

FACTORS AFFECTING LIFETIME COSTS OF WATER SUPPLY PIPELINES

Mike Shand

Aurecon SA, P.O. Box 494, Cape Town 8000; Tel.+2721 5265790;

E-mail HYPERLINK "mailto:mike.shand@aurecongroup.co.za" mike.shand@aurecongroup.co.za

ABSTRACT

The assurance of supply of water to municipalities for domestic and industrial use depends on the reliability of the water supply infrastructure usually comprising dams, bulk supply pipelines, water treatment plants, reservoirs and reticulation pipelines.

This paper examines the following factors that may affect the desirable 50 year design service delivery lifetime of municipal pipelines:

- Operating conditions and route selection
- Pipe materials (uPVC, HDPE, Ductile Iron, GRP and Steel) and design
- Pipe supply and installation
- Pipeline maintenance

1. INTRODUCTION

The assurance of supply of water to municipalities for domestic and industrial use depends on the reliability of the water supply infrastructure usually comprising dams, bulk supply pipelines, water treatment plants, reservoirs and reticulation pipelines. Typically dams have a design service delivery life of 100 years or more and are subject to regular inspections and maintenance in accordance with Dam Safety requirements, whereas the design service delivery life of a pipeline is usually about 50 years depending on the pipe materials, the degree of care taken in laying the pipes, the operating conditions and the maintenance provided.

This paper examines the following factors that affect the service delivery lifetime of a pipeline:

- Operating conditions and route selection
- Pipe materials and design
- Pipe supply and installation
- Pipeline maintenance

2. OPERATING CONDITIONS AND ROUTE SELECTION

2.1 Introduction

The purpose of the pipeline and its operating conditions, the capacity and the route are some of the aspects that may influence the choice of pipeline material.

2.2 Pipeline Operating Conditions

Municipal water pipelines are utilised for the following:

- To supply raw water from a dam or river to a water treatment works, either by gravity or by pumping.
- To supply treated water to clear water distribution reservoirs by gravity or by pumping.
- To distribute clear water from the reservoirs to urban and industrial consumers via the reticulation system, usually comprising pipelines laid in urban streets and in most cases by gravity.

2.3 Pipeline Route Selection

Pipeline routes frequently follow roads and are often located in the vicinity of power lines and electric railways, which can have a significant impact on the lifetime of steel and ductile iron pipelines unless adequate provision is made for corrosion protection measures including the installation and maintenance of cathodic protection systems. Steel and ductile iron pipelines constructed parallel to power lines may require ground mats to be installed during construction to prevent the development of dangerously high voltages and currents.

Raw and clear water pipelines are often laid in servitudes which could be constrained by unplanned development particularly in the vicinity of urban areas. As encroachment into pipeline servitudes seems to be an increasing problem in South Africa, this should be taken into account when installing a new pipeline. Therefore if it is planned that a pipeline should be duplicated in the future, then serious consideration should be given to initially installing two pipelines over the affected portion of the route.

In open country, construction servitude widths for pipelines with diameters larger than about 1.4 m are typically 40 m and the corresponding permanent servitudes typically 25 m. Servitudes widths are usually constrained in urban areas by existing development.

Other important factors to consider are the consequences of a failure such as the loss of water, the strategic importance of the supply, options for maintaining the supply to the majority of users in an urban area via other pipes of the reticulation, potential damage to properties and other infrastructure and the disruption of traffic as is evident in Figure 1. Integration of pipeline replacement with the reconstruction of roads is also a very important consideration, particularly in confined areas such as the City Centre and the Muizenberg to Fish Hoek Main Road where the main pipeline is currently being relayed, although the existing pipeline is still in relatively good condition with a history of only a few bursts (M Shand 2012).



Figure 1: Pipeline Failure in City of Cape Town (Robertson F 2012)

2.4 Selection of Pipeline Capacity and Diameter

The pipeline diameter may be determined by the following:

- The ultimate demand to be conveyed, the available head and whether pumping or booster pumping is required.
- Economic analyses to determine the optimum diameter or whether phased construction of two pipelines rather than the construction of a single pipeline may be preferable, which in turn may depend on:
 - Whether the route would allow the provision of two pipelines
 - The rate of increase in the demands
 - The capital costs of pumps and of the pipeline, and
 - The costs of electricity for pumping.

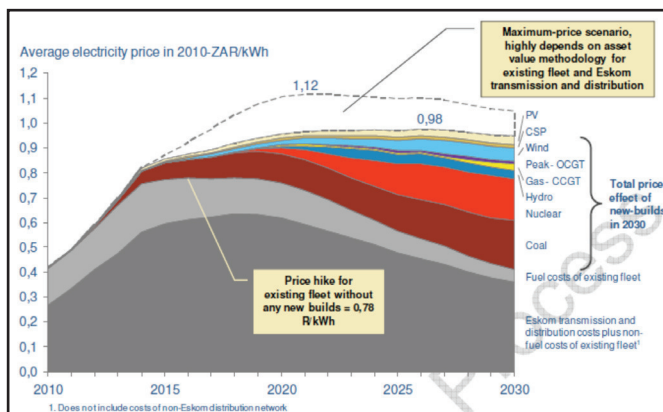
2.5 Cost of Electricity

The cost of pumping depends on the static head, the water demands to be pumped, the friction losses which depend on the diameter and the friction factors discussed in Section 2.6.1, and the possible future cost of electricity.

On 25 March 2011 the South African Department of Energy published its Final Report (Revision 2) of its Integrated Resource Plan (IRP) for Electricity 2010-2030. This report followed two rounds of public participation and was promulgated in the Government Gazette of 6 May 2011. The IRP includes for 10 GW of committed coal power stations (mainly Kusile and Medupi), 9.6 GW of nuclear, 6.3 GW of coal, 17.8 GW of renewables and

8.9 GW of other generation sources. The breakdown of the anticipated average future electricity price path based on 2010 prices and a discount rate of 8% per annum is shown in Figure 2, which indicates that the future price of electricity from about 2010 onwards will need to increase to be about R0.98/kWh based on 2010 prices in order to cover the capital and operating costs of the existing and future generation facilities.

Figure 2: Price Path for Department of Energy's Policy Adjusted Integrated Resource Plan 2010



After the Draft Integrated Resource Plan was published in 2010, NERSA granted Eskom average tariff increases of 24.8% for 2010-2011, 25.8% for 2011-2012 and 16% for 2012-2013. In November 2012 Eskom requested NERSA to approve further tariff increases of 16% per annum for the next 5 years up to 2017, however NERSA only granted increases of 8% per annum. A very approximate estimate of the possible future price of electricity based on 2013 prices has been determined to be about R1.10/kWh as follows:

- The average price of electricity in 2013 was assumed to be R0.70/kWh based on the current price of electricity for large power users in a large metropolitan area.
- Thereafter the price of electricity was assumed to increase for five years at 10% per annum (16% per annum less inflation of 6% per annum).

An alternative approach to determining the future cost of electricity in 2020 based on 2013 prices and on the scenario shown in Figure 1 might be to inflate the long term future cost scenario of about R0.98/kWh by the

inflation rate of say 6% per annum from 2010 to 2013 which would provide a corresponding long term electricity cost of R1.17/kWh.

3. PIPE MATERIALS AND DESIGN

3.1 Selection of Pipe Materials

The main types of pipes that are available in South Africa and their physical characteristics which influence the design and the selection of pipe material are summarised in Table 1 below. It should be noted that the roughness factors shown in Table 1 are not applicable in cases where the growth of biofilm reduces the pipeline diameter and increases the roughness. Professor Fanie van Vuuren is currently undertaking research on this phenomenon for the Water Research Commission.

3.2 Effective Pipe Diameter and Pipeline Roughness

The internal roughness of the pipeline is very important for the following reasons:

- The roughness is a key determinant of the design diameter of a gravity main.
- For rising mains roughness affects the selection of diameter and the pumping costs which together should be optimised to provide the lowest economic or financial cost for the lifetime of the pipeline.

The lining of steel pipes with cement mortar reduces the effective diameter of a steel pipe and increases the roughness. Ductile Pipes are usually also lined with cement mortar and have slightly higher roughnesses as indicated in Table 1.

3.3 Design Stress and Pipeline Lifetime

3.3.1 uPVC, HDPE and GRP Pipes

The strength of uPVC, HDPE and GRP under constant stress declines with time, and in order to ensure that the lifetimes of such pipes are considerably more than 50 years, the factors of safety for the maximum constant operating stresses are specified as indicated in Table 1. It should be noted that external loads must also be taken into account when determining operation stresses.

The water hammer pressures in uPVC, HDPE and GRP pipes are lower than in steel and ductile iron pipes on account of the lower wave speed. On the other hand lower factors of safety are permitted for the short term stresses that arise from water hammer pressures:

- uPVC Factor of Safety: 1.6 – 1.25

- GRP Factor of Safety: 1.4

The factors of safety and corresponding design stresses for uPVC and HDPE pipes are specified for water at 200°C and design pressures must be down rated for higher temperatures.

3.3.2 Steel and Ductile Iron

The strength of steel and ductile iron under constant stress does not decline with time, however if corrosion occurs this will reduce the thickness of the pipe wall and lead to a decline in the pressure rating of the pipeline (however this is not usually a problem as corrosion is usually localised where damage to the coating has occurred). Factors of safety for the yield stresses of these pipes are 2.0 for normal operating pressures and external loads and 1.5 for dynamic loads.

Table: Types of Pipe Materials and Typical Characteristics

Type	Typical Diameters mm	Typical Operating Pressures m	Typical Average Roughness: Colebrook White k mm	Typical Water Hammer Wave Velocity m/s	Typical Safety Factors for Constant 50 Year Design Stress
mPVC	50-500	60-250	0.03	350	
oPVC	110-250	90-160	0.03	300	
uPVC	50-400	40-160	0.03	500	2
HDPE	50-1000	60-200	0.03	500	1.3
GRP (Flowtite)	300-1800	1-320	0.03	350-600	1.8
GRP (Vectus)	300-2200	4-320	0.03		1.8
Ductile Iron (Cement Mortar Lined)	40-2000	100-400	0.10	1200	2
Steel (Cement Mortar Lined)	400-2200	Up to 600	0.15	1100	2
Steel (Epoxy Lined)	400-2200	Up to 600	0.03	1100	2

It can be concluded that provided pipelines are designed to operate within their design stress limitations then the lifetime of pipes manufactured from currently available materials will be at least 50 years and probably considerably longer.

3.4 Above Ground Pipelines

Most pipelines in South Africa are laid underground as pipelines laid above ground are vulnerable to potential damage and deterioration. Therefore if possible it is preferable to bury pipelines for the following reasons:

- All pipelines could be damaged to a lesser or greater extent by fire and are vulnerable to damage by vandalism. Therefore it is preferably that pipelines should be buried unless the additional cost of burying the pipe would be very high such as at river crossings.
- uPVC pipes are very vulnerable to damage by Ultra Violet light and must be buried.
- HDPE pipes should also be buried on account of their high coefficient of thermal expansion.
- GRP pipes are protected against Ultra Violet light but could easily be damaged by vandalism. On the other hand the typical Rika flexible couplings eliminate the need for special expansion joints for above ground installations.
- Ductile Iron pipe coatings are not subject to Ultra Violet light deterioration and the couplings can accommodate expansion and contraction. These pipes are manufactured in 6 m lengths and may require more plinths than for a steel pipe.
- Steel Pipes laid above ground should either be provided with Viking Johnson type couplings or be welded and provided with bellows and bearings to accommodate considerable movement that can arise in long exposed lengths of pipe.

3.5 Buried Pipelines

Buried pipelines are preferred to above ground pipelines for the reasons described above. However buried pipelines also have particular design challenges as follows:

Structural Design

The structural design of pipelines for both the internal pressure loads and soil loads is very important to ensure the long term lifetime of pipelines and particularly the lifetimes of thin uPVC, HDPE, GRP and Steel pipelines. The external loading of ductile pipelines is usually less critical as the ratios of wall thickness to diameter are usually much lower than for steel pipes.

Corrosion

uPVC, HDPE and GRP pipes are not subject to corrosion however these pipes utilise steel fittings at valve and air valve chambers which require excellent corrosion protection so as not to compromise the lifetime of the pipeline.

Ductile Iron pipes are normally protected externally with a metallic zinc coating covered by a finished layer of a bituminous product or synthetic resin compatible with the zinc. An additional external polyethylene coating can be provided where soils are aggressive and where soils are very aggressive or the pipeline follows a power line of more than 22 kV. Internal protection is usually provided by a cement mortar lining. The manufacturers do not recommend the use of cathodic protection however this is favoured by the Department of Water Affairs and by others particularly in the vicinity of power lines and electrified railways.

Steel pipelines can corrode rapidly where there are small defects in the coating unless cathodic protection is provided. The size of any defect in the coating must be limited as otherwise the cathodic protection measures cannot counteract the current drain. Particular measures are required in the vicinity of power lines and electrified railways.

Pipeline Fittings for most pipelines are manufactured from steel which corrodes rapidly unless adequate internal and external protection is provided usually comprising epoxy coatings of adequate thickness.

4. PIPE SUPPLY AND INSTALLATION

4.1 Introduction

The manufacture of pipes, the provision of corrosion protection measures and the laying of the pipes in accordance with the specifications is essential to ensure that a pipeline provides uninterrupted service for its design lifetime, which should usually be about 50 years as indicated above.

4.2 Inspection of Pipe Manufacture and Pipe Laying

The specifications for the manufacture, transport, storage on site and the laying, backfilling and testing of pipelines should be enforced to ensure the long term integrity and trouble free operation of a pipeline. The appointment of independent inspectorates with specialist expertise is essential for checking compliance with the particular aspects of the manufacture and laying specifications. Some of the supply and installation aspects of the different pipeline materials that require particular attention to ensure that a pipeline performs satisfactorily for its planned lifetime are discussed below.

4.2.1 Steel Fittings

The manufacture of steel fittings, as well as the preparation for and application of the coatings and linings, their thickness and integrity should be inspected and subjected to the specified checking procedures required to confirm compliance with the specifications.

4.2.2 uPVC Pipes

Manufacture

SANS 966 recommends a number of tests that should be performed on each lot of uPVC pipes manufactured. The two most important tests are probably the hydrostatic tests of the pipes and the joints and the resistance to vacuum of the pipes and joints. It is recommended that at least some of these tests are witnessed by an independent inspectorate and that all the test records are reviewed by the inspectorate.

Installation

The storage of uPVC pipes should be such that while in storage the pipes are well protected from damage and foreign matter entering the pipes and the rubber rings for joints should be stored in a cool place and not be subject to deformation. Inspection on site should ensure that the bedding, laying, hydrostatic testing comply with the specifications.

4.2.3 HDPE Pipes

Manufacture

The hydrostatic factory tests specified in SANS 4427 should be witnessed by an independent inspectorate and all test records should be reviewed.

Installation

Inspection on site should ensure that the storage, handling, all aspects of the welding of butt joints on site, and the hydrostatic pressure test are complied with in accordance with the specification.

4.2.3 Ductile Iron Pipes

Manufacture

BS EN 545 recommends various tests for the manufacture of ductile iron pipes. An independent inspectorate should witness checks on quality, packing and marking, pipe dimensions, zinc coating and cement mortar lining qualities and thicknesses, hydrostatic testing of pipes, and mechanical property tests.

Installation

The inspection should include inspection of the jointing, the alignment and the angles of deflection and of the bedding, selected backfill and cover to the pipe.

4.2.4 GRP Pipes (Flowtite)

Manufacture

An independent inspectorate should be appointed to undertake the following inspections in the GRP pipe factory:

- Inspect the materials for the manufacture of the pipes and review the test results for conformity with the design requirements, prior to the manufacture of the pipe. The inspectorate should also witness the manufacture and review the records.
- Witness the testing of samples of the pipes and review the results for compliance with the barcol hardness, pipe stiffness, deflection without failure, axial and circumferential tensile load capacity and overall laminate composition.

It is also very important that all dimensions are checked, particularly the pipe ends and those of the couplings, and that the pressure tests of all pipes to twice the pipe design pressure are witnessed.

Installation

At the time of delivery to site the pipes should be carefully inspected for damage, particularly to the pipe ends, as well as to the couplings together with the gaskets and centre registers. The dimensions should be rechecked and appropriate provision should be made for the storage of the pipes along the pipeline route including sealing of the pipe ends.

Immediately prior to installation the pipes should again be checked for damage and particularly the pipe ends. The alignment of the pipe should be in accordance with the drawings and with the allowable angular deviations. The correct positioning of each coupling on the pipes is particularly important as indicated in Figure 3.

The bedding and its compaction, including compaction beneath the pipe is particularly important. Backfilling should be completed as early as possible to prevent flotation of the pipe. The first 1 000 m of pipe laid should be pressure tested to confirm that the laying procedures are satisfactory. Longer sections can be tested thereafter.

4.2.5 Steel Pipes

Manufacture

An independent inspectorate should be appointed to undertake the following inspections in the pipe factory:

Check the records of the steel plate manufacturer and witness physical property tests on samples.

Check the qualifications of coded welders.

Visually inspect all pipe welds and witness the ultrasonic inspection of 100% of welds.

Alternatively witness the radiographic inspection of 100% of the first 10% of welds passing without defects if the first 10% did not pass then extend the radiographic inspection to 20% with 100% passing with further extensions until 100% of welds pass. 100% of the welds of specials should be radio graphically inspected.

The diameters of the ends and other sections of each pipe should be measured as well as the pipe straightness. An independent inspectorate should also inspect the surface preparation for the coating and lining systems, the application of the coatings and linings and the layer thicknesses. Holiday detection of defects to the coatings and linings should be undertaken and all defects repaired.

Installation

At the time of delivery to site the coatings and linings of all pipes should be checked for damage, particularly the pipe ends and also the storage



Figure 3: Positioning of GRP Pipe Coupling

of the pipes on site including sealing of the pipe ends. The alignment of pipes laid should be checked and 100% of all welds should be radio graphically inspected as well any repairs.

The independent inspectorate should particularly inspect the integrity of the coatings and linings provided on site at the welds between pipes,



Figure 4: Flotation of Steel Pipe

including surface preparation, the product application, and the layer thicknesses and should check the integrity using holiday detection. Defects that have been repaired should be carefully rechecked.

The bedding and its compaction, including compaction beneath the pipe is particularly important for steel pipes with thin walls and particularly large steel pipes. Backfilling should be completed as early as possible to prevent flotation of the pipe as shown in Figure 4 and also the considerable expansion and contraction that can occur where the daily variation in temperature is considerable and the maximum temperature of empty steel pipes is significantly higher than the air temperature.

The hydrostatic pressures for the testing of various sections of pipe are often specified.

5. PIPELINE MAINTENANCE

Maintenance of isolation, scour and air valves is very important for the satisfactory operation of a pipeline. All valves should be fully opened and closed at least once per annum.

The cathodic protection system for steel pipelines and if provided for ductile iron pipes should be monitored, probably at least monthly to ensure that this is functioning correctly and that current drains are not excessive. The ground mats and cathodic protection ground mats must also be checked and replaced from time to time.

6. CONCLUSIONS

All types of materials commonly used for water pipelines could provide a service delivery design life of 50 years provided that the pipelines are correctly designed, the materials and construction of the pipeline are in accordance with the specifications and the pipelines are maintained.

GRP and steel pipelines probably require the most careful installation and steel pipelines also require frequent ongoing monitoring to ensure that the cathodic protection system is providing the necessary protection of the pipeline.

REFERENCES

South African Department of Energy: Final Report (Revision 2)
Integrated Resource Plan (IRP) for Electricity 2010-2030 25 March 2011.

Robertson F: Photograph of Pipeline Failure in City of Cape Town.

SANS 966-1: Components of Pressure Pipe Systems: Part 1:
Unplasticized Poly(vinyl chloride) (PVC-U) Pressure Pipe Systems 2013.

SANS-1: Plastics piping systems - Polyethylene (PE) Pipes and Fittings for
Water Supply Part 1 2008

Shand MJ, 2012. Chapter 10: Ageing Infrastructure: The Sustainable
Water Resources Handbook, Volume 3, The Essential Guide, South Africa
(www.alive2green.com/water).