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# Pipe technologies for urban water conveyance distribution systems

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**Abstract:** Urban water conveyance and distribution systems are designed for securing the distribution of water to the customers with sufficient quantity and appropriate quality. Therefore, the water distribution systems are designed to convey the required flow at the acceptable head whereas the material used in the components of the system should be compatible with the quality requirements for water distributed for human consumption. Since the major components of a water distribution system are the pipelines, the designer should pay attention to the type of the pipes to use and, in particular, to the materials used for the production of pipes. Changes and innovations related to the pipe technologies are very frequent and the designers should be aware of these developments when they design a new system or they renovate an existing system. The aim of this paper is to review some of the recent development in pipe technologies and provide information useful for the designer.

**Keywords:** Pipe technologies, urban water distribution systems, potable water, pipeline design, pipe materials

## 1. INTRODUCTION

Urban water distribution systems are designed for providing good quality water to the inhabitants of municipalities. Water intended for human consumption requires that the materials used in all the components of the system are of appropriate quality so that public health is protected.

It goes without saying that the major components of a water distribution system are the pipelines. Therefore, the attention of the designer of the system should be focused on the type of pipes to use and in particular on the pipe material.

Several changes and innovations related to the pipe technologies have occurred during the last few decades. Therefore, it is of importance for the designer to be informed on the technologies available and the advantages and disadvantages of each technology.

This paper aims at providing information on the various pipe technologies and presenting the key characteristics of each technology. Also, some recommendations and limitations in the use of each technology are provided.

Obviously the aim of the paper is just to highlight some of the properties of the various types of pipes which may be useful for the designer of a water conveyance and distribution system. The decision on the type of pipes to be selected for a project remains at the hands of the designer. The designer is responsible for weighing of the various criteria and reach a final decision.

## 2. CHANGES OF THE PAST

The principles of the design of urban water distribution systems (WDS) remained relatively stable during the post second war era. The objective always was to construct a distribution network which could guarantee the distribution of water to the customers in a reliable and safe way.

Although the objectives and the principles of the design remain practically unchanged, we have observed significant changes in the related technology, economics, attitudes and planning framework.

More specifically the technological innovations in pipe manufacturing during the last decades include the polyvinyl chloride (PVC) pipes, the coated steel pipes, the new ductile iron pipes (DI), the polyethylene pipes (PE) and more recently the Glass Reinforced Polymer pipes (GRP).

In the sector of Economics the design of the WDS has been affected by changes such as the energy prices, petrol crisis, conflicts in several areas of the world and the recent economic crisis.

Also, several attitudes towards the design and operation of the WDS have changed more focused to health issues (e.g. asbestos – cement pipes are not produced anymore in the developed world), to water demand reduction, to more strict specifications (e.g. European norms – EN), to reliability of the water utility services and to minimization of water loss through the WDS.

Finally, in the planning framework, changes have been observed in the ownership of water services (e.g. public/private), in the town planning, in the available information (new tools can store and retrieve bulk of information with geo-reference), in skills and equipment, in the desired reduction of imports (the EU does not allow this criterion to be applied) and in the participation of stakeholders in all stages of design, construction and operation of water distribution systems.

## 3. ADVANTAGES AND DISADVANTAGES OF PIPE MATERIALS

When designing a new WDS, one of the most important decisions is the selection of the type of pipes. This selection is obviously dependent on a number of factors, among which the most important are the cost, the reliability, the allowed range of pressures, the range of diameters, the time required for the construction, the life horizon (durability), the availability in the market of pipes and fittings throughout the life of the system, the local skills for operation and maintenance.

It goes without saying that most of the existing pipe types are used extensively under the conditions for which they are appropriate. In general, there is not a unique guideline of what type of pipes to use. However, from time to time some tendencies are developed, which however, can change after a number of years. For instance, for small diameters and relatively low pressure requirements in the 70s the asbestos-cement pipes were the most popular. Then in the 80s, the PVC pipes were considered as the first choice. During the post 2000 period, the Polyethylene pipes have gained wide acceptability as being more suitable for the urban water distribution networks.

Regarding the large diameters and the high pressures, the first choice was always the steel pipes. However, in the recent years the ductile iron (DI) and the glass reinforced polymer pipes (GRP) appeared as strong competitors in the market. Recently, the steel pipes coated with cement or epoxy internally and polyethylene externally, seem to gain preference again. It is widely supported by experts that even the corrosion protection of steel pipe is not necessary anymore, due to the protection offered by the coating. As known, corrosion was always the principal factor for limiting the useful life of the steel pipes.

Since the choice of the pipe type is crucial for the design of a WDS, we present Table 1 with the main advantages and disadvantages of the different types of pipes. Needless to say, that the weight on each item is still on the hands of the designer who is aware of the local conditions and the available skills and financing conditions.

Table 1 is self explanatory; however apart from the advantages and disadvantages presented in the table there are other conditions which may influence the selection of the type of pipes. The availability of the pipes in the local market, the availability of spares throughout the useful life of the pipeline and the preference on the locally produced pipes which reduce the imports and strengthen the country's economy maybe some of the most important additional criteria which should be considered seriously in the pipe selection procedure.

*Table 1. Main advantages and disadvantages of various pipe materials*

| Pipe Material | Advantages | Disadvantages |
|---|---|---|
| Asbestos Cement (AC) | Strength and rigidity<br>Corrosion resistant to most soils and water<br>Flexible joints can be used to allow some deflection | Danger of asbestos dust for human health<br>Susceptible to impact damage<br>Low beam strength<br>Susceptible to corrosion from certain soils<br>Permeable to certain soil conditions<br>Difficult to locate<br>Leak detection more difficult than metallic pipes<br>Complex repair |
| Cast Iron (CI) | Strength and rigidity<br>High mechanical strength<br>Good resistance for corrosion<br>Leak location straightforward | Very heavy weight<br>Strong but brittle |
| Ductile Iron (DI) | High mechanical strength<br>Good corrosion resistance<br>Ease of jointing<br>Easy to locate<br>Leak location straightforward | Very heavy weight<br>Potential pH problems with soft water<br>Susceptible to corrosion if coating damaged<br>Difficulties in not straight alignment<br>Expensive joints<br>Low shock resistance<br>Double coating required<br>Difficult to repair |
| Steel | High mechanical strength, shock resistant<br>Ability to deflect without breaking<br>Lighter weight than ductile iron pipes<br>Ease of fabrication of large pipes<br>Availability of special configurations by welding<br>Variety of strengths available<br>Ease of field modification<br>Easy repair | Susceptible to corrosion*<br>Double coating required |
| Glass Reinforced Plastic (GRP) | Light weight<br>Corrosion resistant<br>Ease of jointing | Low mechanical strength<br>Difficult to locate<br>Leak location difficult<br>Low beam strength |
| Polyvinyl Chloride (PVC) | Corrosion resistant<br>Light weight and flexible<br>Easy to join | Susceptible to impact damage<br>Ultraviolet degradation for exposed pipes<br>Difficult to locate<br>Leak location difficult<br>Low beam strength<br>Not suitable for large diameters |
| Polyethylene (MDPE/ HDPE) | Corrosion resistant<br>Light weight and flexible<br>Joints can be welded<br>Small diameters easy to repair | Difficult to locate<br>Leak location difficult<br>Fusion jointing requires skilled installers and special equipment<br>Low beam strength<br>Not suitable for large diameters |

** The new production of steel pipes with external coating with polyethylene and internal coating with cement or epoxy has extended the useful life of the pipes and therefore made the steel pipes corrosion resistant curing one of the most important drawbacks of the unprotected steel pipes.*

## 4. PIPE ROUGHNESS

Fully related to the selection of the type of pipes is the roughness factor which is fundamental for estimating the head losses in each branch of the pipeline. Unfortunately, there are values of roughness in the literature which create confusion to the designer. The manufacturers present low values which can, under certain conditions, create problems in the heads required at the nodes of the system if they are adopted at the design stage. On the other hand several institutions propose much higher values of roughness for a more safe design of WDSs. For the information of the readers Table 2 is included presenting the most common values of the roughness factor as proposed by manufacturers and institutions responsible for the design of pipe networks, respectively.

It is interesting to note that the values shown in Table 2 should be considered as the expected values of roughness (e.g. mean values) whereas the range of possible values can be as high as ±25% of the mean.

*Table 2. The pipe roughness factor of pipes with different materials*

| **Pipe Material** | **Industrial Pipe Roughness Factor [1] (mm)** | **Design Pipe Roughness Factor [2] (mm)** |
|---|---|---|
| Steel, welded and seamless | 0.061 | 0.25 |
| Ductile iron | 0.061 | 0.25 |
| Steel or Ductile asphalt coated or cement | 0.120 | 0.50 |
| Steel or Ductile Iron epoxy coated | 0.003 | 0.15 |
| Copper and Brass | 0.061 | 0.25 |
| Glass | 0.0015 | 0.06 |
| Thermoplastics (PVC, PE etc.) | 0.0015 | 0.06 |
| Drawn Tubing | 0.0015 | 0.06 |
| Cast Iron | 0.25 | 1 |
| Concrete | >0.5 | >1.50 |

[1] *Values proposed by the manufacturers*
[2] *For design use in real conditions including aging. Minor losses should be calculated separately*

It should be stressed that the variability of the roughness factor has been studied in a number of studies which have shown that it affects significantly the performance of the entire network.

## 5. BASIC NOTIONS IN THE CURRENT PRACTICE OF WDS DESIGN

In a municipal water distribution system the water consumption is realised from along the pipes by the consumers. However, in the professional practice, in order to simplify the computational procedures, the consumption is assumed to occur at the nodes of the network. It is also assumed that the nodal consumption is constant and known from the beginning (Spiliotis and Tsakiris, 2012).

In a looped system connected to fixed-grade nodes (such are the elevated water tanks), the number of equations required for the solution of the system is equal to the number of unknowns (that is the flow in all the pipes of the system). The number of independent equations needed for the solution (N) is equal to the number of nodes (junctions) ($N_J$), plus the number of loops ($N_L$) plus the number of fixed-grade nodes $N_F$ minus 1. That is:

$$N=N_J+N_L+N_F-1 \quad (1)$$

Continuity equations for each node and equation of energy head around any closed loop are written together with any pseudo-loop equations connecting fixed-grade nodes and then are solved using one of the following methods: Hardy Cross Method, Linear Method, the Newton-Rapshon and the Gradient method. The methods are described in textbooks and specialised publications (Larock et al 2000; Wurbs and James 2002; Tsakiris and Salahoris 1993; Tsakiris 2009). Also important points for the analysis of WDS may be found in numerous papers on the subject (e.g. Barker 1993; Williams et al. 1993). From these methods the Linear Method has the advantage to be relatively simpler computationally without requiring a fair initial estimate of flow in each pipe as the other two methods. However the Newton-Rapshon method seems to be more accurate in general, although it requires initial guess of the flow in each pipe. Recently, an improvement modification was proposed for Newton-Rapshon method (Spiliotis and Tsakiris 2011a; b).

## 6. PROFESSIONAL SOFTWARE PACKAGES

Water distribution systems analyses are customarily performed in professional practice using software packages based mostly on steady-flow conditions. The most widely used packages are KYPIPE, WaterCAD, WADISO and EPANET.

KYPIPE exists in various versions and was originally developed at University of Kentucky. WaterCAD is a modeling system supported and distributed by Haestad Methods. WADISO (Water Distribution Simulation and Optimisation) was developed by the USACE Waterways Experiment Station. Finally, EPANET was developed and distributed by the Environmental Protection Agency.

The first two are proprietary products sold by the corresponding entities, whereas the second two are public domain models.

Apart from the above models a number of other packages can be found in the literature. Some of these packages are AQUIS, PIPE-FLO, SynerGEE Water, WATER NETWORKS, WATER PAC and others.

## 7. DEVELOPMENTS IN STEEL PIPE PRODUCTION

Steel pipes have been used extensively in the past for the water mains and parts of the pipe network which operates under high pressures. In some cases “steel pipes” was the only solution for a variety of conditions. However, the major problem of the past was that the unprotected pipes suffered from corrosion. As mentioned earlier, the steel pipes are now produced with internal and external coatings for securing longer duration of their life horizon. The external coating by polyethylene is also used to avoid cathodic protection.

Coating combinations are currently used such as (external – internal):

- polyethylene – cement
- epoxy – epoxy
- asphalt - asphalt

From these combinations the first two are appropriate for the supply of water for human consumption.

It should be stressed here that the pipe roughness factor and the internal diameter of the pipes are directly affected by these internal coatings. A guide for the internal coating by cement is presented in Table 3 which shows the range of coating depth for several pipe diameters as dictated by the corresponding standards.

As an example for a steel pipe with external diameter 508mm and thickness of steel plate 6mm, the choice of using internal coating by cement means that at least 5mm more thickness should be counted for. In this case the internal diameter is 508 – 2 (6+5) = 486mm. Also, the pipe roughness factor, according to Table 2, is estimated 0.50mm.

For the same pipe with internal epoxy coating, the internal diameter is 508 – 2 (6+1) = 494mm and the pipe roughness factor is only 0.15mm (Table 2).

*Table 3. Recommended internal cement coating depth for steel pipes*

| Pipe diameter D (mm) | Min depth of internal coating (mm) | Max depth of internal coating (mm) |
|---|---|---|
| ≤ 150 | 3 | 8 |
| 150 < D ≤ 300 | 4 | 9 |
| 300 < D ≤ 600 | 5 | 10 |
| 600 < D ≤ 900 | 6 | 13 |
| 900 < D ≤ 1200 | 8 | 15 |

## 8. COST COMPARISON FOR VARIOUS TYPES OF PIPES

For most of water distribution networks of municipalities the first choice for small diameters and relatively low heads are polyethylene (PE) and PVC-u pipes. Both types of pipes are superior in these conditions than the other types of pipes. The cost of using these pipes is relatively low with the PE pipes to be more expensive than PVC-u pipes.

It should be mentioned that for the construction of public works the prices of pipes are not those of the market. On the contrary, logistic prices are established by the ministry responsible for the public construction works, which follow, to a large extent, the market prices. However, in many cases the logistic prices are quite different from the market prices as can be seen in the example of steel pipes of figure 1. This discrepancy makes the optimisation of the system design of very limited usefulness. The reason for this consideration is that the designer can optimise the system by finding the most economical sequence of pipe diameters based on the Ministry's logistic prices and finally other prices will be used at the phase of constuction..In other words it is really confusing to optimize the system reaching the choice of the least logistic cost since at the construction phase the constructor has to pay for the market cost of the pipes.

In Figure 1 it is important to note that the deviation between logistic and market prices is increasing as the diameters are increasing. This is probably due to the persistence of the Greek Ministry for Public Works to calculate the logistic prices of steel pipes based on the price of steel per kg and not on the length (m) as is the ritual for all other types of pipes.

Now some examples for comparison of different types of pipes are presented for illustration purposes. Table 4 presents the cost (euros/m) for the nominal diameters D110 and D280 for the pipes of two plastic types PE and PVC. The prices presented in this table are the logistic prices proposed by the Greek ministry for Public works to the designers (prices Feb 2012), for medium size projects (projects with total cost between 1.5 and 5 million euros).

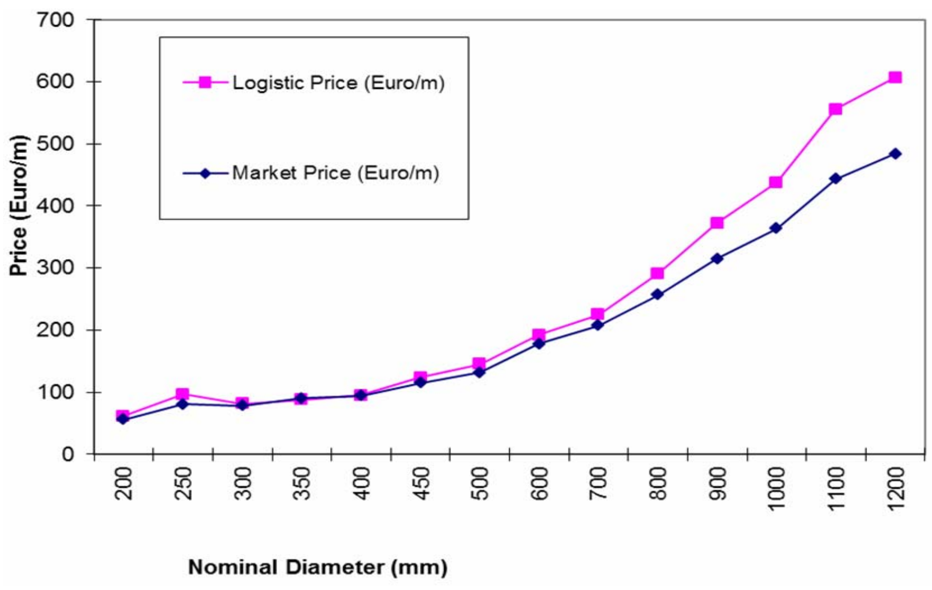


*Figure 1. Logistic prices of Steel pipes (February 1012) compared with the market prices of the same period.*

In general, from the extract Table 4 and the complete list of logistic prices it can be observed that the cost difference between PE and PVC-u pipes is decreasing with the diameter and the pressure class of the pipes. It can be also observed that the cost of PE pipes is much greater than that of PVC pipes. In some cases the increase of cost can reach percentages of 80% of the cost of PVC pipes.

For bigger diameters and relatively high pressures plastic pipes are not suitable regardless of their low purchase cost. On the contrary steel, ductile iron and GRP pipes are the most suitable. As explained in Table 1 these types of pipes have different characteristics and the choice may be dependent upon a number of factors, which will be weighted by the designer. Regarding the cost comparison between steel, ductile iron and GRP pipes, the GRP pipes seem to have in general, the lowest cost, whereas the ductile iron pipes are in general the most expensive.

*Table 4. Logistic prices for PVC-u and PE pipes for medium size projects for 2012. (extract from a complete table)*

| Nominal Diameter (mm) | Type of Pipe | Logistic Prices (Euros /m) | |
|---|---|---|---|
| | | 10Atm | 16Atm |
| 110 | PE | 9.80 | 13.70 |
| 110 | PVC-u | 5.50 | 9.60 |
| 280 | PE | 47.30 | 73.50 |
| 280 | PVC-u | 28.40 | 60.90 |

One of the main criteria which may lead to a smaller cost of the pipeline is the variety of diameters and pressure classes of the pipes available in each type of pipes. In this domain the steel pipes are well ahead against the other two types. This is so because steel pipes are manufactured in a wide range of diameters coupled with a large number of steel plate thickness. On the contrary the ductile iron pipes are produced in a limited range of diameters and pressure classes.

Last but not least when comparing the cost of different types of pipes is the origin of pipes. That is whether a certain type of pipe is produced in the country of the project. By using locally produced pipes the benefits of the economy of the country are multiple. For instance the ductile iron and the GRP pipes are not produced in Greece and should be imported, a fact that limits the direct availability of spare parts and the prompt repair of damages in the pipelines. This rather indirect item should be also taken into account when the cost of the pipeline is estimated.

The same applies to other countries (apart from Greece) which do not produce ductile iron and GRP pipes.

## 9. CONCLUSIONS

The paper presented some updated information useful for the selection of pipes in the water conveyance and distribution systems. Useful data for all types of pipes were presented to the professional engineers for designing new networks and rehabilitating existing ones.

It was shown that the detailed information on all technological developments on the pipe manufacturing is critical for designing robust water conveyance and distribution systems keeping the cost at low levels.

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