.11, but that with mild or strong odor might contain a high level of OPPs, despite of the pungent odor of phorate. It could result from some combination between C&D waste and OPPs.

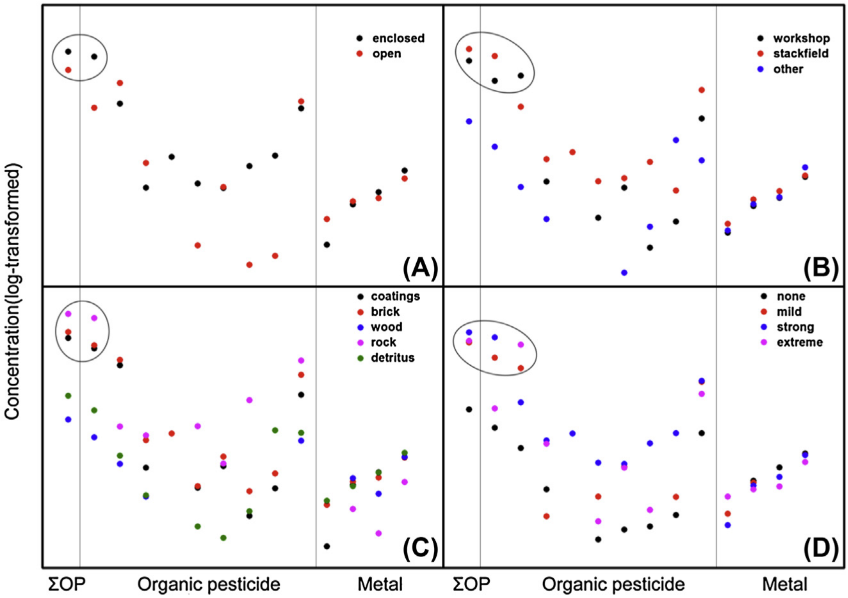

Figure 4.11 Pollutant content of construction and demolition waste under various conditions.

4.4.7 Hierarchical Cluster Analysis

Hierarchical cluster analysis was carried out based on the practical sampling so as to further demonstrate the correlation among C&D waste. The dendrogram of different sampling sites are demonstrated in Fig. 4.12 as four groups were identified. Most C&D waste formed group 1, which showed complex distribution of pollutants due to the diversified processing line of this plant along with the reaction with surroundings in multiphase. BK-1, BK-2, and WS-3, which belonged to group 2, were highly correlated with the mixture of organic pesticide pollutants and could reflect the entire processing operation of the whole plant. Group 3 contained BK-4, BK-7, and BK-3, also showing a highly confounding contamination pattern. Whether the admixture of pollutants was deliberated probably made a distinction between group 2 and group 3. Based on the sampling, C&D waste from group 2 was either centralizedly collected with soil after demolition, or assembled together before packaging during manufacturing. C&D waste from group 3 was mainly stacked randomly in disorder. GT-1 contained the most kinds of pollutants and the unique existence in tanks compared with other C&D waste made it an independent group. Results

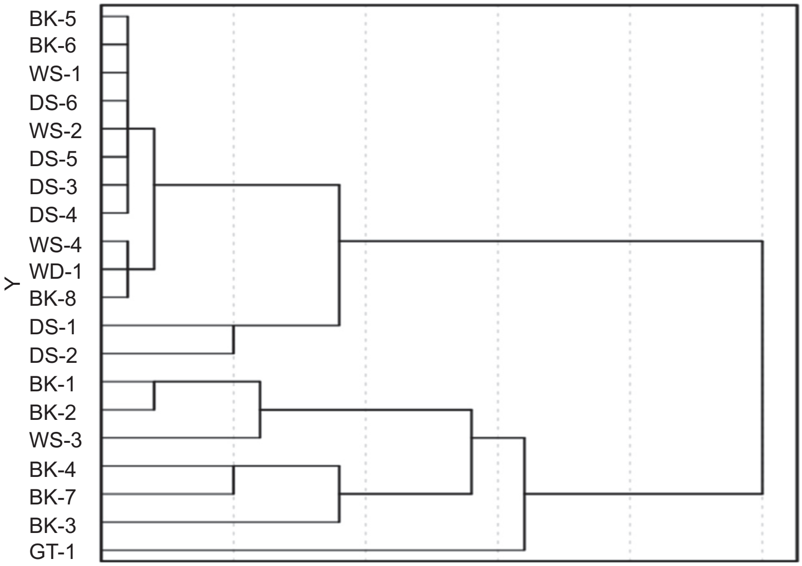

Figure 4.12 Dendrogram of sampling sites by means of Ward's method.

of the cluster analysis emphasized the importance for the regulated disposal of polluted C&D waste.

4.4.8 Principal Component Analysis

Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The results of PCA using SPSS 20.0 are listed in Tables 4.15 and 4.16, and Fig. 4.13.

The first four principal components variance summed up a contribution rate of 85%, the first five of 93%, among which the first principal component variance had a contribution of 36%. In factor 1, ethion, chlormethylfos, and phorate sulfone had relatively large contributions. In factor 2, O,O,O-triethylphosphorothioate and terbufos had large contributions.

4.5 ENVIRONMENTAL RISK OF INDUSTRIAL C&D WASTE IN ORGANOPHOSPHORUS PESTICIDE MANUFACTURING PLANT

Industrial C&D waste, especially that contaminated by organophosphorus pesticides had great potential environmental risks even after decades

Table 4.15 The Variance Contribution Rate for Principal Component Analysis

	Sums of Squared Loadings		
Component	**Total**	**% of Variance**	**Cumulative %**
1	3.978	36.167	36.167
2	2.657	24.154	60.320
3	1.554	14.126	74.446
4	1.179	10.714	85.161
5	0.950	8.632	93.793
6	0.476	4.324	98.117
7	0.187	1.699	99.816
8	0.014	0.126	99.942
9	0.005	0.045	99.988
10	0.001	0.012	99.999
11	7.246E-005	0.001	100.000

Table 4.16 Factor Loading Matrix for Principal Component Analysis

	Component			
	1	**2**	**3**	**4**
O,O,O-Triethyl phosphorothioate	−0.026	0.990	0.080	0.009
O,O-Diethyl dithiophosphate	0.368	0.583	0.119	0.389
Phorate	0.511	0.138	0.800	0.155
Parathion	−0.122	0.023	0.010	0.943
Terbufos	0.034	0.942	−0.122	0.105
Ethion	0.948	0.041	0.296	0.057
Chlorpyrifos	−0.019	−0.020	0.937	−0.153
Sulfotep	0.033	0.591	0.413	0.667
Chlormefos	0.991	0.051	−0.062	0.009
Phorate sulfone	0.991	0.047	0.024	−0.018
Cypermethrin	−0.095	−0.075	0.181	−0.307

of exposure under the nature. Environmental Risk Assessment is a process for estimating the likelihood or probability of an adverse outcome or event to the human health and ecosystem resulting from the hazardous pollutants. It can be divided into human health risk assessment and ecological risk assessment. Currently, the risk assessment of contaminated site is generally based on principles of human health risk assessment, and is an extremely complex project, including the analysis of potential harm and degree to exposed human health due to the contaminated waste (industrial C&D waste in this

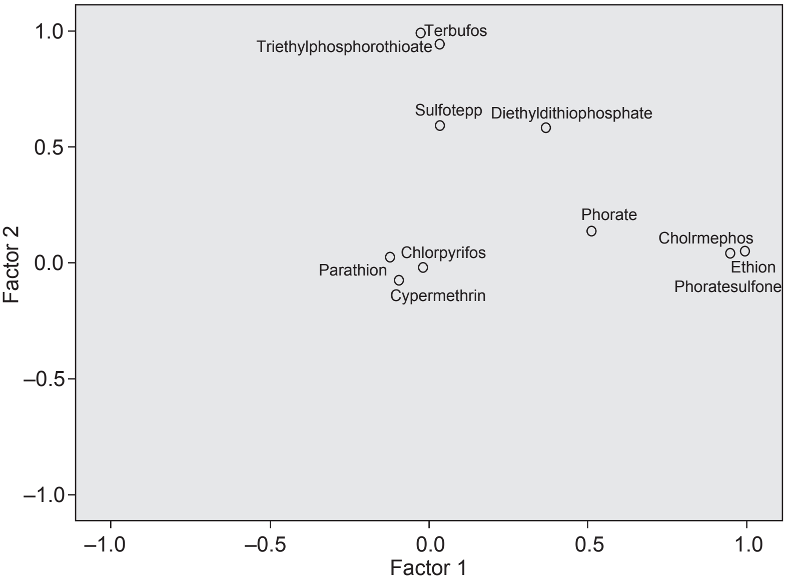

Figure 4.13 Loading plot onto plates factor 1 versus factor 2 for principal component analysis.

book), air, dust, water, food, and other factors. According to the results of the risk assessment, the target value for the site remediation is proposed.

Due to the lack of risk assessment system for contaminated C&D waste, that for soil system was referred to in this section. The assessment would be performed based on the four procedures below.

1. Pollution identification. Based on the distribution of pollutants, relevant toxicity reports, and information obtained in background research, as well as the total amount of pollutants, combining with the information of the exposed population, a quality control system is established.
2. Exposure assessment. It is the process of estimating or measuring the magnitude, frequency, and duration of exposure to the pollutants, along with the number and characteristics of the population exposed. Generally, the land can be divided into industrial land, agricultural land, and residential land. In this project, the site contaminated by pesticide companies is not likely to be reused as agricultural and residential land. So industrial land is determined as an evaluation criterion.
3. Toxicity assessment is a major procedure in risk assessment. It is a process of the investigation of the potential for a substance to cause harm, and how much causes what kind of harm. All substances are toxic in quantity.

The toxicity data mainly include reference dose (RfD), RfC, and slope factor (SF), among which RfD and RfC are the estimated values for the average daily exposure dose or concentration. These three indexes can all be found in database. In addition, toxicity assessment can be divided into noncarcinogenic toxicity and carcinogenicity assessment, which will be described in detail in the example.

4. Risk assessment. It refers to the estimation of the likely health impact or probability on the basis of exposure assessment and toxicity assessment, including uncertainty analysis and risk calculations.

4.5.1 Analysis of Contaminated Industrial C&D Waste and Its Evaluation

The guidance values regulated in "Alberta Tier 1 Soil and groundwater remediation guidelines" is used and the results are listed in Table 4.17. Only those pollutants with existing relevant standards are involved in this evaluation. For other pollutants without standards, it is not possible to be evaluated currently. The calculated excess of pollutants in C&D waste is listed in Table 4.18.

4.5.2 Exposure Pathways and Variables for Industrial C&D Waste

4.5.2.1 Exposure Pathways Analysis

The type of land use has been determined as industrial and commercial sites. The exposed population may be residents and professional workers. In this environment, the exposure pathways under pollutants are listed in Table 4.19.

4.5.2.2 Exposure Quantification

The quantification of the exposure through various pathways is performed using risk-based corrective action model.

a. Oral ingestion

$$\mathrm{CDI_{oral}} = \frac{C_s \times \mathrm{IR} \times \mathrm{CF} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}$$

where $\mathrm{CDI_{oral}}$ is the oral ingestion amount [mg/(kg·d)], C_s the concentration of pollutants in waste (soil in the original model, but C&D waste in this section; it would not be mentioned again) (mg/kg), IR the ingestion amount of waste per hour (mg/d), CF the conversion coefficient (10^{-6} kg/mg), EF the exposure frequency (d/a), ED the duration of exposure (a), BW the

Table 4.17 Reference Value for Evaluation

Pollutant	**Standards for the Aquatic Environment (μg/L)**	**Guidance Value of the Highest Concentration of Pollutants in Soil (mg/kg)**	**Source of Standards**
Phorate	2	0.075	Alberta Tier 1 soil and groundwater remediation guidelines
Parathion	0.013	7.2	
Terbufos	1	0.08	
Chlorpyrifos	0.002	49	
Dichlorvos	—	0.1	Allowable soil concentrations in the former Soviet Union

Table 4.18 Calculated Excess of Pollutants

Pollutant	**Excess in Aquatic System (%)**	**Excess in Construction and Demolition Waste (%)**
Phorate	50	100
Parathion	/	95
Terbufos	/	85
Chlorpyrifos	/	10
Dichlorvos	/	16.7

average weight of exposed populations (kg), and AT the averaging time (d). For noncarcinogens, the averaging time (AT) generally consists of a limited exposure duration. For carcinogens (DDVP in this sample), the AT is generally an individual's lifetime, assumed to be 70 years.

b. Inhaled particle:

$$\mathrm{CDI}_{\text{inhaled particle}} = \frac{-C_s \times \left(\frac{1}{\mathrm{PEF}}\right) \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}$$

Inhaled vapor:

$$\mathrm{CDI}_{\text{inhaled vapor}} = \frac{C_a \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}$$

where $\mathrm{CDI}_{\text{inhaled particle}}$ is the concentration of pollutants in the particles inhaled through breathing [mg/(kg·d)], $\mathrm{CDI}_{\text{inhaled vapor}}$ the concentration of pollutants in the vapor inhaled through breathing [mg/(kg·d)], C_s the concentration of pollutants in the waste (mg/kg), C_a the volatile exposure

Table 4.19 Exposure Pathways for Industrial and Commercial Sites

Environment	Mechanism	Industrial and Commercial Site
Contaminated C&D waste (less than 1 mm in size)	Direct contact	Direct ingestion
	Wind erosion	Inhalation of particulate matter
	Volatilization	Inhalation of volatiles
	Percolation	Exposure to indoor air
		Exposure to the underground water contaminated by C&D waste leachate
		Inhalation of the particulate matter generated by trucks or equipment
		Skin absorption
Contaminated C&D waste (more than 1 mm in size)	Direct contact	Direct ingestion
	Wind erosion	Skin absorption
	Volatilization	Inhalation of volatiles
	Percolation	Exposure to indoor air
		Exposure to the underground water contaminated by C&D waste leachate
		Inhalation of the particulate matter generated by trucks or equipment
		Skin absorption
Surface water	Run-off	Ingestion through drinking water
	Percolation	Inhalation of volatiles
		Skin absorption
Underground water	Percolation	Ingestion through drinking water
		Inhalation of volatiles
		Skin absorption
Atmosphere	Volatilization	Ingestion though inhalation
		Skin absorption

concentration of pollutants indoor/outdoor (mg/kg), PEF the diffusion coefficient of waste, and IR the breath rate (L/min).

c. Ingestion amount through skin contact:

$$\mathrm{CDI}_{\text{skin contact}} = \frac{C \times \mathrm{CF} \times \mathrm{SA} \times \mathrm{AF} \times \mathrm{ABS} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}$$

where $\mathrm{CDI}_{\text{skin contact}}$ is the ingestion amount through skin contact [mg/(kg·d)], C the concentration of pollutants in the waste (mg/kg), CF the conversion coefficient (10^{-6} kg/mg), SA the skin surface area available for contact to C&D waste (cm^2), AF the waste to skin adherence factor (mg/cm^2), and ABS the absorption factor (dimensionless).

Table 4.20 Features of the Pollutants in Concern

Pollutants	Chemical Abstracts Service	Soil Adsorption Coefficient Log(Koc)	Air Diffusion Coefficient (cm^2/s)	Water Diffusion Coefficient (cm^2/s)	Solubility in Water 20–25°C (mg/L)	Henry's Constant
Phorate	298-02-2	3.74	0.08	8.0×10^{-6}	44.00	5.0×10^{-4}
Parathion	56-38-2	3.75	0.017	5.8×10^{-6}	11.75	2.37×10^{-5}
Terbufos	13071-79-9	4.14	0.042	5.1×10^{-6}	6.84	0.06827
Chlorpyrifos	2921-88-2	3.70	0.048	5.1×10^{-6}	0.9	1.70×10^{-4}
Dichlorvos	62-73-7	1.70	0.023	7.8×10^{-6}	16,000	3.98×10^{-5}

d. Ingestion through diets

$$\mathrm{CDI}_{\mathrm{drinking}} = \frac{C_w \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}$$

$$\mathrm{CDI}_{\mathrm{diet}} = \frac{C_F \times \mathrm{IR} \times \mathrm{FI} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}$$

where $\mathrm{CDI}_{\mathrm{drinking}}$ is the ingestion amount through drinking water [mg/(kg·d)], C_w the concentration of pollutants in water (mg/L), C_F the concentration of pollutants in diets (mg/kg), FI the proportion of contaminated diets to all diets (dimensionless), IR the ingestion rate of water/diets (L/d, kg/meal), EF the exposure frequency (d/a, meal/a), and $\mathrm{CDI}_{\mathrm{diet}}$ the ingestion amount of pollutants through meals [mg/(kg·d)]. The features of the pollutants in concern are listed in Table 4.20. The selected exposure variables are listed in Table 4.21.

Ingestion amount through the mouth is calculated in Table 4.22.

Ingestion amount through breathing can be divided into two categories, outdoor and indoor ingestion. It is mainly composed of the vapor of pollutants and the particles of contaminated industrial C&D waste. The results are listed in Table 4.23. Ingestion amount through diets is calculated in Table 4.25.

Ingestion amount through the skin is calculated in Table 4.24.

4.5.3 Toxicity Values of Existing Pollutants

The toxicity values of the pollutants in concern are listed in Table 4.26.

4.5.4 Risk Evaluation of Industrial C&D Waste in Pesticide Manufacturing Plant

The calculation of carcinogenic risk of oral ingestion of single pollutant (DDVP) in C&D waste is performed as:

$$\mathrm{R}_{\mathrm{oral}} = \mathrm{CDI} * \mathrm{SF} = 8.3 * 10^{-5} * 0.29 = 2.4\mathrm{e} - 5$$

Table 4.21 Exposure Variables

Variable	Introduction	Industrial Land (Adult)
BW	Body weight (kg)	60
EF	Exposure frequency (d/a)	261
ED	Exposure duration (a)	30
IR	Inhalation rate of waste (mg/d)	100
SA	Skin surface area available for contact (cm^2)	2800
AT	Averaging time (noncarcinogens/carcinogens)	9165/25,550
AF	Waste to skin adherence factor (mg/cm^2)	0.2
ABS	Absorption factor	Varies with pollutants
TSP	Total suspended particulate content in air (mg/m^3)	0.3
INH	Inhaled amount of air by an adult	15
PIAF	Retention ratio of inhalable waste particles in body	0.75
ET (out)	Proportion of the daily exposure time outdoor	1/3
ET (ind)	Proportion of the daily exposure time indoor	1/3
IR_w	Ingestion rate of underground water (L/d)	1
IR_f	Ingestion rate of food (kg/d)	1.2

Table 4.22 Ingestion Amount Through Mouth

Pollutant	Concentration (mg/kg)	Daily Ingestion Amount (mg/d)	Exposure Time (d)	Averaging Body Weight (kg)	Averaging Time (a)	Ingestion Amount Through The Mouth (mg/kg·d)
Phorate	16,868	100	7830	60	9165	2.4×10^{-4}
Parathion	6521	100				9.0×10^{-3}
Terbufos	170	100				2.4×10^{-4}
Chlorpyrifos	167.5	100				2.4×10^{-4}
Dichlorvos	163.3	100			25,550	8.3×10^{-5}

Table 4.23 Ingestion Amount Through Breathing

	Outdoor Ingestion (mg/kg·d)		Indoor Ingestion (mg/kg·d)	
Pollutant	Vapor	Particle	Vapor	Particle
Phorate	1.2×10^{-4}	1.0×10^{-4}	2.5×10^{-4}	1.6×10^{-4}
Parathion	—	6.2×10^{-5}	—	4.0×10^{-5}
Terbufos	—	1.6×10^{-6}	—	1.1×10^{-6}
Chlorpyrifos	—	1.6×10^{-6}	—	1.0×10^{-6}
Dichlorvos	—	3.6×10^{-7}	—	5.6×10^{-7}

Table 4.24 Ingestion Amount Through Skin Contact

Pollutant	Concentration (mg/kg)	Contact Area (cm^2)	Skin Contact Coefficient	Exposure Time (d)	Averaging Body Weight (kg)	Averaging Time (a)	Ingestion Amount Through the Skin (mg/kg·d)
Phorate	16,868	2800	0.1	7830	60	9165	1.3×10^{-2}
Parathion	6521						5.2×10^{-3}
Terbufos	170						1.4×10^{-4}
Chlorpyrifos	167.5						1.4×10^{-4}
Dichlorvos	163.3					25,550	4.7×10^{-5}

Table 4.25 Ingestion Amount Through Diets

Pollutant	Ingestion Amount Through Drinking Water (mg/kg·d)	Ingestion Amount Through Meals (mg/kg·d)
Phorate	0.018	—
Parathion	—	—
Terbufos	—	—
Chlorpyrifos	—	—
Dichlorvos	—	—

Table 4.26 Toxicity Values of Organic Pollutants

Pollutants	SF$_o$ (mg/kg·d)$^{-1}$	SF$_i$ (mg/kg·d)$^{-1}$	SF$_d$ (mg/kg·d)$^{-1}$	RfD$_o$ (mg/kg·d)	RfD$_i$ (mg/m^3)	RfD$_d$ (mg/kg·d)
Phorate	—	—	—	0.0005	—	0.0005
Parathion	—	—	—	0.006	0.0005	0.006
Terbufos	—	—	—	0.000125	—	0.000125
Chlorpyrifos	—	—	—	0.003	—	0.003
Dichlorvos	0.29	—	0.29	0.0005	0.0005	0.0005

RfD, reference dose; *RfD$_d$*, dermal chronic RfD; *RfD$_i$*, inhalation chronic RfD; *RfD$_o$*, oral chronic RfD; *SF$_d$*, dermal slope factor; *SF$_i$*, inhalation slope factor; *SF$_o$*, oral slope factor.

The calculation of carcinogenic risk of dermal ingestion of single pollutant (DDVP) in C&D waste is performed as:

$$R_{\mathrm{dermal}} = \mathrm{CDI} * \mathrm{SF} = 4.7 * 10^{-5} * 0.29 = 1.4\mathrm{e} - 5$$

The noncarcinogenic value of oral ingested pollutants in C&D waste is listed in Table 4.27. The noncarcinogenic value of dermal ingested pollutants in C&D waste is listed in Table 4.28.

The noncarcinogenic value of inhaled pollutants outdoor in C&D waste is listed in Table 4.29.

The noncarcinogenic value of inhaled pollutants indoor in C&D waste is listed in Table 4.30.

Table 4.27 Noncarcinogenic Value of Oral Ingested Pollutants in C&D Waste

Pollutant	Exposure Amount (mg/kg·d)	Oral Ingested Amount (mg/kg·d)	Noncarcinogenic Value of Single Pollutant
Phorate	2.4×10^{-2}	0.0005	48.00
Parathion	9.0×10^{-3}	0.006	1.50
Terbufos	2.4×10^{-4}	0.000125	1.92
Chlorpyrifos	2.4×10^{-4}	0.003	0.08
Noncarcinogenic value of all pollutants			51.5

Table 4.28 Noncarcinogenic Value of Dermal Ingested Pollutants in Construction and Demolition Waste

Pollutant	Exposure Amount (mg/kg·d)	Dermal Ingested Amount (mg/kg·d)	Noncarcinogenic Value of Single Pollutant
Phorate	1.3×10^{-2}	0.0005	26.00
Parathion	5.2×10^{-3}	0.006	0.87
Terbufos	1.4×10^{-4}	0.000125	1.12
Chlorpyrifos	1.4×10^{-4}	0.003	0.05
Noncarcinogenic value of all pollutants			28.0

Table 4.29 Noncarcinogenic Value of Inhaled Pollutants Outdoor in Construction and Demolition Waste

Pollutant	Exposure Amount (mg/kg·d)	Inhaled Amount (mg/m^3)	Noncarcinogenic Value of Single Pollutant
Phorate	2.2×10^{-4}	—	—
Parathion	6.2×10^{-5}	0.0005	0.124
Terbufos	1.6×10^{-6}	—	—
Chlorpyrifos	1.6×10^{-6}	—	—
Noncarcinogenic value of all pollutants			0.1

Table 4.30 Noncarcinogenic Value of Inhaled Pollutants Indoor in Construction and Demolition Waste

Pollutant	Exposure Amount (mg/kg·d)	Inhaled Amount (mg/m^3)	Noncarcinogenic Value of Single Pollutant
Phorate	1.6×10^{-4}	—	—
Parathion	4.0×10^{-5}	0.0005	0.08
Terbufos	1.1×10^{-6}	—	—
Chlorpyrifos	1.0×10^{-6}	—	—
Noncarcinogenic value of all pollutants			0.1

Table 4.31 Noncarcinogenic and Carcinogenic Values and Risks of All Pollutants

	Toxicity Effect			Carcinogenic Risk	
Exposure Pathway	**Maximum**	**Total**	**Whether it Exceeds the Risk Limits or Not**	**Total**	**Whether it Exceeds the Risk Limits or Not**
Inhaled indoor	0.1	0.1	No	–	No
Inhaled outdoor	0.1	0.1	No	–	No
Dermal ingestion	26	28	Yes	1.4×10^{-5}	No
Ingestion through meals	36	36	Yes	–	No
Oral ingestion	48	52	Yes	2.4×10^{-5}	No

The noncarcinogenic value of ingested pollutants through drinking water in C&D waste is calculated as:

$$R_{\text{drinking}} = 0.018/0.0005 = 36$$

The noncarcinogenic and carcinogenic values and risks of all pollutants are summed up and listed together in Table 4.31.

As shown in Table 4.31, none of the carcinogenic risks in industrial C&D waste of pesticide manufacturing industry exceeded the limits, but highly noncarcinogenic risks were found, especially in dermal (skin) contact and oral ingestion.

4.6 CYANIDE-CONTAMINATED C&D WASTE GENERATED IN A FIRE/EXPLOSION ACCIDENT

Fire and explosion are also an important generation sources of industrial C&D waste. According to statistics in China, 207 accidents happened in factories during Nov. to Dec. in 2011, including mining accidents, traffic accidents, explosion, fire, leakage of poison and toxic materials, and other accidents, among which 7.73% resulted from fire, whereas 6.28% were resulted from explosion. During 2012–15, various notices, regulations, and alarms were issued and put forward by the government including "a notice of the safe production and specific treatment of manufactured aluminum and magnesium products". However, accidents still happened frequently; large accidents like Tianjin, particularly the serious fire explosion in 2015, caused great damage and resulted in huge casualty. A management program explaining the disposal of C&D waste generated in fire/explosion accidents has been established based on the laboratory simulation experiments and field research experience. In this section, a fire accident that happened in north China is introduced and the C&D waste at the scene is analyzed.

Based on the survey on site, it was found that the C&D waste was piled in a complex way and was of a large amount. Main components of C&D waste were concrete blocks, bricks, muck, scrap metal, etc. The northern part of the explosion spot was stacked mainly of scrap metal, which was once the containers, whereas the southern part of the explosion spot were scattered by C&D waste and muck. The picture of C&D waste debris is shown in Fig. 4.14.

The contamination and diffusion process of C&D waste generated in explosion was that the pollutants (mainly the chemicals in stock, highly contaminated equipment, pipelines, and other industrial waste) and C&D waste experienced a complex reaction of crushing, polymerization, melting, and other physical or chemical mechanism under the condition of highly compressed air flow and high temperature. Then the contaminated waste migrated with the gas diffusion, resulting in the proliferation of pollution. Large blocks of waste would fall earlier before small blocks. The simulation of gas flow and C&D waste is demonstrated in brief in Fig. 4.15. In addition, a large portion of the contaminants may be directly injected downward into the central pit with the explosion shock wave. That meant this part of the

Figure 4.14 Pictures of construction and demolition waste generated in a great fire/explosion accident.

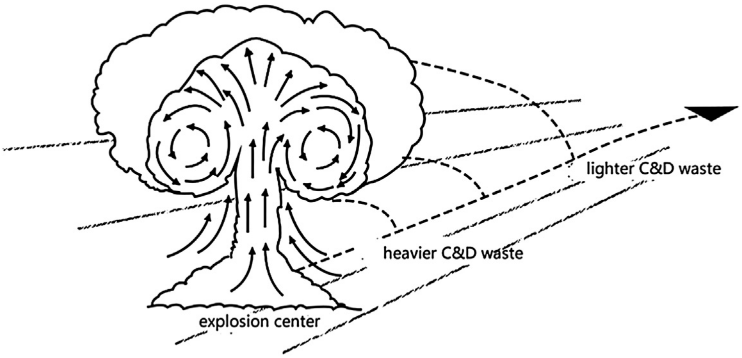

Figure 4.15 Simulation of gas flow and construction and demolition waste in an explosion.

contaminated C&D waste was unable to be sampled. According to information obtained, the explosion had covered an area of a radius of about 2 km. The sampling information at about 1—1.5 km around the center of the explosion is shown in Fig. 4.16.

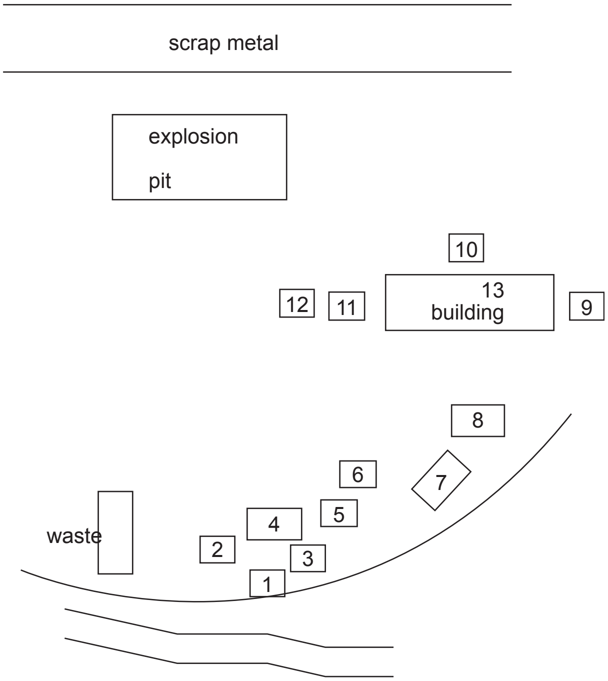

Figure 4.16 Sampling information in a great fire/explosion accident.

After preliminary characterization, the C&D waste collected sent out a strong flavor of almond, which meant cyanide or sulfide might exist. According to the gas chromatography—mass spectrometry analysis, the extracts contained the following substances:

- cumene (an important organic chemical raw material)
- diacetone alcohol
- acetone cyanohydrin (hydrocyanic acid is made of concentrated sulfuric acid and sodium cyanide, whereas the acetone cyanohydrin is produced by acetone and hydrocyanic acid, which is purified by distillation)
- musk xylene (explosive, may cause an explosion in nitration workshops due to high temperature)
- dicyclohexyl disulfide
- *p*-phenylenediamine

Results of the cyanide analysis are listed in Table 4.32. The rule of waste number could be described using C&D 1 as an example. 1-1 was the muck waste, which was the smallest in size, 1-2 was the particulate waste, 1-3 was

Table 4.32 Pollution of the Cyanide-Contaminated Construction and Demolition (C&D) Waste Generated in an Explosion

C&D Waste	Concentration (Cyanide) (mg/kg)
1-1	160
1-2	12.1
1-3	105
1-4	110
2-1	1.53×10^3
2-2	5.76×10^3
3-1	3.49×10^3
3-2	6.10×10^3
4-1	2.08×10^3
4-2	5.38×10^3
5	2.41×10^3
6	981
7	39.8
8	38.4
9	59.0
10	46.7
11-1	43.7
11-2	33.5
12	195
13	33.3
14	2.62×10^3

the C&D waste in blocks, 1-4 was the stripped waste on the surface of large blocks of C&D waste. As shown in the table, large amounts of contaminated waste that diffused through the gas flow were attached to the C&D waste blocks. C&D waste from chemical, metallurgical, and other industrial enterprises generated in the fire/explosion could be serious secondary pollution sources. Soil was also sampled and detected. It was found that among the solid waste scattered on the ground, the concentration of pollutants in soil was much lower than that on the surface of C&D waste. Overall, the most severely contaminated part of C&D waste came from the small pieces of waste.

CHAPTER FIVE

Pollution Mechanism of Contaminated Construction and Demolition Waste

5.1 STATIC CONTAMINATION PROCESS OF HEAVY METALS

Construction and demolition (C&D) waste with particle size of 30 mm was put in 1000 mL PE sealed bottle and soaked in different solutions consisted of 50 g/50 mL Zn, Cu, Pb, Cd, and Cr and solid to liquid ratio of 1:10, respectively, as is listed in Table 5.1. After soaking for 1, 2, 3, 5, 7, 17, and 27 days, supernatant was sampled. pH and heavy metals were measured. Sample was digested and tested by inductively coupled

Table 5.1 Initial Soaking Concentrations

No	Type of Solution	Heavy Metal Concentration (mg/L)
1	$Zn^{2+}(Zn(NO_3)_2 \cdot 6H_2O)$	100
		150
		300
2	$Cu^{2+}(Cu(NO_3)_2 \cdot 3H_2O)$	100
		150
		300
3	$Pb^{2+}(Pb(NO_3)_2)$	100
		150
		300
4	$Cd^{2+}(Cd(NO_3)_2 \cdot 4H_2O)$	100
		150
		300
5	$Cr^{3+}(Cr(NO_2)_3 \cdot 9H_2O)$	20
		50
		100
6	Zn, Cu, Cd, Cr, Pb mixed solution	100
		150
		300

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plasma-optical emission spectrometry (ICP-OES). Heavy metal absorptive capacity was evaluated by difference.

5.1.1 pH Variation During Static Contamination Process

pH variation of single heavy metal with time is shown in Fig. 5.1A—E. pH variation of mixed heavy metals with time is shown in Fig. 5.1F. As shown in the figure, pH had kept rising in different heavy metal solution. pH of control group using distilled water as soaking solution rising from 8.56 to 10.00 at the first 2 days, then keeping rising to 10.85 at 27th day. Different heavy metal solution turned from acidity to alkalinity due to the dissolution of alkaline matter such as calcium carbonate, silicate etc. Zn, Cu, Pb, Cd, and Cr nitric solution had neutralization effect on C&D waste exhibiting in control experiment. The higher concentration of heavy metal, the higher neutralization capacity obtained. pH variation of Pb solution had the same pattern with the control. pH of mixed heavy metal solution rose slowly and stayed acid throughout the period up to 27th day.

5.1.2 Absorptive Capacity Variation of Single Heavy Metal Solution

Figs. 5.2—5.6 (A) shows absorptive capacity variation of single heavy metal solution with time. Figs. 5.2—5.6 (B) shows variation of concentration and removal rate of single heavy metal solution with time. Single heavy metal concentration descended gradually. Absorptive capacity and removal rate kept rising. Variation of absorptive capacity was in consistent with removal rate.

Heavy metal in three different concentrations of soaking solutions descended gradually with removal rate and absorptive capacity rising. After 7 days, 100 mg/L and 150 mg/L Zn solution reached approximately 0 mg/L with removal rate of 95%, whereas 300 mg/L took 17 days for reaching 0 mg/L. After 17 days, the concentration of Cu in the former 100 mg/L, 150 mg/L, and 300 mg/L solution reached approximately zero with a removal rate of 95%. After reaching adsorption equilibrium, heavy metal concentration started to rise at 27th day. Concentration variation of three different Pb solutions was consistent and reached 0 mg/L and a removal rate of 95%. After 17 days, 100 mg/L and 150 mg/L Cd solution reached approximately 0 mg/L with removal rate of 95%, whereas 300 mg/L took 27 days for reaching 0 mg/L. Variation of Cr showed a similar pattern with Zn. After 7 days, 100 mg/L and 150 mg/L Cr solution reached approximately 0 mg/L with a removal rate of 95%, whereas 300 mg/L took 17 days for reaching 0 mg/L.

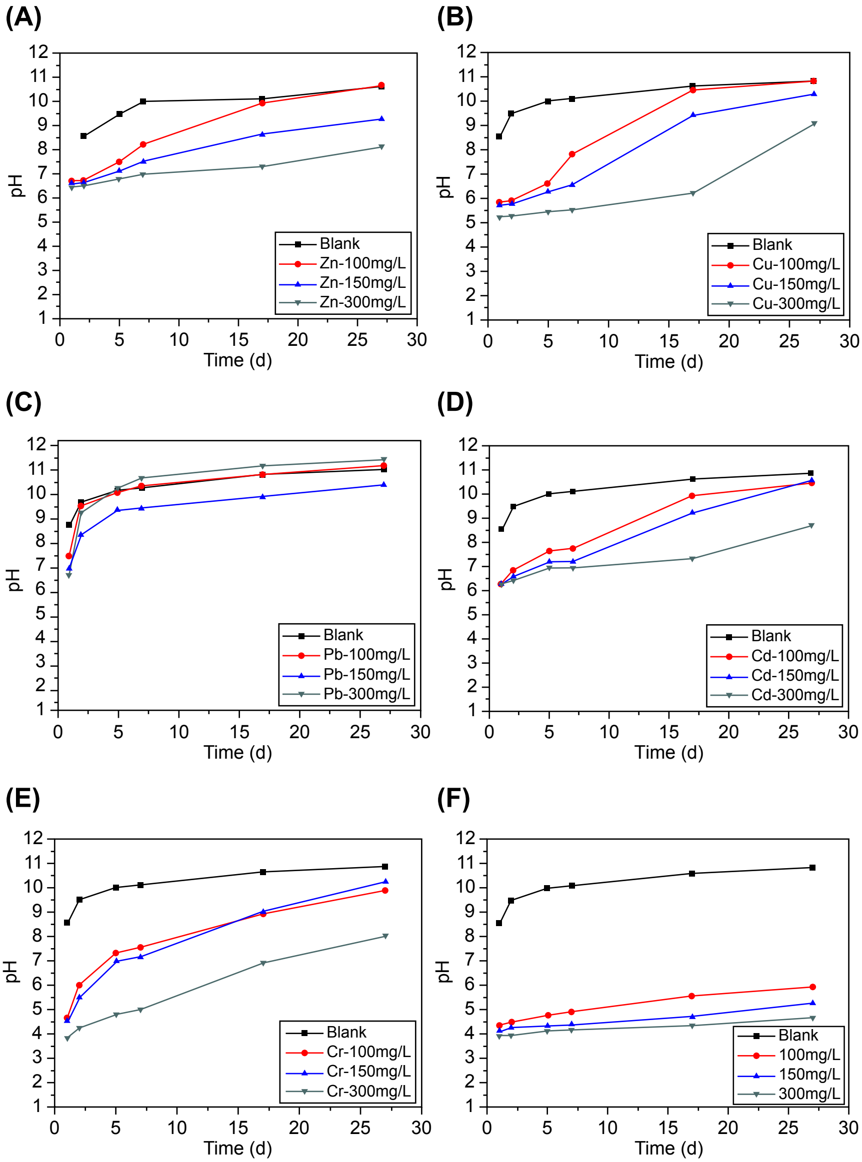


Figure 5.1 pH variation of heavy metal soaking solution for C&D waste. (A) pH variation of Zn soaking solution, (B) pH variation of Cu soaking solution, (C) pH variation of Pb soaking solution, (D) pH variation of Cd soaking solution, (E) pH variation of Cr soaking solution, and (F) pH variation of mixed heavy metal soaking solution.

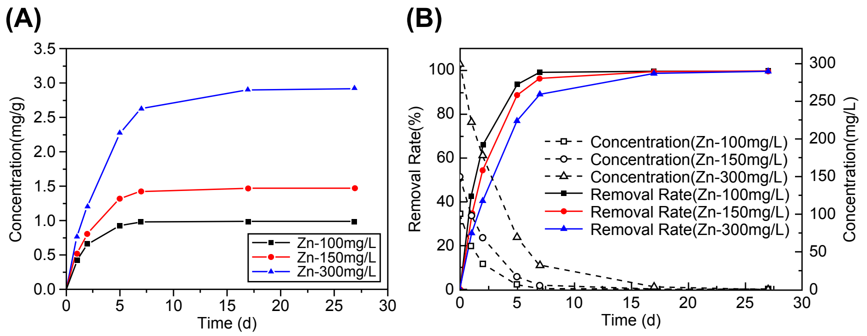


Figure 5.2 Zn variation of single heavy metal solution during soaking for construction and demolition (C&D) waste. (A) Absorptive capacity variation of Zn and (B) removal rate and concentration of Zn.

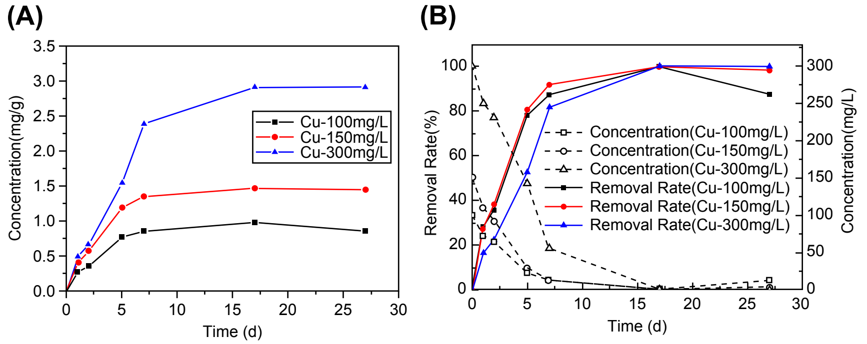


Figure 5.3 Cu variation of single heavy metal solution during soaking for C&D waste. (A) Absorptive capacity variation of Cu and (B) removal rate and concentration of Cu.

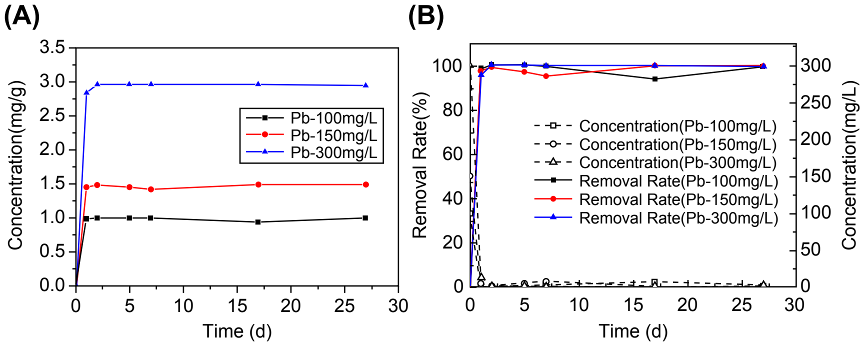


Figure 5.4 Pb variation of single heavy metal solution during soaking for C&D waste. (A) Absorptive capacity variation of Pb and (B) removal rate and concentration of Pb.

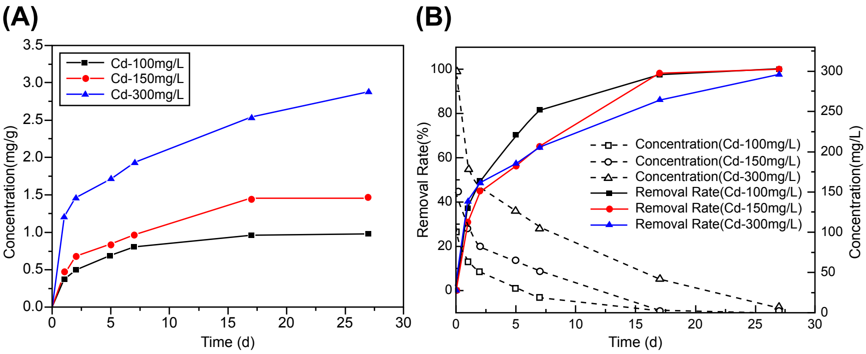


Figure 5.5 Cd variation of single heavy metal solution during soaking for C&D waste. (A) Absorptive capacity variation of Cd and (B) removal rate and concentration of Cd.

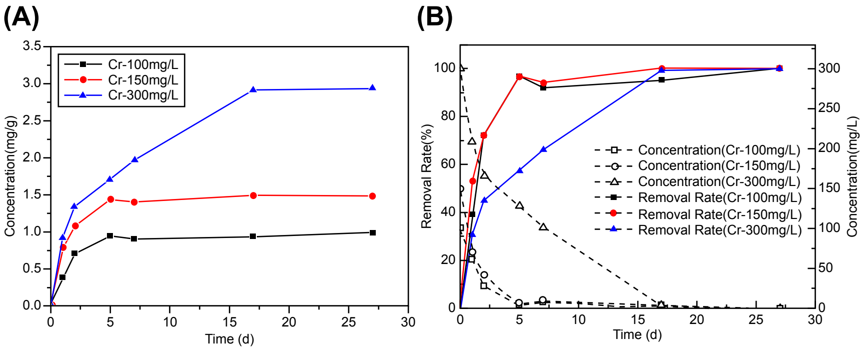


Figure 5.6 Cu variation of single heavy metal solution during soaking for C&D waste. (A) Absorptive capacity variation of Cr and (B) removal rate and concentration of Cr.

5.1.3 Absorptive Capacity Variation of Mixed Heavy Metal Solution

Figs. 5.7—5.11 (A) show the absorptive capacity variation of mixed heavy metal with time, whereas Figs. 5.7—5.11 (B) show the concentration variation and the removal rate of Zn, Cr, Cd, Pb, and Cu with time. As shown in these figures, the absorption of most heavy metals reached its maximum ratio (Pb, Cr, and Cd), but the subsequent absorption patterns differed. The absorption of Pb, Cr, and Cd after 2 days gradually decreased, remained fluctuated and gradually increased, respectively. The absorption of Zn reached its equilibrium at day 2. Variation of 100, 150, and 300 mg/L of Pb in mixed heavy metal solution had a similar pattern in these four heavy metal absorption systems. At 27th day, 300 mg/L Zn and Cd solution obtained the maximum adsorptive capacity and removal rate, whereas 100 mg/L solution

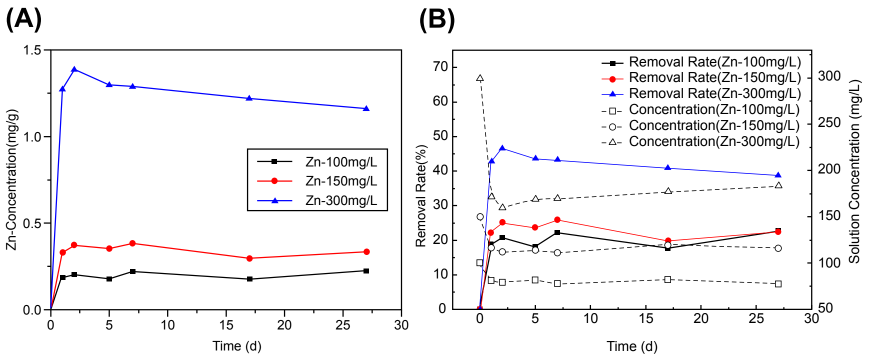


Figure 5.7 Variation of Zn in mixed heavy metal solution for C&D waste. (A) Absorptive capacity variation of Zn in mixed heavy metal solution and (B) concentration variation and removal rate of Zn in mixed heavy metal solution.

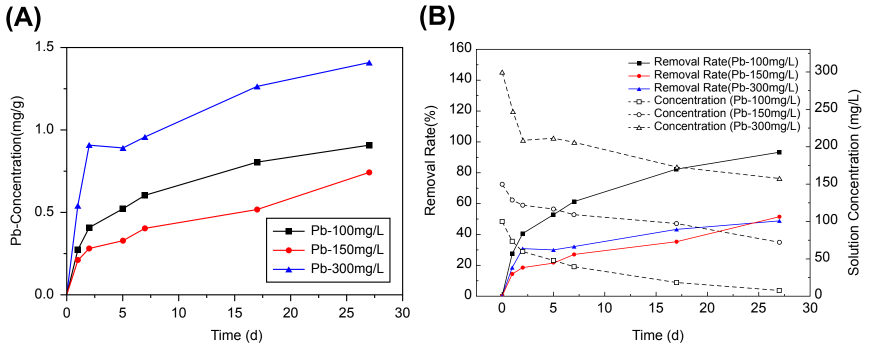


Figure 5.8 Variation of Pb in mixed heavy metal solution for C&D waste. (A) Absorptive capacity variation of Pb in mixed heavy metal solution and (B) concentration variation and removal rate of Pb in mixed heavy metal solution.

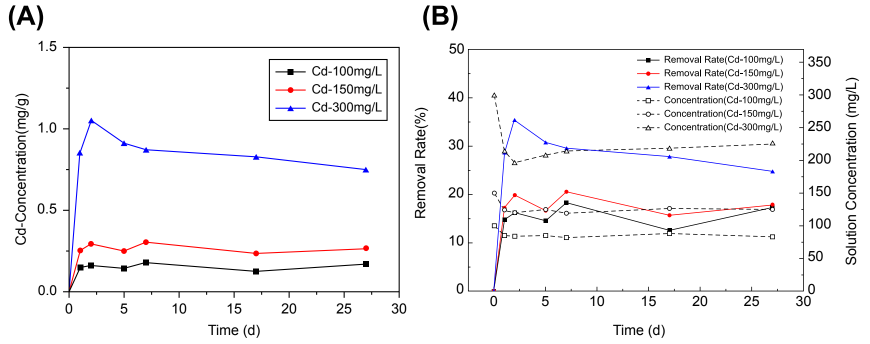


Figure 5.9 Variation of Cd in mixed heavy metal solution for C&D waste. (A) Absorptive capacity variation of Cd in mixed heavy metal solution and (B) concentration variation and removal rate of Cd in mixed heavy metal solution.

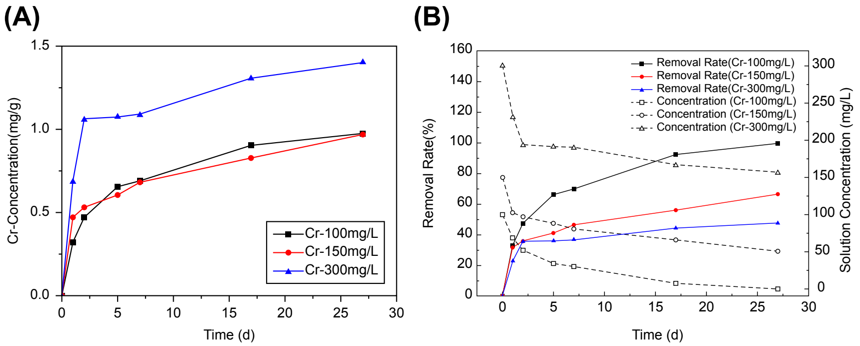


Figure 5.10 Variation of Cr in mixed heavy metal solution for C&D waste. (A) Absorptive capacity variation of Cr in mixed heavy metal solution and (B) concentration variation and removal rate of Cr in mixed heavy metal solution.

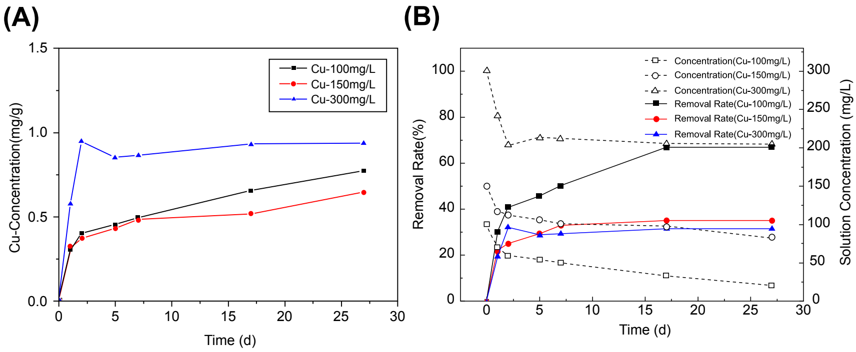


Figure 5.11 Variation of Cu in mixed heavy metal solution for C&D waste. (A) Absorptive capacity variation of Cu in mixed heavy metal solution and (B) concentration variation and removal rate of Cu in mixed heavy metal solution.

obtained the minimum adsorptive capacity and removal rate. Contrary results were gained in Pb and Cr solution where 100 mg/L obtained the maximum adsorptive capacity and removal rate.

Absorption pattern of Cu solution on C&D waste was different from the other two metals. Variation trends of 100 and 150 mg/L of Cu in mixed heavy metal solution had a similar pattern. Adsorption rate was fast on the first day and then slowed down. Removal rate of 150 mg/L reached the maximum value on the seventh day. The 150 mg/L Cu solution reached adsorption equilibrium on the 17th day. The 300 mg/L Cu mixed solution obtained the maximum adsorption capacity after 2 days and started descended on the fifth day then reached equilibrium. When the absorption process came to the end, the 300 mg/L solution obtained maximum adsorptive capacity of Cu, whereas the 150 mg/L solution obtained the minimum value. The 100 mg/L solution reached the maximum removal rate of Cu, whereas the 300 mg/L reached the minimum value.

5.2 DEPTH OF CONTAMINATION THROUGH SURFACE CONTACT

Commercial C20 concrete was used for research in this chapter. The external dimension of the test block was 200 × 200 × 150 mm, and thickness of the bottom and side was 50 mm, with 100 × 100 × 100 mm recess space set in the middle for storage of heavy metal solution.

Different heavy metal solutions including zinc, copper, lead, cadmium, chromium solutions, and a mixed solution of concentration of each heavy metals was 100 mg/L. Sampling was carried out in day 1, 2, 5, and 10, respectively, using a pipette to collect the supernatant in different locations of the concrete. pH and heavy metals were determined, and the heavy metal adsorption amount was calculated using the differential method.

Solid concrete samples were collected at different depths in the concrete after the solution was totally evaporated and stabled for 3 months. The sampling depth was 0–0.5 cm, 0.5–1.0 cm, 1.0–1.5 cm, 1.0–2.0 cm, 2.0–2.5 cm, 2.5–3.0 cm, 3.0–4.0 cm, and 4.0–5.0 cm, respectively.

5.2.1 pH Variation During Surface Contact

Hydration substances of cement products such as silicates, aluminates, and calcium hydroxide released during the soaking in solution and would cause a rise of pH. Results showed that pH of the single Zn, Cu, Pb, Cd, and Cr solution was rose up to more than 9 after 1 day and eventually stabilized at 10 to 11. However, pH of the mixture of heavy metal solution remained below 7 even 1 day later and ceased to rise rapidly at pH 10.95, as the amount of heavy metal ions in the mixed solution was five times higher than that in the single metal solutions.

5.2.2 Variation of Heavy Metals Concentrations in Solution

Concentration of heavy metals in concrete was decreasing, which was different from the pH value, as shown in Fig. 5.12. Concentrations of heavy metals in single solution rapidly reduced from 100 to 2–5 mg/L in the first day and then further down to 0.792, 0.385, 0.261, 0.001, and 0.038 mg/L for Zn, Cu, Pb, Cd, and Cr, respectively.

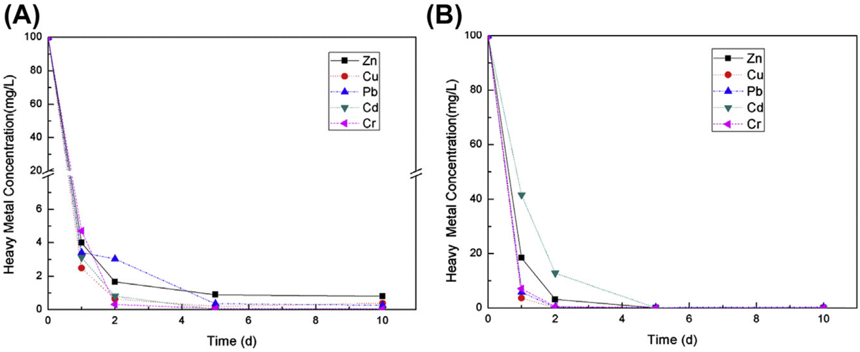


Figure 5.12 Variation of the concentration of heavy metals in the solution for C&D waste. (A) Solution with single heavy metal and (B) mixed solution.

Concentration of heavy metals in mixed solution in the first day varied in a similar way as pH which was due to the relatively higher acid in the solution and hydroxide precipitate could not be formed immediately. The concentration of Zn, Cu, Pb, Cd, and Cr concentration at day 10 were 0.047, 0.159, 0.315, <0.002 (less than detection limit), and 0.0519 mg/L, respectively.

5.2.3 Distribution of Heavy Metals in Concrete

Concentration of heavy metals in different depths without contamination was set as the background value that is listed in Table 5.2.

Concentration of heavy metals in concrete is demonstrated in Fig. 5.13, where (A)—(E) are distribution of Zn, Cu, Pb, Cd, and Cr under single contamination and (F) is distribution of Zn, Cu, Pb, Cd, and Cr under multiple contamination. Results showed that Zn, Cu, Pb, and Cr existed in different depths under both single and multiple contaminations, whereas Cd could not be detected below 1 cm.

It was indicated in (A)—(E) from Fig. 5.13 that heavy metals were mainly concentrated within 1 cm below the surface. Alkaline substances might be released that resulted in the concentration and fixation of heavy metals on the surface. The concentration of Cu in the depth of 2.0—2.5 cm was higher than the background value. It was proved that Cu had a higher tendency of migration in the concrete than other heavy metals. Cd had the lowest migration capacity as it was found only in the depth of 0.5—1.0 cm.

Distribution of Zn, Cu, Pb, Cd, and Cr in the depth of 0—0.5 cm under multiple contaminations was similar in pattern, and the concentration was 1057, 1220.5, 1154, 1296.6, and 1220.4 mg/kg, respectively, all of which

Table 5.2 Concentration of Heavy Metals in Different Depths Without Contamination for Construction and Demolition (C&D) Waste

Depth/cm	Zn/(mg/kg)	Cu/(mg/kg)	Pb/(mg/kg)	Cd/(mg/kg)	Cr/(mg/kg)
0–0.5	38.4	23.4	10.3	–	38.7
0.5–1.0	56.3	77.3	9.1	–	37.6
1.0–1.5	30.5	27.9	9.6	–	107.0
1.5–2.0	34.1	23.9	10.0	–	80.4
2.0–2.5	49.8	24.2	18.0	–	75.7
2.5–3.0	106.6	55.9	7.2	–	50.5
3.0–4.0	58.4	27.2	8.2	–	40.4
4.0–5.0	66.4	14.1	11.1	–	35.8
Average	55.1	34.2	10.4	–	58.2

–, undetected.

were lower than those under single contamination. However, in the depth of 0.5–1.0 cm, the concentration of heavy metals under multiple contamination were higher than those under single contamination, which might be due to the increase of penetration capacity of heavy metals resulted from the higher amount of ions. Little heavy metals existed below 1 cm except Cr, the concentration of which was higher than the background value in the depth of 1.5–2.0 cm, 2.0–2.5 cm, and 3.0–4.0 cm and was also higher than that under single contamination. Therefore the penetration capacity of Cr increased under multiple contaminations.

5.3 SIMULATION OF GASEOUS MERCURY ADSORPTION OF DIFFERENT BUILDING MATERIALS

Five different commercial building materials tested were cement block, foam concrete, red brick, regeneration sandstone from Pudong, and recycled aggregates from Dujiangyan, respectively, with three different particle sizes (defined as α: 10–100 mesh, β: 100–200 mesh, γ: >200 mesh). They were exposed to gaseous mercury (the average level of 200 ng m^{-3}) in constant temperature, so as to test mercury content in 5, 10, 20, and 150 days. The mercury penetration tube was used as a gaseous mercury source, and it kept stable concentration of gaseous mercury under the condition of room temperature (25°C) and the constant flow of carrier gas (pure N_2), monitored by RA-915M portable gas mercury analyzer. Cement brick was mainly made up of stone powder 60%, fine stone 3%, cement 8–10%, lime 3%, and ash powder 0.2%; foam concrete mainly made up of cement 55–65%, coal ash 34–45%, foaming agent 0.2–0.6%,

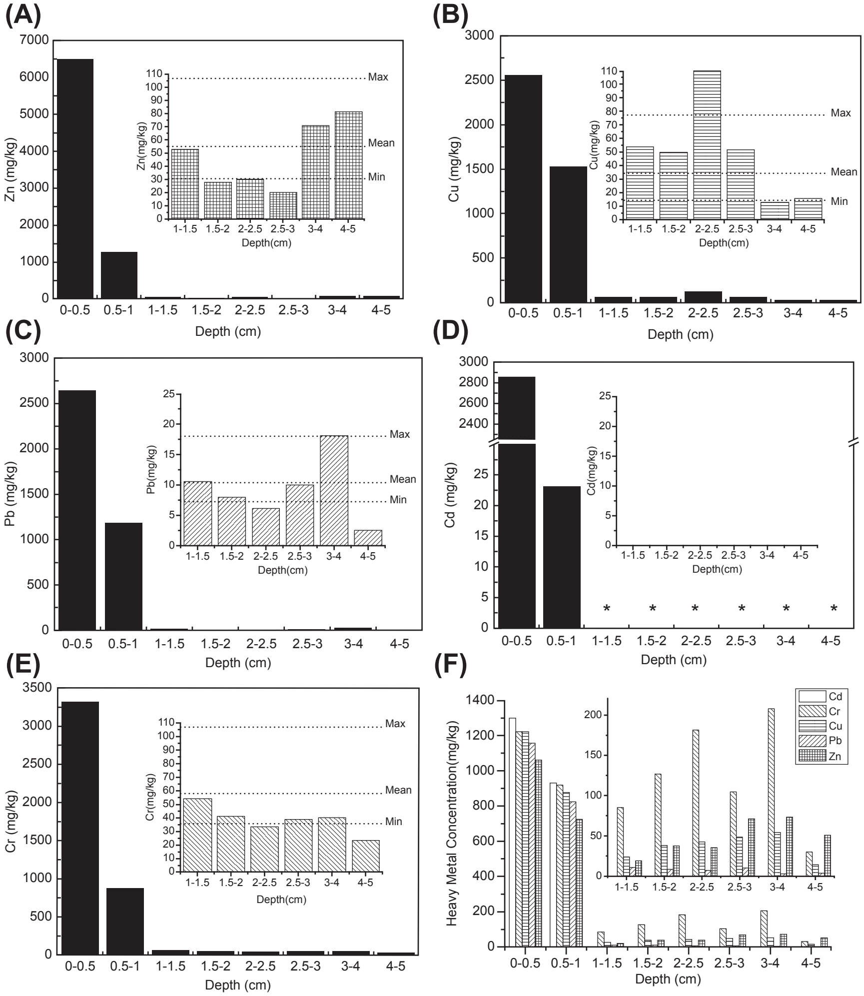


Figure 5.13 Distribution of heavy metals in different depth of concrete (*: undetected) for C&D waste (A) Zn, (B) Cu, (C) Pb, (D) Cd, (E) Cr, and (F) heavy metals.

and additives 0.2—0.5%; red brick mainly made up of clay 80%, coal gangue 6—12%, and fly ash 8—14%; regeneration sandstone made of loose mixture of sand and gravel; and recycled aggregate included gravel, sand, slag etc.

5.3.1 Characterization of Building Materials

5.3.1.1 X-Ray Fluorescence Analysis of Building Materials

XRF data analysis of cement block, foam concrete, red brick, regeneration sandstone from Pudong, and recycled aggregates from Dujiangyan, respectively, are shown in Table 5.3. Cement block was mainly made up of SiO_2 (34.869%) and CaO (26.247%). Foam concrete was mainly made up of SiO_2 (66.919%) and Al_2O_3 (14.263%). Regeneration sandstone from Pudong and recycled aggregates from Dujiangyan are mainly made up of SiO_2 and CaO. It is visible that SiO_2 is the main ingredient of five building materials.

5.3.1.2 SEM Analysis of Building Materials

SEM graph of cement block, foam concrete, red brick, regeneration sandstone from Pudong, and recycled aggregates from Dujiangyan, respectively, are shown in Fig. 5.14. The cement block had the minimum pores on the surface, regeneration sandstone came second, and foam concrete, red brick, and recycled aggregates had more pores among the five building materials.

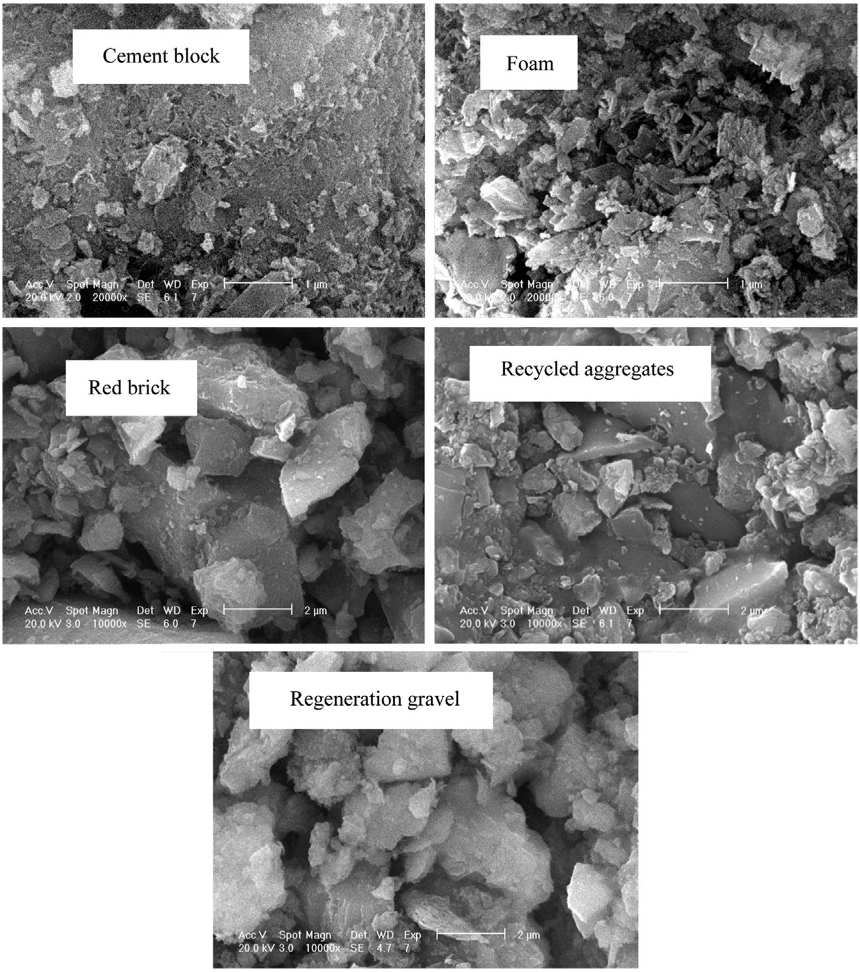
The five building materials in the figure below were cement block, foam concrete, red brick, regeneration sandstone from Pudong, and recycled aggregates from Dujiangyan, respectively.

5.3.1.3 Analysis of Particle Sizes

Particle size distribution of five building materials were expressed as Dv10, Dv50, and Dv90, which is shown in average particle size of five building materials (μm) (Table 5.4). The results of average particle size distribution were as follows: (1) 90% of the particle size between 100 and 10 mesh were under 1117.4 μm, 50% of which were under 476 μm, (2) 90% of the particle size between 100 and 200 mesh were under 194.4 μm, 50% of which were under 89.76 μm, and (3) 90% of the particle size less than 200 mesh were under 68.54 μm, 50% of which were under 31.76 μm. Due to the relative standard deviation below 10%, three were distributed evenly among five materials. Hence, red bricks were chosen as the representative materials for particle size grading.

Table 5.3 Main Mineral Composition of Building Materials, Expressed as a Percentage (%) of Mineral Oxides

Samples	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O
Cement block	34.869	7.222	2.982	1.989	26.247	1.471	0.761
Foam concrete	37.363	15.565	4.003	0.996	20.033	1.269	0.441
Red brick	66.919	14.263	5.842	1.115	1.884	1.909	1.385
Recycled aggregates (Dujiangyan)	48.452	11.707	5.492	1.921	12.495	2.091	0.865
Regeneration sandstone (Pudong)	50.121	10.348	4.338	1.33	15.553	2.009	1.204


Cement block

Foam

Red brick

Recycled aggregates

Regeneration gravel

Figure 5.14 SEM graph of five building materials.

5.3.2 Gaseous Mercury Adsorption Analysis of Different Building Materials

Background mercury content of five building materials values were cement block (10 μg/kg), foam concrete (80 μg/kg), red brick (12 μg/kg), recycled aggregates from Dujiangyan (15 μg/kg), and regeneration sandstone from Pudong (20 μg/kg) (Fig. 5.15A). Mercury concentration at a constant room temperature in which the samples were exposed remained about 200 ng/m^3 (regularly monitored by RA-915M portable gas mercury analyzer) and detected the mercury content of samples after 5, 10, and

Table 5.4 Average Particle Size of Five Building Materials

Particle Size (mesh)	Dv10	Dv50	Dv90
100-10	211 ± 12.06	476 ± 26.66	1117.4 ± 96.54
200-100	23.64 ± 2.69	89.76 ± 4.3	194.4 ± 11.36
<200	8.24 ± 0.99	31.76 ± 3.91	68.54 ± 4.76

20 days respectively. Three kinds of particle size α 10—100 mesh, β 100—200 mesh, and $\gamma < 200$ mesh were called α, β, and γ for short in the following.

Mercury contents of three kinds of particle size (α, β, and γ) of the cement block, foam concrete, red brick, recycled aggregates from Dujiangyan, and regeneration sandstone from Pudong were measured after 5 days' mercury adsorption, indicating that the smaller the particle size was, the bigger adsorption capacity would be obtained. Mercury contents of the foam concrete α, β, and γ were measured as 83.66, 102.57, and 102.60 μg/kg, respectively, after 5 days' mercury adsorption, and the difference between the adsorption quantity of β and γ was very small; mercury content of the red brick α, β, and γ were measured as 15.41, 33.81, and 497.22 μg/kg, respectively, after 5 days' mercury adsorption, and adsorption capacity of γ was much higher than β and α. Mercury levels increased after 10 and 20 days' adsorption, but rate of increase was very small. The mercury levels of red brick β and α were still very low after 10 and 20 days' adsorption.

Mercury contents of the cement block α, β, and γ were measured as 50.04, 173.77, and 168.14 μg/kg after 150 days respectively. Adsorption capacity of the three was 40, 160, and 158 μg/kg respectively compared with background mercury content (10 μg/kg). The reason why adsorption quantity of β was only slightly larger than γ might be that the adsorption quantity of the two had reached a saturation level. It could be inferred that cement brick powder below 100 mesh would be contaminated after 150 days; mercury contents of three particle size of foam concrete samples were measured, and adsorption capacity of the particle size (α, β, and γ) were 172, 194, and 240 μg/kg, respectively, compared with background mercury content (80 μg/kg). Difference among adsorption quantity of the three was very small, and overall the smaller the particle size was, the bigger adsorption capacity would be obtained; mercury levels of red brick α, β, and γ was were measured and adsorption capacity of β or α was still much lower than γ. Adsorption capacity of the three were 83, 128, and 1112 μg/kg, respectively, compared with background mercury content (12 μg/kg). It can be

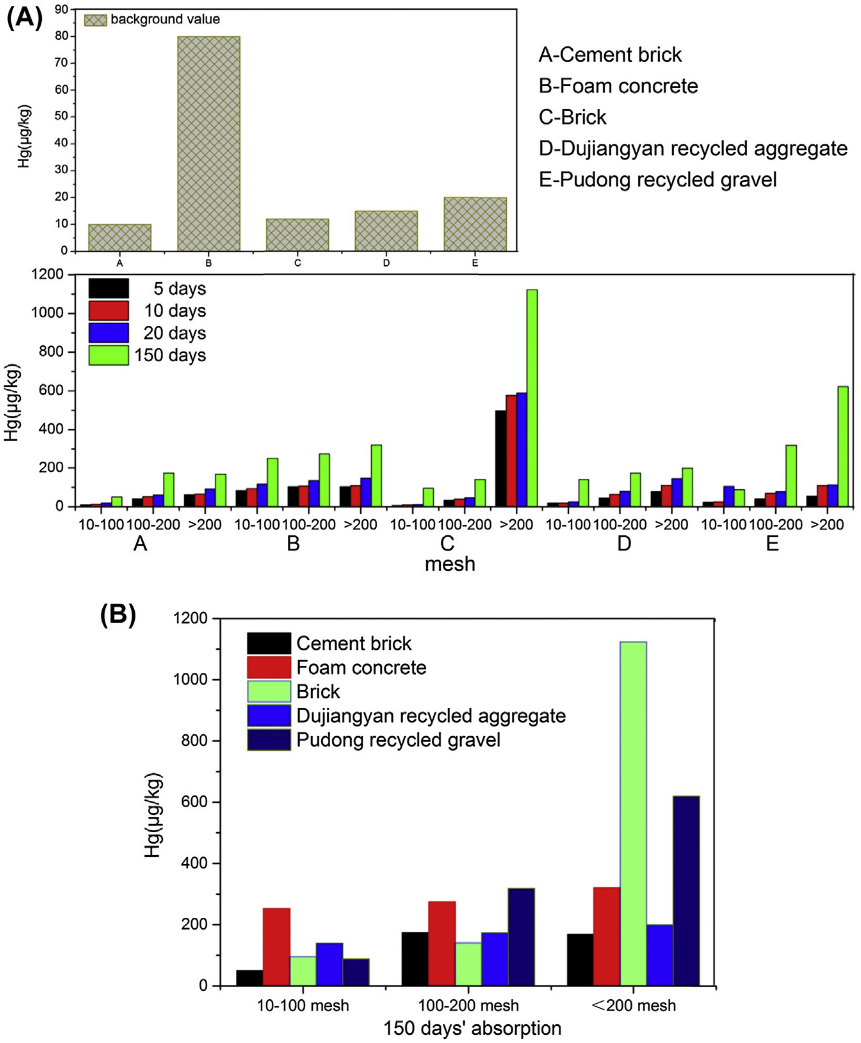


Figure 5.15 Gaseous mercury adsorption simulations of different building materials: (A) background values and 5—150 days' absorption amount and (B) 150 days' absorption amount.

inferred that red brick powder below 200 mesh were vulnerable to be contaminated; mercury content of three particle size of recycled aggregates from Dujiangyan were measured after 150 days, and adsorption capacity of the three were 172, 194, and 240 μg/kg, respectively, compared with background mercury content (15 μg/kg). Difference among adsorption quantity of the three was very small, indicating that different particle sizes had little effect on mercury adsorption for recycled aggregates; mercury contents of regeneration sandstone (α, β, and γ) from Pudong was measured as 88.13, 318.75, and 629.12 μg/kg, respectively, after 150 days. Adsorption capacity of the three were 68, 299, and 609 μg/kg, respectively, compared with background mercury content (20 μg/kg), indicating that the smaller the particle size was, the bigger adsorption capacity was, and mercury content of γ was nearly 2 times β and 10 times α.

Mercury content of five kinds of building materials were compared after 150 days' mercury adsorption as given in Fig. 5.15B, indicating that small particle contributed to a large mercury adsorption, however, different performance was found among various materials. The largest mercury content of α was the foam concrete content, the largest mercury content of β was the regeneration sandstone from Pudong, and the largest mercury content of γ was red brick. Compared with several other materials of γ, mercury content of red brick was 6.7 times that of the cement block, 3.5 times that of the foam concrete, 5.7 times that of the recycled aggregates from Dujiangyan, and 1.8 times that of the regeneration sandstone from Pudong, indicating that red brick was the most vulnerable building material to mercury contamination. Compared with secondary standard threshold of GB15168-1995 (300 μg/kg), the regeneration sandstone from Pudong of β went over the threshold, as well as the foam concrete, red brick, and regeneration sandstone from Pudong of γ after 150 days' mercury adsorption. Buildings will produce C&D waste powder in the process of demolition and reconstruction, of which foam concrete, red brick, and sand may be polluted by mercury.

5.3.3 Gaseous Mercury Adsorption Simulation of Standard Concrete Block

Standard concrete block, of which the strength was C15, was made into 15-centimeter—side length tubes, exposed to mercury concentration of 200 ng/m^3 and constant room temperature for 1.5 years. Its invasion depth profile of mercury is shown in Fig. 5.16. The reason why initial mercury content for concrete block was 39 ± 12 μg/kg was that uneven mercury distribution of raw materials in the process of mixing made some fluctuations. It could be seen from figure that mercury adsorption quantity of standard concrete block was up to 1020.21 μg/kg within the limits of 0—0.5 cm and decreased sharply to 377.40 μg/kg within the limits of 0.5—1.0 cm, indicating that mercury pollution mainly focused on the limits of 0—0.5 cm.

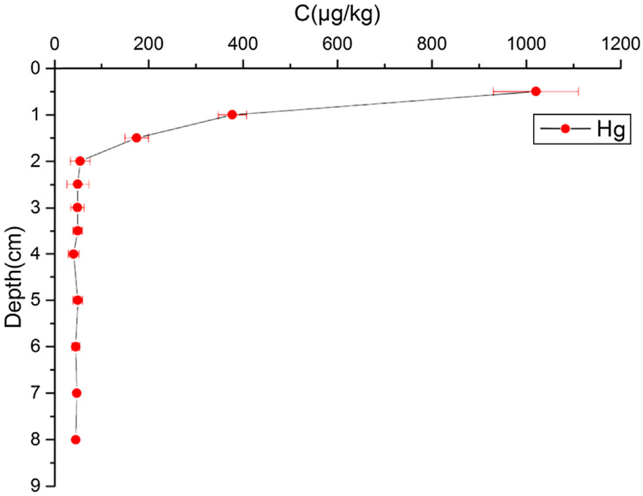


Figure 5.16 Mercury profile distribution of standard concrete block.

Furthermore, mercury adsorption quantity of standard concrete block was up to 174.79 μg/kg within the limits of 1.0—1.5 cm and to 55.02 μg/kg within the limits of 1.5—2.0 cm, indicating that mercury pollution mainly focused on the limits of 1.0—1.5 cm, which was much higher than the initial content (39 ± 12 μg/kg). As a result, for some seriously mercury polluted factories and workshops, mercury pollution could be removed by peeling the skin of the concrete blocks before demolition and renovation process after full utilization.

XRD and XRF analysis of cement block, foam concrete, red brick, regeneration sandstone, and recycled aggregates, respectively, showed that five kinds of building materials were given priority to silicon dioxide, followed by calcium carbonate. SEM microscopic analysis on surfaces of five kinds of building material showed that the porosity of cement block and recycled aggregates was greater than that of the red brick, recycled sand, and foam concrete. Results showed that small particle contributed to large mercury adsorption, however, different performance was found among various materials.

5.4 INTERACTION OF EXOGENOUS ORGANIC POLLUTANTS AND CONSTRUCTION WASTE

5.4.1 SEM Analysis of Contaminated Waste

In addition to thermal effects, many substances also changed in quality in the heating or cooling process. The chemical composition and structure of the target substances are closely related to changes in the size and quality when the temperature varies. The test sample was heated from room temperature to 800°C while the heating rate was 15°C/min. Because of the differences in boiling point of different organic pollutants, as well as the combination of pollutants and C&D waste, the temperature at which C&D waste began to lose weight fluctuated. The weight loss at the temperature of around 200°C was the volatilization and degradation of organic pollutants. The cement hydration product CH started to decompose at 700°C in wall and ground waste (made of concrete, cement), which had resulted in a large weight loss. However, there was no weight loss around this temperature in the brick waste, probably due to its large difference in composition with concrete and cement. When the temperature reached 800°C, 75% of the initial weight remained as ash content in C&D waste that was not able to be degraded.

Fig. 5.17 is the SEM photos of heavy metals/organic pollutants contaminated C&D waste. Among which (A) and (A) were 5000x and 20,000x photos of heavy metal contaminated C&D waste whereas (B) and (D) were 5000x and 20,000x photos of organic pollutants contaminated C&D waste. According to the photos, large damage in the morphology was found in heavy metal contaminated C&D waste. There were many loose pores on the surface of C&D waste and the waste particles were wrapped by crystal substances, which might be the hydroxides and oxides of heavy metals. The damage in morphology was not so evident in organic pollutant contaminated C&D waste. The waste was not significantly eroded and was wrapped in a layer of cotton-like substances.

5.4.2 Analysis of Pollutants and Industrial C&D Waste Combination Using FT-IR

The FTIR spectra of different industrial C&D waste along with clean C&D waste are given in Fig. 5.18. It was concluded that peaks around 2974 and 2875 cm^{-1} was due to the symmetric and asymmetric stretching vibration of C—H. The peak at 1457 cm^{-1} corresponded to the deformation vibration of C-H, confirming the presence of $-CH_3$ and $-CH_2$. Compared to clean and slightly contaminated industrial C&D waste (BK-5, not given, sample collected in an organophosphorus pesticide plant, which can be consulted to chapter 4.4.3), several peaks (950 and 820 cm^{-1}) were found in other spectra, which might indicate the symmetric stretching vibration of P-O-C and C-O-S. A strong peak around 1393 cm^{-1} existed in contaminated industrial C&D waste and standard OPPs spectra (not given), which was due to the asymmetric stretching vibration of $R1O\text{-}SO_2\text{-}OR_2$ in

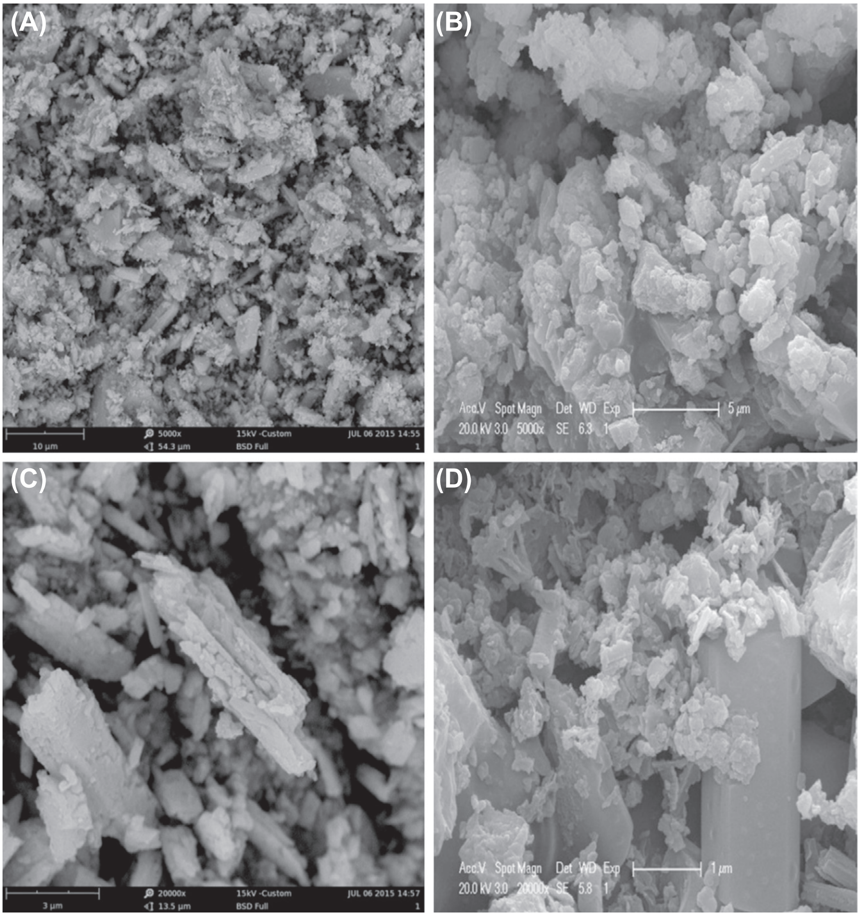


Figure 5.17 SEM photos of heavy metals— and organic pollutants—contaminated C&D waste. (A) 5000x photos of heavy metal contaminated C&D waste, (B) 5000x photos of organic pollutants contaminated C&D waste, (C) 20,000x photos of heavy metal contaminated C&D waste, and (D) 20,000x photos of organic pollutants contaminated C&D waste.

OPPs. A peak in contaminated industrial C&D waste at 870—872 cm^{-1} could represent their possible combination of Si-O-CH. Basic framework of industrial C&D waste was not changed as demonstrated from the spectrum, showing that SiO_2 component was dominating. However, the zoomed spectra showed that some peaks strongly shifted (1007 to 980 cm^{-1}) while some disappeared and some appeared. Besides, complete different peaks were found between 704 and 660 cm^{-1}, corresponding to

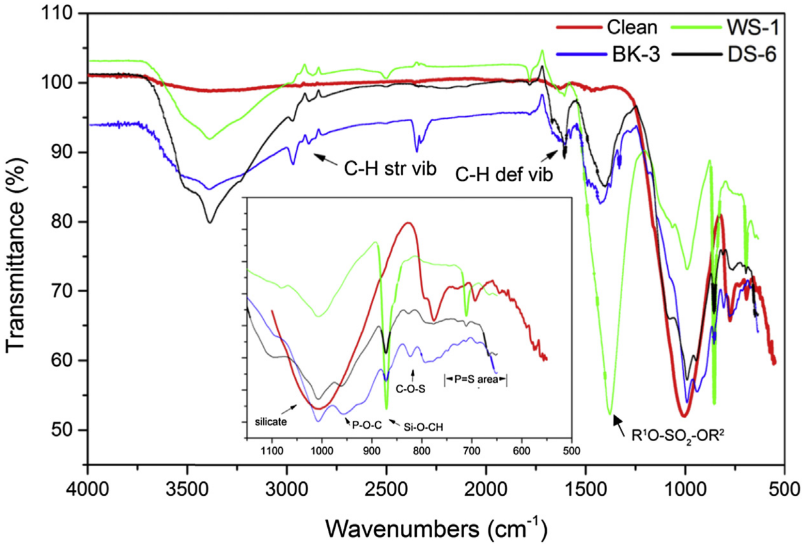


Figure 5.18 FT-IR spectrogram of organic pollutants contaminated C&D waste.

the complex combination of P═S or C-S with industrial C&D waste. These changes suggested that new chemical bonds were created. However, physical absorption ought to be the main combination due to the large quality of OPPs transferred into water while immersed.

5.4.3 Absorption of Heavy Metals and Organic Matters on C&D Waste

Adsorption of heavy metal pollutants (Zn, Pb, Cu, Cr, Cd) and organic pesticide (dichlorvos, phorate, dithiophosphate diethyl, triethyl phosphorothioate) on the surface of C&D waste was introduced, including (1) equilibrium adsorption amount of heavy metal on C&D waste at different times, with different amount and types of C&D waste and (2) equilibrium adsorption amount of organic pesticide on C&D waste at different times, with different amount and types of C&D waste.

Samples were crushed into particulates and powders from clean C&D waste was dried at 105°C for 12 h before use. The heavy metal contaminated C&D waste was simulated by soaking in metal solution of a certain concentration for 2 days and was dried at 80°C for 12 h before use.

Granular or powder samples (5 g) were weighed and placed in a batch of 100 mL brown bottles. A solution of 25 mL deionized water, 5 mL phorate, or 5 mL diethyl dithiophosphate was added into the bottle and sealed. Bottles were placed in a shaker and shaked at 25 ± 2°C for several hours with the rotation speed of 150 rpm. The supernatant was centrifuged at 1000 rpm for 1 min and extracted three times using hexane (5, 3, 2 mL) after being filtered through the PTFE membrane. Reconduct the steps above twice using and blank as a reference. The equation of equilibrium adsorption of organic pollutants on C&D waste was $q_e = (C_0 - C_e)V/W$.

It was found that the pH value of solution with gypsum and brick powder was weak acid in which pH adjustment was not necessary. The other C&D waste would make the pH into strong alkaline in solution. Large interference would be caused in absorption experiments as metals would become hydroxide precipitate in this environment, while the too much acid for pH adjustment would make it hard to determine the volume. Therefore brick powder was used as the research subject as it was more common in industrial C&D waste.

Effects of the amount of C&D waste on adsorption of Pb (II), Zn (II), Cu (II), Cd (II), and Cr (III) is also introduced in this section. When the amount of C&D waste increased, the total heavy metal adsorption would no doubt. With the amount increased from 0.5 to 3.5 g, the absorption capacity of all heavy metals per gram decreased except Cr (III), in which the absorption capacity of Pb decreased most (from 2.4 to 0.7 mg/g). It was possibly due to the strength of the mutual reaction among C&D waste powder or particles with the increase of the amount of waste. The contact time and area between the waste and heavy metals would be reduced, which ultimately resulted in the decrease of absorption capacity.

Effects of the contact time on adsorption of Pb (II), Zn (II), Cu (II), Cd (II), and Cr (III) is reflected in this section. It was found that the absorption of five heavy metals was fast as the maximum absorption capacity was obtained 20 min later while the adsorption equilibrium was reached at around 30 min.

Adsorption of organic pollutants was investigated, the same adsorption capacity was also calculated using subtraction. As can be seen from the figure, the adsorption equilibration of diethyl dithiophosphate was obtained at about 120 min, while the highest adsorption capacity was 251 μg/g. The adsorption of triethyl phosphorothioate was largely influenced by the particle sizes, and the adsorption equilibration was also obtained at about 120 min. The absorption capacity of phorate was 90 μg/g, smaller than the other two organic pollutants, and no significant relationship with time was found. The absorption capacity of particulate C&D waste was larger than waste in powder, which was different with most absorbates.

CHAPTER SIX

Migration Patterns of Pollutants in Construction & Demolition Waste

6.1 ACID NEUTRALIZING CAPACITY AND DISSOLUTION OF HEAVY METAL

The construction and demolition (C&D) waste samples soaked in heavy metal solution were dried at 100°C and grinded by electromagnetic pulverizer. The ground samples was sieved by 150 meshes and dried at 100°C. Sample (4 g) was taken for the leaching experiment with HNO_3 as the extraction solvent. Under the condition of 1:10 solid to liquid ratio, the sample was extracted for 24 h on a shaker with 110 ± 10 rpm. The extraction solution was centrifuged with 4000 rpm for 20 min, and then filtered with 0.22 μm membrane. pH of the extraction solution was adjusted to 2.0 before measuring concentration of Zn, Cu, Pb, Cr, and Cd.

6.1.1 Acid Neutralizing Capacity

pH is one of the most important factors influencing the leaching of heavy metal. It could test the buffering capacity of C&D waste as well as stabilization ability in acid solution by measuring acid neutralizing capacity (ANC). Many minerals in the sample will dissolve during acid neutralization reaction. Therefore ANC is related to dissolution of $CaCO_3$, C—S—H, and SiO_2 gel.

Fig. 6.1 is the ANC capacity curve of C&D waste. Y-axis is ANC with unit acid equivalent, meq/kg. Initial pH of ordinary C&D waste was high and up to 11.02. With the addition of acid, pH dropped dramatically. The linear regression equation of ANC and pH was determined to be $y = -1.687x + 10.316$, with $R^2 = 0.9631$. At confidence level of $\alpha = 0.05$, the critical value of R was 0.754. There was close correlation between x and y, the fitting equation was credible.

The pH of heavy metal contaminated C&D waste sample was lower than ordinary C&D waste due to the pretreatment. The slope value of heavy metal contaminated C&D waste was lower than the ordinary sample. With the addition of nitric acid, the decreasing rate was less than the ordinary

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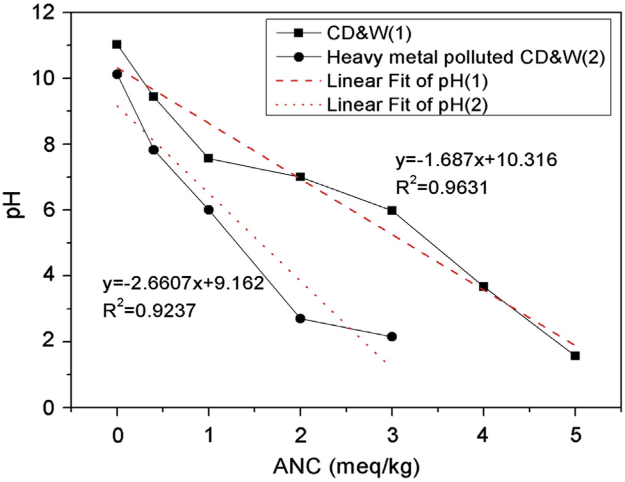


Figure 6.1 Acid neutralizing capacity (ANC) curve of construction and demolition (C&D) waste.

sample. The linear regression equation of ANC and pH was determined to be $y = -2.660x + 9.162$, with $R^2 = 0.9237$. At confidence level of $\alpha = 0.05$, the critical value of R was 0.878. There was close correlation between x and y, the fitting equation was credible.

6.1.2 Dissolution Ability of Heavy Metals

Heavy metal dissolution ability in C&D waste at different pH is shown in Fig. 6.2, which was largely influenced by the acid dose. When ANC < 2 and dissolution pH > 7, Zn, Cu, Pb, Cr, and Cd were not detected in the solutions, and when ANC < 2 and dissolution pH < 6, Zn, Cu, Pb, Cr, and Cd concentrations in the solutions increased with the decrease of pH.

Heavy metal dissolution ability of contaminated C&D waste at different pH is shown in Fig. 6.3, which was largely influenced by the acid dose. When ANC < 2 and dissolution pH > 7, Zn, Cu, Pb, Cr, and Cd concentrations in solutions were very low. When 1 ≤ ANC ≤ 4 and dissolution pH < 6, Zn, Cu, Pb, Cr, and Cd concentrations in solutions increased with the decrease of pH and stopped rising with ANC > 4.

6.2 MIGRATION OF HEAVY METALS UNDER ACID RAIN

Cylinder made of plexiglass was used to simulate the C&D waste landfilling process. The diagram of setup is shown in Fig. 6.4, with 1.6 m in

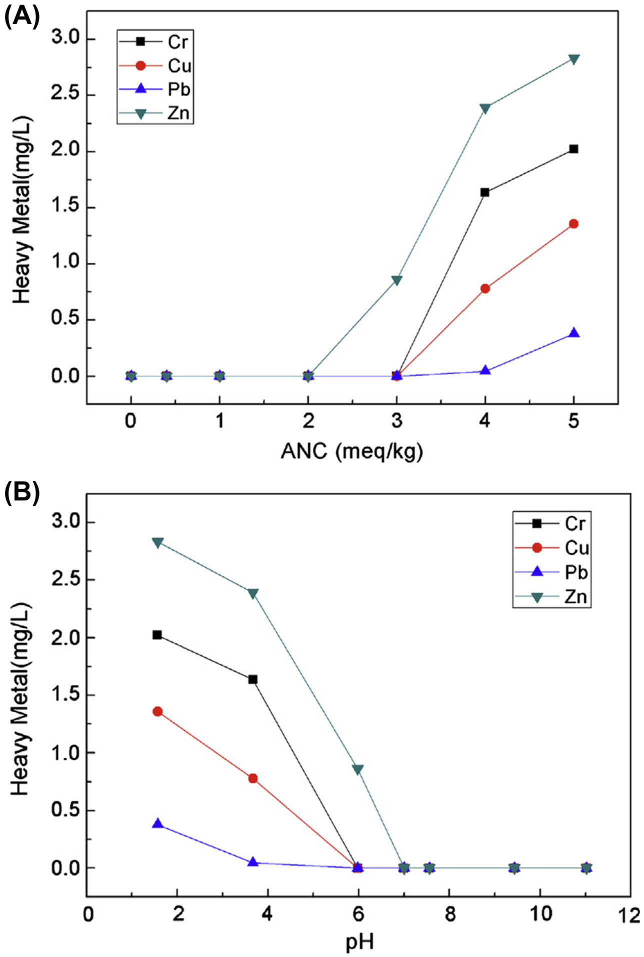


Figure 6.2 Heavy metal dissolution ability of ordinary construction and demolition waste. (A) Acid neutralizing capacity (ANC) and heavy metal dissolution curve and (B) pH and heavy metal dissolution curve.

height, 1.6 m in diameter, 2 m in thickness, and rainfall area of 0.028 m^2. Landfilling quantity of each cylinder was 46.1 kg.

pH of rainfall at 74 monitoring station was found to be among 4.0–7.5. During 1993–2004, average pH of rainfall in East China was 4.96. At the same time, average pH of rainfall around China was 5.39. The anion in the rainfall was mainly $SO_4{}^{2-}$ and $NO_3{}^{-}$. Criteria of acid rain intensity classified by EPA of China are listed in Table 6.1.

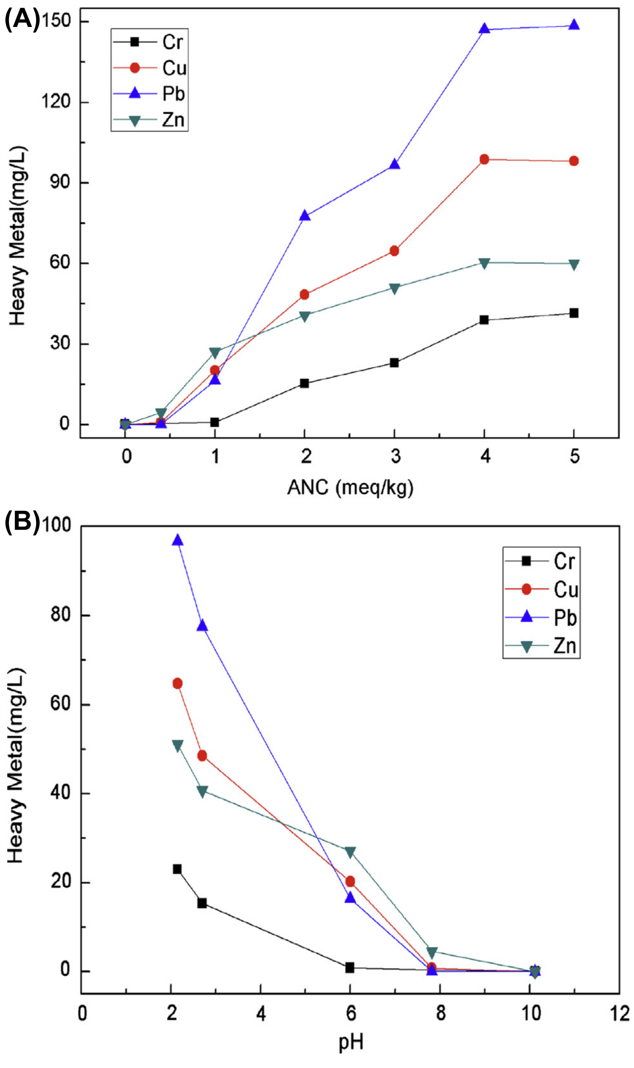


Figure 6.3 Heavy metal leaching ability of contaminated construction and demolition waste. (A) Acid neutralizing capacity (ANC) and heavy metal leaching curve and (B) pH and heavy metal leaching curve.

Migration of heavy metal in contaminated C&D waste under three kinds of acid rain (strong acid rain, neutral rain, and weak acid rain) conditions is introduced. Simulated rain pH of 5.8, 4.8, and 3.2 was made with H_2SO_4 and HNO_3.

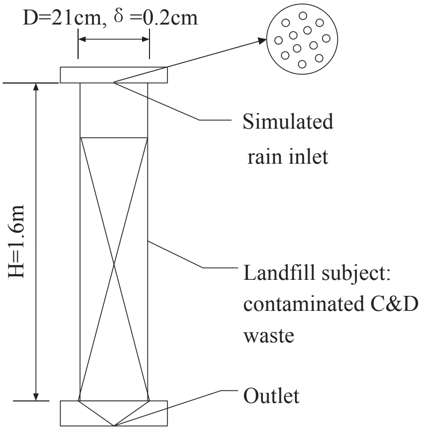


Figure 6.4 Diagram of landfill lysimeter setup.

Table 6.1 Classification Criteria of Acid Rain Intensity

pH	Acid Rain Intensity
≤4.00	Strong acid
>4.00 and ≤4.50	Relative strong acid
>4.50 and ≤5.60	Weak acid
>5.60 and ≤7.00	Neutral
>7.00	Alkaline

Data of rainfall was cited from Chinese National Statistics Yearbook (2003—12). At the prophase of the landfilling (the first 50 days from middle May to the end of June), rainfall was applied the highest amount of Shanghai monthly rainfall from 2003 to 2012 with every 2 days. At the middle phase of landfilling, rainfall amount was 95% confidence interval upper limit value of Shanghai monthly rainfall amount from 2003 to 2012. From 51st to 82nd day, rainfall was every 3 days one time. From 83rd to 114th day, rainfall was 6 times every month as every 5 days one time. From 115th to 206th day, rainfall was 4 times every month as every 7 days one time.

Every acid condition was adapted to one landfill setup. The experimental condition is given in Table 6.2. For the first period of landfilling, leachate produced at 28th day. Later leachate came out when simulated rainfall was conducted. Leachate amount, pH, electrical conductivity (EC), total dissolved solid (TDS), concentration of heavy metals (Zn, Cu, Pb, Cr, Cd), and calcium were measured.

Table 6.2 Landfill Setup at Simulated Rainfalls Conditions

Number	Landfill Amount (kg)	Rain pH	Acid Rain Intensity
1	46.1	5.8	Neutral
2	46.1	4.8	Weak acid
3	46.1	3.2	Strong acid

6.2.1 Leachate Amount Generated in Landfilling

After simulated rainfall was spilled into landfill body, C&D waste absorbed rain and reached saturated state, then leachate came out from the setup. At the 28th day, leachate began to come out from the landfill body. The relationship of leachate amount and simulated rainfall is shown in Fig. 6.5.

According to the figure above, it was shown that leachate came out at 28th day. From 28th day and 36th day, the variation tendency of rainfall amount and leachate amount differed due to the absorbing of C&D waste. Later, the difference between rainfall amount and leachate amount got smaller. After 50—80 days, leachate amount of the three landfill setup varied. Leachate amount under neutral acid (pH = 5.8) was less than that under weak acid (pH = 4.8). Under strong acid rain, powder was corroded inside C&D waste and porosity formed, leading to the less rainfall absorbed. The intensity of corrosion decreased with the increase of pH of rainfall, which led to the decrease of leachate amount. At late stage of 84—149 days, leachate amount and rainfall amount was equal under neutral condition and the water stored in former period was released.

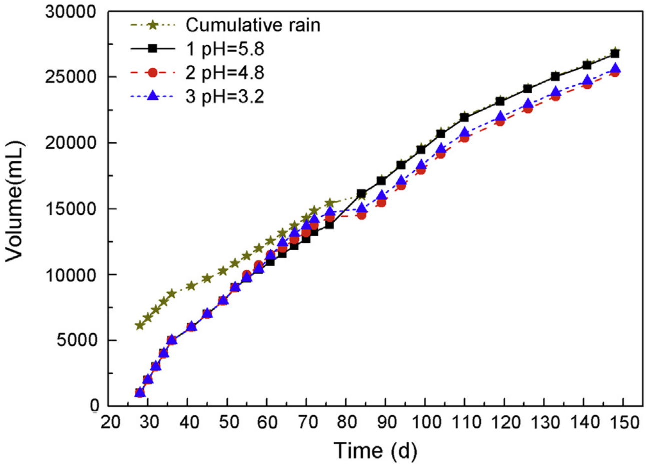


Figure 6.5 Relationship between leachate amount and simulated rainfall during landfilling of heavy metals contaminated construction and demolition waste.

6.2.2 Variation of pH During Landfill Process

A large amount of alkaline matters exist in concrete. Hydration products in cement such as silicate, aluminate, calcium hydroxide, etc. released into the leachate with rainfall, which ultimately led to the increase of pH. pH of leachate was about 11—12, which was nearly the same under three kinds of rainfall conditions. The variation of pH with time is shown in Fig. 6.6. With increase of landfilling time, pH showed a cyclic variation which decreased during the early period and then increased. pH of leachate flowed out during later period was lower. Then pH under these three conditions slowly increased to 11.55, 11.59, and 11.49, respectively.

According to Environmental Quality Standard for Surface Water (GB3838-2002), pH of level I—V water is 6—9. Based on Discharge Standard of Pollutants for Municipal Wastewater (GB18918-2002) and Integrated Wastewater Discharge Standard (GB8978-1996), the demand for the discharged wastewater is 6—9. C&D waste leachate should be neutralized before being discharged.

6.2.3 Electrical Conductivity and Total Dissolved Solid in Leachate

Variation of EC and TDS is shown in Fig. 6.7. EC of C&D waste leachate under neutral acid (pH = 5.8) was lower than that under weak acid (pH = 4.8), while EC of C&D waste leachate under weak acid (pH = 4.8)

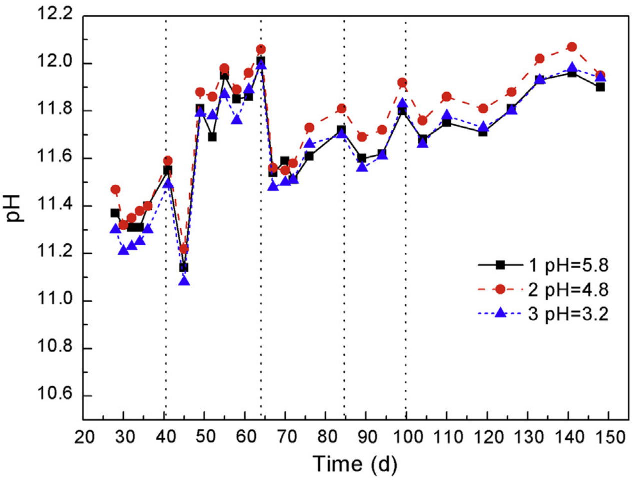


Figure 6.6 pH variation in heavy metals contaminated construction and demolition waste leachate.

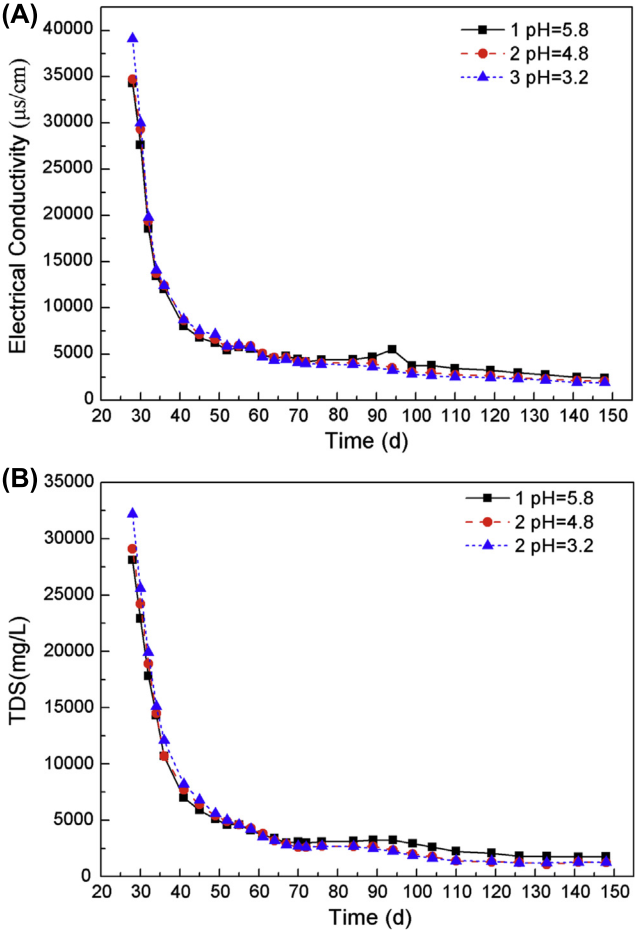


Figure 6.7 Electrical conductivity (EC) and total dissolved solid (TDS) of heavy metals contaminated construction and demolition waste leachate. (A) EC and (B) TDS.

was lower than that under strong acid (pH = 3.2). There was no significant distinctiveness among the pattern of the three kinds of leachate. The initial leachate EC under neutral acid (pH = 5.8), weak acid (pH = 4.8), and strong acid (pH = 3.2) was 34,300 μs/cm, 34,700 μs/cm, and 39,100 μs/cm, respectively. EC dropped gradually with time in later landfilling phase. EC at 41st day was much lower than the initial leachate EC.

Variation of TDS in the leachate showed similar trend to the variation of EC. TDS of C&D waste leachate under neutral acid (pH = 5.8) was lower

Table 6.3 Linear Regression Between Total Dissolved Solid (TDS) and Electrical Conductivity (EC) of Heavy Metal Contaminated C&D Waste Leachate

Rainfall Condition	Regression Equation	R^2
pH = 5.8	TDS = 0.853 EC	0.9817
pH = 4.8	TDS = 0.859 EC	0.9819
pH = 3.2	TDS = 0.870 EC	0.9798
Total	TDS = 0.861 EC	0.9809

than that under weak acid (pH = 4.8), while TDS of C&D waste leachate of weak acid (pH = 4.8) was lower than that under strong acid (pH = 3.2). The initial TDS under the three conditions was 28,084 mg/L, 29,084 mg/L, and 322,236 mg/L, respectively, and also dropped gradually then. Compared to the initial leachate TDS, the TDS of leachate at 40th day decreased one percent.

Good correlation between TDS and EC existed. Liner regression between TDS and EC of 28 leachate samples are shown in Table 6.3. The ratio of TDS and EC increased with the decrease of pH, which indicated that more inorganic matters were released with the decrease of pH.

TDS and EC ratio of municipal wastewater was 0.55, while that of natural water and city water was 0.54 and 0.60, respectively. Linear regression equation between TDS and EC of heavy metal C&D waste leachate was TDS = 0.861 EC ($R^2 = 0.9809$). C&D waste was mainly composed of inorganic matter. Leaching of inorganic matter during landfilling would cause higher TDS and EC than those of municipal wastewater and industrial wastewater. Treatment of leachate should focus on the removal of inorganic matters.

6.2.4 Migration of Heavy Metal and Calcium

Heavy metals and a large amount of calcium in C&D waste migrated from landfill body into water. Variation of Zn, Cu, Pb, Cr, Cd, and Ca concentration of C&D waste leachate is shown in Figs. 6.8–6.12 and 6.14A. Cumulative release of Zn, Cu, Pb, Cr, Cd, and Ca is shown in Figs. 6.8–6.12 and 6.14B.

With the increase of landfill time, concentration of Zn and Cr fluctuated, while that of other heavy metals remained relatively stable. The average Zn concentration was 90–2000 μg/L and reached its maximum value at 50–60 day. Cu concentration of initial leachate under three conditions was 1828.6 μg/L, 1776.1 μg/L, and 2252.4 μg/L, respectively. For Cr, the

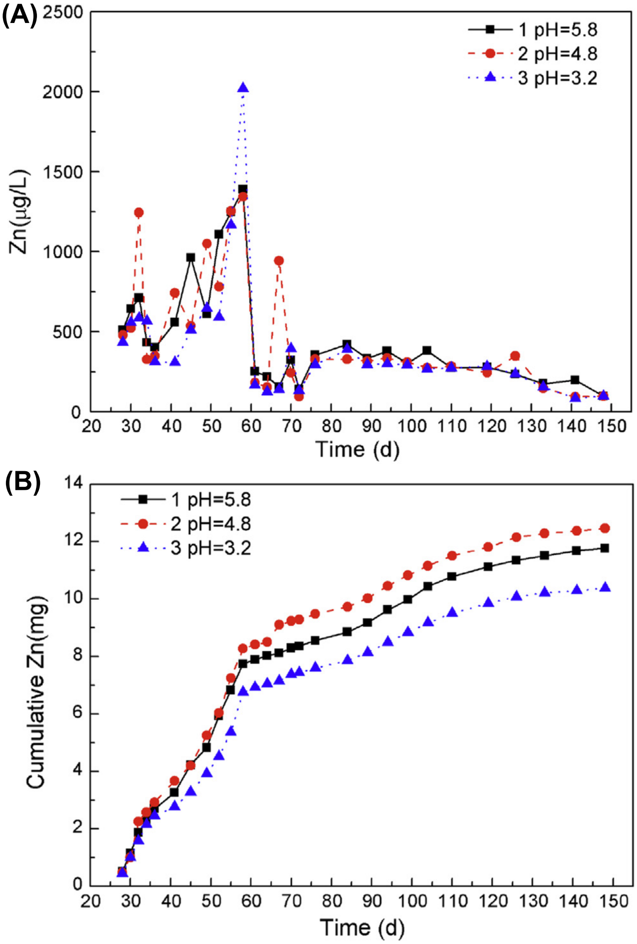


Figure 6.8 Migration of Zn during construction and demolition waste landfilling. (A) Zn concentration in leachate and (B) cumulative release of Zn.

concentration of initial leachate was 39.1 μg/L, 39.8 μg/L, and 40.5 μg/L, respectively. During the early period of the landfilling course, Cr concentration rose to 500 μg/L (after 55–58 days) with minor fluctuation, experienced a dramatic dropping and then began to rise. Almost the concentration of these heavy metals in all initial leachate exceeded the water limit value level III (Environmental Quality Standard for Surface Water). There was no regulation of Cr in this criterion. However, Cr concentration in all leachate met the demand of Integrated Wastewater Discharge Standards

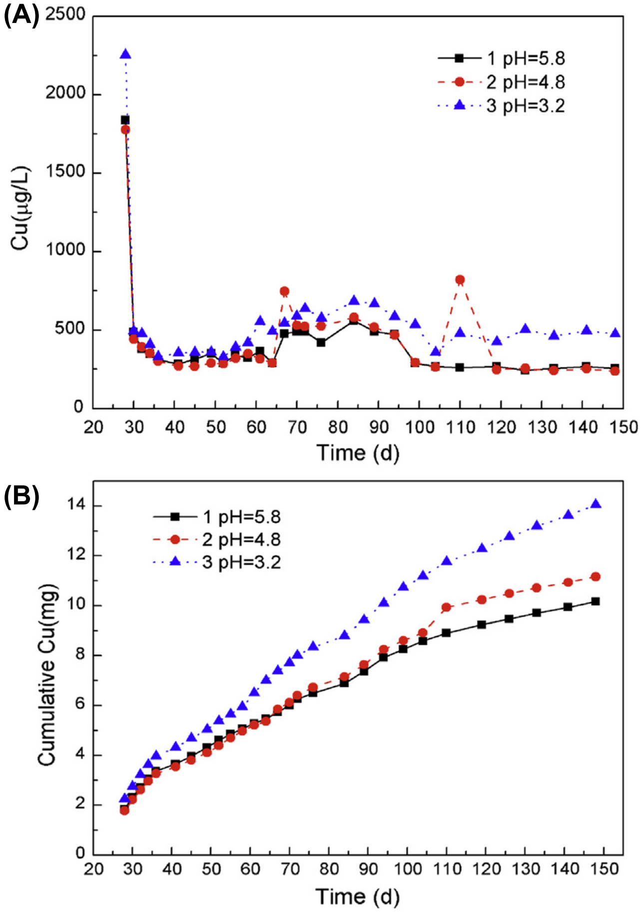


Figure 6.9 Migration of Cu during construction and demolition waste landfilling. (A) Cu concentration in leachate and (B) cumulative release of Cu.

(GB8978-1996). Cd concentration fluctuated within 0–5 μg/L. After 61st day, Cd concentration in leachate decreased below the detection limit.

Cumulative release of Zn under three conditions was arranged in the order of strong acid rain < neutral rain < weak acid rain. For Cu, it was weak acid rain < neutral rain < strong acid rain condition. The pattern is different for Cr and Cd, of which were both neutral rain < weak acid rain < strong acid rain condition. The amount of Cd migrated from C&D waste to leachate was lower than other heavy metals, indicating its poorest migration capacity in cement.

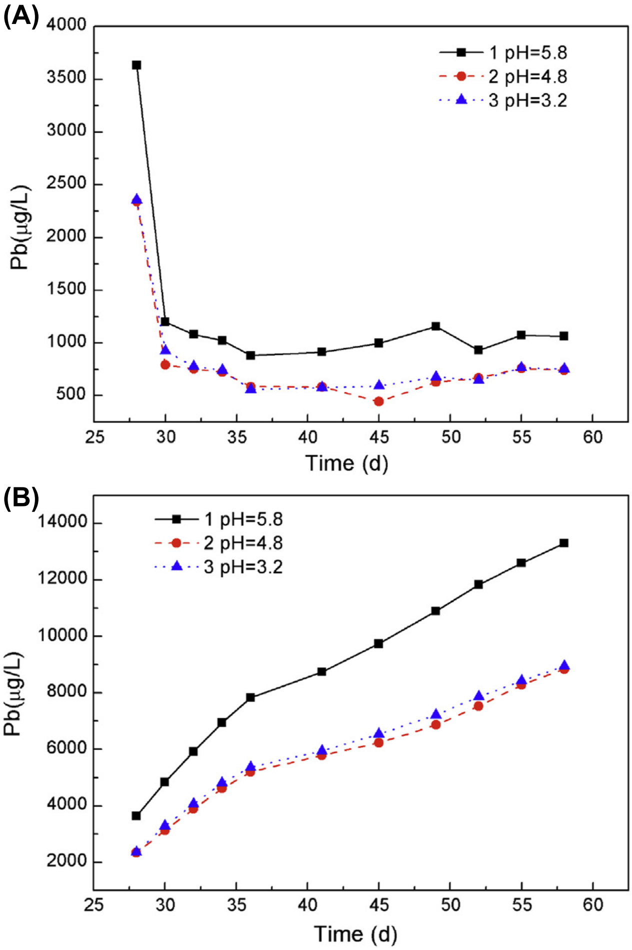


Figure 6.10 Migration of Pb during construction and demolition waste landfilling. (A) Pb concentration in leachate and (B) cumulative release of Pb.

When the monitoring is over, the proportion of the average accumulated release amount in the total amount of the C&D waste landfilling column is demonstrated in Fig. 6.13. The relative release potential is ordered as Zn > Cr > Cu > Pb > Cd.

Variation of Ca concentration in leachate was similar and decreased with time under the three conditions. In waste cement, calcium carbonate was generated with carbonation and controlled the dissolution of Ca.

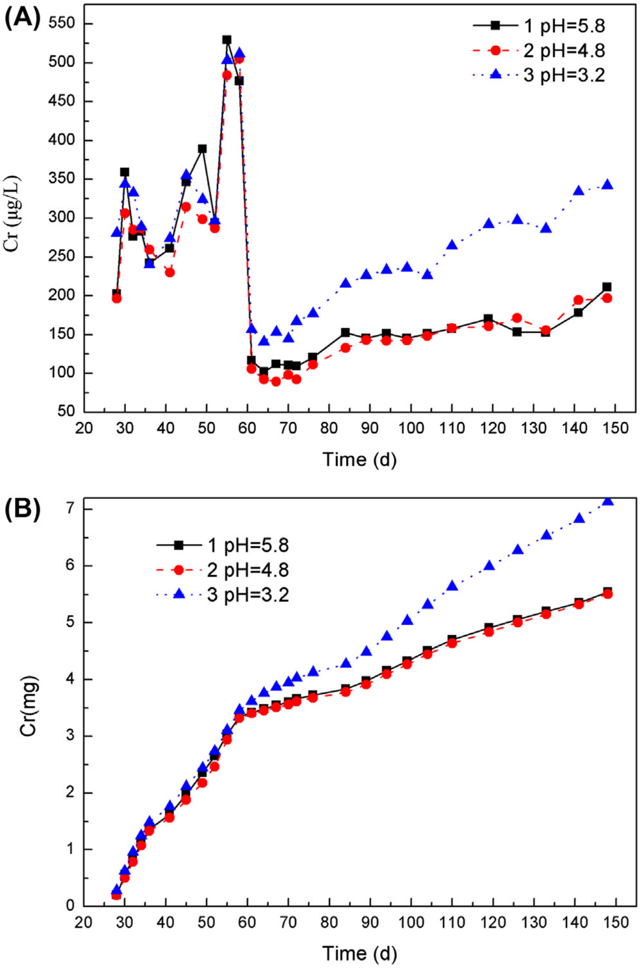


Figure 6.11 Migration of Cr during construction and demolition waste landfilling. (A) Cr concentration in leachate and (B) cumulative release of Cr.

A large amount of Ca was detected in the leachate. Under the condition of pH = 3.2, for example, Ca concentration gradually decreased from 7372 mg/L to 226 mg/L. The cumulative release of Ca was arranged in the order of neutral rain < weak acid rain < strong acid rain condition before 110 days' landfilling, while it changed to weak acid rain < neutral rain < strong acid rain condition after 110 days.

First order reaction equation, Elovich equation and negative exponential decay equation were used to analyze the regression between cumulative

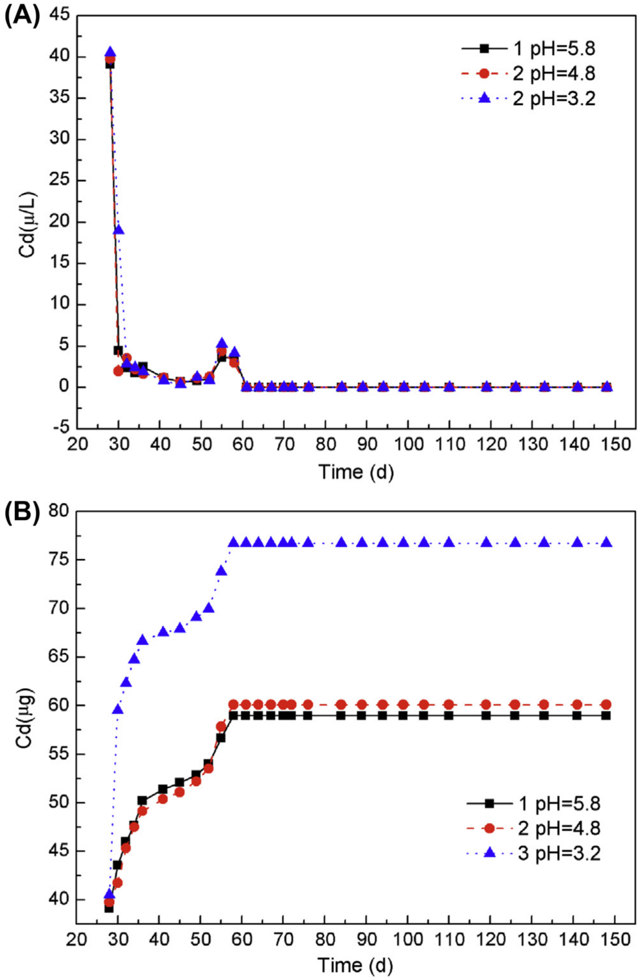


Figure 6.12 Migration of Cd during construction and demolition waste landfilling. (A) Cd concentration in leachate and (B) cumulative release of Cd.

release of heavy metals (y, mg) and time (x, d). These equations are listed below in order.

$$y = A(1 - e^{-bx})$$

$$y = y_0 + A \times \ln x$$

$$y = y_0 + Ae^{-x/t}$$

Results are listed in Table 6.4. For Zn, R^2 of first order reaction model was less than 0.9. R^2 of Elovich model and negative exponential model

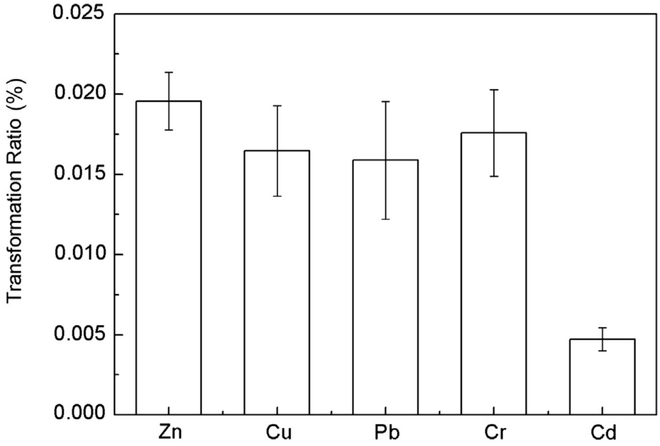


Figure 6.13 Proportion of the average accumulated release amount in the total amount of the construction and demolition waste landfilling column.

decay model was higher 0.9. For Cu, Pb, and Cr, R^2 of all the three models were higher than 0.9. For Cd, first order reaction model failed to fit the migration pattern while R^2 of Elovich model was less than 0.8. For Ca, R^2 of Elovich model and first order reaction model was 0.8—0.9 and R^2 of negative exponential mode was higher than 0.9. Results showed that negative exponential model decay model accorded well with the cumulative release pattern of all the heavy metals and calcium.

6.3 MIGRATION AND TRANSFER PATTERNS OF ORGANIC POLLUTANTS UNDER VARIOUS CONDITIONS

6.3.1 Effect of Sunlight, Ventilation, Temperature, and Moisture

Concentration and release potential of pesticides and other nonpersistent organic pollutants varied widely with external environmental conditions. Different climatic and environmental factors had been controlled and regulated to investigate the degradation of pyrethroid and other pesticide on surface of C&D waste. Due to the difficulty in the in situ identification of organic pollutants, a system of quick determination of the possible pollution areas with high potential environmental risks should be established.

Persistent organic pollutants usually have long decay time and may be difficult to degrade in the soil or sediment even for years. DDT, a typical representative of high durability, high pollution, high environmental risk pesticide, was already prohibited in the 1980s. As a result, the solid waste

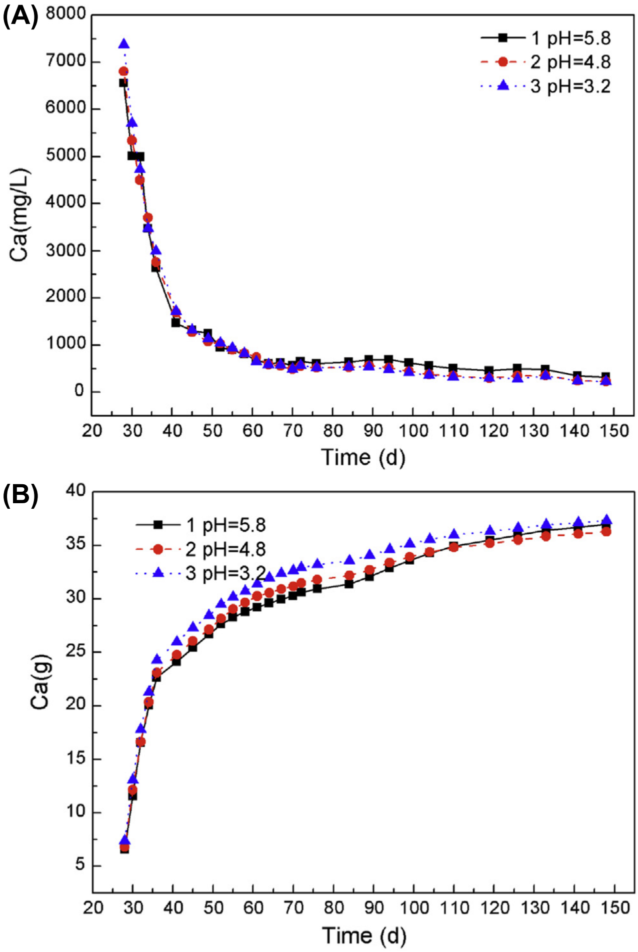


Figure 6.14 Migration of Ca during construction and demolition waste landfilling. (A) Ca concentration in leachate and (B) cumulative release of Ca.

contaminated by DDT gradually deposited in the part of the river sediment and soil after being prohibited. The concentration DDT in C&D waste was very small currently. Therefore pyrethroids were selected as the subject due to its large production and wide usage.

Simulated extreme environments and condition of abandoned industrial C&D waste within the workshops were carried out, pyrethroid pesticide-contaminated were placed in a cool, dry, and enclosed place with good

Table 6.4 Regression Between Cumulative Release of Metals and Time

Landfill Condition	**First Order Reaction Model**		**Elovich Model**		**Negative Exponential Decay Model**	
	Regression Equation	**R^2**	**Regression Equation**	**R^2**	**Regression Equation**	**R^2**
Zn						
pH = 5.8	$y = 23.56(1 - e^{-0.005x})$	0.886	$y = -21.61 + 6.89\ln x$	0.964	$y = 12.11 - 24.01e^{-x/38.419}$	0.987
pH = 4.8	$y = 23.98(1 - e^{-0.006x})$	0.875	$y = -23.12 + 7.38\ln x$	0.958	$y = 12.83 - 26.68e^{-x/36.434}$	0.988
pH = 3.2	$y = 23.16(1 - e^{-0.005x})$	0.886	$y = -19.61 + 6.19\ln x$	0.966	$y = 10.95 - 20.65e^{-x/51.487}$	0.984
Cu						
pH = 5.8	$y = 20.77(1 - e^{-0.005x})$	0.989	$y = -15.04 + 5.02\ln x$	0.989	$y = 14.18 - 15.68e^{-x/105.32}$	0.987
pH = 4.8	$y = 46.81(1 - e^{-0.002x})$	0.987	$y = -18.02 + 5.79\ln x$	0.974	$y = 20.02 - 21.48e^{-x/158.70}$	0.988
pH = 3.2	$y = 57.38(1 - e^{-0.002x})$	0.990	$y = -22.19 + 7.13\ln x$	0.978	$y = 24.75 - 26.52e^{-x/159.54}$	0.984
Pb						
pH = 5.8	$y = 58.12(1 - e^{-0.004x})$	0.977	$y = -41.26 + 13.5\ln x$	0.997	$y = 32.51 - 39.73e^{-x/80.46}$	0.997
pH = 4.8	$y = 48.68(1 - e^{-0.003x})$	0.979	$y = -28.92 + 9.34\ln x$	0.994	$y = 23.72 - 28.16e^{-x/92.48}$	0.997
pH = 3.2	$y = 39.45(1 - e^{-0.004x})$	0.976	$y = -27.91 + 9.13\ln x$	0.996	$y = 22.08 - 26.91e^{-x/80.97}$	0.996

(*Continued*)

Table 6.4 Regression Between Cumulative Release of Metals and Time—cont'd

Landfill Condition	**First Order Reaction Model**		**Elovich Model**		**Negative Exponential Decay Model**	
	Regression Equation	**R^2**	**Regression Equation**	**R^2**	**Regression Equation**	**R^2**
Cr						
pH = 5.8	$y = 11.30(1 - e^{-0.005x})$	0.909	$y = -9.47 + 3.03\ln x$	0.977	$y = 5.56 - 9.85e^{-x/43.35}$	0.985
pH = 4.8	$y = 12.07(1 - e^{-0.004x})$	0.907	$y = -9.55 + 3.04\ln x$	0.976	$y = 5.55 - 9.74e^{-x/44.58}$	0.983
pH = 3.2	$y = 62.82(1 - e^{-0.0008x})$	0.951	$y = -12.51 + 3.87\ln x$	0.991	$y = 8.68 - 26.91e^{-x/81.45}$	0.987
Cd						
pH = 5.8	–	–	$y = 15.63 + 9.47\ln x$	0.695	$y = 59.26 - 143.95e^{-x/13.77}$	0.967
pH = 4.8	–	–	$y = 10.30 + 10.87\ln x$	0.717	$y = 60.64 - 122.51e^{-x/15.80}$	0.955
pH = 3.2	–	–	$y = 19.27 + 12.57\ln x$	0.580	$y = 76.12 - 844.00e^{-x/8.28}$	0.884
Ca						
pH = 5.8	$y = 39.67(1 - e^{-0.02x})$	0.872	$y = -30.37 + 13.99\ln x$	0.857	$y = 34.87 - 93.17e^{-x/20.53}$	0.938
pH = 4.8	$y = 38.89(1 - e^{-0.02x})$	0.854	$y = -27.73 + 13.46\ln x$	0.822	$y = 34.40 - 128.9e^{-x/16.66}$	0.955
pH = 3.2	$y = 39.86(1 - e^{-0.02x})$	0.850	$y = 26.96 + 13.55\ln x$	0.811	$y = 35.49 - 144.1e^{-x/15.80}$	0.957

Table 6.5 Residual Rate of Pyrethroid Pesticides on C&D Waste After 120 days (%)

Residual Rate (%)													
73.3	84.4	42.9	100.6	82.3	79.5	70.6	74.5	49.1	56.1	78.3	77.3	79.7	92.1

ventilation, the pesticide residues were detected 120 days later, and the residual rate is shown in Table 6.5.

Based on the results listed above, the decay rate was slow in simulated enclosed workshops even for volatile pesticides. The residual rate could be up to 70% or more for most waste samples, and some kinds of pesticide hardly degraded. The similar conditions appeared around the reaction pool, leaked pipes of enclosed manufacturing workshops and should be the contaminated regions with high potential risks.

To further explore effects on pesticide degradation, other climatic conditions such as ventilation, sunshine were separately regulated. Contaminated C&D waste was placed under different ventilation and sunshine simulated environment for 48 h, and the pesticide residue was detected once every 6 h. The results are shown in Fig. 6.15.

As shown in Fig. 6.15, the decay rate continued to slow down under certain conditions. As the ventilation conditions got better, pesticide decay rate increased first and then decreased. In cool, dry and enclosed environments, decay rate of volatile pesticides was still slow, which matched the

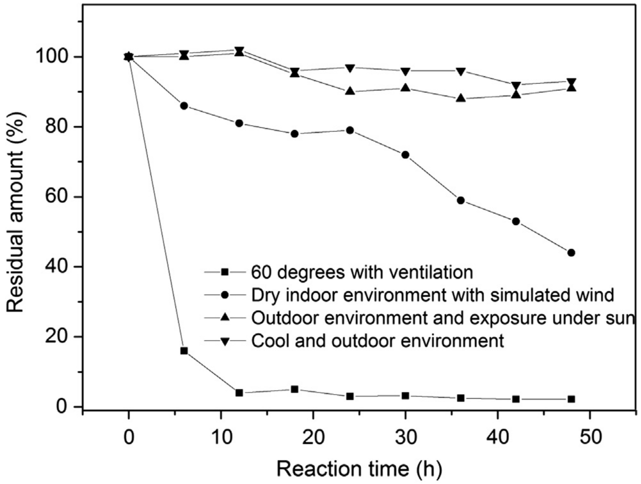


Figure 6.15 Effects of different conditions on the pyrethroid residue (X1: 60°C with ventilation, X2: Dry indoor environment with simulated wind, X3: Outdoor environment and exposure under sun, and X4: Cool and outdoor environment).

results of residual rate under simulated environments. Sunlight and temperature were the most important regulators that meant the potential environmental risks of pyrethroid contaminated C&D waste would be largely reduced under sun or high temperature.

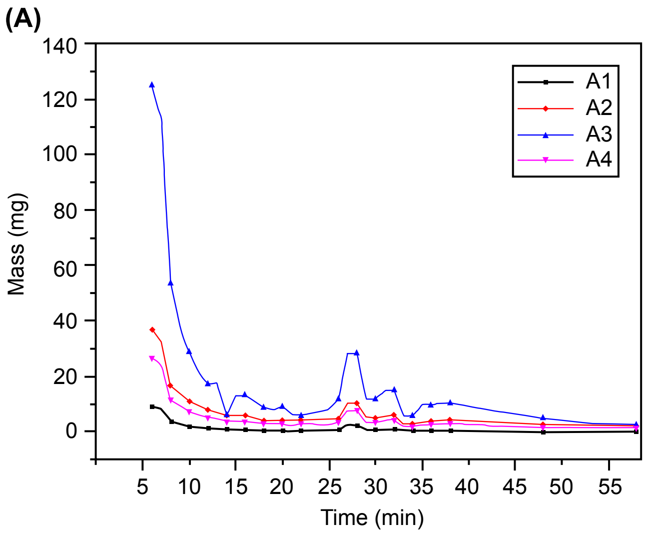
6.3.2 Migration of Pesticides in Simulated Washing Procedure

Decay time of volatile pesticides under the cool environment with low ventilation is long and potential environmental risk exists. For this kind of C&D waste, the possible migration and wash off with water should be investigated to get a further knowledge of its contamination and transformation pathways. The pyrethroid pesticides with low water solubility were used as target pollutants. Simulated seepage of water was carried out by adding water from the top. The flow was set as medium-intensity. The sampling outlet was set on the bottom. The water was continuously added for 24 h and added for another 24 h after a day's interval. The leachate was collected and analyzed in frequency. According to the results, four pollutants with typical patterns were selected (A1 bifenthrin, A2 fenpropathrin, A3 beta-cyfluthrin, and A4 cypermethrin). The relationship between concentration in water (a) and in C&D waste (b) and the duration is demonstrated in Fig. 6.16.

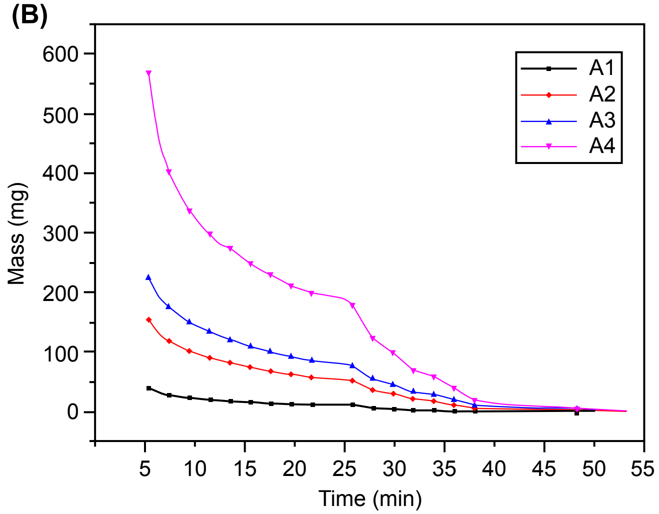
The elution pattern figure showed that in early time period, large amounts of pesticides could be taken away with water. With the increase of injection time, the amount of pesticide taken away in certain time period rapidly reduced, and then gradually stabilized. The removal rate of pesticide with water tended to be constant.

When the flow stopped, the holding capacity of the surface water of C&D waste had some influence on the migration of pesticides, which is reflected in the curve projection in Fig. 6.16A. In the 24 h without injection of water, the pesticides on the surface of waste continuously dissolved in the residual water while the holding capacity of water of C&D waste prevented the water from dropping down. When the injection of water began, this portion of pesticide was washed off through water, which caused the immediate increase of pesticide amount in the wash-off water.

Different types of pyrethroid pesticide varied widely in release curve that may be due to the characteristic (e.g., solubility and viscosity) of pesticide itself. In the environment of the real industrial workshops, C&D waste is often mixed with soil, and make up a multisystem of water—C&D waste—soil. To further study the potential migration risk in a complex system, a new elution column based on this system was established. Fenvalerate was chosen



Elution rate curve



Pesticide Residues - elution time curve

Figure 6.16 Elution pattern of pyrethroids in construction and demolition waste by simulated seepage. (A) Elution rate curve and (B) pesticide residues—elution time curve.

as the contaminant and the device is shown in Fig. 6.17. The device is devised as enclosed except for the inlet and outlet to minimize the volatilization of organic pollutants.

The wash-off water of 5—10 min, 15—20 min and 30—35 min was collected and analyzed using GC—MS. Results showed that the concentration

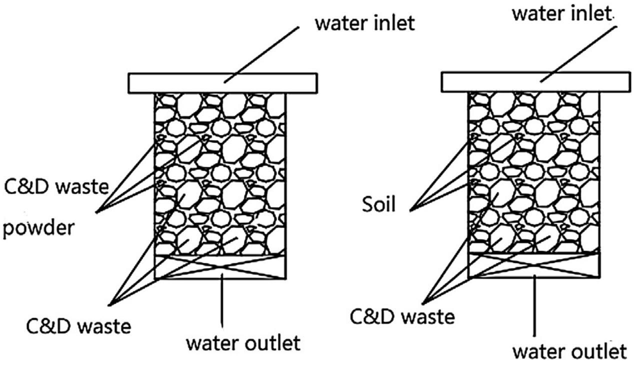


Figure 6.17 Water— construction and demolition (C&D) waste system (left), water—soil—C&D waste system (right).

Table 6.6 Concentration of Fenvalerate in Two Systems in Different Time Period

Time Period (min)	Concentration (mg/L)	Concentration (mg/L)
5—10	11.37	9.18
15—20	7.32	7.12
30—35	5.50	4.83

of fenvalerate in system 2 was lower than that in system 1, which is listed in Table 6.6. The procedures were repeatedly conducted and all the C&D waste were collected and extracted. The extraction liquid was merged with the elution (wash-off water) and pretreated for GC—MS analysis. Results showed that the total amount of fenvalerate in system 2 was about 7% less than that in system 1.

CHAPTER SEVEN

Pollution Control for Contaminated Construction and Demolition Waste

7.1 POLLUTION CONTROL FOR HEAVY METAL–CONTAMINATED WASTE

Construction and demolition (C&D) wastes from chemical and metallurgical industries were contaminated severely by various heavy metals such as Zn, Cu, Cr, Pb, and Cd. The high risks posed by the wastes impeded the recycling work. While recycling the aggregates from such contaminated C&D waste, environmentally friendly processes such as mobilization and immobilization should be taken before reuse, otherwise it will cause harm to the environment and human health.

Nowadays various remediation technologies have been developed for heavy metals, which are mainly categorized as immobilization and mobilization. Immobilization amendments such as phosphate compounds, liming materials, and metal materials are able to prevent free movement of the contaminants in wastes. Previous studies have shown that monopotassium phosphate (KH_2PO_4) can increase the pH and surface charge, effectively enhance ion immobilization, and decrease bioavailability, and is commonly used to remediate the Cd, Cu, Pb, Ni, and Zn contaminated soil. It is well known that the addition of lime can decrease heavy metal solubility and enhance adsorption and/or precipitation of metal compounds by raising pH, such as Cr, As, Zn, Pb, Ni, Cd, Cu, and Co.

Nano-iron is also a suitable material for heavy metal contaminants in situ remediation with high remediation efficiency of Zn(II), Cu(II), Cd(II), Cr(VI), and Pb(II), owing to their large surface area. Complex reactions with organic ligands are known to influence the mobility of metal by decreasing its sorption on mineral surfaces. So some organic matters and chelating/complexing agents can be used as mobilization amendments. Humic acids (HAs) are a highly effective adsorbent for heavy metal ions under acidic or neutral conditions, which has absorptivity over Cu(II), Cd(II), Zn(II), Cr(III), Pb(II), Co(II), Hg(II), etc. The complex chemical structure

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of HAs contains a wide variety of functional groups, which can react with metals.

Glyphosate has the complexing ability over heavy metals, such as Fe, Al, Cu, Ca, Co, Mg, Pb, Cd, and Zn. Since the glyphosate molecule has amino, carboxyl, and phosphate groups that can coordinate with heavy metal ions, the complexing ability increased in the order of $Fe^{3+} > Cu^{2+} > Zn^{2+} > Mn^{2+} > Mg^{2+} \approx Ca^{2+}$. To evaluate the effects of different remediation methods on heavy metals contaminated recycled gravel (CRG), three immobilization agents (monopotassium phosphate, lime, Nano-iron) and two mobilization agents (glyphosate, HA) have been taken into consideration and compared.

7.1.1 Citric Acid Elution Process

Many organic and inorganic acids can be used for heavy metal elution. However, C&D waste contains large amounts of alkaline substances during elution. These substances would react with the elution agent while other substances would also be eluted, resulting in a large consumption of inorganic acid. In addition, the physical and chemical characteristics of C&D waste would be changed after elution, which would not be conducive to the subsequent use and disposal. Organic acids like ethylenediaminetetraacetic acid, ethylene diamine disuccinic acid, oxalic acid, and citric acid (CA) can chelate heavy metals and are often used in the disposal of heavy metal—contaminated waste. Taking into consideration the removal efficiency, economic costs, and environmental impact, 0.05 and 0.1 mol/L CA was selected as the eluent. The solid—liquid ratio was set as 1:10 (L/kg), the mixture was shaken at 120 rpm for 24 h. Relevant conditions and the pH of the elution are shown in Table 7.1.

Effect of elution by CA was demonstrated in Fig. 7.1; 0.1 mol/L CA had a better elution effect on heavy metal than 0.05 mol/L CA. Double factor

Table 7.1 Relevant Conditions and the pH of the Elution

Number	Concentration of Citric Acid (mol/L)	Particle Diameter (mm)	Solid—Liquid Ratio (L/kg)	Speed (rpm)	Contact Time (h)	pH of the Elution
1	0.05	<20	1:10	120	24	5.34 ± 0.8
2	0.05	<0.2				5.66 ± 0.5
3	0.1	<20				3.72 ± 0.3
4	0.1	<0.2				5.13 ± 0.9

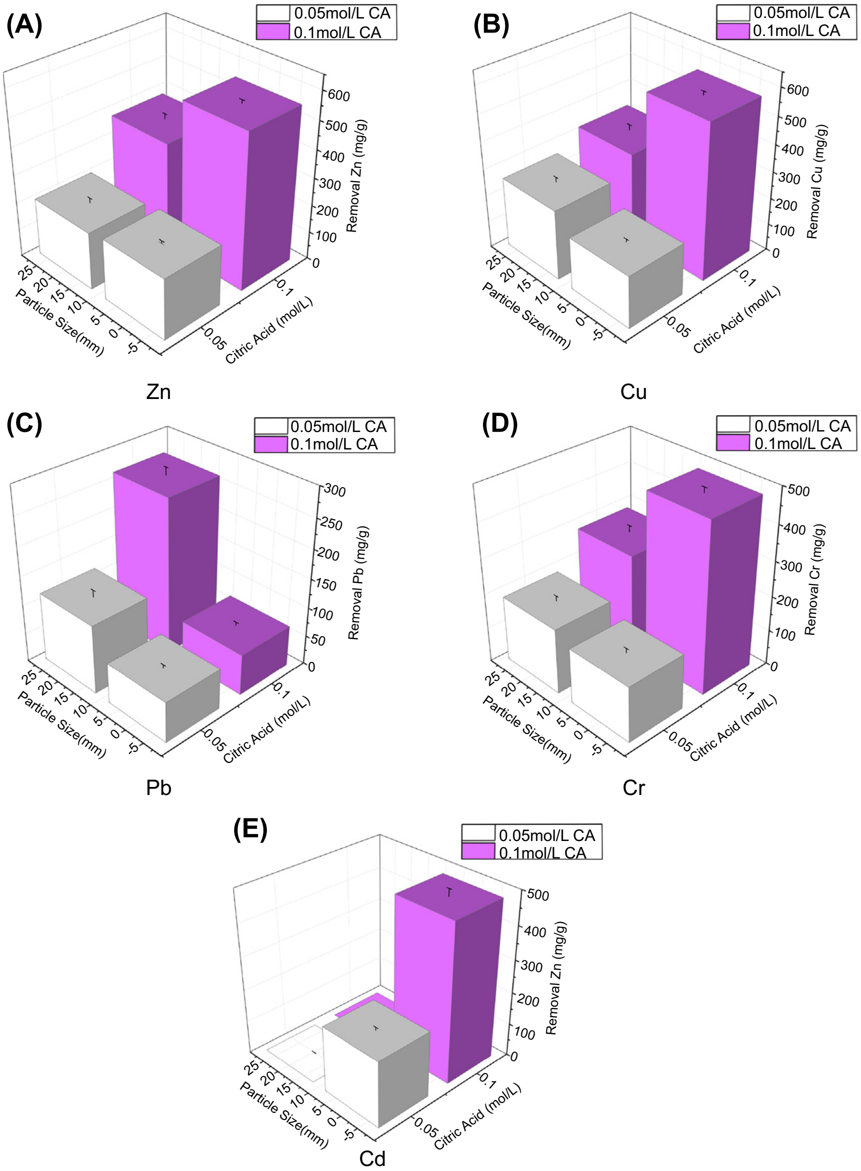

Figure 7.1 Elution of heavy metals from contaminated recycled gravel using citric acid. (A) Zn, (B) Cu, (C) Pb, (D) Cr, (E) Cd.

variance analysis was performed using Microsoft Excel; F values of the removal efficiency of Zn, Cu, Pb, Cr, Cd elution were 4319.3, 4693.9, 830.1, 1362.2, and 526.2, respectively, and were all greater than the critical value ($F_{crit} = 5.3$). Therefore the concentration of CA had a significant influence on the removal of heavy metals.

7.1.2 Washing Test of Contaminated Recycled Gravel With Different Eluting Agents (Glyphosate)

Eluting efficiencies of fenvalerate, dichlorvos, glyphosate, and HA solution are summarized in Fig. 7.2. The elution rates washed by fenvalerate and dichlorvos were all less than 10%. Fenvalerate and dichlorvos were pesticides used in the similar environmental condition as glyphosate, but incapable of complexing heavy metals for their molecular structures.

The metal-binding capacity of HAs means they have the sequestering ability to reduce the bioavailability of the heavy metals, and HA is a highly effective adsorbent for heavy metal ions under acidic or neutral conditions. However, CRG is an alkaline material, and the activity of HAs could have been restrained during the elution process so that the elution rates were all lower than that of glyphosate. The removal efficiency of glyphosate was about two to three times that of HAs for Zn and Cu, and four to five times for Cr, Pb, and Cd.

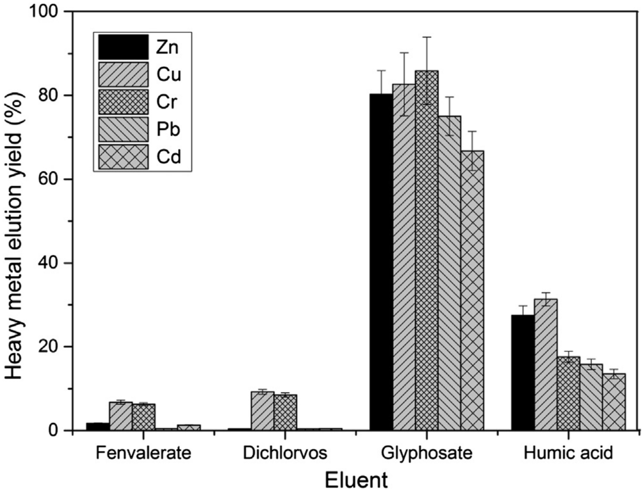

Figure 7.2 Contaminated recycled gravel (CRG) eluting efficiencies for mobilization test. Fenvalerate, CRG samples eluted by fenvalerate; dichlorvos, CRG samples eluted by dichlorvos; glyphosate, CRG samples eluted by glyphosate; humic acid, CRG samples eluted by humic acid.

Elution rates of HAs are shown in Fig. 7.2. The highest removal rate was 31.3% for Cu, followed by Zn 27.5%, and the lowest was Cd, about 13.5%. The removal rates of heavy metals by HAs decreased in the order of Cu > Zn > Cr > Pb > Cd. More than 80% of Cr, Cu, and Zn were removed by glyphosates; the highest was Cr, 85.9%, and the lowest was Cd, about 66.7%. Especially, glyphosate has a strong ability to absorb and remove some of the bound Cu and to form Cu-glyphosate complexes. In addition, glyphosate also acted as a bridge between the waste and Cd/Zn, forming complexes of Cd/Zn and glyphosate. The metal complexation ability with glyphosate increased in the order of Cr > Cu > Zn > Pb > Cd in which trivalent metal ion was stronger than the divalent ions.

In summary, glyphosate is a very effective eluent for heavy metal mobilization of CRG. Moreover, due to the widespread use of glyphosate, glyphosate and HAs may be present in the natural environment, resulting in the mobilization of heavy metals in nontreated CRG, which inevitably leads to serious soil and groundwater contamination.

7.1.3 Immobilization Heavy Metals in Contaminated Recycled Gravel

The immobilization capabilities of KH_2PO_4, lime, and Nano-iron powder were compared by the leaching rates through the leaching method EANEN7371 (Fig. 7.3). After treatment by KH_2PO_4, the leaching rates of Zn, Cu, Cr, Pb, and Cd were 1.1%, 2.3%, 4.4%, 0.8%, not detected, respectively.

The leaching rates of Zn, Cu, Cr, Pb, Cd were 2.1%, 1.1%, not detected, 4.1%, not detected, respectively, after being fixed by lime. Obviously, lime was a viable established immobilization reagent to remediate heavy metal pollution especially for Cr and Cd. In contrast, Nano-iron powder was the best fixing agent. After being immobilized by Nano-iron powder, the leaching rates of Zn, Cu, Cr, Pb, Cd were 1.2%, 0.6%, 1.0%, 0.5%, not detected, respectively. The mobility of metal elements could have been reduced by Nano-iron powder encapsulation in addition to precipitation at a high pH value like lime, as shown in the equations listed below in order.

$$2Fe^0_{(s)} + O_{2(g)} + 2H_2O \rightarrow 2Fe^{2+}_{(aq)} + 4OH^-_{(aq)}$$

$$Fe^0_{(s)} + 2H_2O \rightarrow Fe^{2+}_{(aq)} + H_{2(g)} + 2OH^-_{(aq)}$$

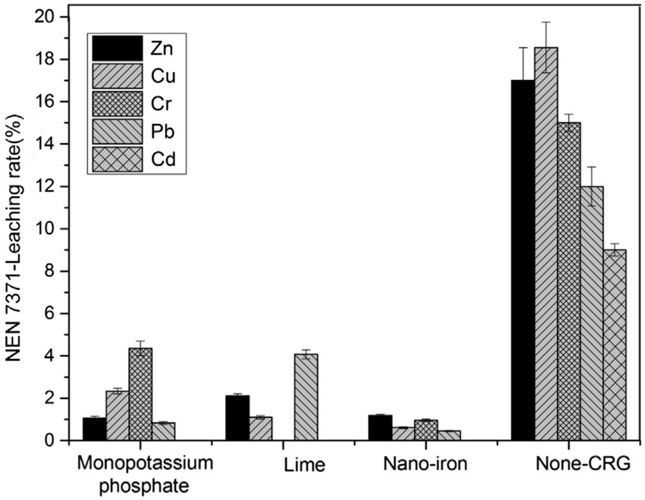

Figure 7.3 Dependence of leaching rate of contaminated recycled gravel (CRG) on the immobilization process. Monopotassium phosphate, CRG samples treated by KH_2PO_4; lime, CRG samples treated by lime; nano-iron, CRG samples treated by nano-iron powder; none-CRG, CRG samples without treatment.

7.1.4 Comparison of Treatment Effect Between Mobilization and Immobilization

The purpose of the EANEN7371 leaching tests on CRG after treatment was to further evaluate the performance of glyphosate versus Nano-iron, and to determine the most effective remediation measure, eluting or in situ immobilization. The results are presented in Fig. 7.4 and Table 7.2.

After immobilization by Nano-iron, the highest leaching rate was 1.18% of Zn, followed by 0.96% of Cr, 0.61% of Cu, and only 0.45% of Pb, Cd was not detected. After elution by glyphosate, the leaching rates of Zn, Cr, and Pb were lower than Nano-iron powder. There was no obvious difference between the two methods and all the leaching rates were less than 1.2%.

All the leachate concentrations of heavy metals were far below the national standard of Integrated wastewater discharge standard (China GB 8978-1996), standard for pollution control on the security landfill site for hazardous wastes (China GB 18598-2001), and Identification standards for hazardous waste—Identification for extraction toxicity (China GB 5085.3-2007). The two remediation reagents of glyphosate and Nano-iron powder can meet all these standards.

X-ray diffraction (XRD) analysis was conducted to examine the change of crystalline phases after treatment. Five groups of initial recycled gravel

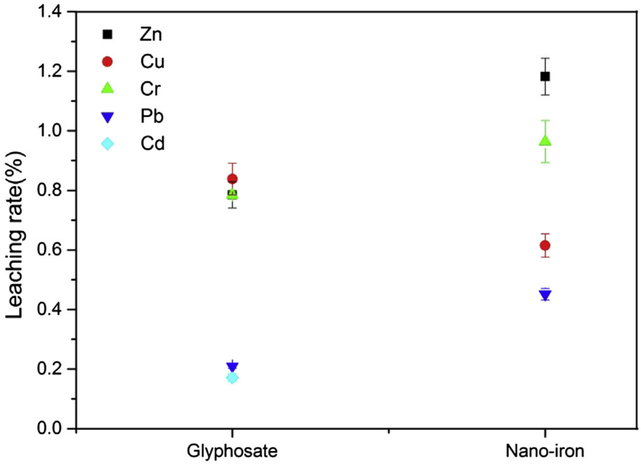

Figure 7.4 EA NEN 7371 leaching test for immobilization of contaminated recycled gravel (CRG). Glyphosate, CRG samples eluted by glyphosate; nano-iron, CRG samples immobilized by nano-iron powder.

Table 7.2 Leaching Concentration of Heavy Metals in Treated Recycled Gravel (mg/L)

	Zn	Cu	Cr	Pb	Cd
Glyphosate	0.13 ± 0.007	0.12 ± 0.008	0.12 ± 0.002	0.03 ± 0.001	0.03 ± 0.002
Nano-iron	0.19 ± 0.010	0.09 ± 0.006	0.15 ± 0.011	0.07 ± 0.003	ND[a]
Wastewater(III)[b]	20	5.0	1.5	1.0	0.1
Landfill HW[c]	75	75	12.0	5.0	0.5
Identification HW[d]	100	100	15.0	5.0	1.0

[a] Not detected.
[b] Integrated wastewater discharge standard (China GB 8978-1996).
[c] Standard for population control on the security landfill site for hazardous wastes (China GB 18598-2001).
[d] Identification standards for hazardous waste—Identification for extraction toxicity (China GB 5085.3-2007).

(IRG) (Fig. 7.5) and CRG samples were corresponding to five different heavy metals. In each group, S0 sample was IRG, S1 was CRG, S2 was immobilized CRG by Nano-iron, S3 was eluted CRG by glyphosate (Fig. 7.6). The principal crystalline phases identified in all the IRG (S0) were quartz (SiO_2), silicon oxide (SiO_2), and small amounts of calcite ($CaCO_3$) and magnesium calcite ($Ca_{(1-x)}Mg_xCO_3$) (Fig. 7.6).

From the X-ray diffractograms of the Zn-(S0, S1, S2, S3) samples (Fig. 7.6 Zn), the calcium zinc hydroxide hydrate [$CaZn_2(OH)_6 \cdot 2H_2O$] was identified in Zn-S1 sample, which was the result of the reaction between Zn^{2+} and $CaCO_3$ or [$Ca_{(1-x)}Mg_xCO_3$]. After being immobilized by Nano-iron powder, it still existed in Zn-S2 sample. The content of

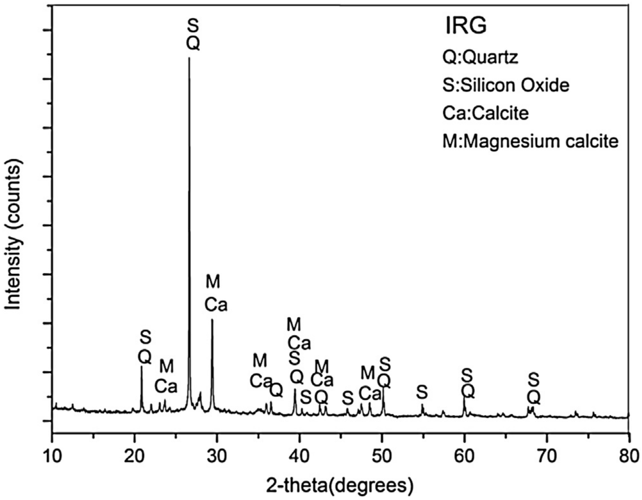

Figure 7.5 X-ray diffractogram analysis of the initial recycled gravel.

calcite ($CaCO_3$) and magnesium calcite [$Ca_{(1-x)}Mg_xCO_3$] decreased over contamination procedure (Zn-S1) and immobilization period (Zn-S2) as a lot of calcium ions were released and reacted with Zn^{2+} through the equations listed below in order.

$$CaCO_{3(s)} + H^+_{(aq)} \rightarrow HCO^-_{3(aq)} + Ca^{2+}_{(aq)}$$

$$Ca_{(1-x)}Mg_xCO_{3(s)} + H^+_{(aq)} \rightarrow (1-x)Ca^{2+}_{(aq)} + xMg^{2+}_{(aq)} + HCO^-_{3(aq)}$$

$$Ca^{2+}_{(aq)} + 2Zn^{2+}_{(aq)} + 8H_2O \underset{25^\circ C}{\rightarrow} CaZn_2(OH)_6 \cdot 2H_2O_{(s)} + 6H^+_{(aq)}$$

On the other hand, the mineralogical compositions were the same between S3 and S0, which meant good cleaning effect by glyphosate.

From the X-ray diffractograms of the Cu CRG (Cu-S0, S1, S2, and S3) samples (Fig. 7.6 Cu), the posnjakite [$Cu_4(SO_4)(OH)_6(H_2O)$], potassium copper chloride ($KCuCl_3$), and lithium copper phosphate [$Li_2Cu(P_2O_7)$] were identified in Cu-S1 samples. When soaked in Cu^{2+} aqueous solutions at temperature 25°C, the posnjakite [$Cu_4SO_4(OH)_6H_2O$] was formed through the equation given below.

$$\begin{aligned} &Cu^{2+}_{(aq)} + 0.25SO^{2-}_{4(aq)} + 1.5OH^-_{(aq)} + 0.25H_2O \\ &\underset{25^\circ C}{\rightarrow} 0.25Cu_4(SO_4)(OH)_6(H_2O)_{(s)} \end{aligned}$$

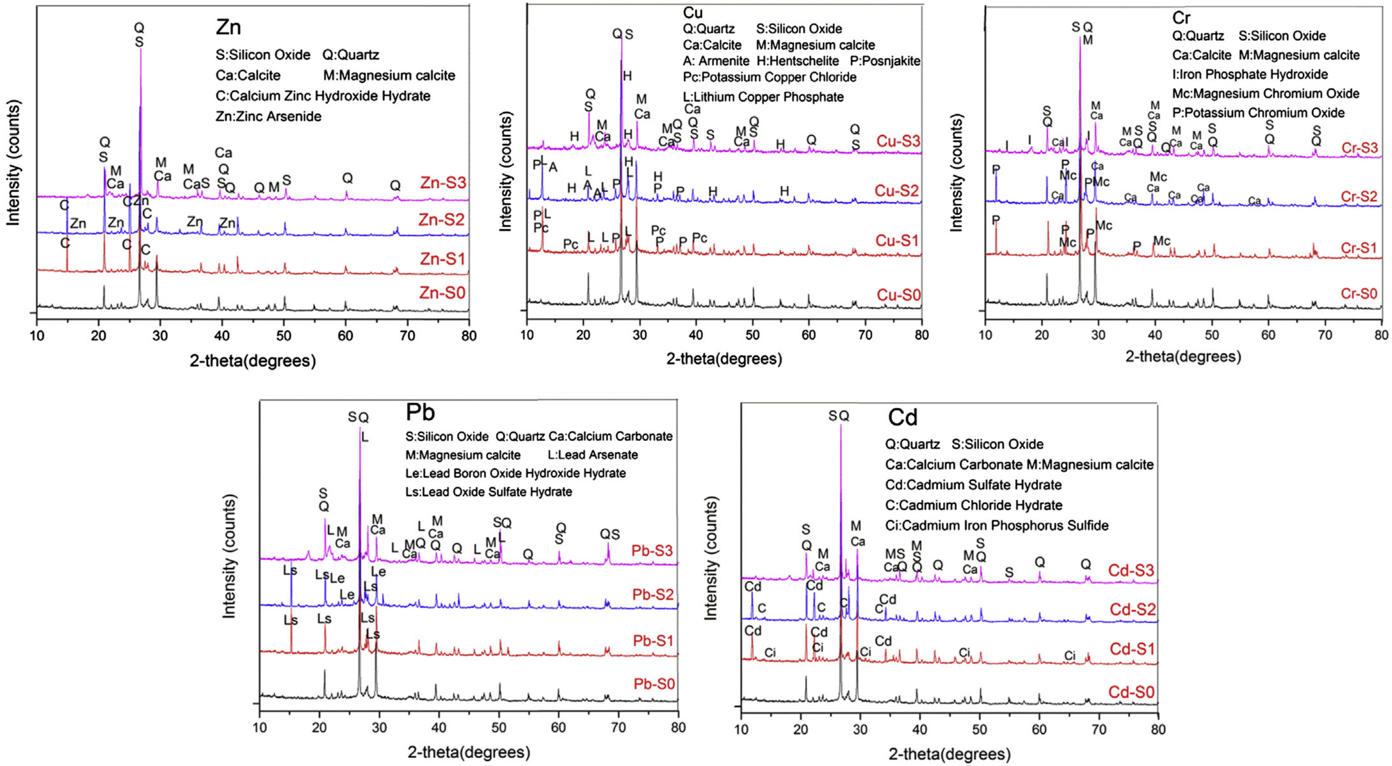

Figure 7.6 X-ray diffractograms of the initial recycled gravel (IRG) and contaminated recycled gravel (CRG) samples. S0, IRG-initial recycled gravel; S1, CRG-contaminated recycled gravel by Zn, Cu, Cr, Pb, and Cd, respectively; S2, immobilized CRG by nano-iron; S3, eluted CRG by glyphosate.

Furthermore, the posnjakite [$Cu_4(SO_4)(OH)_6(H_2O)$], lithium copper phosphate [$Li_2Cu(P_2O_7)$], armenite [$BaCa_2Al_6Si_9O_{30}(H_2O)_2$], and hentschelite [$CuFe_2(PO_4)_2(OH)_2$] were detected in Cu-S2 sample, but the potassium copper chloride ($KCuCl_3$) crystalline phase disappeared. After elution by glyphosate, crystalline phases were similar between Cu-S0 and Cu-S3. Obviously, the copper crystal phases were damaged by glyphosate, further forming Cu-glyphosate complexes, ultimately to achieve good elution effect.

Cr-S1 and S2 samples of the magnesium chromium oxide ($MgCrO_4$) was newly identified and generated through Eq. (7-7), which can be enhanced by the strong alkalinity of IRG. The crystalline phases were the same between Cr-S1 and Cr-S2, but the elution rates of Cr were totally different due to the results discussed earlier. That meant before immobilization by Nano-iron powder, the mobility of magnesium chromium oxide ($MgCrO_4$) was loosely attached to the CRG by weak van der Waals forces of attraction. After elution by glyphosate, crystalline phases were similar between Cr-S0 and Cr-S3, except for a small amount of iron phosphate hydroxide [$Fe_4(PO_4)_3(OH)_3$].

$$Cr_2O^{2-}_{7(aq)} + H_2O + 2Mg^{2+}_{(aq)} \rightarrow 2MgCrO_{4(s)} + 2H^{+}_{(aq)}$$

In XRD patterns for the Pb-(S0,S1,S2,S3) samples (Fig. 7.6 Pb), the peaks of lead arsenate, lead boron oxide hydroxide hydrate, and lead oxide sulfate hydrate appeared in the [Pb-S1,S2,S3] samples. Moreover, a new substance, lead boron oxide hydroxide hydrate $Pb_5[B_3O_8(OH)_3]$ (H_2O) was also found after fixing by the Nano-iron powder. After washing by glyphosate, the pattern was similar to S0, except a very small amount of lead arsenate [$Pb(As_2O_6)$]. Obviously, the cleaning effect of glyphosate for Pb was not as good as the former metals (Zn, Cu, and Cr).

According to Fig. 7.6 Cd, the cadmium sulfate hydrate [$(CdSO_4)_3(H_2O)_8$] and cadmium chloride hydrate [$CdCl(H_2O)_4$] were identified in Cd-S1. In the pattern of Cd-S2, cadmium iron phosphorus sulfide [$CdFeP_2S_6$] was newly formed, whereas the cadmium sulfate hydrate had been retained. However, after being cleaned by glyphosate, the peaks related to cadmium-containing compounds disappeared. It meant glyphosate can remove all of the cadmium-containing compounds in CRG.

In summary, glyphosate is capable of removing most heavy metals (Zn, Cu, Cr, and Cd) with a small amount of residual lead arsenate left. Nano-iron powder can basically retain the original crystalline, and may form a new more stable phase. Both glyphosate and Nano-iron powder achieve good remediation effect according to the results.

To gain more information about the surface morphology characteristic and crystalline phases of IRG and CRG under different processing conditions, scanning electron microscopy (SEM) analysis was conducted, and also to confirm the results from the XRD analysis. Fig. 7.7 shows the SEM images of IRG and CRG samples: S0, IRG; S1, CRG of stationary contact, respectively, with Zn, Cu, Cr, Pb, and Cd solutions for 60 days; S2, immobilization CRG by Nano-iron; S3, elution CRG by glyphosate.

The littered, irregular, and fractured surface of IRG prior to immersion is depicted in Fig. 7.7 (S0-IRG). Fig. 7.7 (Zn-S1) is a typical image of the IRG after 60 days of stationary contact with Zn^{2+} solution. The surface morphology was severely damaged, and easily distinguishable. The following was immobilized CRG by Nano-iron powder with further destruction on the surface morphology structure. However, after being washed by glyphosate, the surface morphology and crystalline phases were almost the same between S0 and Zn-S3 Fig. 7.7 (Zn-S3) and Fig. 7.7 (Cu-S2).

Three distinct copper-bearing images were observed to have formed on the surface of CRG in Fig. 7.7 Cu-S1, Cu-S2, and Cu-S3. The mineral surface morphology of IRG was severely damaged (Fig. 7.7 Cu-S1). Notably, Nano-iron powder exerted a crucial role in changing the surface morphology of CRG, showing spherical shaped dense parcel in Cu-S2 (Fig. 7.7 and Fig. 7.7 Cu-S2). Even after being cleaned by glyphosate, remarkable eroded traces were shown on the surface, which made difference between Cu-S0 and Cu-S3.

Small white spots exist in Fig. 7.7 Cr-S1. The surface morphology of CRG was not destroyed, just dominated by visible sediment, highly consistent with XRD results. After being fixed by the Nano-iron, the spots become denser (Fig. 7.7 Cr-S2). When being washed by glyphosate, the chromium compound was mostly removed (Fig. 7.7 Cr-S3), whereas there were some small holes left, providing the evidence of the place where the chromium compounds were cleaned.

Fig 7.7 Pb-S1, Pb-S2, and Pb-S3 show the surface morphology of Pb-CRG samples. The morphology of Pb-S1 was overall integrity, although small cave appeared on the surface (Fig. 7.7 Pb-S1). After the treatment by the Nano-iron powder, the surface morphology became dense. Pb-bearing compound might have been wrapped or reprecipitated in the CRG. After being cleaned by glyphosate, the surface morphology still presented a high degree of damage.

Fig. 7.7 Cd-S1 also presents the phases evolution of CRG after 60 days' contact with Cd^{2+} solution. It can be clearly seen that the surface structure

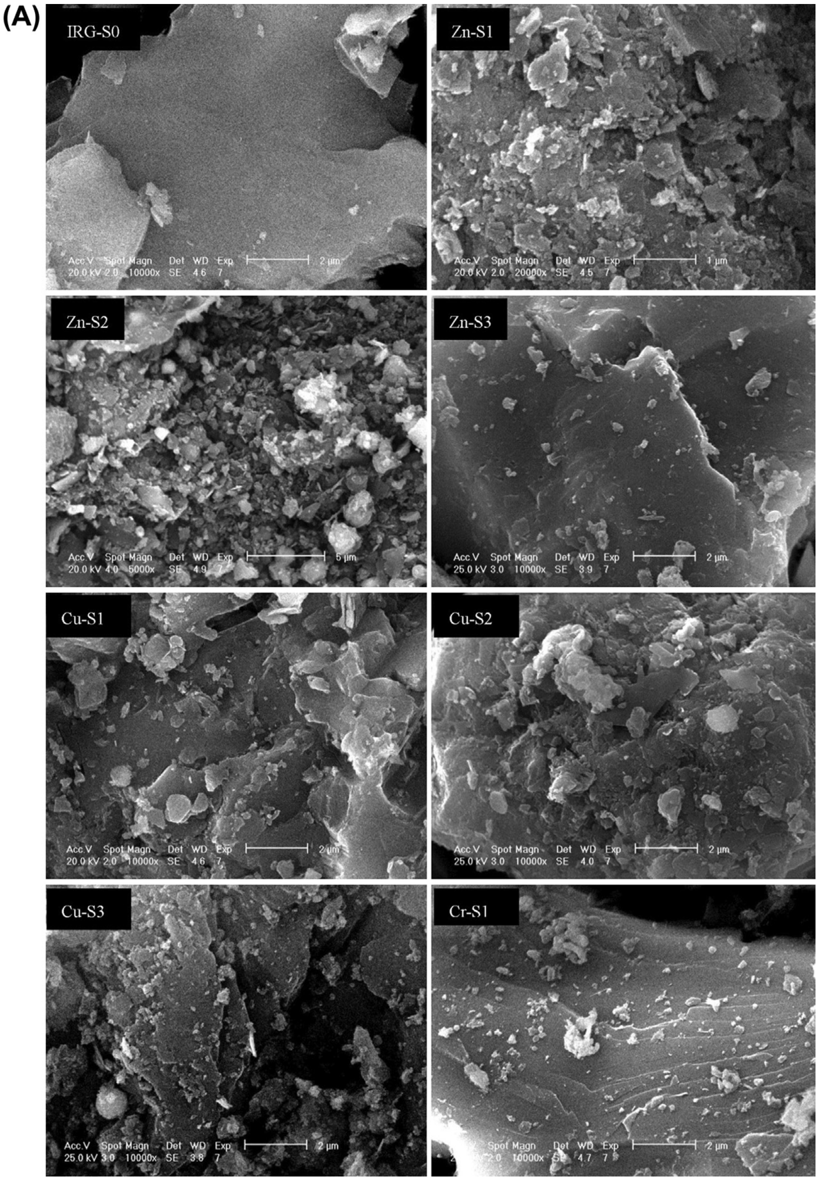

Figure 7.7 (continued).

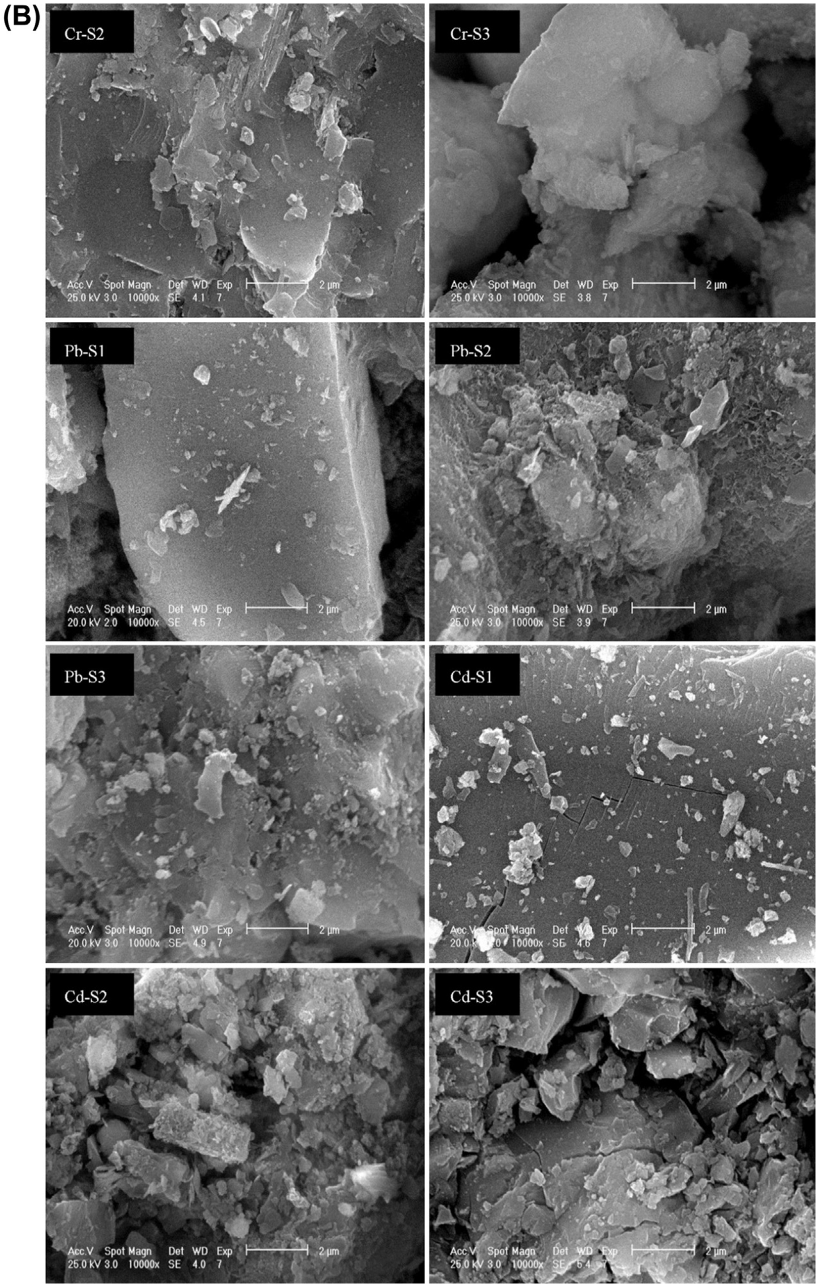

Figure 7.7 Scanning electron microscopy images depict the surfaces of various initial recycled gravel (IRG) and contaminated recycled gravel (CRG) samples: (A) IRG-S0 to Cr-Si, (B) Cr-S2 to Cd-S3. S0, IRG-initial recycled gravel; S1, CRG-contaminated recycled gravel by Zn, Cu, Cr, Pb, and Cd, respectively; S2, immobilized CRG by nano-iron; S3, eluted CRG by glyphosate.

was relatively intact, except for some small cracks on it. But in Cd-S2, large-scale change occurred during the fix. Compared with Cd-S2, the surface was not so rough in the samples washed by glyphosate, but was still damaged severely (Fig. 7.7 Cd-S3).

Thus it can be seen that Nano-iron powder was more effective than lime and monopotassium phosphate to immobilize heavy metals of CRG. The mobility of metal elements was likely reduced by Nano-iron powder encapsulation within CRG, whereas lime and monopotassium can cause a high pH condition to generate precipitation. The elution efficiency of glyphosate was much higher than that of HA with removal rates of more than 80% for Cr, Cu, and Zn, and the lowest removal efficiencies of 66.7% for Cd. The removal efficiencies with glyphosate decreased in the order of $Cr > Cu > Zn > Pb > Cd$. Both the Nano-iron immobilization method and the glyphosate mobilization method can achieve good effect for all the heavy metals, and leaching rates of CRG were lower than 1.2% and the concentration of heavy metals in the leachate were far below certain legal limits (GB 5085.3-2007) set in China. For Zn, Cr, and Pb, the glyphosate mobilization method can achieve lower leaching rates. But for Cu and Cd, the Nano-iron immobilization method was more suitable. The XRD and SEM analyses on crystalline phases and morphological surface structures firmly confirmed the formation and disappearance of metal (Zn/Cu/Cr/Pb/Cd) compounds.

7.1.5 Citric Acid Elution—Washing—Stabilization Process

Heavy metal might still remain in C&D waste after the elution of CA. Stabilization of heavy metal–contaminated C&D waste could be achieved by adding a washing procedure after the elution (listed in Table 7.3).

CA elution–washing–stabilization process was performed based on solid waste-extraction procedure for leaching toxicity—HJ Sulfuric acid and nitric acid method (HJ/T299-2007). Results are shown in Fig. 7.8. The leaching toxicity of C&D waste after the CA elution–washing–stabilization process was far lower than untreated C&D waste. Double factor variance analysis results indicated that significant difference existed in the effect of heavy metal stabilization among different curing agents. According to Fig. 7.8, calcium dihydrogen phosphate and lime had a better heavy metal stabilization effect than the other two agents.

The F value of calcium dihydrogen phosphate was 4.720 and 4.927, respectively, when the amount of curing agent used was 25 and 80 g/kg after the elution of CA, both of which were larger than the critical value $F_{crit} = 3.458$ at $\alpha = 0.05$ and were smaller than the critical value

Table 7.3 Variables of the Heavy Metal—Contaminated Construction and Demolition Waste Stabilization

Number	Curing Agent	Dosage of Curing Agent (g/kg)	Amount of Regulating Water (wt%)	Shake Time (h)	Rotate Speed (rpm)	Stabilization Time (days)
1	Bentonite	25 80	50	24	30	7
2	Calcium dihydrogen phosphate	25 80				
3	Superphosphate	25 80				
4	Lime	25 80				
0	Blank	0				

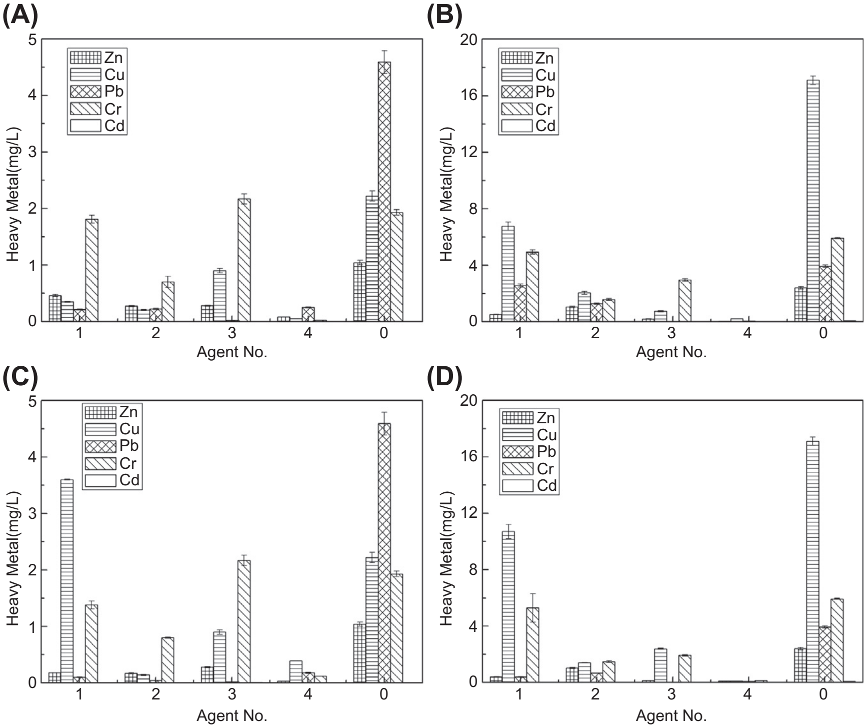

Figure 7.8 Leaching toxicity of construction and demolition waste after stabilization using curing agents. (A) 0.05 mol/L CA eluted—25 g/kg curing agent. (B) 0.1 mol/L CA eluted—25 g/kg curing agent. (C) 0.05 mol/L CA eluted—80 g/kg curing agent. (D) 0.1 mol/L CA eluted—80 g/kg curing agent.

Table 7.4 Results of Double Factor Variance Analysis of the Stabilization Effect

	Amount					
	0.05 mol/L Citric Acid		**0.1 mol/L Citric Acid**		$\mathbf{F_{crit}}$	
	25 g/kg	**80 g/kg**	**25 g/kg**	**80 g/kg**	$\alpha = 0.05$	**A = 0.1**
Agent						
Bentonite	2.817	0.776	0.821	0.489	3.458	5.318
Calcium dihydrogen phosphate	4.720	4.927	2.479	2.796		
Superphosphate	2.193	2.189	2.863	2.758		
Lime	6.006	5.583	3.859	3.845		

$F_{crit} = 5.318$ at $\alpha = 0.1$. The F value of lime was 6.006 and 5.5583, respectively, and were both larger than the F_{crit} at $\alpha = 0.05$. A significant effect of stabilization of lime was proved. The average stabilization of calcium dihydrogen phosphate and lime was 87.0% and 98.2%, respectively, whereas that of the other two agents were less than 70% as shown in Table 7.4.

7.1.6 Elution Process Using Glyphosate

Glyphosate isopropylamine was used as eluent. The molecular structure of glyphosate is made up of phosphoric acid group, a carboxyl group, an amino group, etc., which can be combined with heavy metals in different proportions. For example, the amino group in glyphosate has a strong affinity with Cu^{2+}. The content of these groups will be a determination of the combination capacity. The combination capacity of (aminomethyl) phosphonic acid, the degradation product of glyphosate, is also strong. Most heavy metal ions will be combined with glyphosate and transformed into the ineffective and stable phase, which will greatly reduce its toxicity. The combination capacity between glyphosate and trivalent metal ions is the strongest, whereas that with monovalent is the weakest.

1. Glyphosate elution process

   The elution process of heavy metal–contaminated C&D waste by glyphosate is shown in Fig. 7.9.

   a. Surface stripping

      About 3–6 mm of the surface of C&D waste contaminated by high concentrations of heavy metals was stripped off and immersed in commercial caustic soda solution of industrial 2–8 M grade.

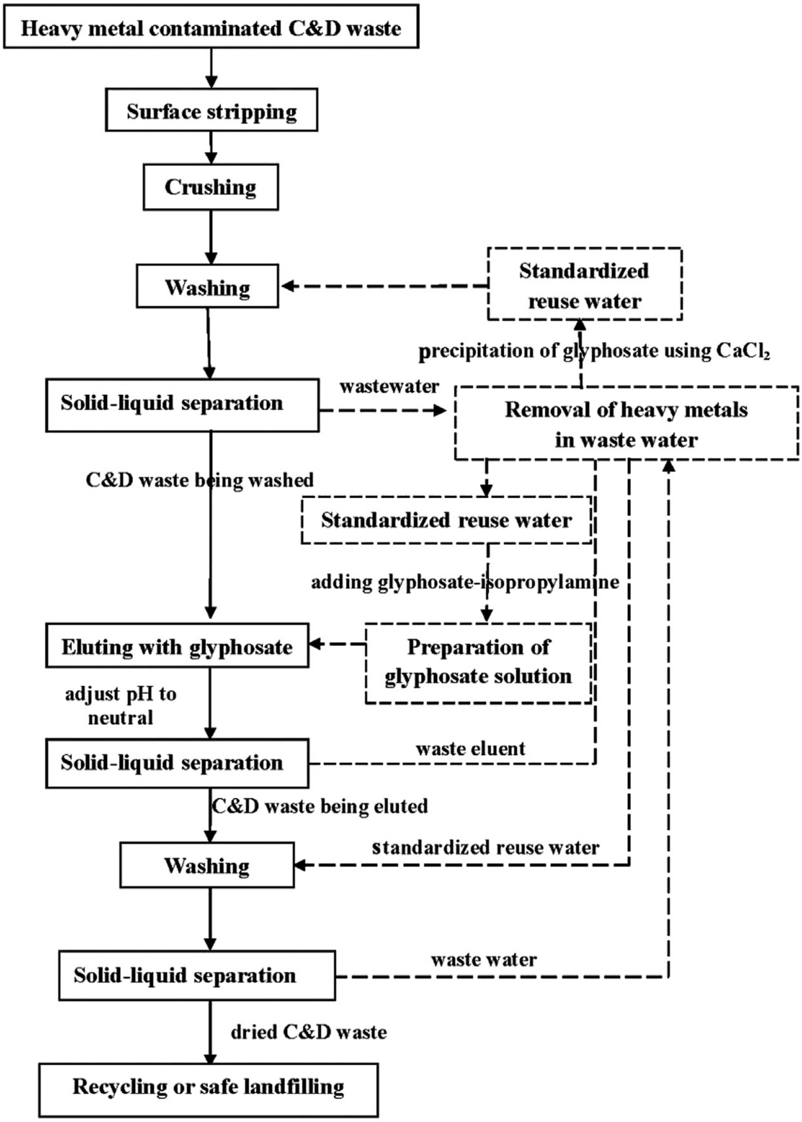

Figure 7.9 Elution process of heavy metal–contaminated construction and demolition waste by glyphosate.

Electrolysis treatment was performed upon the leaching solution to recycle the heavy metals.

b. Crushing
The C&D waste obtained in procedure (a) was crushed to particles whose size was less than 4–5 mm.

   c. Washing and solid—liquid separation
   The crushed C&D waste was washed with water (liquid:solid = 5:1) and solid—liquid separation performed. The wash water was treated by adding Nano-iron powder (20 nm). The washed C&D waste was eluted with glyphosate according to procedure (d).
   d. Eluting with glyphosate and solid—liquid separation
   Glyphosate was added into the washed C&D waste (liquid:solid = 2:1) and eluted one to three times. Most heavy metal ions would be combined with glyphosate and transformed into the ineffective and stable phase. Solid—liquid separation was performed after the pH had been adjusted to neutral. The waste water was treated while the eluted C&D waste was sent for further washing.
   e. Eluted C&D waste
   Eluted C&D waste was washed with water (liquid:solid = 5:1) before solid—liquid separation was performed. C&D waste was dried and sent for heavy metals detection.

2. Effects of the elution process
   a. Treatment of the C&D waste contaminated by electroplating industry
   Huge contamination existed in the concrete and brick waste of different workshops in a chemical factory in Guangdong. The concentration of the heavy metals in the C&D waste of four workshops were Zn 2122.31 mg/kg (workshop A), Cu 59,434.02 mg/kg (workshop B), Cr 7511.03 mg/kg (workshop C), and Ni 2867.77 mg/kg (workshop D) (Table 7.5).
   The variation of heavy metal contents and the elution ratio is listed in Tables 7.5 and 7.6. The concentration of heavy metals in eluted C&D waste was lower than the guidelines (GB15618-1995). The leaching results using HJ/T299 method are listed in Table 7.7, and were lower than the hazardous waste criteria (GB 5085.3-2007).
   b. Treatment of the Construction and Demolition Waste in Zinc Smelting Plant

Table 7.5 Heavy Metals in Construction and Demolition Waste Before and After Elution (mg/kg)

Construction and Demolition Waste	Workshop A (Zn)	Workshop B (Cu)	Workshop C (Cr)	Workshop D (Ni)
Initial	2122.31	59,434.02	7511.03	2867.77
Washed by water	553.74	21,369.78	2086.25	1818.15
Washed by glyphosate	137.92	384.11	299.26	169.70

Table 7.6 Removal Ratios of Heavy Metals in Construction and Demolition Waste From Different Workshops (%)

Workshop	Removal Ratio
Workshop A (Zn)	93.50
Workshop B (Cu)	99.35
Workshop C (Cr)	96.02
Workshop D (Ni)	94.08

Table 7.7 Leaching Results of the Eluted Construction and Demolition Waste (mg/L)

Workshop	Leaching Concentration
Workshop A (Zn)	25.37
Workshop B (Cu)	19.08
Workshop C (Cr)	9.12
Workshop D (Ni)	1.21

Zn concentration of C&D waste in the electrolytic workshop and cleaning workshop from a zinc smelting plant in Yunnan Province, China, was 49,280.00 and 29,738.72 mg/kg, respectively (Table 7.8).

The concentration of heavy metals in eluted C&D waste is also listed in Table 7.8, which was lower than the guided values (level III, GB15618-1995). The leaching amount using HJ/T299 method was 39.27 and 17.42 mg/L, which was far lower than the guided values in hazardous leaching criteria (GB 5085.3-2007).

c. Treatment of Industrial Contaminated Gravels

Concentration of Cu and Zn of C&D gravels in a workshop was 27,155.32 and 4087.06 mg/kg, respectively (Table 7.9). The results of the elution process are also listed in Table 7.9. The concentration

Table 7.8 Variation of Concentration, Removal Ratio, and Leaching Amount of Zn in Construction and Demolition Waste From Different Workshops

Zn	Initial (mg/kg)	Washed by Water (mg/kg)	Washed by Glyphosate (mg/kg)	Removal Ratio (%)	Leaching Amount (mg/L)
Electrolytic workshop	49,280.00	32,146.32	493.49	98.99	39.27
Cleaning workshop	29,738.72	16,385.18	498.91	98.32	17.42

Table 7.9 Variation of Concentration, Removal Ratio, and Leaching Amount of Cu and Zn in Construction and Demolition Gravels From an Industrial Workshop

Heavy Metal	Initial (mg/kg)	Washed by Water (mg/kg)	Washed by Glyphosate (mg/kg)	Removal Ratio (%)	Leaching Amount (mg/L)
Cu	27,155.32	7234.35	391.69	98.56	1.19
Zn	4087.06	1536.62	217.41	94.68	50.58

of heavy metals was lower than the guided values (level III, GB15618-1995). The leaching amount using HJ/T299 method was far lower than the guided values in hazardous leaching criteria (GB 5085.3-2007).

7.2 THERMAL TREATMENT OF ORGANIC POLLUTANTS IN CONSTRUCTION AND DEMOLITION WASTE

A typical thermal treatment of organic pollutants in C&D waste performed in this book is demonstrated in Fig. 7.10.

7.2.1 Influencing Factors in Microwave Treatment Process

7.2.1.1 Effect of Concentration of Pollutants (Phenanthrene)

Samples were crushed and screened so that the particle size range was within 0.45—1.25 mm. Samples were placed in corundum boat B (60 × 25 × 15) and treated for 30 min under the microwave power of 800 W. The results of treatment are shown in Fig. 7.11, which indicated that the removal efficiency varied little with the concentration of pollutants between 200 and 300 mg/kg.

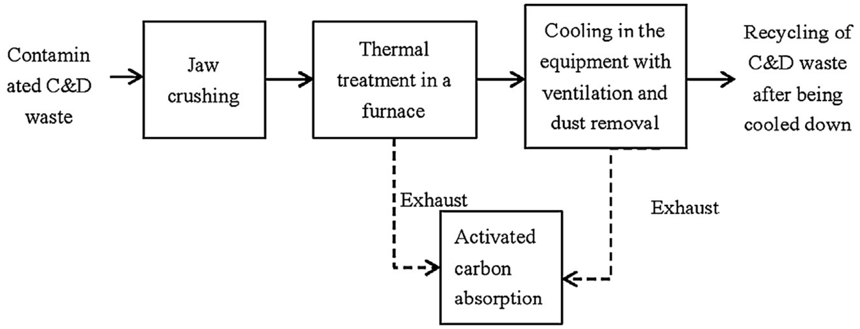

Figure 7.10 Thermal treatment of organic pollutants in construction and demolition waste.

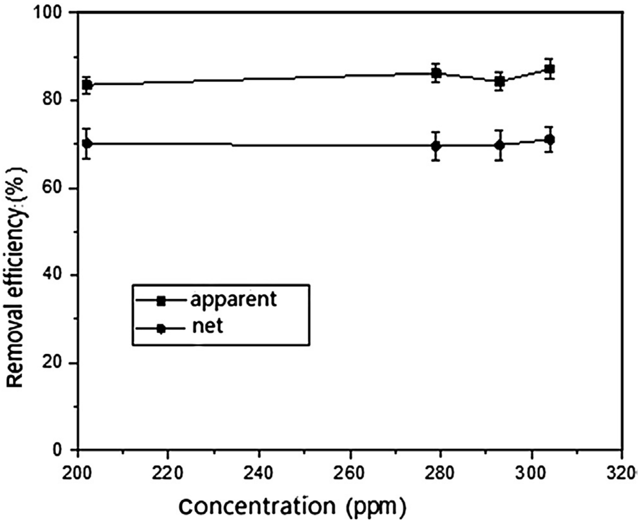

Figure 7.11 Effects of phenanthrene concentrations on the removal efficiency using microwave treatment process. Note: Apparent removal refers to the proportion of the total removal amount (including those ventilated and degraded) in the total amount of pollutants before treatment, while net removal only included those degraded pollutants.

7.2.1.2 Effect of Size of Construction and Demolition Waste and Stack Height

Samples with different sizes were treated for 40 min under the microwave power of 800 W, and the results are shown in Fig. 7.12. When the particle size was less than 1.25 mm, the apparent removal and net removal of phenanthrene sharply decreased with the decrease of particle size. The C&D waste within 1.25–2.5 mm in diameter had good removal efficiency; apparent removal efficiency was above 90%, whereas the net removal was more than 80%. The removal efficiency got worse when the particle diameter was larger than 2.5 mm. According to Fig. 7.13, similar heating characteristic curve was found in different sizes of C&D waste.

C&D wastes were placed in different types of boats to investigate the effects of stack height on the removal efficiency of pollutants. The results are shown in Fig. 7.14. The stack height of C&D waste in boats A, B, and C was 12, 8, and 4 mm, respectively. According to the results, in a certain range of stack height, the removal efficiency of pollutants increased with the decrease of stack height.

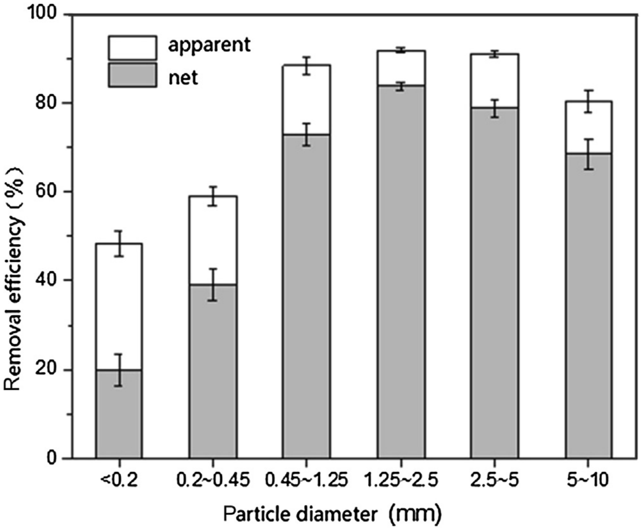

Figure 7.12 Effects of particle size on the removal efficiency using microwave treatment process.

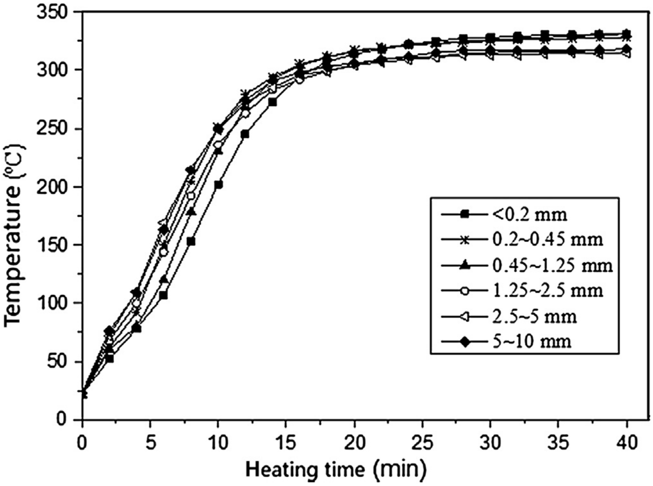

Figure 7.13 Curve of the temperature–heating time of construction and demolition waste using microwave treatment process.

Part of the microwave that reached the surface of C&D waste will be reflected, whereas part of that will get into the waste and transfer into heat energy. The energy of microwave decreased exponentially while it got far into the C&D waste. The microwave penetration depth (d_w, m) is

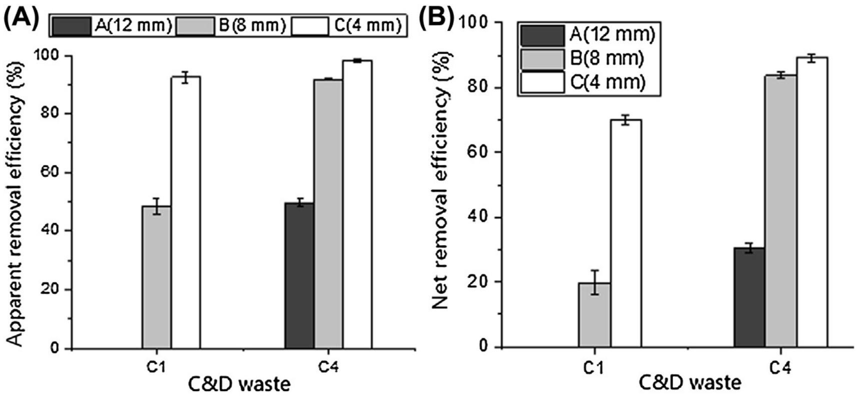

Figure 7.14 Effects of stack height on the removal efficiency of pollutants using microwave treatment process. (A) Apparent removal efficiency. (B) Net removal efficiency. *C&D*, construction and demolition.

the distance that energy of microwave is decreased to the extent that it is not sufficient to remove the organic contaminants. Under certain conditions (power, time, etc.) of microwave irradiation, the average value of d_w is defined as microwave radiation depth (h_w, m). d_w varies with the characteristics of C&D waste and the microwave power while h_w also varies with the distribution of C&D waste. When the diameter of C&D waste $D > d_w$, the microwave is not able to penetrate the waste. Therefore the removal efficiency of heat treatment will decrease with the increase of the size of C&D waste, which is demonstrated in Fig. 7.15A. As shown in

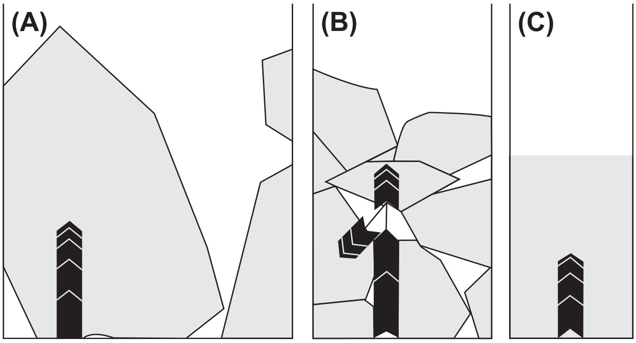

Figure 7.15 Transmission of microwave in construction and demolition (C&D) waste of different sizes. Note: (A), (B), and (C) represent the situation of the C&D waste of large, appropriate, and small size. The *black arrows* refer to the transmission and decay of microwave.

Fig. 7.15C, if the C&D waste is too small in size, the whole waste stack can be treated as a system, h_W is similarly equal to d_W, the height of waste stack is far larger than d_W, and the removal efficiency gets worse.

Fig. 7.15B shows that the size of C&D waste is appropriate enough to make the microwave able to cover the whole C&D waste stack, which will result in high treatment efficiency. In conclusion, the h_W varied with the transmission ways of microwave in C&D waste of different sizes. When $h \geq h_W$, the theoretical removal efficiency of pollutants can be calculated in the equation listed below:

$$\eta = \frac{h_W}{h} + \alpha$$

where η is the removal efficiency of pollutants (%), and α is the correction coefficient.

7.2.1.3 Effect of Pollutants

C&D waste contaminated by phenanthrene and *p*-aminoazobenzene were placed in boat B (60 × 25 × 15) and treated for 40 min under the microwave power of 800 W. The gas flow was 20 mL/min. Results are shown in Fig. 7.16. The results showed that microwave treatment under this condition was not suitable for the removal of *p*-aminoazobenzene-contaminated C&D waste. As discussed earlier, when the temperature of

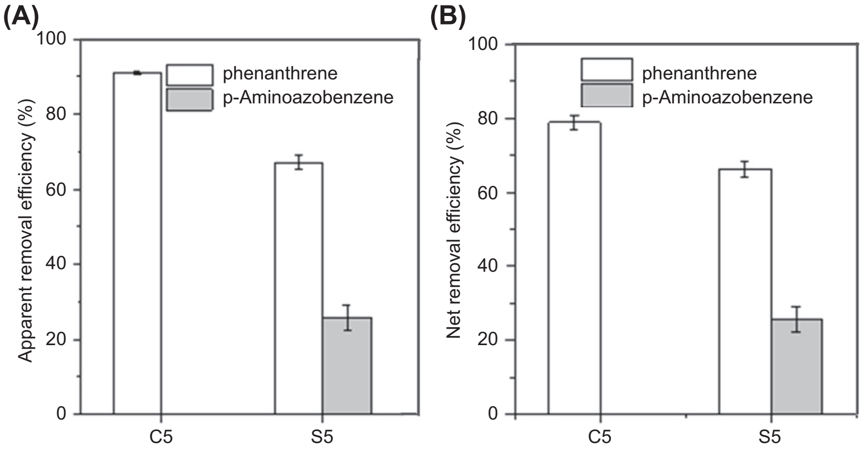

Figure 7.16 Removal efficiency of different pollutants using microwave treatment process. (A) Apparent removal efficiency. (B) Net removal efficiency.

C&D waste reached 310°C, the removal efficiency of phenanthrene sharply rose to more than 80%. The temperature of C&D waste stabilized at 310–330°C under the microwave power of 800 W, whereas this temperature was not high enough for the degradation of *p*-aminoazobenzene.

7.2.1.4 Effect of Power of Microwave

C&D waste (C5) was placed in boat B (60 × 25 × 15) and treated for 40 min under the microwave power of 800 W. The gas flow was 20 mL/min. Results are shown in Fig. 7.17. It was found that the removal efficiency of pollutants increased with the increase of microwave power. The change in removal efficiency was much sharper between the power of 600–700 W than that of 400–600 W. Fig. 7.18 shows the increase pattern of temperature of C&D waste under different power of microwave. It was found that the temperature stabilized at 300–310°C when the power of microwave was set at 700 W, whereas the temperature was below 300°C if the power was within 400–600 W.

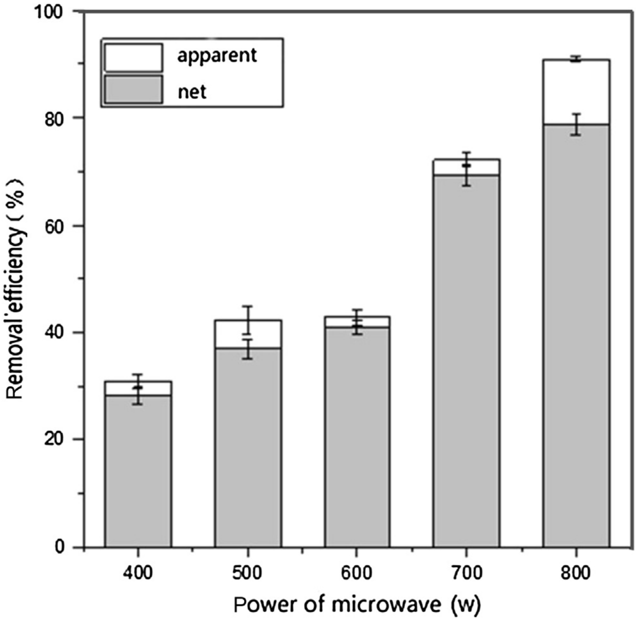

Figure 7.17 Removal efficiency of phenanthrene under different power of microwave.

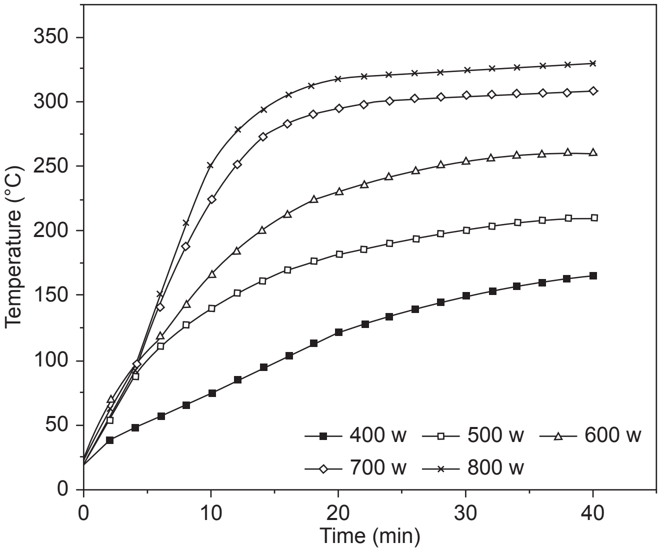

Figure 7.18 The increase pattern of temperature of construction and demolition waste under different power of microwave.

7.2.1.5 *Effect of Reaction Time*

C&D waste (C5) was placed in boat B (60 × 25 × 15) and treated for different times under the microwave power of 800 W. The gas flow was 20 mL/min. The results are shown in Fig. 7.19. It was found that the

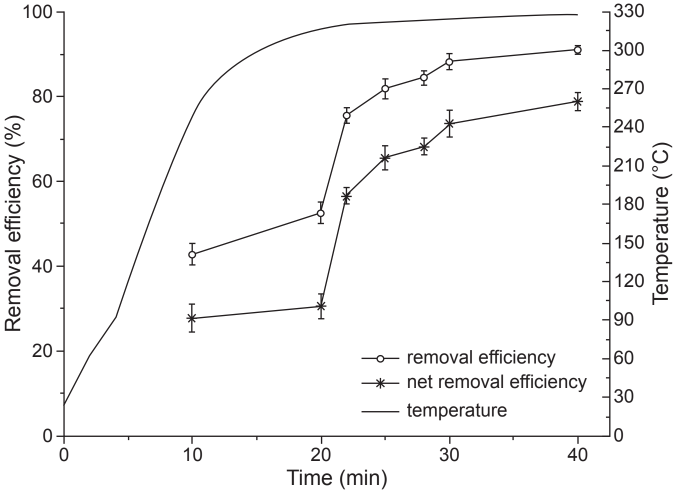

Figure 7.19 Effects of reaction time on the removal efficiency using microwave treatment process.

removal efficiency increased with reaction time. There was a turning point at 20 min in the removal efficiency−time curve. A sharp increase was found between 20 and 22 min.

7.2.1.6 Effect of Gas Flow

C&D waste (C5) was placed in boat B (60 × 25 × 15) and treated for 40 min under the microwave power of 800 W and with different gas flow. The results are shown in Fig. 7.20. It was found that gas flow had little effect on the removal efficiency or organic pollutants within 0−30 mL/min. When the gas flow was zero, the apparent removal efficiency was low because the volatile pollutant was not carried away by gas flow and was condensed on the surface of C&D waste. When the gas flow reached 30 mL/min, the apparent removal efficiency was low because the large gas flow would take more heat away thus decreasing the amount of volatile pollutants.

7.2.2 Conventional Heating Treatment Using Electric Oven

7.2.2.1 Effects of Construction and Demolition Waste Size on the Removal Efficiency

Samples C1−C6 were placed in boat B using electric furnace. The temperature program under microwave was simulated as: $20^\circ\mathrm{C} \xrightarrow{30\ \mathrm{min}} 320^\circ\mathrm{C} \xrightarrow{10\ \mathrm{min}} 340^\circ\mathrm{C}$. Conventional heat treatment was carried

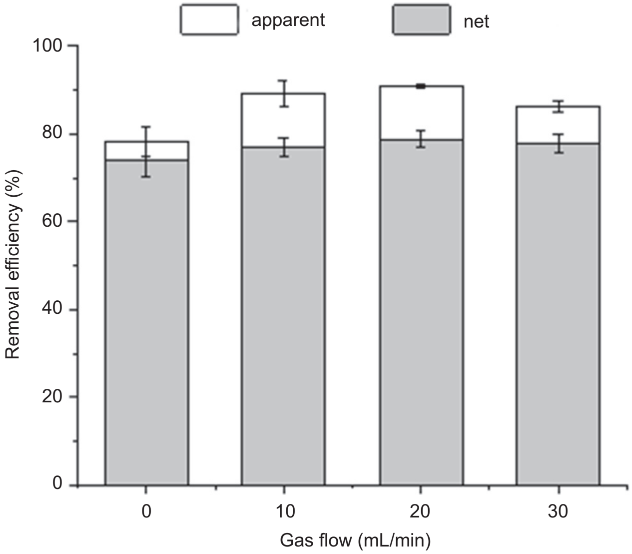

Figure 7.20 Effects of gas flow on the removal efficiency using microwave treatment process.

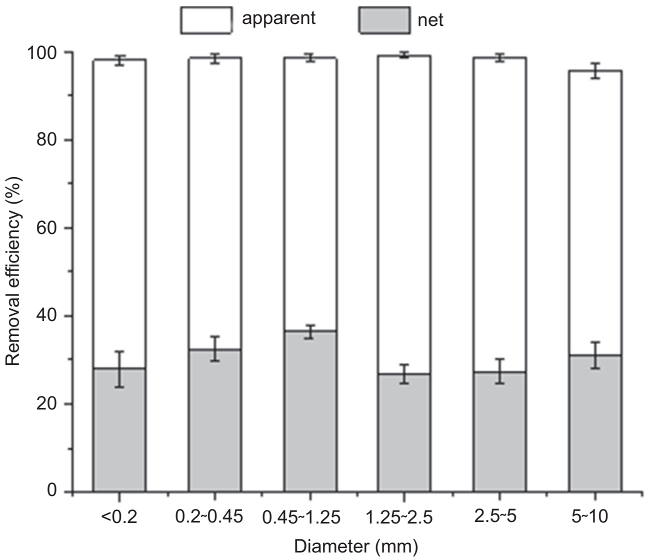

Figure 7.21 Removal efficiency of pollutants among different construction and demolition waste size using electric oven.

out using this simulation and the results are shown in Fig. 7.21. The variation of particle size hardly posed any influence on the removal efficiency. Although the apparent removal efficiency was above 95%, the highest net removal efficiency was only 36% (C3), which would lead to severe secondary pollution.

7.2.2.2 Effects of Temperature

Sample S5 was placed in boat B and the gas flow was set at 20 mL/min. When the temperature in the oven reached the target value, put the boat inside and treated at this temperature for 20 min. Results are shown in Fig. 7.22. It was found that little change happened in the apparent removal efficiency at 400–600°C and all of them were above 90%. The removal efficiency of *p*-aminoazobenzene was stabilized around 65% at 400–600°C. The removal efficiency of phenanthrene was 45% at 400–500°C, whereas that sharply increased to 70% at 600°C. In conventional heat treatment, the degradation activation temperature (T_e) of phenanthrene was around 600°C.

7.2.3 Comparison Between Conventional Heat Treatment and Microwave Treatment of Organic Pollutants

According to Figs. 7.12 and 7.21, inappropriate particle sizes and stack height would pose great influence on the removal efficiency of the organic

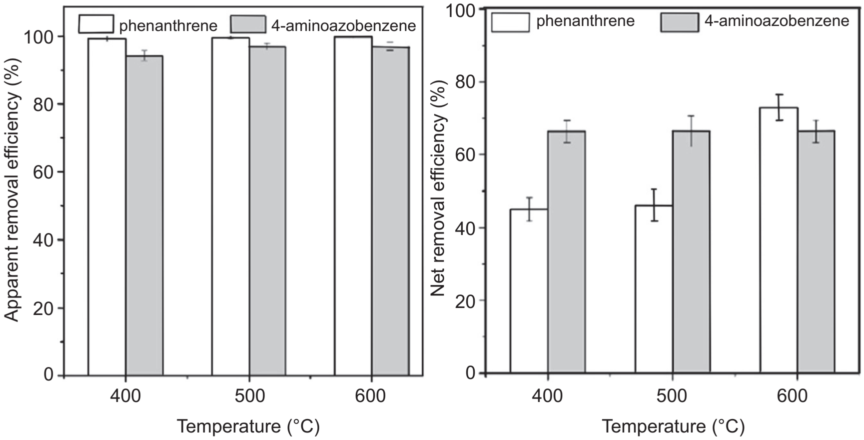

Figure 7.22 Removal efficiency of pollutants at different temperatures using conventional heat treatment.

pollutants in C&D waste, whereas there were no such restrictions in conventional heat treatment. However, under appropriate conditions, the removal efficiency of phenanthrene in microwave treatment was far larger than that in conventional treatment. As shown in Fig. 7.22, the applicable temperature for pollutant removal was 600°C in conventional treatment, which was much higher than that in microwave treatment (300°C). Conventional heat treatment would cause large energy consumption.

According to Figs. 7.13 and 7.18, there were limits for the highest temperature under specific power of microwave, which meant microwave treatment was not suitable for all organic pollutants. The conventional heat treatment might be able to treat more organic pollutants than microwave treatment.

7.3 STABILIZATION OF POLLUTANTS USING HIGH PRESSURE FORMATION

Large amounts of dust would be generated in the demolition, transport, handling, and other processes, which are regarded as an important component of smog. The clean or contaminated C&D waste (mainly in granules or powder) was filled in the hydraulic mold model, and the hydraulic pressure was set within 10—21 MPa. The C&D waste was pressed for a few minutes and would be formed to a module in blocks. Far less dust would be generated from the pressed C&D waste blocks in their transport and landfill processes. Besides, the density and volume of C&D waste blocks would

Figure 7.23 Press device for block formation of heavy metals and organic pollutants–contaminated construction and demolition waste.

be increased and decreased, respectively. As a result, the standardization of transport and efficient disposal management would be achieved. The device is shown in Fig. 7.23, the model of the hydraulic machine was YQ32-500 and the press force was 5000 kN.

Leaching toxicity tests were performed before and after the formation of heavy metals and organic pollutants–contaminated C&D waste. The test method was Toxicity characteristic leaching procedure specified in US Environmental Protection Agency method and results are listed in Table 7.10.

Table 7.10 Comparison of Leaching Toxicity of Construction and Demolition Waste Before and After Formation (Single Pollutant and Multipollutants)

	Leaching Amount (mg/L)			**Leaching Amount (mg/L)**	
Single Pollutant	**Before Formation**	**After Formation**	**Multipollutants**	**Before Formation**	**After Formation**
Phorate	8.3	5.9	Phorate	8.1	6.2
O,O-diethyl dithiophosphate	10.7	4.9	O,O-diethyl dithiophosphate	11.6	5.6
O,O,O-Triethylphosphorothioate	1.7	0.7	O,O,O-Triethylphosphorothioate	1.5	0.7
Cypermethrin	0.7	0.7	Cypermethrin	0.7	-
Cd	39.8	32.4	Cd	31.5	29.2
Cr	23.9	29.6	Cr	22.8	18.7
Cu	36.5	37.2	Cu	28.5	30.1
Pb	47.9	44.8	Pb	36.9	33.5
Zn	19.6	19.2	Zn	18.5	16.2

According to Table 7.10, the leaching amount of both heavy metals and organic pollutants decreased after the block formation of C&D waste. The decrease of leaching amount of single-pollutant-contaminated C&D waste was higher than multipollutant-contaminated C&D waste, assuming the competitive effects like coupling/fixation of multipollutants in the formation process.

7.4 MILLING—OXIDATION TECHNIQUE FOR DEGRADING ORGANIC CONTAMINANTS FROM CONTAMINATED CONSTRUCTION AND DEMOLITION WASTE

The milling—oxidation technique is that the oxidants fully contact with and destruct organic contaminants in C&D waste under milling condition. Compared with the microwave technique, it is adaptable for higher-boiling-point organic pollutants.

7.4.1 Effectiveness of Oxidants

$KMnO_4$, MnO_2, K_2FeO_4, Na_2CO_4, CaO_2, and $(NH_4)_2S_2O_4$ were the possible effective oxidants for the milling—oxidation process to be used. Samples of 5.0000 g S1 with different oxidants were numbered A—H and listed in Table 7.11. The rotation speed of milling was 800 rpm and milling time was 1 h. The removal effects are shown in Fig. 7.24.

Samples of 5.0000 g S1 with 200 μL H_2O and different oxidants were numbered AW-DW, as shown in Table 7.12. The rotation rate of milling was 800 rpm and the time was 1 h. The removal effects are shown in Fig. 7.25.

As indicated in Fig. 7.24, the phenanthrene and *p*-aminoazobenzene was hardly removed in the milling process without chemical oxidants, and reached its maximum with the addition of potassium permanganate, more than 85% under dry conditions and more than 75% under aqueous conditions, respectively. Ammonium persulfate had a better removal of *p*-aminoazobenzene, which was 83% under anhydrous conditions, whereas that of phenanthrene was only 30%. Potassium permanganate should be the best oxidant in the milling solid phase reaction process.

7.4.2 Influencing Factors for Milling—Oxidation Technique for Degrading Organic Contaminants From Contaminated C&D Waste

7.4.2.1 Milling Time

5.0000 g sample S1 was accurately weighed and the speed of miller was set as 400 rpm (the actual speed was 800 rpm). Potassium permanganate was used

Table 7.11 Arrangement of Oxidants for Different Construction and Demolition Waste Samples

	Samples							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Oxidant								
$KMnO_4$	0.0450	—	—	—	—	0.0500	—	—
MnO_2	0.005	—	—	—	—	—	0.0500	—
K_2FeO_4	—	0.0500	—	—	—	—	—	—
Na_2CO_4	—	—	0.0500	—	—	—	—	—
CaO_2	—	—	—	0.0500	—	—	—	—
$(NH_4)_2S_2O_4$	—	—	—	—	0.0500	—	—	—

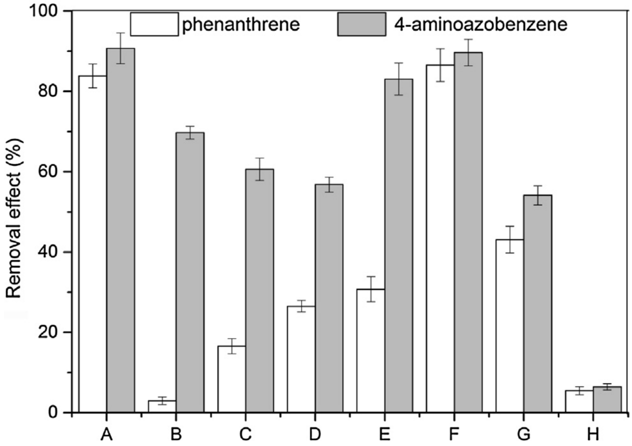

Figure 7.24 Effects of oxidants on milling–oxidation technique for degrading organic contaminants from contaminated construction and demolition waste.

as the oxidant and the treatment results at different time are shown in Fig. 7.26. It was indicated that the removal efficiency of pollutants increased with time, and the removal efficiency of *p*-aminoazobenzene between 20 and 60 min and that of phenanthrene between 30 and 60 min became stabilized at above 80%. In summary, potassium permanganate and organic pollutants were able to fully react for decomposition at 30 min.

Particle size distribution before and after milling was evaluated using the Malvern laser particle size analyzer. The variation of average size of the surface area (D[3,2]) and the surface area with milling time are shown in Fig. 7.27. D[3,2] decreased and became stabilized with time. Their

Table 7.12 Oxidant Combinations of Different Construction and Demolition Waste Samples

	Samples			
	AW	BW	CW	DW
Oxidant				
$KMnO_4$	0.0500	—	—	—
Na_2CO_4	—	0.0500	—	—
CaO_2	—	—	0.0500	—
$(NH_4)_2S_2O_4$	—	—	—	0.0500

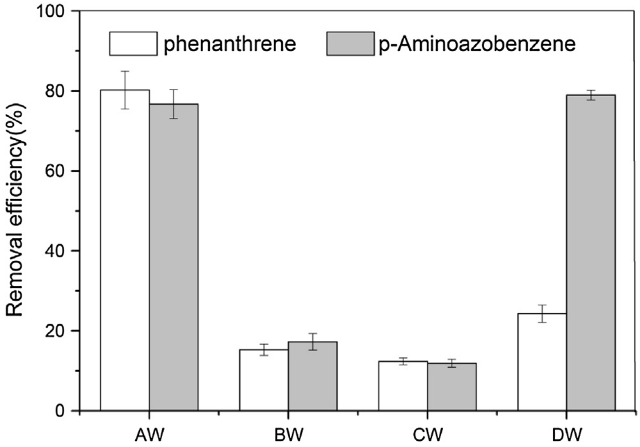

Figure 7.25 Treatment efficiency of different oxidants with the moisture content of 4% using milling—oxidation technique for degrading organic contaminants from contaminated construction and demolition waste.

functional relationship was emulated using Origin, which are shown in the equations listed below in order. The R^2 was 0.9999 and 0.9992, respectively.

$$D = \frac{1.904 + 6.456}{\left(1 + 1.400 \times 10^{-2} T^{1.834}\right)}$$

$$S = \frac{3181 - 2464}{\left(1 + 3.548 \times 10^{-3} T^{1.791}\right)}$$

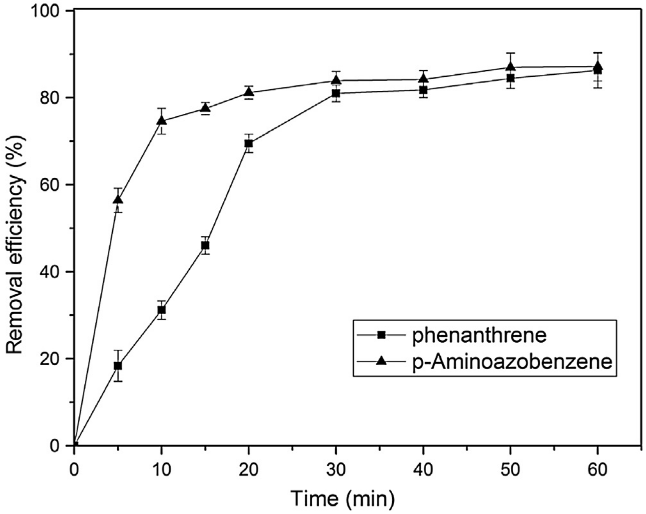

Figure 7.26 Removal efficiency of organic pollutants using potassium permanganate with time using milling–oxidation technique.

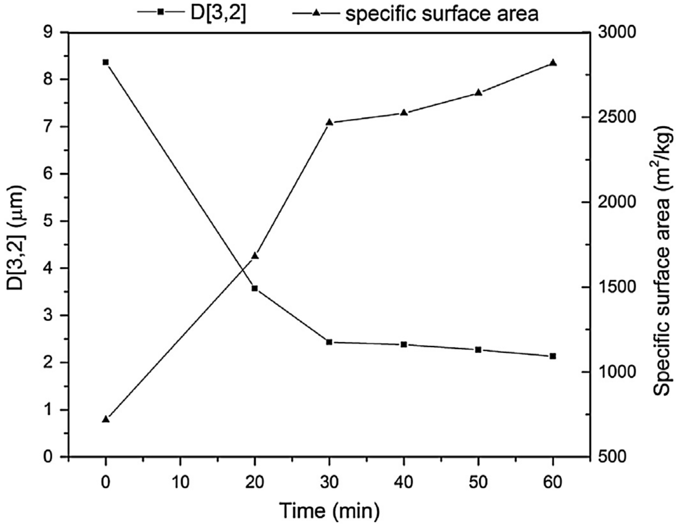

Figure 7.27 Variation of D[3,2] and specific surface area with milling time.

where D is the average size of the surface area after milling (D[3,2]), μm; T is the milling time, min; S is the specific surface area of C&D waste after milling, m^2/kg.

The variation of removal efficiency and specific surface area was similar, as a breaking point existed at 30 min. It was supposed that the milling was fully at this time and potassium permanganate was completely mixed with the pollutants. The large specific surface area had a positive effect on the removal efficiency, which reached its maximum at 30 min.

7.4.2.2 Milling Speed

Five grams sample S1 was accurately weighed and the milling time was set as 30 min; 0.0500 g potassium permanganate was used as the oxidant and the treatment results at different times are shown in Fig. 7.28. It was shown that the removal efficiency of organic pollutants increased with the milling speed. The removal efficiency of *p*-aminoazobenzene reached 80% at 600 rpm and became stabilized as speed increased, whereas the removal efficiency of phenanthrene reached 80% at 800 rpm.

Particle size distribution before and after milling was evaluated using the Malvern laser particle size analyzer, the variation of average size of the surface area (D[3,2]) and the specific surface area with milling time is shown in Fig. 7.29. D[3,2] decreased, whereas the specific surface area increased with milling speed. Their functional relationship was emulated using Origin,

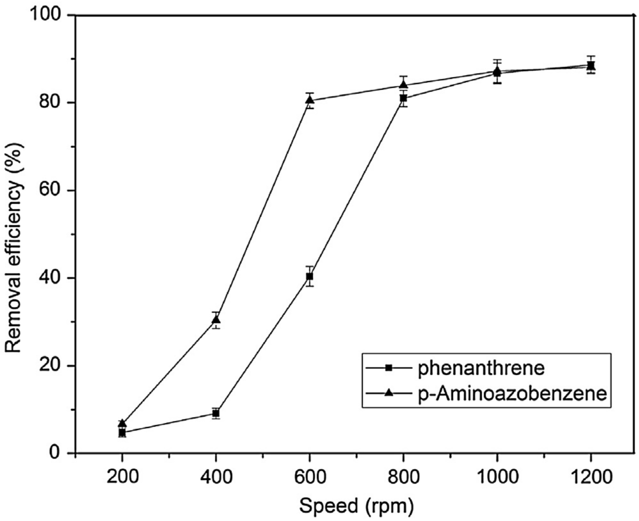

Figure 7.28 Removal efficiency of organic pollutants using potassium permanganate at different milling speeds.

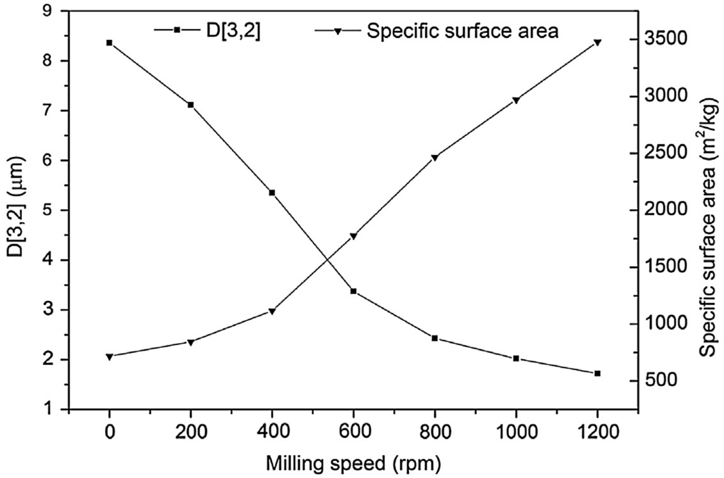

Figure 7.29 Variation of D[3,2] and specific surface area with milling speed.

which was shown in the equations listed below in order. The R^2 was 0.9975 and 0.9977, respectively.

$$D = \frac{0.704 + 7.597}{(1 + 2.049 \times 10^{-6} R^{2.126})}$$

$$S = 4385 - \frac{3633}{(1 + 1.867 \times 10^{-9} R^{2.986})}$$

where R was the milling speed, rpm.

It can be seen that the removal efficiency of *p*-aminoazobenzene was 81.53%, the specific surface area was 1778 m^2/kg, and D[3,2] was 3.37 μm at 600 rpm (30 min), respectively.

7.4.2.3 Moisture Content

Five grams sample S1 was accurately weighed and the milling time was set as 30 min and the milling speed was 400 rpm. Different volumes of deionized water were spiked to simulate different moisture content; 0.0500 g potassium permanganate was used as the oxidant and the treatment effect with different moisture contents is shown in Fig. 7.30. The removal efficiency decreased with the increase of moisture content in general.

Particle size distribution before and after milling was evaluated using the Malvern laser particle size analyzer; the variation of average size of the surface area (D[3,2]) and the specific surface area with milling time are shown in Fig. 7.31. Results showed that the removal efficiency decreased with the

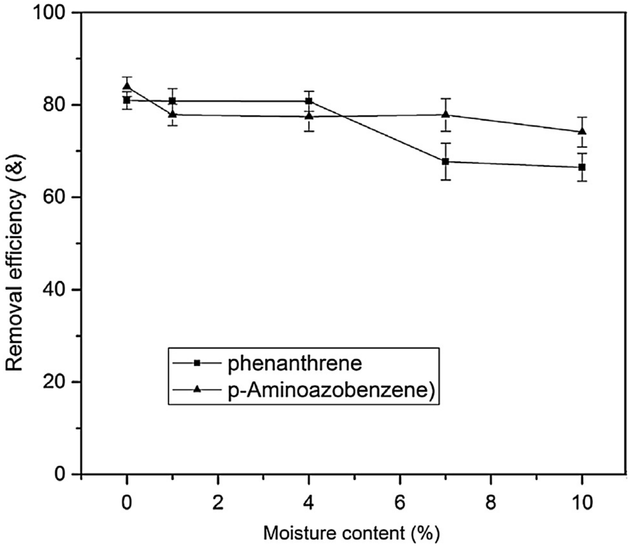

Figure 7.30 Removal efficiency of organic pollutants using potassium permanganate with different moisture contents.

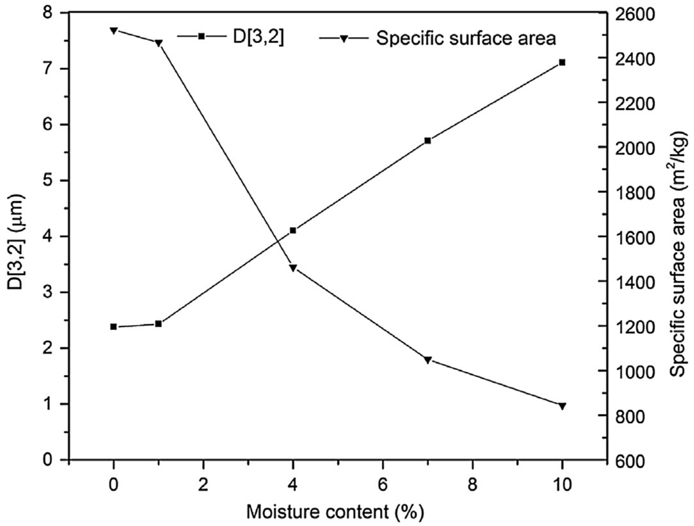

Figure 7.31 Variation of D[3,2] and specific surface area with different moisture contents.

increase of water content. The existence of moisture was supposed to promote the contact between oxidant and pollutants; however, the increase of water content might also decrease the specific surface area. Overall, the removal efficiency under dry conditions was better.

7.4.2.4 Oxidant Amount

Five grams sample S1 was accurately weighed and the milling time was set as 30 min and the milling speed was 400 rpm. Different amounts of potassium permanganate were added as the oxidant and the treatment efficiency is shown in Fig. 7.32. In general, the removal efficiency of both pollutants increased with the addition of oxidants, which became stabilized when the amount added up to 1%.

7.4.3 Modeling Treatment of Milling–Oxidation Process

7.4.3.1 Relationship Between Removal Efficiency and the Specific Surface Area of Construction and Demolition Waste

Five grams sample S1 was accurately weighed and 0.0500 g potassium permanganate was used as the oxidant. The fit curve of D[3,2] and the specific surface area under different milling speed and time were demonstrated in Figs. 7.33 and 7.34. Results showed that good correlation existed, which further proved their effect on the removal efficiency.

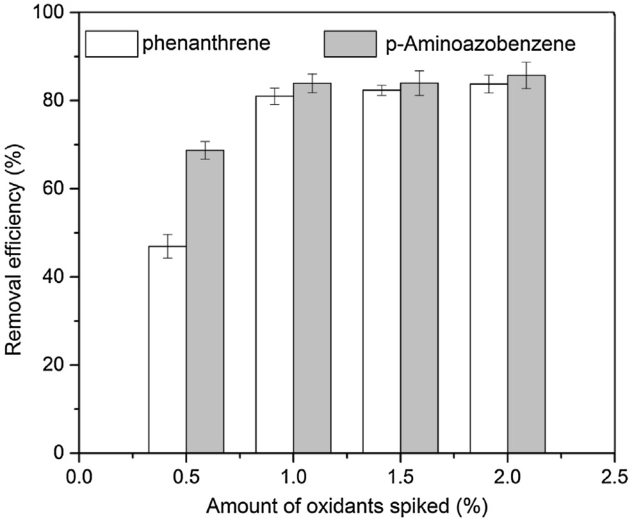

Figure 7.32 Removal efficiency of organic pollutants with different amounts of potassium permanganate.

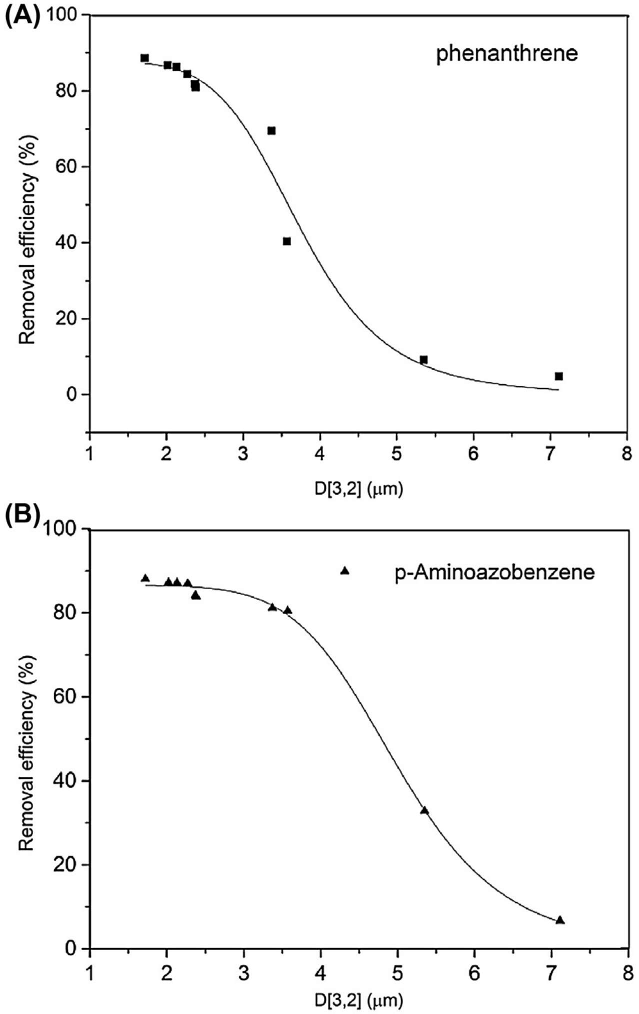

Figure 7.33 Curve of removal efficiency and D[3,2] in milling—oxidation process for construction and demolition waste: (A) phenanthrene, (B) *p*-aminoazobenzene.

The functional relationship between the removal efficiency of phenanthrene and the D[3,2] of samples after milling is shown in the first equation below ($R^2 = 0.974$), and that between the removal efficiency of phenanthrene and the specific surface area was reflected in the second equation below ($R^2 = 0.974$). As for *p*-aminoazobenzene, the relationship was reflected in the third ($R^2 = 0.998$) and fourth ($R^2 = 0.998$) equations below, respectively. Good correlation was found among these factors.

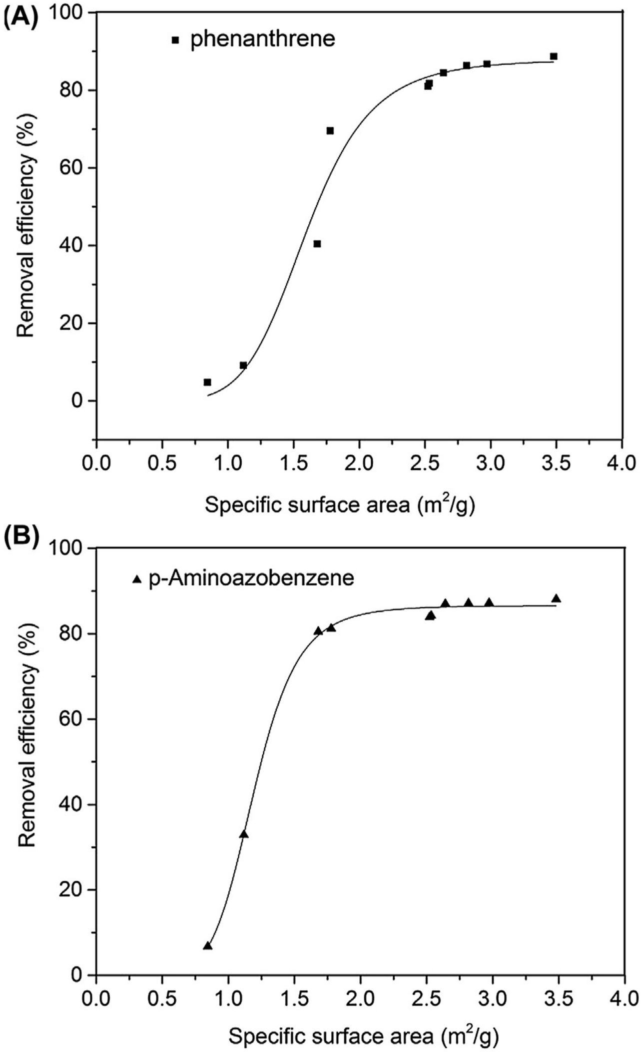

Figure 7.34 Curve of removal efficiency and specific surface area in milling−oxidation process for construction and demolition waste: (A) phenanthrene, (B) *p*-aminoazobenzene.

$$Y_f = \frac{1}{(1.139 + 2.060 \times 10^{-4} D^{6.532})}$$

$$Y_f = \frac{4.204 S^{6.455}}{(100 + 4.783 S^{6.455})}$$

$$Y_a = \frac{1}{(1.155 + 1.124 \times 10^{-5} D^{7.168})}$$

$$Y_a = \frac{2.412 S^{7.158}}{(10 + 2.787 S^{7.158})}$$

where Y_f is the removal efficiency of phenanthrene; Y_a is the removal efficiency of *p*-aminoazobenzene, %; D is D[3,2] of the C&D waste after milling, μm; S is the specific surface area of the C&D waste after milling, m^2/g.

In this condition, the calculated value and actual value of the removal efficiency of phenanthrene and *p*-aminoazobenzene at different milling times using the aforementioned equations are listed in Table 7.13.

The calculated value and actual value of the removal efficiency of phenanthrene and *p*-aminoazobenzene at different milling speeds using the aforementioned equations are listed in Table 7.14.

Table 7.13 Comparison of the Calculated Value and Actual Value of the Removal Efficiency in Milling–Oxidation Process for Construction and Demolition Waste

	Removal Efficiency of Phenanthrene			**Removal Efficiency of *p*-Aminoazobenzene**		
Milling Time (min)	**Calculated Value 1[a] (%)**	**Calculated Value 2[b] (%)**	**Actual Value (%)**	**Calculated Value 1 (%)**	**Calculated Value 2 (%)**	**Actual Value (%)**
20	58.34	58.38	69.51	81.77	81.81	81.17
30	78.57	78.41	80.98	85.57	85.53	83.92
40	83.27	83.22	81.79	86.14	86.11	84.23
50	84.83	84.84	84.47	86.31	86.28	86.99
60	85.52	85.56	86.28	86.38	86.35	87.19

[a] Calculated by D[3,2].
[b] Calculated by specific surface area.

Table 7.14 Comparison of the Calculated Value and Actual Value of the Removal Efficiency in Milling–Oxidation Process for Construction and Demolition Waste

	Removal Efficiency of Phenanthrene			**Removal Efficiency of *p*-Aminoazobenzene**		
Milling Speed (rpm)	**Calculated Value 1[a] (%)**	**Calculated Value 2[b] (%)**	**Actual Value (%)**	**Calculated Value 1 (%)**	**Calculated Value 2 (%)**	**Actual Value (%)**
200	1.15	1.00	4.76	5.64	4.69	6.72
400	9.36	7.60	9.11	37.93	32.27	32.85
600	50.58	54.72	40.40	79.51	80.83	80.48
800	80.63	82.49	80.98	85.83	86.03	83.92
1000	86.38	86.50	86.72	86.46	86.44	87.24
1200	87.41	87.29	88.65	86.55	86.50	88.09

[a] Calculated by D[3,2].
[b] Calculated by specific surface area.

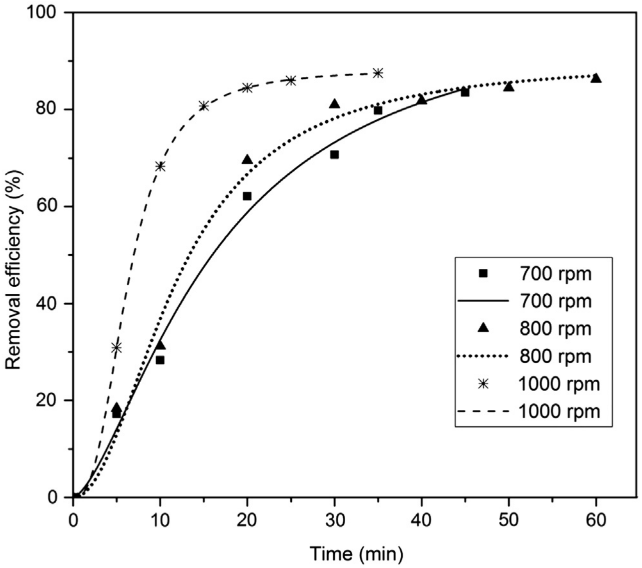

Figure 7.35 Curve of phenanthrene removal efficiency and milling time for construction and demolition waste.

7.4.3.2 Relationship Between Removal Efficiency and the Milling Time

The fit curves at different milling times and the speed of 700, 800, and 1000 rpm are demonstrated in Figs. 7.35 and 7.36. The time used to reach the highest removal efficiency was shortened with the increase of the milling speed.

The fit function of removal efficiency and milling time at 700, 800, and 1000 rpm was reflected in the following six equations, and the R^2 was 0.987, 0.992, 0.983, 0.992, 0.999, and 0.999, respectively.

$$Y_f = \frac{137.4T^{1.540}}{(100 + 1.345T^{1.540})}$$

$$Y_a = \frac{140.2T^{1.418}}{(10 + 1.616T^{1.418})}$$

$$Y_f = \frac{56.59T^{2.040}}{(100 + 0.627T^{2.040})}$$

$$Y_a = \frac{137.0T^{1.533}}{(10 + 1.569T^{1.533})}$$

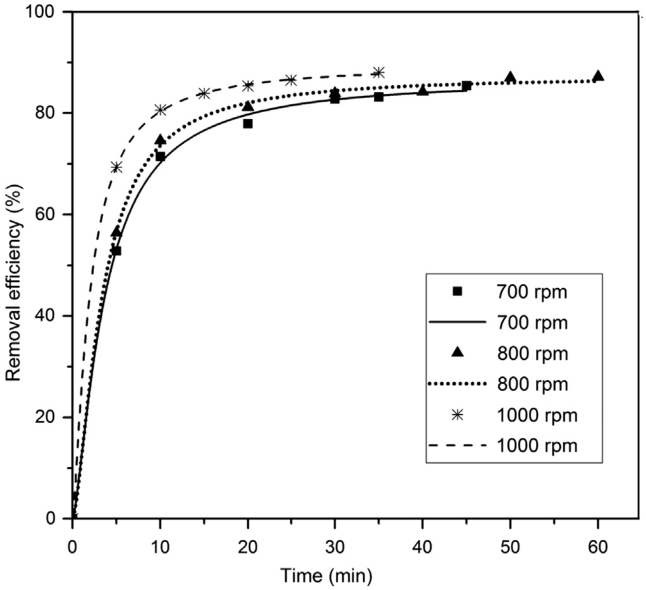

Figure 7.36 Curve of *p*-aminoazobenzene removal efficiency and milling time for construction and demolition waste.

$$Y_f = \frac{63.43T^{2.681}}{(100 + 0.718T^{2.681})}$$

$$Y_a = \frac{357.9T^{1.338}}{(10 + 3.995T^{1.338})}$$

The calculated value and actual value of the removal efficiency of phenanthrene and *p*-aminoazobenzene using the above-mentioned equations are listed in Table 7.15.

Table 7.15 Comparison of the Calculated Value and Actual Value of the Removal Efficiency for Construction and Demolition Waste

		Removal Efficiency of Phenanthrene		**Removal Efficiency of *p*-Aminoazobenzene**	
Milling Time (min)	**Milling Speed (rpm)**	**Calculated Value**	**Actual Value**	**Calculated Value**	**Actual Value**
40	700	81.49	81.14	83.98	83.81
15	800	55.17	46.02	79.35	77.50
30	1000	87.01	86.72	87.28	87.24

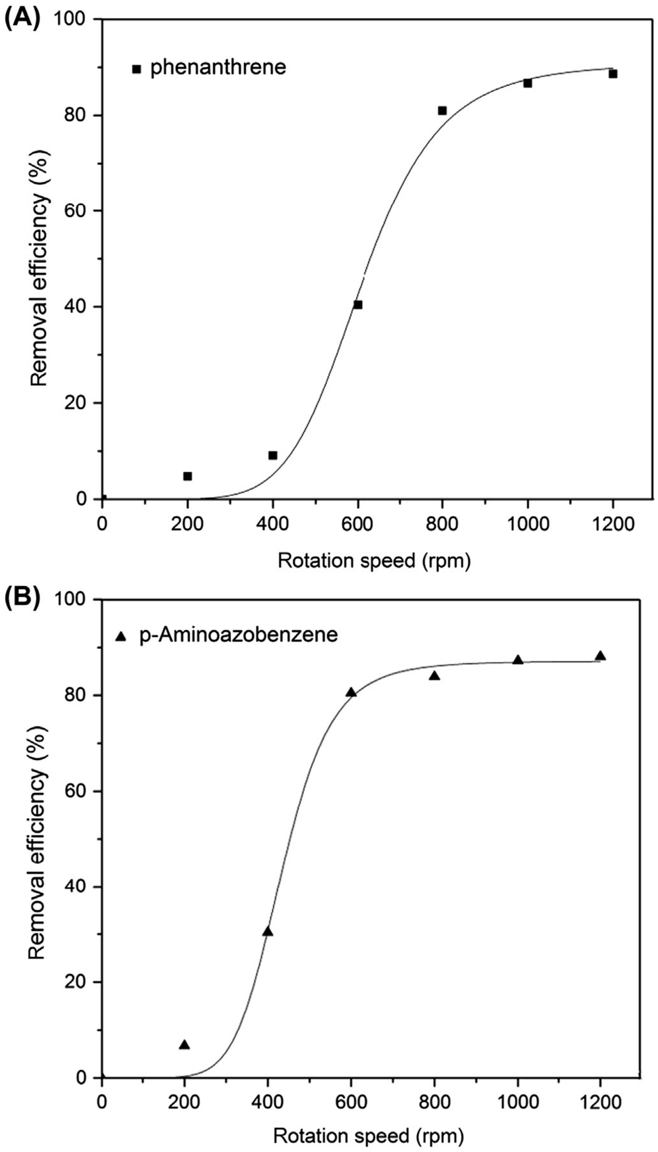

Figure 7.37 Curve of removal efficiency and rotation speed (milling time 30 min) for construction and demolition waste: (A) phenanthrene, (B) *p*-aminoazobenzene.

7.4.3.3 *Relationship Between Removal Efficiency and the Milling Speed*

The fit curve at different milling speeds is demonstrated in Fig. 7.37; the milling time was set to 30 min.

The fit function of removal efficiency of phenanthrene and milling speed was reflected in the first equation below ($R^2 = 0.993$). The fit function of removal efficiency of *p*-aminoazobenzene and milling speed was reflected in the second equation below ($R^2 = 0.992$).

$$Y_f = \frac{5.471 \times 10^{-4} R^{6.641}}{(1 + 6.024 \times 10^{-6} R^{6.641})}$$

$$Y_a = \frac{1.927 \times 10^{-3} R^{7.293}}{(1 + 2.212 \times 10^{-5} R^{7.293})}$$

where Y_f is the removal efficiency of phenanthrene, %; Y_a is the removal efficiency of *p*-aminoazobenzene, %; R is the rotation speed, 10^2 rpm.

Table 7.16 Comparison of the Calculated Value and Actual Value of the Phenanthrene Removal Efficiency for Construction and Demolition Waste

Rotation Speed (rpm)	**Calculated Value 1[a] (%)**	**Calculated Value 2[b] (%)**	**Calculated Value 3[c] (%)**	**Actual Value (%)**
500	25.58	25.33	18.97	23.77
700	70.65	74.59	64.62	70.67
900	84.73	85.36	84.39	85.66

[a] Calculated based on $D = \frac{0.704+7.597}{(1+2.049\times10^{-6}R^{2.126})}$ and $Y_f = \frac{1}{(1.139+2.060\times10^{-4}D^{6.532})}$.

[b] Calculated based on $S = 4385 - \frac{3633}{(1+1.867\times10^{-9}R^{2.986})}$ and $Y_f = \frac{4.204S^{6.455}}{(100+4.783S^{6.455})}$.

[c] Calculated based on $Y_f = \frac{5.471\times10^{-4}R^{6.641}}{(1+6.024\times10^{-6}R^{6.641})}$.

Table 7.17 Comparison of the Calculated Value and Actual Value of the *p*-Aminoazobenzene Removal Efficiency for Construction and Demolition Waste

Rotation Speed (rpm)	**Calculated Value 1[a] (%)**	**Calculated Value 2[b] (%)**	**Calculated Value 3[c] (%)**	**Actual Value (%)**
500	65.09	64.79	64.00	63.04
700	84.36	85.00	84.49	82.81
900	86.30	86.33	86.69	86.49

[a] Calculated based on $D = \frac{0.704+7.597}{(1+2.049\times10^{-6}R^{2.126})}$ and $Y_a = \frac{1}{(1.155+1.124\times10^{-5}D^{7.168})}$.

[b] Calculated based on $S = 4385 - \frac{3633}{(1+1.867\times10^{-9}R^{2.986})}$ and $Y_a = \frac{2.412S^{7.158}}{(10+2.787S^{7.158})}$.

[c] Calculated based on $Y_a = \frac{1.927\times10^{-3}R^{7.293}}{(1+2.212\times10^{-5}R^{7.293})}$.

Table 7.18 Example of Cost Summary of Construction and Demolition Waste Project

Treatment of heavy metals—contaminated C&D waste generated from a manufacturing workshop (source identification to ultimate disposal)
Construction area: 2000 m^2
Contaminated C&D waste: 800 t
Duration: 30 days
Site: Former industrial factory

Capital Costs

Description	Quantity	Unit ($)	Total ($)	Notes
Source Identification and Sampling				
Engineering evaluation	1	800	800	Project establishment, feasibility study
Construction staking and field surveys	1	2200	2200	Field survey
Stripping equipment	1	11,000	11,000	Sampling of the surface C&D waste
Drilling equipment	2	3000	6000	Sampling of the inner C&D waste
Collection	1	330	330	Collection of the debris sampled
Crusher	1	11,000	11,000	Large mobile crusher
Dust controller	1	1900	1900	Remove the dust generated during the demolition
Transportation	1000	2	2000	\$2/m^3 within the factory, 1 t C&D waste/$m^2$of construction area, 1/2 of the C&D waste needed to be transported during the demolition
Analysis	200	15	3000	\$15 for each sample, 1 sample/10 m^2
Subtotal			38,230	
Treatment Process				
Sorting machine	1	800	800	Sorting of C&D waste of different sizes and types
Solid—liquid separator	3	900	2700	Separation of solid waste and liquid

Table 7.18 Example of Cost Summary of Construction and Demolition Waste Project—cont'd

Chemical reagents	800	6	4800	\$6/m^3 hazardous waste
Elution equipment	1	500	500	Pipes, spilling machines, collector
Water treatment	20	100	2000	\$100/day
Pump	6	220	1320	Pump for waste water and chemical reagents
Field installation	1	3300	3300	Installation of equipment and other materials
Surface cover	1	180	180	Prevention of rain
Driving device	6	180	1080	Conveyor belts and machines
Electricity and water	28	110	3080	Mostly caused by equipment
Analysis	220	15	3300	\$15 for each sample, 20 water samples and 200 solid samples
Transportation	1	2300	2300	Including the transportation of mobile crusher and other equipment to the industrial site
Subtotal			25,360	
Ultimate Disposal				
Backfilling	1200	4	4800	\$4/m^3, the clean C&D waste was backfilled nearby
Landfilling	800	10	8000	\$10/t
Transportation	320	13	4160	Including the transportation of treated C&D waste to landfill sites/recycling factories, average distance was 50 km, \$13/m^3, 2.5 t/m^3, 800 t treated C&D waste
Vehicles	2	13,000	26,000	Used for the transportation of waste (not including C&D waste)
Subtotal			42,960	
Total cost			106,550	

The calculated value and actual value of the removal efficiency of phenanthrene and *p*-aminoazobenzene using the aforementioned equations are listed in Tables 7.16 and 7.17.

7.5 ECONOMIC PERFORMANCE OF TREATMENT FOR HEAVY METAL—CONTAMINATED WASTE: CASE STUDY

This section will briefly give an overview of potential costs for treatment of contaminated C&D waste introduced in this chapter. The cost is listed in detail in Table 7.18.

CHAPTER EIGHT

Recycling Technologies and Pollution Potential for Contaminated Construction and Demolition Waste in Recycling Processes

8.1 LEACHING CHARACTERISTICS OF RECYCLED CONCRETE GENERATED FROM HEAVY METALS–CONTAMINATED WASTE

Based on the results of pollution characterization, the most severely contaminated construction and demolition (C&D) waste was used as raw materials to produce recycled concrete blocks so as to reveal the leaching toxicity of recycled aggregates. Concentration of heavy metals of the six C&D wastes selected is listed in Table 8.1. The maximum content was: Cu (59,434.02 mg/kg), Zn (49,280 mg/kg), Pb (1054.34 mg/kg), Cr (7511.03 mg/kg), Cd (15.40 mg/kg), and Ni (2867.77 mg/kg), respectively.

The mix design of recycled concrete was based on the procedures for the Production of ordinary concrete. Natural aggregate (or gravel) was replaced by contaminated C&D waste.

Leaching experiments were performed using the HJ/T299-2007 method, and the results are listed in Table 8.2. The most severely contaminated C&D waste by Cu was obtained in the copper workshop from an electroplating factory, with an amount of 59,434.02 mg/kg and the leaching amount of 4.19 mg/L, higher than the Integrated wastewater discharge standard (2.0 mg/L) but lower than the Standard for pollution control on the security landfill site for hazardous wastes (75 mg/L). Results indicated that these kinds of C&D waste should not be disposed randomly but could be sent to landfill site as hazardous wastes. The leaching amount lowered to 0.75 mg/L after it was produced into recycled aggregates, lower than the Standards for drinking water quality and Environmental quality standards for surface water (level III).

The most severely contaminated C&D waste by Zn was obtained in the zinc electrolysis workshop, with an amount of 49,280 mg/kg and the leaching

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Table 8.1 Maximum Content of Heavy Metals in Contaminated Construction and Demolition (C&D) Waste

	Heavy Metal (mg/kg)						
C&D Waste	**Cu**	**Zn**	**Pb**	**Cr**	**Cd**	**Ni**	**As**
Cu-CI8	59,434.02[a]	3685.82	7.56	97.36	2.24	591.11	132.50
Zn-MI1	3743.74	49,280	412.45	113.33	13.65	101.12	155.09
Pb-MI29	82.72	467.59	1054.34	461.87	ND[b]	68.69	18.37
Cr-CI9	309.66	290.55	438.90	7511.03	ND	10.21	18.84
Cd-MI2	476.36	29,738.72	879.45	83.29	15.40	34.09	232.31
Ni-CI10	3190.11	312.83	58.84	306.46	ND	2867.77	17.20
Max	59,434.02	49,280	1054.34	7511.03	15.40	2867.77	232.31
Min	82.72	467.59	7.56	83.29	ND	10.21	17.20
De/An[c]	6/6	6/6	6/6	6/6	3/6	6/6	6/6
TVHM (level-I)	35	100	35	90	0.2	40	15
TVHM (level-II)	100	250	300	200	0.6	60	25
TVHM (level-III)	400	500	500	300	1	200	40

CI, chemical industry; *MI*, metallurgical industry; *TVHM*, "the threshold values of heavy metals level III (CEPA, GB 15618-1995)."

[a] Average ± SD.

[b] Undetected.

[c] Samples in which pollutants were detected/all samples.

amount of 4.29 mg/L. The highest leaching amount of the six wastes was 5.17 mg/L, higher than the Integrated wastewater discharge standard (5 mg/L). The two highest leaching amounts of C&D waste after being produced into recycled products were 1.19 and 1.09 mg/L, both higher than the Environmental quality standards for surface water (level III), which indicated that they had potential risk to the surface water. No Zn was detected in the leachate of aggregates produced by other Zn-contaminated C&D wastes.

The most severely contaminated C&D waste by Pb was the firebrick in steelmaking plant, the amount was 1054.34 mg/kg and the leaching amount was 0.04 mg/L, higher than the Standards for drinking water quality (0.01 mg/L), but lower than the Environmental quality standards for surface water (level III) (0.05 mg/L). The highest initial leaching amount was 2.13 mg/L from the cleaning workshop in zinc factory, higher than the Integrated wastewater discharge standard (1.0 mg/L) but lower than the Standard for pollution control on the security landfill site for hazardous wastes (5 mg/L). It would cause aquatic pollution if abandoned, but landfill disposal was feasible. The leaching amount after recycling process was lower than the detection limit, which meant that the recycling process would largely reduce the environmental risk.

Table 8.2 Leaching Amounts of Heavy Metals From the Contaminated Construction and Demolition Waste Before and After Recycling

	Heavy Metal (mg/L)						
	Cu	**Zn**	**Pb**	**Cr**	**Cd**	**Ni**	**As**
Cu-CI8 BR	4.19	5.17	ND[a]	ND	ND	1.80	ND
Cu-CI8 AR	0.75 (82%)[b]	ND (100%)	ND	0.14 (–)	ND	ND (100%)	ND
Zn-MI1 BR	1.19	4.29	0.50	ND	ND	ND	0.93
Zn-MI1 AR	0.49 (60%)	1.19(72%)	ND (100%)	0.10 (–)	ND	ND	2.71 (−191%)
Pb-MI32 BR	0.05	0.64	0.04	ND	ND	ND	ND
Pb-MI32 AR	ND (100%)	ND (100%)	ND (100%)	0.89 (–)	ND	ND	ND
Cr-CI9 BR	ND	ND	ND	450.10	ND	ND	ND
Cr-CI9 AR	ND	ND	ND	154.31 (66%)	ND	ND	ND
Cd-MI2 BR	0.29	4.82	2.13	ND	ND	ND	3.09
Cd-MI2 AR	0.15 (48%)	1.09 (77%)	ND (100%)	2.29 (–)	ND	ND	6.00 (−94%)
Ni-MI10 BR	0.50	ND	ND	5.32	ND	ND	ND
Ni-MI10 AR	0.10 (80%)	ND	ND	1.75 (67%)	ND	ND	ND
De/An[c]	9/12	6/12	3/12	8/12	0/12	1/12	4/12
[d]Standards for drinking water quality	1.0	1.0	0.01	0.05	0.005	0.02	0.05
[e]Environmental quality standards for surface water (level III)	1.0	1.0	0.05	0.05	0.005	-	0.05
[f]Integrated wastewater discharge standard	2.0	5.0	1.0	1.5	0.1	1.0	0.5
[g]Standard for pollution control on the security landfill site for hazardous wastes	75	75	5	12	0.5	15	2.5
[h]Identification standards for hazardous wastes	100	100	5	15	1	5	5

AR, after recycling; *BR*, before recycling; *CI*, chemical industry; *MI*, metallurgical industry.

[a] Undetected.

[b] Stabilization efficiency (percentage of the reduced leaching ratio).

[c] Samples in which pollutants were detected/all samples.

[d] Standards for drinking water quality (GB 5749-2006).

[e] Environmental quality standards for surface water (level III) (GB 3838-2002).

[f] Integrated wastewater discharge standard (China GB 8978-1996).

[g] Standard for pollution control on the security landfill site for hazardous wastes (China GB 18598-2001).

[h] Identification standards for hazardous wastes (China GB 5085.3-2007).

The most severely Cr-contaminated C&D waste was obtained in the Cr workshop from an electroplating factory, the amount was 7511.03 mg/kg and the initial leaching amount was 450.10 mg/L, which was 30 and 38 times that in the Identification standards for hazardous wastes and Standard for pollution control on the security landfill site for hazardous wastes, respectively, with huge environmental risk. Appropriate treatment should be performed before landfilling. Cr was detected in all the six leachate samples of recycled concrete. The highest amount was from the recycled concrete produced by C&D waste in Cr workshop from the electroplating factory, which was 154.31 mg/L, 10 times that in the Identification standards for hazardous wastes. The C&D waste should be treated properly before recycling.

The leaching amount of recycled aggregate produced by C&D waste from Ni workshop was 1.75 mg/L, which was higher than the Integrated wastewater discharge standard and lower than the Standard for pollution control on the security landfill site for hazardous wastes. It is worth pointing out that the leaching amount of four C&D wastes was lower than detection limit, whereas that of aggregate produced by these wastes was higher. The leaching amount of recycled aggregate produced by C&D waste from the cleaning workshop of Zn factory was 2.23 mg/L, which would cause aquatic pollution in its recycling process.

Most Cd in C&D waste was hard to be leached out. The results showed that none of the leachate of these samples contained Cd below detection limit, which indicated Cd had a relatively lower environmental risk.

The two most severely As-contaminated C&D waste was obtained in the cleaning workshop from zinc manufacturing factory and electrolysis plant, the amounts were 232.31 and 155.09 mg/kg, whereas the initial leaching amounts were 3.09 and 0.93 mg/L, respectively. However, the leaching amount of recycled aggregate was even higher, which was 6.0 and 2.71 mg/L, respectively. The former was higher than the Identification standards for hazardous wastes (5 mg/L), whereas the latter was higher than the Standard for pollution control on the security landfill site for hazardous wastes. Results indicated that As might cause a large environmental risk in the recycling of C&D waste.

8.1.1 Preparation of Metal-Contaminated Construction Materials

Six different construction materials were selected and the background content of heavy metals is listed in Table 8.3. The pollution concentration was set as 5000 mg/kg.

Table 8.3 Background Content of Heavy Metals in Six Different Construction Materials

	Heavy Metal (mg/kg)						
Sample	**Cu**	**Zn**	**Pb**	**Cr**	**Cd**	**Ni**	**As**
Cement brick—RS1	24.98	1057.45	26.03	245.16	ND[a]	27.98	68.68
Foam concrete—RS5	28.22	846.09	34.03	39.91	ND	10.58	54.94
Brick—RS3	40.24	328.18	20.19	74.20	ND	5.29	2.08
Dujiangyan recycled aggregate—RC3	28.67	1292.15	25.69	82.64	ND	21.07	76.93
Pudong regeneration gravel—RC4	21.74	115.50	17.95	52.96	ND	ND	ND
Steel firebrick—MI32	11.47	35.72	0.85	269.64	ND	51.4	20.27
Max	40.24	1292.15	34.03	269.64	ND	51.4	76.93
Min	11.47	35.72	0.85	39.91	ND	ND	ND
De/An[b]	6/6	6/6	6/6	6/6	0/6	5/6	5/6
TVHM (level-I)	35	100	35	90	0.2	40	15
TVHM (level-II)	100	250	300	200	0.6	60	25
TVHM (level-III)	400	500	500	300	1	200	40

MI, metallurgical industry; *RC*, recycled aggregates; *RS*, residential aggregates; *TVHM*, "the threshold values of heavy metals level III (CEPA,GB 15618-1995)."

[a] Undetected.

[b] Samples in which pollutants were detected/all samples.

8.1.2 Preparation of Recycled Concrete and Its Leaching Toxicity

Recycled concrete was produced by six different contaminated construction materials. Coir fiber was added to stabilize the heavy metals in the concrete. The coir fiber was treated with 2% NaOH so that various pores were generated on its service, which largely increased the combination between coir fiber and concrete. It could also increase the bending and compressive strength of the concrete products.

Three kinds of products were produced: normal recycled concrete, normal recycled concrete blocks with coir fiber, and alkali-treated recycled concrete blocks with coir fiber. Environmental risk of construction materials produced by contaminated C&D waste and the heavy metal stabilization effects of coir fiber were performed on the basis of the leaching toxicity. Results are shown in Table 8.4.

The leaching toxicity of the recycled concrete produced by six different construction materials is listed in Table 8.4. In general, the leaching amount of recycled concrete produced by steel fire bricks was the highest, followed by that produced by cement bricks. Those recycled concrete produced by

Table 8.4 Leaching Toxicity of Recycled Concrete Produced by Six Different Construction Materials

	Heavy Metal (mg/L)						
Sample	**Cu**	**Zn**	**Pb**	**Cr**	**Cd**	**Ni**	**As**
A1-cement block	–	–	–	–	–	–	–
A2-standard recycled concrete	0.009	–	–	0.346	–	–	–
A3-coir fiber recycled concrete	0.019	–	–	0.467	–	–	–
A4-alkali-treated coir recycled concrete	–	–	–	0.21	–	–	–
B1-foam concrete	–	–	–	–	–	–	–
B2-recycled concrete standards	–	–	–	0.178	–	–	–
B3-coir fiber recycled concrete	–	–	–	0.128	–	–	–
B4-alkali-treated coir recycled concrete	–	–	–	0.069	–	–	–
C1-brick	–	–	–	0.344	–	–	–
C2-standard recycled concrete	–	–	–	0.013	–	–	–
C3-coir fiber recycled concrete	–	–	–	0.005	–	–	–
C4-alkali-treated coir recycled concrete	–	–	–	0.016	0.019	–	–
D1-Dujiangyan recycled aggregate	–	–	–	–	–	–	–
D2-standard recycled concrete	–	–	–	0.121	–	–	–
D3-recycled concrete coir fiber	–	–	–	0.078	–	–	–
D4-alkali treated coir recycled concrete	–	–	–	0.107	–	–	–
E1-Pudong recycled gravel	–	–	–	–	–	–	–
E2-standard recycled concrete	–	–	–	0.147	–	–	–
E3-coir fiber recycled concrete	–	–	–	0.138	–	–	–
E4-alkali-treated coir fiber recycled concrete	–	–	–	0.112	–	–	–
F1-Baosteel firebrick	–	0.389	–	–	–	–	–

Table 8.4 Leaching Toxicity of Recycled Concrete Produced by Six Different Construction Materials—cont'd

	Heavy Metal (mg/L)						
Sample	**Cu**	**Zn**	**Pb**	**Cr**	**Cd**	**Ni**	**As**
F2-standard recycled concrete	0.018	31.017	0.524	–	58.925	–	–
F3-coir fiber recycled concrete	–	–	–	–	32.672	–	–
F4-alkali-treated coir fiber recycled concrete	0.055	41.823	0.632	–	68.642	–	–
Standards for drinking water quality	1.0	1.0	0.01	0.05	0.005	0.02	0.05
Environmental quality standards for surface water (level III)	1.0	1.0	0.05	0.05	0.005	–	0.05
Integrated wastewater discharge standard	2.0	5.0	1.0	1.5	0.1	1.0	0.5
Standard for pollution control on the security landfill site for hazardous wastes	75	75	5	12	0.5	15	2.5
Identification standards for hazardous wastes	100	100	5	15	1	5	5

foam concrete, red bricks, and recycled gravel had the lowest leaching capacity. Among all the heavy metals, Cd showed the highest leaching potentials, whereas Cu, Ni, and As showed the lowest. The leaching toxicity of recycled materials after treatment by coir fiber or alkali was lower than others.

8.2 RECYCLING EQUIPMENT AND TECHNOLOGIES

Typical recycling ways of construction and demolition waste are listed in Table 8.5.

8.2.1 Classified Utilization of Recycled Materials

Classified categories of recycled materials produced by concrete, bricks, and renovation construction waste are listed in Tables 8.6–8.8, respectively.

The classified utilization of recycled building materials is listed in Table 8.9. It is divided into road engineering materials and building

Table 8.5 Typical Recycling Ways of Construction and Demolition Waste

Wall materials	Normal load-bearing and non-load-bearing building blocks (190, 280, 300 series) 80 types, including single row of holes, multiple rows of holes, blind holes, lintels, and solid standard bricks Decorative building blocks 40 types, including normal single-sided splitting blocks, double-sided splitting blocks, color splitting tiles, and striped wall tiles Functional building blocks 20 types, including bearing thermal insulating blocks and sound insulating blocks
Floor materials	Paving bricks 50 types, including normal (bearing) paving bricks, water permeable paving bricks, and classic paving bricks Road traffic stones 10 types, including road curbstones and gardening hoarstones Lawn bricks 20 types, including normal grass-planting bricks and bearing lawn bricks
Green building materials	Retaining blocks Segmental retaining blocks, other gardening blocks Slope protection blocks (hydraulic block) 20 types, including interlocking revetment blocks, articulated slope protection blocks, embedded protective bricks, and grass bricks

Table 8.6 Classified Categories of Recycled Materials Produced by Concrete

Classified Categories	Particle Size (mm)	Stacking Density (kg/m^3)
Recycled muck	<5	<1200
Recycled coarse aggregate	<37.5	<1500
Recycled fine aggregate	<4.75	<1200
Recycled powder material	<0.075	<700

Table 8.7 Classified Categories of Recycled Materials Produced by Bricks

Classified Categories	Particle Size (mm)	Stacking Density (kg/m^3)
Recycled muck	<5	<1200
Recycled coarse aggregate	<37.5	<1500
Recycled fine aggregate	<4.75	<1000
Recycled powder material	<0.075−0.010	<700
Recycled fuel	<10	<500

Table 8.8 Classified Categories of Recycled Materials Produced by Renovation Construction Waste

Classified Categories	Particle Size (mm)	Stacking Density (kg/m^3)
Recycled muck	<5	<1000
Recycled coarse aggregate	<37.5	<1300
Recycled fine aggregate	<4.75	<1000
Recycled fuel	<10	<500

engineering materials. The types of recycled building materials and the aggregate used are also introduced.

8.2.2 Crushing Equipment and Technologies for C&D Waste

Crushing equipment can be divided into impact crusher and laminated crusher based on the operating principles. They can also be classified into three groups according to the hourly production capacity (t/h) of each crushing device:

Large crusher: production capacity between 300 and 1500 t/h;
Middle crusher: production capacity between 100 and 300 t/h;
Small crusher: production capacity between 0 and 100 t/h.

There are also other classification methods depending on the rotor, for instance, crusher with single rotor and double rotors.

Three kinds of crushers are introduced in this chapter, whereas DPF specific crusher for construction and demolition waste will be introduced in detail.

DPF Specific Crusher for C&D Waste

Two-stage crushing is commonly used in C&D waste recycled fine aggregate crushing due to the physical characteristics of the material itself, and the particle size of the crushed materials is about 0—10 mm. The two-stage crushing can be replaced by three-stage crushing to improve the production amount of fine aggregate and the diameter of most crushed materials is under 10 mm. DPF crusher is designed to overcome the common problems raised in the production process including complex process arrangement, and large electricity and investment consumptions. The crusher is demonstrated in Fig. 8.1.

The raw materials entering the crusher are stacked on the middle plate inside, while the hammer operating in the gap of the plate continuously crushes and breaks the large bulks of materials. The falling small pieces of

Table 8.9 Classified Utilization of Recycled Building Materials

Utilization of Construction and Demolition Waste	Type of Recycled Building Materials	Aggregate Used
Road engineering materials	Pavement structure layer: subgrade cushion material	Concrete, brick, recycled coarse and fine renovation aggregate
	Pavement structure layer: subgrade stabilization material	Concrete, brick, recycled coarse and fine aggregate
	Recycled concrete road blocking pier	Concrete, brick, recycled coarse and fine renovation aggregate
	Recycled concrete noise barrier	Concrete, brick, recycled coarse and fine renovation aggregate
	Recycled concrete road traffic stone	Concrete, brick, recycled coarse and fine renovation aggregate
	Recycled concrete water permeable brick	Concrete, brick, recycled coarse and fine renovation aggregate
	Recycled concrete barrier	Concrete, brick, recycled coarse and fine renovation aggregate
	Composite product in municipal facilities	Concrete, brick, recycled coarse and fine renovation aggregate
Building engineering materials	Floor, plaster, masonry mortar	Concrete, recycled fine brick aggregate, powder material
	Recycled concrete	Recycled coarse and fine concrete aggregate
	Thermal insulation recycled concrete in structure	Recycled coarse and fine brick aggregate
	Aerated concrete block, brick	Recycled fine brick aggregate, recycled powder material
	Recycled concrete cavity block	Recycled fine brick aggregate, recycled powder material
	Recycled concrete wallboard	Recycled fine brick aggregate, recycled powder material
	Recycled concrete decorative board	Recycled fine brick aggregate, recycled powder material
	Composite admixture	Recycled concrete powder, recycled brick powder

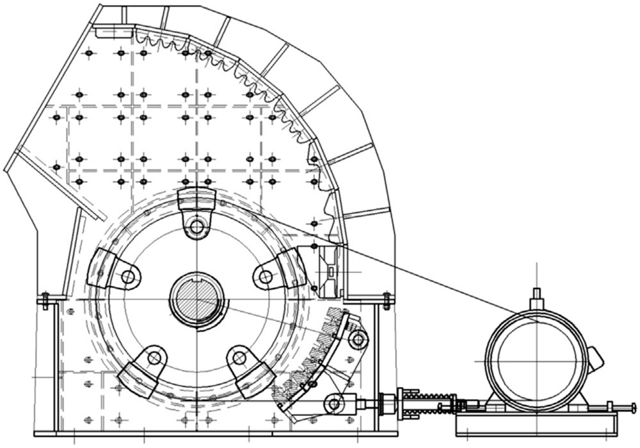


Figure 8.1 Diagram of the DPF crusher.

materials are finely crushed by the contact with the high-speed operating hammer and then fall to the homogenizing section and discharge. Meanwhile, grooves are set on the plate of the homogenizing section where the mixed reinforced bars are impeached out. The distance between the homogenizing plate and the hammer is adjustable. The smaller the distance is set, the smaller the outlet particle size will be obtained.

The diagram of a rotor is demonstrated in Fig. 8.2, which is composed of the principle axis, belt pulley, main bearings, bearing support, hammerhead, hammer shaft, and other parts. A rotor should be equipped with a good dynamic balance, wear resistance pieces, and principle axis support of high durability to perform well in crushing and avoid frequent maintenance.

The external shell is the supporting component of the crusher, which supports the rotor and bears the crushing force task for the crusher. Plates and crushing boards with high strength are equipped in the shell the function of which is to crush and collect the materials during the hammer crushing. The crushed materials coming through the coarse and fine crushing chambers are discharged through the grate plate at the bottom.

The kinetic energy generated by the host engine is conveyed from the cone belt to the large pulley of the crusher by the electric motor pulley. The entire rotor is driven in a circular motion by the large pulley and the continuous operation and crushing is achieved.

The function of the drive system is to transfer the kinetic energy from the host engine to the crusher. The pulley should be manufactured using high-quality cast iron to avoid deformation in long-term use. As for the structure,

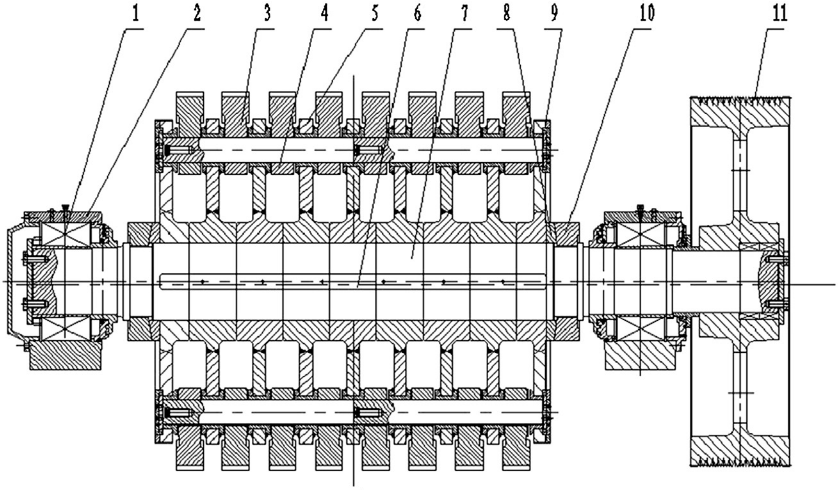


Figure 8.2 Diagram of rotors of the DPF crusher. 1-bearing, 2-bearing support, 3-hammerhead, 4-hammer shaft, 5-hammer plate, 6-key principle axis, 7-principle axis, 8-terminal cover, 9-terminal plate, 10-clamp, 11-belt pulley.

the wrapping angle of the small pulley should be as large as possible to increase the transmission efficiency. The diagram of the drive system is demonstrated in Fig. 8.3.

The energy generated in impact crushers is produced by the impact of hammerhead on the materials while the materials are crushed when being hit on the crushing board. The wearing pieces are the fundamental components during the crushing of materials. Enough surface and internal hardness is required for the wearing pieces to reduce crushing cost and increase the operation efficiency of the crusher.

The hydraulic system is a supporting section in a crusher which is designed for easier maintenance and operation. The hydraulic system should be fully enclosed. The diagram of the hydraulic system is demonstrated in Fig. 8.4.

Jaw Crusher

The main features of a jaw crusher are large crushing ratio, even granularity, simple structure, reliable operation, easy maintenance, and low operating costs. The jaw crusher is widely used in many fields where the breaking strength is less than 320 MPa like mining, smelting, building material production, highway, railway, water conservancy, and chemical industries, and is the preferred primary crushing equipment.

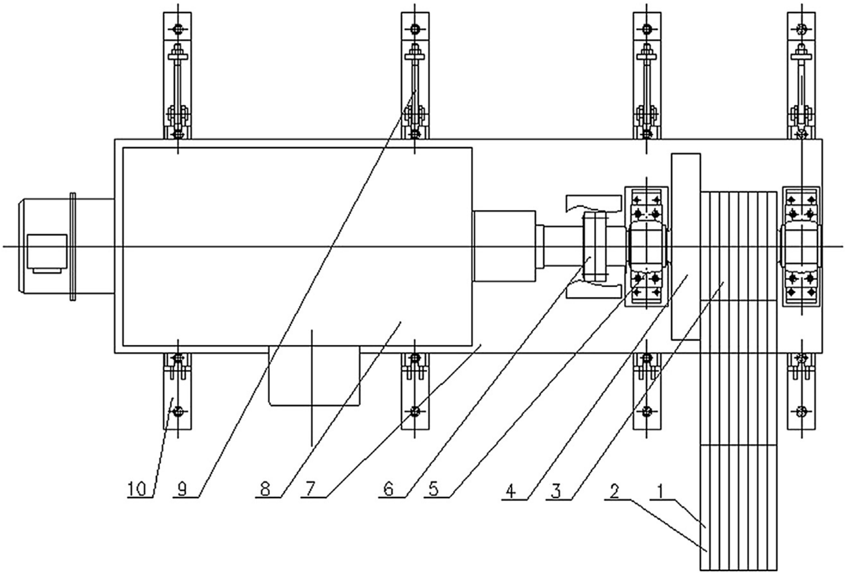


Figure 8.3 Diagram of the drive system. 1-main engine pulley, 2-narrow V-belt, 3-small pulley, 4-flywheel, 5-bearing support, 6-coupling, 7-motor base, 8-motor, 9-rail, 10-draw rod.

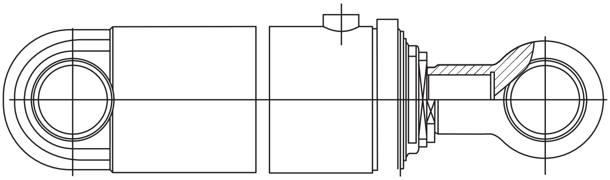


Figure 8.4 Hydraulic cylinder.

Impact Crusher

The impact crusher (typically PE series) is widely used and of high production efficiency and good safety performance. The finished product is of cube shape and the tension force and crack is avoided. Compared with hammer crusher, the impact crusher is able to fully utilize the high-speed impact energy of entire rotor. However, due to the crushing board that is easy to wear, it is also limited in the hard material crushing. The impact crusher is commonly used for the crushing of limestone, coal, calcium carbide, quartz, dolomite, iron pyrites, gypsum, and chemical raw materials of medium hardness. Effect of process conditions on the production capacity of crushed materials is listed in Table 8.10.

Table 8.10 Effect of Process Conditions on the Production Capacity of Crushed Materials

	Production Capacity of Limestone		**Production Capacity of Chamotte**	
Process Condition	**Particle Size of 85% Outlet Materials Is <25 mm**	**Particle Size of 85% Outlet Materials Is <75 mm**	**Particle Size of 85% Outlet Materials is <5 mm**	**Particle Size of 85% Outlet Materials Is <10 mm**
Large inlet particle size	Decrease	Decrease	Decrease	Decrease
Small inlet particle size	Increase	Increase	Increase	Increase
Large outlet particle size	Increase	Increase	Increase	Increase
Small outlet particle size	Decrease	Decrease	Decrease	Decrease
Large water content	Decrease	Decrease	Decrease	Decrease
Small water content	Increase	Increase	Increase	Increase
Materials easy to be crushed	Increase	Increase	Increase	Increase
Materials hard to be crushed	Decrease	Decrease	Decrease	Decrease
High rotor rotation speed	Increase	Increase	Increase	Increase
Low rotor rotation speed	Decrease	Decrease	Decrease	Decrease
Large surplus motor power	Increase	Increase	Increase	Increase
Small surplus motor power	Decrease	Decrease	Decrease	Decrease

8.2.3 Screening and Auxiliary Equipment

8.2.3.1 Vibrating Screen Feeder

Vibrating screen feeder is widely used in metallurgy, mineral processing, building material production, chemistry, coal, and other industries and can be used to remove the natural fine substances, transfer, and screen for the next process. The vibrating feeder is the combination of screening and conveying and both the functions can be achieved under the vibrating motion.

The vibrating screen feeder is mainly used in the following conditions: (1) It can be used for continuous and even feeding before the coarse crushing and screening, and separate the fine substances to increase the crushing capacity. (2) The bulk and granular materials can be evenly, regularly, and continuously sent into the feeding device from the storage house during the operation. (3) It can be used for the coarse screening of materials. The double screening feeder can be used to remove the mud and other small impurities in the materials.

8.2.3.2 Belt Conveyor

Belt conveyor is necessary in the production line of gravel and construction waste, and is mainly used to connect the broken equipment of different levels, sand production facilities, and screening equipment. It is also widely used in cement, mining, metallurgy, chemical, foundry, and building materials industries. The operating condition of the belt conveyor can be in the range of −20°C to +40°C, whereas the temperature of the materials conveyed can be below 50°C. In the industrial production process, the belt conveyor can be used as a link among production facilities to achieve the continuity and automation of production processes, thus improving the productivity and reducing the labor intensity. Approximately four to eight sets of belt conveyors are involved in sand and gravel production line.

8.2.3.3 YKF Circular Vibrating Screen

This series of vibrating screen with multiple layers is in a circular motion while it is specifically designed for the screening of stone materials in a quarry. It can also be applied in product classification in coal preparation, mineral processing, building materials production, electricity, and chemical industries. The main features of circular vibrating screen are listed as follows.

(1) The flow rate can be easily and stably changed through the adjustment of the exciting force. (2) The circular vibrating screen is of stable vibration, reliable operation, and long operating life. (3) The structure is simple while operation is reliable. The relative light weight and small

volume makes maintenance much easier. (4) The enclosed structure of screen body effectively prevents dust pollution. (5) Low noise intensity and small electricity consumption is produced during the operation of the vibrating screen.

8.2.3.4 Dust Catcher

The dust collection devices mainly include bag filter, pulse bag filter, and electrostatic precipitator. The main purpose of the dust collector is to remove the dust in the air. thus improving the environment and reducing pollution. Another function of dust catcher is to screen and collect the powder products such as the collection of finished cement products.

8.2.3.5 XS Sand Washing Machine With Wheel Type, Spiral Sand Washing Machine

XS Sand Washing Machine With Wheel Type

This kind of sand washing machine is mainly used for washing of mixed soil and dust, along with the sand lifting in mining. The transmission parts of this machine are isolated from the water and sand, which largely reduce the failure rate during the operation process. The main features of this kind of machine are listed as follows.

(1) The loss of fine sand and stone powder in sand washing process is small. The washed sand is of good gradation, the fineness modulus can easily meet the requirements of relevant standards. (2) The structure is simple. The bearing device of impeller driving is isolated from the washing water and sand thus largely decreasing the failure rate. (3) The washed sand is of high degree of cleanliness. Meanwhile, large operation capacity, low power consumption, and long service life can also be obtained.

Spiral Sand Washing Machine

The spiral sand washing machine (XL series, for example) is able to wash and separate the soil and other impurities in sand and gravel aggregate. The enclosed structure, adjustable overflow weir plate, and reliable transmission parts increase the cleaning and dehydration effect, which can be applied to road, hydraulic, and construction industries. The main features are listed below.

(1) The structure is simple. The bearing device of impeller driving is isolated from the washing water and sand thus largely decreasing the failure rate. (2) The loss of fine sand and stone powder in sand washing process is small. The washed sand is of good gradation; the fineness modulus can easily meet the requirements of relevant standards. (3) Almost no components of the machine are vulnerable to wearing and breaking down except the screen.

8.2.4 In Situ or Mobile Crushing and Regeneration Device

8.2.4.1 General Introduction

Building garbage recycling equipment in Western developed countries is generally mobile crushing station and mobile screen station, which can be divided into two categories, i.e., wheeled and tracked, shown in Figs 8.5 and 8.6. They can be used either alone or in combination with multiple devices. Characteristics of rubber-tired mobile crushing plant are as follows:

1. strong mobility;
2. integrated complete sets of equipment;
3. reduced cost of material handling;
4. flexible combination and strong adaptability;
5. work directly and effectively; and
6. the installation form of integrated complete sets of equipment eliminates complex installation work caused by site and infrastructure of fission components, thus cutting down the consumption of the material and working hours.

Characteristics of crawler-type mobile crushing plant:

1. Low noise and low fuel consumption has realized the real economic and environmental protection.
2. The machine adopts all-wheel drive and it can realize spin in situ. Standard configuration and quick change device with perfect function of security protection is especially suitable for narrow space and complex area.
3. Chassis adopts crawler-type rigid hull structure, which is of high strength, low specific pressure of ground connection, good trafficability, and good adaptability to mountain and soft land.

Figure 8.5 Wheeled mobile crushing station for construction and demolition waste.

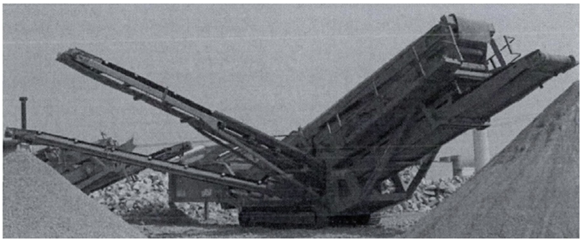


Figure 8.6 Mobile screen station for construction and demolition waste.

4. Typical multifunction engineering machinery products integrated machine, electricity, and liquid have compact structure and different models of complete machine dimension.
5. Convenient transportation, crawler walking, no damage to the road surface, equipped with multifunction apparels, and wide adaptation.

Compared with the traditional crushing screening equipment, the mobile crushing station has characteristics of mobility, reconfigurability, and automation. The crushing, screening, and debris sorting of construction waste can be realized if these features are applied to the recycling of construction waste, which can completely meet the requirements of comprehensive treatment of construction waste. In addition, the combination of different types of mobile crushing station screened by the mobile screen substation, which manage the primary and secondary crushing of construction waste, cannot only improve the performance of recycled aggregates, but also get the recycled aggregates piled up in accordance with the aggregate graded, facilitating the recycle of recycled aggregates.

In the process of construction waste treatment with mobile crushing station, the interaction of the waste concrete with itself contains a mix of collision and friction with each other using vibrating equipment, such as vibrating feeder and the original vibrating screen, which can reduce relatively loose waste mortar on its surface. Compared with the mechanical rub method, there is an effect gap between the two, but it plays the same role as well, which improves the performance of the recycled aggregates to some extent.

New renewable equipment can not only break, but also sieve. Mobile crushing screening equipment produced by Atlas Copco, take PC1375 type I crusher, for example, its high efficiency and flexibility, simplicity of operation, product design for easier transportation make it very suitable for field use in harsh environment, and most important of all, products broken by this device is of high capacity and good quality. PC1375 type I crusher is equipped with a special design of 19-mm-thick conveyor belt with high-strength steel wire, which effectively prolongs its service life. Its standard configuration is high-intensity magnetic belt, which can separate all the metal materials out before conveying crushing material to the dump, producing clean broken end products and the separated metal materials can earn extra income. The discharging mouth of the crusher is equipped with rollers, the impact absorption plate with special design is composed of replaceable rubber and steel, and the conveyor belt is removable, which makes obstruction cleaning and equipment maintenance very convenient.

8.2.4.2 Introduction of the Rockster Mobile Crushing Station

The design of the overall structure is demonstrated in Fig. 8.7. Features of the five main functional components, the feeding device, crushing section, presieving, drive system, and unloading parts, are highlighted in the figure.

The partial enlarged drawing of the impact crusher is shown in Fig. 8.8. The main features including the swing rollers, rotor, bearing and bearing shaft, impact plate, and unloading part are listed on the left.

The partial enlarged drawing of the jaw crusher is shown in Fig. 8.9. The main features including the crushing gap, bearing, and bearing shaft are listed on the left.

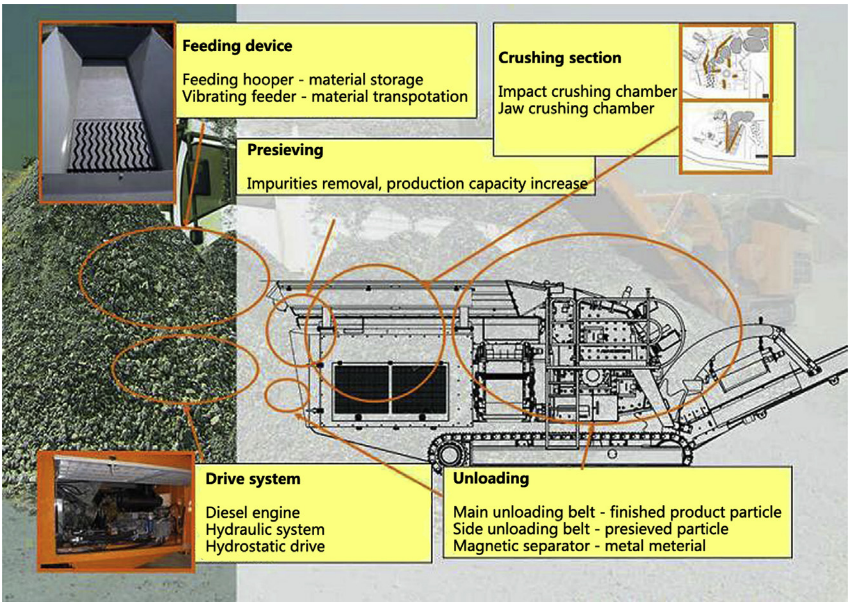


Figure 8.7 Design of the overall structure of the Rockster mobile crushing station.

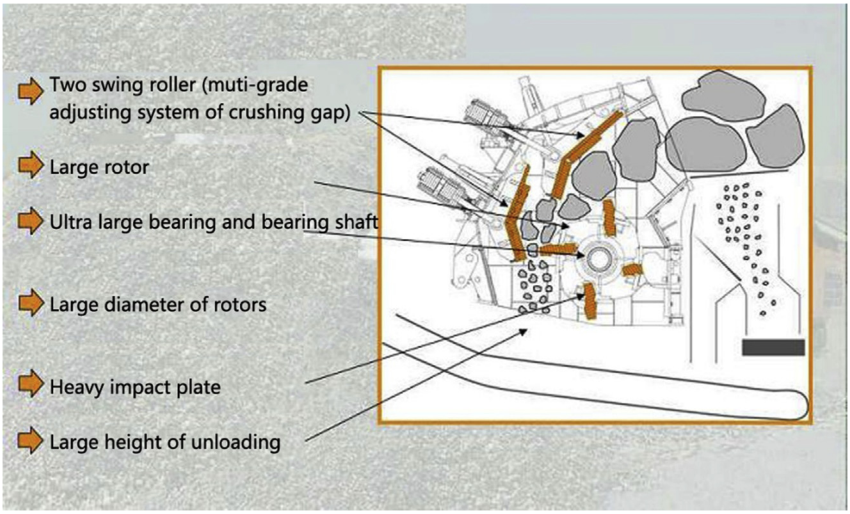


Figure 8.8 The impact crusher of the mobile crushing station.

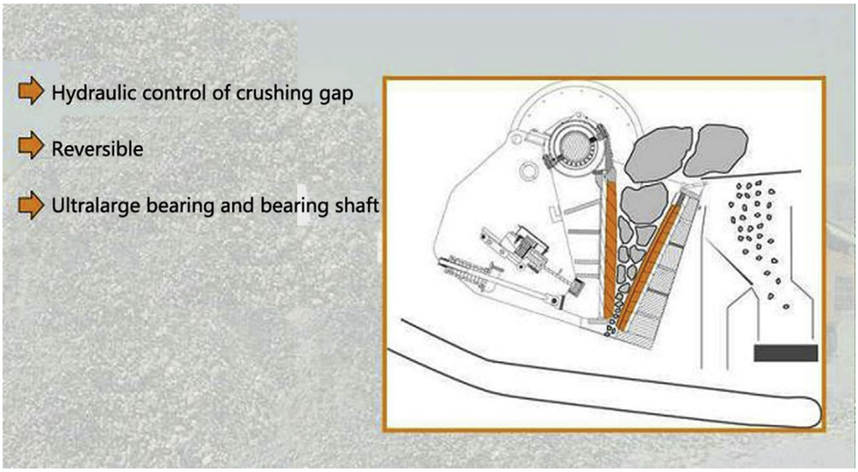


Figure 8.9 The jaw crusher of the mobile crushing station.

Hydrostatic Transmission Drive System of the Crushing Device

1. No clutch and energy and material loss.
2. The speed of crusher can be continuously variable between 0 and 850 rpm.
3. The operating direction can be adjusted (duplex dual suited replacement system).

4. Best adapted adjustment between the performance of the engine and the requirement of the power of the crusher.

Accessories of the Rockster Mobile Crushing Station

1. Main unloading belts—wear resistance protection
   The adjustable wear-resistance plate installed at the outlet of the crushing chamber provides protection for the main unloading belts.
2. Lubrication—central lubrication
   Automatic lubrication measures can be performed on all the parts required in the crushing station.
3. Other accessories
   - **a.** Air compressor: used for device cleaning (the cooler, for example) and is connected to the hydraulic system.
   - **b.** Replace device of hammers: equipped on the lifting bracket of the crushing chamber.
   - **c.** Water pump: used for the external water supply of the dust removal system.

A high production capacity of the Rockster impact crusher can be obtained and maintained even under the condition of high crushing ratio. The dual swing rollers are based on the hydraulic adjustment and the easily controlled rotors, and the size of the finished products can be optimally adjusted. The wear-resistance materials effectively reduced the operation loss.

8.2.5 Crushing and Grinding Technologies of C&D Waste

Lamination of construction waste is the extrusion and regeneration process of the groups of material layers and is of high crushing power utilization. In traditional sand and gravel crushing line process, little kinetic energy is produced during the hit motion, whereas most crushing power is transferred into sound energy (large noise generation) and heat energy.

The energy consumption of the three main recycled materials, namely, recycled coarse aggregate, recycled sand powder, and recycled ultrafine powder is 2, 5, and 50 kWh/t (half of that of cement production), respectively.

Jaw crushing is a kind of intermittent crushing by jaw squeezing, which will cause the wrapping of concrete around the reinforced bars. However, the concrete and reinforced bars of prestressed reinforced concrete floor board can be separated in composite lamination and crushing. The selective regenerated lamination of construction waste can be especially applied for the crushing of mixed construction waste, brittle waste bricks, and waste concrete, along with the compression of tough materials like wood and fabric, etc.

A small amount of dust and noise is generated in C&D waste lamination and regeneration. The applicability analysis of this treatment in different sections is discussed below in detail.

8.2.5.1 Applicability Analysis of C&D Waste Lamination

1. Coarse Composite Crushing in the Cut Roll Crusher

The composite crushing, which consists of the sheer force produced by bite of gears on the coarse roller, and the roll crushing increases the crushing capacity. When it is used for the crushing of brick and concrete C&D waste, the reinforced bars in the prestressed concrete floor can be easily peeled and separated. When it is used for the crushing of renovation C&D waste, the packed bags can be easily broken.

2. Intermediate Selective Crushing in the Cut Roll Crusher

The intermediate crushing in the cut roll crusher is mainly used for the crushing of brittle materials like concrete and clay sintered bricks, along with the compression of rough materials like wood and fabric (to avoid being too small in size) after the coarse (primary) crushing. The selective crushing in this process is good for the separation of impurities. Impact crushers are commonly applied in intermediate crushing. However, when used in crushing of mixed C&D waste, the wood and fabric materials will be broken and mixed in recycled aggregate materials by the high-speed operating rotors and are difficult to be separated.

3. Fine Crushing in the Cut Roll Crusher and Recycled Sand Production

The C&D waste debris after the intermediate (secondary) crushing is further crushed in which the sand and gravel can also be the grinding media for the extrusion and crushing of brick particles. Those bricks of low strength will be crushed to recycled powder materials while the sand and gravel will become coarse and fine sand materials. The raw materials (sand and gravel) and chamotte (clay sintered brick, cement paste) are classified and regenerated.

4. Hoop-Roller Grinding and Ultrafine Powder Material Production

The particle size of recycled powder materials after hoop-roller grinding can be adjusted from 1 to 80 μm (300–3000 mesh), and the market adaption capacity of recycled powder material can be greatly enhanced. Particles of size less than 30 μm are called ultrafine powder.

The recycled hoop-roller grinder can be applied as the corollary equipment in C&D waste disposing companies due to the small volume, negative pressure operation, and mediate production capacity.

The building materials made up of silicon aluminum powder have been developed to a major category of building materials, such as aerated concrete blocks, aerated concrete panels, foam concrete plates, and powder concrete. Powder material production technology will be widely applied in the near future.

5. Separation of Lightweight Substances

The drum-type lightweight combustible separator is particularly suitable for the separation of lightweight material and construction waste. The particle size of most brittle materials in the mixed crushed C&D waste after intermediate (secondary) crushing is below 30 mm, whereas that of rough materials is above 30 mm. The lightweight materials larger than 30 mm in diameter like wood and fabric are attached on the screen and lifted so that the screen mesh blinding is avoided and the 30 mm size of particles are successfully separated.

The construction waste recycled coarse aggregate below 30 mm in size falls down through the sieve drum. The mixed construction waste materials, which are mostly brittle and 5 mm or less, between 5 and 30 mm, are finely cut and roll. The particle size of the brittle materials in mixed C&D waste debris after being finely crushed is mostly above 5 mm, whereas that of rough materials is between 5 mm and 30 mm. They can be separated similarly.

The vibrating screen used in traditional sand and gravel industry is suitable for sand grading but not for the separation of mixtures due to the flat screen machine. Lightweight substances are absorbed on the flat screen and easily cause mesh blinding, which will severely affect the screen efficiency. Meanwhile, this process must be performed under the dry weather.

8.2.5.2 Applicability Analysis of Three Processes Involved in the C&D Waste Lamination

One-Stage Composite Impact Crushing Pretreatment Process

As the strength of C&D waste is relatively low, the impact crusher can basically meet the demand for coarse crushing and the particle size of 70% crushed waste can be below 50 mm after primary crushing (once). The peeling efficiency of cement paste from concrete blocks, reinforced bars from prestressed floor boards, and the package breaking is lower for traditional impact crushing. The composite impact crusher is equipped with gears capable of shearing and impact crushing. The rotors with gears can easily peel the cement paste or reinforced bars mentioned earlier in the corresponding processes.

Roll Crushing + Roll Grinding Combined Recycling Process

The rolling machine along with the hoop-roller grinder can be used in C&D waste debris grinding and the recycled fine aggregate and recycled powder can be recycled, respectively. The crushing ratio and energy consumption of both facilities are high and low, respectively.

Fine crushing of brick and concrete waste can be easily achieved using the high-pressure rolling machine, the particle size of about 90% of which will be below 5 mm when crushed once. Peeling of concrete from the prestressed reinforced bars can also be achieved.

Single-stage or multiple-stage hoop-roller grinder should be selected depending on the powder specification and energy production demands. The multiple-stage hoop-roller grinder is widely used in the production of inorganic powder and mineral powder.

Rolling + Rolling Combined With Extrusion Treatment Process

The main task of renovation construction waste handling is the separation of lightweight impurities and construction waste. The rolling crusher with opposite rollers is capable of crushing the brittle debris and compressing the lightweight materials by the low-speed and high-pressure extrusion of the two opposite rollers. As the gap between the opposite rollers, rotation speed, and pressure are all adjustable, materials of different scales in renovation construction waste can be handled.

The concrete C&D waste recycling process of "impact crusher + cone crusher + hoop-roller grinder" is also capable of handling brick waste. In general, the secondary crushing using the cone crusher in this process with an enclosed crusher is a process of multicrushing, and the water content of waste will become an important affecting factor. The wet waste will be adhered on the wall of the grinding chamber, and the crushing efficiency and waste discharging will be affected. When the climate is humid, only coarse impact crushing is performed and in this case the crushed materials are used for roadbase materials. Otherwise, three consecutive crushings are performed and the recycled coarse aggregate, fine aggregate, and powder materials are collected, respectively.

The brick and concrete C&D waste recycling process of "impact crusher + rolling crusher + hoop-roller grinder" is also capable of handling the concrete waste. In this case, the water content of waste will not be an important affecting factor. This process is suitable in the regions with wet climates.

The renovation C&D waste recycling process of "rolling crusher (coarse/ primary crushing) + rolling crusher (intermediate/secondary crushing) + rolling crusher (fine/tertiary crushing)" is also capable of handling the two kinds of waste discussed earlier. The particle size of debris is crushed less than 20 mm and the lightweight materials are compressed, and they are separated using the drum sieve. The energy consumption is low in this process; however, the shape of products is not good (usually flat and with cracks). There is no problem in roadbase material and raw materials of prefabricated product production. But molders (the rotation of rotors in crusher is used to polish the edge and corner) should be used for premixed concrete and mortar production.

8.2.6 Manufacturing System of Sand and Gravel Aggregate

8.2.6.1 General Information

Sand and gravel aggregate includes sand, gravel, detritus, pebble, stone, rock, and other materials and is the main construction material used in concrete and other piling structures. Particle size of this kind of aggregate is usually larger than 4.75 mm and is called coarse aggregate in concrete application. It is commonly composed of two kinds, gravel and pebbles. Gravel is a kind of rock particle produced by mechanical crushing and sieving of natural rock, whereas pebble is the rock particle generated from natural weathering, water transportation, and sorting, and the particle size of both is above 4.75 mm.

Sand generally refers to particles of size less than 4.75 mm, and it belongs to fine aggregate in concrete application. Sand generally includes river sand, artificial sand, mountain sand, dilute sand, and lake sand. It can be classified into four grades according to fineness modulus:

Coarse sand: fineness modulus of 3.7—3.1, with an average particle diameter of 0.5 mm or more;

Medium sand: fineness modulus of 3.0—2.3, with an average particle size of 0.5—0.35 mm;

Fine sand: fineness modulus of 2.2—1.6, with an average particle diameter 0 35—0 25 mm;

Special fine sand: fineness modulus of 1.5—0.7, with an average particle diameter of 0.25 mm or less.

The larger the fineness modulus is, the coarser the sand will be. The appropriate range of fineness modulus of the sand aggregate used in normal concrete is 3.7–1.6. Both medium sand and coarse sand spiked with some fine sand (coarse:fine = 4:1) are applicable.

Sand aggregate plays a significant role as a skeleton and in passing the stress in concrete. Aggregates can also bear the load even without grout while suppressing the shrinkage and prevent cracking. The cement mortar produced from sand and cement is able to improve the workability and flowability of concrete.

The coarse aggregate can be classified as follows according to the particle diameter:

One-graded 5–20 mm
Two-graded 5–20, 20–40 mm
Three-graded 5–20, 20–40, 40–80 mm
Four-graded 5–20, 20–40, 40–80, 80–120 (150) mm

The fine aggregate should meet the requirement regulated in Table 8.11.

Traditional aggregates production process includes the following procedures: primarily crushing by jaw crusher after blasting of rocks, then use impact crusher or cone crusher for further crushing according to the fineness

Table 8.11 Quality Requirement Regulated for Fine Aggregate

Item	Index	Note
Mud content in natural sand (%)	<3	(1) Mud content is the total amount of the silt, clay the size of which is less than 0.08 mm
Clay content (%)	<1	(2) Should not contain clay cluster
Rock powder in artificial sand (%)	6–12	Particle size less than 0.15 mm
Consistency (%)	<10	Loss amount after five circulations of sodium sulfate solution method
Mica content (%)	<2	
Lightweight material content (%)	<1	Density less than 2.0 g/cm^3
Density (%)	>2.5	
Sulfide and sulfosalt content (%)	<1	By weight (SO_3)
Organic matter content (%)	Lighter than standard color	If darker, mortar should be prepared for strength comparison

Cited from Chinese standard quality control of sand and gravel production.

of stone and production demands. Standard sand and gravel aggregate particles are subsequently produced by sand production machines. For wet sand process, cleaning is also required for sand production machines.

8.2.6.2 Production Process

1. Classification of sand and gravel aggregate production process:
    - a. Single-stage aggregate production process;
    - b. Multistage aggregate production process;
    - c. Manufactured-sand production line process;
    - d. Fixed production line process;
    - e. Mobile production line process.
2. Selection of regular construction stone aggregate line

    Factors affecting the selection of sand and gravel production line equipment:
    - a. fragility of materials
    - b. feeding particle size of materials
    - c. output particle size of finished materials
    - d. geographical limitations of the production site
    - e. shape requirements for finished products
3. Case analysis of aggregate production line

    Type selection of common facilities used during aggregate process line is listed in Table 8.12.

    Selection of crushers under specific application cases is listed in Table 8.13.
4. Flow sheet of various processing lines
    - a. Typical sand and gravel aggregate processing line flow sheet with secondary crushing with 500 t/h

Table 8.12 Type Selection of Common Facilities Used for Aggregate Process Line

No.	Production Capacity (t/h)	Primary Crushing Facilities	Secondary Crushing Facilities (Normal Material)	Secondary Crushing Facilities (Material of High Silica Content)
1	50—130	PE600 × 900	PF1214	PYS-B0917
2	110—250	PE750 × 1060	PF1315	PYSB-1321
3	160—380	PE900 × 1200	PF1416	PYS-B1624
4	310—550	PE1000 × 1200	PF1520	PYS-B1626
5	400—800	PE1200 × 1500	PF1620	PYS-B2133

Table 8.13 Selection of Crushers Under Specific Application Cases

Case	Feature	Selection	
		Standard	**Recommendation**
Single-stage crushing	**1.** Large output **2.** Large crushing ratio **3.** Large feeding particle size **4.** Simple process layout **5.** Large one-time investment	**1.** DPC (single-stage hammer crusher): Used for crushing of normal brittle ores like limestone, shale, gypsum, coal, shale, and siltstone mixture of limestone and clay. Used in primary crushing and large output particle size **2.** DPF (single-stage impact crusher): (A) Used in crushing of construction waste, brittle ore; (B) Used in primary crushing and small output particle size. **3.** PE (jaw crusher): (A) Used for crushing of materials the compression strength of which is less than 320 MB; (B) Used in primary crushing and large output particle size	**1.** DPC **2.** DPF **3.** PE
Gravel processing line with multiple-stage crushing	**1.** High yield rate **2.** Low investment	**1.** DPC/PE + PF **2.** PE + PYS (hard abnormal raw materials)	PE + PF + YK PE + PYS + YK
Sand processing line	**1.** Large loss of wearing piece **2.** Low yield rate	**1.** PE + PEX + PCX (hard raw materials) **2.** DPX + PCX (normal raw materials)	PE + PEX + PCX
Shortened sand processing line	**1.** Large production capacity **2.** Large feeding particle size **3.** Little loss of rotor	PE + BHS	PE + BHS
Precrushing before grinding	**1.** Low investment, large loss of hammerhead **2.** 10–20% of production increase and energy saving	Enclosed system made up of XPCF (high-efficiency fine crusher) and YK (vibrating sieve)	XPCF + YK

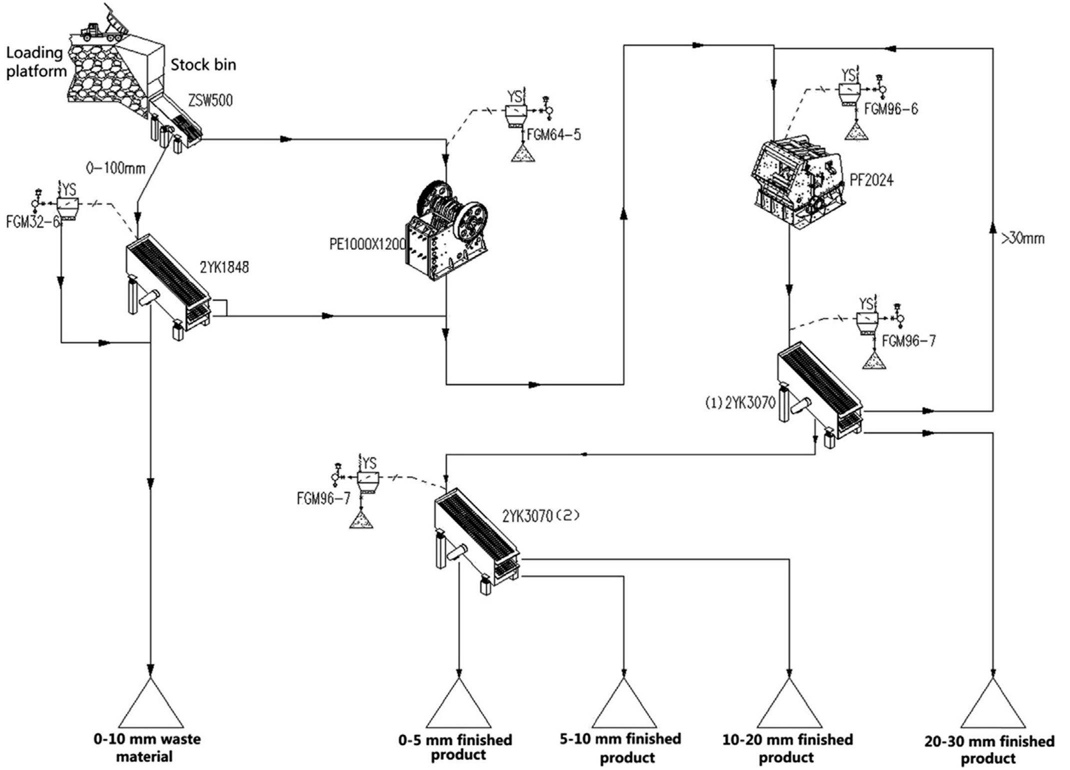


Figure 8.10 Typical sand and gravel aggregate processing line flow sheet with secondary crushing with 500 t/h.

Typical sand and gravel aggregate processing line flow sheet with secondary crushing at 500 t/h is demonstrated in Fig. 8.10. Material being sent into the stock bin by forklift is divided into two groups: materials of size 0–100 mm and >100 mm through the outlet of feeder ZSW500. Those materials of size 0–100 mm are sent to the vibrating sieve 2YK1848 by belt conveyor, whereas those >100 mm are to be broken by jaw crusher PE1000 × 1200. Two kinds of materials (0–10 and >10 mm of size) are obtained after 2YK1848; the former materials are sent by conveyor to the stockage piles of finished materials, whereas the latter materials along with those being crushed by PE1000 × 1200 are sent together to the impact crusher [PF2024] for further crushing. The crushed materials are then sent to No. 1 vibrating sieve 2YK3070 through the conveyor, the materials obtained here are classified as particle size of >30, 20–30, and <20 mm. Particles with sizes larger than 30 mm are sent back to the impact crusher [PF2024], those with sizes between 20 and 30 mm are conveyed to stockage piles of finished materials, and those with sizes smaller than 20 mm are transported to No. 2 vibrating sieve 2YK3070. Three classified groups of materials based on their sizes are gained after this sieve, namely, 10–20, 5–10, and <5 mm, all of which are conveyed to stockage piles of finished materials separately. Dust removal equipment can be added to each device in accordance with local environmental regulations.

b. Limestone processing line flow sheet with single crushing stage with 500 t/d

Limestone processing line flow sheet with single crushing stage with 500 t/d is demonstrated in Fig. 8.11. Material being sent into the stock bin by forklift is divided into two groups: materials of size 0–80 and >80 mm through the outlet of feeder ZSW630. Materials of size 0–80 mm are sent to the vibrating sieve 2YK1848 by belt conveyor, whereas those >80 mm are to be broken by hammer crusher ZPC1620. Two kinds of materials (0–10 and >10 mm of size) are obtained after 2YK1848 like the process (a) discussed earlier, the former materials are sent by conveyor to the stockage piles of finished materials, whereas the latter materials are sent back to the hammer crusher ZPC1620 for further crushing. The crushed materials are then sent to No. 1 vibrating sieve 2YK3070 through the conveyor, the materials obtained here are classified as particle size of >30, 20–30, and <20 mm. Particles with sizes larger than 30 mm are sent back to hammer crusher ZPC1620, those with sizes

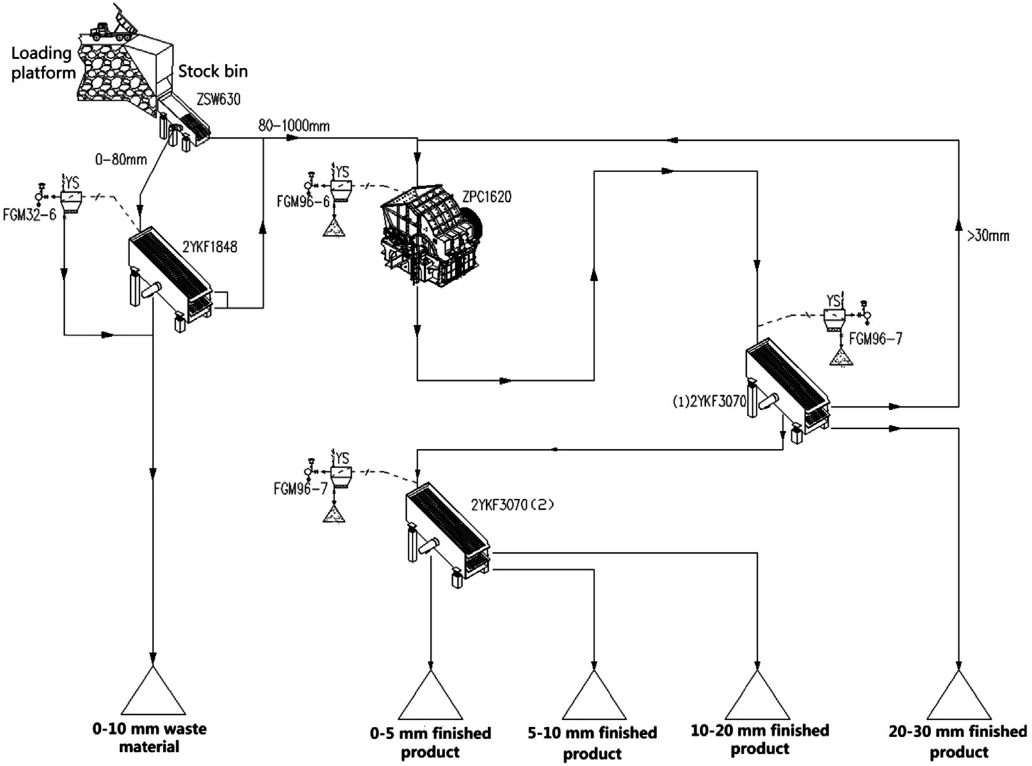


Figure 8.11 Limestone processing line flow sheet with single crushing stage with 500 t/d.

between 20 and 30 mm are conveyed to stockage piles of finished materials, and those with sizes smaller than 20 mm are transported to No. 2 vibrating sieve 2YK3070. Three classified groups of materials based on their size are gained after these sieves, namely, 10—20, 5—10, and <5 mm, all of which are conveyed to stockage piles of finished materials separately. Dust removal equipment can be added to each device in accordance with local environmental regulations.

c. Typical flow sheet of stone processing line: normal raw material (project of hourly production of 400 t sand and gravel processing line in Henyang City)

The typical flow sheet of stone processing line is demonstrated in Fig. 8.12. Material being sent into the stock bin by forklift is crushed by jaw crusher PE1000 × 1200 after the loader ZSW500, and then is further crushed by impact crusher PF1620. Those materials are sent to the vibrating sieve YKF2460 for screening and two classified materials (of size >60 and 0—60 mm) are obtained. The former materials are sent by conveyor back to the impact crusher PF1620, whereas the latter materials are conveyed to the transit storage bin and separated to two processing lines with the same production capacity for crushing. These materials are transferred from electromagnetic vibrating feeder to the German sand producing machine GZD 130-5. The crushed materials are then sent to the vibrating sieve 2YKF2865 and two classified materials (of size 0—5 and >5 mm) are thus produced. Those materials (0—5 mm) are lifted by the bucket elevator NE200 to the separator YND1000, whereas the other materials are sent back to BHS 1222 for further crushing. Two classified materials (of size 0—0.075 and 0.075—5 mm) are produced from YND1000 and are sent separately to the finished product stockpiles.

d. Hard raw materials (350—400 t/h granite processing project)

Hard raw materials processing project (350—400 t/h granite processing project) is demonstrated in Fig. 8.13. Material being sent into the stock bin by forklift is crushed by jaw crusher PE1000 × 1200 after the loader ZSW500, and then is further crushed by cone crusher PYS-1626 through the transit storage bin and the electromagnetic vibrating feeder GZD110-4. Two kinds of materials (of size >35 and 0—35 mm) are obtained after the crushed materials are sent to the vibrating sieve 2YK1848. Those >30 mm are sent for further crushing by PYT-1200 and then screened by YK2460, whereas the other materials are conveyed to the impact sand producing facility PCX1400 and the materials obtained are screened by 2YK2460. The materials obtained here are classified as particle size of

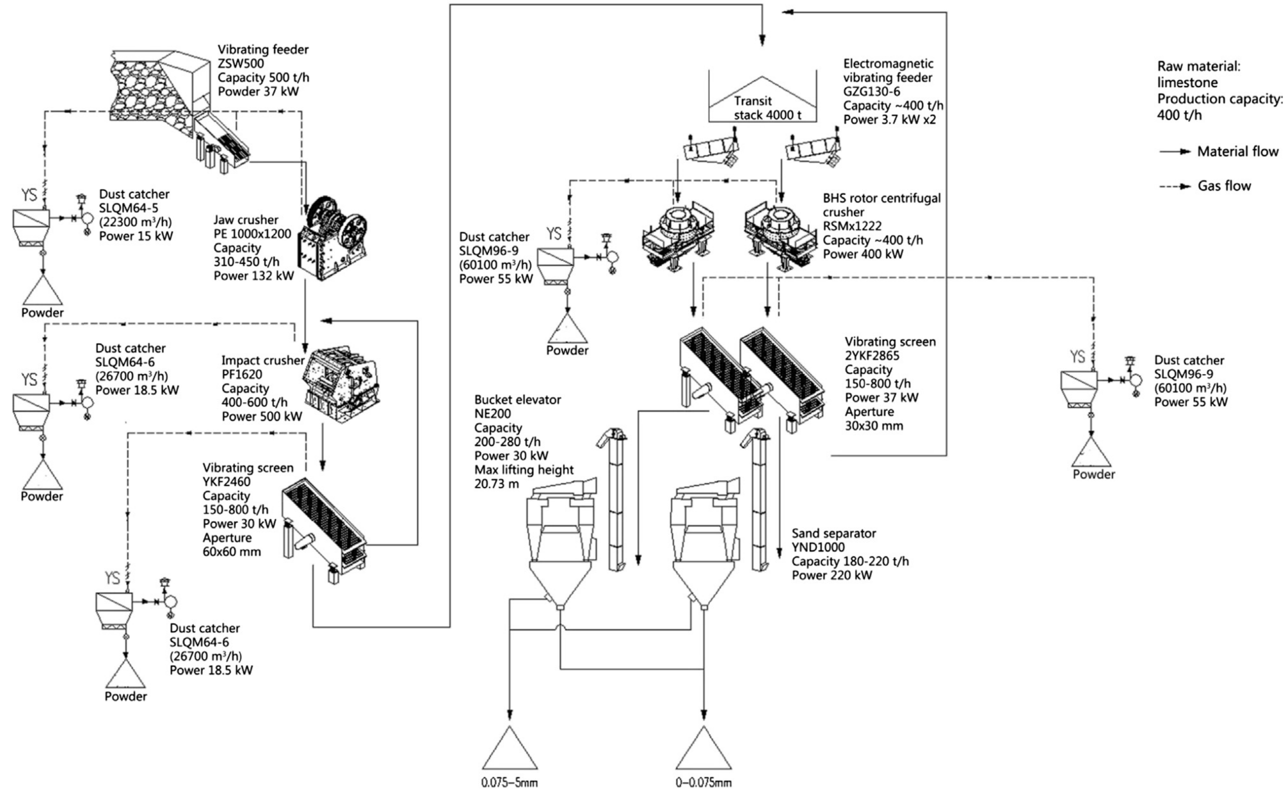
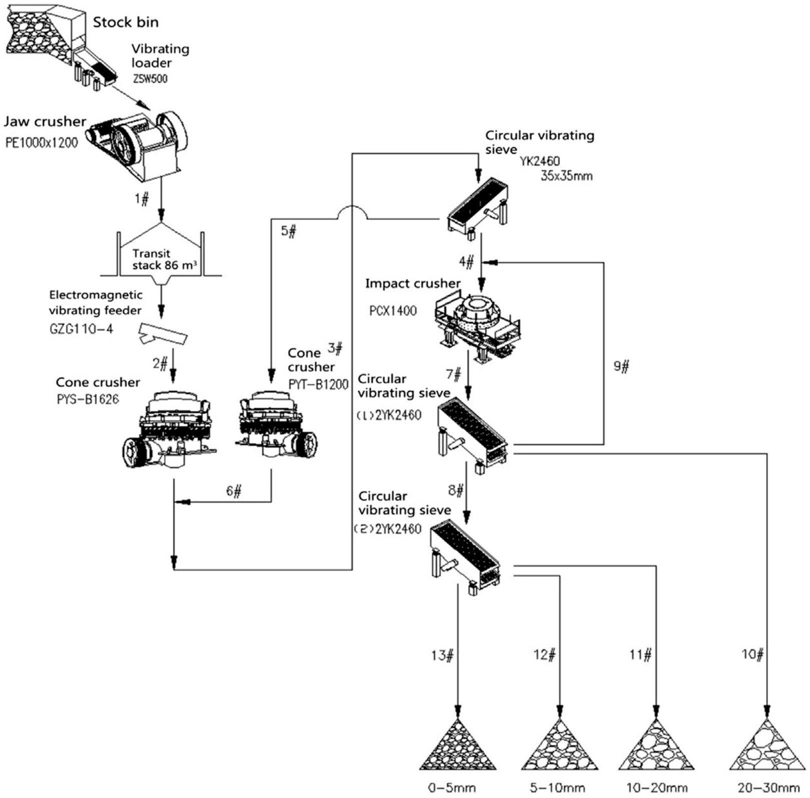


Figure 8.12 Typical flow sheet of stone processing line.



Raw material: granite
Production capacity: 350-400 t/h
Inlet size: 600-800 mm

				1228	
9	Belt conveyor	B800x20m	4	11	10~14#
		B650x26m	1	11	9#
		B1200x26m	1	22	7~8#
		B650x20m	1	7.5	6#
		B650x24m	1	11	5#
		B1200x24m	3	18.5	2~4#
		B1200x20m	1	15	1#
8	Circular vibrating sieve	2YK2460	2	30	
7		YK2460	1	30	
6	Impact crusher	PCX1400	1	2X220	
5	Cone crusher	PYT–B1200	1	110	
4		PYS–B1626	1	250	
3	Electromagnetic vibrating feeder	GZG110–4	1	2x1.5	
2	Jaw crusher	PE1000x1200	1	132	
1	Vibrating loader	ZSW500	1	37	

Figure 8.13 Hard raw materials processing project (350—400 t/h granite processing project).

>30, 20–30, and <20 mm. The subsequent process is similar to the project discussed earlier. Three classified groups of materials based on their size are gained after another crushing and screening, which are 10–20, 5–10, and <5 mm, respectively. All of them are conveyed to stockage piles of finished materials separately. Dust removal equipment can be added to each device in accordance with local environmental regulations.

8.2.7 System of Sand Processing Line

Sand and gravel industry provides the basic raw materials of construction engineering and has largely contributed to the rapid development of construction and traffic industry. With the gradual decrease of natural sand resources, production of sand and gravel aggregate using low-grade limestone mines or other waste mineral for the replacement of natural resources should be encouraged.

8.2.7.1 Division of Sand and Gravel Materials

1. Natural Sand

It is naturally generated, and the particle size is less than 4.75 mm after artificially mining and sieving, including river sand, lake sand, mountain sand, and sea sand, not including soft and weathered rock particles.

2. Manufactured Sand

Manufactured sand is produced by mechanic crushing and screening and the particle size is less than 4.75 mm. Most manufactured sand is rock, mine tailings, or industrial waste particles, not including soft and weathered rock particles.

3. Category of Sand

Sand can be divided into class I, II, and III according to the technical requirements.

4. Clay Content

Clay content refers to the particle content of size less than 75 μm in natural sand. Clay content of natural sand class I is $\leq 1.0\%$.

5. Powder Content

Powder content is the particle content of size less than 75 μm in manufactured sand. Powder content of sand class I is $\leq 10.0\%$.

6. Specification of Sand

Sand can be classified into three specifications according to the fineness modulus.

- Coarse: 3.7–3.1
- Medium: 3.0–2.3
- Fine: 2.2–1.6

Sand production process can be divided into dry production and wet production.

8.2.7.2 Dry Production Line

The dry production process is established later than wet production process, and is further developed on the basis of the traditional wet production. Main facilities involved in this process include hoppers, vibrating loaders, belt conveyors, impact sand producing machines, SZZ vibrating sieves, elevators, high-efficiency separators, and storage bins. During this process, no water is needed and added in the cleaning of clay powder from the sand.

The key components of shortened dry sand processing system is German BHS sand producing machine and the air mesh, the closed-loop controlling system is made up of the feeder, regulatory panel, recycled filter, and dust collector. Automatic control of fineness modulus is the key technology in this process. Typical features are listed below in detail.

1. German BHS sand producing host machines are equipped and of low energy consumption, low cost, good particle shape, and stable grading. The impact rotors in two cavities largely increase the crushing effect and reduce the power.
2. The sorting technology using air mesh is able to simultaneously separate the qualified and unqualified products in the crushed materials. The classification process is even more accurate. Those dusts of particle size below 0.075 mm will be removed by the dust catcher. Grading adjustment can be performed by regulation, while unqualified products will be sent back to the crusher.
3. Target products of particle size between 0.7 and 1.5 mm used to be difficult to produce and can be largely increased by the application of the backward closed system. The particle shape of products can be as good as that of natural sand (solid content 57–59%). Appropriate moisture content can also be obtained using spraying devices.

4. High energy performance in the system and high sand production ratio (60–70%) is found. Low electricity consumption of less than 2.3 kWh for a ton of sand production can also be achieved.
5. The frame structure requires small land occupation, short construction time period, and low civil engineering investment. The enclosed structure largely decreases the dust emission, which is far lower than the regulated value 30 mg/Nm^3.

A shortened dry sand processing line is demonstrated in Fig. 8.14.

The raw materials coming out of the electromagnetic vibrating feeder GZG850-4 are lifted by the elevator NE300 to HBS1222 sand producing machine for crushing. The crushed materials are transported to the winnower screening 4FX2460 and separated into four groups. The large particles on the top layer are sent back to sand producing machine for crushing, whereas the other three groups of materials are conveyed to the product stockpiles. The bag filter SLQM96-10B is also equipped for dust removal and the small particles collected are elevated to the powder storage bin.

The distribution control system of the dry sand processing line involved is demonstrated in Fig. 8.15.

8.2.7.3 Wet Production Line

Wet artificial sand aggregates production process is more suitable in regions rich in water resources. Typical flow sheet of process line is demonstrated in Fig. 8.16.

The crushed materials coming from the jaw crusher PE1200 × 1500 through the vibrating feeder ZSW630 are then conveyed to the transit storage bin, where these materials are separated and, respectively, sent to the impact crusher PFG1822 and two cone crusher (for coarse crushing) PYS-B1636. The crushed materials are transported to the vibrating sieve No. 1 2YK3270, where three classified grades of materials (of particle size >30, 20–30, and <20 mm) are obtained. Particles of size larger than 30 mm are conveyed to PYS-B1626 cone crusher (for fine crushing) and then sent back to the vibrating sieve. Particles of size between 20 and 30 mm are transported to the finished product stockpiles. The rest of the materials are conveyed to the vibrating sieve No. 2 2YK3270 where three other classified grades of materials are got (size 10–20, 5–10, and 0–5 mm). Those materials of particle size smaller than 5 mm are sent to the spiral sand washing machine for clay and mud removal before entering the finished product stockpiles.

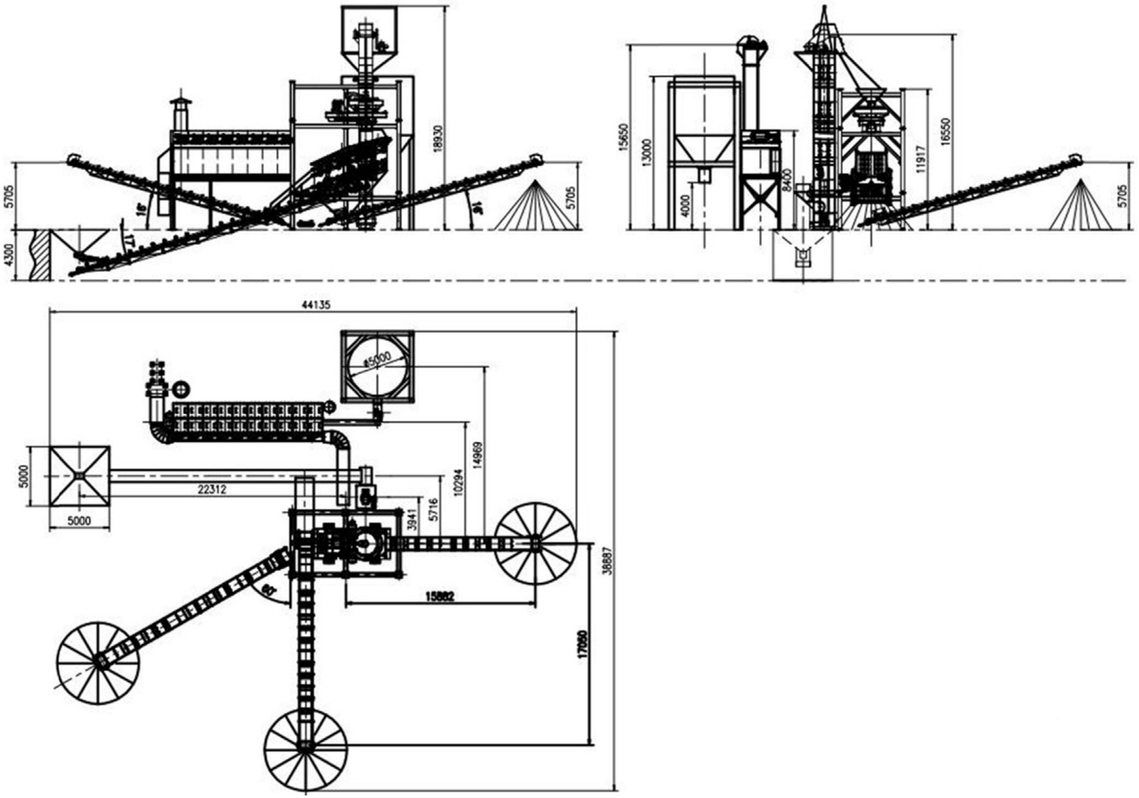


Figure 8.14 Shortened dry sand processing line.

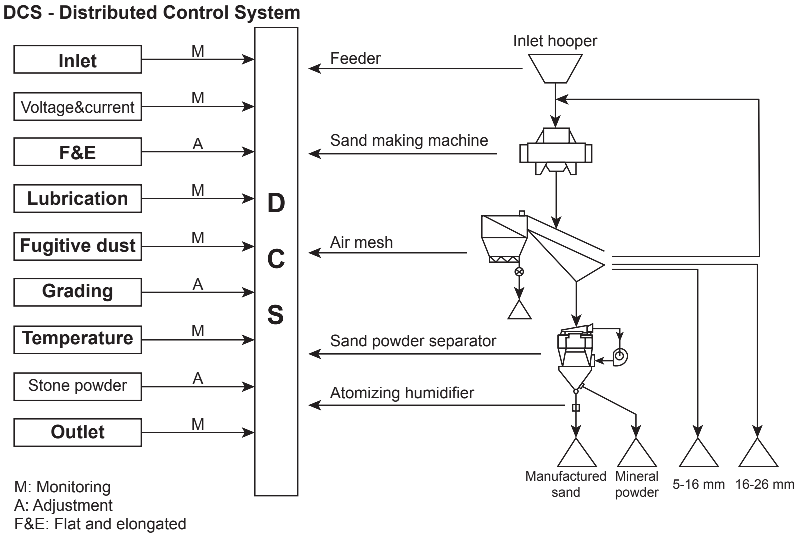


Figure 8.15 Distribution control system of dry sand processing line.

Wet artificial sand aggregate processing has the following advantages:

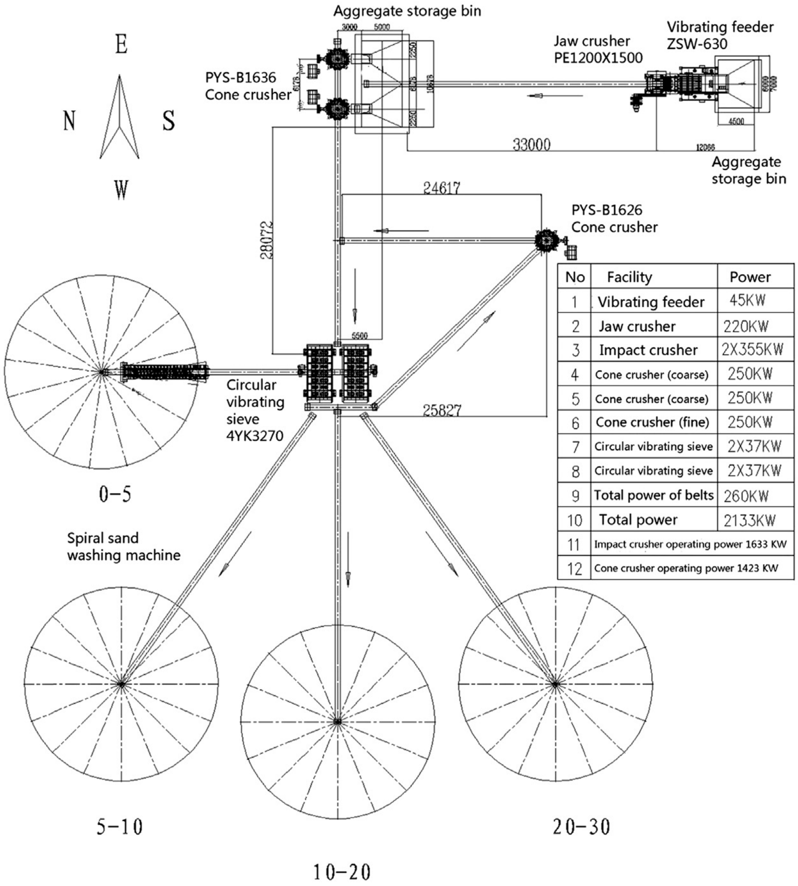
1. The aggregates produced are clean on the surface and the quality is better.
2. No dust pollution is caused due to the water washing procedure.

8.2.8 Integration Technology of Renewable Wall Materials

At present, most infilled walls of residential construction buildings of frame structure in big cities are composed of small pieces of materials and are built piece by piece, followed by huge amount of leveling, painting, and other wet work like brick structure. In this case, wet wall painting and plastering accounts for over 50% of the total wall construction work. The cost of wet wall construction work is more than twice that of wall materials. Meanwhile, the wet wall construction work may also result in slow construction work, low efficiency, and large resource consumption.

8.2.8.1 Eco-Friendly Ecological Wall Board

It refers to the ecological environment construction materials. The production amount of building materials is the largest while the resource consumption and pollution level are also the highest among all kinds of materials. Human health is also closely related to the pollution level of building materials. On the other hand, it is most likely to use other solid wastes as raw



No	Facility	Power
1	Vibrating feeder	45KW
2	Jaw crusher	220KW
3	Impact crusher	2X355KW
4	Cone crusher (coarse)	250KW
5	Cone crusher (coarse)	250KW
6	Cone crusher (fine)	250KW
7	Circular vibrating sieve	2X37KW
8	Circular vibrating sieve	2X37KW
9	Total power of belts	260KW
10	Total power	2133KW
11	Impact crusher operating power 1633 KW	
12	Cone crusher operating power 1423 KW	

Figure 8.16 Wet sand processing line (600 t sand aggregate processing line in Linxiang City).

materials to produce building materials to improve the ecological environment. Ecological building materials is a class of new building materials, which might meet the following principles: (1) low resource and energy consumption and environmental pollution level in their production and usage; (2) recycling and utilization of waste; (3) capable of improving living environment and health condition; (4) of good feature and performance, capable of meeting the requirements of various construction projects.

Technical Route of EF Ecological Wall Board Processing

1. Recycled aggregate production process

Initial classification of C&D waste, coarse crushing, fine crushing, screening, recycled aggregate.

2. Ecological wallboard manufacturing process
   Mixing of cementitious materials, recycled aggregates, modified materials, additives, conveying, extrusion molding, cutting, packaging, steam curing, storage.
3. Ecological wallboard assembly construction process
   The first layer, setting out, adhesive plastering on wallboard joints, wallboard installing, correction, construction of the second block is similar. The construction of the second and third layers is the same as that of the first layer. The vertical joint of layers should be stagger-jointed to avoid the crack resulting from stress concentration. Assembly of the entire wall completed—direct scraping of 2 mm putty once or twice—painting of coatings.

Structure–Function Integration of EF Ecological Wallboard

EF ecological wallboards, as assembled wallboards, are not identical to sheets, strip boards, and blocks in specification and structure. "Slabs" and "ribs" (the joint portions among holes), as components of EF wallboards, are manufactured through a composite extrusion in the factory, thus avoiding the combination of flat boards (slabs) and channels (ribs) and improving the efficiency of construction. Functions of EF boards are as follows. The thickness, density, strength, etc. of EF boards meet the sound insulation, hanging force, and other functional requirements of frame structured residential infilled walls. The holes of ecological wallboards both successfully reduce the weight and save materials. The good mechanical properties of the round holes improve the flexural strength of the boards. Pipelines are easy to be arranged and can run through the holes. The "slabs" of EF ecological boards molded by machines are highly flat and can reduce the cement mortar wet paint work on construction sites.

Specifications of EF ecological wallboards can be classified into two series: 6, 8, 10 series and 6, 9, 12 series (which means the length is 60, 80, 100 mm and 60, 90, 120 mm, respectively). The main specification size is 1000 × 500 × 100–150 mm (L × H × D), 1200 × 600 × 100–150 mm (L × H × D), respectively, which corresponds with the construction module. The thickness of EF wallboards correspond with that module required by frame-structured residential infilled walls. The height of EF wallboards correspond with the connecting bars module of wall columns in reinforced concrete-structured residential buildings. The length of EF boards corresponds with the physical efficiency of manual construction (the length is correlated with board weight). EF ecological wall structure meets the demand of frame-structured residential buildings and thus can be the structure—function integration of infilled wall materials.

Modular Assembly Construction

Construction method of EF ecological wallboards is modular staggered joint and assembly combined. Thirty-six pieces of ecological wallboards are needed for the construction of a chamber wall (3 × 6 m) and the construction time is about 2 h for workers in pairs. For clay hollow bricks (240 × 115 × 90), the amount required is 720 blocks and the construction time is about 2 days. For small concrete blocks (390 × 390 × 190), 225 blocks and 1 day are needed, respectively.

8.2.8.2 Green Building Materials: High-Efficiency Self-Insulation Wall Material

The substances used in the raw material application, product manufacturing, usage, recycling process, and waste disposal of green building materials should be of no harm to human health and have low environmental burdens. It is also regulated in "Evaluation standard for green building" (GB/T 50378-2006) that: (1) The building materials used should be reusable and recycled. (2) For the building materials produced using solid waste as raw materials, the waste amount added should not be less than 30%, the usage amount among the same kind of building materials should not be less than 30%.

The self-insulation wall materials and products not only have good insulation effect, but are also long in their service life, which belong to green building materials. Take the hollow blocks with high insulation properties produced in France, for example, the heat transfer coefficient of 300-mm-thick brick wall can be reduced to 0.75—1.0 $W/m^2 \cdot K$.

At present, self-insulation wall production can mainly refer to the wall insulation technology using composite insulation block, lightweight sand aerated concrete block, aerated concrete plate, porous brick shale modulus, etc.

Composite Insulation Block

The production process of composite insulation block is introduced as follows. The lightweight concrete aggregate or common concrete hollow block is used as the basic material. High-efficiency insulation materials (such as polystyrene material, slag, rice husk, perlite, and foam insulation materials) are used as filling materials in the holes of hollow blocks. The automatic process line is applied in which the block shells and insulation materials are molded together as the composite insulation block. The composite blocks with good insulation properties and economic value can be divided into three types: non-load-bearing, load-bearing, and interior wall blocks. The main features are high strength, low weight, low structure loading, low investment of manufacturing plant, various strength grades, feasible construction method, easy waste utilization, etc. Those hollow blocks with double or triple rows of holes are generally used of which the porosity is $\geq$40%. The main performance index is listed in Table 8.14.

Lightweight Sand Aerated Concrete Block

This self-insulation system of sand aerated concrete block is composed of reinforced concrete frame and sand aerated concrete block. The external side of the insulation part is mainly waterproof interface agent, paint layer (partially with alkali-resistant fiberglass mesh), and surface layer. The internal side is mainly the putty layer (partially with alkali-resistant fiberglass mesh) and the surface layer.

The main features of sand aerated concrete block are listed as follows.

1. Low density. The density of this building block is only 1/5—1/3 of that of common building materials like concrete and clay brick. The weight of constructed building can be largely reduced thereby reducing the construction costs.
2. Strong fire resistance. This building material is mainly made up of inorganic noncombustible substances of strong fire resistance. The duration of fire resistance can be longer than 4 h. No harmful gas will be emitted at high temperature.
3. Good temperature, heat, and sound insulation performance. Many small open or closed gas pores will generate inside the block in the production process. In this case, static air layers will be formed inside the block and cause the decrease of thermal conductivity. The materials used are also low in thermal conductivity (1/3 of that of clay brick).
4. Strong antipermeability. The large number of open and closed pores lengthens the time required for water absorption and temperature conductivity. It would take four more times longer to its water saturation than the clay brick.

Table 8.14 Main Performance Index of Composite Insulation Blocks

Item			Requirement	Test Result
Polystyrene board	Dimensional stability (%)		≤3.0	1.71
	Water absorption ratio (in volume) (%)		≤4.0	2.10
Foam concrete	Compressive strength (MPa)		≥0.50	0.64
	Drying shrinkage value (mm/m)		≤1.0	0.72
	Water absorption ratio (in volume) (%)		≤12.0	7.3
Composite insulation block	Compressive strength (MPa)		≥5.0	6.0
	Drying shrinkage value (mm/m)		≤0.20	0.16
	Relative water content (%)		≤40	29
	Frost resistance (D_{15})	Mass loss (%)	≤5	0.2
		Strength loss (%)	≤25	6
	Thermal resistance ($m^2 \cdot K/W$)		≥2.5	3.06
	Carbonation coefficient		≥0.8	0.91

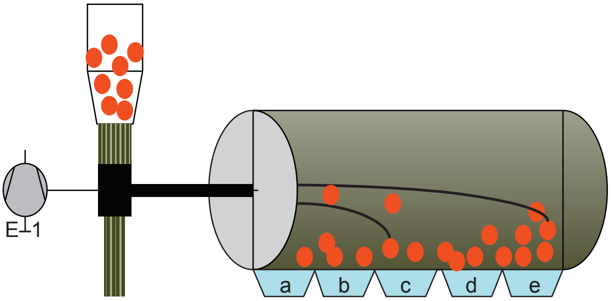


Figure 8.17 Pilot scale winnowing device of construction and demolition waste powder for enrichment of heavy metals.

8.3 RECOVERY AND UTILIZATION OF HEAVY METALS FROM INDUSTRIAL CONSTRUCTION WASTE POWDER

8.3.1 Winnowing Enrichment of Zinc and Lead From Construction Waste Powder

The winnowing device includes a QUINCY screw air compressor (QGF30), a cylindrical gravity sedimentation chamber (6 × 1 m) and a Venturi tube (ZH15DS/L—10-12-12). Five sampling units (a, b, c, d, e) are evenly located in the chamber, which is demonstrated in Fig. 8.17.

The industrial construction waste polluted by lead and zinc were ball milled until the particle size was below 0.5 mm, and then sent to the winnowing device. The solid–gas ratio of the feed stream of the inlet C&D

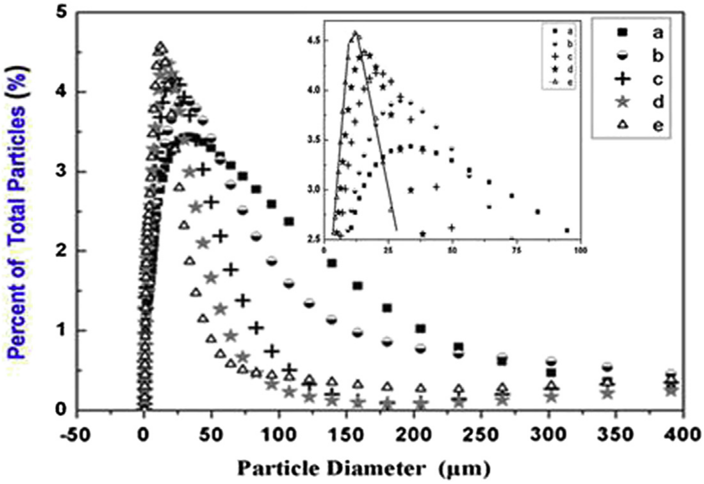


Figure 8.18 Size distribution of construction and demolition (C&D) waste powder in a, b, c, d, and e in the pilot scale winnowing device of C&D waste powder for enrichment of heavy metals.

Table 8.15 Components of the Waste Powder in Different Sampling Spots

	Sampling Spots				
Weight (%)	**a**	**b**	**c**	**d**	**e**
Zn	34.35	32.17	19.22	8.55	6.72
Si	6.18	9.52	16.33	30.09	43.36
Ca	3.67	5.24	9.25	17.71	26.30

waste was set to less than 1/1000, and the flow rate was 438 m^3/h. When the particle sedimentation was finished, the test samples were collected from the five sampling spots and their chemical composition and particle size distribution were analyzed. The results are reflected in Fig. 8.18 and Table 8.15.

The particle size of 50% of the waste in spot a was smaller than 22.4 μm, the average specific surface particle size D was 5.82 μm. The particle sizes of the waste in spot b, c, d, and e were sequentially decreased. As the waste in spot e, the D50 was 9.35 μm, whereas D was 4.01 μm. The zinc content (Wt) in C&D waste of spots a and b was over 30%, and the silicon content was also quite high (6—10%).

The wastes from sampling spots a, b, and c were collected and leached under the condition: 5 mol/L NaOH, L/S = 10:1. The recovery rate of zinc thus obtained is demonstrated in Fig. 8.19.

The zinc recovery of the waste powder from spot a was the highest, in which 65% of zinc can be recovered in 1 h of leaching. The silicon and

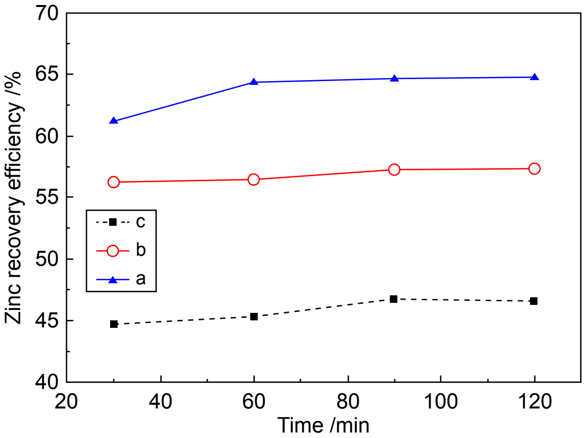


Figure 8.19 Zinc recovery rate of the waste in different sampling spots.

Table 8.16 Impurity Content of the Waste Samples From Different Spots

Concentration (mg/L)	Sampling Spots		
	c	b	a
Al	140 ± 8	119 ± 15	103 ± 7
Ca	46 ± 7	47 ± 13	40 ± 1.3
Si	262 ± 19	235 ± 29	169 ± 15

calcium of waste powder from spot c is the highest, which largely inhibited the zinc leaching process, resulting to a lower leaching rate. To further evaluate the leaching process, the main impurity content in leachate was determined and the results are listed in Table 8.16. Concentration of aluminum and silicon in the leachate was less than 300 mg/L, whereas the calcium concentration was approximately 50 mg/L. The leaching rate of silicon was less than 2%, which was due to the fact that calcium silicate was the combination form of silicon and calcium in this case, and insoluble in sodium hydroxide. Meanwhile, the presence of zinc inhibited the leaching of silicon in alkaline solution. Ammonia was also used as the leaching solution, and the optimum conditions were found to be 4 mol/L ammonia, L/S = 50:1, and leaching time of 70 min. The silicon and lead content in the ammonia leaching solution was lower compared with NaOH leaching solution, but the calcium content increased by about 75 mg/L and the zinc recovery rate decreased by 20–30%.

8.3.2 Sequential Stepwise Recovery of Selected Metals From Flue Dusts of Secondary Copper Smelting Manufacturing Workshop

Metallurgical industries generate vast quantities of different types of wastes such as the flue dust of secondary copper smelting, which might be attached to construction materials in workshops and mixed with demolition waste when the workshop is abandoned or demolished. These wastes could be used to recover metallic values or they may be disposed of. However, the disposal of such material is now becoming expensive due to increasingly stringent environmental regulations. Furthermore, the chemical nature of these dust/ash particles is such that these are classified as hazardous waste under the US Environmental Protection Agency classification.

The flue dusts used in this chapter were obtained in a secondary Cu industries manufacturing workshop from the city of Fuyang, Zhejiang. The composition of the dusts varies considerably, and it is dependent not only

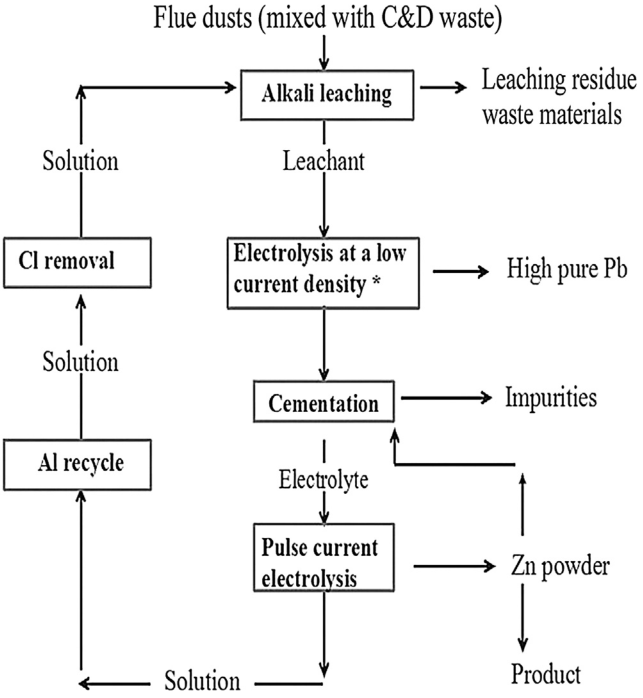


Figure 8.20 General scheme for treating flue dusts from secondary copper smelting workshop in alkaline solution process.

on the waste used, but also on the operating conditions. However, some general trends have been noted. For example, most of these dusts are rich in Zn, Cu, Cl, Pb, and Al. It is advisable to leach the dusts with caustic soda, because the chlorides will not be tolerated in the acid electrolyte, as even a very small amount can cause severe corrosion problems and thereby damage the electrolysis. Moreover, the washing section for removing Cl produces secondary pollutants and complicates the process.

An alkaline hydrometallurgical route is presented in this work, as shown in Fig. 8.20, for the metal recovery from the flue dusts of secondary copper smelters enriched from C&D waste. In the alkaline zinc electrowinning,

Table 8.17 Chemical Analysis of the Main Elements Present in the Waste

Element	Zn	Cu	Pb	Al	Cl
Weight (%)	40.21	7.53	6.62	2.58	8.47

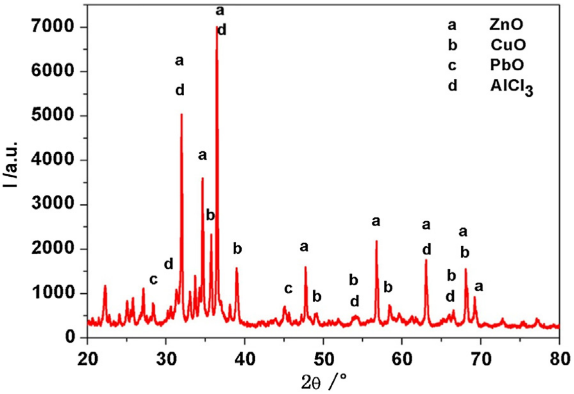


Figure 8.21 Mineralogical phases of flue dusts used.

Na_2S has been used to remove Pb from the leach solution, and this approach can recover lead selectively and quantitatively.

The sample was dried and homogenized, and its chemical composition is listed in Table 8.17. It demonstrated that the major elements present in the sample were zinc, copper, lead, aluminum, and chlorine. An X-ray diffraction (XRD) (BRUKER D8 ADVANCE) analysis of the samples as received is displayed in Fig. 8.21. It showed that most of metal elements were in combination with oxygen, but there can also be chloride.

The leaching processes were carried out at 30–90°C under atmospheric pressure. In electrowinning process, stainless steel electrodes were used as both anode and cathode. The anode to cathode distance was kept at 3 cm and all electrowinning experiments were carried out at room temperature (30–50°C). Electrolysis of lead was attained by applying a low current density of (100–250 A/m^2).

Fig. 8.22 shows that the presence of $Zn[OH]_4^{2-}$ as the main zinc species for pH values higher than 14.4. In addition, $Zn[OH]_4^{2-}$ becomes the main lead species progressively as the pH value increases gradually from 14.4 to 14.7, while most of Cu begins to dissolve at a higher pH value. Hence, NaOH concentrations of 3–5 M (pH = ~14.4~14.7) were applied in this process.

Factorial design and analysis of experiments were used to determine the main effects and interactions of the leaching factors. Three quantitative variables were investigated at two levels, as shown in Table 8.18. These were NaOH concentration (A), leaching temperature (B), and solid/liquid ratio

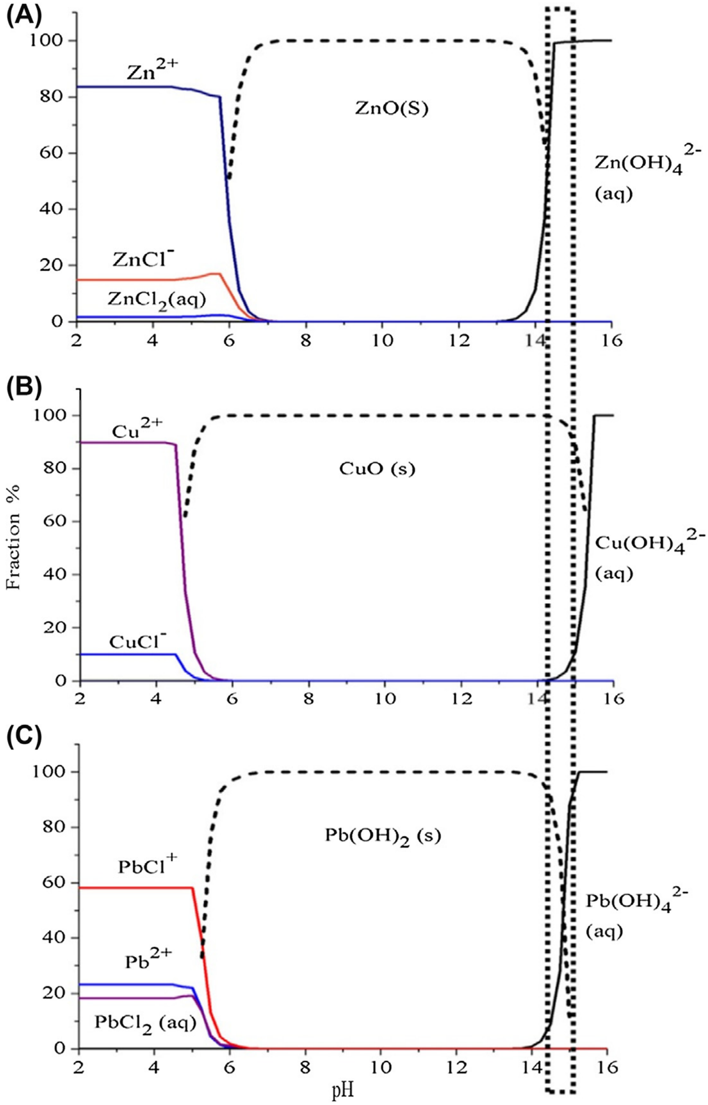


Figure 8.22 Speciation of metals in solution with a chemical equilibrium computer program (MINEQL+).

(C). The levels of the variables are given as follows: (A) [4(−), 5(+)] mol/L, (B) [65(−), 80(+)]°C, (C) [100(−), 125(+)] g/L. Reaction time was kept fixed at 1.5 h. The main response under investigation was the percentage of metal (Zn/Pb) recovery in the leach liquor. Table 8.18 presents that the influence of the parameters on Zn leaching followed the order: S/L

Table 8.18 Experimental Runs and Response Analysis According to Yates' Algorithm

	Variables Studied				Yate's Analysis			
Code	**A**	**B**	**C**	**Zn %**	**1**	**2**	**3**	**Effects**
1	−	−	−	80.47	165.35	337.78	646.73	−
a	+	−	−	84.88	172.43	308.95	27.21	6.80
b	−	+	−	83.91	151.29	9.02	13.45	3.36
ab	+	+	−	88.52	157.66	18.19	1.25	0.31
c	−	−	+	71.36	4.41	7.08	−28.83	−7.21
ac	+	−	+	79.93	4.61	6.37	9.71	2.29
bc	−	+	+	74.02	8.57	0.2	−0.71	−0.18
abc	+	+	+	83.64	9.62	1.05	0.85	0.21

ratio > NaOH concentration > leaching temperature > interaction between NaOH concentration and S/L ratio. The other factors, such as interaction between leaching temperature and NaOH concentration, interaction between S/L ratio and leaching temperature, and three-factor interaction have a minor effect on the zinc leaching. Moreover, the same trend in the lead leaching behavior has also been found.

In this leaching process, together with Zn and Pb, Al and Cu may also be dissolved in strong alkaline solution. However, the solubility of Cu was found to be negligible in the presence of zinc and lead, and the concentration of Cu in leach solutions was lower than 0.5 g/L. The typical concentration of Al in the leach solution was also depressed by the Zn and Pb, but it may be accumulated when the leach solutions were recycled. Hence, part of Al should be removed in certain stage of recycling. Under the optimum condition, the typical contents of the leach solution were (g/L) 35−40 Zn, 6−8 Pb, 0.3−0.8 Al, and 0.2−0.5 Cu. The dissolved copper is removed from the leach liquor by lead cementation at a Pb/Cu molar ratio of 2 within 15 min, and the residual Cu in the solution was 10−50 mg/L, which was used for the following electrolysis of lead and zinc.

Pb could be recovered at low current densities (Table 8.19), which correspond to higher cathodic potential values shown in Fig. 8.23. About

Table 8.19 Electrowinning Conditions for Lead and Zinc Recovery

	Cell Voltage (V)	**Current Density (A/m^2)**	**CE (%)**	**PC (kWh/kg)**
Pb	1.58	150	74	0.55
Pb	1.90	250	85	0.58
Zn	2.70−3.18	1000−1500	80−93	2.38−3.26

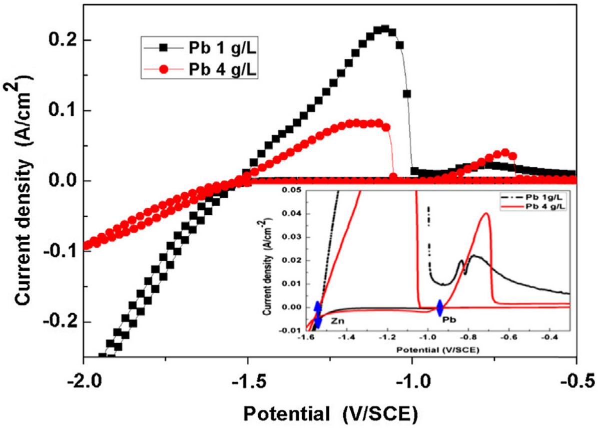


Figure 8.23 Cyclic voltammograms of lead (1—4 g) and zinc (35 g/L) electrowinning in the alkaline leach solution.

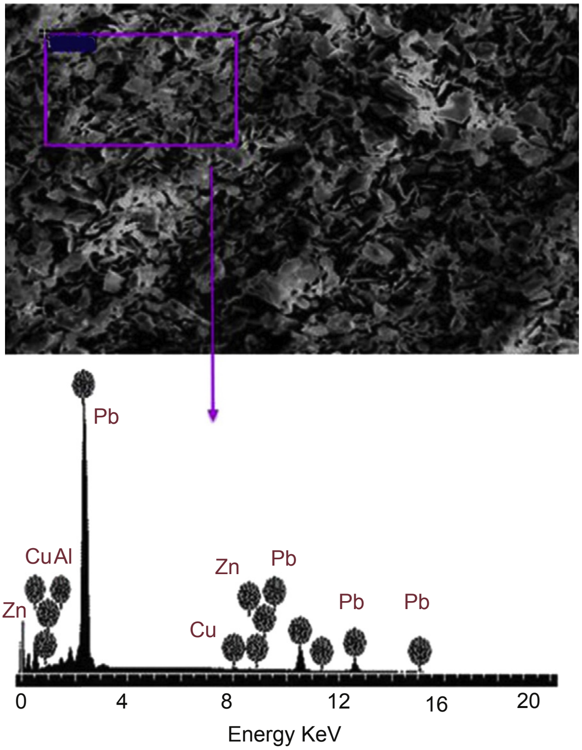


Figure 8.24 Scanning electron micrograph of the produced lead with EDS of selected particles.

Table 8.20 Results of the Cementation Experiments (1.15 Zn/Pb Ratio, 50°C)

	Removal Efficiency of Pb (%)	
Time (min)	**Zn Powders (30–50 μm)**	**Zn Powders (60–90 μm)**
20	59.05	49.38
40	66.55	52.50
60	82.28	66.64
90	91.83	81.22

83–87.5% lead was recovered. Chemical analysis showed the purity of the lead deposits (~97.18%) and the presence of only traces of copper (~1.18%), zinc (~0.72%), and aluminum (~0.87%) elements. Fig. 8.24 shows the identified elements in the sample by SEM-EDS. The data confirmed the presence of lead as the main element.

The solution resulting from low current density electrolysis of Pb contained Zn 35–40 g/L, Pb < 1 g/L, Cu 0.01–0.04 g/L, Al 0.3–0.8 g/L. Hence, the cementation by adding zinc powders, was carried out to reduce the Pb to lower levels (100 mg/L), as presented in Table 8.20. The optimum conditions for this cementation were found to be: stoichiometric × 1.15 zinc powders (30–50 μm), 35–50°C, and 1.5 h.

Production of zinc powders by pulse current was then conducted. Fig. 8.25 demonstrates that the average cell voltage increased from ~2.9 V at $T_{on} = 5$ ms to ~3.2 V at $T_{on} = 15–25$ ms, whereas it decreased from ~3.2 V at $T_{off} = 5$ ms to ~2.6 V at $T_{off} = 20$ ms. These behaviors

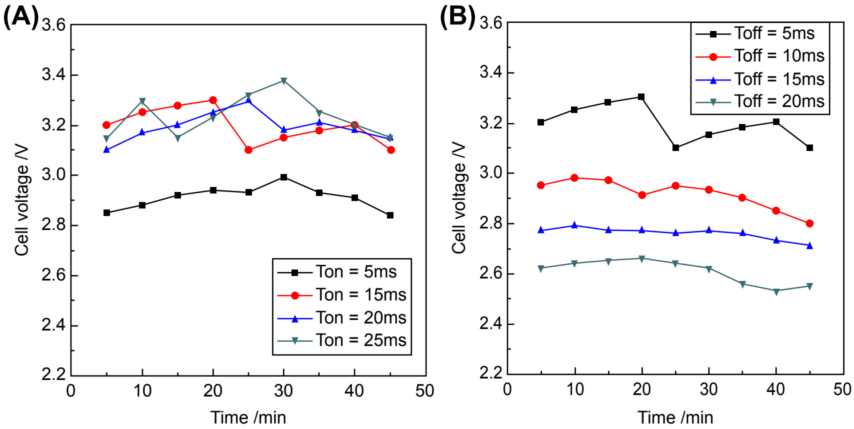


Figure 8.25 Cell voltages alkaline zinc electrowinning at different conditions: (A) $T_{off} = 5$ ms; (B) $T_{on} = 15$ ms.

Table 8.21 CE and PC of Zinc Powder Production at Different Conditions

	$T_{off} = 5$ ms; $T_{on} = 5-25$ m				$T_{off} = 15$ ms; $T_{on} = 5-20$ m			
Variable (ms)	5	15	20	25	5	10	15	20
CE (%)	96.2	69.9	67.2	58.8	69.9	81.0	92.86	76.12
PC (kWh/kg)	2.48	3.73	3.89	4.51	3.73	2.93	2.39	2.81

may be related to the decline in the electrolyte electrical conductivity resulting from a longer current-on time. Table 8.21 presents that sequentially increasing T_{on} from 5 to 25 ms results in a progressive decrease in the CE down to 58.8%. The explanation for this can be that increasing the T_{on} did not feed a sufficient and constant amount of zinc to the cathode, which lowered the reduction rate and consequently the CE. On the contrary, the increase in T_{off} from 5 to 15 m exerted a positive effect on the CE, and the maximum value (92.86%) was achieved at $T_{off} = 15$ ms. Further increase in T_{off} decreased the CE substantially; this decrease may be attributed to the adsorption of $[OH]^-$ species on the cathode surface, which blocked the active sites of cathode.

The CE and the cell voltage were used to compute the PC. Table 8.21 shows a negative effect of pulse current, compared with direct current, on the PC. However, this adverse effect could be counteracted by adjusting the T_{on} and T_{off}. For example, at $T_{on} = 15$ and $T_{off} > 10$, the PC was 2.4–3.0 kWh/kg, less than the typical industrial value of 3.1–3.2 kWh/kg. In addition, the actual rate for zinc electrowinning could be promoted considerably by pulse electrolysis.

The influence of T_{on} and T_{off} on the morphologies of zinc powders, with constant pulse current density, are illustrated in Fig. 8.26. The zinc powders obtained at $T_{on} = 5$ ms were irregular, and relatively rough, with a morphology constituted by a mixture of wide leaf-like particles and boulder deposits. By contrast, dendrites and secondary growth in Zn-$T_{on} = 15$ ms were more evident. It was suggested that the reduction of Zn ions at a higher T_{on} inhibited the diffusion of adatoms across the surface into the proper sites of the growing crystal lattice. Subsequently, increasing T_{off} to 15 ms resulted in a rise in grain size of zinc powders. Zinc particles with an average grain size of 43.1 mm were formed at $T_{on} = 15$ ms, $T_{off} = 15$ ms. This increase in grain size can be explained by a reduced number of nucleation sites caused by the lower overpotential at a longer T_{off}. However, the zinc powders obtained with further increasing T_{off} (20 ms) showed a reduced size as indicated in Fig. 8.26D. This result could be due

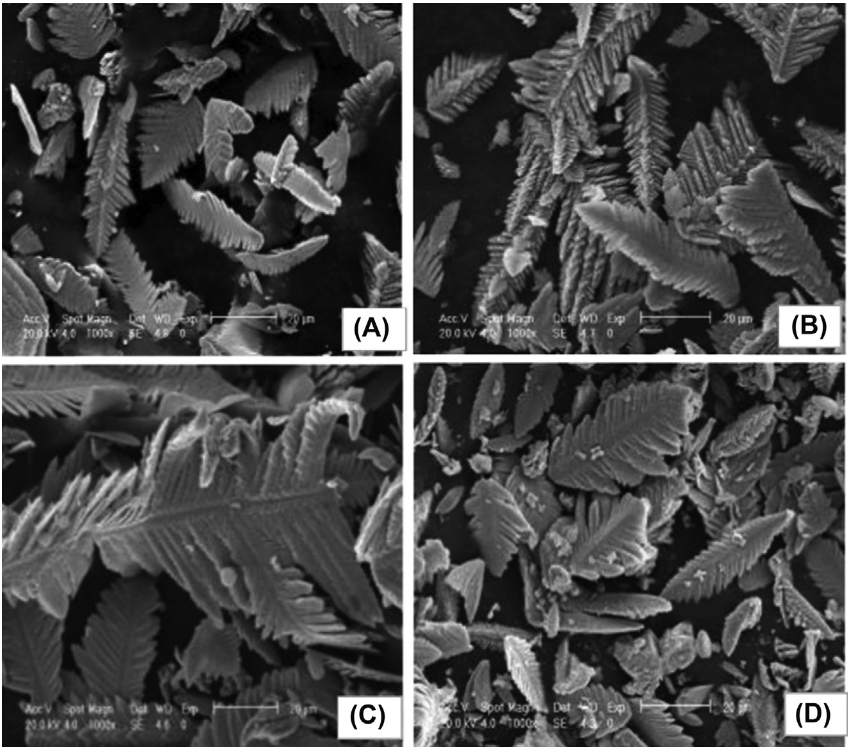


Figure 8.26 Scanning electron microscopy images of zinc powders produced at different conditions: (A) $T_{on} = 5$, $T_{off} = 5$; (B) $T_{on} = 15$, $T_{off} = 5$; (C) $T_{on} = 15$, $T_{off} = 15$; (D) $T_{on} = 15$, $T_{off} = 20$.

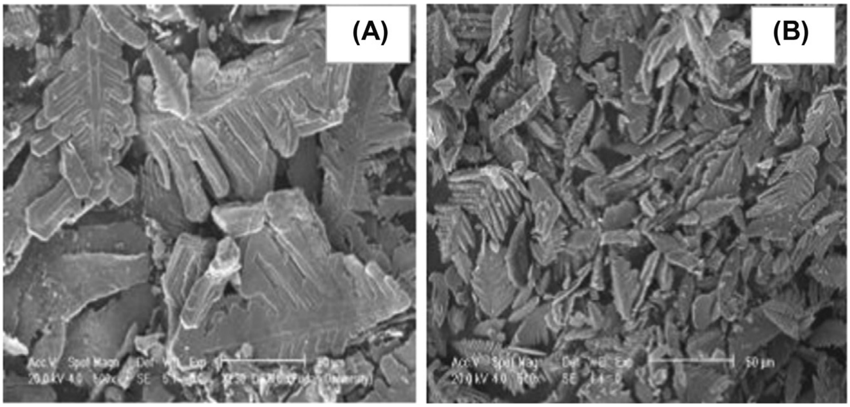


Figure 8.27 Surface morphologies of zinc powders produced at T = 35°C and average current density = 1000 A/m^2: (A) direct current electrolysis; (B) pulse current electrolysis.

Table 8.22 Comparisons of Pulse Current and Direct Current Electrolysis in Zinc Powder Production

Particle Size[a] (μm)	Pulse Current $T_{on} = 15$ ms; $T_{off} = 10$ ms; Average Current Density = 1000 A/m^2	Direct Current Current Density = 1000 A/m^2
D [3,2]	36.3	63.3
D [4,3]	60.1	118.0
D [50]	50.9	92.0
D [90]	101	235

to the polarization resulting from the $[OH]^-$ absorbed. Overall, the pulse electrolysis of $T_{on} = 15$ ms and $T_{off} = 10$ ms gave the best performance in terms of homogeneity and average size of zinc powders, and in such way 88−92% Zn was recovered from the leach solution.

Electron micrographs of the surface morphology of zinc powders obtained by direct electrolysis and pulse electrolysis are displayed in Fig. 8.27A and B, respectively. Both of them were dendrite-like and highly porous; the pulse electrolytic zinc powders were more homogeneous and finer. About 90% of the direct electrolytic powders were smaller than 235 mm, whereas 90% of the powders produced by pulse current were smaller than 101 mm (Table 8.22). From XRD it can be seen that the characteristic (101), (100), (002), (102), (103), and (110) peaks of a powder sample from the material shown in Fig. 8.27A are the same as those of a direct current sample in Fig. 8.27B (Fig. 8.28A and B). By comparison, irregular peaks were decreased and crystallization of particles was facilitated by using pulse current. This result could be due to the polarization resulting from the pulse electrolysis, which provided sufficient energy for the crystallization.

The solution resulting from pulse electrolysis contained Al (0.3−0.8 g/L) and Cl (4.5−7 g/L). They may be accumulated when the leach solutions are recycled. Maximum allowable concentrations of Al and Cl were found to be 7 and 25 g/L in this process, respectively. Further increasing the amount of Al and Cl could affect adversely the process. At higher levels (>7 g/L), Al could decrease the electrolyte conductivity, thus inhibiting the zinc ion reduction, and consequently increases the cell voltage and PC. Thus Al was separated from the electrolyte by adding CaO due to the following reaction:

$$3CaO + 2Al(OH)_4^- + 3H_2O = Ca_3\left[Al(OH)_6\right]_2 + 2OH^-$$

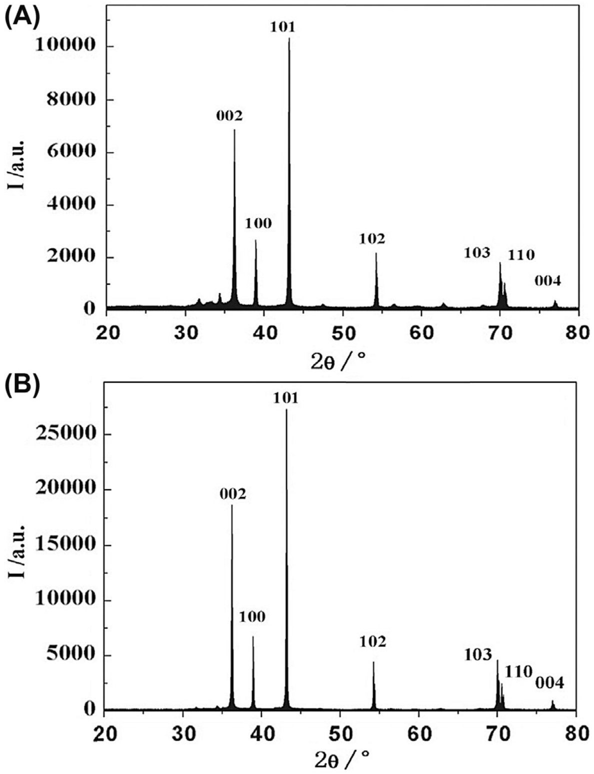


Figure 8.28 Microstructure analysis of zinc powders produced at T = 35°C and average current density = 1000 A/m^2: (A) direct current electrolysis; (B) pulse current electrolysis.

When sufficient CaO was added to make the molar ratios of Ca to Al in the solution equal to 1.8–2.0, 65–72% Al could be recovered from the solution within 4 h. Subsequently, an evaporation step was carried out at 90°C. In this step, NaOH concentration was increased up to 450 g/L allowing NaCl precipitation, and consequently 92–93% Cl was removed from the electrolyte. The concentrated electrolyte was recycled to the leaching.

Hence, the zinc and lead-enriched C&D waste can be leached using a 5 M NaOH solution at 100 g/L S/L ratio and 80°C for about 1.5 h. Electrolysis of leach liquor at current densities of 100–250 A/m^2 allowed a lead recovery of 83–87.5%. And then pulse current electrolysis of the resulting solution at T_{on} = 15 ms and T_{off} = 10 ms can obtain homogeneous zinc powders, and a recovery of 88–92% of Zn. Precipitation of Cl and Al when their concentrations exceeded 25 and 7 g/L, respectively, using CaO, avoided the accumulation of Al and Cl when reusing the solution in the alkaline leaching stages.

8.4 RECYCLING TECHNOLOGIES AND PROCESSES: CASE STUDY

8.4.1 Recycling Project of C&D Waste in Shangrao City

Recycling project of the C&D waste in Shangrao city is a comprehensive project started in 2014. The annual treatment planning in the first stage is 300,000 t of C&D waste and 50,000, 80,000, 120,000, and 60,000 t of recycled aggregate, renewable powder, recycled fine sand, and recycled construction materials, respectively. The whole process is able to reduce the spread of dust, while also using source separation process which aimed at separating solids and reusing for the production of raw materials. The waste water being removed of solid substances after precipitation is reused as wash water. Meanwhile, the heavy metal–contaminated construction waste is sorted, separated, and eluted of harmful substances in the relevant sections, to achieve zero emissions in the whole process, as demonstrated in Fig. 8.29. The process is divided into six sections: pretreatment and stacking section, clean waste crushing and sorting section, heavy metal pollution control section, classified storage section, deep processing combined with grinding section, and manufacturing section of products.

8.4.1.1 Pretreatment and Stacking Section

Primary crushing, manual sorting, and stacking of raw material are performed in this section.

After being transported from off-site to the disposal site into the working area, the C&D waste is sent into the jaw crusher. In this period, large blocks of waste are primarily crushed to facilitate the crushing and separation of reinforced concrete blocks in subsequent sections. The approaching working area is to provide space for the transport of vehicles, also being capable of storing a small amount of waste.

The crushed waste is then sent to the manual sorting platform for the separation of larger iron blocks, cloth, plastic, fabric, etc. Due to the complex components of C&D waste, manual sorting is able to ensure the successful separation of large blocks while making the subsequent process more efficient.

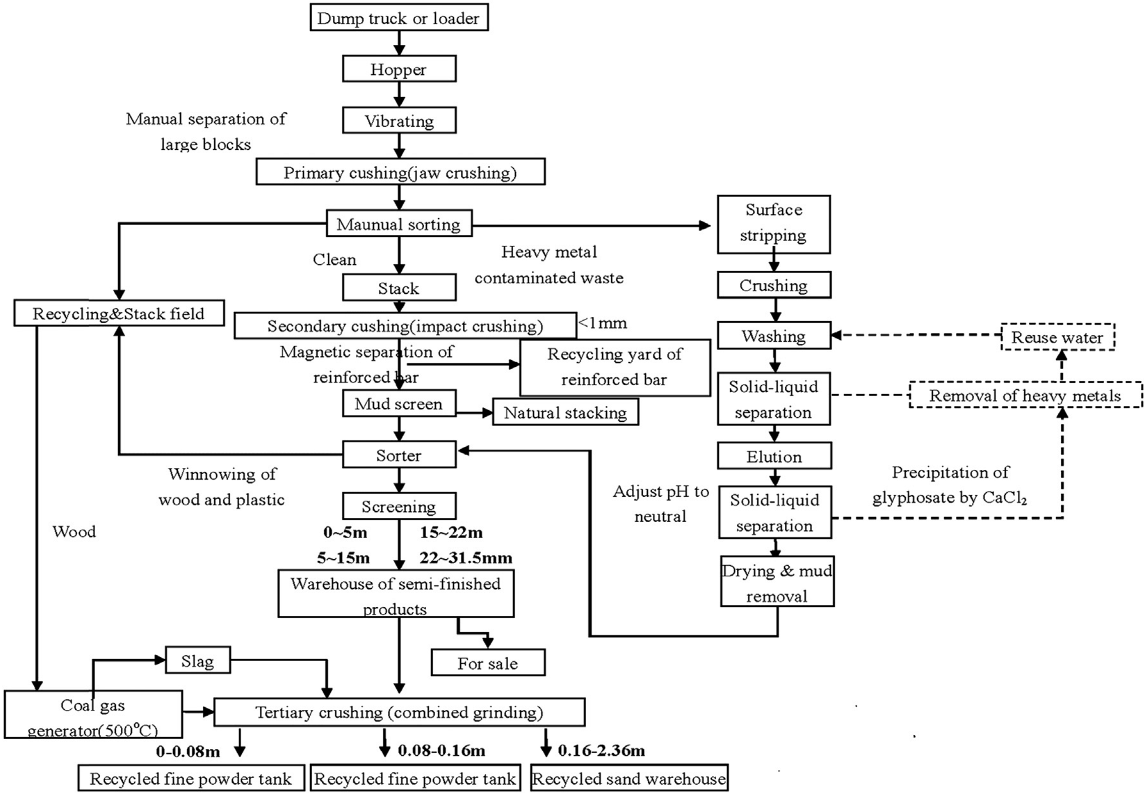


Figure 8.29 Process of construction and demolition waste recycling project of Shangrao City.

The materials are transported into automatic enclosed stacking system through a manual sorting platform. The stacker is able to store 18,000 m^3 waste, which could meet the demand for the storage amount of a week, and is a transition and buffer between the storage and disposal of C&D waste. This section is necessary due to the discontinuous collection of C&D waste.

8.4.1.2 Crushing and Sorting Section of C&D Waste

This section is the major process in which C&D waste is produced into aggregates, and is aimed at finely crushing and separating the impurities. This section is equipped with impact crusher, powerful iron drawer, mud remover, wind-conveyor sorting machines, and circular sieve.

The materials are first transported into the impact crusher, of which the outlet particle size is less than 40 mm. Then they are sent to the three-layer mud sieve by belt conveyor. The slim reinforced bars, steel nails, and other metals (not including heavy metal pollutants) are also removed in this section.

The linear mud sieve is aimed at removing the materials of particle size less than 1 mm. Most of these wastes contain mud, which is hard to be recycled. The materials above the sieve are sent back to the crusher, whereas those in the middle are transported to the next sorter.

Wind-conveyor sorting machines are used to sort the light waste like wood. Then they are screened in the circular sieve and are classified into four different classes based on the particle size. Dust removers are also equipped in this section.

8.4.1.3 Treatment Section of Heavy Metal—Contaminated C&D Waste

Surface Stripping

About 3—6 mm of the surface of C&D waste contaminated by high concentrations of heavy metals is stripped off and immersed in commercial caustic soda solution of industrial 2—8 M grade. Electrolysis treatment is performed upon the leaching solution to recycle the heavy metals.

Crushing

The C&D waste obtained in procedure a is crushed to particles of size less than 4—5 mm.

Washing and Solid—liquid Separation

The crushed C&D waste is washed with water (liquid:solid = 5:1) and is solid—liquid separated. The wash water is treated by adding nano-iron powder (20 nm). The washed C&D waste is eluted with glyphosate according to procedure d.

Eluting With Glyphosate and Solid—liquid Separation

Glyphosate is added into the washed C&D waste (liquid:solid = 2:1) and eluted one to three times. Most heavy metal ions would be combined with glyphosate and transformed into the nonleachable and stable phase. Solid—liquid separation is performed after the pH has been adjusted to neutral. The waste water is treated while the eluted C&D waste is sent for further washing.

Eluted C&D Waste

Eluted C&D waste is washed with water (liquid:solid = 5:1) before solid—liquid separation is performed. C&D waste is dried and sent for heavy metals detection.

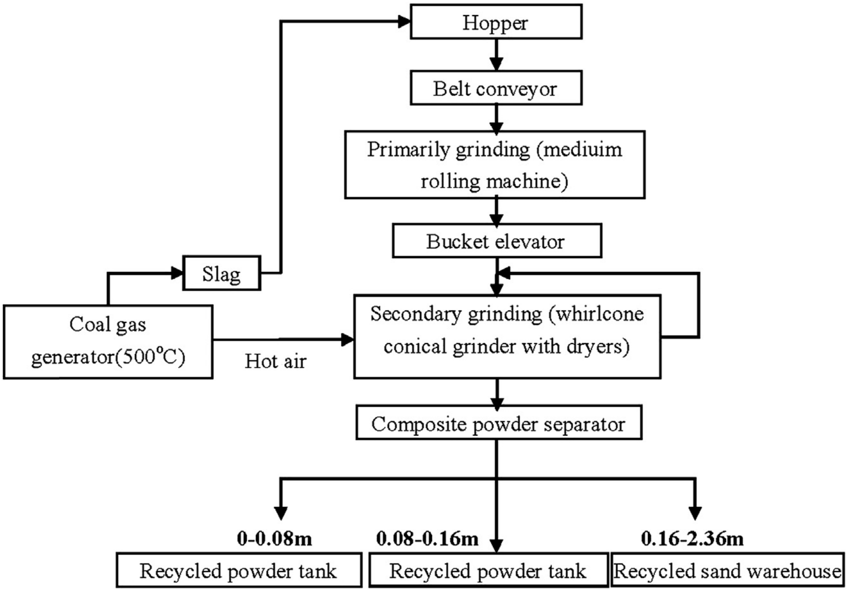


Figure 8.30 Process of deep processing and combined grinding section.

8.4.1.4 Classified Storage Section

The materials in this section are semifinished products, which are divided into four classes: 0−5, 5−15, 15−22, and 22−31.5 mm. The storage capacity of each room of the warehouse is 350 m^3, the functions of which are continuous feeding for the combined grinding and loading for sale of semifinished products.

8.4.1.5 Deep Processing and Combined Grinding Section

A detailed process of this section is demonstrated in Fig. 8.30. The materials has already been sorted and removed of mud, impurities, and iron and are high in quality and the mud content is less than 1% before being set into the combined grinding system. They are first transported into the roll press and grinded to particles less than 5 mm. These small particles are then sent to thermal whirlcone conical grinder with dryers. The high-speed rotating grinding parts are able to crush by stirring, rolling, and vibrating. The front of this grinder is crushed by mainly hitting and the back by mainly squeezing. The low-intensity waste like sintered bricks and cement stones are ground to powder, which are high-activity metakaolin, whereas the high-intensity waste like natural rocks or river sand are ground to fine sand.

The ground materials are classified into three classes: 0−0.08, 0.08−0.16, and 0.16−2.36 mm and are collected in the tanks, respectively.

8.4.1.6 Manufacturing Section of Products

Detailed process of manufacturing section of products is demonstrated in Fig. 8.31. Recycled aggregates in the crushing and sorting section are used as raw materials, those of 0−5 and 5−15 mm are generally selected. Main products include recycled blocks, recycled bricks, road bricks, permeable bricks, and wall materials.

The overall layout distribution and the land coverage of each section are listed in Table 8.23.

The main pollutants in the manufacturing process are the inorganic mineral dust generated in the transportation of materials. In this project, sealed storage warehouse is adopted while dust caps are equipped on the belt conveyors. The inlet and outlet sections of materials are equipped with steel covers along with bag filters for dust catching. All crushing facilities are equipped with fully enclosed soundproofed rooms in which negative pressure is generated. Meanwhile, the rotation speed and gap between transfer stations are minimized to strengthen the airtight thus controlling the spread of dust.

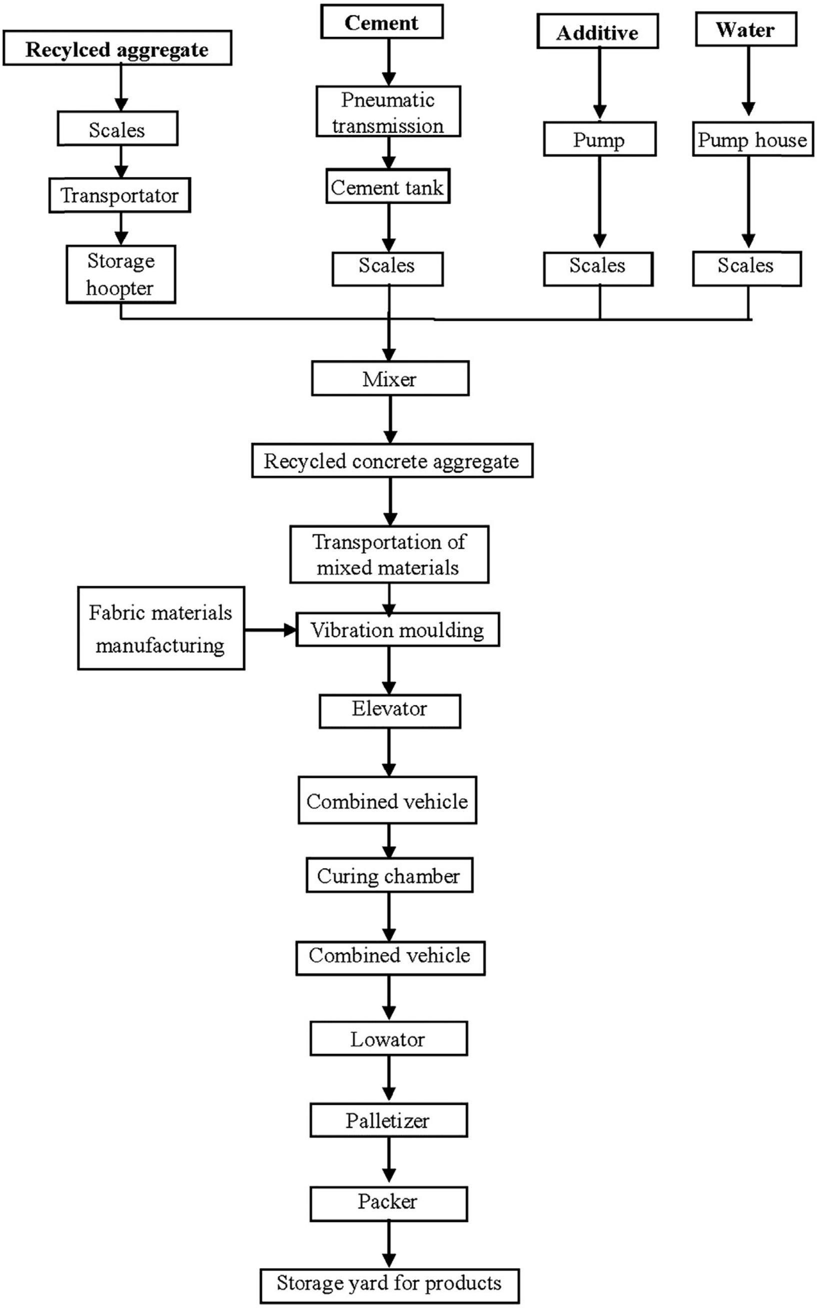


Figure 8.31 Process of manufacturing section of products derived from construction and demolition waste.

Table 8.23 General Layout and Land Coverage of This Project for Annual Treatment Scale of 300,000 t of Construction and Demolition Waste

No.	Item	Land Coverage (m^2)	Building Construction Area (m^2)	Structure Construction Area (m^2)
1	Stack area of demolition waste	403		403
2	Pretreatment stack area	4943	9886	
3	Crushing, sorting, and classified storage workshop	2889	5778	
4	Deep processing workshop	1099	2198	
5	Metal pollutants disposing workshop	550	1100	
6	Storage warehouse of recycled micropowder	320		900
7	Repair shop, warehouse	763	763	
8	Controlling center	479	479	
9	Test building	1008	3024	
10	Multifunctional building	1008	3024	
11	Product storage yard	5000		
12	Guard room	40	46	

Sand and gravel separation facilities are adopted in the wastewater treatment system. The solid materials separated from this section can be used as producing raw materials while the wastewater deprived of solid substances is also reused.

Main facilities and their parameters for the production of recycled products using C&D waste are listed in Tables 8.24–8.27.

8.4.1.7 *Labor Organization*

Labor organization information of this project is introduced below.

Annual working days: 252–300 days;
Main manufacturing posts: two shifts;
Auxiliary manufacturing posts: one shift;
Working time per shift: 8 h.
Information of labor force involved is listed in Table 8.28.

8.4.2 Centralized Disposal and Recycling Project of C&D Waste in Nantong City

8.4.2.1 *General Introduction of This Project and Its Processes*

The annual treatment planning in the first stage is 1,000,000 t of C&D waste and 100,000 m^3 of recycled concrete aggregate, 200,000 t of premixed mortar, 200,000 t of cementing materials, and 400,000 t of recycled aggregate (sand, gravel). A comparison of the disposal process and recycled products is listed in Table 8.29.

Table 8.24 Facilities in Pretreatment Section for Annual Treatment Scale of 300,000 t of Construction and Demolition Waste

Facility	Style	Parameter	Power	QTY	Function
Vibrating feeder	ZSW600 × 130	**1.** Size: 3800 × 960 mm **2.** Max feed size: 500 mm **3.** Rotation speed of eccentric shaft: 500–710 r/min **4.** Feeding capacity: 96–160 t/h	15 kW	1	Jaw crushing, feeding
Jaw crusher	PESS5010-220		220 kW	1	Coarse crushing
Electromagnetic iron separator	RCDD-8	**1.** Rated lifting height: 300 mm **2.** Material thickness: $\leq$250 mm **3.** Magnetic intensity: $\geq$70 mT	3.0 kW	2	Removal of the residual steel
Mechanical iron removal platform		L2m		1	Iron removal work
Manual sorting platform		L5m		1	Manual sorting work
Straight vibrating sieve for C&D waste	BST1836		15 kW	1	
Plate chain bucket elevator	NE150	**1.** Max size: 80 mm **2.** Material lifting speed: 0.5 m/s **3.** Unit weight: 0.6–1.8 t/h^3 **4.** Production capacity: 150–180 m^3/h	15 kW	1	Lifting of materials to windrow after manual sorting to save land
Belt stocker	DBJD5001	Stack volume: 14,000 m^3	37 kW + 5.5kW + 2.2 kW × 2	1	Stacking of the material after coarse crushing
Pneumatic unloading valve		Driven by cylinder and controlled by solenoid valve		9	Unloading
Air pump	Piston		5.5 kW	1	Supply of air for pneumatic valve
Ridge conveyor belt	B800	L100m	37 kW	1	Feeding of materials into the crushing and sorting section

QTY, quantity.

Table 8.25 Facilities in Crushing and Sorting Section for Annual Treatment Scale of 300,000 t of Construction and Demolition Waste

Facility	Style	Parameter	Power	QTY	Function
Electromagnetic iron remover	RCDD-8	**1.** Rated lifting height: 250 mm **2.** Material thickness: $\leq$200 mm **3.** Magnetic intensity: $\geq$70 mT	2.2 kW	2	Iron removal
Impact crusher	PFY1214	**1.** Inlet size: 1430 × 400 mm **2.** Max feed size: 350 mm **3.** Discharging size: 20–60 mm **4.** Production capacity: 90–145 t/h	132 kW	1	Fine crushing
Straight vibrating screen	3ZK1860	**1.** Screen size: 6000 × 1800 mm **2.** Max feed size: 400 mm **3.** Layers: three	22 kW	4	Mud removal, classification
Air duct tape sorter	DBF-80	Size: 5550 × 2660 × 4290 mm	15 kW	2	Removal of light materials
Dust catcher for solid waste	KZHS96-7	**1.** Air volume: 65,200–87,000 m^3/h **2.** Filtration velocity: 1.2–1.7 m/min **3.** Number of filter bags: 96 × 7 **4.** Allowable inlet dust concentration: $\leq$200 g/Nm^3 **5.** Outlet dust concentration: $\leq$50 mg/Nm^3	45 kW	1	Dust removal for straight screen, circular screen and air duct tape sorter
Plate chain bucket elevator	NE150	**1.** Max size: 60 mm **2.** Material lifting speed: 0.5 m/s **3.** Unit weight: 0.6–1.8 t/h^3 **4.** Production capacity: 50–60 m^3/h	11 kW	4	Lifting of materials to conveyor belt after circular screening
Belt conveyor	B650	L30m	11 kW	1	Transfer of materials to classified storage section
Belt conveyor	B650	L25m	11 kW	1	
Pneumatic unloading valve				4	Unloading in storage house
Air pump	Piston		4 kW	1	Supply of air for pneumatic valve
Storage house for semiproduct	Steel structure			4	Storage of semiproducts

QTY, quantity.

Table 8.26 Facilities in Deep Processing Section for Annual Treatment Scale of 300,000 t of Construction and Demolition Waste

Facility	Style	Parameter	Power	QTY	Function
Coal gas producer				1	Drying
High-pressure rolling machine	G1260	**1.** Max inlet size: <30 mm **2.** Outlet size: <5 mm **3.** Production capacity: 100–120 t/h	2 × 90 kW	1	Pregrinding
Bucket elevator	NE100		15 kW	1	Lifting of materials from roller to grinder
Thermal whirl conical grinder with dryers	DBJM5001	**1.** Max feed size: ≤50 mm **2.** Max feed water content: <20% **3.** Outlet water content: <1–2% **4.** Production capacity: 100 t/h	132 kW	1	Grinding
Heat-resistant air locking unloader	YJD-AE			1	From the elevator to dryer
Multipowder concentrator	JND-V	**1.** Disposal capacity: 100–130 t/h **2.** Disposal airflow: 50,000 m^3/h **3.** Rotation speed of rotor: 180–260 r/min	45 kW	1	Classification
Dust catcher for solid waste	KZHS96	**1.** Air volume: 5200–7000 m^3/h **2.** Filtration velocity: 1.2–1.7 m/min **3.** Number of filter bags: 96 **4.** Allowable inlet dust concentration: ≤200 g/Nm^3 **5.** Outlet dust concentration: ≤50 mg/Nm^3	45 kW	1	Dust removal for grinding in deep processing section
Storage tank	1000T	Storage capacity: 1000 t		3	Storage of recycled powder and sand

QTY, quantity.

Table 8.27 Facilities in Product Manufacturing Section for Annual Treatment Scale of 300,000 t of Construction and Demolition Waste

No.	Item		Model & Specification	QTY
1	Ingredient storage bin 3 × 4 m^3 (body fabric)	Aggregate storage bin	4 m^3	3
		Measuring bin	1200 kg ± 2%	1
		Sensor	CST-2000	4
		Cylinder	SC80 × 300-S-CB-Y	3
		Vibrator	B-0.5	3
		Motor	7.5 kW	1
		Belt	B500 × 17.1 m	1
		Frame	Steel structure	1
2	Blender (body fabric)	Blending barrel	JS750	1
		Motor reducer	30 kW	1
		Lifting motor	7.5 kW	1
		Lubrication system		1
		Cylinder	SC160 × 300-S-TC-M-Y	1
3	Cement measuring system (body fabric)	Cement weighing hopper	350 kg ± 1%	1
		Sensor	CSB-250	3
		Butterfly valve	DN250	1
		Vibrator	B-0.25	1
4	Water measuring system (body fabric)	Water measuring cylinder	200 kg ± 1%	1
		Transmission pump	2.2 kW	1
		Pipeline	2″	1
		Sensor	CST-500	1
		Butterfly valve	DN80	1
		Filling valve	DN25	1
5	Belt conveyor (body fabric)	Flat belt	B600 × 8 m (center distance)	1

		Planet-cycloid retarder	4 kW	1
		Frame	Steel structure	1
		Tightener		1
		Receiving hopper		1
6	Grading station 1 × 4 m^3 (plus material)	Aggregate storage bin	4 m^3	1
		Measuring bin	800 kg ± 2%	1
		Sensor	CST-1000	4
		Cylinder	SC80 × 300-S-CB-Y	1
		Vibrator	B-0.5	1
		Motor	2.2 kW	1
		Belt	B500 × 5 m	1
		Frame	Steel structure	1
7	Vertical blender (plus material)	Blending barrel	JN350	1
		Motor reducer	7.5 kW	1
		Lifting motor	4 kW	1
		Cylinder	SC80 × 250-S-TC-Y	1
8	Cement measuring system (plus material)	Cement weighing hopper	150 kg ± 1%	1
		Sensor	CSB-250	3
		Butterfly valve	DN250	1
		Vibrator	B-0.25	1
9	Water measuring system (plus material)	Water measuring cylinder	80 kg ± 1%	1
		Transmission pump	1.1 kW	1
		Pipeline	1 1/4″	1
		Sensor	CST-250	1
		Butterfly valve	DN80	1
		Filling valve	DN25	1

(*Continued*)

Table 8.27 Facilities in Product Manufacturing Section for Annual Treatment Scale of 300,000 t of Construction and Demolition Waste—cont'd

No.	Item		Model & Specification	QTY
10	Belt conveyor (plus material)	Flat belt	B500 × 7 m (center distance)	1
		Planet-cycloid retarder	2.2 kW	1
		Frame	Steel structure	1
		Tightener		1
		Receiving hopper		1
11	Block molder	Host machine	QT10-15	1
		Vibrating motor (with frequency conversion, without independent fans)	11 kW	2
		Distributing motor	4 kW	1
		Pallet conveyor		1
		Hydraulic system	22 kW	1
		Random mold		1
12	Plus material device			1
13	Heat insulating board conveying device			1
14	Wet product conveyor line	Sweeping motor	0.18 kW	1
		Frame		1
		Spacing device		1
15	Elevator 10F	Frame	SBJ10	1
		Motor power	7.5 kW	1
		Lifting device		1

16	Lowerator 10F	Frame	SBJ10	1
		Motor power	7.5 kW	1
		Lifting device		1
17	Composite vehicle	Conveyor (carrier)		1
		Actuating device for conveyor	3 kW	1
		Subequipped vehicle (10 floor)		1
		Actuating device for subequipped vehicle	3 kW	1
		Speed control device		1
		Positioning device	1.5 kW	1
18	Dry product conveyor line	Frame		1
		Sweeping machine	0.18 kW	1
		Spacing device		1
19	Plate recycling line	Plate turnover machine	SF10	1
		Gear motor	0.75 kW	1
		Overpass		1
20	Stacking machine	Walking device	1.1 kW	1
		Clamp device		1
		Lifting device		1
		Rotation device	0.55 kW	1
		Prestack device		1
		Hydraulic system	15 kW	1
21	Pitch conveyor	Tank chain	7.5 kW	1
22	Wood tray separator	Wood tray	2.2 kW	1

(*Continued*)

Table 8.27 Facilities in Product Manufacturing Section for Annual Treatment Scale of 300,000 t of Construction and Demolition Waste—cont'd

No.	Item		Model & Specification	QTY
23	Processing line hydraulic system	Triphase asynchronism motor	Y180L-4 22 kW	1
24	Electronic controlling system	Electric cabinet		3
		Control console		4
		Industrial computer	19″ LED display	2
		PLC		4
		Touch screen	TP-177A (Siemens)	3
		Transmission instrument	GM8802F	6
		Connecting cable		1
25	Control room		6000 × 2250 × 2500	1
26	Packaging system	Horizontal packing machine		1
		Packaging machine		1
		Winding machine		1
		Transporting line	2.5 m	4
		Packaging control console		1
27	Pneumatic system	Air compressor	5.5 kW	1
		Pipe		1
		FR, FRL		1
28	Spiral conveyor	XL219	φ219 × 6 m	1
		XL165	φ165 × 5.5 m	1

FR, filter + regulator; *FRL*, filter + regulator + lubricator; *QTY*, Quantity.

Table 8.28 Number of Labor Force

	Number of Staff					
Department	**Day Shift**	**Morning Shift**	**Swing Shift**	**Night Shift**	**Non Shift**	**Total**
Construction & demolition waste pretreatment		3	3		1	7
Crushing and sorting		4	4		1	9
Deep grinding process		3	3		1	7
Storage and loading	2					2
Product manufacturing	5		5		1	11
Mechanical maintenance	2					2
Technical production (experiment)	2	1	1			4
Guard	1			1	1	3
Logistics, administration	3		1			4
Financing	3					3
Management	5					5
Total	23	11	17	1	5	57

Table 8.29 Comparison of Handling Process and Recycled Products in Nantong City Project

No.	Item	Plan 1	Plan 2	Plan 3
1	Resource products	Concrete products, mortar, concrete aggregate and cementing materials	Concrete products, mortar	Road material (cushion)
2	Pretreatment	Multistage crushing, screening	Multistage crushing, screening	Single-stage crushing
3	Separation of bricks, gravel, concrete	Relatively complete	Relatively complete	Mixed
4	Usage of recycled aggregate			
4.1	Stone	Various classes (5—25 mm), able to be produced into concrete products and aggregate	Various classes (5—25 mm), able to produce into concrete products and aggregate	Those particle size larger than 25 mm account for more than 60%, can only be produced into road construction materials
4.2	Grit	0—5 mm, able to be produced into concrete products and premixed mortar	0—5 mm, able to be produced into concrete products and premixed mortar	
4.3	Powder	$\leq$0.16 mm, specific surface area of about 3000 cm^2/g, can be used as cementing (blending) material		
5	Variety of recycled products	Diversified	Small	Single (very small)
6	Sales of recycled products			

6.1	Annual treatment capacity of 300,000 t	Smooth, low market share	Risk existing, large amount which will hit the market	Risk existing
6.2	Annual treatment capacity of 500,000 t	Smooth, low market share	Large risk, cannot be accommodated in market	Large risk
6.3	Annual treatment capacity of 800,000–1,000,000 t	Small risk, diversified market	Huge risk	Huge risk
7	Environmental pollution	Little	Little	Much
8	Installed capacity	Very large	Large	Small
9	Land occupation	Large	Large	Small
10	Investment	Very large	Large	Small
11	Technical sophistication	Very high	High	Low
12	Reliability	High	High	High
13	Value of recycled products	Very high	High	Low
14	Sustainability	Good	Normal	Bad

Table 8.30 Components of Projects and Their Functions and Construction Area for Annual Treatment Scale of 1,000,000 t of Construction and Demolition Waste in Nantong City Project

No.	Section	Function	Construction Area (m^2)
1	No. 1 combined workshop	Production of recycled powder and sand	12,606
2	Product manufacturing and steam curing workshop	Products manufacturing	1730
3	Comprehensive building	Office work	2700
4	Technical center	Research work	2700
5	Office	Dork business	228
6	Maintenance workshop	Maintenance of facilities	48
7	Entrance	Inspection	48
8	Canteen	Dinner	1238
9	No. 2 combined workshop	Manufacturing of recycled aggregates	3230
		Total	24,528

Table 8.31 Material Balance of Annual Production of 100,000 m^3 Recycled Concrete Products in Nantong City Project

Material	Unit Consumption, t/m^3	Hourly Consumption, t	Daily Consumption, t	Annual Consumption, t
Cement	0.30	6.67	100	30,000
Sand	0.15	3.33	50	15,000
Recycled fine aggregate	0.85	18.9	283.3	85,000
Recycled coarse aggregate	0.45	10	150	45,000
Additive	0.003	0.067	1	300
Water	0.18	4	60	18,000

The general construction area of each section is listed in Table 8.30.

8.4.2.2 Material Balance

The material balance of the annual production of 100,000 m^3 recycled concrete products is listed in Table 8.31.

The material balance of the annual production of 100,000 m^3 recycled concrete is listed in Table 8.32.

Table 8.32 Material Balance of Annual Production of 100,000 m^3 Recycled Concrete in Nantong City Project

Material	Unit Consumption, t/m^3	Hourly Consumption, t	Daily Consumption, t	Annual Consumption, t
Cement	0.28	11.2	112	28,000
Stone	0.625	25	250	62,500
Sand	0.35	7.78	116.7	35,000
Recycled fine aggregate	0.35	7.78	116.7	35,000
Recycled coarse aggregate	1.25	25	250	62,500
Fly ash	0.065	2.6	26	6500
Mineral powder	0.084	3.36	33.6	8400
Additive	0.0059	0.235	2.36	590
Water	0.22	8.8	88	22,000

Table 8.33 Material Balance of Annual Production of 200,000 t of Premixed Mortar in Nantong City Project

Material	Proportion, %	Hourly, t/h	Daily, t/day	Annual, t/year
Cement	20	7.56	113.3	40,000
Recycled fine aggregate	56	24.8	373.3	112,000
Sand	14	6.22	93.3	28,000
Fly ash	10	4.44	66.7	20,000
Additive	0.3	0.133	2	600

The material balance of the annual production of 200,000 t of premixed mortar is listed in Table 8.33.

8.4.2.3 Main Facilities

Main facilities involved in this project are listed in Table 8.34. The facilities are classified into six groups according to the different producing sections.

8.4.2.4 Layout and Structures

Engineering Project

The engineering design elevation is ±0.000, the interior height difference of manufacturing workshop is 150 mm, and the interior height difference of nonmanufacturing workshop is 450 mm.

Table 8.34 Main Facilities Involved in This Project for Annual Treatment Scale of 1,000,000 t of Construction and Demolition (C&D) Waste in Nantong City Project

No.	Facility	Style & Specification	Disposing (Producing) Capacity	Quantity	Note
1	C&D waste pretreatment section				
1)	Feeder	SEFTG-490	140 t/h	2	
2)	Primary crusher	SEFPE-750	100—150 t/h	2	
3)	Secondary crusher	SEFPF-1315	100—150 t/h	2	
4)	Tertiary crusher	SEFPY-1300	100 t/h	2	
5)	Metal separator	SEFF1000		6	
6)	Screening device	SEF3YK2460	200 t/h	6	
7)	Fine material grading device	SEFYK1854	16 t/h	2	
8)	Plenum pulse dust collector	XLPM6A	12,000 m^3/h	6	
9)	Plenum pulse dust collector	XLPM2A	3000 m^3/h	6	
10)	Belt conveyor	B650-1000	50—60 t/h	26	
11)	Loader	ZL50		3	
2	Storage and transportation section for recycled aggregate				
1)	Belt conveyor	B650-1000	50—00 t/h	10	
2)	Batching system			6	
3)	Plenum pulse dust collector	XLPM2A	3000 m^3/h	8	
3	Recycled products manufacturing section				
1)	Measuring and batching system			2	
2)	Blender	2 m^3	30 m^3/h	2	
3)	Fabric material blender	350 L		2	
4)	Blender	0.5 m^3		1	

5)	Plenum pulse dust collector	XLPM2A	3000 m^3/h	2	
6)	Building block molder	QT10-15		2	
7)	Elevator			2	
8)	Lowerator			1	
9)	Palletizer			1	
10)	Multifunctional large extruding machine	SEF90-120 × 1200	40,000 m^3/a	2	
11)	Curing device			1	
12)	Packaging machine	JHDKB		1	
13)	Forklift	2 t		3	
4	Concrete production section				
1)	Blender	2 m^3	120 m^3/h	1	Theoretical capacity
2)	Sand separating and recycling system			1	
5	Premixed mortar				
1)	Sand drying machine	Φ2.5 × 5.4 m	35 t/h	1	5% water
2)	Vibrating screen			1	
3)	Blender	6 m^3	30 t/h	2	
4)	Packaging machine			2	
5)	Bag filter		6000 m^3/h	1	
6	Cementing material production section				
1)	Rolling machine	GM800	Throughput: 48 t/h	1	
2)	Powder concentrator	O-X500	20–40 t/h	1	
3)	Bag filter		36,000 m^3/h	1	
4)	Bag filter		4500 m^3/h	1	

General Layout

1. General layout should possibly take advantage of terrain conditions and surrounding facilities, and should have a clear functional partition. The material storage area, production areas, and administrative welfare facilities must be separated, whereas the latter should be located at the upwind of the prevailing wind direction.
2. Make full use of terrain elevation, the direction of terrain height variation should be correlative to the process flow of the project to avoid useless work and to shorten the transportation distance, thus making the process more compactly and reasonably arranged.
3. Layout of the process should comply with the arrangement order from raw materials to finished products. The location of storage house of materials should be close to the users to shorten the transportation distance.
4. The arrangement of buildings and structures should be in line with the fire prevention interval and meet the fire requirements.
5. The site elevation and road elevation should be conducive to the discharging of rainwater and sewage. In the premise of meeting the requirements regulated in relative standards, integrated arrangement of each facility should be performed on basis of the whole process, fire, health, wind direction, transportation, and maintenance requirements.
6. The amount of site leveling work should be possibly minimized, balanced earthworks should be achieved.

Construction Materials and Structures

1. Construction for productive purposes

   Wall: Reinforced concrete (or masonry brick, block) is used in the materials of the structures between fundamentals to the window, whereas those above the window are constructed by profiled steel sheets.

   Door and window: PVC steel doors and windows and normal light steel doors are applied except those in substations or with dust and sound prevention.

   Floor: Various floors are designed based on load of different floor like storage, workshop, yard, and other ground.

   Roof: Unorganized free drainage and increased roof slope is applied to facilitate and promote drainage.
2. Construction for nonproductive purposes

   Wall: Solid blocks are used in walls below ±0.000, whereas hollow block infilled walls are used in those above ±0.000.

Door and window: PVC steel doors and windows.

Floor: Fine concrete aggregate surface is generally applied, whereas special floors such as those in laboratories or toilets are made of antislip tile surface.

Roof: Organized drainage with UPVC pipes.

Features of Main Construction Buildings

1. C&D waste pretreatment workshop
   The C&D waste pretreatment workshop is built on the basis of the initial height difference on the site and is constructed using fully enclosed structure. Crushing and grading of C&D waste are performed in this workshop.
2. Storage of recycled fine aggregate
   Enclosed circular structure is applied in storage house of recycled fine aggregate. The upper part is composed of six steel plates of diameter 10 m, whereas the lower part are two layers of reinforced concrete frame structure. The first layer is used as power distribution room and the other is used as batching room.
3. Recycled aggregate storage house
   Reinforced concrete retaining walls are applied around and below the house while light steel structure is used on the upper portion of the house.
4. Recycled aggregate processing workshop
   Product processing and curing sections are the two main processes in this workshop, which are of concrete frame structure. Concrete roof with solar panel and hot water supply system is applied in product processing section while several curing rooms are separated in the curing section.
5. Laboratory
   The laboratory, which is also the technical and production scheduling control center in this project, is constructed by two layers of reinforced concrete and infilled walls. The first floor is the detection station for raw materials and product quality with different manufacturing, curing, and detecting equipment, and the second floor is product researching laboratory.
6. Production control center
   Production control center is constructed by two layers of reinforced concrete and infilled walls. The first floor is used as canteen and bath room and the second floor is for production scheduling and office.
7. The buildings of production control center and laboratory are of energy conservation design.

Structure

1. Seismic fortification

   The seismic fortification intensity is set as 6 degree for the region, and the basic earthquake acceleration value designed is 0.05 g.
2. Design load adopted

   Basic wind pressure: 0.45 kN/m^2.

   Load of productive structures is provided by the engineering process.

   Load of nonproduction workshops are adopted according to Load code for the design of building structures (GB 50009-2012).
3. Structure selection and application
   - **a.** The C&D waste pretreatment workshop is applied with the reinforced concrete column frame-bent structure with light steel roofs.
   - **b.** The recycled aggregate storage house is applied with the reinforced concrete column frame-bent structure with light steel roofs and retaining wall around it.
   - **c.** The storage house of recycled fine aggregate is applied with steel plate silo structure, which is sustained by two layers of cast-in-site reinforced concrete framework.
   - **d.** The mortar and concrete workshop is applied with the reinforced concrete column frame-bent structure with light steel roofs.
   - **e.** The recycled aggregate production workshop is applied with the reinforced concrete column frame-bent structure with light steel roofs.
   - **f.** The cementing material production workshop is applied with the reinforced concrete column frame-bent structure with light steel roofs.
   - **g.** The control center is applied with three layers of cast-in-site reinforced concrete framework.
   - **h.** The laboratory is applied with two layers of cast-in-site reinforced concrete framework.
   - **i.** The mechanic maintenance workshop, warehouse, substation, and guard are applied with one layer of cast-in-site reinforced concrete framework.
   - **j.** The car washing and water treatment buildings are applied with cast-in-site reinforced concrete framework structure.
   - **k.** The C&D waste storage yard is applied with the reinforced concrete column frame-bent structure with light steel roofs.

There are two entrances (primary and secondary entrance) in the project to shunt the traffic flow and people. The main entrance is located in the southwest of the plant, the width of entrance is not less than 14 m and is connected with the planned roads. The road in the plant is the circular

Table 8.35 Main Index of General Layout of This Project for Annual Treatment Scale of 1,000,000 t of Construction and Demolition Waste in Nantong City Project

No.	Item	Unit	Quantity	Note
1	Land occupation of this project	m^2	107,060	
2	Land occupation of buildings and structures	m^2	34,653	Not including the area of storage yards
3	Construction area of buildings and structures	m^2	41,790	Not including the area of storage yards
1)	Administrative auxiliary facilities	m^2	3,069	
2)	Industrial buildings	m^2	38,721	
4	Area of storage yards	m^2	15,826	
5	Building density	%	32	
6	Floor area ratio		0.39	
7	Building coverage	%	47	Including the area of storage yards
8	Road area	m^2	20,880	
9	Landscaping area	m^2	21,410	
10	Landscaping ratio	%	20	
11	Parking space		12	Small
12	Length of bounding walls	m	1,250	
13	Earthwork volume	m^3		
1)	Amount of excavation	m^3		
2)	Amount of filling	m^3	43,000	

road around the main producing workshop. The main roads are 14–10 m wide and the turning radius is not less than 9 m. The other roads are 7–4 m wide and the turning radius is not less than 6 m. The roads are all city roads with road traffic stones and gullies for drainage. The cross slope of the road is 1% and the longitudinal slope is not less than 0.3%.

Cement concrete is the main material of the roads. The structure is 22 cm of C30 concrete layer, 30 cm of gravel fundamental layer, and 5 cm of sand-gravel cushion.

The main index of general layout of this project is listed in Table 8.35.

Main Buildings and Construction Structure in Nantong City Project

Main buildings and construction structure in this project for annual treatment scale of 1,000,000 t of C&D waste are listed in detail in Tables 8.36–8.38.

Table 8.36 Main Buildings and Construction Structure in Nantong City Project (1—5)

Item		C&D Waste Storage Yard	C&D Waste Pretreatment Workshop	Recycled Aggregate Storage House	Recycled Fine Aggregate Storage House	Concrete Workshop
No.		1	2	3	4	5
[a]Construction grade		V	V	V	V	V
[a]Fireproof endurance rating		II	II	II	II	II
[b]Seismic precautionary intensity		6 degree	6 degree	6 degree	6 degree	6 degree
Main structure		Reinforced concrete column frame-bent structure	Reinforced concrete column frame-bent structure	Reinforced concrete column frame-bent structure	Reinforced concrete column frame-bent structure	Reinforced concrete column frame-bent structure
Storey, total height		One, 9.6 m	One, 14 m	One, 14 m	Three, 27 m	Four, 24 m
Base area (m^2)		6768	3564	3060	1260	300
Total construction area (m^2)		6768	3564	3060	3840	309
Structure and decoration	Wall	Color steel plate, concrete retaining wall	Color steel sandwich panel	Color steel plate, concrete retaining wall	Concrete	Concrete
	Ground	Concrete	Concrete	Concrete	Concrete	Concrete
	Floor				Concrete	Concrete
	Roof	Color steel sandwich panel	Color steel sandwich panel	Color steel sandwich panel	Color steel sandwich panel	Color steel sandwich panel
	Door	Steel	Steel	Steel	Steel	Steel
	Window				PVC steel	PVC steel

C&D, construction and demolition.

[a] Regulated in Code for design of building fire protection (GB 50016-2014).

[b] Regulated in Code for seismic design of buildings (GB 50011-2010).

Table 8.37 Main Buildings and Construction Structure in Nantong City Project (6–10)

Item	Mortar Workshop	Cementing Material Workshop	Cementing Material Warehouse	Recycled Aggregate Production Workshop	Car Washing and Water Treatment
No.	**6**	**7**	**8**	**9**	**10**
[a]Construction grade	V	V	V	V	V
[a]Fireproof endurance rating	II	II	II	II	II
[b]Seismic precautionary intensity	6 degree	6 degree	6 degree	6 degree	6 degree
Main structure	Reinforced concrete column frame-bent structure	Reinforced concrete column frame-bent structure	Reinforced concrete column frame-bent structure	Reinforced concrete column frame-bent structure	Reinforced concrete structure
Storey, total height	Four, 24 m	Four, 24 m	Three, 27 m	One, 8.4 m	
Base area (m^2)	3748	1440	850	9775	528
Total construction area (m^2)	4460	1780	2600	8641	
Structure and Wall decoration	Concrete	Color steel plate	Upper: Steel Lower: Porous concrete block concrete	Color steel sandwich panel	Reinforced concrete
Ground	Concrete	Concrete	Concrete	Concrete	Reinforced concrete
Floor	Concrete	Concrete	Reinforced concrete		
Roof	Color steel sandwich panel	Color steel sandwich panel	Concrete	Concrete, color steel sandwich panel	
Door	Steel	Steel	Steel	Steel	
Window	PVC steel	PVC steel	PVC steel	PVC steel	

[a] Regulated in Code for design of building fire protection (GB 50016-2014).

[b] Regulated in Code for seismic design of buildings (GB 50011-2010).

Table 8.38 Main Buildings and Construction Structure in Nantong City Project (11—16)

Item		Mechanic Maintenance	Substation	Laboratory	Production Control Center	Guard (I)	Guard (II)
No.		11	12	13	14	15	16
[a]Construction grade		V	V	V			
[a]Fireproof endurance rating		II	II	II	II	II	II
[b]Seismic precautionary intensity		6 degree	6 degree	6 degree	6 degree	6 degree	6 degree
Main structure		Frame structure	Frame structure	Frame structure	Frame structure	Frame structure	Frame structure
Storey, total height		One, 8 m	One, 5.5 m	Two, 8 m	Three, 11.6 m	One, 3.6 m	One, 3.6 m
Base area (m^2)		840	315	1008	1008	20	25
Total construction area (m^2)		840	315	2016	3024	20	25
Structure and decoration	Wall	Reinforced concrete	Reinforced concrete	Porous concrete block	Porous concrete block	Porous concrete block	Porous concrete block
	Ground	Reinforced concrete	Reinforced concrete	Concrete, ground tile	Concrete	Concrete	Concrete
	Floor	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete
	Roof			Reinforced concrete, ground tile	Reinforced concrete, ground tile		
	Door	Steel	Steel	PVC steel	PVC steel	PVC steel	PVC steel
	Window	PVC steel	PVC steel	PVC steel	PVC steel	PVC steel	PVC steel
	Inner wall	Inner wall coatings	Inner wall coatings	Inner wall coatings	Inner wall coatings	Inner wall coatings	Inner wall coatings
	Outer wall	Outer wall coatings	Outer wall coatings	Outer wall coatings	Outer wall coatings	Outer wall coatings	Outer wall coatings

[a] Regulated in Code for design of building fire protection (GB 50016-2014).

[b] Regulated in Code for seismic design of buildings (GB 50011-2010).

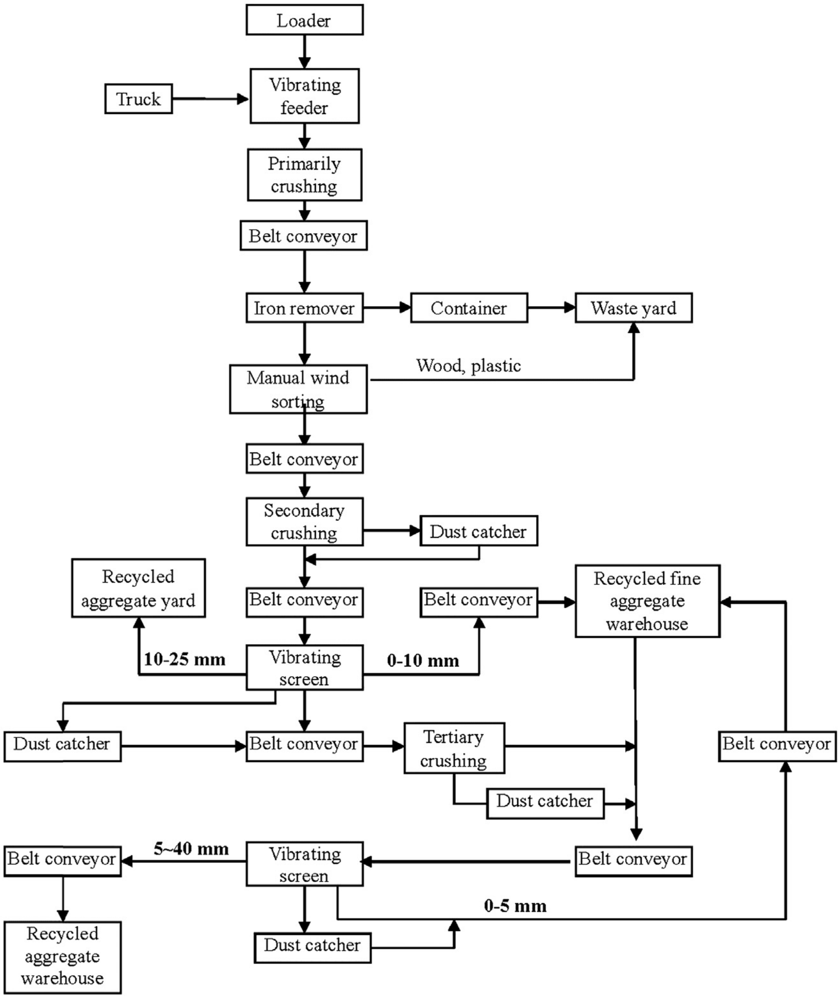


Figure 8.32 Process of construction waste disposal and production of recycled aggregate in Nantong city project.

The process of construction waste disposal, production of recycled aggregate and premixed mortar is demonstrated in Figs. 8.32 and 8.33, respectively. An overview of the engineering project is demonstrated in Fig. 8.34.

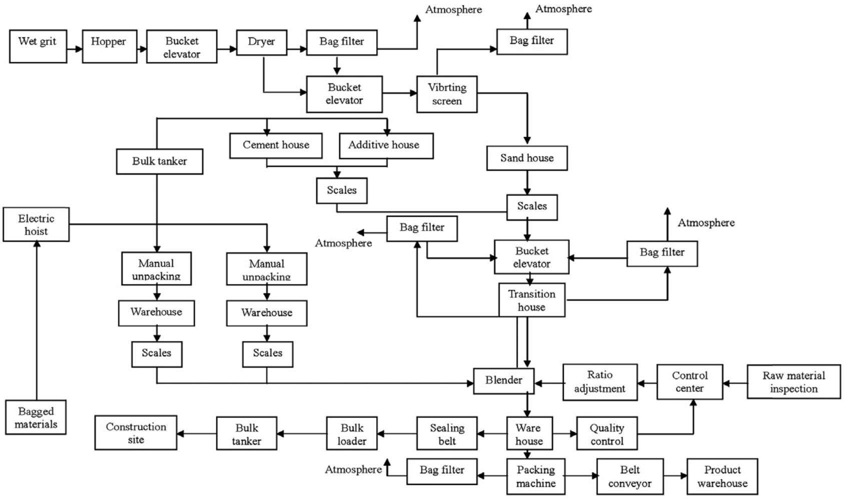


Figure 8.33 Production process of premixed mortar for construction and demolition waste in Nantong city project.

Figure 8.34 Overview of centralized disposal and recycling project in Nantong city project.

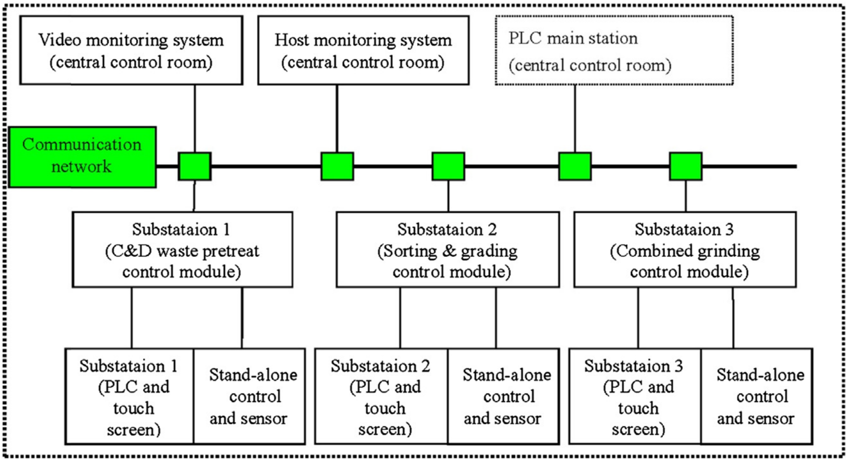


Figure 8.35 General electronic control system of construction and demolition waste processing line.

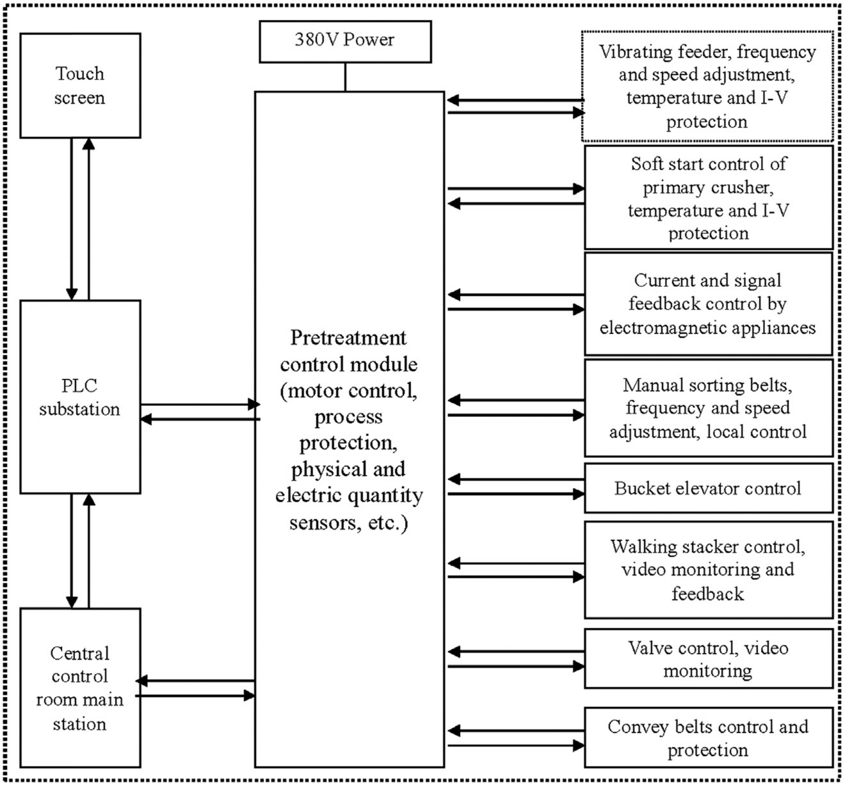


Figure 8.36 Pretreatment section control system.

8.4.2.5 Design of Electronic Control System

General Proposal of Electronic Control System

The core control unit of the electronic control system is PLC control of Siemens S7-300 series. The whole system includes PLC network operating system, touch screen and intelligent host monitoring systems, industrial TV monitoring systems, centralized control, and decentralized stand-alone control system (divided into three module control system, shown in Figs. 8.36–8.38). The general structure of the system is shown in Fig. 8.35. The control functions include "Environmental protection control without secondary dust generation," "intelligent production line process control," "intelligent diagnostic control of key devices," and "industrial system control."

PLC network operating system is applied with the structure of one main station and multiple substations. The main station is settled in the central control room, and the substations are located in different sections of the

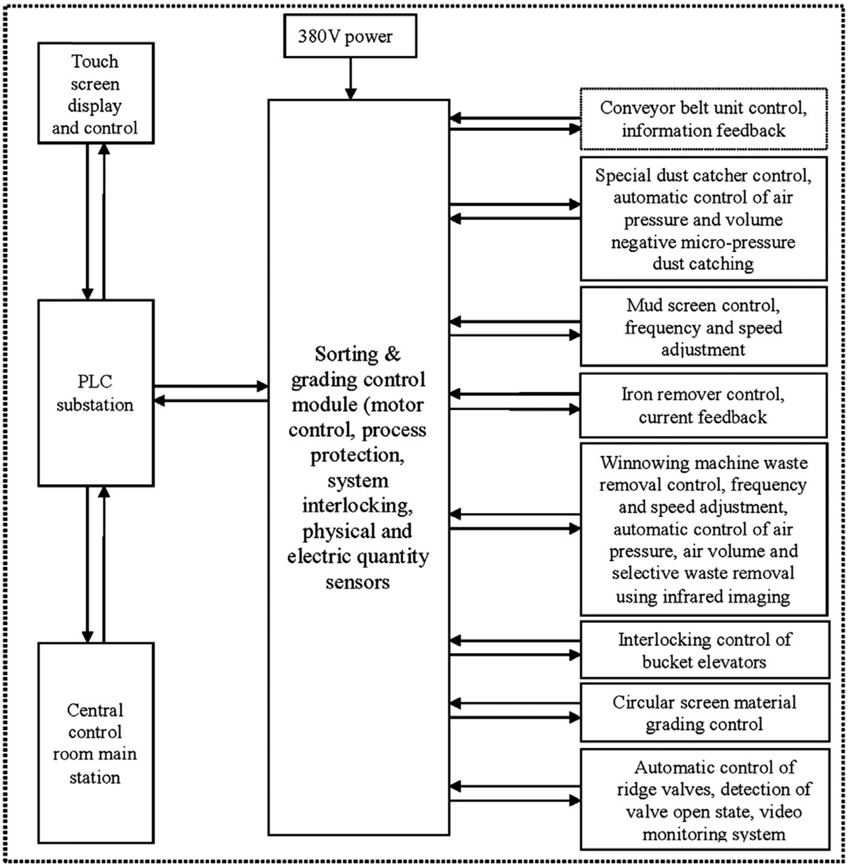


Figure 8.37 Crushing and sorting section control system.

combined production line (for instance, the pretreatment section, fine crushing and sorting section, and recycled powder material production section). The data exchange between the main station and substations is achieved using the network communication.

Control and monitoring of the whole production line can be operated in the main station, where countercurrent sequence start control and downstream parking control can also be performed. In substations, the control and monitoring of different modules and sections can be achieved. Operation boxes are equipped for debugging and maintenance of each module.

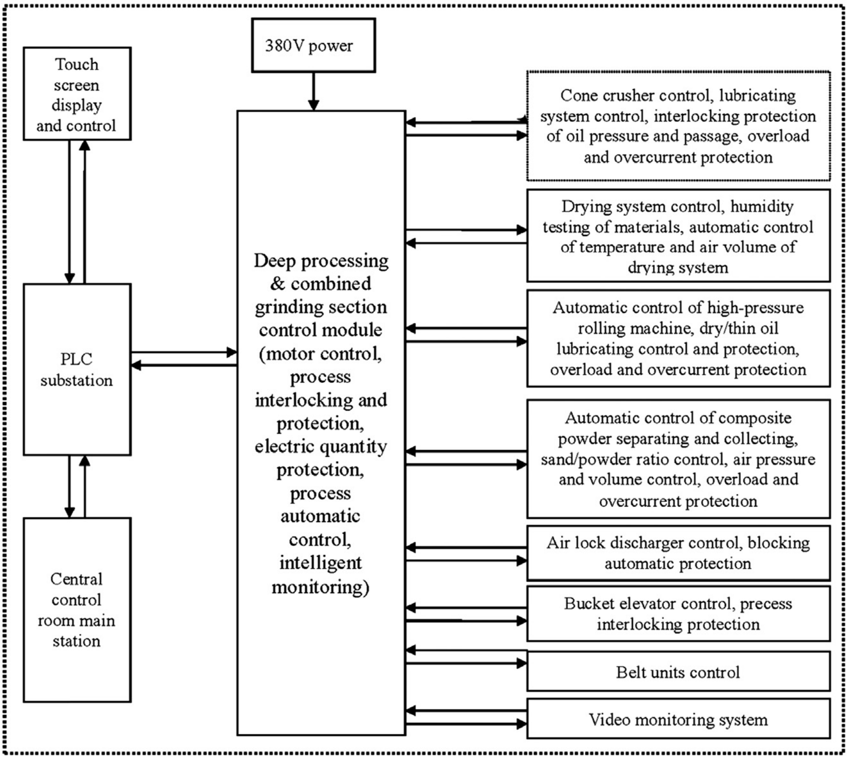


Figure 8.38 Deep processing combined grinding section module control system.

Control of each device and its data collection can be obtained by PLC control through sensors. Physical and mathematical models can be established according to process requirements to achieve the best control effect.

PLC control system is capable of remote diagnostic via the observation and analysis of each input port, output port, and intermediate parameters among the electronic control system. Completely intelligent surveillance monitoring can be achieved in this system.

Each substation is equipped with touch screens, whereas host machine is set in the main station. Dynamic display of the equipment operating status and parameters in each station is reflected on the touch screen (voltage,

Table 8.39 Main Products Manufactured in Nantong City Project

Product	Recycled Powder Material	Recycled Fine Sand	Recycled Product
Annual production capacity (t)	150,000	250,000	100,000

Table 8.40 Main Features and Index of Recycled Building Materials

Product	Size (mm)	Performance Index	Standard Consulted
Recycled micropowder material	0–0.075	Fineness (45 μm square mesh residue) <20%	GB/T 1596-2005
		Water content <1.0%	
		Water requirement ratio <105%	
		Loss on ignition <8.0%	Fly ash used for cement and concrete
		7 d activity >60%	
		28 d activity >70%	
Recycled fine sand	0.16–2.36	Micropowder content <3%	GB/T 25176-2010
		Clay lump content <0.5%	
		Light material content <0.5%	
		Firmness <8%	Recycled fine aggregate for concrete and mortar
		Crushing index <25%	
		Apparent density >2450 kg/m^3	
		Fineness module 1.90–2.60	
Recycled fine aggregate	0–5	Micropowder content <7%	GB/T 25176-2010
		Clay lump content <1%	
		Light material content <1%	
		Firmness <10%	Recycled fine aggregate for concrete and mortar
		Crushing index <25%	
		Apparent density >2350 kg/m^3	
		Fineness module 2.30–3.00	
Recycled aggregate	5–15	Micropowder content <1%	GB/T 25177-2010
		Clay lump content <0.5%	
Recycled aggregate	15–22	Water absorption <5%	
		Impurities <1%	Recycled coarse aggregate for concrete
Recycled aggregate	22–31.5	Firmness <10%	
		Crushing index <12%	
		Apparent density >2350 kg/m^3	

current, bearing temperature, humidity, vacuum, etc.). Dynamic display of the operating status and parameters of equipment in all production lines equipment can be reflected on the PC screen in the master station.

Terminal of the industrial TV monitoring system is located in the central control room. The complete set of equipment includes display screen, image segmentation, camera, optical terminal, and cable. Either centralized control in central control room and centralized control or independent, decentralized local control is applicable.

8.4.2.6 Products

The main products manufactured in this project include recycled aggregate, recycled powder materials, recycled sand, and gravel. Recycled aggregate is the primary intermediate product and can be used as raw materials for the production of recycled powder materials and other products. Meanwhile, it can also be sold directly as finished products based on the real market condition. Main products manufactured in this project are listed in Table 8.39.

Main products are recycled micropowder material and recycled fine sand. All the products should meet the regulation that is listed in detail in Table 8.40.

Recycled micropowder is the recycled material produced after the grinding of waste clay and waste cement debris in C&D waste, the particle size of which is less than 0.075 mm. Recycled micropowder is of hydration activity and can be used as supplementary cementitious material. The activity index reaches 70% and the surface area exceeds 410 m^2/kg, meaning it can partially replace the cement or fly ash in concrete. It is also suitable as a kind of cement admixture, which can effectively reduce the energy consumption and save the cost of cement.

Dry sand is the main raw material in dry mortar production. River sand and manufactured sand should generally be dried in the process. The less than 1% water content of recycled fine sand avoids the drying procedure and thus save the project investment. Meanwhile, the circular particle size of recycled fine sand is suitable as the raw material of mortar production.

8.4.2.7 Water Engineering

Water Supply

Production water (except that outside the mixing station) and domestic water is directly supplied from the municipal water supply network (an inlet pipe DN150, water pressure $\geq$0.25 MPa). To ensure the reliability of production water, a 150-t homogenize tank is set near the product

Table 8.41 Detailed Amount of Water Used in Nantong City Project

		Amount of water (m^3)				
No.	**Water Used**	**Day & Night**	**Average (h)**	**Maximum (h)**	**Pressure (MPa)**	**Note**
1	Production water					
1.1	Concrete workshop	88	8.8	8.8	0.25	2 shift production
1.2	Washing	6.4	0.64	0.64		10% water supply
1.2.1	Washing of mixing station	16	1.6	1.6	0.2	Recycled use
1.2.2	Washing of mixing vehicle	48	4.8	4.8	0.4–0.5	Recycled use
1.3	Product manufacturing workshop	60	4	4		2 shift production
1.4	Hot water for product curing (85°C)	53	2.2	2.2		3 shift production
1.5	Curing water (sprinkling)	13	1.63	1.63		1 shift production
1.6	Laboratory	13	0.82	2.04		2 shift production
	Subtotal	233.4	18.1	19.4		
1.7	Unforeseen demand: 10%	23.4	1.81	1.94		
	Total	256.8	20.0	21.4		
2	Domestic water					
2.1		42	1.75	4.38		300 people/day
2.2	Subtotal	42	1.75	4.38		
2.3	Unforeseen demand: 10%	4.2	0.18	0.44		
	Total	46.2	1.93	4.82		
3	Firewater					
3.1	Outdoor	144	72	72		Once, 2 h
3.2	Indoor	108	54	54		Once, 2 h
	Total	252	126	126		

Maximum daily water amount used: 303 m^3/d (not including firewater).

manufacturing workshop. The production water in this plant is delivered by the pump next to the tank.

The automatic water softener is equipped for the disposal of hot water in product curing section to reduce the hardness of water.

Hot Water

The main methods of preparation of hot water for product curing are: the solar heat collector + air-source heat pumps + hot water tank set on the roof of recycled aggregate production workshop, with heating tubes inside the tank for auxiliary heating.

The preparation of hot bathing water is similar to that of hot water for product curing, the main methods are: the solar heat collector + air-source heat pumps + hot water tank set on the roof of production control center.

The detailed amount of water used in listed in Table 8.41.

Drainage Engineering

1. The combined sewage and wastewater discharged from the domestic facilities after being treated through septic tanks, along with the kitchen water with oil after being treated through the oil separating tank, is discharged into the municipal sewage systems on the south of the plant with an emission flow rate of about 41 m^3/d.
2. The car washing waste water is recycled for reuse after solid—liquid separation to save water.
3. The rainwater and washing water in the production field is collected through the drainage ditch and discharged into the riverway in the west side of the plant.
4. No production waste water is discharged during the whole production process.
5. The rainwater is calculated using the rainstorm intensity calculation formula in Nantong city: $q = 2007.34\ (1 + 0.752\ \lg p)/(t + 17.9)^{0.71}$.

$P = 2.0$ (years), $t = 15$ min, $\psi = 0.60$, the discharging amount is about 1323 L/S.

Other Materials and Facilities Involved in Water Engineering

1. Pipes
    - **a.** Water supply:
      Indoor: PVC steel composited pipes and PP-R pipes.
      Outdoor: Steel mesh skeleton plastic composited pipe for water supply (SPE)

  Fire prevention: Steel mesh skeleton plastic composited pipe for water supply (SPE)
  - **b.** Drainage:
    Indoor: UPVC pipes.
    Outdoor: Reinforced UPVC pipes.

2. Facilities
  - **a.** Stable high-pressure water pump set for outdoor fire fighting
    Main pump: XBD3/20-KDB (two pumps, one for backup)
    Q = 20 L/S, H = 30 m, P = 11 kW.
    Pressure-Stabilizing Pump: XBD3.2/5-KDB (two pumps, one for backup)
    Q = 5 L/S, H = 32 m, P = 4 kW.
    Scale of diaphragm air pressure tank: SQL%% C400 × 1400−1.6 V = 70L
  - **b.** Water pump set for indoor fire fighting
    XBD5.4/15-DL (two pumps, one for backup)
    Q = 15 L/S, H = 54 m, P = 15 kW.
  - **c.** Roof stainless steel firewater tank (12 t, 3 × 2.5 × 2 m) One
  - **d.** Hot water for product curing
    Flat-plate solar collector: 300 m^2
    Air-source heat pump set:
    MWV-L200T2/S One.
    MWV-L1200T2/S One.
    8.25-t stainless steel heating water tank (2 × 2.5 × 2 m) One.
    33-t stainless steel heat preservation water tank (4 × 5 × 2 m) One.
    Power: 105 kW, 380 V/3N-50 Hz.
  - **e.** Hot bathing water preparation
    Flat-plate solar collector: 150 m^2
    Air-source heat pump set: FM-20Q (R) One.
    15-t stainless steel heat preservation water tank (3 × 2.5 × 2.5 m) One.
    Power: 46.3 kW, 380 V/3N-50 Hz.
  - **f.** Automatic water softener: JDRF-S180T-600/J942T-600 One
    Q = 4−6 t/h Resin loading: 375 kg.

8.4.2.8 Dust Prevention and Removal

The main dust pollutant in the production line of material manufacturing process is the inorganic mineral dust produced in the transportation section. To control its emissions, series of measures are taken, including closed material storage reservoir, pneumatic conveying of powder in pipes strictly

Table 8.42 Dust Controlling Devices Involved in Nantong City Project

Dust Collecting Point	Dust Catcher	QTY	Air Volume (m^3/h)	Emission Concentration (mg/m^3)	Emission Amount		Note
					kg/h	kg/d	
Pretreatment	Bag filter	6	12,000	≤30	2.16	30.24	
Pretreatment	Bag filter	6	3000	≤30	1.35	18.9	
Recycled fine aggregate warehouse	Bag filter	8	3000	≤30	0.45	6.3	2 for regular use
Mortar, concrete	Bag filter	2	3000	≤30	0.18	2.52	
Recycled aggregate production	Bag filter	2	3000	≤30	0.18	2.52	
Cementing material	Bag filter	1	60,600	≤30	1.818	43.63	
Cementing material	Bag filter	1	12,000	≤30	0.36	8.64	
Cementing material	Bag filter	6	3000	≤30	0.45	10.8	5 for regular use
Total		32			6.95	123.55	

QTY, Quantity.

sealed, application of pipe screw conveyors, and belt conveyor (with cover) used for bulk material transportation while minimizing the gap between the speed and transfer points.

1. Wet construction work should be applied while prevention caps are equipped to prevent the diffusion of dusts.
2. Dust catchers are set in the pretreatment and screening sections.
3. Pneumatic conveying equipment are used for the unloading of bulk powder materials, sealed pipes are used throughout the whole process.
4. Bag filters are equipped on top of the powder material warehouse.
5. Spiral pipe conveyors are used for the powder materials transportation.
6. Bag filters are equipped in the blending device of recycled product manufacturing section.
7. Dust prevention caps are covered on the belt conveyors.
8. Enclosed structures are applied in the pretreatment workshops and recycled aggregate warehouses.
9. Bag filters are equipped on top of the recycled aggregate warehouse.
10. The material drop distance should be minimized.

Thirty-two dust catchers (for 32 dust production points) are set throughout the plant and the dust collecting efficiency can be up to 99.5% and the dust emission is less than 30 mg/Nm^3. The dust controlling devices involved in this project are listed in Table 8.42.

8.4.2.9 Labor Organization

The shift arrangement in this project is listed below:

252–300 annual working days;
The main production posts: two shifts, three shifts;
The auxiliary production posts: one-shift;
Eight working hours per shift.

Information of labor force involved in this project is listed in detail in Table 8.43.

8.4.3 Utilization Center of Recycled Resources Produced by C&D Waste in Suzhou City

8.4.3.1 General Introduction

Annual generation amount of C&D waste in Suzhou city is about 5 million tons. The annual handling capacity of this project is 1,000,000 t while the generation of recycled products is about 900,000 t.

8.4.3.2 Main Structures and Processes

Main structures including office buildings and manufacturing workshops are listed in Table 8.44.

Table 8.43 Information of Labor Force Involved in Nantong City Project

	Labor					
Department	**Day Shift**	**Morning Shift**	**Swing Shift**	**Night Shift**	**Nonshift**	**Total**
C&D waste storage	1	1	1	1	1	5
C&D waste pretreatment		11	11		6	28
Recycled aggregate warehouse		1	1		1	3
Recycled fine aggregate warehouse		1	1		1	3
Recycled aggregate production		8	8		6	22
Product curing		2	2	2	2	8
Mortar		8	8		6	22
Concrete		4	4		4	12
Cementing material		5	5	5	5	20
Cementing material storage house		3	3	3	3	12
Mechanic, auto maintenance	5	2	2	2	2	13
Storage yard for finished products	2	2	2	1	1	8
Technical (including experiments)	6	1	1		1	9
Guard	1	2	2	2	2	9
Car washing and water pool	1	1	1			3
Driver (forklift)	2	7	7	2	6	24
Driver (mortar and concrete vehicle)	5	5	5		5	20
Logistics	2	4	2	1	1	10
Financing	3					3
Administration	4	2	2			8
Management	3					3
Total	35	70	68	19	53	245

C&D, construction and demolition.

Table 8.44 Main Structures Including Office Buildings and Manufacturing Workshops for Annual Handling Capacity of 1,000,000 t Construction and Demolition Waste in Suzhou City Project

No.	Item	Land Occupation (m^2)	Construction Area (m^2)	Note
1	Comprehensive office building	400	1200	3 floors
2	Mechanical repair workshop	210	210	1 floor
3	Distribution room	120	120	1 floor
4	Fire-fighting pool and pump house	92	12 (pump houses)	Pool area 480 m^3
5	Guard room	24	24	1 floor
	Metering room	24	24	1 floor
6	Exhibition area for recycled building materials	1566		
7	Exhibition area for finished building materials	11,926		
8	Storage area for raw materials	12,950		
9	Pretreatment and brick production workshop	5400	5400	Partially exposed basement, 12 m height
10	Recycled mortar production workshop	4500	4500	Partially exposed basement, 12 m height

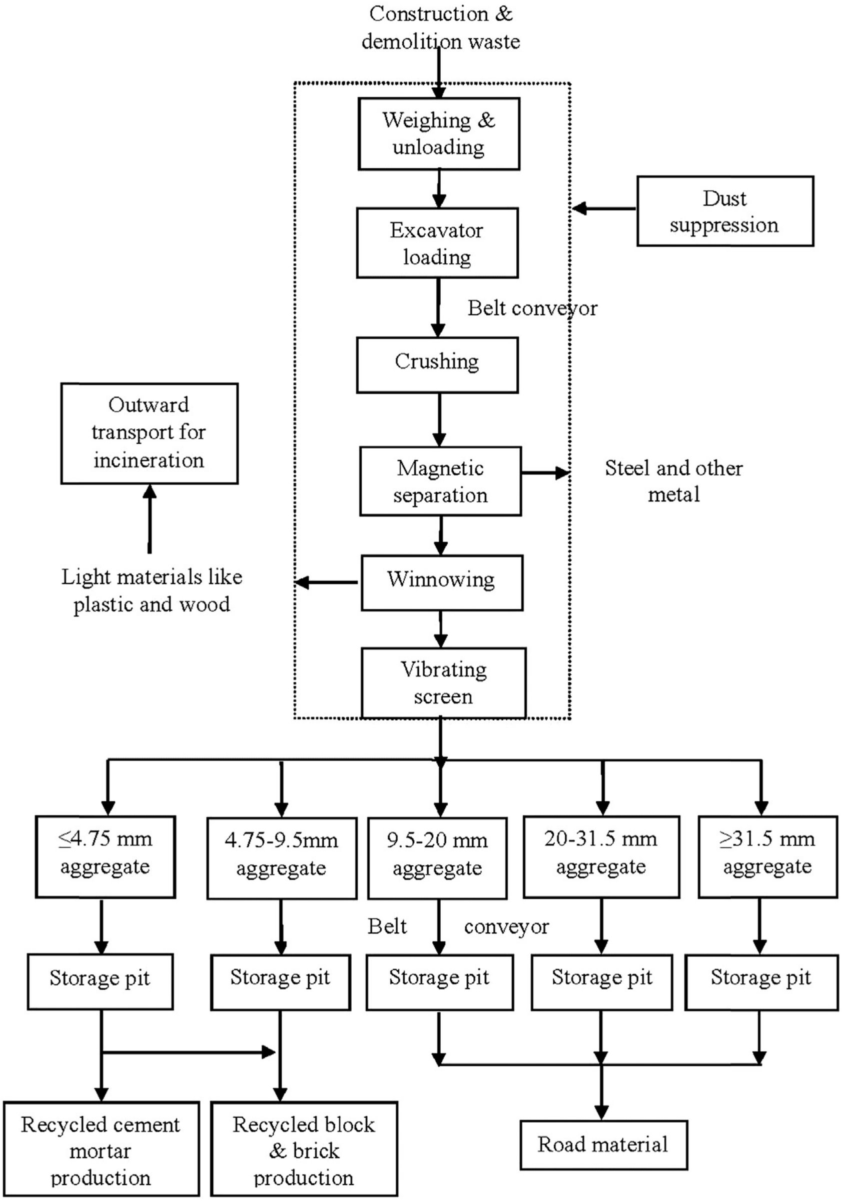


Figure 8.39 Whole process of construction and demolition waste disposal of utilization center in Suzhou city project.

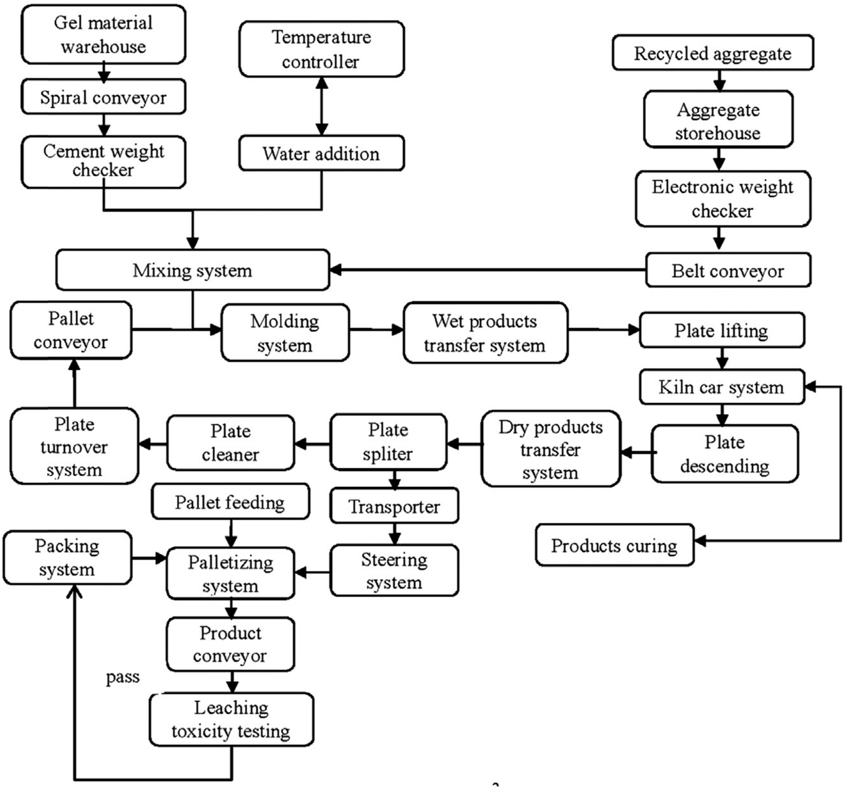


Figure 8.40 Process of manufacturing of recycled blocks and bricks in Suzhou city project.

Comprehensive disposal of C&D waste in this project includes unloading, pretreatment (crushing, magnetic and air sorting, screening, etc.), manufacturing of and curing of recycled blocks and bricks, production of recycled cement mortar, and building materials. C&D waste is sent into the storage area for unloading and stacking. Feeders and enclosed belt conveyors are equipped in this section, whereas excavators are used for loading of raw materials into feeders and transporters, in which C&D waste is conveyed to the pretreatment section. The first process is crushing; materials coming out of the outlet are classified into different sizes so that they can meet the demands for the subsequent recycled products. The crushed materials are removed of iron and metal substances and then sent for air sorting, where light materials like plastics and wood are separated. Materials are classified into five different groups based on their size through the vibrating screener ($\leq$4.75, 4.75–9.5, 9.5–20, 20–31.5, and $\geq$31.5 mm). These aggregates are sent to isolated storage pits through belt conveyors. The whole process is demonstrated in Fig. 8.39.

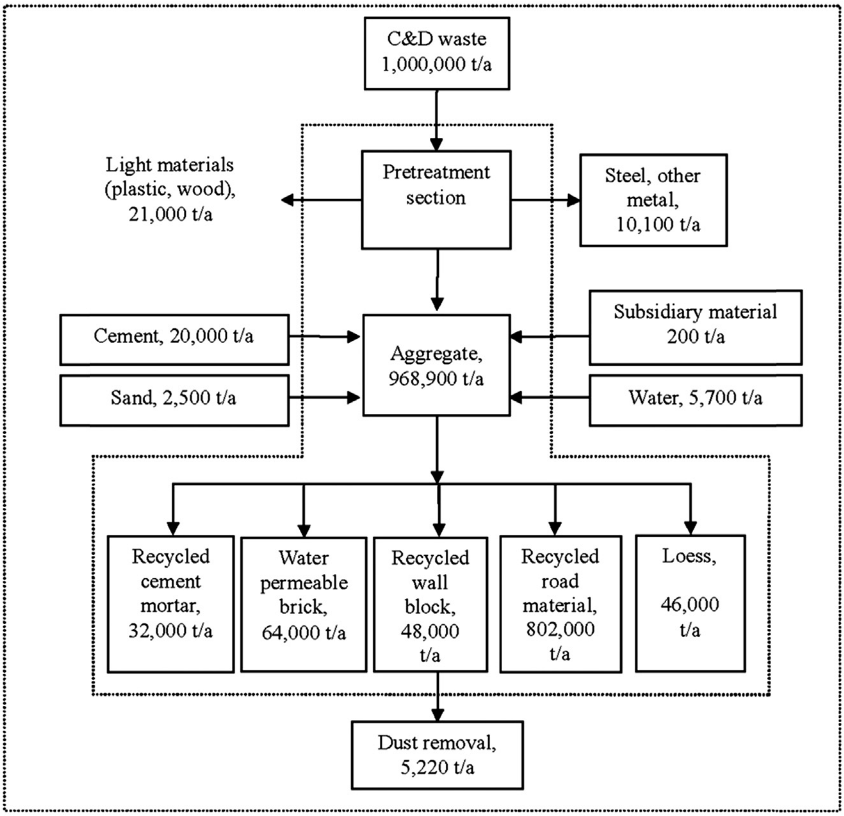


Figure 8.41 Material balance of the whole utilization project in Suzhou for annual handling capacity of 1,000,000 t construction and demolition waste in Suzhou city project.

Materials of size below 4.75 mm are fine aggregates and can be used as raw materials for recycled cement mortar, blocks, and bricks production. Materials of size between 4.75 and 9.5 mm are coarse aggregates and can be used as raw materials for recycled blocks. Materials of size between 9.5 and 20 mm, 20 and 31.5 mm, and above 31.5 mm can be used as road materials like stable layer of water below the pavement.

Process of manufacturing of recycled blocks and bricks is introduced below and demonstrated in Fig. 8.40.

The crushed C&D waste is used as raw materials and is mixed with certain ratio of water, cement, and paint. Then it is sent through an automatic process line including proportioning, mixing, molding, curing, splitting, and stacking. Main manufacturing equipment are proportioning and mixing process line, concrete product molders, conveyors, curing plates, and molders for recycled products.

8.4.3.3 Material Balance

The material balance of the whole utilization center of recycled resources produced by C&D waste in Suzhou city is demonstrated in Fig. 8.41.

8.4.3.4 Layouts and Land Coverage

Land coverage of unloading and storage area is 12,950 m^2 in which the hopper and enclosed belt conveyors are equipped. Excavators are used as loading machines for waste and materials. Land coverage of pretreatment and brick manufacturing workshop is 90.00 × 60.00 m, which is separated into pretreatment area, classified storage area of aggregate, brick manufacturing facilities area, and steam curing area. The pretreatment area is about 40.00 × 30.00 m in size with crushers, magnitude and airblow separators, vibrating screens, and belt conveyors.

The temporary storage area consisted of five separated storage pits and its coverage area is about 45.00 × 15.00 m. (1) Storage pit for aggregate of size less than 4.75 mm, land coverage 5.00 × 15.00 m, storage volume 200 m^3, (2) Storage pit for aggregate of size 4.75–9.5 mm, land coverage 7.50 × 15.00 m, storage volume 300 m^3, (3) Storage pit for aggregate of size 9.75–20.00 mm, land coverage 10.00 × 15.00 m, storage volume 400 m^3, (4) Storage pit for aggregate of size 20.00–31.50 mm, land coverage 12.50 × 15.00 m, storage volume 500 m^3, (5) Storage pit for aggregate of size larger than 31.50 mm, land coverage 10.00 × 15.00 m, storage volume 400 m^3.

Land coverage of brick manufacturing workshop is 45.00 × 30 m, in which additive storage house, mixing system, twin-shaft mixer, brick producer, stacker, and composite carts are equipped. Land coverage of steam curing workshop is also 45.00 × 30 m, in which steam curing kiln and boilers are installed. Oil-fired boilers are used of which the steam volume is 2 t/h and the steam pressure is 0.20–0.25 MPa.

Table 8.45 Comparison of Two Dust Removal Methods

	Bag Filter	Micron Dry Fog Spraying
Energy cost	High	Low, less water consumption
Operation	Complex	Easy
Land coverage	Large	Small
Installation	Heavy machines, large size of wind tubes, complex installation	Easy
Investment	Large	Small
Removal effect	Low for small particles	High for comprehensive treatment, especially PM 2.5

Table 8.46 Main Dust Removal Facilities Involved

No.	Item	Style	QTY	Note
1	Centrifugal fan	Gas flow 2000 m^3/h, air pressure 400–600 Pa, rotation speed 1400 r/min, N = 2.2 kW	3	
2	Pulse bag filter	N = 5 kW	1	
3	Flue pipe	320 × 120 mm	320	PVC
		160 × 120 mm	480	PVC
		φ400 mm	120	Galvanized steel
4	Cover	1000 × 1000 mm	12	Stainless steel
5	Micron dry fog dust removal system	Sauter mean diameter SMD: 1–10 μm, with host device, gas tank, electric controlling system, spray tank, heating and insulation systems	2	
6	Remote fog spraying system	Approximately 50–100 μm	2	

QTY, quantity.

Waste, materials, and aggregate are transferred to recycled mortar workshop from pretreatment section through belt conveyor, the land coverage of this workshop is 90.00 × 50.00 m, in which ingredients storage house, dryers, and mixers are equipped. All the transportation facilities are fully enclosed. Meanwhile, coverage of storage house of products and demonstration area of recycled products is 11,926 and 1566 m^2.

8.4.3.5 Dust Controlling System

Dust controlling system is also an important section in this project. The main process is "micron dry fog spraying at initial + bag filter at terminal," the comparison of the two methods is listed in Table 8.45. The equipment used includes centrifugal blower (CF-11, 2000 m^3/h, pressure 400–600 Pa, rotation speed 1400 rpm, N = 2.2 kW), pulse-jet bag series dust filter (N = 5 kW), micro dry fog spraying system (Sauter mean diameter SMD: 1–10 μm), and remote spray system (50–100 μm).

Main dust removal facilities involved are listed in Table 8.46, including three centrifugal fans, a pulse bag filter, flue pipes, covers, micron dry fog dust removal systems, and remote fog spraying systems.

Table 8.47A Main Facilities Throughout the Utilization Project for Annual Handling Capacity of 1,000,000 t Construction and Demolition Waste in Suzhou City Project

No.	Item	Style	Power (kW)	Unit	QTY
Feeding Section					
1	Excavator	Volume 1.5 m^3	10	Set	2
2	Hopper	2800 × 2800		Set	3
3	Belt conveyors			Suit	1
Pretreatment Section					
1	Crusher	CPSJ-40	355	Set	3
2	Electromagnetic separators	RCDD-12		Set	3
3	Winnowing			Set	2
4	Vibration sieve	4.75 mm/9.5 mm/ 20 mm/31.5 mm		Set	3
5	Belt conveyors			Suit	1
Temporary Storage Section for Aggregates					
1	Double flap grabbers (2 t)	DS2 (1.0) 1.2—00	15	Set	2
2	Fabric machine (with belt)	500 × 1000		Set	2
Brick Production Section					
1	Host computer	MT130-70S	200	Suit	2
2	Fully automatic brick molding machine	MT130-70S		Suit	2
3	Lifting and transportation section	MT130-70S Matic		Suit	2
4	Palletizing section	MT-CUBER-ST		Suit	2
5	Ingredients mixing section	MP1500/ 1000 MP500/ 300		Suit	2
6	Automatic cart pits	MT130/70S LSC		Suit	1
7	Steel pallets	2592 pallets		Suit	2
8	Wood pallets	10,000 pallets		Suit	2
9	Conservation kiln			Suit	2
10	Excavator				2
11	Forklift				2
12	Scraper				4
13	Steam boiler	2 t/h		Suit	1
Manufacturing Section for Recycled Mortar					
A	Raw material storage section		170		
1	Aggregate warehouse	3 m^3			8
2	Accessories warehouse	2.5 m^3			5

Table 8.47A Main Facilities Throughout the Utilization Project for Annual Handling Capacity of 1,000,000 t Construction and Demolition Waste in Suzhou City Project—cont'd

No.	Item	Style	Power (kW)	Unit	QTY
3	Feeding belt	Variable frequency, B = 600 mm		Set	3
B	Drying section	Tumble dryer, D = 1.5 m		Set	1
C	Screening and lifting system for thermal materials				
1	Screw conveyor			Set	1
2	Vibratory screening machine	D = 2.5 mm		Set	1
3	Central chain bucket elevator			Set	1
D	Classified sieving machine	0.3 mm/0.6 mm/ 1.2 mm		Set	1
E	Intensive mixer	Evenness 1:100,000		Set	1
F	Pneumatic system			Suit	1
G	Electronic controlling system			Suit	1
H	Dust removal section			Suit	1
Corollary Facilities					
1	Crane	8 t	13	Set	1
2	Loader	Volume 5 m^3			2
3	Dump truck	12 t			4
4	Mobile crushing facility	Disposal capacity 80 t/h, gas/ electric	80	Set	1
5	Mobile screening facility	Disposal capacity 80 t/h, gas/ electric	50	Set	1
Mechanic Repair Facilities					
1	Lathe	CD6140 A		Set	1
2	Bench drill	Z520-2 ф12.7		Set	1
3	Grinder	S35L-250		Set	1
4	Welder	BX3-550		Set	1
5	Vise			Set	2
6	Gas welding system			Set	1
7	Charger	GCA804/0−160V		Set	1
8	Planer	BD6063		Set	1

QTY, quantity.

Table 8.47B Main Facilities Throughout the Utilization Project for Annual Handling Capacity of 1,000,000 t Construction and Demolition Waste in Suzhou City Project

No.	Item	Style/Specification	Quantity	Note
1	Centrifugal air blower	CF-11, flow rate 2000 m^3/h, air pressure 400–600 Pa, rotation speed 1400 r/min, N = 2.2 kW	3	2 for use, 1 for backup
2	Pulse bag filter	N = 5 kW	1	
3	Flue pipe	320 × 120 mm	320	PVC
		160 × 120 mm	480	PVC
		φ400 mm	120	Galvanized steel
4	Collecting cover	1000 × 1000 mm	12	Stainless steel
5	Micro dry atomized dust suppression system	Atomization particle size 1–10 μm, host machine, gas tank, electric control system, spray tank assembly, sprayer with universal joints, electric tracer, and heat preservation system	2	
6	Remote atomized spraying system	Particle size of about 50–100 μm	2	

Table 8.48 Features and Quality Requirements of the Recycled Cement Mortar

					Frost Resistance	
Mortar	**Strength Grade**	**Consistency (mm)**	**Water Retention Rate (%)**	**14 d Tensile Bond Strength (MPa)**	**Strength Loss Ratio (%)**	**Mass Loss Ratio (%)**
Masonry mortar	M2.5/M5/M7.5/M10/M15	50—90	≥82	-	≤25	≤5
Plastering mortar	M5/M10/M15	70—100	≥82	≥0.15	≤25	≤5
Ground mortar	M15	30—50	≥82	-	≤25	≤5

Table 8.49 Compression Strength Grade of the Recycled Water Permeable Road Bricks

Compression Strength Grade	Average (MPa)	Minimum of Single Block (MPa)
Cc20	≥20.0	≥15.0
Cc25	≥25.0	≥20.0
Cc30	≥30.0	≥25.0
Cc35	≥35.0	≥30.0
Cc40	≥40.0	≥35.0
Cc50	≥50.0	≥42.0
Cc60	≥60.0	≥50.0

8.4.3.6 Main Facilities

The main facilities throughout the utilization project are listed in Table 8.47, which include all manufacturing sections like pretreatment, storage, sorting, and recycling processes. This table can be consulted to as a reference in other C&D waste recycling and utilization projects.

8.4.3.7 Products

The final products in this engineering project can be classified into four groups: Recycled cement mortar, recycled water permeable road bricks, recycled wall blocks, and recycled roadbed materials. The features and quality requirements of the four products are introduced below.

1. Recycled cement mortar. Recycled cement mortar using the recycled fine aggregate after presorting in this project can be produced into masonry mortar, plastering mortar and ground mortar (cannot be used as ground surface layers). The features and quality requirements of the recycled cement mortar are listed in Table 8.48.
2. Recycled water permeable road bricks. These are the road bricks with large water permeability produced using the C&D waste recycled aggregate and cement as raw materials along with proper amount of admixture; they are then molded and formed with mixture of water and naturally or steam curing is finally performed. The compression strength grades of the recycled water permeable road bricks are listed in Table 8.49.

Features and quality requirements of the water-permeable road brick produced by recycled aggregate are listed in Table 8.50.

3. Recycled wall blocks. The nominal diameter of aggregate used for recycled wall blocks should be less than 10 mm and the requirements are the same as those discussed earlier. The compression strength of recycled wall blocks is listed in Table 8.51.

Table 8.50 Features and Quality Requirements of the Water-Permeable Road Brick

Item		Features and Requirements
Maximum projection size of frontal adhesive skin and defect parts (mm)		≤10
Maximum projection size of losing angle/corner (mm)		≤15
Crack	Maximum projection size of the nonpenetrating cracks (mm)	≤10
	Penetrating cracks	Not allowed
Delamination		Not allowed
Variegated color, color deviation		Not obvious
Abrasion resistance		Pit length not large than 38 mm
Water-retaining property		Not less than 0.6 g/cm^2
Water permeation coefficient		Water permeation coefficient (15°C) ≥ 0.01 cm/s
Frost resistance		Strength loss should be less than 20.0% after 25 freezing–thawing cycles

Table 8.51 Compression Strength of Recycled Wall Blocks

Strength Grade	Average (MPa)	Minimum of Single Block (MPa)
MU3.5	≥3.5	≥2.8
MU5	≥5.0	≥4.0
MU7.5	≥7.5	≥6.0
MU10	≥10.0	≥8.0
MU15	≥15.0	≥12.0
MU20	≥20.0	≥16.0

Table 8.52 Features and Quality Requirements of the Recycled Wall Blocks

Item		Features and Requirements
Minimum wall thickness (mm)	As load-bearing walls	≥30
	Not as load-bearing walls	≥16
Rib thickness (mm)	As load-bearing walls	≥25
	Not as load-bearing walls	≥15
Defected corner	Number	≤2
	Minimum projection size in three directions (mm)	≤20
Accumulative extended projection size of cracks (mm)		≤20
Bend (mm)		≤2
Frost resistance index (D25)	Mass loss ratio (%)	≤5
	Strength loss ratio (%)	≤25

Features and quality requirements of the recycled wall blocks are listed in Table 8.52.

4. Roadbed materials. Those particles of size larger than 31.5 mm coarse aggregate can be used as the roadbed materials like the water stable layer under the sidewalk, or the lower cushion of the roadbed. The compression strength should meet the demand regulated in Technical guidelines for construction of highway road bases (JTJ034-2000).

8.4.4 Demonstration Project of C&D Waste Resource Reuse in Xi'an City

The annual disposal capacity of this project in Xi'an city is 1,000,000 t, whereas the generation of recycled aggregate, premixed mortar, cement admixture, building blocks, and wallboards products is about 500,000, 200,000, 40,000, 200,000, and 200,000 t, respectively.

Table 8.53 Main Materials Consumed in This Project for Annual Handling Capacity of 1,000,000 t Construction and Demolition (C&D) Waste in Xi'an City Project

Product	Recycled Coarse Aggregate	Recycled Fine Aggregate	Cement Admixture	Premixed Mortar	Building Blocks	Wallboard	/
Annual yield	334,000 t	253,000 t	40,000 t	200,000 t	100,000 m^3 × 2 lines	200,000 m^2	/
							Total
Coarse aggregate	33.4	/	4.0	/	12.3	1.3	50
Fine aggregate	/	25.3	/	13.4	9.1	0.9	48.7
Powder materials	/	/	/	/	1.2	0.1	1.3
Cement	/	/	/	5.5	3.1	0.3	8.9
Other materials	/	/	/	1.1	1.9	0.2	3.2
Annual C&D waste consumed	33.4	25.3	4.0	13.4	22.6	2.3	100

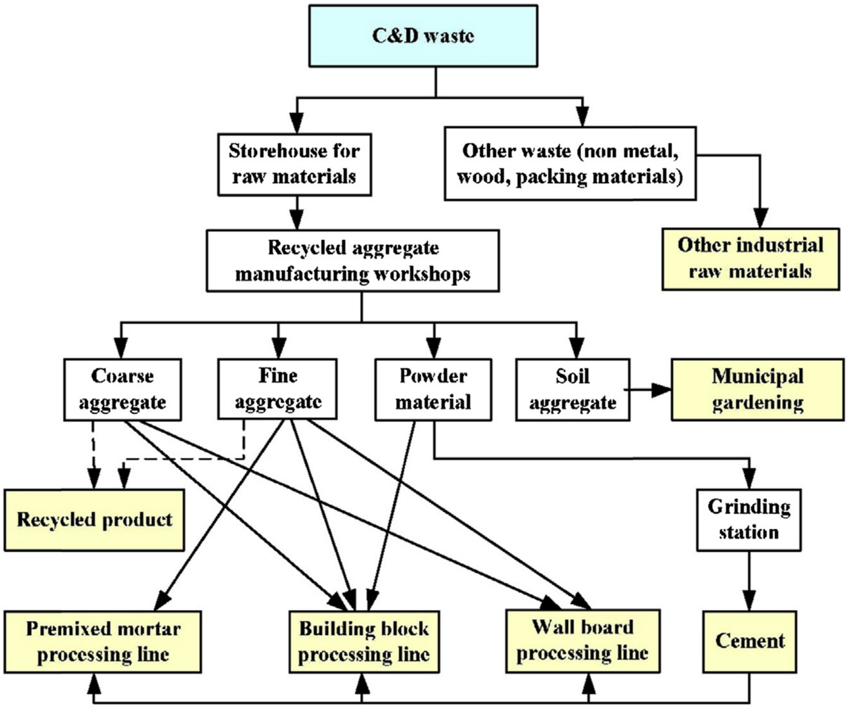


Figure 8.42 Overall process of construction and demolition waste disposal in Xi'an city project.

Enclosed workshops are applied in this project while multiple dust and noise prevention method are used. For instance, the crushing workshops are located underground, finished aggregated are stored in enclosed tanks, covers are equipped around the belt conveyors, PPDC pulse bag filters are set near the dust emission spots. Meanwhile, the double-layer walls and acoustic insulating material are also added to the structure of the workshop.

The main materials consumed are listed in Table 8.53.

8.4.4.1 Engineering Technical Process

The overall disposal process is demonstrated in Fig. 8.42. The whole demonstration project includes storage field of C&D waste, recycled aggregate production workshops, premixed mortar and concrete products manufacturing workshops, storehouse for finished products, test building, office building, and residual area.

Recycled aggregates that are able to replace natural sand and gravels are produced in this project through classified crushing and screening. Some of

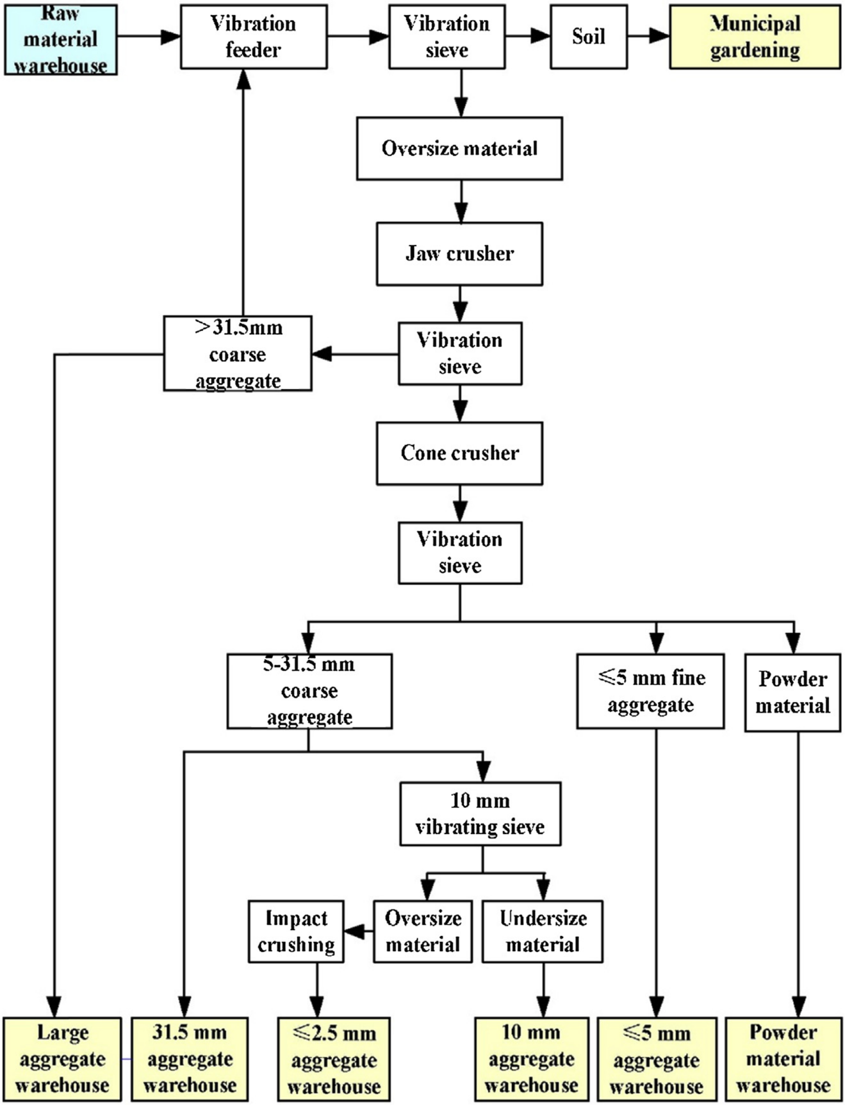


Figure 8.43 General process of aggregate production in Xi'an city project.

these aggregates can be applied as raw materials in deep processing process and are used to produce premixed mortar, cement admixture, and concrete. The rest are sold as commercial aggregates to concrete mixing stations, mortar plants, and backfilling of road base. The fine powder sorted is used

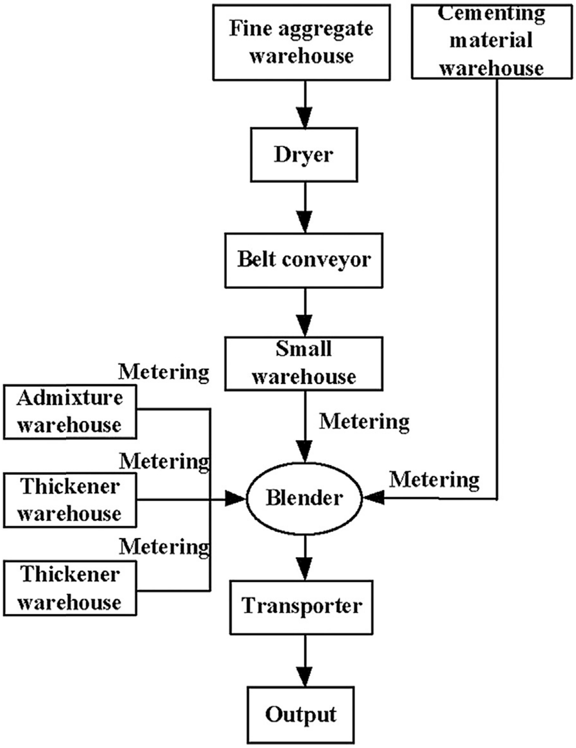


Figure 8.44 Process of premixed mortar production in Xi'an city project.

in concrete production while the loess screened out is directly supplied to garden department as soil.

The recycled products should meet the demand required in relevant standards, including those of aggregates, gravel, concrete units, mortar, and wallboards. General process of aggregate production is demonstrated in Fig. 8.43.

Wood, paper, plastic, and iron blocks are separated manually after C&D waste is transferred into the mixing house. Then the waste is conveyed to aggregate production workshops for deep processing. The 5—31.5 mm coarse aggregate, 0—5 mm fine aggregate and powder materials are delivered separately.

Process of premixed mortar production is demonstrated in Fig. 8.44.

Process of concrete production in this project is demonstrated in Fig. 8.45.

Fine aggregate and powder material belts are operated on and used to transport them directly to the mortar production workshop. The water

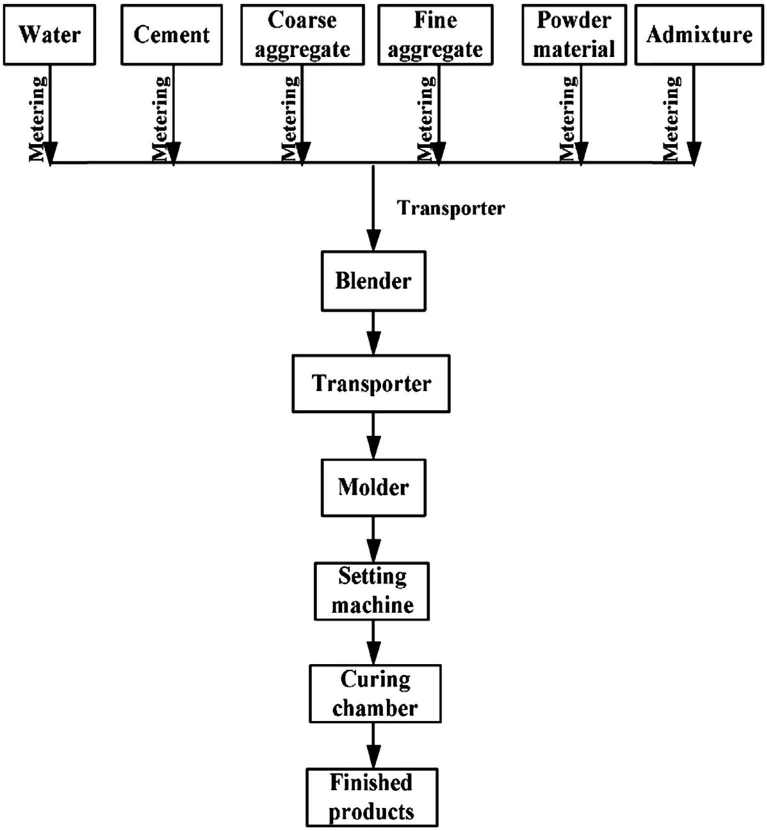


Figure 8.45 Process of concrete product manufacturing in Xi'an city project.

content can be reduced to below 0.5% using horizontal drying machines. Cement is added based on the target strength and application.

Process of wallboard production in this project is demonstrated in Fig. 8.46.

The main facilities used in this project are crushing, screening, transporting, gravel manufacturing, drying, mortar dry premixing, and wallboard and bulk components manufacturing sections, which are listed in detail in Table 8.54.

Annual disposal capacity of construction and demolition waste is 1 million tons in this project. A stockpile for raw materials of size 175 × 110 × 15 m is equipped to ensure the continuity and stability of production. The stockage volume is 182,000 m^3 and holding capacity of C&D waste is $182{,}000 \times 1.3 = 240{,}000$ t based on 10 m of stack height,

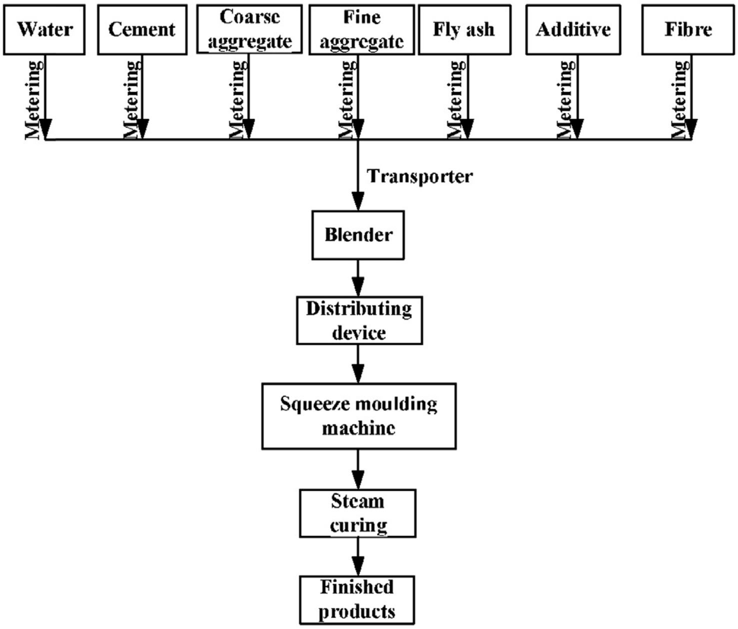


Figure 8.46 Process of wallboard production in Xi'an city project.

40 degrees of natural repose angel of C&D waste, and 1.3 t/m^3 of stacking density. The land coverage area is 175 × 110 = 19,250 m^2, and the stockage area is divided into four districts, namely, waste brick warehouse, waste concrete warehouse, and two mixed warehouses. All these warehouses are enclosed steel framework structures with concrete walls to prevent the rain and dust.

The land coverage area of aggregate manufacturing workshop is 120 × 50 m = 6000 m^2, and that of mortar and wallboard-component combined manufacturing workshops are 100 × 50 = 5000 m^2, and 220 × 70 = 15,400 m^2, respectively, with a sum of 26,400 m^2.

Silo structures are used in aggregate warehouses to improve land utilization ratio. The volume of the 31.5-mm coarse aggregate warehouse, for instance, is Φ40 × 20 m = 25,000 m^3 (storage capacity of about 3.5 million tons), which covers an area of 1256 m^2. As for other warehouses, the volume, storage capacity, and land coverage area can be consulted to Table 8.53.

Silo structures are also used in premixed mortar warehouses, which include the decorative mortar warehouse (storage capacity of 1500 t, land

Table 8.54 Main Facilities Involved and Their Parameters for Annual Handling Capacity of 1,000,000 t Construction and Demolition Waste in Xi'an City Project

No.	Item	Building Dimensions (m)	Storage Volume (t)	Land Coverage (m^2)	Total (m^2)	Architectural Style
1	Stockpile for raw materials	175 × 110	240,000	19,250	19,250	Frame-shear wall structure
2	Aggregate manufacturing workshop	120 × 50	/	6000	6000	Frame-shear wall structure
3	Mortar manufacturing workshop	100 × 50	/	5000	5000	Frame-shear wall structure
4	Concrete product manufacturing workshop	220 × 70	/	26,400	26400	Frame-shear wall structure
5	Aggregate warehouse	/	/	/	6000	/
5.1	3.15-mm coarse aggregate warehouse	Φ40 × 20	35,000	1256	/	Steel silo
5.2	10-mm coarse aggregate warehouse	Φ31.4 × 20	20,000	744	/	Steel silo
5.3	5-mm coarse aggregate warehouse	Φ31.4 × 20	20,000	744	/	Steel silo
5.4	2.5-mm coarse aggregate warehouse	Φ16 × 20	5200	201	/	Steel silo
5.5	Earth material warehouse	Φ16 × 20	5200	201	/	Steel silo
5.6	Fine powder warehouse	Φ16 × 20	5200	201	/	Steel silo
6	Mortar warehouse	/	/	/	5000	/
6.1	Decorative mortar warehouse	Φ12 × 20	1500	114	/	Steel silo
6.2	Masonry mortar warehouse	Φ13 × 20	1800	266	/	Steel silo
6.3	Masonry mortar warehouse	Φ13 × 20	1800	266	/	Steel silo

(Continued)

Table 8.54 Main Facilities Involved and Their Parameters for Annual Handling Capacity of 1,000,000 t Construction and Demolition Waste in Xi'an City Project—cont'd

No.	Item	Building Dimensions (m)	Storage Volume (t)	Land Coverage (m^2)	Total (m^2)	Architectural Style
6.4	Packed decorative mortar warehouse	20 × 6	500	111	/	Frame-shear wall structure
6.5	Packed masonry mortar warehouse	20 × 12	1000	222	/	Frame-shear wall structure
7	Curing room	/	/	/	18,525	Frame-shear wall structure
8	Office, residual, gardening area	210 × 70	/	/	14,700	Frame-shear wall structure
9	Road	/	/	/	7150	/
Total land coverage		100,875 m^2				

Table 8.55 Main Facilities Involved for Annual Handling Capacity of 1,000,000 t Construction and Demolition Waste in Xi'an City Project

No.	Main Facilities	Style	Power (kW)	Unit Cost (Dollar)	Total (Dollar)	Note
Recycled Aggregate Workshop						
1	Vibrating feeder	ZSW490 × 110	15	12,712	12,712	
2	Jaw crusher	PE900 × 1200	110	103,188	103,188	
3	Simmons cone crusher	CSB240	240	209,368	209,368	
4	Centrifugal impact crusher	VS I 1140	400	86,738	86,738	
5	Circular vibrating screen	2YA2160	30	20,937	20,937	
6	Circular vibrating screen	3YA2160	74	22,432	44,865	2 screens
7	Vibrating feeder	GZD200 × 120	4.4	5234	5234	
			873.4		483,041	
Premixed Mortar Workshop						
1	Dryer	Horizontal	50	/		
2	Mortar processing line	SHEF-20SJ	200	747,742	747,742	
			250		747,742	
Wallboard-Component Combined Workshop						
1	50 blending stations × 4			29,910	119,639	
2	Recycled aggregate board processing line	SHEF-20BC	120	747,742	747,742	
3	Recycled aggregate board processing line	SHEF-10 KC	220	299,097	299,097	
			340		1,166,477	
Other						
1	Belt conveyor	650 mm	5.5	1,944,129/m	74,774	
2	5 loaders	Wheel XG951-III	162	59,819	299,097	
			167.5		373,871	
		Total	1630.9		2,786,086	

Table 8.56 Typical Mix Proportion of C30 Concrete

Material	Cement	Sand	Stone	Fly Ash
Amount, kg/m^3	300	700	1100	100

coverage 114 m^2), masonry mortar warehouse (storage capacity of 1800 t, land coverage 266 m^2), and packed decorative and masonry mortar warehouses. The detailed features are listed in Table 8.55. All these warehouses are enclosed steel framework structures with concrete walls to prevent the rain and dust.

The land coverage of wallboard-component combined workshop is 18,525 m^2.

The residual and office area is divided into office building, laboratory building, restaurant, dormitories, staff area, gardening districts, etc. The total land coverage area is $210 \times 70m = 14{,}700\ m^2$.

The total land coverage area of the plant in this project is 100,875 m^2.

8.4.4.2 *Main Facilities Involved*

The main facilities involved in this demonstration project are listed in detail in Table 8.55.

8.4.4.3 *Economic Performance of C&D Waste Resource Reuse in This Project*

Recycled Aggregate

Studies on the recycled aggregate reveal that those produced by C&D waste are mainly cracked concrete, mortar, and bricks. Production from recycled aggregate to concrete of high strength is unpractical due to its complex components and diversified material strength, but production of C30 and below C30 concrete is feasible. Take C30 as an example (Table 8.56).

Table 8.57 Economic Analysis of Recycled Aggregate, \$/t

Item	Unit Cost	Amount used in 1 t of Recycled Aggregate	Cost of 1 t of Recycled Aggregate, \$/t
Power consumption	\$0.074/kW·h	7.3 kW·h/t	0.55
Labor cost	\$2.48/person·h	0.21 person·h/t	0.52
Administrative expense	/	/	0.30
Depreciation allowances of equipment	/	/	0.75
Production cost	/	/	2.12
Sale price	/	/	\$3.00/t

Table 8.58 Parameters of Recycled Coarse and Fine Aggregate Processing Line and economic Analysis

Annual Output	Total Power	Production Capacity	Annual Output Value	Production Cost	Marketing Cost (10% of Output Value)	Profit
987,000 t	873.4 kW	210 t/h	\$2.95 M	\$2.10 M	\$0.29 M	\$0.56 M

It is indicated by some researchers that the amount of recycled aggregate used for C30 concrete is 1020 kg/m^3, R28 intensity reaches 42.0 MPa after the spike of plasticizer. According to the background information of this area, the annual production amount of concrete is about 15 million m^3, among which C30 and below C30 concrete is approximately 4.5 million m^3 with a proportion of 30%. The apparent density of coarse and fine aggregates is 1.5—1.6 t/m^3, which makes the amount of coarse and fine aggregate used 4.5 and 3 million tons annually. Taking into that 30% of C30 concrete uses recycled aggregate, the amount of coarse and fine aggregates required is 1.35 and 0.9 million tons annually, respectively. This demonstration project locates in the north rural area and provides 25% of recycled aggregate, the final amount of coarse and fine aggregate is 0.337 and 0.225 million tons annually, respectively. As aggregate might be used in the production of other products, the annual production capacity of coarse and fine aggregates in this project is set as 0.5 and 0.487 million tons, respectively. The economic analysis of recycled aggregate is listed in Table 8.57. The parameters of recycled coarse and fine aggregate processing line and economic analysis are listed in Table 8.58.

Premixed Mortar

Construction mortar is the second mostly used materials in construction projects following concrete. Traditional process, mixing on site, has the disadvantage of inaccurate metering, large amount of materials wasted, and large fluctuation in quality. Use of commercial mortar (premixed mortar) reduces the material consumed by 50—70%. Natural sand is replaced by concrete and waste bricks in this project for the production of construction mortar. The annual production capacity is 0.2 million tons.

According to the statistics, the annual construction area in this city is more than 25 million square meters. The amount of mortar consumed is calculated based on quota: the amount of mortar used in multistorey residual building is 0.198 m^3/m^2 (construction area), and that in high-rise residual building is 0.0889 m^3/m^2. Given that the proportion of multistorey and high-rise residual building is 7:3, the mortar used in each square meter of

Table 8.59 Typical Mix Proportion and Intensity of Masonry Mortar

	Unit mix proportion, kg/m^3						Compressive Strength, MPa	
Grade	**Cement**	**Fly Ash**	**Sand**	**Consistency, mm**	**Water-Retentive Thickening Admixture JTC-1**	**Retarder Admixture I**	**7 d**	**28 d**
M5 (S-3)	192	62	1365	60	38	0.635	11.5	17.1
M10 (S-4)	256	34	1378	90	43.5	0.58	18.2	20.6
M15 (S-8)	270	80	1400	90	52.5	0.7	18.7	26.6

Table 8.60 Typical Mix Proportion and Intensity of Plastering Mortar

	Unit Mix Proportion, kg/m^3						Compressive Strength, MPa	
Grade	Cement	Fly Ash	Sand	Consistency, mm	Water-Retentive Thickening Admixture JTC-2	Retarder Admixture II	7 d	28 d
M5 (Y-2)	180	78	1359	110	38.7	0.387	8.8	10.9
M10 (Y-6)	296	56	1419	110	52.8	0.88	10.5	16.5
M15 (Y-11)	263	85	1356	110	52.2	0.696	10.9	18.5

Table 8.61 Parameters of Recycled Aggregate Premixed Mortar Processing Line and economic Analysis

Annual Output	Total Power	Production Capacity	Annual Output Value	Production Cost	Marketing Cost (10% of Output Value)	Profit
200,000 t	250 kW	80 t/h	\$6.88 M	\$4.54 M	\$0.69 M	\$1.65 M

construction area is 0.16527 m^3. Meanwhile, the unit weight of mortar is 1500 kg/m^3, the annual mortar used in this city should be above 6 million – tons. The typical mix proportion and intensity of masonry mortar and plastering mortar are listed in Tables 8.59–8.60. Parameters of recycled aggregate premixed mortar processing line and economic analysis is listed in Table 8.61.

Recycled Concrete Product

Given that the construction area in recent years is 25 million square meters, the wall materials of each square meter involves 200 standard bricks and that of each cubic meter involves 512 standard bricks, the total amount of wall materials required in this city is 10 million cubic meters. The production capacity of blocks and wallboards are both 0.2 million square meters, which is 2% of the total market requirements and can be sold in this region.

Main products include concrete blocks and concrete boards.

Block Processing Line Characteristics of recycled concrete blocks and the raw materials required are listed in Table 8.62 and their typical mix proportion is listed in Table 8.63.

The main index of the 200,000 m^3 recycled concrete block processing line is listed in Table 8.64.

Wall Board Processing Line General lightweight wallboards produced nowadays in this city include GRE perlite wallboard and GRC ceramic wallboard. As filling materials of high-rise buildings wall, there is circular hole in the middle which has the characteristics of heat and sound insulation. Mix proportion of wallboard material is listed in Table 8.65.

The dimension of the hole in recycled board material is $\Phi 60 \times 6$, the width and length of board are 0.6 and 2.6 m, respectively, and the density and thickness are 2345 kg/m^3 and 0.034 m, respectively. The weight of board a meter long $= \gamma \times (V_{board} - V_{hollow}) = 2345 \times [0.6 \times s\ 1.0 \times 0.09 - \pi/4 \times 0.06^2 \times 1.0 \times 6] = 2345 \times [0.054 - 0.0275] = 2345 \times 0.0265 = 62$ kg. The weight loss is regarded as 5% so the actual weight is

Table 8.62 Characteristics of Recycled Concrete Blocks and The Raw Materials Required

Annual Production	Voidage	Density	Water	Cement	Fine Aggregate	Coarse Aggregate	Fly Ash	Powder Material
200,000 m^3	30%	2300 kg/m^3	26,000 t	70,000 t	124,000 t	200,000 t	24,000 t	16,000 t

Table 8.63 Typical Mix Proportion of Concrete Blocks

Material	Water	Cement	Fine Aggregate	Coarse Aggregate	Fly Ash	Powder Material
Amount, kg/m^3	130	350	620	1000	120	80

Table 8.64 Main Index of the 200,000 m^3 Recycled Concrete Block Processing Line

Annual Output	Total Power	Production Capacity	Annual Output Value	Production Cost	Marketing Cost (10% of Output Value)	Profit
200,000 m^3	220 kW	60 m^3/h	\$5.09 M	\$4.30 M	\$0.51 M	\$0.28 M

Application: walls, tiles, retaining block, filling wall.
Cited from Shanghai SHEF resource technology and facilities of construction waste disposal.

Table 8.65 Mix Proportion of Wallboard Materials, Kg/m^3

Material	Water	Cement	Fine Aggregate	Coarse Aggregate	Fly Ash	Powder Material	Material
Amount, kg/m^3	160	350	1050	700	80	0.7	5.0

Table 8.66 Parameters of SHEF Recycled Wallboard Processing Line

Annual Output	Total Power	Production Capacity	Annual Output Value	Production Cost	Marketing Cost (10% of Output Value)	Profit
200,000 m^2	120 kW	100 m^2/h	\$1.20 M	\$0.84 M	\$0.12 M	\$0.24 M

Table 8.67 Amount of Raw Materials Required in Cement Process Line

Material P.O42.5 Cement	Clinker	Fly Ash	Cement Admixture	Gyp
Amount, kg/t	650	250	50	50
Annual amount consumed, t	520,000	200,000	40,000	40,000

Table 8.68 Personnel Allocation Information for Annual Handling Capacity of 1,000,000 t Construction and Demolition Waste in Xi'an City Project

No.	Group	Item		Post	Number of People per Shift	Number of People Required	Note
1	Recycled aggregate manufacturing workshop	Administration		3	3	84	8 h/shift, 2 shifts/day
		Technique		1	3		
		Loaders on raw material stockage field	Driver	5	5		
			Dispatcher	1	1		
		Raw material stockage field	Sorting staff	1	10/shift		
		Aggregate warehouse	Feeding, unloading	2	6/shift		
		Aggregate processing line	Mechanic, dust catching, belt sorting, electrician	4	20/shift		
2	Premixed mortar manufacturing workshop	Administration		2	3	34	8 h/shift, 2 shifts/day
		Technique		1	2		
		Blender		/	5/shift		
		Dryer		/	3/shift		
		Raw material management, admixture and additive measurement		/	3/shift		
		Product discharge measurement		/	2/shift		
		Repair		/	3		
3	Building block manufacturing workshop	Administration		2	3	89	8 h/shift, 2 shifts/day
		Technique		1	3		
		Blending		2	5/shift		
		Delivering		2	10/shift		
		Molder		2	10/shift		
		Setting machine		1	10/shift		

(*Continued*)

Table 8.68 Personnel Allocation Information for Annual Handling Capacity of 1,000,000 t Construction and Demolition Waste in Xi'an City Project—cont'd

No.	Group	Item		Post	Number of People per Shift	Number of People Required	Note
4	Wallboard manufacturing workshop	Assistance		4	4/shift	38	8 h/shift, 2 shifts/day
		Repair		2	5		
		Administration		1	3		
		Technique		1	2		
		Blender		1	5/shift		
		Molder		1	4/shift		
		Processing line maintenance		2	5		
		Curing		2	5/shift		
5	Administrative department	Administrative staff:	Administration	/	5	66	/
			Technical inspection	/	5		
			Finance	/	4		
			Logistics	/	2		
			Seller, material supply	/	10		
		Auxiliary service staff:	Guard, supply and marketing	/	20		
			Plumber/electrician	/	3		
			Boiler	/	3		
			Mechanical maintenance (vehicles, facilities)	/	6		
			Canteen	/	5		
			Oil depot	/	3		
Total				/	/	311	/

Table 8.69 Hazardous Substances in the Atmosphere Inside Recycled Aggregate Manufacturing Workshops (μg/m^3)

	Chemical Industry		Metallurgical Industry	
Pollutants	**Average**	**Maximum**	**Average**	**Maximum**
Cu	50.5	475.5	1.6	29.6
Zn	7.3	17.0	26.7	394.2
Pb	0.7	3.4	1.6	10.0
Cr	7.5	60.1	1.9	10.4
Cd	0.02	0.02	0.05	0.12
Ni	4.6	22.9	0.4	2.0
Hg	5.4	12.3	0.5	5.0
As	0.3	1.1	0.4	1.9

Table 8.70 Hazardous Substances in the Atmosphere Around Recycled Aggregate Manufacturing Workshops (μg/m^3)

	Chemical Industry		Metallurgical Industry	
Pollutant	**Average**	**Maximum**	**Average**	**Maximum**
Cu	5.0×10^{-1}	4.8	1.6×10^{-2}	3.0×10^{-1}
Zn	7.3×10^{-2}	1.7×10^{-1}	2.7×10^{-1}	3.9
Pb	6.6×10^{-3}	3.4×10^{-2}	1.6×10^{-2}	1.0×10^{-1}
Cr	7.5×10^{-2}	6.0×10^{-1}	1.9×10^{-2}	1.0×10^{-1}
Cd	1.6×10^{-4}	1.6×10^{-4}	4.8×10^{-4}	1.2×10^{-3}
Ni	4.6×10^{-2}	2.3×10^{-1}	4.3×10^{-3}	2.0×10^{-2}
Hg	5.4×10^{-2}	1.2×10^{-1}	4.9×10^{-3}	5.0×10^{-2}
As	3.4×10^{-3}	1.1×10^{-2}	3.9×10^{-3}	1.9×10^{-2}

Table 8.71 Risk Index in Production of Recycled Aggregate Using Hazardous Construction and Demolition Waste

	Chemical Industry		Metallurgical Industry	
Pollutants	**Workers**	**Nearby Population**	**Workers**	**Nearby Population**
Cu	0.7	0.3	0.04	0.02
Zn	0.003	0.003	0.06	0.06
Pb	2.4	0.2	7.2	0.5
Cr	48.7	4.3	8.5	0.7
Cd	0.4	0.1	2.1	0.6
Ni	42.4	13.8	3.7	1.2
Hg	7.3	0.3	2.7	0.1
As	11.9	0.5	20.3	0.8
Total	113.8	19.5	44.6	4.0

Table 8.72 Gastrointestinal Absorption Rate (FI) Values of Hazardous Substances

Substance	Cu	Zn	Pb	Cr	Cd	Ni	Hg	As
FI	1	1	1	0.025	0.025	1	0.07	1

65 kg. Parameters of SHEF recycled wallboard processing line is listed in Table 8.66.

Cement Admixture

Current total cement production capacity in this place is 800,000 t/a. Approximately 5% (weight of cement) can be replaced by recycled aggregate. Cement admixture is used to produce cement in this project and the detailed use is determined by the production amount and type of cement; taking marketing into consideration is not necessary. Amount of raw materials required in cement process line is listed in Table 8.67.

8.4.4.4 Personnel Allocation

Labor requirement: 311 people. More detailed information is listed in Tables 8.67 and 8.68.

8.5 REUSE RISK OF HAZARDOUS C&D WASTE

8.5.1 Production of Recycled Aggregate Using Hazardous C&D Waste

No effective treatment was performed on demolition waste from chemical and metallurgical industries, and concentrations of the hazardous substances in the atmosphere inside and around the workshops are shown in Tables 8.69 and 8.70.

The risk index in production of recycled aggregate using hazardous C&D waste is shown in Table 8.71. Results showed that a high environmental risk existed among the workers and population nearby if the hazardous C&D waste was not treated properly, especially among workers. The risk index in C&D waste of chemical industry among them was up to 113.8 and 19.5, respectively. The risk index in C&D waste of metallurgical industry among them was up to 44.6 and 4.0, respectively. Pollution of Cr, Ni, and As with high risk in C&D waste of chemical industry, as well as that of As with high risk in C&D waste of metallurgical industry should be strictly controlled.

Table 8.73 Exposure Amount in Reuse of Recycled Aggregate

	Chemical Industry				Metallurgical Industry			
Path	**Concentration in Air, $\mu g/m^3$**		**Ingestion Through Mouth, mg/kg·day**		**Concentration in Air, $\mu g/m^3$**		**Ingestion Through Mouth, mg/kg·day**	
Substance	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
Cu	31.5	297.2	7.4×10^{-3}	7.0×10^{-2}	1.02	18.5	2.4×10^{-4}	4.3×10^{-3}
Zn	4.6	10.6	1.1×10^{-3}	2.5×10^{-3}	16.7	246.4	3.9×10^{-3}	5.8×10^{-2}
Pb	0.4	2.1	9.6×10^{-5}	5.0×10^{-4}	1.0	6.3	2.4×10^{-4}	1.5×10^{-3}
Cr	4.7	37.6	2.8×10^{-5}	2.2×10^{-4}	1.2	6.5	6.8×10^{-6}	3.8×10^{-5}
Cd	0.01	0.01	5.9×10^{-8}	5.9×10^{-8}	0.03	0.08	1.8×10^{-7}	4.4×10^{-7}
Ni	2.9	14.3	6.7×10^{-4}	3.4×10^{-3}	0.3	1.3	6.3×10^{-5}	2.9×10^{-4}
Hg	3.3	7.7	5.5×10^{-5}	1.3×10^{-4}	0.3	3.1	5.0×10^{-6}	5.1×10^{-5}
As	0.2	0.7	4.9×10^{-5}	1.5×10^{-4}	0.2	1.2	5.8×10^{-5}	2.7×10^{-4}

Table 8.74 Risk Index in Direct Reuse of Recycled Aggregate Produced by Industrial Construction and Demolition Waste

Industry	Cu	Zn	Pb	Cr	Cd	Ni	Hg	As	Total
Chemical	6.3	0.01	1.6	31.2	0.2	26.7	5.6	9.2	80.7
Metallurgical	0.4	0.2	4.6	5.4	1.3	2.3	2.1	15.7	31.9

Table 8.75 Concentration of Hazardous Substances in Workshops During Production of Recycled Building Materials Using Recycled Aggregates (μg/m^3)

	Chemical Industry		Metallurgical Industry	
Pollutant	**Average**	**Maximum**	**Average**	**Maximum**
Cu	35.3	332.8	1.1	20.7
Zn	5.1	11.9	18.7	276.0
Pb	0.5	2.4	1.1	7.0
Cr	5.3	42.1	1.3	7.2
Cd	0.01	0.01	0.03	0.08
Ni	3.2	16.1	0.3	1.4
Hg	3.8	8.6	0.3	3.5
As	0.2	0.7	0.3	1.3

Table 8.76 Risk Index in Production of Recycled Building Materials Using Recycled Aggregates

Industry	Cu	Zn	Pb	Cr	Cd	Ni	Hg	As	Total
Chemical	0.5	0.002	1.7	34	0.3	29.7	5.1	8.3	79.6
Metallurgical	0.3	0.04	5.0	5.4	1.3	2.3	2.1	15.7	31.2

8.5.2 Direct Reuse of Recycled Aggregate

Suppose there are no loss of toxic and hazardous substances in production of recycled aggregate, the gastrointestinal absorption rate (FI) in US Environmental Protection Agency "Regional Screening Levels" database is listed in Table 8.72, and the exposure amount in the construction section of recycled aggregate direct reuse produced by industrial C&D waste is listed in Table 8.73. The risk index in the direct reuse of recycled aggregate produced by industrial C&D waste is listed in Table 8.74. It was indicated that the risk in direct reuse section was lower than that in production section. However, high risk still existed. The risk of recycled aggregate produced by chemical industry C&D waste was larger. In addition, the pollution

Table 8.77 Concentration of Hazardous Substances in Utilization of Recycled Building Materials ($\mu g/m^3$)

	Chemical Industry				Metallurgical Industry			
Path	**Concentration in Air, $\mu g/m^3$**		**Ingestion Through Mouth, $mg/kg \cdot day$**		**Concentration in Air, $\mu g/m^3$**		**Ingestion Through Mouth, $mg/kg \cdot day$**	
Substance	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
Cu	22.1	208.0	5.2×10^{-3}	4.9×10^{-2}	0.7	13.0	1.7×10^{-4}	3.0×10^{-3}
Zn	3.2	7.4	7.5×10^{-4}	1.7×10^{-3}	11.7	172.5	2.7×10^{-3}	4.1×10^{-2}
Pb	0.3	1.5	6.7×10^{-5}	3.5×10^{-4}	0.7	4.4	1.7×10^{-4}	1.0×10^{-3}
Cr	3.3	26.3	1.9×10^{-5}	1.5×10^{-4}	0.8	4.6	4.8×10^{-6}	2.7×10^{-5}
Cd	0.007	0.007	4.1×10^{-8}	4.1×10^{-8}	0.02	0.05	1.2×10^{-7}	3.1×10^{-7}
Ni	2.0	10.0	4.7×10^{-4}	2.4×10^{-3}	0.2	0.9	4.4×10^{-5}	2.1×10^{-4}
Hg	2.3	5.4	3.8×10^{-5}	8.9×10^{-5}	0.2	2.2	3.5×10^{-6}	3.6×10^{-5}
As	0.1	0.5	3.5×10^{-5}	1.1×10^{-4}	0.2	0.8	4.0×10^{-5}	1.9×10^{-4}

Table 8.78 Risk Index in Utilization of Recycled Building Materials

Industry	Cu	Zn	Pb	Cr	Cd	Ni	Hg	As	Total
Chemical	4.4	0.01	1.1	21.8	0.2	18.7	3.9	6.4	56.5
Metallurgical	0.3	0.12	3.2	3.8	0.9	1.6	1.4	11.0	22.4

Table 8.79 Risk Index of Whole Process of Hazardous Construction and Demolition Waste Utilization Without Proper Disposal

Industry	Cu	Zn	Pb	Cr	Cd	Ni	Hg	As	Total
Chemical	6.3	0.01	2.4	48.7	0.4	42.4	7.3	11.9	113.8
Metallurgical	0.4	0.2	7.2	8.5	2.1	3.7	2.7	20.3	44.6

risk of Cu and Zn was higher in this section than that in aggregate production section.

8.5.3 Production of Recycled Building Materials Using Recycled Aggregates

The concentrations of hazardous substances in the workshops during the production of recycled building materials using recycled aggregates are listed in Table 8.75; the risk index is listed in Table 8.76. It was found that, although the risk index in this section was lower than that in direct reuse of recycled aggregate, high environmental risk existed.

8.5.4 Utilization of Recycled Building Materials

Given that 70% of recycled building materials are the recycled aggregates and there is no loss of hazardous substances during the production process, the exposure amount of hazardous substances in the utilization of recycled building materials is listed in Table 8.77, and the risk index is listed in Table 8.78. It was found that, although the risk index in this section was the lowest, high environmental risk existed.

8.5.5 Results of Risk Assessment During the Entire Recycling Process

The risk index of the whole process of hazardous C&D waste utilization without proper disposal is listed in Table 8.79. It was found that the C&D waste from chemical and metallurgical industries had large environmental risk, 113.8 and 44.6, respectively. The risk index of Cr and Ni from chemical industry was larger than 40, which should be severely contaminated.

The risk index of As from metallurgical industry was 20.3, which was of high pollution risk.

Thus the environmental risk assessment model in the resource utilization of hazardous C&D waste has been established. The relationship between risk assessment and value of P was no risk ($P < 0.1$), potential risk ($0.1 \le P < 1$), low risk ($0.1 \le P < 1$), medium risk ($5 \le P < 10$), and high risk ($P \ge 10$). Results showed that the C&D waste from both chemical and metallurgical industry had large environmental risk, and the risk index was up to 113.8 and 44.6, respectively.

CHAPTER NINE

Policy and Management of Contaminated Construction and Demolition Waste

9.1 POLLUTION PREVENTION METHODS APPLIED IN INDUSTRIAL WORKSHOP STRUCTURES

9.1.1 Pollution Protection Design and Construction

Construction and demolition (C&D) waste is generated in the process of construction, renovation, and demolition of building products. The life cycle of building materials includes "conceptual design phase—construction acceptance phase—operation and service phase—end of service phase—regeneration phase." In this section, countermeasures for heavy metal contaminated C&D waste management have been put forward based on the whole life cycle of construction products. Firstly, pollution control should be taken into consideration from the design and construction phase.

The pollution sources of heavy metal contaminated C&D waste are mainly the mutual contact between the medium containing heavy metals and the structure. Therefore there should be close relationship between source reduction and pollution prevention. Sophisticated antipollution and anticorrosion methods can be devised and performed in the design and construction phase of construction projects to avoid direct contact with pollutants, thus reducing the possibility of heavy metal exposure.

A number of industrial plants built before 2000 tend to be of low degree of standardization, lack of supporting anticorrosion, and anticorrosion measures after decades of service, which ultimately resulted in infiltration of contaminants. Heavy metal pollution, particularly evident in electroplating and metallurgical industry, was presented for many years. In buildings and structures constructed within or before this period, the aim of anticorrosion design and construction was to enhance the operation, while pollution prevention was often been neglected.

9.1.1.1 Grade of Protection

To prevent heavy metal pollution in the selection stage of building materials the corrosive effect of commonly used liquid solution containing heavy

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metals and salts on building materials should be taken into consideration. According to the provisions of corrosive level in "Industrial Construction Anticorrosion Design" (GB 50,046-2008) the corrosion degree can be classified in four grades: strong, moderate, weak, and minor in electroplating, metallurgy, and other industries, which are shown in Tables 9.1 and 9.2. The selection of protection materials should be based on the corrosion intensity.

9.1.1.2 Selection of Materials

Selection of ground layer materials is listed in Table 9.3. In industrial plant design, pollution prevention should be strengthened, and appropriate selection of the ground floor should be made in relevant regions involving the agents containing heavy metals. For example, acid-resistant bricks and stones should be used as the main materials of the floors and walls around the tanks in electroplating workshops, where as asphalt mortar, anticorrosion wear coatings, self-leveling resin coating, polymer cement mortar, concrete, and other building materials should not be applied in these kinds of regions. For heavily polluted areas, such as the building materials of the electroplating and wastewater treatment tanks, the depth of acid-resistant bricks and stones should not be less than 30 mm. Resin-based materials or water glass—based materials can be used as the masonry materials. Meanwhile, thick protective coatings should be set on the surface.

Table 9.1 Corrosion Grades of Liquid Solution to the Building Materials

	Solution	**pH or Concentration**	**Reinforced Concrete, Prestressed Concrete**	**Cement, Plain Concrete**	**Sintered Brick**
Inorganic acid	Sulfuric acid, hydrochloric acid, nitric acid, chromic acid, plating solution, electrolyte, acid water (pH)	<4.0	Strong	Strong	Strong
		4.0—5.0	Moderate	Moderate	Moderate
		5.0—6.5	Weak	Weak	Weak
Alkali	NaOH (%)	>15	Moderate	Moderate	Strong
		8—15	Weak	Weak	Strong
	Ammonia (%)	≥ 10	Weak	Minor	Weak
Salt	Sulfate of sodium, potassium, sodium, magnesium, copper, cobalt, iron (%)	≥ 1	Strong	Strong	Strong

Table 9.2 Corrosion Grades of Solid Agent to the Building Materials

Solubility	Hygroscopicity	Agent	Relative Humidity	Reinforced Concrete, Prestressed Concrete	Cement, Plain Concrete	Ordinary Carbon Steel	Sintered Brick	Wood
Insoluble	—	Carbonates and sulfates of barium and lead, oxides and hydroxides of chromium	>75	Weak	Minor	Weak	Minor	Weak
			60–75	Minor	Minor	Weak	Minor	Minor
			<60	Minor	Minor	Weak	Minor	Minor
—	Hard	Nitrate of barium and lead	>75	Weak	Weak	Moderate	Weak	Weak
			60–75	Weak	Weak	Moderate	Weak	Weak
			<60	Minor	Minor	Weak	Minor	Minor
—	Easy	Sulfate of chromium, nickel, manganese, and copper	>75	Moderate	Moderate	Strong	Moderate	Moderate
			60–75	Moderate	Moderate	Moderate	Moderate	Weak
			<60	Weak	Weak	Moderate	Weak	Minor

Table 9.3 Selection of Floor Surface Materials

			Bulk Floor Surface												
Medium			Bulk Material		Mortar Joint				Monolithic Floor Surface						
Type	Name (% or value)	pH or concentration	Acid-resistant brick	Acid-resistant stone	Sodium silicate mastic/mortar	Resin-bonded mastic/mortar	Asphalt mastic	Polymer cement mortar	Sodium silicate concrete	Polymer concrete	Resin mortar	Asphalt mortar	Corrosion-resistant coating	Polymer cement mortar	Dense concrete
Inorganic acid	Sulfuric acid	>70	√	√	√	O	×	×	√	×	×	×	×	×	×
	Nitric acid	>40													
	Chromic acid	>20													
	Sulfuric acid	50–70	√	√	√	√	×	×	√	√	√	×	×	×	×
	Hydrochloric acid	≥20													
	Nitric acid	5–40													
	Chromic acid	5–20													
	Sulfuric acid	<50	√	√	√	√	√	O	√	√	√	√	O	O	×
	Hydrochloric acid	<20													
	Nitric acid	<5													
	Chromic acid	<5													
	Pickle, plating solution (pH)	<1													
	Acid solution	1.0–4.0	√	√	O	√	√	√	O	–	√	√	√	√	×
		4.0–5.0	–	–	–	–	–	√	–	–	√	√	√	√	O
		5.0–6.5	–	–	×	–	–	√	×	–	√	√	√	√	√
Alkali	Sodium hydroxide	>15	√	√	×	√	O	O	×	–	√	O	O	O	O
		8–15	–	–	×	–	–	–	×	–	√	√	√	√	√
	Ammonia	≥10	–	–	×	–	–	–	×	–	√	√	√	√	√
Salt	Copper sulfate, cadmium sulfate	≥1	√	√	O	√	O	O	O	–	√	×	O	√	×
Solid	Insoluable salt	Any	–	–	–	–	–	–	–	–	–	–	–	–	√
	Solid salt	Any	–	–	–	–	–	–	–	–	√	√	√	√	O
	Alkaline solid salt	Any	–	–	×	–	–	–	×	–	–	√	√	√	√

(1) "√" means applicable, "O" means occasionally applicable, "×" means inapplicable, "–" means not recommended. (2) When the solid medium is wet, it should be regarded as liquid medium.

In metallurgy industry, granite and antiacid corrosion bricks should be applied as the layer protective materials. The hydrometallurgical process includes leaching, purification, filtration, sedimentation, evaporation, crystallization, etc., and most of them are performed in acid or alkaline salt solution. Therefore protection of the salt solution containing heavy metals and other pollution prevention is particularly important.

9.1.1.3 Surface Protection Coating

The coatings should be determined by the corrosion of industry solution and the service period of concrete structure. The materials of coatings include alkyd primer, iron red epoxy paint, PVC fluorescent prime, zinc-rich primer, etc.

1. Surface protection of concrete structure
   If the corrosion intensity is high, 120, 160, and 200 μm protective layer should be applied for the service life of 2—5 a, 5—10 a, and 10—15 a, respectively. If the corrosion intensity is moderate the depth of protective layer should be at least 80 μm for the service life of 2—5 a, or replaced by treatment twice using a polymer slurry. If the corrosion intensity is low and the service life is 2—5 a, surface protection is not necessary in this situation. For the service life of 5—10 a, the depth of protection layer should be more than 80 μm or treating twice using polymer slurry could be replaced. For the service life of 10—15 a, the depth should be at least 120 μm.
2. Surface protection of masonry structure
   If the corrosion intensity is high, 80, 120 , and 160 μm protective layer should be applied for the service life of 2—5 a, 5—10 a, and 10—15 a, respectively. If the corrosion intensity is moderate the protective layer should be treated twice using polymer slurry for the service life of 5—10 a. The depth of layer should be at least 80 and 120 μm for the service life of 5—10 a and 10—15 a, respectively. If the corrosion intensity is low and the service life is 2—5 a, surface protection is not necessary in this situation. For the service life of 5—10 a, the protection layer should be treated twice using polymer. For the service life of 10—15 a, the depth should be at least 80 μm.

9.1.2 Operation and Maintenance of Pollution Prevention

The exposure conditions of heavy metals during the service period of industrial structures largely determine the levels of pollution when they ultimately become C&D waste. The safe production, strict operation, and regular maintenance will become an important part of pollution prevention.

Pollution control during the service period of industrial structures should be focused on. The managing personnel are responsible for the operations and maintenance of pollution prevention. The operating workers have the obligation to identify and report problems. In industrial manufacturing processes, relative equipment which might be exposed to pollutants should be placed in an enclosed system to avoid the spilling, leakage or dribbling, or pollutants.

Timely repair and maintenance should be performed on the damage caused during manufacture. In the case of emergency, pollutants should be removed efficiently to avoid the spread of contamination. If there is corrosion on prevention materials and the pollutants infiltrate, the corrupted debris should be removed and the rest should be washed by diluted alkali and water before reinforcement. The stripped C&D waste containing heavy metal and organic pollutants is sent for harmless treatment before landfill.

9.2 RECOMMENDATION ON SUPERVISION AND MANAGEMENT OF INDUSTRIAL CONSTRUCTION AND DEMOLITION WASTE

9.2.1 Guidance of Pollution Prevention and Management (A Case Study in China)

The main responsibilities and organization of local housing and urban construction departments and environmental protection departments should be adjusted. The proposed regulatory mode and preliminary plan in China is shown in Fig. 9.1. As a case study in China the identification of C&D waste pollution is carried out by relevant qualified companies certificated by the Department of Environmental Protection, contaminated C&D waste is supervised and managed by the Department of Environmental Protection, where as ordinary C&D waste is sent for recycling by the housing and urban construction administrative departments. The relevant qualified companies are responsible for the subsequent treatment. Construction of solid waste management center should be strengthened. For the demolition or renovation of all chemical and metallurgical plants, environmental impact assessment should be carried out.

9.2.2 Problems and Countermeasures of Pollution Prevention of Industrial Waste Generated in Fire and Explosion Accidents

9.2.2.1 Main Characteristics of C&D Waste Generated in Fire and Explosion Accidents Are Listed as Follows

1. Heavy metals and organic pollutants largely exist, especially those from chemical, metallurgical, and pesticide industries. About 1–2% of all

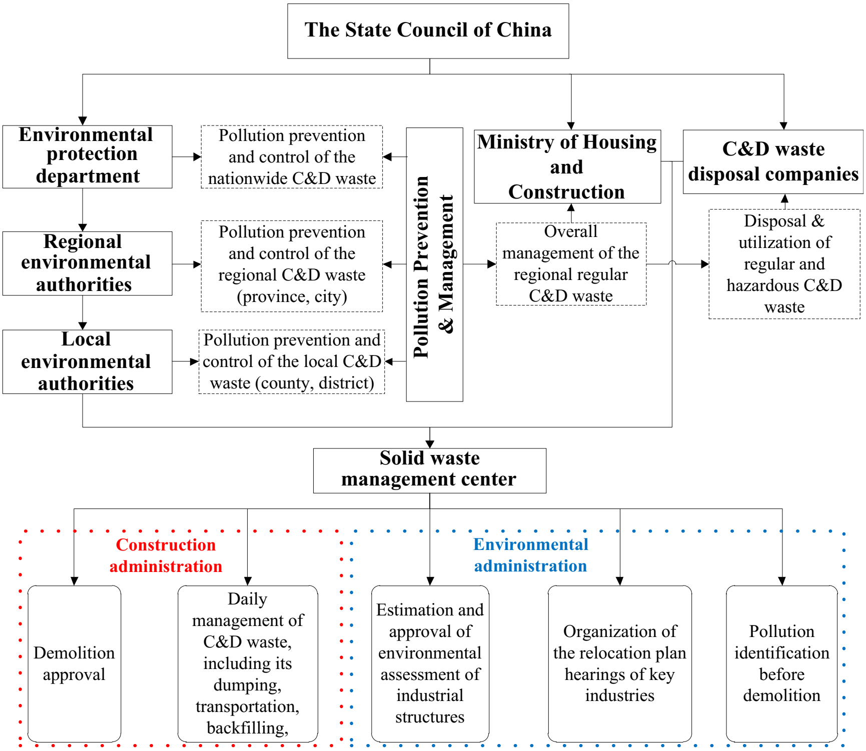

Figure 9.1 Recommendation on the administration of industrial construction and demolition waste in China.

these C&D waste are hazardous waste, up to 1–2 million t/a without any treatment. Huge amounts of these wastes will generate and the pollutants will spread when the fire and explosion accident breaks out.

2. Lots of hazardous substances will leak in explosion, most of which transmit into the atmosphere and aquatic system, others attach on the surface of C&D waste or soil. The existing emergency plans mainly focus on the monitoring of the atmosphere and surrounding water, mostly limited on conventional pollutants like nitrogen oxides and sulfur monoxide, etc. No sufficient attention has been paid to this situation, and the knowledge of the chemical materials and multiple contaminants generated still lacks. Most waste is stacked and discarded in a centralized way.

9.2.2.2 Recommendations on the Pollution Prevention and Control of Industrial C&D Waste Produced During Fire and Explosion Accidents

1. Laws and standards on industrial C&D waste produced during fire and explosion accidents should be established; the main focuses should be its pollution prevention regulations, collection and transportation regulations, identification criteria, disposal alternatives, etc.
2. Identification and classified management responsibilities of C&D waste produced during fire and explosion accidents should be established.

The waste should be divided into hazardous waste and ordinary waste. For those C&D waste with the spilling or leakage of dangerous substances, those with high volatility and low flash point, and those with high toxicity should be collected separately as hazardous wastes. The remaining C&D waste should be on-site investigated, sampled, and identified by environmental protection departments so that the scope of possible diffusion range of contamination is marked and the physicochemical properties are publicized. The housing and urban construction department, cooperating with fire department, executes the treatment work until all hazardous waste has been cleared as confirmed by Department of Environmental Protection.

3. In situ standardized disposal of C&D waste after accident should be developed.

C&D waste generated in accidents should be sorted based on the identification. Ordinary waste and heavy metal contaminated waste should be cleaned by elution of citric acid, where as organic pollutants contaminated waste should be treated using microwave heating method. Those C&D waste in which chemical materials might exist should be spilled by dry powder or foam in case of reburning and then should be humidified to prevent the diffusion of dust. In situ disposal or centralized transfer should be performed after being stabilized.

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'*Note*: Page numbers followed by "f" indicate figures, "t" indicate tables.'