

EXECUTIVE SUMMARY

1 Background and motivation

The geographical mismatch of the water demand centres and the water resources necessitate the transport of water over long distances and high elevation differences. On average water is transported about 350 km in South Africa (Basson, Van Niekerk & Van Rooyen, 1997). High energy costs and the increasing demand require that the water transfer infrastructure should function optimally. Since the 1930's various researchers contributed to the identification and development of factors and relationships to quantify the energy loss in pipelines, which led by 1958 to the development of pressures, head losses and discharge relationships (Chadwick and Morfett, 1999) for the design and evaluation of pipes and pipe systems.

There are various factors that influence the hydraulic capacity and pipeline designers need to take all of these into consideration during the design. For instance the estimation of roughness parameter for a pipeline has a significant effect on the hydraulic capacity and operational costs. An underestimation of this parameter can be catastrophic when the required demand cannot be met. The better quantification and identification of these factors required investigation, reviewing the available literature, conducting experimental investigations, perform field investigations and develop software that will assist designers in evaluating a pipeline system over its full life cycle.

2 Aims of this study

The aims of the study were:

- The quantification of the factors influencing the friction loss in pipelines.
- Establish the relationship between water quality, operating conditions and the hydraulic performance of different liner systems and pipe materials.
- Development of selection criteria for liner systems and pipe material.
- Quantify the economic influence of increasing friction losses in a pipe system.
- Development of a computer model to evaluate whether to replace, refurbish or extend existing infrastructure components.
- Establish the effectiveness of different pipe rehabilitation options on the friction loss characteristics and liner integrity.

3 Research Findings

An extensive literature review has been conducted from which valuable information have been gathered and used in the design and set-up of experimental and field investigations.

The literature contains details and focussed on the following topics:

- Determining the friction loss in pipelines.
- Hydraulic performance of liner systems and pipe materials.
- The characterization, growth and influence of the bio-film on pipe friction.
- The influence of couplings on the friction loss in pipe systems.
- The influence of friction loss on operating capacity and cost of pipe systems.

The two main contributing factors of energy losses are:

- Inherent resistance against flow exerted by the fluid (i.e. viscosity) and
- The friction losses resulting from the interface between the fluid and the conduit boundary (i.e. shear), as well as secondary losses resulting from abrupt local changes in the system.

The friction losses can be further sub-divided into sub-factors that will ultimately influence the total energy loss, such as:

- Roughness parameter
- Friction formulae selection
- Pipe material selection
- Additional losses due to couplings
- Age of pipeline
- The presence of biofilm and the composition of the biofilm
- Effect of water quality on liner deterioration

During this study it was attempted to quantify some of these sub-factors by means of field and experimental work.

Roughness parameters and ageing effect

During the field work, pressure readings and flow rates were measured on a number of the pipelines of Rand Water, Umgeni Water, Magalies Water and Bloem Water. From these field tests the friction factors were back calculated.

All these tests indicated that the actual roughness parameter is significantly higher than the roughness parameter usually used in the design. A typical pipeline profile with measured hydraulic gradelines and theoretical hydraulic gradelines are shown in **Figure i**.

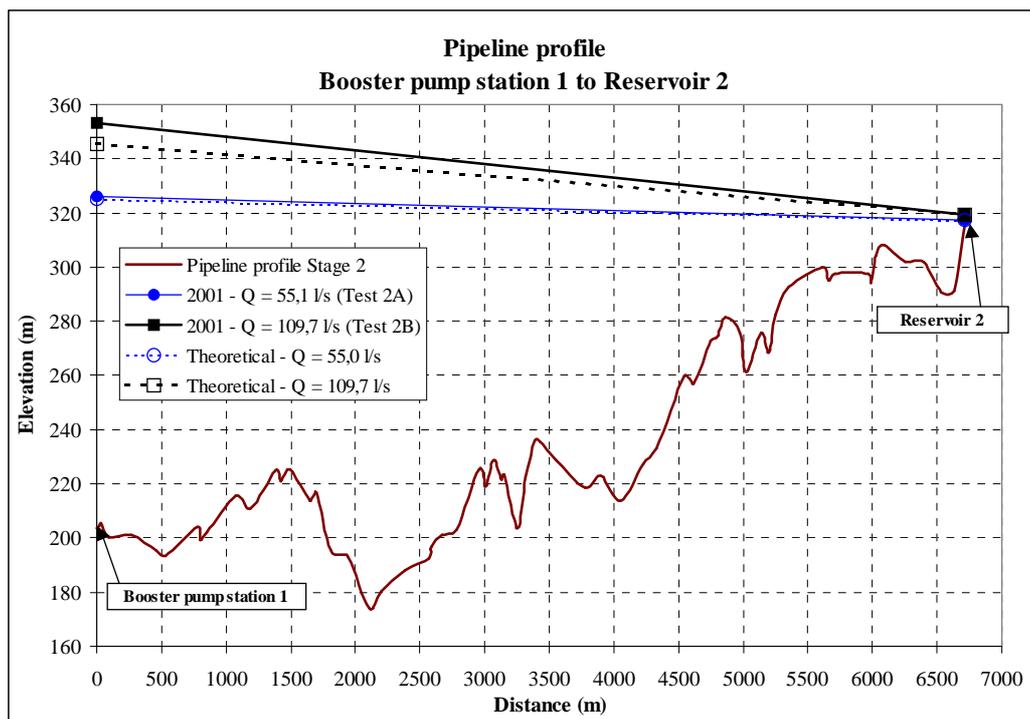


Figure i: Typical pipeline profile (Ndwedwe pipeline, Umgeni Water)

The calculated roughness parameters are summarised in **Table i** below:

Table i: Summary of field test results

Water board	Pipeline	Test date	Velocity	Colebrook-White (k_s) (mm)
Bloem Water	Welbedacht pipeline (1168 mm pre-stressed concrete)	1981	Unknown	0,094
		2003	0,306	Too low velocity
		2003	0,308	1,865
		2003	1,141	1,037
	Lieuwkoop pipeline (700 mm steel and GRP)	2003	1,349	0,073
		2003	1,384	0,057
	Lesaka pipeline (648 mm steel)	1985	0,901	0,0141
		2003	1,132	0,0437
2003		1,213	0,0684	
Umgeni water	Ndwedwe Pipeline System Stage 1 (500 mm steel)	2001	0,317	Too low velocity
		2001	0,631	0,310
	Ndwedwe Pipeline System Stage 1 (350 mm steel)	2001	0,648	0,214
		2001	1,290	0,250
	Ndwedwe Pipeline System Stage 1 (350 mm steel)	2001	0,532	0,460
		2001	0,860	0,290
Ndwedwe Pipeline System Stage 1 (320 mm steel)	2001	0,622	0,443	
	2001	1,020	0,308	
Rand Water	C3 pipeline (760 to 900 mm steel with CML)	2004	1,47*	2,48 [#]
		2004	2,09*	5,18 [#]
	C16 pipeline (840 mm steel with bitumen)	2004	1,23*	7,43 [#]
		2004	1,81*	13,90 [#]
	C13 pipeline (840 to 1220 mm steel with bitumen)	2004	1,09*	6,29 [#]
2004		1,46*	10,55 [#]	
Magalies Water	Wallmannsthal - Bulk supply reservoir (500 mm steel)	2001	0,272	0,690
		2001	0,700	0,117
		2001	1,003	0,110
	Wallmannsthal to Baviaanspoort reservoir (400 mm steel)	2001	0,573	1,111
		2001	0,562	0,764
	Baviaanspoort reservoir to Kameelfontein (250 mm FC)	2001	0,390	1,327

Note: * Average velocity

Roughness parameter according to Barr's equation

Calculated roughness parameters as well as the annual rate of increase in roughness parameter were all significantly higher than that prescribed in theoretical references.

There are numerous difficulties in obtaining accurate reliable roughness parameters for existing pipelines. Insufficient details, uncertainty about the condition of the internal protection (liner type and status), accurate flow measurements (without leaks and cross connections), inaccurate coordinates of the position where the pressure measuring points have been set-up and lack of historical measured data are all factors that complicates the calculation of the roughness parameter.

Presence of biofilm and the composition of the biofilm

During the field work the cement mortar lined B12 Rand Water pipeline was inspected and biofilm was found to be present in the line and that the level of the SRB was extremely high. This was an important finding because the intuitive expectation was that the cement mortar lining, should have created an alkaline environment, which would not be conducive for SRB.

Since the field work indicated the unexpected in terms of biofilm growth an experimental set-up was constructed where the following aspects could be investigated:

- Composition of biofilm also reflecting the procedures that are used to determine the biofilm status (growth);
- determining the growth characteristics of biofilm on different pipe materials;
- establishing the influence of disinfecting on the re-establishment of the biofilm; and
- quantification of the ability of biofilm to restrain high flow velocities.

Different typical pipe materials were tested and it has been proven that biofilm exists on all piping surfaces in a potable water distribution system and that there is an increase of biofilm with time. These increases are dependant on the type of substrate used and the reigning flow conditions (see **Figure ii**).

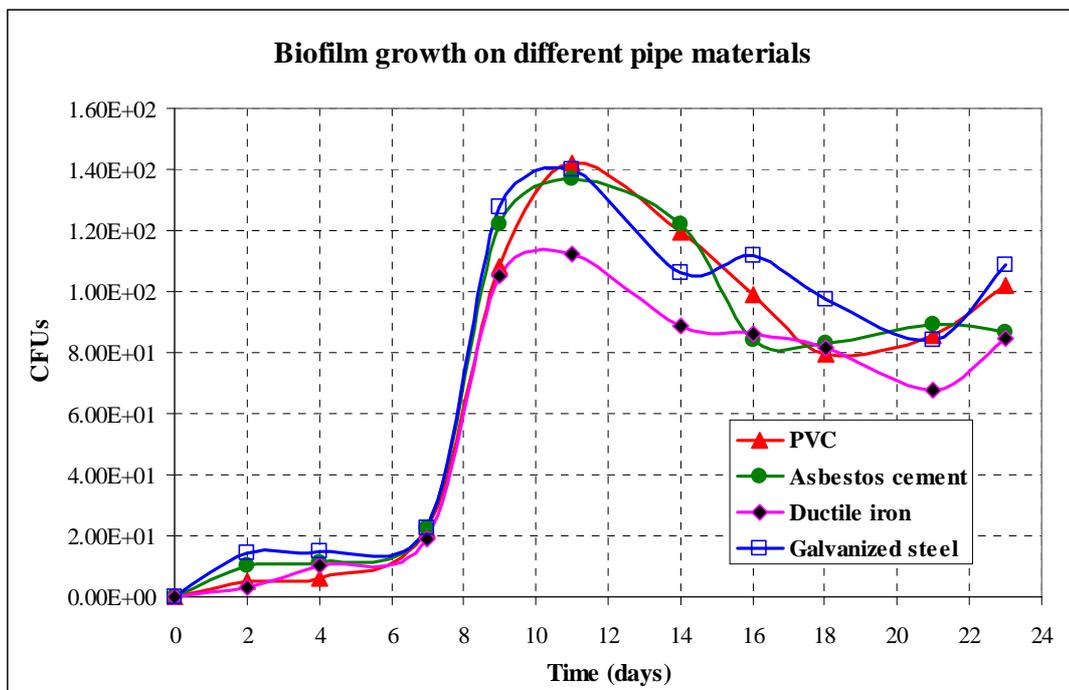


Figure ii: Biofilm growth on different pipe materials

The problem with the determination of the exact effect biofilm has on the effective roughness of a surface is that the growth pattern of biofilm fluctuates with time and the amount of available nutrients and disinfectant residuals. Even when all the parameters were kept constant, the growth rate of the biofilm still kept on fluctuating (Coetzee, 1999).

The need arose to develop equipment to monitor the growth of biofilm in pipelines. Light reflectance was identified as a possible method to determine biofilm growth on different pipe materials. The Rotoscope (Version 2) was developed which is an effective early monitoring system that quantifies in real time the biofilm growth.

The rate of the growth could also be detected with the Rotoscope and correlated with the results from the DAPI stained technique and the plate counts.

It was identified that the biofilm will grow at different rates on the different pipe materials and the type of surface is important for planktonic cell adhesion when biofilm starts to form. What is clear from all the experimental work performed is that biofilm is present on all surfaces and the current measures of trying to remove or destroy it have limited success.

The incapability of chlorine to kill off biofilm completely was demonstrated with the disinfection of the slides with chlorine. Although chlorine did not kill all the biofilm, it had a decreasing effect on the rate of growth and adhesion. The results showed that the effectiveness of disinfection depends not only on the concentration of the disinfectant, but also on the duration of the disinfection process.

With the testing of the effect of increased velocity on the growth of biofilm it was found that each substrate had its own detaching velocity where the adhesion of the biofilm was overcome. The range of detaching velocities fell between 3 m/s and 4 m/s. A flow velocity within this range would thus be ideal for achieving reduced biofilm growth in the distribution system although this is not a velocity, which can easily be achieved, in potable water systems.

Energy losses due to couplings

An experimental test set-up was made to determine the additional losses associated with couplings. Different sets and combinations of coupling dimensional configurations were incorporated in the pipe system in order to produce the necessary variations and to obtain a hydraulic performance, which could be analysed.

In the experimental set-up the step size of the coupling (D_s) and the length of the discontinuity (L_s) at the coupling were varied.

The tests confirmed that the couplings resulted in additional energy loss (see **Figure iii**).

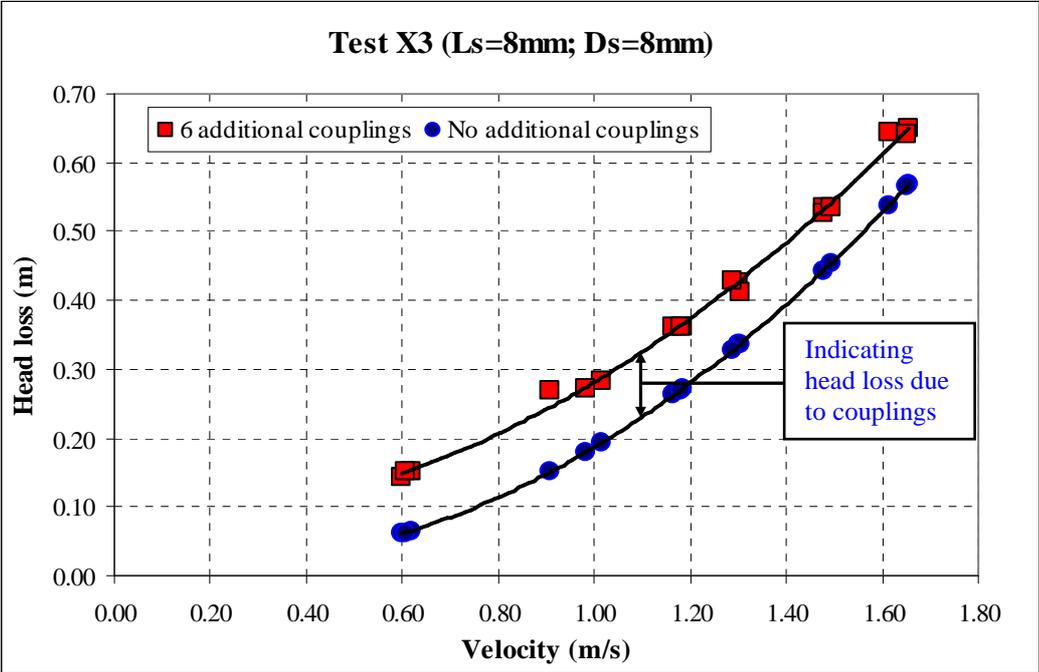


Figure iii: The additional head loss caused by couplings

Based on the definition of the coupling geometry, relationships were developed with which the friction factor (λ) should be increased to include the influence of the couplings.

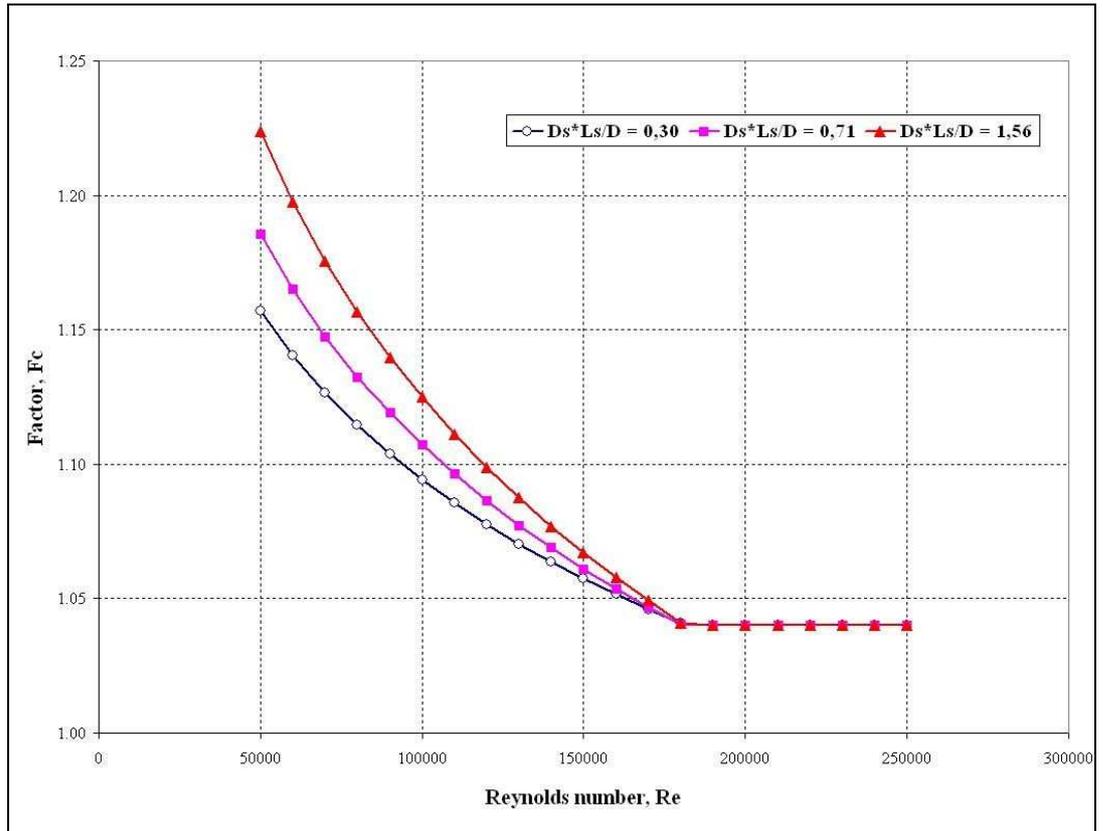


Figure iv: Design curve for the increase of λ in relation to the Reynolds number for a given L_s , D_s and D

The effect of the coupling was also modelled numerically and it is clear from the results that couplings do have an influence on the head loss in a pipe, although the effect is somewhat smaller than the primary frictional losses. The effect is also less in the larger pipes, where the coupling is proportionally smaller from a geometric perspective. In some of the large pipe diameter cases, the pressure drop is reduced by the couplings, which may be attributable to a more turbulent boundary layer, induced by the couplings, creating a local energy loss.

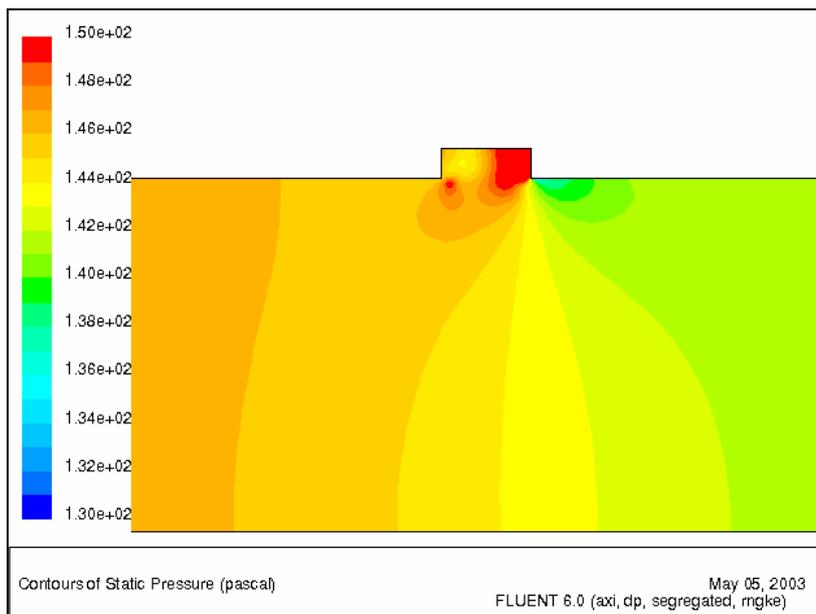


Figure v: Plot of static pressure contours ($D = 120$ mm; $L_s = 15$ mm; $D_s = 5$ mm; $V = 0,5$ m/s)

Life Cycle Costing Analyses of pipeline systems

One of the governing issues during the planning and implementation stages of a pipeline, or a distribution network, is the selection of the most appropriate pipe material for the specific operational and field conditions. During the planning stages it becomes tedious to analyse all the different alternatives and to compare them on a sound and equal basis. To assist the planner/designer in the evaluation process existing software that performs life cycle costing was adapted called *AQUA Hydraulic Utilities*. The program determines the life-cycle cost by calculating the Nett Present Value (NPV) and the Internal Rate of Return (IRR) for the different pipe system alternatives. The software is described in a Water Research Commission report entitled “*Life cycle costing analyses for pipeline design and supporting software*”.

Websites for downloading software and updates:

<http://www.wrc.org> or <http://www.sinotechcc.co.za>

Energy loss

The factors, investigated during this study, that influence energy loss in pipelines have noteworthy effects:

- The field work indicated roughness parameters as well as the annual rate of increase in roughness parameter were all significantly higher than that prescribed in theoretical references.
- Biofilm exists on all piping surfaces in a potable water distribution system and that there is an increase of biofilm with time.
- Biofilm has an effect on the hydraulic capacity of a pipe system but the quantification thereof is difficult due to the fluctuating growth pattern thereof.
- The current measures of trying to remove or destroy biofilm (velocity or disinfectants) have limited success.
- Experimental tests and numerical modelling confirmed that the pipe couplings result in additional energy loss.
- The roughness parameters that are normally quoted by manufacturers tend to be too low.

4 Further research

It is recommended that the following aspects be researched further to build a long term understanding of the hydraulic performance of pipelines:

- Water service providers be urged to maintain an up to date asset register that will contain description of the physical hardware but also the operational variations and hydraulic performance (pipeline asset management).
- Undertaking further measurements of the energy losses and the dimensions of the couplings should verify the relationships that have been developed for the inclusion of the energy losses at couplings.
- The influence and build-up of biofilm on the hydraulic capacity be developed further.
- That an asset database of the hydraulic performance for different pipe materials and water quality be created, which will assist designers in the selection of pipe material.

- Set-up an operational and maintenance guide to assist local authorities to describe their water assets.
- Based on the current understanding of biofilm growth, resistance to disinfections and possible influence on hydraulic capacity, the influence of the biofilm on the roughness parameter and shear should be reviewed further.
- The current work focussed on treated water and needs to be extended to determine the influence of the parameters for pipelines that conveys untreated water.
- A long term research project is required where a number of pipelines are monitored over a longer period (say 15 to 20 years). The pipeline characteristics such as pipe type, diameters, lining, operating flow rate, etc. of specific pipelines (DWAF, ESKOM, Water Boards) should be obtained and the energy loss monitored over a long period. This should be done to establish the effect of pipeline age on the energy loss and to build a database of the hydraulic performance for different systems which will assist designers of pipeline systems.