NON-NEWTONIAN LOSSES THROUGH DIAPHRAGM VALVES

By

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ABSTRACT

The prediction of head losses in a pipe system is very important because head losses affect the performance of fluid machinery such as pumps. In a pipe system, two kinds of losses are observed: major losses and minor losses. In Newtonian and non-Newtonian flow, major losses are those that are due to friction in straight pipes and minor losses are those that are due to pipe fittings such as contractions, expansions, bends and valves. Minor losses must be accurately predicted in a pipe system because they are not negligible and can sometimes outweigh major losses (Edwards *et al.,* 1985). There is presently little data for the prediction of non-Newtonian head losses in pipe fittings in the literature and little consensus amongst researchers (Pienaar *et al., 2004*).

In the case of diaphragm valves, usually, only one loss coefficient value is given in turbulent flow or in laminar flow with no reference to a specific size of the valve, assuming geometrical similarity that would lead to dynamic similarity. However, no one has done a systematic study of various sizes of diaphragm valves from the same manufacturer to establish if this is true. This could be the main reason for discrepancies found in the literature (Hooper, 1981; Perry & Chilton, 1973; Miller, 1978 and Pienaar *et al.*, 2004). This work addresses this issue.

A literature review on the flow of Newtonian and non-Newtonian fluids has been presented. The work of Hooper (1981) on diaphragm valves and the works of Edwards *et al.*, (1985), Banerjee *et al.*, (1994) and Turian *et al.*, (1997) for non-Newtonian fluids in globe and gate valves were found to be relevant to this work. An experimental facility referred to as the Valve test rig was built and commissioned. Diaphragm valves of 40, 50, 65, 80, 100 millimetre nominal bore diameters from the same manufacturer were used. The tests were carried out on these valves in the fully open position. Seven different Newtonian and non-Newtonian materials were tested in each valve. The experimental results are presented in the form of valve loss coefficient (k_v) against the Slatter Reynolds number (Re_3).

Loss coefficients obtained in this investigation confirmed the general qualitative trend given in the literature that in laminar flow the loss coefficient increases significantly with the decreases of Reynolds number and is a hyperbolic function of Reynolds number. In turbulent flow, the loss coefficient is constant, for any type of fluid, Newtonian or non-Newtonian. It also confirms the general theory that in fittings in general and valves in particular, the transition from laminar to turbulent occurs earlier than in straight pipes. This work also shows that the Slatter Reynolds number is a useful tool and compared to other Reynolds numbers (the Newtonian Reynolds number and the Metzner and Reed generalised Reynolds number), can be used for design purposes. From our analysis, it was established that geometric and dynamic similarity was not achieved in the diaphragm valves tested.

DECLARATION

I, Dieudonné Matang'a Kazadi hereby declare that this thesis represent my own unaided work and has not been submitted for a degree at another university. Further more it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Dieudonné Matang'a Kazadi

DEDICATION

I dedicate this work to my parents: Papa Kasongo and Maman Milemba who continuously insisted that I studied and encouraged me during my studies.

To my wife Therese (Théthé) and son Ronald Kazadi for their encouragement, moral support and affection.

To my brothers, sisters and all my future children.

Psalm 23:

"The Lord is my shepherd; I shall not want. He maketh me to lie down in green pastures; he leadeth me beside still waters. He restoreth my soul; he leadeth me in paths of righteousness for his name's sake. Yea, though I walk through the valley of the shadow of death, I will fear no evil: for thou art with thy rod; thy staff, and me they comfort me. Thou preparest a table before me in the presence of mine enemies; thou hast anointed my head with oil; my cup runneth over. Surely, goodness and loving-kindness shall follow me all the days of my life; and I will dwell in the house of the Lord for the length of the days".

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NOMENCLATURE

Symbol	Description	Unit
a	acceleration	m/s^2
A	cross sectional area	m^2
C_v	laminar flow valve loss coefficient	-
D	internal pipe diameter	m
E	sum of mean error squared	-
f	Fanning friction factor	-
g	gravitational acceleration	m/s^2
H	head	m
I	intercept	-
K	fluid consistency index	$Pa.s^n$
K'	apparent fluid consistency index	$Pa.s^n$
k	hydraulic roughness	m
k_{fitt}	fitting loss coefficient	-
k_v	valve loss coefficient	-
L	pipe length	m
Le	equivalent length	m
M	mass	kg
m	slope	-
N	number of data points	-
n	flow behaviour index	-
n'	apparent flow behaviour index	-
p	pressure or static pressure	Pa
Q	volumetric flow rate	m^3/s
R	radius	m
Re	Reynolds number	-
Re_{crit}	Critical Reynolds number at the transition	-
Re_{MR}	Metzner & Reed Reynolds number	-
Re_3	Slatter Reynolds number	-

r	correlation coefficient	-
r	radius from the centre line	-
t	time	s
u	point velocity	m/s
V	average velocity	m/s
z	elevation from datum	m

α	kinetic energy correction factor	–
$\dot{\gamma}$	shear rate	s^{-1}
Δ	difference	–
μ	dynamic viscosity	Pa.s
μ'	apparent or secant viscosity	Pa.s
ρ	fluid or slurry density	kgm^{-3}
t	shear stress	Pa
τ_o	wall shear stress	Pa
τ_y	yield stress	Pa
σ	standard deviation	-

Subscripts

o	at the wall
ann	annulus
calc	calculated
US	upstream
DS	downstrewam
fitt	fitting
v	valve
obs	observed

max	maximum
m	model
p	prototype

CHAPTER 1

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

The prediction of head losses in a pipe system is very important because head losses affect the performance of fluid machinery such as pumps. In a pipe system, two kinds of losses are observed: major losses and minor losses. In Newtonian and non-Newtonian flow, major losses are those that are due to friction in straight pipes and minor losses are those that are due to pipe fittings such as contractions, expansions, bends and valves. Minor losses must be accurately predicted in a pipe system because they are not negligible and can sometimes outweigh major losses (Edwards *et al.,* 1985). There is presently little data for the prediction of non-Newtonian head losses in pipe fittings in the literature and little consensus among researchers (Pienaar *et al.,* 2004).

In the case of diaphragm valves, usually, only one loss coefficient value is given in turbulent flow or in laminar flow with no reference to a specific size of the valve, assuming geometrical similarity that would lead to dynamic similarity. However, no one has done a systematic study of various sizes of diaphragm valves from the same manufacturer to establish if this is true. This could be the main reason for discrepancies found in the literature (Hooper, 1981; Perry & Chilton, 1973; Miller, 1978 and Pienaar *et al.*, 2004). This work addresses this issue.

This investigation gives loss coefficients data for diaphragm valves and analyses dynamic similarities of diaphragm valves, using the hydraulic grade line (HGL) approach, in the different flow regimes. The diaphragm valve is used owing to its importance and wide usage in the industry dealing with slurries (Brown & Heywood, 1991). This work also contributes to the commissioning, optimisation and verification of the reliability of the new state-of-the-art valve test rig.

1.2 STATEMENT OF RESEARCH PROBLEM

There is no experimental loss coefficient data available for a range of diaphragm valves of different sizes from the same manufacturer for both Newtonian and non-Newtonian fluids in laminar, transitional and turbulent flow regimes.

1.3 OBJECTIVES OF THE STUDY

The objectives of this study were:

- To commission the Valve test rig.
- To determine the loss coefficients for diaphragm valves of 40, 50, 65, 80 and 100 millimetre nominal bore diameter, in laminar, transitional and turbulent flow for both Newtonian and non-Newtonian fluids using the valve test rig.
- To evaluate dynamic similarity.

1.4 RESEARCH DESIGN AND METHODOLOGY

The experimental tests were carried out in the slurry laboratory of the Flow Process Research Centre at the Cape Peninsula University of Technology in Cape Town using the Valve test rig.

Diaphragm valves of 40, 50, 65, 80, 100 millimetre nominal bore diameter were used. The tests were carried out on these valves in the fully open position.

Different materials at different concentrations were used: water and glycerine (100% and 75% volume concentrations) as Newtonian fluids and carboxyl methyl cellulose (CMC)(5% and 8% weight concentrations) and kaolin slurries (10% and 13% volume concentrations) as non-Newtonian materials.

These materials were rheologically characterised by tube viscometry. The hydraulic grade line (HGL) approach was used to determine the valve loss coefficients. In this later approach, each test section as it will be explained later, consisted of two removable pipes of the same diameter in series joined by a diaphragm valve. On each pipe, upstream and downstream of the valve were tapping points where the static pressure drop was measured along the test section. The results for each test were presented in the form of valve loss coefficient (k_v) against the Slatter Reynolds number (Re_3).

1.5 DELINEATION

This work was limited to Newtonian and non–Newtonian fluids flowing through diaphragm valves in laminar, transitional and turbulent flow regimes. Only national trading company (NATCO) diaphragm valves were investigated in the fully open position. These 5 diaphragm valves were tested in the fully open position only due to time factor and also due to the workload as one of the objectives of this work was to commission the test rig.

Fluids, which have time-dependent and settling behaviour, were not investigated.

1.6 IMPORTANCE AND BENEFITS

This work provides loss coefficients data in laminar, transitional and turbulent flow regimes for non-Newtonian slurries flowing through 5 different sizes diaphragm valves from the same manufacturer. This data can be used directly for practical plant design. It also provides a dynamic similarity study and contributes to the commissioning, optimisation and verification of the reliability of the new Valve test rig.

CHAPTER 2

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, fundamental concepts on fluid classification and fluid rheological characterisation are presented. The relevant theory on fluid flow in straight pipes, pipe fittings and valves is also presented. Both of these are presented in laminar and turbulent flow regimes, with the emphasis on non-Newtonian fluids. The need for an in-depth understanding of the flow phenomena of non-Newtonian fluids through valves is very important in this work, especially through diaphragm valves. This explains the emphasis on flow through diaphragm valves. The theory on dynamic similarity of geometrically similar valves is also presented and its application for non-Newtonian flow in valves.

2.2 CLASSIFICATION OF FLUIDS

Generally fluids are classified according to the way they respond to externally applied pressure or to the effects produced on them by the action of shear stress. In this investigation all the fluids tested are assumed to be incompressible fluids and the effects produced by the action of a shear stress is of high interest (Chhabra & Richardson, 1999). These fluids include single-phase liquids, solutions, and pseudo-homogenous mixtures such as slurries that may be treated as a continuum if they are stable (Govier & Aziz, 1972)

In general, fluids belong to one of the three main categories: Newtonian fluids, non-Newtonian fluids and settling slurries (Brown & Heywood, 1991).

2.2.1 Newtonian Fluids

A Newtonian fluid is one in which an infinitesimal shear stress will initiate flow and for which the shear stress is directly proportional to the shear rate.

The flow curve of a Newtonian fluid at a certain temperature and pressure is a straight line passing through the origin. The slope of the flow curve is constant and is the viscosity of the fluid (Chhabra & Richardson, 1999).

The Newtonian fluid flow curve equation is:

$$\tau = \mu_N \dot{\gamma} \tag{2.1}$$

where μ_N is the Newtonian viscosity.

Some common examples of Newtonian fluids are: water, mineral oil, glycerine and glycerine-water mixture. Figure 2.1 illustrates the flow curve of a Newtonian fluid.

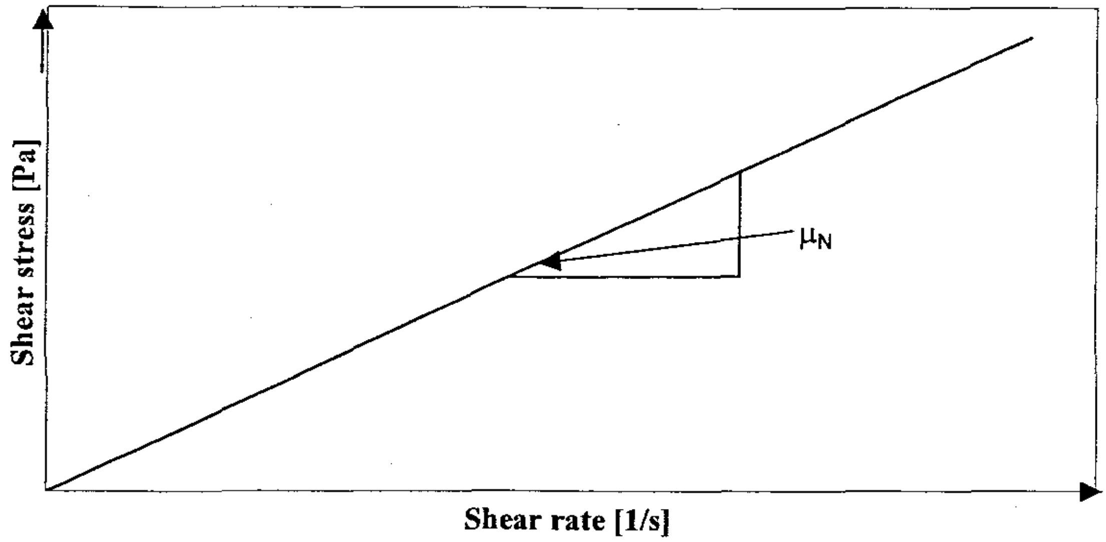

Figure 2. 1 Newtonian fluid flow curve

2.2.2 Non-Newtonian Fluids

A fluid is said to be non–Newtonian when the relationship between the shear stress and shear rate is non-linear or does not pass through the origin (Chhabra & Richardson, 1999). Non-Newtonian fluids are classified into three main categories:

- Time independent non-Newtonian fluids (pseudoplastic, dilatant, Bingham plastic and yield pseudoplastic fluids)
- Time dependent non-Newtonian fluids (thixotropic and rheopectic fluids) and
- Viscoelastic fluids.

Time dependant non-Newtonian fluids and viscoelastic fluids are not in the scope of this investigation.

2.2.3 Time Independent Non-Newtonian Fluids

Time independent non-Newtonian fluids are fluids for which the shear rate at any point is determined only by the value of the shear stress at that point at that instant (Chhabra & Richardson, 1999).

The constitutive equation of time independent fluids can be written as:

$$\dot{\gamma}_{yx} = f(\tau_{yx}) \qquad \textbf{(2.2)}$$

or its inverse form:

$$\tau_{yx} = f^{-1}\left(\dot{\gamma}_{yx}\right) \qquad \textbf{(2.3)}$$

Time independent non-Newtonian fluids are classified into three main categories:

- Pseudoplastic or shear thinning fluids
- Dilatant or shear thickening fluids and
- Viscoplastic fluids (Bingham plastic and yield pseudoplastic)

2.2.3.1 Pseudoplastic or Shear Thinning Fluids

Pseudoplastic or shear thinning fluids are time independent non-Newtonian fluids in which the apparent viscosity decreases with increasing shear rate (Chhabra & Richardson, 1999). For these fluids, an infinitesimal shear stress will initiate flow, the flow curve passes through the origin.

Generally these fluids are modelled using the power law model equation, which is a two parameter equation:

$$\tau = K\dot{\gamma}^{n} \qquad \textbf{(2.4)}$$

where K is the fluid consistency index in $Pa.s^n$ and n is the flow behaviour index or power law exponent and $n < 1$.

2.2.3.2 Dilatant or Shear Thickening Fluids

Dilatant or shear thickening fluids are time independent non-Newtonian fluids in which the apparent viscosity increases with increasing shear rate. In this case, as for pseudoplastic fluids, an infinitesimal shear stress will initiate flow, the flow curve passes through the origin.

Generally these fluids are also modelled using the power law model equation (2.4).

But in this case the flow behaviour index or power law exponent n is greater than one ($n > 1$).

2.2.3.3 Viscoplastic Fluids

Viscoplastic fluids are fluids characterised by a yield stress (τ_y), which must first be exceeded before the fluid deforms or flows (Chhabra & Richardson, 1999).

Such materials will deform elastically when the applied shear stress is lesser than the yield stress. In this category they are classified Bingham plastic fluids and yield pseudoplastic fluids.

- *Bingham Plastic Fluids (BP)*

Bingham plastic fluids are fluids that require a non-zero shear stress in order to initiate a significant flow. The flow curve of Bingham plastic fluids does not pass through the origin and there is a linear relationship between shear stress in excess of the yield stress and the resulting shear rate (Chhabra & Richardson, 1999).

The Bingham plastic model is described by a two parameter equation:

$$\tau = \tau_{yB} + \mu_B \dot{\gamma} \qquad \textbf{(2.5)}$$

Where τ_{YB} is the Bingham yield stress and μ_B is the Bingham plastic viscosity.

- *Yield Pseudoplastic Fluids (YPP)*

Yield pseudoplastic fluids are fluids that require a non-zero shear stress in order to initiate flow. In yield pseudoplastic fluids the increase in shear stress with shear rate in excess of the yield stress decreases with increasing shear rate (Chhabra & Richardson, 1999).

The flow curve does not pass through the origin and is non-linear.

Yield pseudoplastic fluids can be modelled using the Herschel–Bulkley equation, this model is a three parameter equation:

$$\tau = \tau_{yHB} + K\dot{\gamma}^n \qquad \textbf{(2.6)}$$

where τ_{YHB} is the Herschel-Bulkley yield stress K is the fluid consistency index and n the flow behaviour index.

2.2.4 Time Dependent Non-Newtonian Fluids

Time dependent non-Newtonian fluids are fluids that have an apparent viscosity that varies with the shear rate and the time of application of the shear rate (Chhabra & Richardson, 1999).

Time dependent non-Newtonian fluids are also classified into two categories: Thixotropic and rheopectic.

2.2.4.1 Thixothropic Fluids

Thixothropic fluids are fluids when sheared at constant shear rate, their apparent viscosity decreases with the time of shearing (Chhabra & Richardson, 1999).

2.2.4.2 Rheopectic Fluids

A fluid is said to be rheopectic when its apparent viscosity increases with time of shearing. Figure 2.2 illustrates the flow curves of different non-Newtonian fluids as classified above.

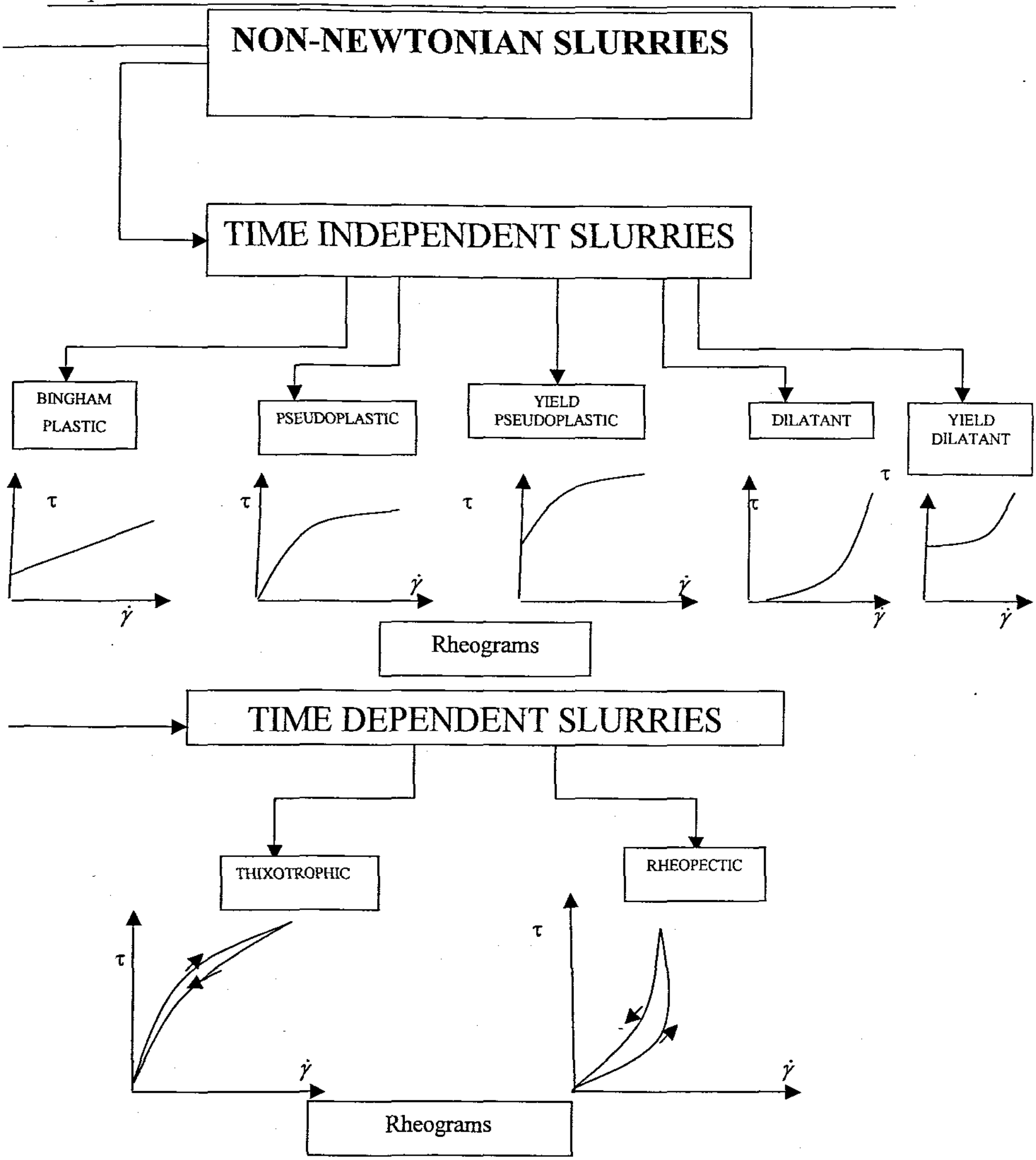

Figure 2. 2 Non-Newtonian fluids flow curves (Paterson & Cooke, 1999)

2.2.4.3 Settling Slurries

Settling slurries are solutions or pseudo-homogeneous mixtures where particles in suspension settle very quickly relatively to their residence time in the pipeline (Brown & Heywood, 1991) or a mixture in which solid and liquid phases are separated and the liquid properties are generally considered to be unaltered by the presence of solids. Particles are supported by turbulent mixing and antiparticle collisions (Paterson & Cooke, 1999)

2.2.5 Rheology

2.2.5.1 Definition

Rheology is defined as the viscous characteristics of a fluid or homogeneous solid-liquid mixture (Chhabra & Slatter, 2002).

2.2.5.2 Rheological Models

Various rheological models may describe the viscous characteristic of fluids. In this investigation the following models were used:

- The Newtonian model
- The Pseudoplastic model or Oswald-de-Waele model
- The Bingham plastic model and
- The Herschel-Bulkley or yield pseudoplastic model.

2.2.5.3 Rheological Characterisation

Rheological characterisation in the context of this work is the choice of a convenient rheological model that fit better the experimental data. The choice of a suitable rheological model is very important in the characterisation of non-Newtonian fluids and there is divided opinions on which rheological model to use in the literature to model laminar flow.

The choice of models is in fact extremely important not only for rheological characterisation in laminar flow but even more important in turbulent flow predictions (Hanks & Ricks, 1975). The reason for this is that the data is usually extrapolated (Thomas & Wilson, 1987) to much higher shear stresses for turbulent flow predictions than can be measured in laminar flow, even in small diameters (Shook & Rocco, 1991). Table 2.1 gives different rheological model available in the literature, showing the depth of the field of Rheology.

Table 2. 1 Rheological Models available in the literature. (Chhabra & Richardson, 1985)

Fluid model	Constitutive equation	Number of Parameters	Parameters
Newtonian	$\tau = \mu\left(-\frac{du}{dr}\right)$	1	μ
Bingham plastic	$\tau = \tau_y + K\left(-\frac{du}{dr}\right)$	2	τ_y and K
Casson	$\sqrt{\tau} = \sqrt{\tau_y} + \sqrt{\mu_c\left(-\frac{du}{dr}\right)}$	2	τ_y and μ_c
e-function	$\mu = \mu_o \exp\left[m\left(-\frac{du}{dr}\right)\right]$	2	μ_o and m
Oswald de Waele or power-law (pseudoplastic)	$\tau = K\left(-\frac{du}{dr}\right)^n$	2	K and n
Ellis	$\mu = \frac{\mu_o}{1+\left(\tau/\tau_{1/2}\right)^{\alpha-1}}$	3	μ_o,α and $\tau_{1/2}$
Herschel-Bulkley or Yield pseudoplastic	$\tau = \tau_y + K\left(-\frac{du}{dr}\right)^n$	3	τ_y, n and K
Carreau	$\frac{\mu-\mu_o}{\mu_o\mu_\infty} = \left[1+\left(\lambda\left(-\frac{du}{dr}\right)\right)^2\right]^{\frac{n-1}{2}}$	4	μ_∞, μ_o, λ and n
Cross	$\frac{\mu-\mu_\infty}{\mu_o\mu_\infty} = \left[1+\left(\lambda\left(-\frac{du}{dr}\right)\right)^{\frac{n-1}{2}}\right]$	4	μ_∞, μ_o, λ and n

Cross and Carreau models are mainly used for polymer solutions, zero shear viscosity is usually associated with very low flow, shear rate 10^{-3} s^{-1} (Malkin, 1994).

For suspensions, yield pseudoplastic, Bingham plastic and power law models are more appropriate (Malkin, 1994). Also because the effects produced by the action of a shear stress is of high interest in pipe flow (Chhabra & Richardson, 1999), these equations are also used in this work because, in pipe flow the shear rate is directly calculated.

2.2.5.4 The Yield Pseudoplastic Model

The yield pseudoplastic model will be used in this work to characterise all fluids as it is explained in section 2.3.8. The yield pseudoplastic model (YPP) incorporates the features of all models used in this work: The rheogram curvature of the pseudoplastic model and the yield stress for the Bingham plastic.

The yield pseudoplastic model is very sensitive to small variations in the rheological parameters and requires a sufficient amount of good laminar data to ensure reproducibility of the model to different data sets (Johnson, 1982).

The constitutive equation of the yield pseudoplastic model is given by equation (2.6):

$$\tau = \tau_{yHB} + K\dot{\gamma}^{n} \qquad \textbf{(2.6)}$$

This equation is a three parameters equation:

- The yield stress (τ_{yHB})
- The fluid flow behaviour index (n)
- The fluid consistency index (K)

Rheometry or viscometry deals with the establishment of a relationship between shear stress and shear rate. This is required to establish the rheological parameters such as τ_{yHB}, K, and n, which are used for the specific fluid.

2.3 FLOW IN STRAIGHT PIPES

2.3.1 Shear Stress Distribution in a Straight Pipe

The shear stress distribution in a pipe is given by the relationship:

$$\tau = \frac{\Delta pr}{2L} \tag{2.7}$$

where: Δp is the pressure gradient in the portion of a straight pipe of length L and the radial distance r (Chhabra & Richardson, 1999).

At the pipe wall equation (2.7) becomes:

$$\tau_o = \frac{\Delta pD}{4L} \tag{2.8}$$

where D is the pipe diameter.

2.3.2 Energy Loss in Straight Pipe

When a fluid flows in a straight pipe the dissipation of energy manifests itself as head loss and can be calculated using the Darcy-Weisbach formula (Massey, 1970):

$$\Delta H = \frac{4fL}{D}\left(\frac{V^2}{2g}\right) \tag{2.9}$$

Where f is the Fanning friction factor defined as (Massey, 1970):

$$f = \frac{2\tau_o}{\rho V^2} \tag{2.10}$$

The velocity V is obtained from the continuity equation and is given by:

$$V = \frac{Q}{A} \tag{2.11}$$

Equations (2.7), (2.8), (2.9), (2.10) and (2.11) do not depend on the nature of the fluid (Newtonian or non-Newtonian) or on the nature of the flow (laminar or turbulent). They depend on the homogeneity of the fluid and on the development of the flow (Massey, 1970).

2.3.3 Newtonian Transition from Laminar to Turbulent and Reynolds Number

There are two types of flow: laminar or streamline flow and the turbulent flow. Laminar flow occurs at lower velocities, the fluid particles are moving in straight lines, but the velocity with which the particles move along one line is not the same as along another line (Massey, 1970).

In turbulent flow, the path of individual fluid particles are not straight anymore but are sinuous, intertwining and crossing each other in a disorderly manner so that a mixing of the fluid takes place (Massey, 1970).

Experimental work has shown that the transition from laminar to turbulent flow happens at some fixed value of a dimensionless group called Reynolds number (Massey, 1970).

The Reynolds number is the ratio of the inertial to viscous forces and is given for Newtonian fluids by:

$$Re = \frac{\rho VD}{\mu} \qquad \textbf{(2.12)}$$

where ρ is the fluid density, V the fluid velocity, D the pipe diameter and μ the fluid viscosity.

The general accepted point of transition from laminar to turbulent flow is Re=2100. But the transition can happen at a Reynolds number higher than 2100 or lower than 2100 depending on the vibrating nature of the surroundings (Massey, 1970).

2.3.4 Newtonian Laminar Flow in Straight Pipes

2.3.4.1 Velocity Distribution

The velocity distribution in a pipe in laminar flow (if there is no slip or hold up effect at the pipe wall) is (Massey, 1970):

$$u = \frac{\tau_o}{2\mu R}\left(R^2 - r^2\right) \qquad \textbf{(2.13)}$$

u is maximum for r=0 and is:

$$u_{max} = \frac{\tau_o R}{2\mu} \qquad \textbf{(2.14)}$$

And the mean velocity is:

$$V = \frac{u_{max}}{2} \tag{2.15}$$

$$V = \frac{\tau_o R}{4\mu} \tag{2.16}$$

2.3.4.2 Hagen-Poiseuille Formula

For an incompressible Newtonian fluid in laminar flow, the Hagen-Poiseuille formula is (Massey, 1970):

$$Q = \frac{\pi\tau_o R^3}{4\mu} \tag{2.17}$$

2.3.4.3 Friction Factor

In general the friction factor is determined using equation (2.10). The friction factor is generally a function of both the Reynolds number and the pipe wall roughness. In Newtonian laminar flow, the pipe wall roughness has no effect on the friction factor and the friction factor is given by (Massey, 1970):

$$f = \frac{16}{Re} \tag{2.18}$$

2.3.5 Newtonian Turbulent Flow in Straight Pipes

Turbulent flow is a flow characterised by large, random, swirling or eddy motions.

Particle path cross and velocity (both direction and magnitude) and pressure fluctuate on a continuous and random basis.

Turbulent flow is very complex and a consistent mathematical analysis is not yet done and predictions are obtained empirically from experiments (Massey, 1970).

The friction factor in turbulent flow is a function of the Reynolds number and the pipe wall roughness k. It can be obtained using the Colebrook and White equation (Massey, 1970):

$$\frac{1}{\sqrt{f}} = -4\log\left[\frac{k}{3{,}7D} + \frac{1{,}26}{Re\sqrt{f}}\right] \tag{2.19}$$

It must be noted that the Moody diagram presents the friction factor f vs. Re and is a useful tool when it comes to the friction factor determination.

Fig 2.3 gives the Moody diagram.

In a case of a smooth pipe and for Reynolds numbers between 3000 and 100000, the Blasius equation is used to determine the friction factor (Massey, 1970).

$$f = \frac{0.079}{(Re)^{0.25}} \tag{2.20}$$

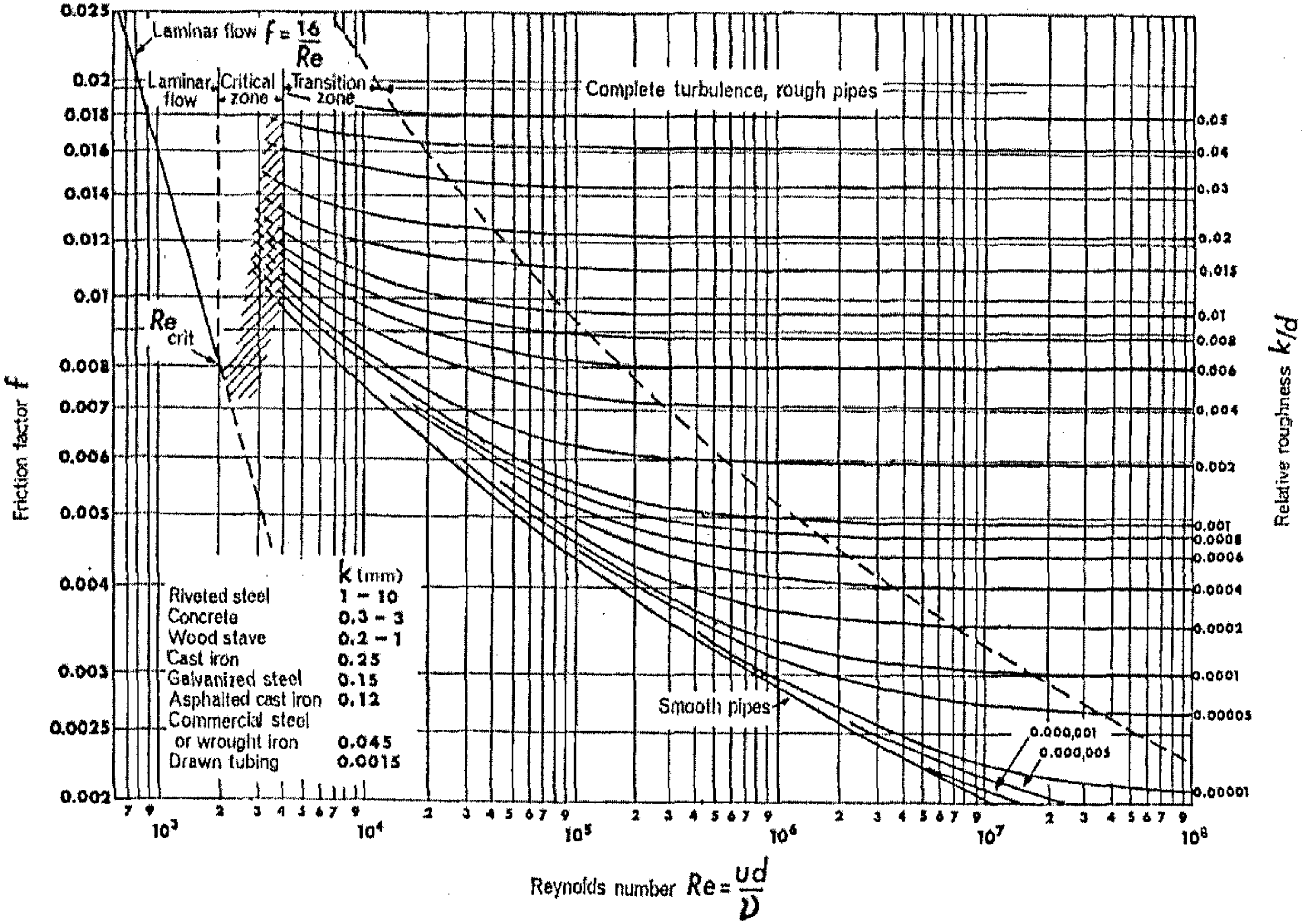

Figure 2. 3 The Moody Diagram (Massey, 1970)

2.3.6 Non-Newtonian Flow in Straight Pipes

The fundamental relationships (2.7), (2.8), (2.9), (2.10) and (2.11) on the shear rate, energy loss in pipes and velocity are also valid for non-Newtonian fluids as stated earlier in sections 2.3.1 and 2.3.2.

2.3.7 Non –Newtonian Transition from Laminar to Turbulent Flow and Non-Newtonian Reynolds Numbers

In this section, the different criteria for the determination of flow regime for non-Newtonian fluids are presented.

In non-Newtonian flow as in Newtonian flow there are also two kinds of flow: laminar and turbulent. Many criteria have been established for the determination of the nature of flow. Although this investigation uses the Slatter Reynolds number, other non-Newtonian Reynolds numbers and criteria relevant to this work are also presented. The Slatter Reynolds number is favoured because it can describe the behaviour of a wide range of non-Newtonian fluids (Chhabra & Slatter, 2002).

2.3.7.1 Newtonian Approximation

In the Newtonian approximation method, in order to evaluate the transition from laminar to turbulent flow, the Newtonian Reynolds number is used but because a non-Newtonian fluid has a variable viscosity, the apparent or secant viscosity is used and in equation (2.12) the term viscosity μ is replaced by μ' the apparent or secant viscosity and equation (2.12) becomes:

$$Re_{Newt} = \frac{\rho V D}{\mu'} \qquad \textbf{(2.21)}$$

with the apparent viscosity:

$$\mu' = \frac{\tau_o}{\left[-\frac{du}{dr}\right]_o} \qquad \textbf{(2.22)}$$

where: $\left[-\frac{du}{dr}\right]_o$ is the velocity gradient at the pipe wall.

2.3.7.2 Metzner & Reed Generalised Reynolds Number

It has been demonstrated that for laminar pipe flow of any given time independent fluid that 8V/D is some unique function of τ_0 only (Metzner & Reed, 1955). This may be expressed as:

$$\tau_o = \frac{D\Delta P}{4L} = K'\left(\frac{8V}{D}\right)^{n'} \quad \textbf{(2.23)}$$

where in the most general case K' and n' are not constants, but vary with 8V/D. Thus on logarithmic plot of τ_0 versus 8V/D, Equation (2.23) is simply the equation of the tangent to the curve at a given value of 8V/D, n' being the slope of this tangent and K' its intercept on the ordinate at 8V/D equal to unity (Skelland, 1967).

Metzner & Reed (1955) developed a generalised Reynolds number from the considerations above as:

$$Re_{MR} = \frac{8\rho V^2}{K'\left(\frac{8V}{D}\right)^{n'}} \quad \textbf{(2.24)}$$

This relation may be rewritten after transformation as:

$$Re_{MR} = \frac{\rho V^{2-n'} D^{n'}}{8^{n'-1} K'} \quad \textbf{(2.25)}$$

In practice, n' is the tangent of the double logarithmic plot of τ_0 versus (8V/D) at any particular value of τ_0 or 8V/D . Log K' is the intercept on the y-axis.

$$n' = \frac{d(\mathrm{Log}\,\tau_o)}{d\left(\mathrm{Log}\frac{8V}{D}\right)} \quad \textbf{(2.26)}$$

It has been found experimentally that for many fluids K' and n' are constant over any range of τ_0 or 8V/D for which the power law is valid. This is not the case in general (the log-log plot is not always a straight line) and care must be taken to ensure that the range of application is narrow. The quantity n' characterises the degree of non-Newtonian behaviour for a given fluid. The greater the departure of n' from unity the more non-

Newtonian is the fluid. The quantity K' is a measure of the consistency of the fluid, the larger the value of K' the thicker or less mobile is the fluid (Metzner & Reed, 1955).

For power law fluids or pseudoplastic models:

$$K' = K\left(\frac{3n+1}{4n}\right)^n \text{ and } n=n' \quad (2.27)$$

Thus (2.25) becomes:

$$Re_{MR} = \frac{\rho V^{2-n} D^n}{8^{n-1} K\left(\frac{3n+1}{4n}\right)^n} \quad (2.28)$$

For a Bingham plastic fluid (Skelland, 1967):

$$n' = 1 - \frac{4}{3}\frac{\tau_y}{\tau_o} \quad (2.29)$$

$$K' = \tau_o\left[\frac{\eta}{\tau_o\left[1 - 4/3(\tau_y/\tau_o) + 1/3(\tau_y/\tau_o)^4\right]}\right]^{n'} \quad (2.30)$$

For yield pseudoplastic fluids, no relationship has been derived for yield pseudoplastic fluids and this has been done as part of this work. It has been demonstrated in this work that (see Appendix 5):

$$n' = \frac{1}{-3 + \frac{(1+n)}{n}\frac{\tau_o}{(\tau_o - \tau_y)} + \frac{2\tau_o(1+n)(\tau_o + 2n\tau_o + n\tau_y)}{(1+n)(1+2n)(\tau_o - \tau_y)^2 + 2\tau_y(\tau_o - \tau_y)(1+n)(1+3n) + \tau_y^2(1+2n)(1+3n)}} \quad (2.31)$$

and

$$K' = \tau_o / \left\{\left[\frac{4n}{K^{\frac{1}{n}}\tau_o^3}(\tau_o - \tau_y)^{\frac{1+n}{n}}\left[\frac{(\tau_o - \tau_y)^2}{1+3n} + \frac{2\tau_y(\tau_o - \tau_y)}{1+2n} + \frac{\tau_y^2}{1+n}\right]\right]^{n'}\right\} \quad (2.32)$$

2.3.7.3 Slatter Reynolds Number

The Slatter Reynolds number takes directly in to account the yield stress of non-Newtonian fluids but other non-Newtonian Reynolds numbers do not take directly into account the yield stress. An unsheared core is formed in laminar pipe flow of a fluid with a yield stress. Slatter has proposed a Reynolds number which seeks to express the ratio of inertial forces to viscous shear forces in the sheared portion of the flow (Shook *et al*, 2002).

The Slatter Reynolds number is given by:

$$Re_3 = \frac{8\,\rho\,V_{ann}^2}{\tau_y + K\left(\frac{8V_{ann}}{D_{shear}}\right)^n} \qquad \textbf{(2.33)}$$

For fluid with a yield stress there is a plug flow at the centre of the pipe in laminar flow and the radius of the plug is:

$$r_{plug} = \frac{\tau_y}{\tau_o} R \qquad \textbf{(2.34)}$$

The sheared diameter is:

$$D_{shear} = D - D_{plug} \qquad \textbf{(2.35)}$$

$$\text{where: } D_{plug} = 2r_{plug} \qquad \textbf{(2.36)}$$

The mean velocity of the annulus is:

$$V_{ann} = \frac{Q_{ann}}{A_{ann}} \qquad \textbf{(2.37)}$$

$$\text{where } Q_{ann} = Q - Q_{plug} \qquad \textbf{(2.38)}$$

$$\text{and } Q_{plug} = u_{plug}.A_{plug} \qquad \textbf{(2.39)}$$

Where u_{plug} is given by equation (2.41) in section 2.3.8.

The transitional value of the Slatter Reynolds number from laminar to turbulent flow in straight pipes is $Re_3 = 2100$ (Shook *et al*, 2002).

The Slatter Reynolds number can accommodate different rheological models: the Newtonian model, the power law model, the Bingham plastic model and the yield pseudoplastic model, as it will be demonstrated in this investigation.

2.3.7.4 Intersection and Deviation Methods

- *Intersection Method*

This is a practical method. It uses the intersection of the laminar and turbulent flow loci to predict the critical point.
The degree of accuracy of this method depends on the turbulent flow model used and this method is also incompatible with Newtonian fluids (Chhabra & Slatter, 2002)

- *Deviation Method*

This method uses the point from which data starts deviating from the laminar flow line to define the transition region and that deviation happens before the intersection.
This method is relevant for this study because in most cases, the transition from laminar to turbulent regime in pipe fittings and valves occurs earlier than in straight pipe flow (Pienaar *et al.*, 2001) and can be detected using the deviation or intersection method.

2.3.8 Non –Newtonian Laminar Flow in Straight Pipes

The following rheological relationship can be accommodated in the yield pseudoplastic model equation (2.6):

Yield dilatant $(\tau_y > 0 \text{ and } n > 1)$

Bingham plastic $(\tau_y > 0 \text{ and } n = 1)$

Dilatant $(\tau_y = 0 \text{ and } n > 1)$

Newtonian $(\tau_y = 0 \text{ and } n = 1)$

Pseudoplastic $(\tau_y = 0 \text{ and } n < 1)$

In laminar flow, the velocity distribution of a yield pseudoplastic fluid is for $R > r > r_{plug}$:

$$u = \frac{R}{K^{\frac{1}{n}}\tau_o}\frac{n}{n+1}\left[\left(\tau_o - \tau_y\right)^{\frac{n+1}{n}} - \left(\tau - \tau_y\right)^{\frac{n+1}{n}}\right] \tag{2.40}$$

When $0 < r < r_{plug}$ the fluid moves as a plug at a uniform plug velocity u_{plug}:

$$u_{plug} = \frac{R}{K^{\frac{1}{n}}\tau_o}\frac{n}{n+1}\left(\tau_o - \tau_y\right)^{\frac{n+1}{n}} \tag{2.41}$$

The volumetric discharge Q and the average velocity are obtained from the relation:

$$\frac{32Q}{\pi D^3} = \frac{8V}{D} = \frac{4n}{K^{\frac{1}{n}}\tau_o^3}\left(\tau_o - \tau_y\right)^{\frac{1+n}{n}}\left[\frac{\left(\tau_o - \tau_y\right)^2}{1+3n} + \frac{2\tau_y\left(\tau_o - \tau_y\right)}{1+2n} + \frac{\tau_y^2}{1+n}\right] \tag{2.42}$$

With τ_o as defined by equation (2.8) and V=Q/A equation (2.11)

For a Newtonian fluid $K=\mu$ and n=1, equation (2.42) becomes:

$$\tau_o = \mu\frac{8V}{D} \tag{2.43}$$

Equation (2.43) shows that wall shear rate at pipe wall for a Newtonian fluid is $\frac{8V}{D}$. For non-Newtonian fluid $\frac{8V}{D}$ is called the pseudo shear rate or nominal shear rate. The plot of τ_o versus $\frac{8V}{D}$ is called the pseudo-shear diagram. It is of great importance in non-Newtonian fluid flow in general and in this investigation in particular.

2.3.8.1 The Rabinowitsch-Mooney Relation

The true shear rate can be obtained from the pseudo shear rate of a non-Newtonian fluid, by multiplying the pseudo shear rate by the Rabinowitsch –Mooney relation:

$$\left[-\frac{du}{dr}\right]_o = \frac{8V}{D}\left[\frac{3n'+1}{4n'}\right] \tag{2.44}$$

n' is calculated as:

$$n' = \frac{d\left(\text{Log}\tau_o\right)}{d\left(\text{Log}\frac{8V}{D}\right)} \tag{2.26}$$

The coefficient n' is obtained as the slope of a double logarithmic plot of τ_o versus 8V/D. In the case the rheological parameters of the fluid are known (τ_y, K and n), n' can be obtained directly using relations (2.27) for pseudoplastic fluids, (2.29) for Bingham plastic fluids and (2.31) for yield pseudoplastic fluids.

2.3.8.2 Friction Factor for Non-Newtonian Fluids

In the case of inelastic non-Newtonian fluids, the fanning friction factor in laminar flow is given by (Chhabra & Richardson, 1999):

$$f = \frac{16}{Re_{MR}} \tag{2.45}$$

with f given by equation (2.10).

Slatter (1999) also developed a friction factor for non-Newtonian fluids with a yield stress:

$$f_{ann} = \frac{2\tau_o}{\rho V_{ann}^2} \tag{2.46}$$

In this case the transition is considered to occur when f_{ann} equals 16/2100.

2.4 RHEOLOGICAL CHARACTERISATION

The rheological characterisation of non-Newtonian fluids is not easy (Chhabra & Richardson, 1999), and can be done using a rheometer or a tube viscometer. In the context of this investigation, tube viscometry was used because the experimental test loop could also be used as an in-line tube viscometer having a range of 5 different pipe diameters.

Rotational viscometry

The instrument used to measure viscous properties of non-Newtonian fluids in this case is known as a rheometer. The rheometer usually consists of a concentric bob and cup, one of which is rotated to produce shear in the test fluid that is in the gap between the bob and the cup. The shear stress is determined by measuring the applied torque on one of the elements.

The rheometer is a very sophisticated instrument and is capable of measuring the full range of rheological phenomena. The rheometers can be found using one of the many geometries, among others: Concentric cylinders, cone and plate, parallel disks. And the main measurements are angular velocity and applied torque. The software connected to these instruments converts these signals into shear rate and shear stress (Chhabra & Slatter, 2002)

Tube viscometry

In a tube viscometer the test fluid flows at a controlled, measured rate through a tube of known diameter and the pressure drop over a known length of the tube is measured.

Data from tube viscometer yields a series of coordinates of pseudo shear rate and wall shear stresses (8V/D, τ_0) these data must be processed in order to give the required rheology.

Assuming a yield pseudoplastic rheology (2.6):

$$\frac{32Q}{\pi D^3}=\frac{8V}{D}=\frac{4n}{K^{\frac{1}{n}}\tau_o^3}\left(\tau_o-\tau_y\right)^{\frac{1+n}{n}}\left[\frac{\left(\tau_o-\tau_y\right)^2}{1+3n}+\frac{2\tau_y\left(\tau_o-\tau_y\right)}{1+2n}+\frac{\tau_y^2}{1+n}\right] \quad \textbf{(2.42)}$$

The following technique was used (Slatter, 1994):

A pseudo shear diagram was plotted using the pseudo shear rate (8V/D) as abscissa and shear stress (DΔp/4L) as ordinate. Data points in laminar flow only from all tubes are used. The best curve is fitted to the data by eye. A realistic value of τ_y is set according to the data as the ordinate intercept. The value of τ_y is then adjusted until the error function is minimised. The error function E is the root square of difference between observed data and calculated as:

$$E=\sqrt{\frac{\sum_{i=1}^{N}\left[\left(\frac{8V}{D}\right)_{i_{obs}}-\left(\frac{8V}{D}\right)_{i_{CALC}}\right]^2}{N-1}} \quad \textbf{(2.47)}$$

and K value for minimum error K_{min} is given by:

$$K_{MIN} = 1/\left[\frac{2\sum_{1}^{N}\left(\frac{8V}{D}\right)_i/8}{n\sum_{i=1}^{N}\left(\tau_o-\tau_y\right)^{\frac{1+n}{n}}\left[\frac{\left(\tau_o-\tau_y\right)^2}{1+3n}+\frac{2\tau_y\left(\tau_{oi}-\tau_y\right)}{1+2n}+\frac{\tau_y^2}{1+n}\right]}\right]^n \quad \textbf{(2.48)}$$

Errors in tube viscometry:

- Wall slip: this effect occurs when the layers of particles near the wall are more dilute than the bulk flow (Heywood & Richardson, 1978). As a result the viscosity near the wall will be reduced and apparent slip will occur. Chhabra & Richardson (1999) warn that serious errors could occur when the wall slip is not accounted for. To account for the wall slip, more than one diameter tube should be tested. Their laminar flow data should coincide if there is no wall slip. If they do not coincide then the slip velocity must be calculated for each tube and deducted from the measured mean velocity (Heywood & Richardson, 1978).
- Entrance and exit losses: it is important that the entrance and exit losses in the tubes that are used are minimised. This is possible by making sure that the flow is fully developed before differential pressure readings are taken.

2.5 FLOW IN PIPE FITTINGS AND VALVES

In this section, the relevant theory on Newtonian and non-Newtonian losses in pipe fittings and valves is given in both laminar and turbulent flow regimes.

2.5.1 Classification of Fittings

Fittings are generally classified in one of the categories below:

- Branching fittings, e.g.: tees, crosses, side outlet elbows, etc.
- Reducing or expending fittings: in which there is a change in the cross section of the pipe e.g.: contraction, expansion, etc.
- Deflecting fittings in which there is a change in the direction of flow e.g.: bends, elbows, return bends and
- Combined or hybrid fittings are a combination of the aforementioned e.g. valves. Other fittings do not offer any resistance to flow such as couplings and unions. (Crane Co., 1981)

2.5.2 Determination of Newtonian and Non-Newtonian Losses Across Pipe Fittings and Valves

2.5.2.1 Losses Across Fittings

The Bernoulli formula gives the macroscopic mechanical energy balance for a pipe system and gives the total head loss in the system and is used in the determination of different losses in the system (Massey, 1970).

The Bernoulli formula for a system of two pipes in series connected by a fitting, can be written as follows:

$$z_1 + \frac{\alpha_1 V_1^2}{2g} + \frac{p_1}{\rho g} = z_2 + \frac{\alpha_2 V_2^2}{\rho g} + \frac{p_2}{\rho g} + H_1 + H_{fitt} + H_2 \qquad \textbf{(2.49)}$$

where z is the elevation of the datum, α is the kinetic energy correction factor, p is the static pressure and, H the head loss.

Subscripts 1 and 2 are for upstream and downstream pipes respectively.

H_{fitt} is the fitting head loss in metres and is predicted using the formula (Massey, 1970):

$$H_{fitt} = k_{fitt} \frac{V^2}{2g} \tag{2.50}$$

For a valve it is written:

$$H_v = k_v \frac{V^2}{2g} \tag{2.51}$$

where k_{fitt} or k_v is the fitting or valve head loss coefficient and is defined as the non-dimensionalised difference in overall pressure between the ends of two long straight pipes when there is no fitting and when the real fitting is installed (Miller, 1978). This is shown graphically on Figure 2.4 for a valve.

$$k_{fitt} = H_{fitt} \frac{2g}{V^2} \tag{2.52}$$

or:

$$k_{fitt} = \frac{\Delta p_{fitt}}{1/2 \rho V^2} \tag{2.53}$$

The loss coefficient can be calculated in two ways, by including or excluding the length of the fitting.

If the length of the fitting is excluded, k_{fitt} is called k_{gros} and is obtained by the equation (Turian *et al*, 1997):

$$k_{gross} = \frac{1}{\frac{\rho V^2}{2}} \left[-\Delta p - \frac{\rho V^2}{2} \frac{4f}{D} (L_u + L_d) \right] \tag{2.54}$$

If the length of the fitting is included, k_{fitt} is called k_{net} and is obtained by the equation (Turian *et al*, 1997):

$$k_{net} = \frac{1}{\frac{\rho V^2}{2}} \left[-\Delta p - \frac{\rho V^2}{2} \frac{4f}{D} (L_u + L_{fitt} + L_d) \right] \tag{2.55}$$

With the exception of abrupt contractions and expansions, all other fittings have a physical length. The length of the test valve was included in all calculations in this work.

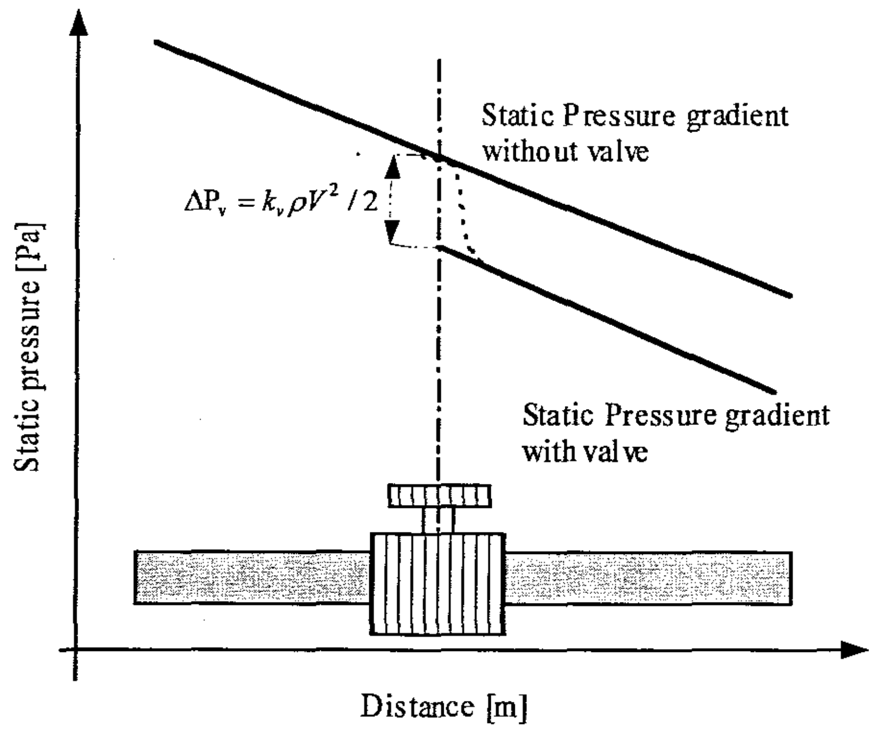

Figure 2. 4 Definition of the loss coefficient (Miller, 1978)

2.6 FLOW IN VALVES

2.6.1 Definition of Valves

In the industry generally valves are used to isolate, regulate or direct the flow (Lahlou, 2002). From an engineering perspective, a valve is a contraction followed by an expansion (Mc Neil & Morris, 1995).

2.6.2 Classification of Valves

According to their resistance to fluid flow, valves are classified either as low resistance valves or high resistance valves. Low resistance valves are those in which there is only a change in the flow cross section and high resistance valves are those where there are both changes in the flow cross section and direction (Crane Co., 1981).

In the industry dealing with non-Newtonian fluids or slurries, valves are used mostly for isolation purposes and rarely for regulating or throttling. However in applications such as polymer processing, valves are used as throttling devices (Mc Neil & Morris, 1995).

It is not possible to do any systematic classification, due to the great variety of valve designs. However, there are five basic valve designs: gate, ball, plug, butterfly, diaphragm and pinch (Heywood, 1999). There are designs intended for a particular application or that combine certain features of other valves for improved performance. These are known as hybrid valves.

According to their mode of operation, valves can be classified as: manual valves, check valves, pressure relieve valves and control valves (Lahlou, 2002).

Diaphragm valves are the objects of this study and a thorough description is given in section 2.6.3 due to their wide usage in the slurry industry and in the mineral processing industry (Brown & Heywood, 1991)

The selection of the right valve in a piping system is crucial because poor selection can lead to problems: excessive high initial and maintenance costs, downtime, leakage, poor performance, dangerous vibration and excessive noise. Many variables are to be considered when doing a slurry valve selection. Slurry valve selection is complex and is not in the scope of this investigation. However the first rule is to avoid the need for valves whenever possible. The need for a valve must be carefully scrutinised. It must also be said that high resistance valves in general are unsuitable for slurry service (Brown & Heywood, 1991).

2.6.3 Diaphragm Valves

The diaphragm valve has a valve body assembly with a single flexible diaphragm, which isolates the actuating mechanism from the flowing fluid.

There are two basics designs: the weir or dam and straight through types.

The body can be manufactured from cast iron, bronze, gunmetal or stainless steel. It can be lined with various elastomers, polymers or glass for highly corrosive and/or abrasive applications.

Diaphragms are in elastomeric material or polytetrafluoroethylene (PTFE) with an elastomer backing. Because the diaphragm isolates the moving parts in the bonnet from the flowing fluid, the bonnet assembly can be manufactured from cast iron or plastic–coated materials. Cast iron is used for most applications. This is because it renders the valve suitable for handling aggressive fluids including those containing suspended solids as well as clean fluid applications (AEA Technology, 1996).

Diaphragm valves can normally operate within a wide temperature range depending on the valve material choice. The application of both types is limited to about 10 bars maximum (lower in large valves) with temperatures and products limited by the diaphragm and optional body linings (typically 100 °C).

The weir or dam type diaphragm valve (Figure 2.5) has a body with a transverse weir above which a flexible diaphragm is mounted. Tight closure of the diaphragm valve is obtained when the diaphragm is screwed down by means of a hand wheel, pneumatic or electric actuator until it touches the weir.

The movement of the diaphragm, even from the fully open to the fully closed position, is relatively short; the result is a long diaphragm life and low maintenance. This type of valve is suitable for throttling applications and is by definition a high resistance valve because there are changes in both the diameter of the cross section and the flow direction.

The straight-through type diaphragm valve (Figure 2.6) may have a parallel or tapered bore through the body. A wedge-shaped diaphragm completes the closure. The method of sealing requires a longer diaphragm movement, which tends to result in a shorter diaphragm life.

The full bore opening offers minimum resistance to flow in the open position and this valve is by definition a low resistance valve because there is change only in the cross section diameter. However, the material choice for the diaphragm is much more limited.

The advantages of the diaphragm valve reside in the fact that the operating mechanism, called the compressor, is above the diaphragm, not in contact with the flowing fluid. Its unlined solid–alloy bodies are relatively less expensive than those of some other types of valves because of the smaller metal mass.

No packing is required. The interior is very smooth and can be easily cleaned.

As limitations, larger sizes of this valve become more difficult and expensive to produce. The valve leaks upon the failure of the diaphragm due, for instance, to excessive cycling.

Diaphragm valves are particularly suitable for less arduous slurry service (Brown & Heywood, 1991). With particularly abrasive slurries, the weir type may be subject to erosive wear and the passage constriction is some times undesirable with large particle slurries.

The straight-through type is better suited for use with high solids content, coarse particles, high viscosity and low pressure, low temperature abrasive slurry systems. It can be found in the brewing, chemical processing, dairy, food, minerals processing, paper and pulp, power generation and water industries (AEA Technology, 1996).

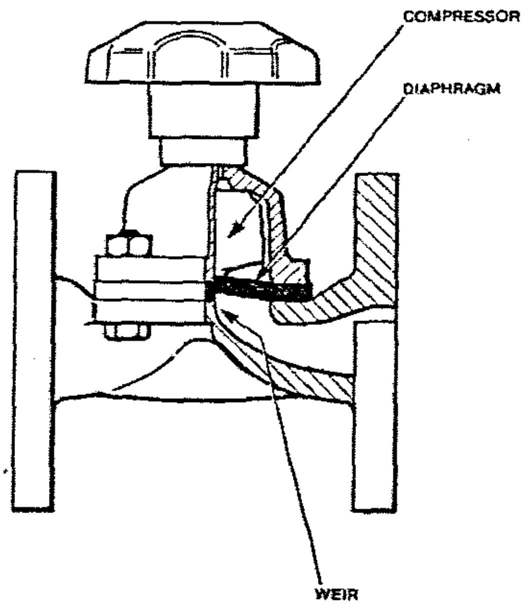

Figure 2. 5 The weir or dam type diaphragm valve

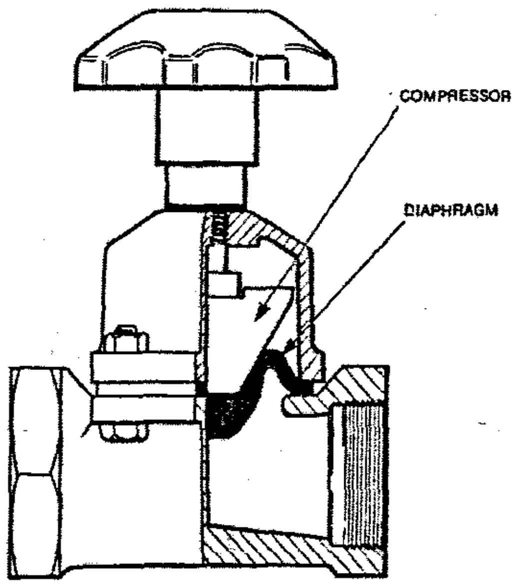

Figure 2. 6 The straight-through type diaphragm valve

2.6.4 Newtonian and non-Newtonian flow in valves

2.6.4.1 Pressure Drop in Valves

The loss of pressure due to a valve consists of three parts (Turian *et al*, 1997):

1. The pressure drop within the valve itself due to the viscous stresses that cause internal friction and separates flows.
2. The pressure drop in the upstream pipe in excess of that which would normally occur if there were no valve in the line. This effect is small.
3. The pressure drop in the downstream pipe in excess of that which would normally occur if there were no valve in the line. This effect may be comparatively large.

2.6.4.2 Valve Loss Coefficient

Friction losses for valves are obtained using equation (2.51) where
k_v is the valve loss coefficient or resistance coefficient and is defined as the number of velocity heads lost due to a valve.
The head loss is independent of the Reynolds number for turbulent flow through valves, because inertia forces dominate. It is clear that the loss coefficient in turbulent flow is independent of the Reynolds number. In laminar flow the valve loss coefficient is Reynolds number dependent and in laminar flow is defined as C_V ,the laminar flow valve loss coefficient(Pienaar *et al.*, 2001):

$$C_v = k_v.Re \quad \textbf{(2.56)}$$

The loss coefficient is usually presented as a function of the Reynolds number. The loss coefficient is on the y-axis and the Reynolds number on the x-axis on logarithmic scale. In laminar flow the loss coefficient is a hyperbolic function of the Reynolds number and it increases significantly as the Reynolds number decreases. Figure 2.7 gives a typical presentation of k_v vs Re.

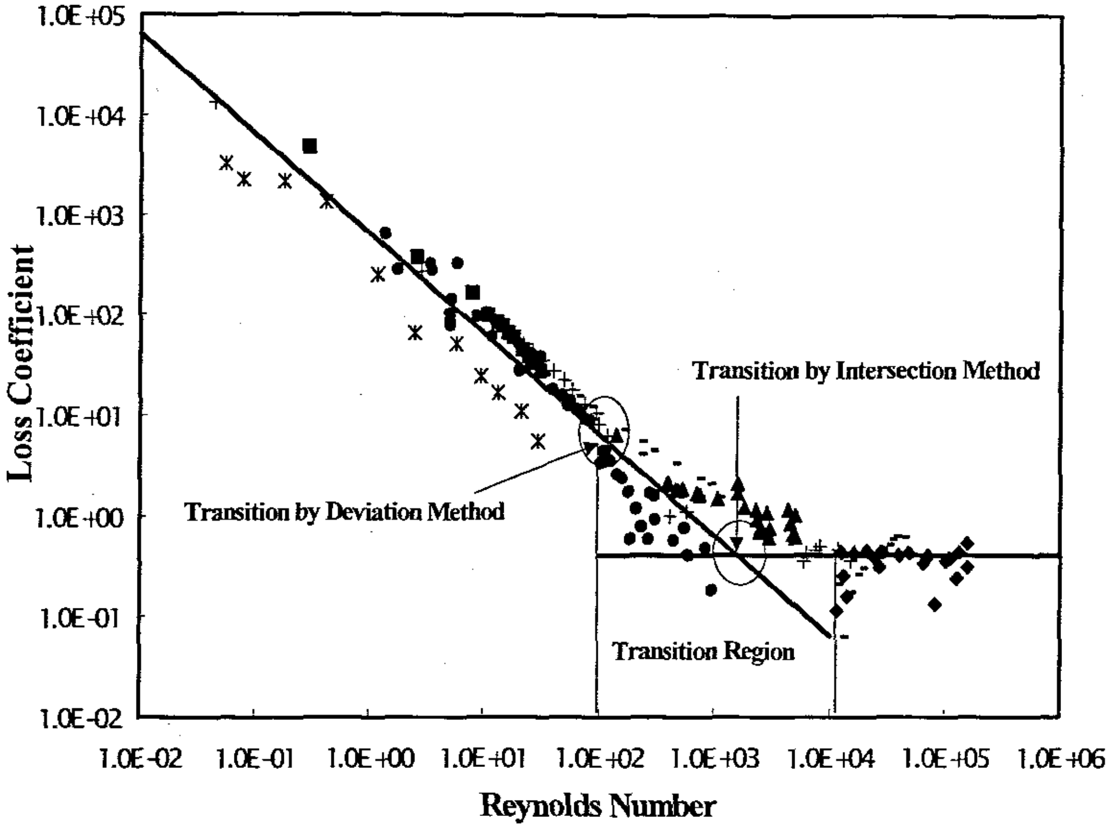

Figure 2. 7 Typical representation of k_v vs. Re for a fitting (Pienaar *et al*, 2001)

Figure 2.7 shows the transition from laminar to turbulent flow. Some authors define it as the intersection of the laminar loss coefficient and turbulent loss coefficient loci and others as a point where the experimental data start to deviate from the laminar flow line (Pienaar *et al*, 2001).

Determination of the laminar valve loss coefficient.

The laminar loss coefficient in equation (2.56) is determined from experimental data in the laminar flow region by the least square method.

It is obtained by minimising the logarithmic least square:

$$\text{Minimum}\sum\left(\text{Log}\frac{C_v}{\text{Re}}-\text{Log}k_{V/obs}\right)^2 \tag{2.57}$$

Methodology

Generally, there are two methods used in the determination of valves or fittings loss coefficient: The hydraulic grade line (HGL) approach and the total pressure method.
Banerjee *et al.*, (1994) and Baudouin, (2003) adopted the hydraulic grade line approach for the determination of loss coefficients, the first for loss coefficients in valves and the latter for loss coefficients in sudden contractions. It consists of measuring and plotting the static pressure gradients upstream and downstream of the valve in the region of fully developed flow far from the valve plan to avoid disturbance of the flow due to the presence of the valve.
The valve pressure loss is obtained as an extrapolation to the valve plane of the pressure gradients measured in the fully developed flow regions upstream and downstream of the valve.
To measure static pressure at different points upstream and downstream of the valve, Banerjee *et al.* (1994) used U-tube manometers containing mercury beneath water connected to pressure tappings. Baudouin (2003) used point pressure transducers and differential pressure cells connected to pressure tapings.

Turian *et al.*, (1997) and Pienaar (1998) used the total pressure method to determine the loss coefficient through fittings and valves. Two pipes in series were joined by a fitting or valve. The method consists of measuring the pressure gradient between two points in the region of fully developed flow in straight pipes around the fitting or valve. Thus knowing the losses in the straight pipe portions one can deduct the fitting or valve loss.
This investigation adopted the hydraulic grade line approach because the experimental loop used was specially designed to accommodate this approach.
The technique for the determination of the valve pressure drop by the hydraulic grade line approach is explained in Figure 2.8 below and will be explained in detail later in chapter 4 (4.4.1).

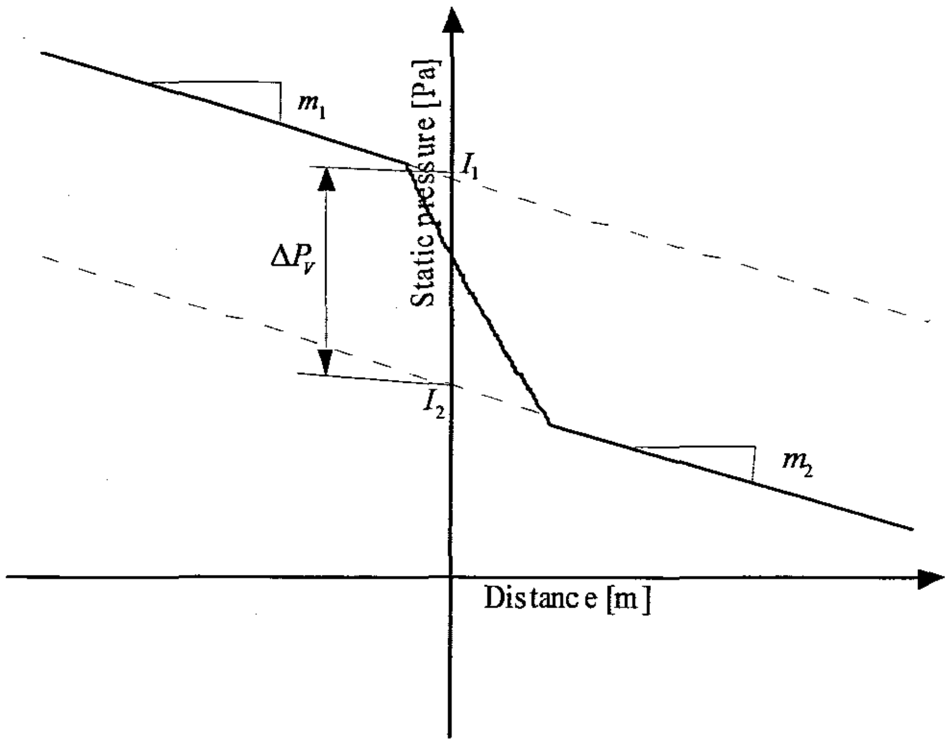

Figure 2. 8 Diagram illustrating the calculation of valve loss coefficient

On a graph, static pressure (P) vs. axial distance (X) points of coordinates (P_i, X_i) are plotted from the experimental data. For the two pipes upstream and downstream of the test valve, the curves of static pressure drops follow a linear law and are straight lines.

The coordinates of the point upstream of the test valve plane which is the y- axis in this case, are used to calculate, by linear regression the slope m_1 and intercept I_1 of the line upstream of the valve. The coordinates of the points downstream of the valve are used to calculate also by linear regression, the slope m_2 and intercept I_2 of the line downstream of the valve.

In the case of valves, the pipes upstream and downstream of the test valve have the same diameters, the two hydraulic grade lines upstream and downstream of the test valve are parallel, m_1 and m_2 are equal and the pressure drop due to the test valve is given by:

$$\Delta p_V = I_1 - I_2 \quad \textbf{(2.58)}$$

And using equation (2.51):

$$k_v = \frac{\Delta p_v}{1/2\rho V^2} \qquad \textbf{(2.59)}$$

$$k_v = \frac{(I_1 - I_2)}{\frac{1}{2}\rho V^2} \qquad \textbf{(2.60)}$$

Equivalent length

Alternatively, the valve loss coefficient can be expressed in terms of the equivalent length of straight pipe of the same diameter and having the same loss as the valve. The equivalent length is expressed in numbers of pipe diameters, (Le/D) and is obtained by equating the Darcy-Weisbach formula, equation (2.9) to equation (2.51):

$$\left(\frac{Le}{D}\right) = \frac{k_v}{4f} \qquad \textbf{(2.61)}$$

The drawback of this method is the fact that the equivalent length for a given fitting is not constant, but depends on Reynolds number and roughness, as well as size and geometry. Therefore, the use of equivalent length method requires consideration of all these factors (Hooper, 1981).

It has been shown using dimensional analysis that k_v for incompressible Newtonian fluids is a dimensionless function of Re and of dimensionless geometric ratios characteristic of the valve (Turian *et al.*, 1997):

$$k_v = \text{fn (Re, geometric ratios)} \qquad \textbf{(2.62)}$$

This relation suggests that the resistance coefficient is the same for all sizes of a given type of valve provided dynamic similarity is enforced for instance equality of Reynolds number and geometric similarity are maintained (Turian *et al.*, 1997).

2.6.4.3 Flow Coefficient

In some branches of the valve industry, particularly for control valves, the capacity of the valve is expressed in terms of a flow coefficient.

However there is no agreement on the definition of a flow coefficient in terms of SI units. In the USA and UK the flow coefficient in use is designated by C_{valve} and in other European countries by K_{valve} and are defined as:

C_{valve} is the rate of flow of water, in either US or UK gallons per minute, at 60°F, at a pressure drop of one pound per square inch across the valve.

K_{valve} is the rate of flow of water in cubic metres per hour at a pressure drop of one kilogram force per square centimetre across the valve (Crane Co., 1981).

$$C_{valve} = 0.0694\, Q \sqrt{\frac{\rho}{\Delta p (999)}} \quad \text{(in US gallons)} \qquad \textbf{(2.63)}$$

where:

Q is the flow rate in litres per min.

ρ is the density of the fluid in kg/m^3

Δp is pressure gradient in bar.

It must be said that C_{valve} is generally a fixed value for a specific type and size of a valve regardless of the operating conditions. In practice however this is true in the turbulent flow regime only where k_v is not a function of Reynolds number (Jadallah, 1980).

2.6.4.4 Previous work on losses in valves

Substantial work has been done on the prediction of minor losses in pipe systems. In this section a brief review of work relevant to this investigation is presented. The different types of valves tested found in the literature are presented in Table 2.2 and for diaphragm valves in turbulent flow in Table 2.3.

The work of Edwards *et al.* (1985), Banerjee *et al.* (1994), and Turian *et al.* (1978), are all based on gate and globe valves not on diaphragm valves. They are relevant to this work by their methodology and mode of presentation of results.

- Edwards *et al.*, (1985), tested a range of Newtonian and non-Newtonian fluid flow through gate, and globe valves of 25 and 50 millimetres fully opened. They found that it is possible to present the data as a relationship between the loss coefficient and a generalised Reynolds number. They observed that in the laminar flow region, the loss coefficient is inversely proportional to the Reynolds number and can be obtained as:

$$k_v = \frac{C_v}{Re} \quad (2.64)$$

This is the same as equation (2.56). At higher Reynolds numbers a rapid transition is observed to a region in which the loss coefficient becomes constant, at about Re=130. In the case of gate valves, for various test fluids and for the two sizes used, the data falls together, and the analysis of experimental data gave the correlation:

$$k_v = \frac{273}{Re} \quad (2.65)$$

For globe valves the data for the two dimensions do not fall together. The transition from laminar flow is very rapid and occurs at a low Reynolds number of about 10. For the particular design of globe valves tested, in the fully open position, the following correlations were obtained:

For 25 millimetres valve: $Re < 12$

$$k_v = \frac{1460}{Re} \quad (2.66)$$

$Re > 12$ $\quad k_v = 122$ **(2.67)**

For a 50 millimetres valve: $Re < 15$

$$k_v = \frac{384}{Re} \quad (2.68)$$

$Re > 15$ $\quad k_v = 25.4$ **(2.69)**

- Banerjee *et al.*, (1994), presented experimental data on the pressure drop across 12.5 millimetres globe and gate valves in the horizontal plane for pseudoplastic fluids in laminar flow. They used generalised correlations in terms of various physical and dynamic variables for the prediction of the frictional pressure drop for each valve.

  Three effects were studied:

  1. The effect of pressure drop across the valve by plotting static pressure against length for a designated fluid.
  2. The effect of the valve opening on pressure drop across the valve by plotting pressure drop against volumetric flow rate at different opening position: The pressure drop increases with an increase in volumetric flow rate for a constant opening. As the opening became smaller, the curve became steeper.

3. The effect of the non-Newtonian characteristics on pressure across the valves by plotting pressure drop across the valve against the volumetric flow rate for different concentration of slurries. At a particular opening of the valve, the pressure drop decreases as the flow behaviour index increases.

The dimensional analysis of the experimental data, suggested the following relationship:

$$\frac{\Delta p}{\rho V^2} = f(Re, \alpha) \qquad \textbf{(2.70)}$$

The functional relationships developed using the above equation through multivariable linear regression analysis were as follows:

Correlation for globe valve:

$$\frac{\Delta p}{\rho V^2} = 8.266 Re^{-0.061 \pm 0.013} \alpha^{-0.797 \pm 0.030} \qquad \textbf{(2.71)}$$

After plotting this the values of $\frac{\Delta p}{\rho V^2}$ predicted using the equation above and the experimental values, the correlation coefficient and variance of estimate are 0.9496 and 1.326×10^{-2}.

Correlation for gate valve:

$$\frac{\Delta p}{\rho V^2} = 1.905 Re^{-0.197 \pm 0.046} \alpha^{-1.987 \pm 0.091} \qquad \textbf{(2.72)}$$

After plotting this the values of $\frac{\Delta p}{\rho V^2}$ predicted using the equation above and the experimental values, the correlation coefficient and variance of estimate are 0.9344 and 1.106×10^{-2}.

- Turian *et al.*, (1997), determined losses for the flow of concentrated slurries of laterite and gypsum solutions through 25 and 50 millimetres globe and gate valves. The loss coefficients were found to be inversely proportional to the generalised Reynolds number for laminar flow and to approach constant asymptotic values for turbulent flow, through gate and globe valves, The following correlations were obtained:

For the 25 millimetres gate valve the transition from laminar to turbulent flow was observed between Re=100 and Re=1000 and k_v=320/Re and after the transition, in turbulent flow, k_v=0,797.

For the 50 millimetres gate valve the transition from laminar to turbulent flow was observed between Re=1000 and Re=10000 and k_v=320/Re for the laminar region and after the transition, in turbulent flow, k_v=0,168.

For the 25 millimetres globe valve, the transition from laminar to turbulent flow was observed earlier for Re<100 and the correlation obtained was k_v=10,039 for turbulent flow.

For the 50 millimetres globe valve also the transition was observed earlier for Re<100 and the correlation obtained was k_v=6,719.

- Hooper, (1981) using the two-K method defined a dimensionless factor K, as the excess head loss in a pipe fitting, expressed in velocity heads. K does not depend on the roughness of the fitting (or attached pipe) or the size of the system, but is a function of the Reynolds number and the exact geometry of the fitting and is given by:

$$K = \frac{K_1}{Re_{MR}} + K_\infty\left(1 + \frac{1}{D}\right) \quad \textbf{(2.73)}$$

where: K_I is K for the fitting at Re_{MR}=1, K_∞ is K for a large fitting at $Re_{MR}=\infty$ and D the pipe internal diameter. He found that: K_I = 1000 and K_∞ = 2 for a dam or weir type diaphragm valve. Doing the analogy with the definition in this study, it can be said that C_v =1000 and k_v =2.

- Pienaar *et al.*, (2004) tested a 40 mm nominal bore diameter diaphragm valve over a Reynolds number range of 1 to 50000 using various Newtonian and non-Newtonian fluids and obtained Cv=1000 and kv=2.5.

- Miller, (1978) classified the valve loss coefficients in three classes:

Class 1 or definitive loss coefficients: Loss coefficients in this class are based on experimental data usually from two or more sources or from research programmes, which have been crosschecked against other work. The loss coefficients are considered definitive.

In practice the loss coefficients in class 1 are usually not directly applicable, because of the severe restraints imposed on inlet and outlet conditions and geometrical accuracy

Class 2 or adequate loss coefficient for design purposes: Experimentally derived loss coefficients from isolated research programmes where no detailed crosschecking is possible against other sources.

Estimated loss coefficients from two or more research programmes whose results do not agree with what could be expected to be the experimental accuracy

Loss coefficients from class 1 converted to apply outside the strict limitations imposed in class 1 coefficients and for which experimental information is available to predict the effects of departing from class 1 conditions.

Class 3 or suggested loss coefficient: Experimentally derived values from less reliable sources

Loss coefficients from class 1 and 2 converted to apply outside their range of application and about which there is little or no information to predict the effects of departing from the conditions under which they were derived.

Loss coefficients in diaphragm valves are classified as class 3 and are given in turbulent flow; these loss coefficients can be obtained from the figure below for both weir and straight through diaphragm valves (Figure 2.9)

In fully open position in turbulent flow, the loss coefficient is approximately 0.8 for the straight-through diaphragm valve.

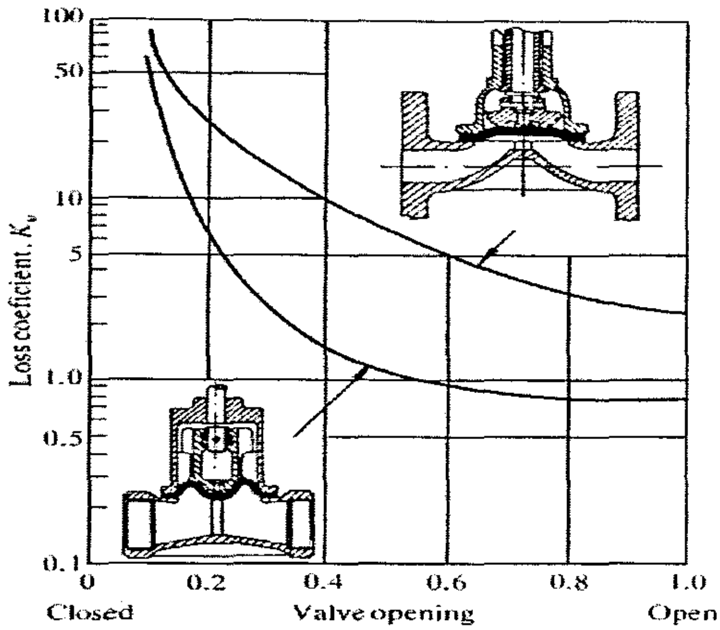

Figure 2. 9 Loss coefficient vs. valve opening (Miller, 1978)

Table 2. 2 Valves (Pienaar *et al.*, 2001)

TYPE	SIZE [mm]	REFERENCE	C_v
	25	Turian *et al.*, 1998	
	50	Turian *et al.*, 1998	320
	25	Edwards *et al.*, 1985	273
Gate	50	Edwards *et al.*, 1985	273
	25	Turian *et al.*, 1998	
	50	Turian *et al.*, 1998	
	25	Edwards *et al.*, 1985	1460
Globe	50	Edwards *et al.*, 1985	384
3-way plug	-	Steffe *et al.*, 1984	
Check valves			
Ball			
Horizontal lift			
Bronze disc swing		Kittredge & Rowley,	
Composition disc swing	12.5	1957	
Diaphragm	-	Hooper, 1981	1000

Table 2. 3 Loss coefficients for turbulent flow through diaphragm valves (Perry & Chilton, 1973)

Operating mode	Loss coefficient, k_v
Open	2.3
¾ open	2.6
½ open	4.3
¼ open	21

2.7 DYNAMIC SIMILARITY

In this section, the theory related to the establishment of dynamic similarity and its application to the flow of non-Newtonian fluids flow in valves is presented.

2.7.1 Geometric Similarity

Geometric similarity is similarity of shape (Massey, 1970) and is the first requirement for the establishment of physical similarity. If two systems are geometrically similar the ratio of any length in one system to the corresponding length in the other system is everywhere the same and this ratio is called the scale factor.

Geometric similarity exists between a model and a prototype if the ratios of all corresponding dimensions in model and prototype are equal (Giles, 1977):

$$\frac{L_{model}}{L_{prototype}} = L_{ratio} \qquad \text{or} \qquad \frac{L_m}{L_p} = L_r \tag{2.74}$$

$$\text{and} \quad \frac{A_{model}}{A_{prototype}} = \frac{L^2_{model}}{L^2_{prototype}} = L^2_{ratio} = L^2_r \tag{2.75}$$

2.7.2 Kinematic Similarity

Kinematic similarity is similarity of motion (Massey, 1970). This implies first, geometric similarity and then similarity of time intervals in the motion.

Kinematic similarity exists between a model and a prototype if the paths of homologous moving particles are geometrically similar and if the ratios of the velocities of homologous particles are equal (Giles, 1977):

$$\text{Velocity ratio:} \quad \frac{V_m}{V_p} = \frac{L_m/T_m}{L_p/T_p} = \frac{L_r}{T_r} \tag{2.76}$$

$$\text{Acceleration ratio:} \quad \frac{a_m}{a_p} = \frac{L_m/T^2_m}{L_p/T^2_p} = \frac{L_r}{T^2_r} \tag{2.77}$$

$$\text{Discharge ratio: } \frac{Q_m}{Q_p} = \frac{L_m^3/T_m}{L_p^3/T_p} = \frac{L_r^3}{L_r} \tag{2.78}$$

2.7.3 Dynamic Similarity

Dynamic similarity is similarity of forces (Massey, 1970). Dynamic similarity exists between geometrically and kinematically similar systems if the ratios of all homogenous forces in model and prototype are the same.

In the case of a fluid flowing in a closed conduit, as in this investigation, in a pipe, the dominant forces are the viscous and inertial forces, other forces like the pressure force, the surface tension force are negligible and do not affect the flow.

The only interesting ratio in this case is the ratio:

$\left|\frac{\text{Inertial force}}{\text{Viscous force}}\right| = \frac{\rho V l}{\mu}$ which for a Newtonian pipe flow is the Reynolds number Re and is in this case, equation (2.12):

$$Re = \frac{\rho V D}{\mu} \tag{2.12}$$

Thus two flows passing geometrically similar boundaries are dynamically similar if the only forces affecting those flows are only viscous, pressure and inertia forces, if the magnitude ratio of inertia and viscous forces at corresponding points are the same. Since this ratio is proportional to the Reynolds number, two systems are dynamically similar when the Reynolds number of the two systems based on corresponding characteristic lengths and velocity are the same for the two flows (Massey, 1978).

2.7.4 The Application of Dynamic similarity for Non-Newtonian Fluid Flows in Valves

If only one kind of forces are dominant, apart from inertia and pressure forces, then complete dynamic similarity is achieved simply by making the values of the appropriate dimensionless parameter the same for model and prototype, in this case the Reynolds number (Massey, 1978).

For the case of a Newtonian fluid, the Reynolds number is easily obtained and is used to establish dynamic similarity, but for non-Newtonian fluids, the task is not simple because of other parameters like the yield stress and the rheogram curvature, which must be well established.

For the flow of non-Newtonian fluids in valves, viscous forces are dominant and forces due to weight and surface tension do not play a role. The dimensionless group known as the Reynolds number is of prime importance and two systems are dynamically similar if their Reynolds numbers are the same. Unlike the Newtonian model, where the rheology is characterised by only one parameter the viscosity, the non-Newtonian model is characterised by three parameters: the yield stress, the fluid consistency index and the flow behaviour index. The Slatter Reynolds number accounts specifically for the yield stress together with the other two parameters and can be used to establish dynamic similarity (Slatter & Pienaar, 1999).

To conclude, two non-Newtonian flows in geometrically similar valves are similar if their Slatter Reynolds numbers are the same.

As said earlier, the first requirement for physical similarity is geometric similarity, thus this similarity establishment will be carried on the same type of valves from the same manufacturer otherwise it will be meaningless (Slatter & Pienaar, 1999).

2.8 CONCLUSION

Far from being comprehensive, this chapter attempts to present the necessary theory on Newtonian and non-Newtonian fluid flow in straight pipes, pipe fittings and valves, but with an emphasis on non-Newtonian materials flowing in valves especially in diaphragm valves.

From the literature review, it was found that data on diaphragm valves are scarce. Perry & Chilton (1973) give some values of the loss coefficient in diaphragm valves for Newtonian fluids in turbulent flow. Miller (1978) gives a graph of k_v vs opening of the valve for the determination of an approximate loss coefficient in turbulent flow. Hooper (1981) presents loss coefficient data for a dam or weir type diaphragm valve in the laminar and turbulent flow regimes. Pienaar *et al.* (2004) present data for one size diaphragm valve in both laminar and turbulent flow.

As said earlier, the work of Edwards *et al.* (1985), Banerjee *et al.* (1994), and Turian *et al.* (1978), are all based on gate and globe valves, not on diaphragm valves. However, they are relevant to this work by their methodology and mode of presentation of results.

2.9 RESEARCH ASPECT IDENTIFIED

After the completion of the literature review it has been obvious that there is a need for much more data on loss coefficients through diaphragm valves for both Newtonian and non-Newtonian fluids and there is also a need to evaluate existing data. Data on diaphragm valves are scarce and are only approximations. Hooper (1981); Miller (1978) and Perry & Chilton (1973) give the loss coefficient without specifying the dimension of the valve. Hooper (1981) gives the laminar loss coefficient C_v and the loss coefficient in turbulent flow. Perry & Chilton (1973) and Miller (1978) give only the loss coefficient in turbulent flow for Newtonian fluids. Miller classifies loss coefficients in diaphragm valves as class 3 data, i.e. data from less reliable sources. Data from other type of valves has been converted to apply to diaphragm valves and about which there is little or no information to predict the effects of departing from the conditions under which they were derived (Miller, 1978).

It also became apparent that there is a need to define experimental procedures in the determination of loss coefficients in valves because the value of the loss coefficient is dependent on the experimental procedure used and definitions (Chhabra & Slatter, 2002).

CHAPTER 3

CHAPTER 3
EXPERIMENTAL WORK

3.1 INTRODUCTION

This chapter describes the experimental test loop. It also provides an in-depth geometric analysis of the type of diaphragm valve tested. The description and calibration of the instrumentation used in the test work, the experimental procedure of the test work, the description of all materials tested and the general theory on errors are also given. Raw results from experimental tests are also presented.

The experimental test loop used is the new Valve test rig. After the construction of the test loop and the calibration of the different instrumentations, commissioning was successfully done by running water tests in all the pipes, followed by tests with non-Newtonian slurries.

3.2 DESCRIPTION OF THE TEST LOOP

The test loop used is the new state-of-the-art Valve test rig. The Valve test rig is 22m long and 2,6m high. It consists of a storage and mixing tank of 1,75 m^3 with a header or weigh tank of 500 litres on top. The fluid is forced in the test loop by a positive displacement pump. Before reaching the test sections, the fluid passes a surge damper, then through a heat exchanger. The fluid passes through two magnetic flow meters in parallel; one for the lines of 50 and 63 millimetre outside diameters and the other one for the lines of 75, 90 and 110 millimetre outside diameters. The test section consists of 6 lines of 50, 63, 75, 90 and two110 millimetre outside diameters respectively. At every entry of a test line there is a diaphragm control valve to direct the fluid. The fluid exits all test lines through a manifold. For each test line there are two pipes of 10 metres long joined in series by a diaphragm valve. Figure 3.1 gives a schematic diagram of the Valve test rig.

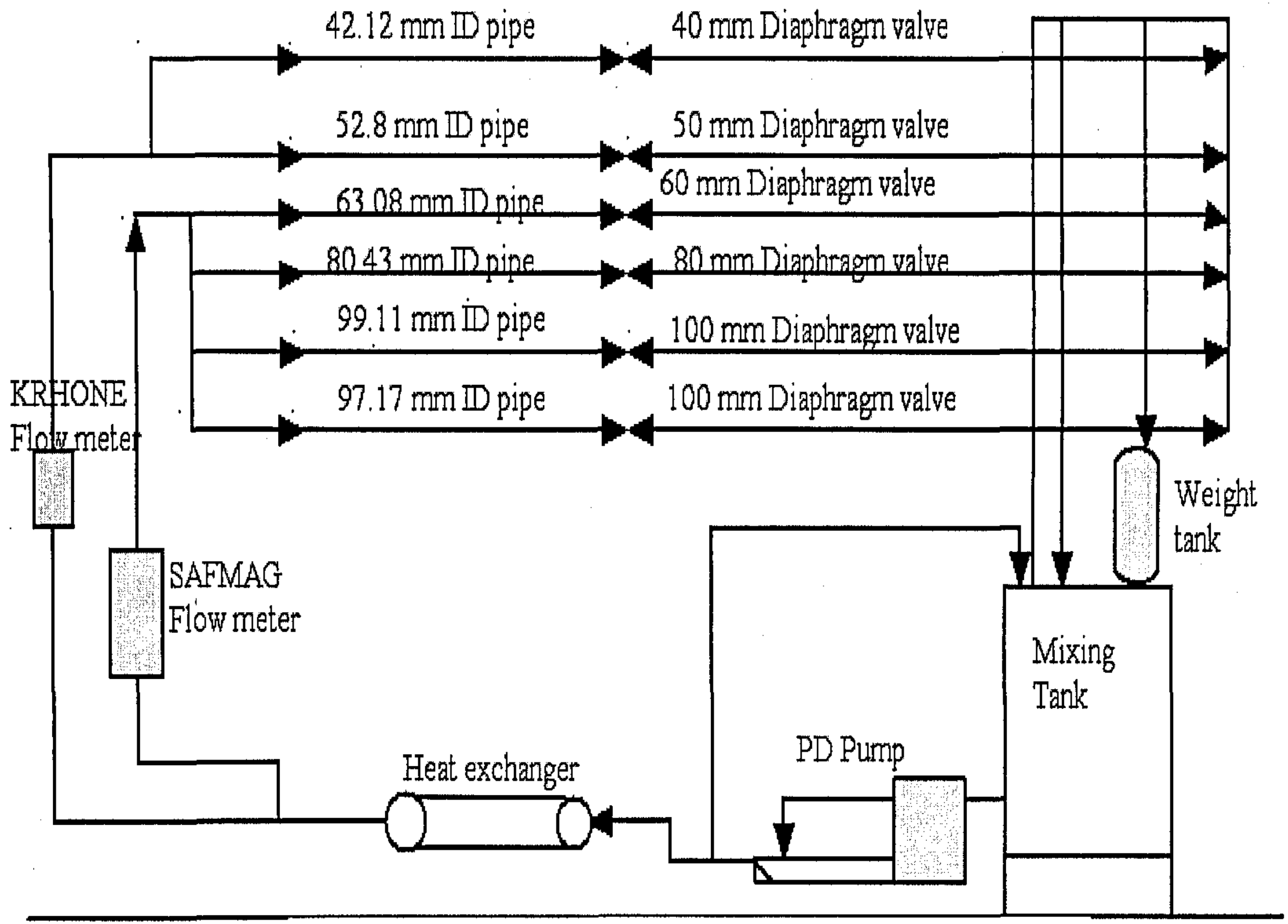

Figure 3. 1 Schematic diagram of the Valve test rig

3.3 INSTRUMENTATION

This section describes the instruments connected to the test loop when running different tests in order to collect experimental data.

3.3.1 Pipes and Valves

The pipes used for the test loop were all PVC pipes clear or non-clear with negligible roughness.

The valves used for determining the loss coefficient are the NATCO straight-through diaphragm valves of 40, 50, 65, 80 and 100 millimetre nominal bore diameter and are low resistance valves.

Table 3.1 gives the outside diameters (OD) or nominal diameter of the six test lines and their internal diameters (ID) as were determined experimentally. The experimental method for the determination of ID is explained later in this Chapter 3 (3.5.12.1).

Table 3. 1 Nominal and internal dimension of pipes and valves.

Test Line Number	Outside Diameter [mm]	Internal Diameter [mm]	Valve Dimension [mm]
1 (Top)	50	42.12	40
2 (2nd Top)	63	52.8	50
3 (3rd Top)	75	63.08	65
4 (4th Top)	90	80.43	80
5 (2nd Bottom)	110	99.11	100
6 (Bottom)	110	97.17	100

Figure 3.2 gives an external view of the diaphragm valve used and Fig.3.3 shows the way these diaphragm valves were connected to pipes, Fig.3.4 shows the internal structure of the diaphragm valves at the fully open position.

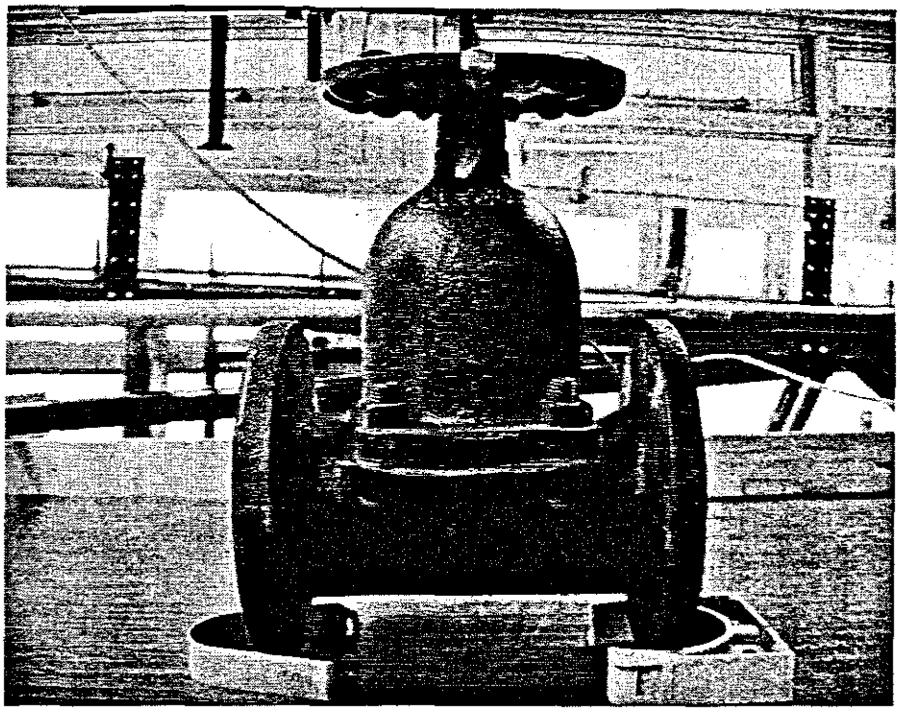

Figure 3. 2 Diaphragm valve

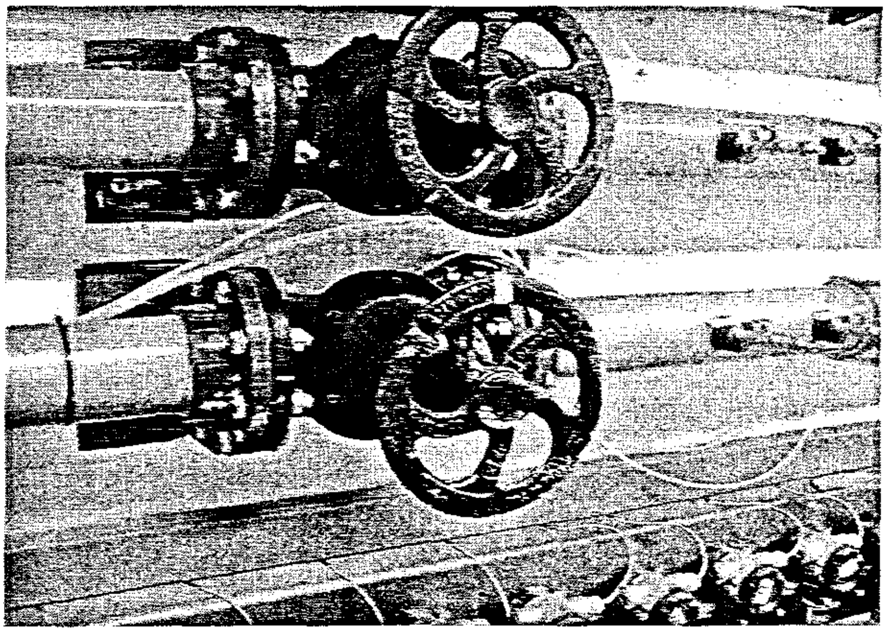

Figure 3. 3 Connection of diaphragm valves with pipes.

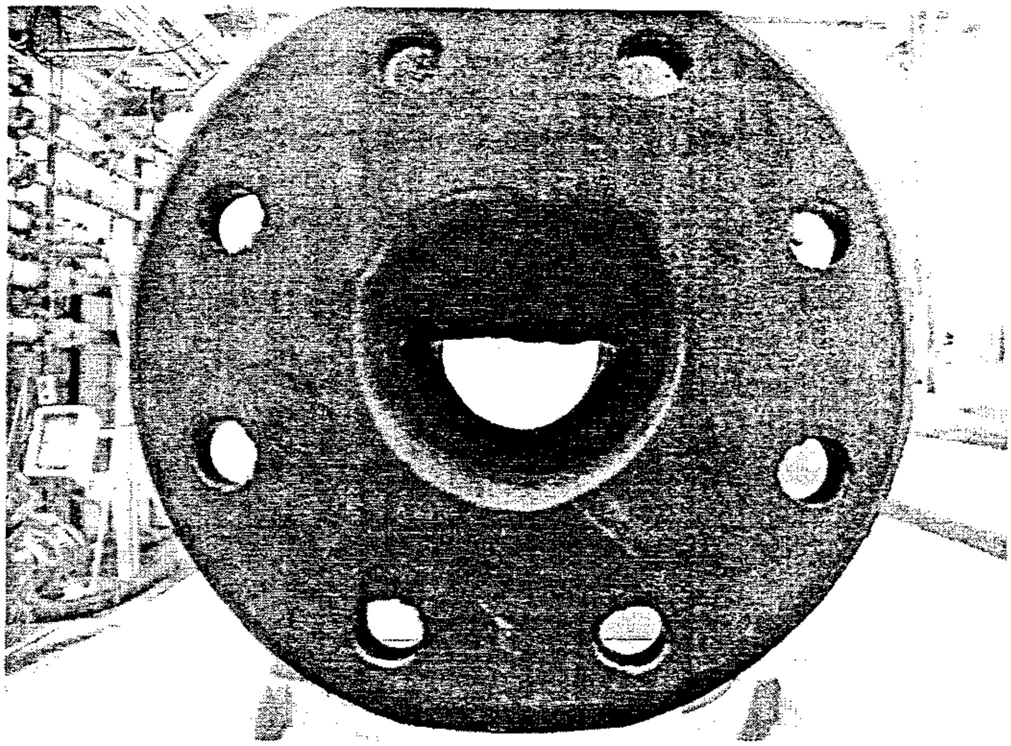

Figure 3. 4 Internal structure of the valve in the fully open position.

The diaphragm valves tested are also characterised by some internal dimensions characteristics that are: *Cross section dimensions* (Width & Depth), Diaphragm dimension (Height, width, Per rev) and bore dimension (A, B and C.). Figure 3.5 gives such approximate dimensions for an 80 mm nominal bore diameter diaphragm valve. The diaphragm valve manufacturer supplied the information given in Table 3.2 and Figure 3.5. It is obvious that the dimensions are not always exactly the same for each nominal bore size valve. They are within a certain tolerance as specified by the manufacturer.

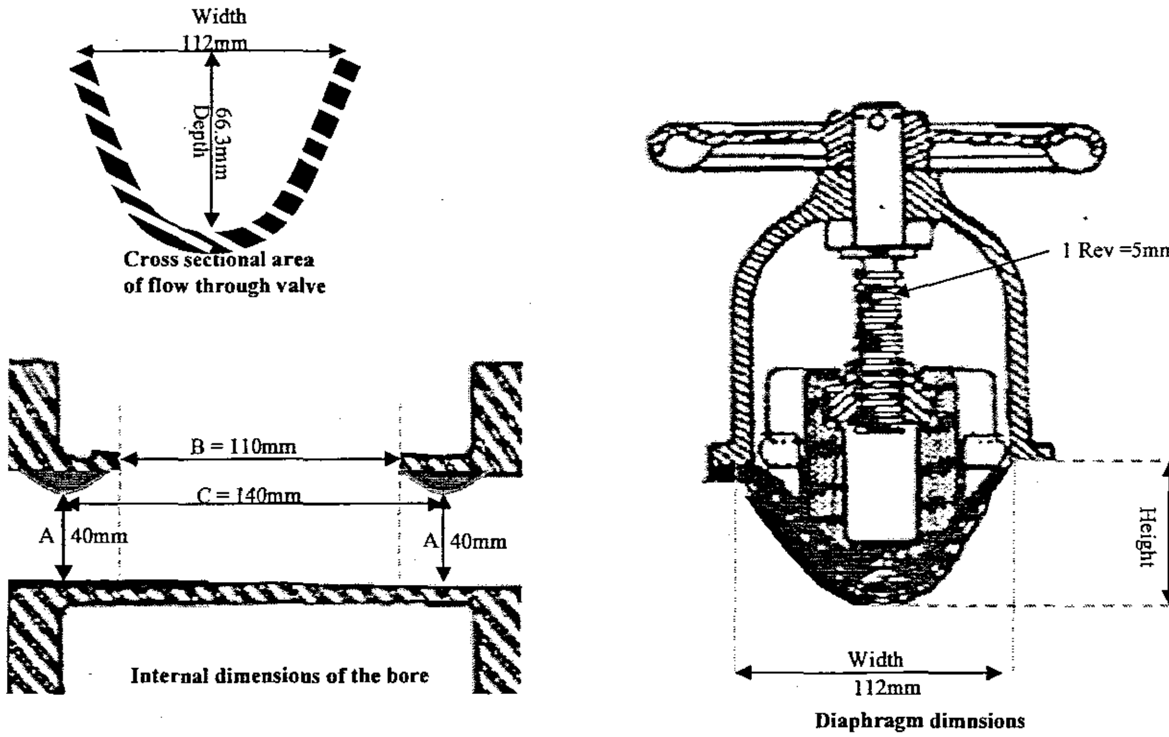

Figure 3. 5 Internal dimension of the 80 mm nominal bore diaphragm valve.

Table 3.2 gives such dimensions (in mm) for all 5 sizes of diaphragm valve tested and Table 3.3 gives such dimensions for all 5 sizes in a dimensionless form, dividing all dimensions of a given valve by the nominal bore size.

Table 3. 2 Internal dimensions of diaphragm valves tested

Bore size	*Cross section area*		*Diaphragm Dimension*			*Bore dimension*		
	Depth	Width	Height	Width	Per Rev	A	B	C
40	35.26	42.78	36.00	47.38	3.00	26.18	45.02	65.34
50	46.65	64.26	47.00	66.34	4.50	36.26	66.71	81.00
65	62.42	90.82	63.00	92.14	5.00	40.00	88.00	125.00
80	68.92	112.00	69.00	114.20	5.70	42.26	111.00	140.50
100	74.72	124.46	75.00	129.92	6.50	62.14	128.00	150.40

Table 3.3 Dimensionless Internal dimensions of diaphragm valves tested

Bore size	*Cross section area*		*Diaphragm Dimension*			*Bore dimension*		
	Depth	Width	Height	Width	Per Rev	A	B	C
1	0.88	1.07	0.90	1.18	0.08	0.65	1.13	1.63
1	0.93	1.29	0.94	1.33	0.09	0.73	1.33	1.62
1	0.96	1.40	0.97	1.42	0.08	0.62	1.35	1.92
1	0.86	1.40	0.86	1.43	0.07	0.53	1.39	1.76
1	0.75	1.24	0.75	1.30	0.07	0.62	1.28	1.50

From these data, a geometric similarity analysis was done based on the fact that geometric similarity exist between a model and a prototype if the ratios of all corresponding dimensions in model and prototype are equal:

$$\frac{L_{model}}{L_{prototype}} = L_{ratio} \tag{2.74}$$

Taking every size as a prototype and comparing with all other sizes and also by analysing the dimensionless sizes of the diaphragm valves tested, it was found that no geometric similarity could be observed between the 5 sizes of diaphragm valves used.

From Fig.3.4, it can be observed that the type of diaphragm valves used has a tapered or narrowed bore through the body of the valve. The full bore opening is characterised by an obstruction of the diaphragm through the opening and the size of the obstruction varies from size to size and is respectively 4.74, 3.35, 2.58, 11.03, 25.28 millimetres for the 40, 50, 65, 80 and 100 millimetres bore nominal diameter. And the scale factor of the height of the obstruction on the nominal bore diameter is 0.12, 0.067, 0.04, 0.14, 0.25 for the 40, 50, 65, 80 and 100 millimetres bore nominal diameter. Once again, no geometric similarity was found. All dimensions above mentioned are tabulated in Table 3.4.

Table 3.4 Obstruction size and scale ration for the diaphragm valves tested

Bore size	Obstruction size	Obstruction/Bore size
40	4.74	0.12
50	3.32	0.07
65	2.58	0.04
80	11.03	0.14
100	25.28	0.25

3.3.2 Pressure lines, pressure lines board, tappings and pods

Nylon tubes of 3 mm internal diameter were used as pressure lines. They were connected to the test section by tappings via pods and the pressure lines board (PLB) to pressure transducers.

Each test line had tappings at various positions from which the experimenter could choose according to the type of the experimental test to be run.

The pressure line board (PLB) as designed by the author of this investigation, is a hydraulic circuit that allows to select points where the static pressure can be read off. It is also used to set the technique to be used while running the experimental tests. As it will be explained later in this chapter there were six techniques using the PLB and the nine point pressure transducers and two differential pressure transducers to run experimental tests on the Valve test rig: automatic mode (AM), manual single (MS), manual all (MA), American standard method (ASM), straight pipe test (SPT), HGL DP Cell mode. The PLB is a very useful tool and consists of a circuit of nylon tubes and ball valves on a perspex board. The nylon tubes are classified in four pressure lines (PL1, 2, 3 and 4) and the ball valves in: deviation valves (D), isolation valves (I), exit valves (E), bypass valves (B) and connecting valves (C). Deviation valves allow to isolate the PLB and to work in automatic mode with all the pressure transducers at the same time. The isolation valves allow to separate two or more given tappings from other tappings. The exit valves allow to isolate a given tapping from the other tappings. The bypass valves allow to isolate a pressure line and the Connecting valves allow to connect a given PL to a pressure transducer. Figure 3.6 gives a schematic diagram of the pressure lines board and Figure 3.7 gives the connection of the PLB (the rectangular central part) to the test line and to pressure transducers.

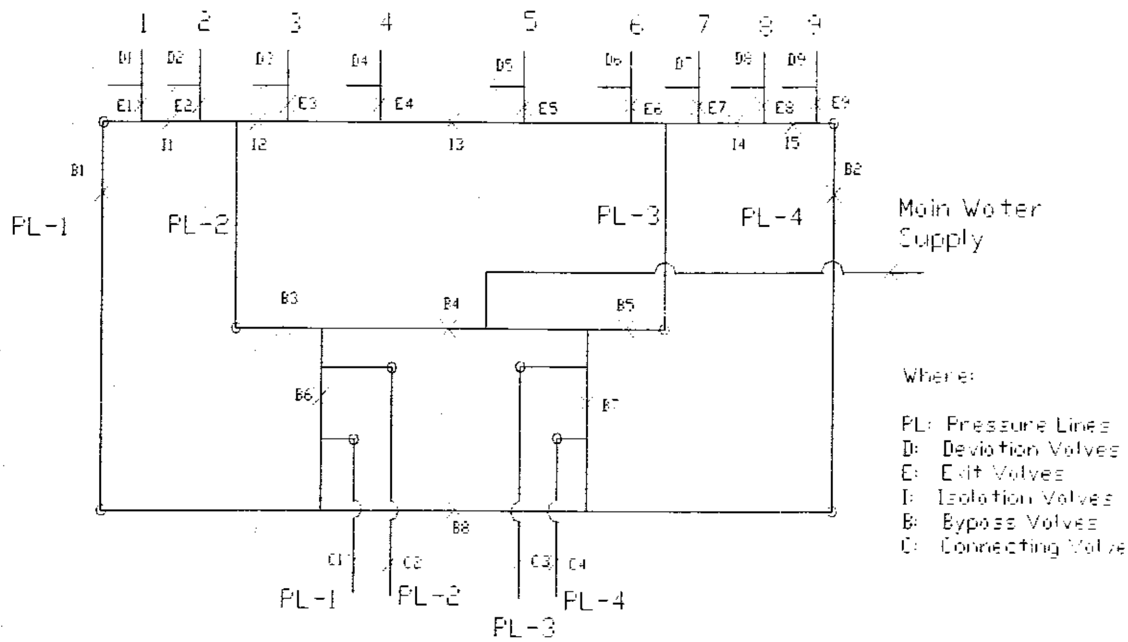

Figure 3. 6 Schematic diagram of the pressure lines board

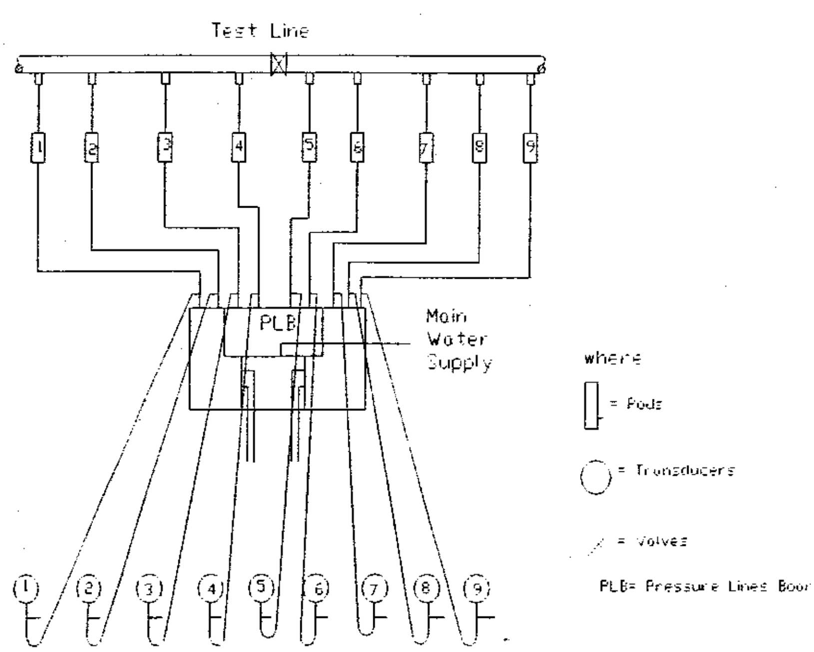

Figure 3. 7 Connection of the PLB (the rectangular central part) to pods and pressure transducers.

3.3.3 Pressure Transducers

Two kinds of pressure transducers were used:

a) The Point Pressure Transducer (PPT): It is used to measure static pressure at a given point in the test line.
b) The Differential Pressure Transducer (DP Cell): It is used to measure the difference of static pressure between two points.

At the time of the completion of this investigation, the Valve test rig had nine PPT and two DP Cells in operation. The nine PPT's have a range span of 130 kPa and are mostly used to run the tests in: automatic mode, manual mode, manual mode all. The two DP Cells, has the range span of 130 kPa and 6 kPa respectively. They are mostly used to run test in the HGL DP cell mode, Straight pipe test and American standard Method. These pressure transducers are connected to the PLB by means of nylon tubes as shown in Figure 3.7 and to the data acquisition unit (DAU) by means of electrical cables.
Included in Appendix 1 is a picture of the pressure transducers used (point pressure transducer and differential pressure transducer).

3.3.4 The Hand Held Communicator

The type of hand held communicator (HHC) used is the FXW 10 AY1- A3. It is a portable instrument with many features and is used for the zeroing, calibration, change of unit, range setting, span and damping time setting of both the differential pressure transducer (DPT or DP Cell) and the point pressure transducer (PPT). The hand held communicator is also a display unit of pressure transducers and the two instruments are twins as one cannot be used successfully without the other.
Included in Appendix 1 is shown the picture of the hand held communicator.

3.3.5 The data acquisition unit or data logger

The data acquisition unit used is the model HP 34970A, which is equipped with many channels and it converts electrical signals from pressure transducers, temperature sensors, flow meters and load cell connected to it into digital signals that are logged to the computer.

Included in Appendix 1 is the picture of the Data Acquisition Unit.

3.3.6 Computer and Software

A Celeron 300 was used for data capturing and processing. Test programs were written in Visual Basic 6. The data capturing, analysis and processing was done in Microsoft Excel.

3.3.7 Flow meters

Two magnetic flow meters were used during test work and they were both mounted vertically:

- A Krohne IFC 010D of 50 millimetre internal diameter
- A Safmag 100A2NESSR0032 of 110 millimetre internal diameter.

Include in Appendix 1is the pictures of the flow meters.

3.3.8 Tank and Mixer

The 1.75 m^3 storage tank was fitted with a mixer of the type SEW EURODRIVE ARF 57 DT 90L4 with power of 3 kW. It also has on top a header or weight tank of 500 litre capacity for the calibration of flow meters and flow rate determination in the flow region where the flow meter reading becomes inaccurate.

Included in Appendix 1 is the picture of the mixing tank and the weight tank on top.

3.3.9 Pump

The pump used is an Orbit reversible positive displacement pump of the type B4001 CI EN8 NIT with a power of 5,5 kW, with a helical rotor. This pump is fitted with a variable speed drive, which allows shifting the speed of rotation of the pump rotor.

Included in Appendix 1 is the picture of the Pump used.

3.3.10 Manometers

Two U-tube manometers were used for calibration of the pressure transducers:

-A mercury- water manometer was used for the calibration of higher pressure ranges.

-A water air manometer was used to calibrate lower pressure ranges.

3.3.11 Pressure Gauges

Digital pressure gauges were used mostly to verify the pressure readings of the hand held communicator and that of the computer programme output after the calibration coefficients have been included.

3.3.12 Temperature probes

The temperature of the slurry was measured at two positions in the Valve test rig using temperature probes. The first position was: at the end of the heat exchanger and the second at the mainstream flow exit. Both temperature probes were linked to the data acquisition unit that reads the temperature in degrees Celsius. As the data acquisition reads the temperature directly, no signal calibration was required.

3.4 EXPERIMENTAL PROCEDURE

3.4.1 Calibration

The calibration of the instruments was done for two major reasons: firstly in order to get reliable results and secondly in order to transform the electrical signal from the instruments in a digital signal to be read to the computer workstation. The computer program needs some calibration constants called signal calibration.

3.4.1.1 DP Cells

Two DP Cells were used during the test works. One of the range span of 130 kPa and another of the range span of 6 kPa.

The calibration of the differential pressure transducers was done in the following manner:

-Prior to everything, the DP Cell is manually zeroed and than electronically zeroed with the Hand Held Communicator when there is no external pressure applied to both sides of the DP Cell.

-Than the DP Cell is connected to the manometer so that the high and low sides are respectively connected to the high and low side of the U-tube manometer

-All the air bubbles are flushed from the lines using the main water supply connected to pressure lines of the DP Cell.

-A differential pressure within the range limit is set up in the U-tube manometer.

-The differential pressure is read digitally using the Hand Held Communicator at the same time the DP Cell DC voltage output is read from the Data logger.

-The differential pressure is than decreased uniformly in 5 parts and the previous step is repeated until the equilibrium is attained.

The calibration line is obtained by performing a linear regression on the pressure difference and the transducer DC voltage output. The coefficient of correlation R^2 should be at least 0.999. Figure 3.8 shows an example of the calibration regression lines of the DP cell of 6 kPa span range for two ranges.

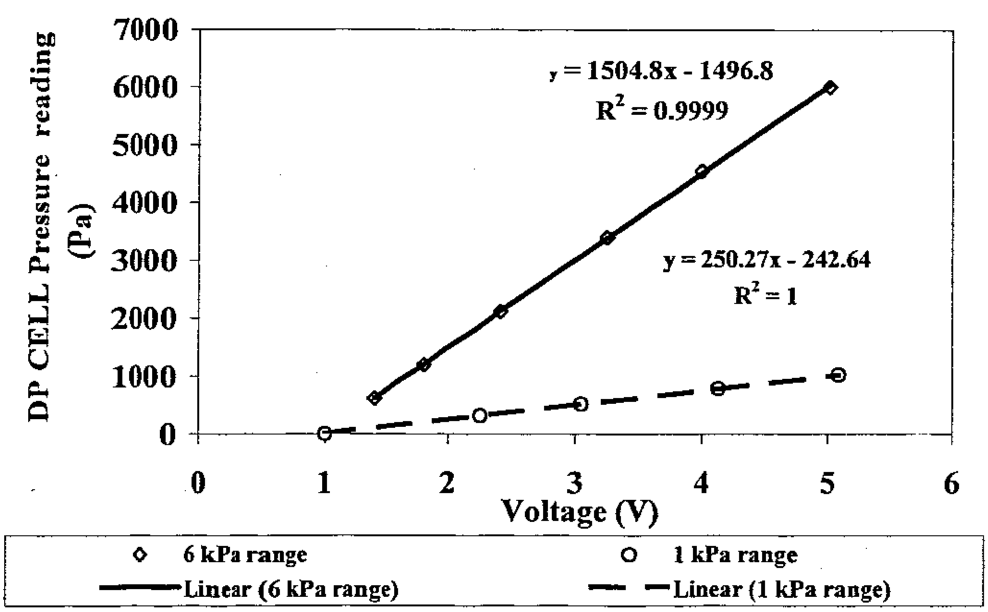

Figure 3. 8 Calibration regression lines of the DP cell of 6kPa span range showing calibration regression lines for 0-6kPa range and 0-1kPa range

3.4.1.2 Point pressure transducer

The calibration of the Point Pressure Transducer was done in the same way as for the DP Cell described above with the only difference being that the pressure line of the PPT was connected to the high side of the U-tube manometer. The differential pressure was read between the higher meniscus and the centre line of the PPT. Figure 3.9 gives an example of the calibration line of a PPT of 130 kPa in the range of 0 to 40kPa. Table 3.3 gives the calibration constants for different transducers.

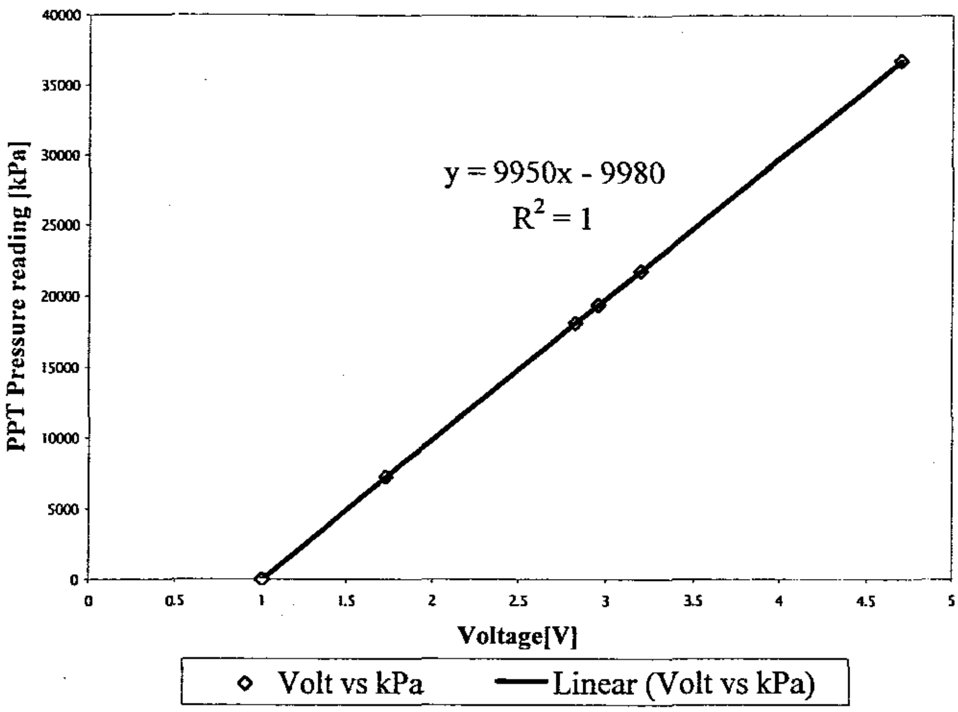

Figure 3. 9 Calibration regression line of a Point pressure transducer of 130 kPa

Table 3. 3 Calibration constants for different transducers

PPT	RANGE	Ax	B	R^2
1	0-40	10010.35x	-10046	1
	0-130	32476.02x	-32544	1
2	0-40	9950.038x	-9980	1
	0-130	32382x	-32498	1
3	0-40	9986.15x	-9996.4	1
	0-130	32783.99x	-32303	1
4	0-40	9990.15x	-9994.7	1
	0-130	32419x	-32478	1
5	0-40	9962.22x	-10046	1
	0-130	32413.23x	-32484	1
6	0-40	9975.65x	-9985.6	1
	0-130	32435x	-32475	1
7	0-40	9973.85x	-9987.4	1
	0-130	32542.59x	-32542	1
8	0-40	9971.99x	-10002	1
	0-130	32422.77x	-32516	1
9	0-40	9987.98x	-9992.4	1
	0-130	32457.46x	-32422	1

3.4.1.3 Load Cell

The load cell that supports the header or weigh tank is depicted in Appendix 1. It is used to weigh the fluid diverted from the mainstream flow. To calibrate it, the fluid is weighed in a container using an electronic scale. The fluid is then poured in the weigh tank, and the container is weighed again to take the difference in masses. Once the difference in mass between the container with fluid and the empty container is taken, the voltage output is recorded. For every increase in load, the increase in voltage is recorded.

The recorded values of the increase in load are plotted against the recorded values of the corresponding voltage as shown in Figure 3.10. A linear regression of the plot will give the relationship between the load and the corresponding voltage. This is then entered in the program to be used to calculate the flow rate.

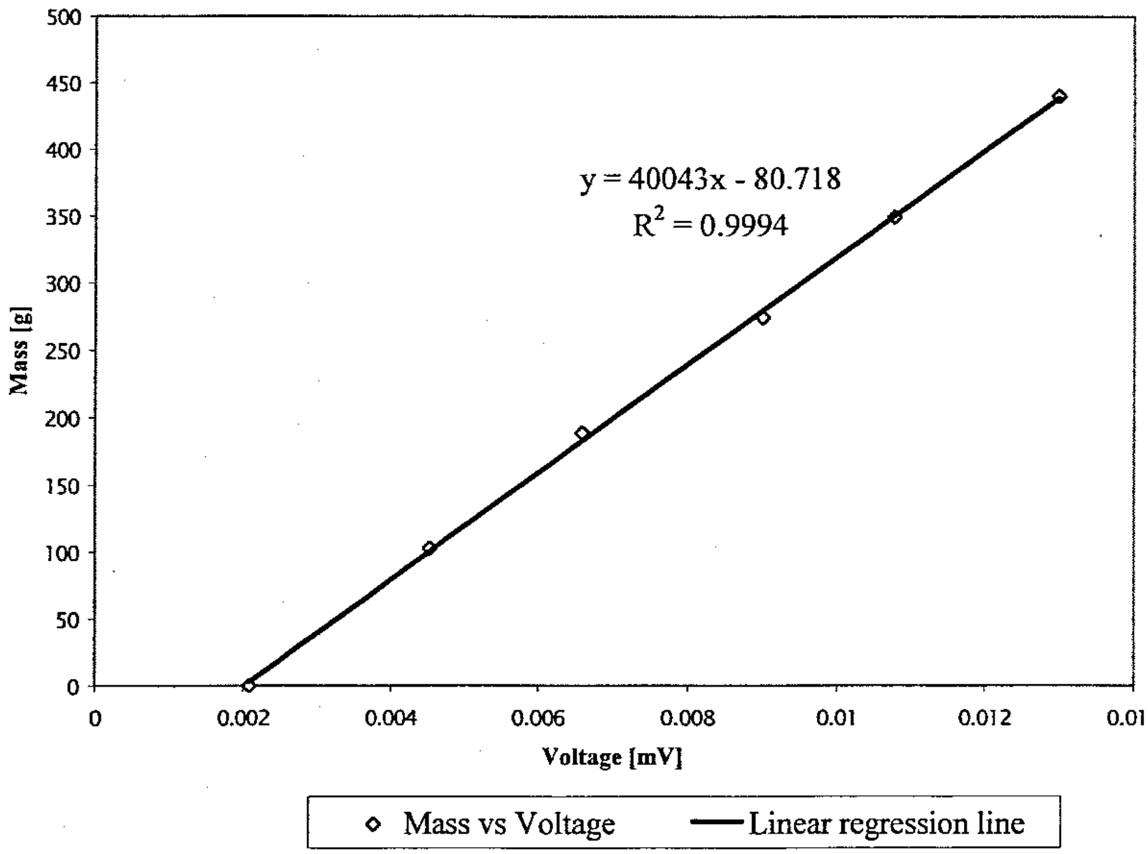

Figure 3. 10 Calibration regression line of Load Cell

3.4.1.4 Flow meter

The materials tested vary in chemical composition and concentration, so each material is tested over the flow rates used by diverting the flow into the weigh tank. The flow meters that measure the flow rates are, according to the manufacturers, accurate for slurries. To confirm this, each flow meter is calibrated with each slurry concentration that will be tested.

The calibration procedure is as follows:

For each flow meter the flow rate range is divided into 12 different flow rates over the whole range that the flow meter can measure. Each flow rate is then weighed with time in the weigh tank. The data logger continuously samples the change in weight with time, and from these readings the average flow rate is calculated. The sampling period varies from 120 s for low flow rates to 12 s for the high flow rates. This is repeated for all the flow rates.

The flow rates versus voltages are then plotted and the straight-line regression gives the relationship between flow rate and volts as well as the error fit. Figure 3.11 gives a typical calibration regression line for a flow meter.

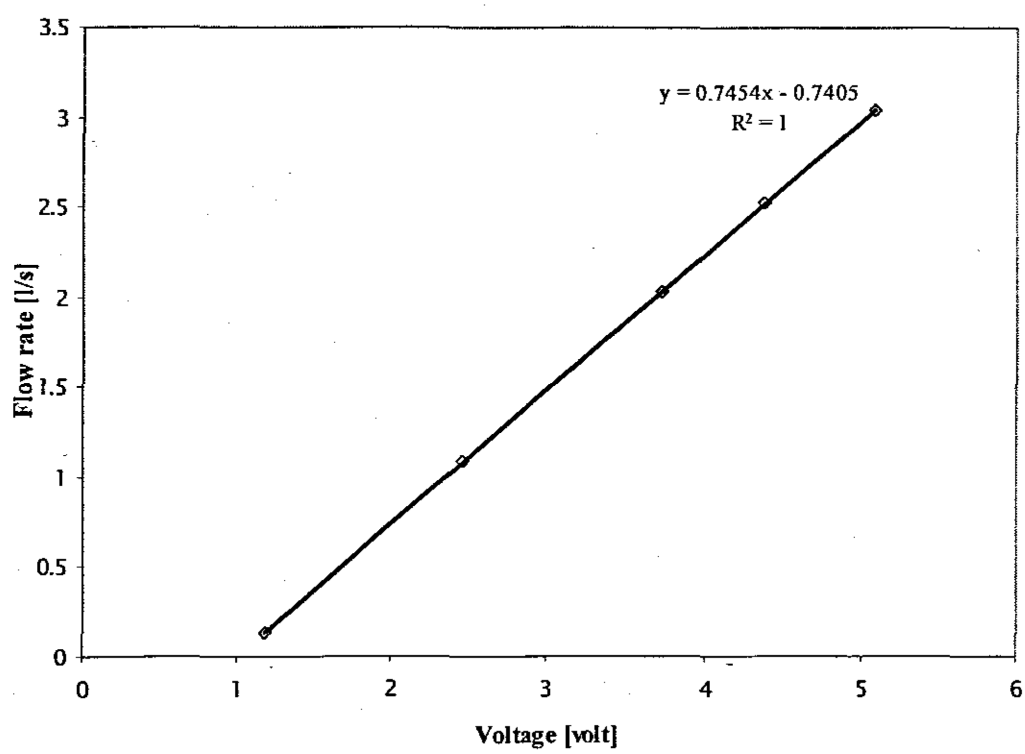

Figure 3. 11 Calibration regression line for the Krohne flow meter

3.4.2 Experimental Test Method (Valve Pressure Drop Test and Straight Pipe Test or Tube Viscometry)

The valve test rig is a versatile instrument and is a miniature pipeline. Two principal types of tests may be conducted on the valve test rig: the viscometry test or straight pipe test and the valve pressure drop test. These tests may be conducted simultaneously or separately.

The rheology or straight pipe test consists of measuring the pressure drop in the straight pipe sections at different flow rates whereas the valve pressure drop test consists of measuring the pressure drop incurred by the test valve at different flow rates.

Generally, there are two approaches to measure the valve pressure drop: The hydraulic grade line (HGL) approach and the total pressure drop approach. In the context of this investigation, as said earlier, the hydraulic grade line approach was used. Because the valve test rig was specially designed for that approach. This approach can be applied in an automatic mode or a manual mode depending on flow conditions as follows:

In automatic mode, all the pressure readings are taken simultaneously using all the nine transducers and every transducer reads a pressure on one tapping.

The HGL automatic mode is selected when the static pressure in the test section is high enough so that different PPT's can measure accurately the pressure gradient along the test section. This condition is likely to happen when testing small diameters (50, 63 and 75 millimetres OD) or bigger diameters at higher flow rates (90, 110 millimetres OD) or testing very dense materials.

The HGL manual mode is the technique in which, one transducer is used to read the static pressure drop at each tapping at a time and this technique is facilitated by the PLB. This technique is selected when the pressure drops between different pressure tapings on the test section are small and can be measured accurately by one Point Pressure Transducer (PPT) at a time. This condition is likely to occur when testing bigger pipes (90 and 110 millimetres OD) or very light materials.

DP Cell mode: this mode is also manual and consists of measuring the HGL but using a DP Cell this mode is also applicable on bigger pipes. Using the PLB, the high side of the DP Cell is connected to the first pod and the low side to the other pods, one by one. The DP Cell mode is also used for the straight pipe test or rheology test.

The American standard method (ASM): this method uses two DP cells at the same time to measure pressure gradients between 10 diameters and 20 diameters upstream and downstream of the valve.

The HGL automatic and ASM may be conducted by one operator whereas the HGL manual and the DP Cell mode require at least two operators.

The operating procedures of the modes cited above are explained in the sections below.

3.4.2.1 Main stream flow

The core of any technique selected is the same, as it requires having a flow of the slurry tested on the test section. This flow is called the mainstream flow. The mainstream flow is set by following this procedure (Figure 3.12)

- Make sure the pump by-pass valve is open to direct the flow back to the tank.
- Switch on the pump, this allows the slurry to mix
- Choose the test line (pipe diameter) to be tested
- Choose the correct route leading to the test line by using control valves 1A or 1B on Figure 3.12. If 1A is chosen then 2A or 2B can be selected.

If 1B is chosen then either 2C, 2D, 2E or 2F can be selected.

Start closing the by-pass valve so that the mainstream flow is established in the selected pipe at the required flow rate.

The flow rate can be regulated by throttling the by-pass valve of the pump or by using the variable speed control.

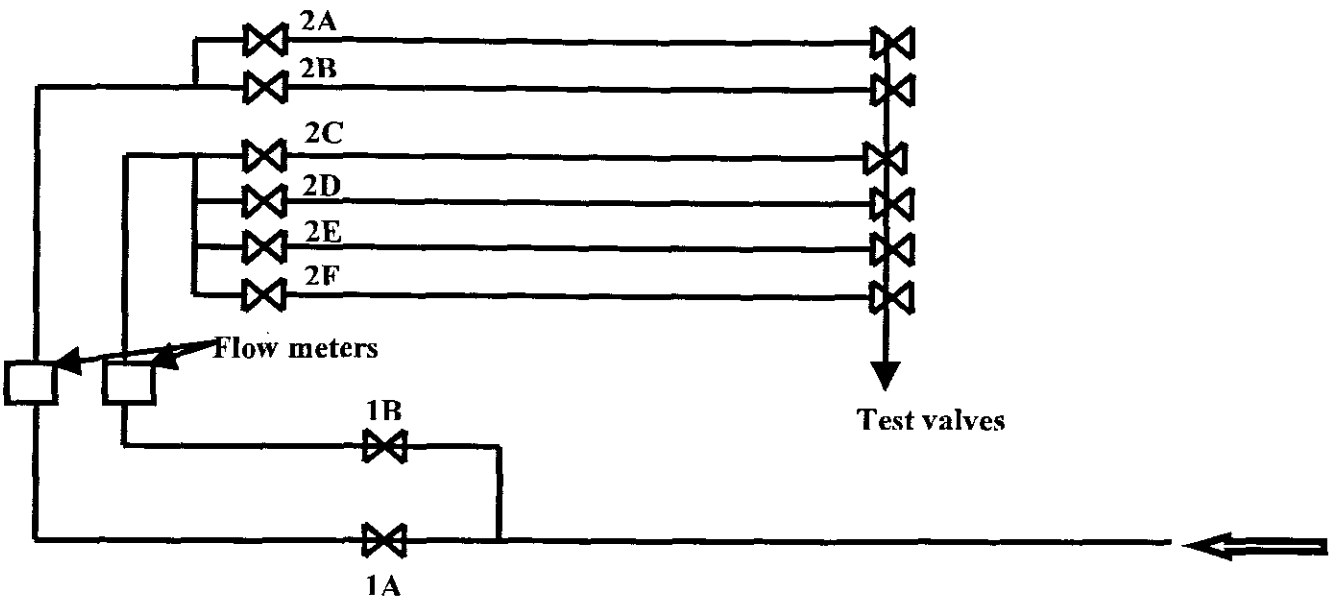

Figure 3. 12 Over view of the Valve test- rig direction valves. Valves (1&2) are on-off valves to direct the mainstream flow

3.4.2.2 HGL automatic mode

The automatic mode on the Valve test rig is achieved by setting the ball valves on the Pressure Lines Board (Figure 3.6) as follows:

The exit valves: E1, E2, E3, E4, E5, E6, E7, E8 and E9 are closed. The deviation valves: D1, D2, D3, D4, D5, D6, D7, D8 and D9 are opened. The pressures coming from all nine tappings and pods are directed straight to the PPT.

In this mode the static pressures are read for all the tapping points simultaneously to obtain the pressure gradient upstream and downstream the test valve.

3.4.2.3 HGL manual mode

The manual mode on the Valve test rig can be conducted by using only one PPT:

- On the PLB (Figure 3.6), the exit valves: E1is open to read the pressure on taping 1
- E2 to E9 are closed.

- The deviation valves: D1to D9 are closed. The isolation valves (I1, I2 I3and I4) are also open
- The by-pass ball valves (B1, B2, B3, B4, B5and B6) are closed, also closed are all the connecting ball valves C except C1.
- C1 is connected to a pressure transducer.
- Take the reading.
- Close valve E1 and open E2
- Read the pressure, close E2 and open E3
- Continue this procedure until valve E9 is open.

3.4.2.4 DP Cell mode

This procedure is used in three ways:

- The straight pipe test
- The hydraulic grade line and
- The American standard method

3.4.2.4.1 Straight pipe test

The straight pipe test can be done simultaneously downstream and upstream of the test-valve and the procedure is as follows.

1. Choose the straight pipe sections in which the pressure drop will be measured, upstream and downstream of the test valve and record the tapping distance respectively.
2. On the pressure lines board (Figure 3.6) close the isolating valve I1 (or I2), I3 and I4 (or I5)
3. Open the valves E according to the test sections chosen, deviation valves D and other E must be closed
4. Close the bypass valve B2, B4, B5 and B6
5. Use the pressure lines PL-1 and PL-2 to measure the pressure drop upstream of the test valve by opening the connecting valves C1 and C2

6. Ensure that the pressure line PL-1 is connected to the high side of the DP Cell and PL-2 to the low side of the DP-Cell
7. Use the pressure lines PL-3 and PL-4 to measure the pressure drop downstream of the test valve by opening the connecting valves C3 and C4.
8. Ensure that the pressure line PL-3 is connected to the High side of the DP Cell and PL-4 to the Low side of the DP Cell.

3.4.2.4.2 The hydraulic grade line

The HGL in this case is done using a DP Cell by isolating the first pod from the others and by opening the pods (pressure tappings) one after another and recording the pressure gradient. The procedure is the same as the straight pipe test described above up to step 8 then proceeds:

9. Open the isolating valve I3
10. Open the respectively E2, take the reading, close E2 and open E3 and continue up to E9
11. Change the flow rate and repeat step 10.

3.4.2.5 The American standard method

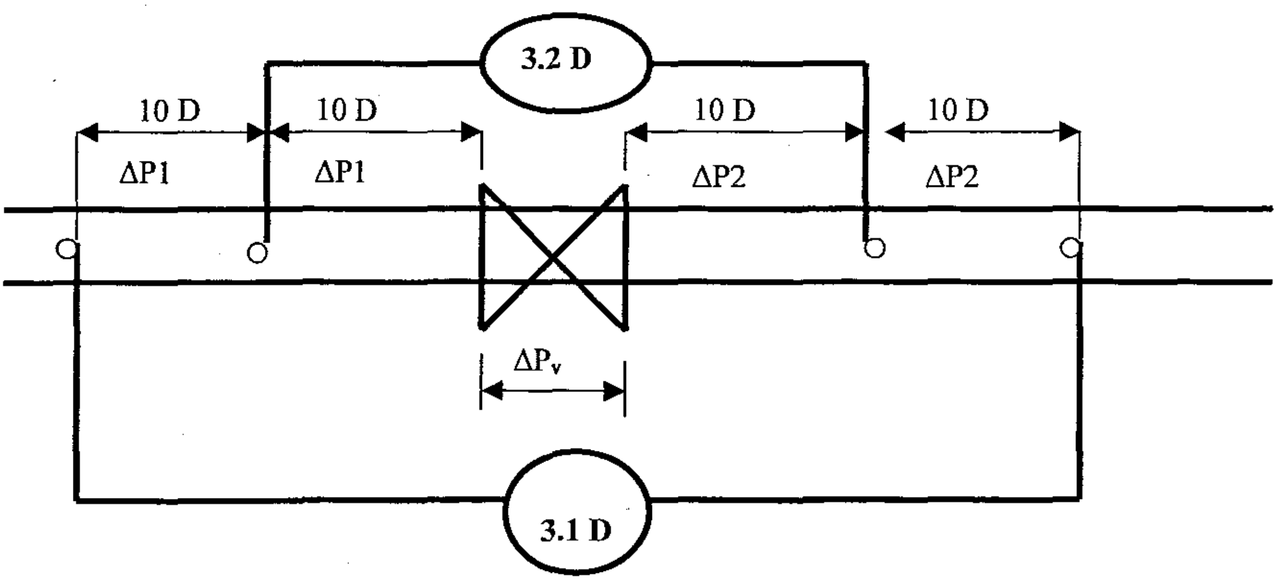

Figure 3. 13 DP Cells position in the American Standard Method

In this procedure two DP Cells are used. The DP Cells are connected as shown in Figure 3.13. The tapping points for the first DP Cell are placed respectively at 10D upstream and downstream of the test valve and the tapping points for the second DP Cell are placed respectively 20D upstream and downstream from the test valve.

The procedure is the same as the straight pipe test described earlier.

3.5 EXPERIMENTAL ERRORS

Absolute accuracy in measuring or counting does not always happen, unless the data are discrete numbers. It is important to be able to determine the margins of error which may be found in a set of data and to know how they are affected by various arithmetic processes such as addition, multiplication, root extraction, etc.

3.5.1 Error Theory

There are three types of error: Gross errors, systematic errors and random errors.

3.5.2 Gross Errors

Gross errors are due to blunders, equipment failure, and power failure. A gross error is immediate cause for rejection of a measurement (Benzinger & Aksay, 1999)

3.5.3 Systematic or Cumulative Errors

Systematic errors result in a constant bias in an experimental measurement. Systematic errors are those that are due to known conditions. These conditions might be:

- Natural (temperature, pressure, humidity, etc.)
- Instrumental (calibration, graduation, range, etc.)
- Personal (poor sight of the experimenter, inability of the experimenter to take correct reading, etc.) size (Barry, 1991).

In this work, systematic errors are not taken into account. Precautions were taken to prevent these errors from occurring: e.g. checking the calibration of instruments by another instrument not related to the instrument in use or independent calibration and also by checking the reproducibility of results.

3.5.4 Random Errors

Random errors are those that are due to chance variation. Most experiments proceed with minor variations that change from event to event and follow no systematic trend. The same quantity may be measured many times, giving close but not identical results. The fluctuations in the measurement are assumed to be random and lead to a distribution of values.

3.5.5 Precision and Accuracy

Precision and accuracy are terms that refer to the quality of data.
Accuracy distinguishes systematic errors, highly accurate measurements have minimal systematic error (Benziger & Aksay, 1999).
Precision distinguishes random errors. Precision is a gauge of the variation of repeated measurements. Precise measurements have minimal random error.

3.5.6 Evaluation of Errors

3.5.6.1 Single error: absolute and relative error

The absolute error is the difference between the true value of any number or quantity and the value obtained or used for that number or quantity in a given circumstance. If the true value of a number or quantity is X, the value obtained or used for that number or quantity is A, and the absolute error is ΔA then:

$$X = A \pm \Delta A \tag{3.1}$$

This means that X is comprised between A-ΔA and A+ΔA. ΔA is called the maximum error or absolute error . If X is a quantity, ΔA is expressed in the same unit. ΔA is here the smallest division of the instrument, the smallest value detected by the instrument (Barry, 1991). ΔA is calculated from the standard deviation of a set of repeated measurements as well. The absolute error for A at 99,9% confidence interval is given by the equation:

$$\Delta A = 3{,}29\sigma \tag{3.2}$$

If a 95% confidence level is considered, then the absolute error may be approximated by:

$$\Delta A = 2\sigma \quad (3.3)$$

The relative or percentage error of a number or quantity is calculated by:

$$\delta A = \frac{\Delta A}{A} \quad (3.4)$$

3.5.6.2 Combined errors

When a variable is a result of a computation of other variables with their subsequent errors, the resulting error is the combination of the independent variable errors (mean quadratic value of the independents errors). If a variable X is a function of n other variables i.e., X=F (a, b, c...n), the expected highest error (Brinckworth, 1968) can be calculated from:

$$\left(\frac{\Delta X}{X}\right)^2 = \sum\left(\frac{\partial X}{\partial n}\right)^2\left(\frac{n}{X}\right)^2\left(\frac{\Delta n}{n}\right)^2 \quad (3.5)$$

Where X is the computed result

ΔX is the computed result absolute error

n are the independent variables involved

Δn are the independent variables absolute errors.

3.5.7 Error in Measurable Variables

3.5.8 Axial Distance

The axial distances or tapping point distances are measured using a measuring tape graduated in millimetres. The absolute error of the measurement is 0,001 m.

3.5.9 Weight

The weights of all the samples were measured using the balance in gramme. The absolute error on measurements is 0,001 kg.

3.5.10 Flow Rate

The flow meters used are accurate to 0,001 l/s, which can be assumed as absolute error.

3.5.11 Pressure

The pressure transducers used are accurate at 0,25%. Care should be taken in calibration so that a correlation coefficient must be 0,999. Such calibration can rise to an average error of 0,35% (Baudouin, 2003).

3.5.12 Error in derived variables

In this section the different equations used in the determination of all derived variables are given. The application of the equation (3.5) to all the equations is also given.

3.5.12.1 Pipe internal diameter

The pipe internal diameter was determined weighing a mass of water (M_{H_2O}) in to a known length of pipe (L). The pipe diameter is then calculated using the formula:

$$D = \sqrt{\frac{4M_{H_2O}}{\pi\rho_{H_2O}L}} \tag{3.6}$$

The highest expected error in calculating the pipe diameter is obtained by applying the equation (3.5) to equation (3.6) and that yields:

$$\frac{\Delta D}{D} = \pm\frac{1}{2}\sqrt{\left(\frac{\Delta M_{H_2O}}{M_{H_2O}}\right)^2 + \left(\frac{\Delta L}{L}\right)^2} \tag{3.7}$$

The highest expected error and experimental errors on the measurements of the five diameters of the valve test rig is given in the Table 3.4:

Table 3. 4 Expected Highest errors and experimental errors in the measurements of the Valve test- rig pipe diameters

Pipe position	Nominal Diameter OD [mm]	Mass-average [kg]	Length [mm]	Highest Expected Error [%]	Experimental Error [%]
Top	50	0.0421	1000	2.38	0.63
2nd Top	63	0.0528	1000	1.90	0.32
3rd Top	75	0.0631	1000	1.59	0.45
4th Top	90	0.0804	1000	1.25	0.22
2nd Bottom	110	0.0991	1000	1.01	0.36
Bottom	110	0.0972	1000	1.03	0.37

3.5.12.2 Velocity

The velocity in a pipe is determined from the continuity equation (2.11):

$$V = \frac{Q}{A}$$

Q and A are respectively, the flow rate and the cross section area of the pipe.
The application of equation (3.6) to equation (3.11) yields the highest expected error on the velocity given by:

$$\frac{\Delta V}{V} = \pm\sqrt{\left(\frac{\Delta Q}{Q}\right)^2 + 4\left(\frac{\Delta D}{D}\right)^2} \quad \textbf{(3.8)}$$

3.5.12.3 Pseudo shear rate

The pseudo shear rate is determined using the relation (2.43):

$$\dot{\gamma}_o = \frac{8V}{D}$$

The application of equation (3.5) to (2.43) gives the expected highest error of the pseudo shear rate and it yields:

$$\frac{\Delta \dot{\gamma}_o}{\dot{\gamma}_o} = \pm\sqrt{\left(\frac{\Delta Q}{Q}\right)^2 + 5\left(\frac{\Delta D}{D}\right)^2} \quad \textbf{(3.9)}$$

3.5.12.4 Wall shear stress

The shear stress is determined from the relation (2.8):

$$\tau_o = \frac{\Delta PD}{4L}$$

The application of equation (3.5) to (2.8) gives the expected highest error of the shear stress and that yields:

$$\frac{\Delta\tau_o}{\tau_o} = \pm\sqrt{\left(\frac{\Delta(\Delta P)}{\Delta P}\right)^2 + \left(\frac{\Delta D}{D}\right)^2 + \left(\frac{\Delta L}{L}\right)^2} \qquad \textbf{(3.10)}$$

3.5.12.5 Viscosity

The rheological characterisation was done most of the time with a correlation coefficient of at least 99%. Thus the error in viscosity or other rheological parameters did not exceed 1%.

3.5.12.6 Reynolds number

The Reynolds numbers errors in this work are evaluated on the Newtonian Reynolds number Re equation (2.12):

$$Re = \frac{\rho VD}{\mu}$$

Application of equation (3.6) to (2.12) yield:

$$\frac{\Delta Re}{Re} = \sqrt{\left(\frac{\Delta\rho}{\rho}\right)^2 + \left(\frac{\Delta Q}{Q}\right)^2 + \left(\frac{\Delta D}{D}\right)^2 + \left(\frac{\Delta\mu}{\mu}\right)^2} \qquad \textbf{(3.11)}$$

3.5.12.7 The valve loss coefficient

The valve loss coefficient is obtained from the equation (2.51):

$$H_v = k_v \frac{V^2}{2g}$$

or the pressure loss due to a valve is related to the head loss by:

$$\Delta P_v = \rho g H_V$$

then:

$$k_V = \frac{\Delta P_v}{\frac{1}{2}\rho V^2}$$

$$\left(\frac{\Delta k_V}{k_V}\right)^2 = \left(\frac{\Delta(\Delta P_v)}{\Delta P_v}\right)^2 + \left(\frac{\Delta \rho}{\rho}\right)^2 + 4\left(\frac{\Delta Q}{Q}\right)^2 + 16\left(\frac{\Delta D}{D}\right)^2 \quad \textbf{(3.12)}$$

In order to determine different quantities entering in the determination of experimental errors, valve pressure drop tests for clear water were run in the Valve test rig, for all the five pipe diameters. The technique consisted of keeping the output of the pump constant and taking 100 runs reading. The data was analysed statistically by determining the following quantities: mean value, average deviation, spread, median value. Equations (3.2) and (3.3) were used to calculate the absolute error and Equation (3.4) to calculate the relative error. For the variables: velocity, pseudo shear rate, shear stress, Reynolds number, valve loss coefficient and valve pressure drop (ΔP_V.).

From the data above mentioned can then be calculated the highest expected errors of each of the above variables mentioned using equations (3.8) to (3.12) and the actual errors of the valve test rig. The highest expected errors and actual errors of the valve test rig are given in tables 3.5, 3.6, 3.7 and 3.8.

Figure 3.14 illustrates the variation of normalised principal tests parameters for the line of 42.12 mm diameter.

On the x-axis is the name of the test and on the y-axis every parameter divided by its average value for the test described above. It can be seen that the wall shear stress and the valve loss coefficient present bigger variations than other parameters and eventually bigger errors.

In Tables 3.5, 3.6, 3.7, and 3.8, all the errors are calculated at 99% confidence level. These errors give the degree of confidence of a variable, the smaller the error, the more precise is the variable and the bigger the error, the less precise is the variable.

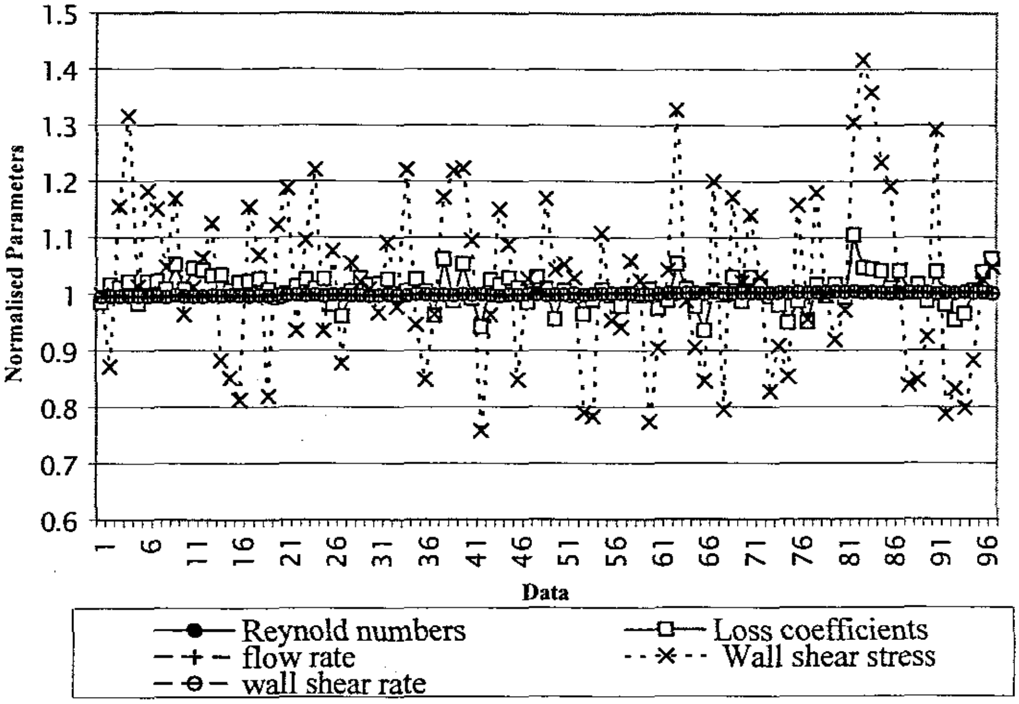

Figure 3. 14 Comparison of variation of principal parameters of the Valve test rig

Table 3. 5 Highest expected error in measurable variables of the Valve test rig:

OD	ID	Average Velocity (V)	Pseudo shear rate, 8V/D	Wall Shear Stree(τ_o)	Reynolds number (Re)
[mm]	[mm]	[l/s]	[s^{-1}]	[Pa]	-
50	42	1.895	1.997	11.802	1.549
63	53	0.668	0.740	0.372	0.372
75	63	17.557	17.562	17.539	17.539
90	80	1.788	2.026	21.910	1.747
110	97	1.298	1.350	16.679	1.129

Table 3. 6 Highest Expected errors of the Valve loss coefficient

Valve Dimension [mm]	Loss Coefficient (k_v)
40	12.38
50	11.16
65	40.80
80	22.20
100	16.88

In Table 3.6 the diaphragm valve of 65 mm nominal bore diameter has the highest expected error on the valve loss coefficient (k_v) compared to the other valves. The standard deviation, the spread and the average deviation of the variables studied (average velocity (V), pseudoshear rate (8V/D), wall shear stress (τ_o) and Reynolds number (Re) are higher than in any other line).

Table 3. 7 Errors of the Valve test rig

OD	ID	Reynolds number (Re)	PseudoShear Rate (8V/D)	Average Velocity (V)	Wall Shear Stress(τo)
[mm]	[m]	-	[1/s]	[m/s]	[Pa]
50	42	0.532	0.532	0.532	45.786
63	53	0.169	0.169	0.169	7.259
75	63	3.016	2.894	2.871	6.443
90	80	1.469	1.469	1.469	28.810
110	97	0.766	0.791	0.791	6.900

Table 3. 8 Errors of the Valve loss coefficient

Valve Dimension	Loss Coefficient (k_v) Error [%]
[mm]	-
40	8.841
50	9.594
60	18.316
80	20.389
100	13.252

3.5.12.8 Slurry Relative Density

The Relative Density Test was done on the tested fluid by collecting a sample of the fluid under test.

The test was performed as followed:

a) Three clean, dry volumetric flasks were weighed respectively (M_1)
b) The fluid was poured in those flasks to approximately half the volume and weighed respectively (M_2)
c) Water was added up to the graduated mark of the flasks, and weighed respectively (M_3). The flasks had to be shaken gently to remove any air bulbs.
d) The flasks were emptied and rinsed with water and alcohol to dry. Afterwards they were filled completely with water and weighed respectively (M_4).

<u>Calculations</u>

Mass of fluid: M_2-M_1

Mass of water filling the flask M_4-M_1

Mass of water filling the space left by the fluid: M_3-M_2

Mass of water having a volume equal to that of the fluid (M_4-M_1)-(M_3-M_2)

therefore:

$$RD = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad \textbf{(3.13)}$$

The arithmetic mean of the values obtained from the three flasks was taken as the actual RD.

The mass was measured with an electronic balance accurate to ±0,001 g, which is an absolute error of $\pm 10^{-6}$ kg.

3.6 MATERIALS TESTED

3.6.1 Introduction

The different materials tested were: water, glycerine, CMC and kaolin. The materials tested were selected in a way to represent different characteristics needed in this investigation. Water and glycerine being Newtonian fluids and CMC and kaolin non-Newtonian fluids, with CMC presenting pseudoplastic behaviour and kaolin yield pseudoplastic behaviour.

Fluids were selected that exhibit Newtonian, pseudoplastic and yield pseudoplastic behaviour to demonstrate that dynamic similarity can be obtained at the same Reynolds number provided that the Reynolds number correctly accounts for the viscous properties of the fluid.

3.6.2 Water

Water was used as a standard liquid, to commission the experimental test loop, to establish its credibility, accuracy and precision, because of its well-known properties and availability.

Tap water was used in both straight pipe tests and the valve pressure drop test (hydraulic grade line).

The water straight pipe results were correlated to the Colebrook & White equation (2.19). Graphs for different pipe sizes are presented in Appendix 2. Figure 3.15 gives a typical graph in linear coordinates and Figure 3.16 in logarithmic coordinates for the pipe of 42.12 mm ID (50 mm OD).

The valve pressure drop tests were also conducted and results were compared to the results found in the literature. These results are presented in Appendix 6. Figure 3.17 gives a typical valve pressure drop test for water.

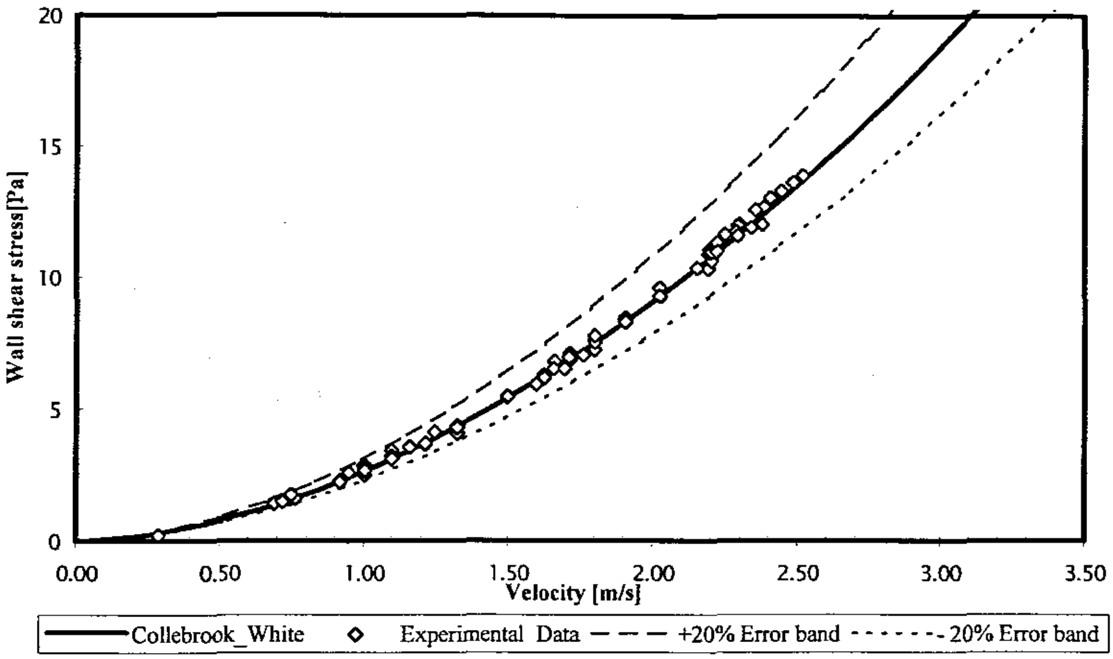

Figure 3. 15 Comparison of water test results with Colebrook & White equation

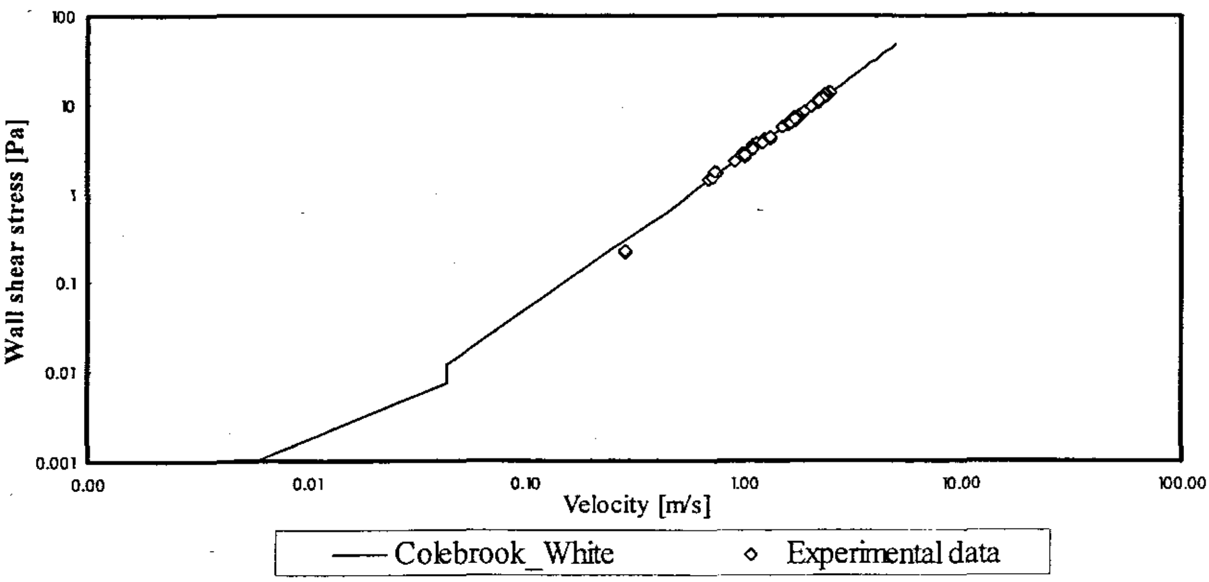

Figure 3. 16 Comparison of water test results with Colebrook & White equation in double logarithmic scale

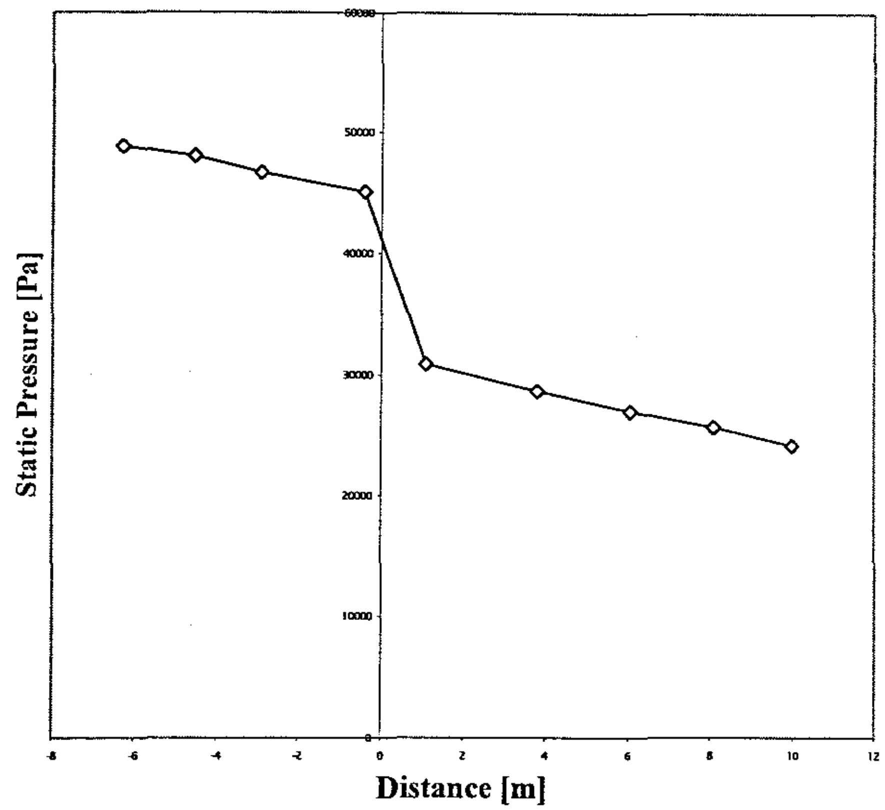

Figure 3. 17 Typical valve pressure drop curve of water in a 40 mm Diaphragm valve (V=1.79 m/s and Re_3=75753.99)

3.6.3 Carboxyl Methyl Cellulose Solution (CMC)

The CMC used in the test work is supplied in a powder form by Protea Chemicals and is dissolved in tap water to make a solution. CMC is widely used in industries as paper glue, protective colloid and resin emulsion (Pienaar, 1999). The powder was slowly dissolved in water and mechanically mixed using an agitator and care was taken to avoid the formation of large lumps. Mass concentration of 5 and 8% were tested.

Figure 3.18 gives a typical straight pipe test for CMC and Figure 3.19 gives typical valve pressure drop curve for CMC.

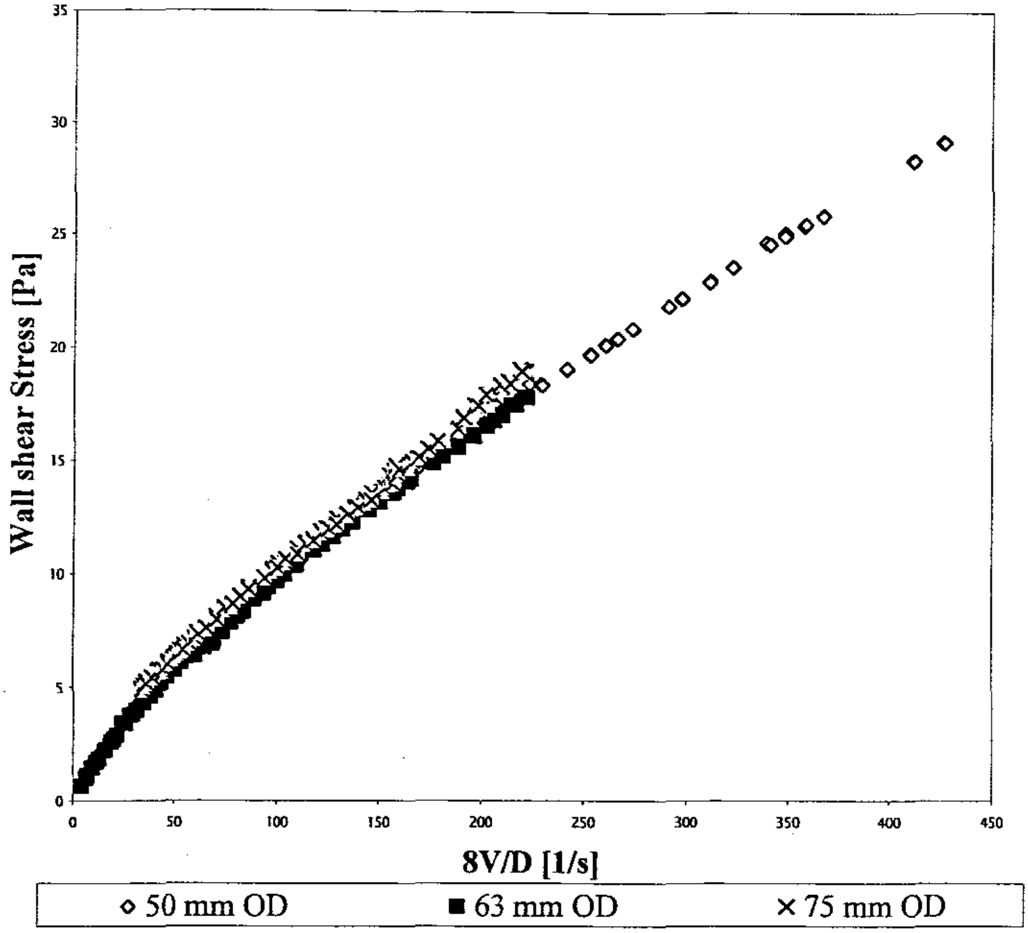

Figure 3. 18 Straight pipe test of CMC 5% in three pipe diameters

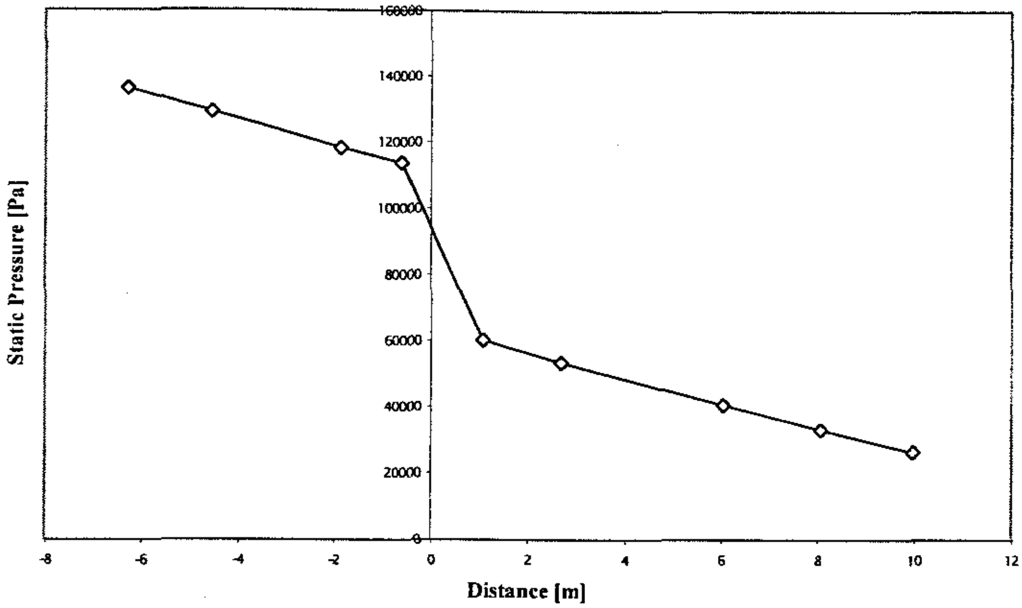

Figure 3. 19 Typical valve pressure drop curve of CMC 5% in a 40 mm nominal bore Diaphragm valve (V=3.04 m/s and Re_3=0.042)

3.6.4 Kaolin Slurry

The kaolin used in the preparation of kaolin suspensions is also supplied in powder form by Serina Kaolin (Pty) Ltd, and is mined in the Fish Hoek area near Cape Town. It is dissolved in tap water to obtain kaolin slurries. Volumetric concentrations of 10% and 13% were tested. Table 3.9 and 3.10 give the physical and chemical properties of dry kaolin and Figure 3.20 gives the particle size distribution (PSD) graph for kaolin powder. Figure 3.21 gives typical straight pipe tests curve for kaolin and Figure 3.22 gives typical valve pressure drop curve for kaolin.

Table 3. 9 Physical properties of dry kaolin

Physical Properties			Typical
1	Abrasiveness (Einlehner tester)		35 g/m²
2	Particle Size Distribution:		
		below 20 micron	100%
		12 micron	94%
		10 micron	90%
		6 micron	80%
		4 micron	70%
		3 micron	60%
		2 micron	48%
3	Reflectance Minimum (Elrepho)		83%
4	pH Value		5
5	Residue (Screen 45 um)		Max 0,20%
6	Specific gravity of kaolin mineral		2,60
7	Moisture:		
		Powder	0 - 1%
		Pellets	8 - 12%
8	Oil absorption of powder		45 - 50%
9	Bulk density of powder in bags		0,7g/cc

Table 3. 10 Chemical properties of dry kaolin.

Chemical Analysis	Typical %
SiO_2	46,00%
Al_2O_3	38,00%
Fe_2O_3	0,85%
TiO_2	0,58%
CaO	0,10%
MgO	0,18%
K_2O	1,00%
Na_2O	0,20%
L.O.I.	13,10%

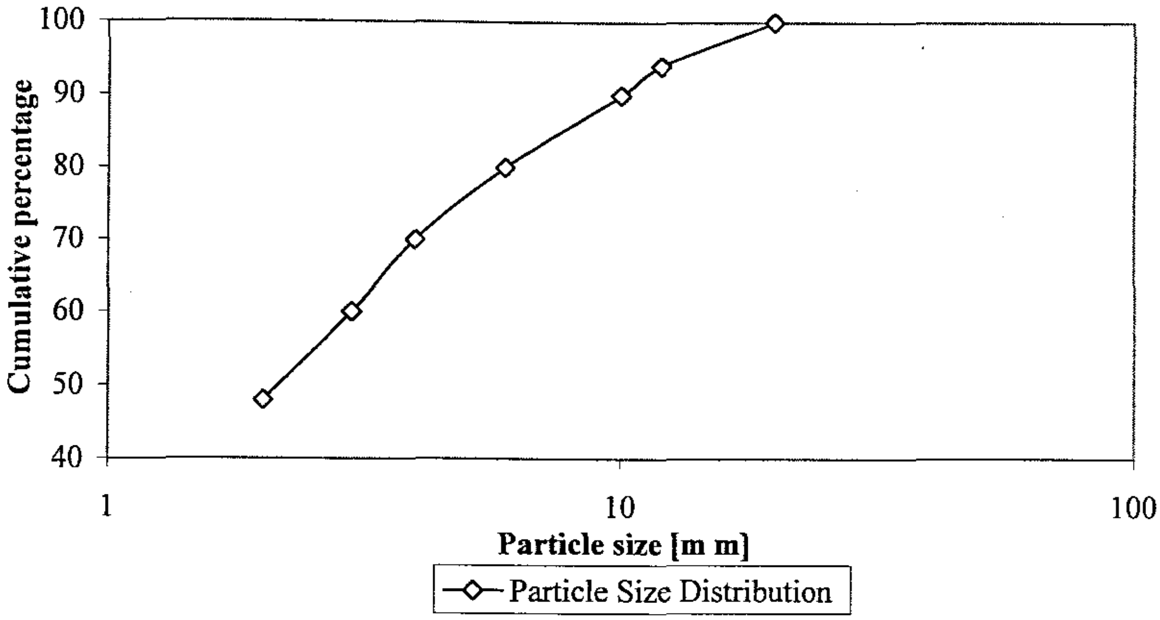

Figure 3. 20 Particle Size Distribution (PSD) Graph for kaolin powder

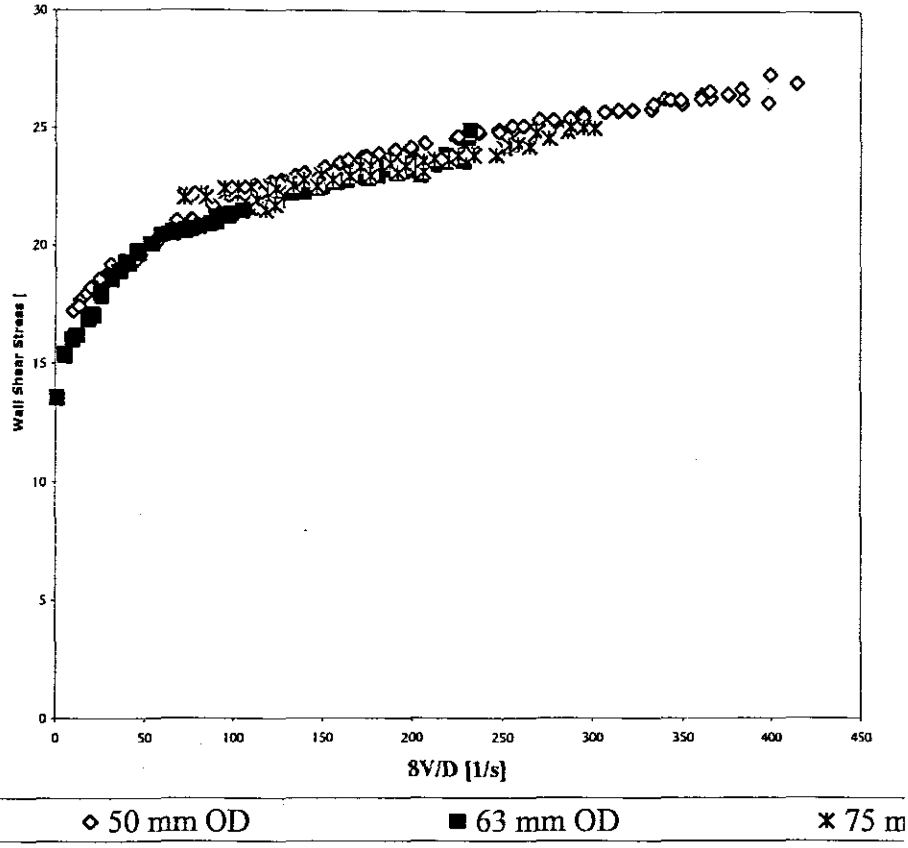

Figure 3. 21 Straight pipe test for kaolin 10% in three pipes diameters.

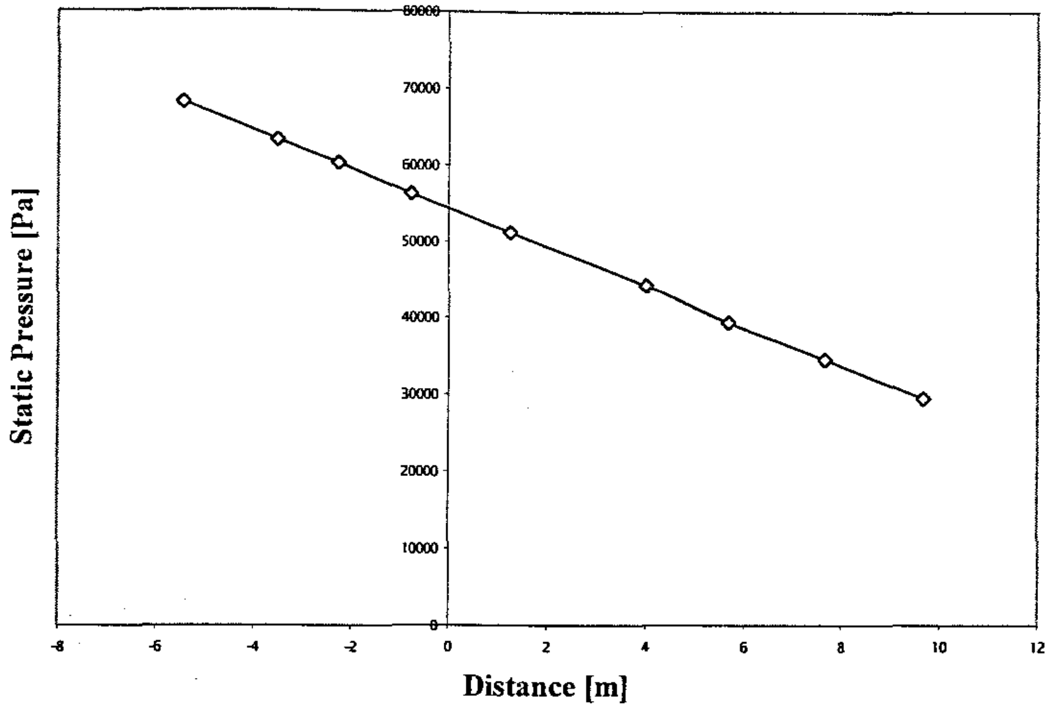

Figure 3. 22 Typical valve pressure drop curve of kaolin 13% in a 65 mm Diaphragm valve (V=0.029m/s and Re_3=4.30)

3.7 CONCLUSION

In this chapter the experimental test loop, the valve test rig, has been described.

The diaphragm valve used has also been analysed and it has been established that there are no geometric similarities among the 5 sizes of the diaphragm valve tested.

Experimental procedures (calibration and experimental tests procedures) have been explained.

Experimental errors have been quantified.

The materials tested have been described and raw experimental tests results of these materials have been presented and will be analysed in the next chapter.

Water test results in straight pipes have been correlated to the Colebrook & White equation and are within 20% error limits.

In conclusion, the valve test rig has been shown to be a reliable tool for valve pressure drop tests and for tube viscometry.

CHAPTER 4

CHAPTER 4
ANALYSIS OF RESULTS

4.1 INTRODUCTION

In this chapter, the analysis of experimental results is explained and presented: This includes the rheological characterisation of materials tested and the presentation of loss coefficients in laminar, transitional and turbulent flow regimes. The study of the effect of the choice of the Reynolds number on the loss coefficient is also done.

4.2 RHEOLOGICAL CHARACTERISATION

Two types of materials were tested: Newtonian fluids and non-Newtonian fluids. In this section, the determination of rheological parameters of these materials is presented.
In this investigation, rheological characterisation was done using tube viscometry. The effect of entrance and exit losses during tube viscometry was avoided by doing the straight pipe test in the region of fully developed flow (50 diameters after the entrance and 50 diameters after the test valve). The wall slip was evaluated by doing straight pipe test in pipes of three different diameters and the no-slip condition was confirmed.

4.2.1 Newtonian fluids

Newtonian materials tested were: water, 100% and 75% volume concentrations of glycerine.
The Newtonian model fitting was done to determine the viscosity of the two concentrations of glycerine.
The flow curve of a Newtonian fluid is a straight line and the slope of the straight line gives the viscosity of the fluid: Considering the laminar flow data (τ_0 , 8V/D) of the fluid through a straight pipe, using excel, a straight line trend passing through the origin is fitted and the slope of the straight line gives the Newtonian viscosity of the fluid μ_N.
An example of such a fit (Figure 4.1) gives the flow curve of glycerine 100%. Table 4.1 and Table 4.2 gives the properties of glycerine 100% and 75% tested.

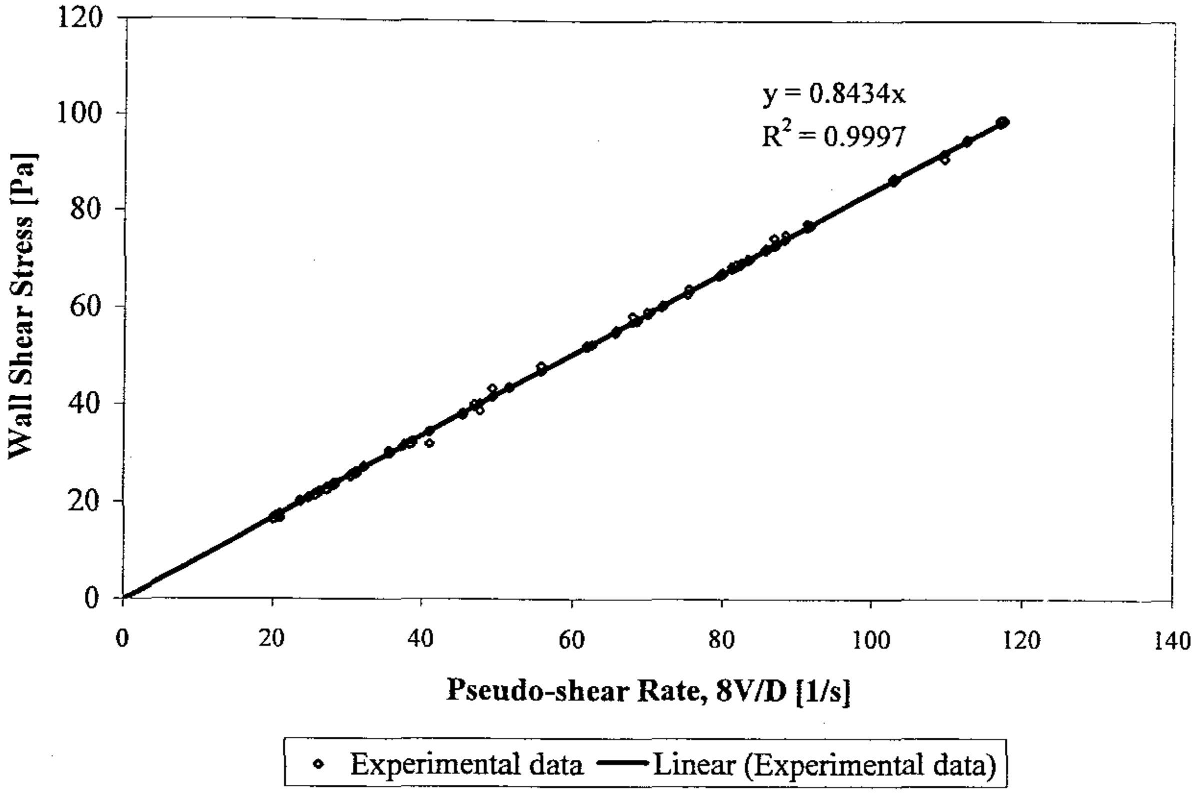

Figure 4. 1 Flow curve of Glycerine 100% at an average temperature of 21 °C

Table 4. 1 Properties of glycerine 100% tested

Date	μ [Pa.s]	R^2	Density [kg/m^3]	Temperature [°C]
23/11/2004	0.842	1	1270	21
24/11/2004	0.843	0.9997	1270	20
25/11/2004	0.844	0.9977	1270	20

Table 4. 2 Properties of glycerine 75% tested

Date	μ[Pa.s]	R^2	Density [kg/m^3]	Temperature [°C]
01/12/2004	0.0196	0.7639	1197.2	21
30/11/2004	0.0184	0.9041	1197.2	22

4.2.2 Non-Newtonian fluids

Non-Newtonian materials tested were: 10% and 13% volumetric concentrations of kaolin, 5% and 8% mass concentration of CMC.

All concentration of CMC were characterised as pseudoplastic fluids and those of kaolin as yield pseudoplastic fluids. The Rabinowitsch-Mooney method was not used for rheological characterisation for non-Newtonian fluids in this work. In this work, an in-depth investigation on the calculation of n' and K' was done. It was observed that when using the classical method of calculating n' by fitting a polynomial equation to the double logarithmic plot of τ_o vs. 8V/D, if the multiple regression correlation coefficient (R^2) of the fit is between 1 and 0.98 the percentage error was acceptable. Below 0.98, the error increased, resulting in higher errors for the calculation of the true shear rate using the Rabinowitch-Mooney relation. An equation was derived for calculating K' and n' for yield pseudoplastic fluids. The derivation is given in Appendix 5.

4.2.2.1 Fitting the pseudoplastic model

All concentrations of CMC were characterised as pseudoplastic fluids: The laminar data from a straight pipe test were plotted on linear scale and using excel, a power law trend curve was fitted to the data to give the constant n' (apparent flow behaviour index) and K' (apparent fluid consistency index) because for non-Newtonian fluids:

$$\tau_o = K'\left(\frac{8V}{D}\right)^{n'} \quad \textbf{(2.23)}$$

To obtain n, for a Pseudoplastic fluid: n = n' and

$$K' = K\left(\frac{3n+1}{4n}\right)^{n} \quad \textbf{(2.27)}$$

Figure 4.2 gives an example of a fit of the pseudoplastic model for a CMC 5% solution based on three pipes tested on the same day confirming that no slip existed at the pipe wall. Table 4.3 and Table 4.4 gives the properties of CMC 5% and CMC 8% tested. It is clear that the fluid behaviour changed daily and the rheology was tested each day and used for calculations. Using the rheology of the previous day could lead to errors on the f-Re graph of up to 6 % in the calculation of the friction factor (f). The reason for changes in the rheology did not form part of this investigation. An effort was however made to accurately account for the changes.

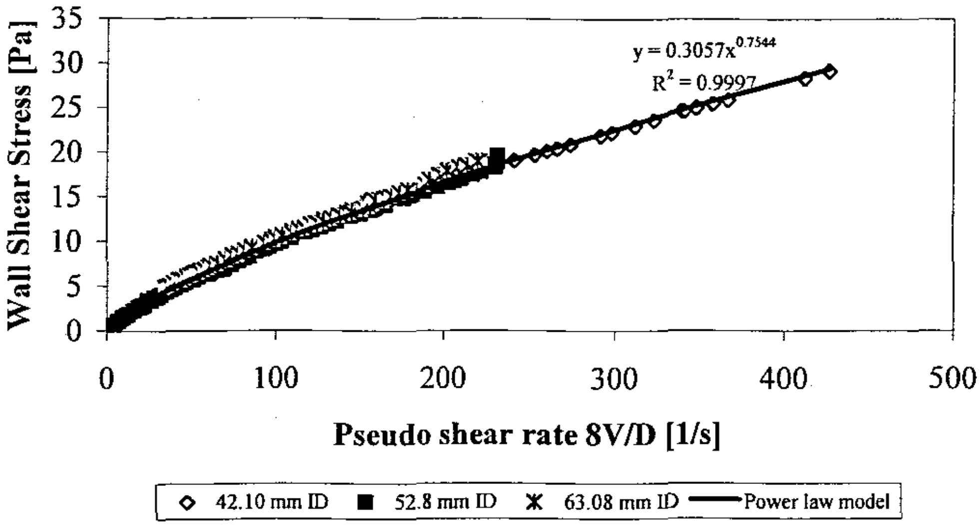

Figure 4. 2 Flow curve of CMC 5%

Table 4. 3 Fluid properties of CMC 5% tested

Date	Density [kg/m^3]	K	n	R^2
22/10/2004	1029	0.304	0.723	0.9993
2/11/2004	1028.2	0.148	1.036	0.9914
3/11/2004	1024	0.442	0.67	0.9937

Table 4. 4 Fluid properties of CMC 8% tested

Date	Density [kg/m^3]	K	n	R^2
5/11/2004	1040	5.252	0.799	0.9976
9/11/2004	1037.5	5.252	0.790	0.9667
11/11/2004	1040	6.434	0.503	0.9948
12/11/2004	1040	5.908	0.799	0.9984

4.2.2.2 Fitting the Yield Pseudoplastic model

All kaolin suspension concentrations were characterised as yield pseudoplastic fluids. The method of characterisation was explained in chapter 2 (2.4).

Figure 4.3 gives an example of a flow curve of a kaolin suspension of 10%. Table 4.5 and Table 4.6 gives the properties of kaolin 10% and kaolin 13% tested. E in Tables 4.5 and Table 4.6 is the root mean square error of the fit function and is given by equation 2.47.

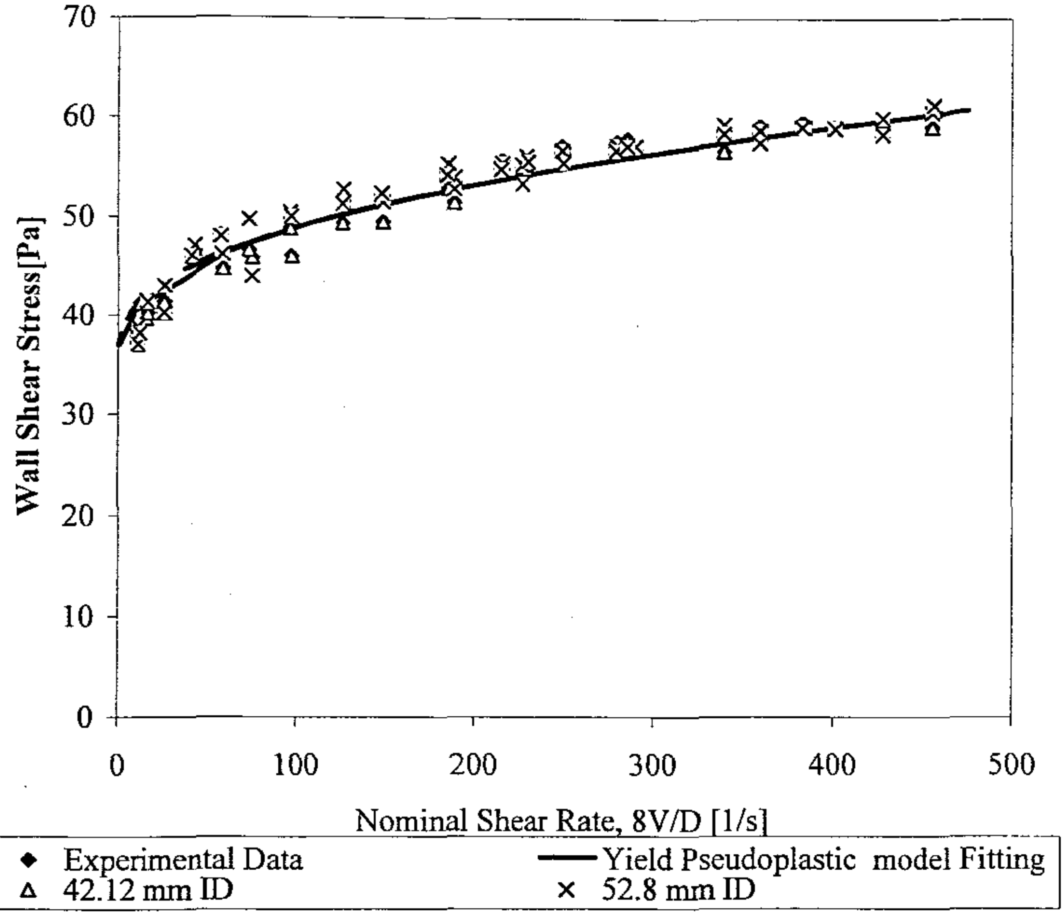

Figure 4. 3 Flow curve of kaolin 13 %

Table 4. 5 Fluids properties of Kaolin 10% tested

Density [kg/m^3]	τ_y [Pa]	K [Pa.s^n]	n	E
1172.4	10.7	2.2	0.32	11.30
1163.4	9.4	2.2	0.32	8.46

Table 4. 6 Fluids properties of Kaolin 13% tested

Density [kg/m^3]	τ_y [Pa]	K [Pa.s^n]	n	E
1214	35	0.8	0.5	2.48
1214	30	1.37	0.5	9.25

4.3 FLOW IN STRAIGHT PIPES

In the laminar flow regime, in straight pipes, the well-known f - Re relation relates the friction factor f and the Reynolds number:

For Newtonian fluids:

$$f = \frac{16}{Re} \qquad \textbf{(2.18)}$$

For non-Newtonian fluids:

$$f = \frac{16}{Re_{MR}} \qquad \textbf{(2.45)}$$

$$\text{and} \quad f = \frac{2\tau_0}{\rho V^2} = \frac{D\,\Delta p}{2\,\rho\,V^2 L} \qquad \textbf{(2.10)}$$

In this investigation, experimental results for straight pipe sections for both Newtonian and non-Newtonian fluids were obtained from the same experiments from which the data for the valve loss coefficient was obtained.

Because the Slatter Reynolds number takes into account the yield stress and can accommodate any rheological model, this Reynolds number was used in the relation f-Re (2.18) and (2.45)

A plot of the Fanning friction factor (f) against the Slatter Reynolds number (Re_3) for both the Newtonian and non-Newtonian fluids tested is shown in Figure 4.4. In Figure 4.4 it can be observed that the experimental results of this work, fall within ±20% of the calculated theoretical line.

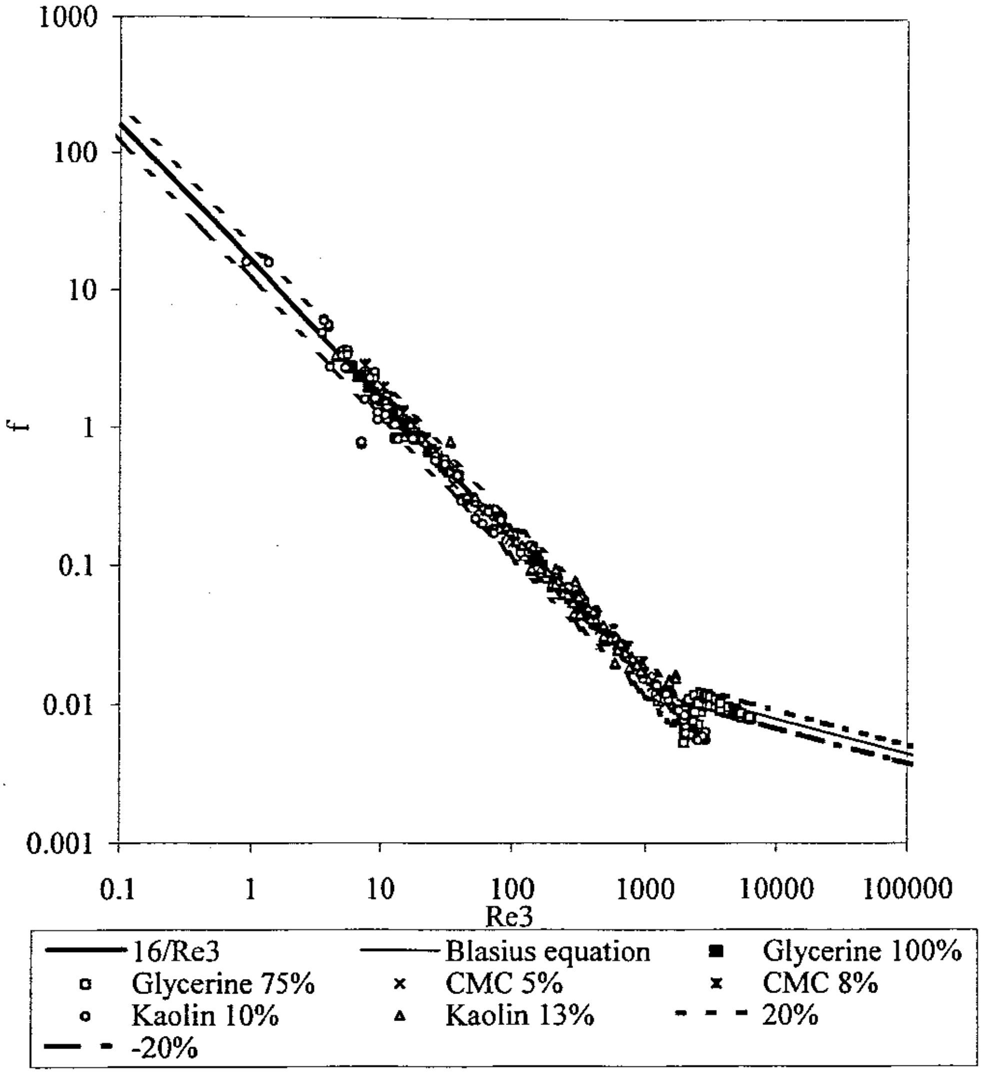

Figure 4. 4 Comparison of experimental values of the friction factor in laminar flow for different fluids in straight pipe of diameter 42.12 mm ID pipe.

Such an agreement indicates the validity and degree of accuracy of the experimental technique and equipment used in this investigation and was used as the first criteria in the validation of experimental results.

In the turbulent flow regime, in straight pipes, the well-known Blasius equation relates the friction factor f and the Reynolds number:

$$f = \frac{0.079}{(Re)^{0.25}} \tag{2.20}$$

In this case also the Slatter Reynolds number was used. This also gives a first good degree of validity of experimental results in turbulent flow. For water in turbulent flow in straight pipes, as said in chapter 3, the experimental data were compared with the Colebrook &White equation:

$$\frac{1}{\sqrt{f}} = -4\log\left[\frac{k}{3,7D} + \frac{1,26}{Re\sqrt{f}}\right] \quad \textbf{(2.19)}$$

It must be noted that for Newtonian fluids the Slatter Reynolds number reverts to the Newtonian Reynolds number and that was observed during calculations made on the experimental results on Newtonian fluids.

4.4 LOSS COEFFICIENTS

4.4.1 Procedure for calculating the valve loss coefficient

The following steps were followed in the calculation of the valve loss coefficient as illustrated on Figure 2.8 (After the establishment of the appropriate f-Re relationship as defined above):

- Measurement of static pressures at different points upstream and down stream of the test valve (In total 9 points were used, 4 points upstream and 5 points downstream of the test valve)
- Calculation of the shear stress in the two pipes upstream and downstream of the test valve in regions of fully developed flow (50 diameters of the entrance length of the pipe upstream the test valve and 50 diameters of the exit length of the pipe downstream the test valve), 6 points were used to calculate the shear stress, 3 points upstream and 3 points downstream respectively of the test valve, all in regions of fully developed flow as defined above. The 3 points close to the test valve, 1 point upstream and 2 points downstream were discarded because they are in the region of influence of the fitting (valve). The shear stress in the two pipes upstream and downstream is calculated using the following equation:

$$\tau_o = \frac{\Delta pD}{4L} \quad \textbf{(2.8)}$$

- The friction factor was calculated using the relation:

$$f = \frac{2\tau_o}{\rho V^2} \tag{2.10}$$

In laminar flow, the above friction factor was compared to:

$$f = \frac{16}{Re} \tag{2.18}$$

and in turbulent flow to the Blasius equation:

$$f = \frac{0.079}{(Re)^{0.25}} \tag{2.20}$$

- The valve pressure loss is obtained as an extrapolation to the test valve plane of the pressure gradients measured in the fully developed flow regions upstream and downstream of the test valve. The slope and intercept upstream and downstream of the test valve (in the regions of fully developed flow) are calculated (in this case using Excel). Six points were used to calculate the slopes and intercepts, 3 points upstream and 3 points downstream respectively of the test valve, all in the region of fully developed flow as explained above. It must be established that the slopes upstream (SUS or m_1) and downstream (SDS or m_2) are parallel, thus the difference of the intercepts upstream (IUS or I_1) and downstream (IDS or I_2) yields the pressure drop due to the valve (Δp_v):

$$\Delta p_V = I_1 - I_2 \tag{2.58}$$

The slopes m_1 and m_2 can be visually parallel but there is always a percentage error difference involved ($\%Error = \frac{m_1 - m_2}{m_1} * 100$) and it was observed that for a percentage error of up to 20 %, the slopes m_1 and m_2 were still parallel and that was retained as a cut-off value. For errors greater than 20% negative pressure drop were observed in extreme cases. The percentage error in this case varies from materials to materials for fluids like CMC and glycerine the percentage error was always less than 10%. For water and kaolin this was not always the case and one had to be careful when observing the data because many points deviated from 20% and had to be discarded.

- Calculation of the valve loss coefficient from the relation:

$$k_v = \frac{\Delta p_v}{\frac{1}{2}\rho V^2} \quad (2.59)$$

which yields:

$$k_v = \frac{(I_1 - I_2)}{\frac{1}{2}\rho V^2} \quad (2.60)$$

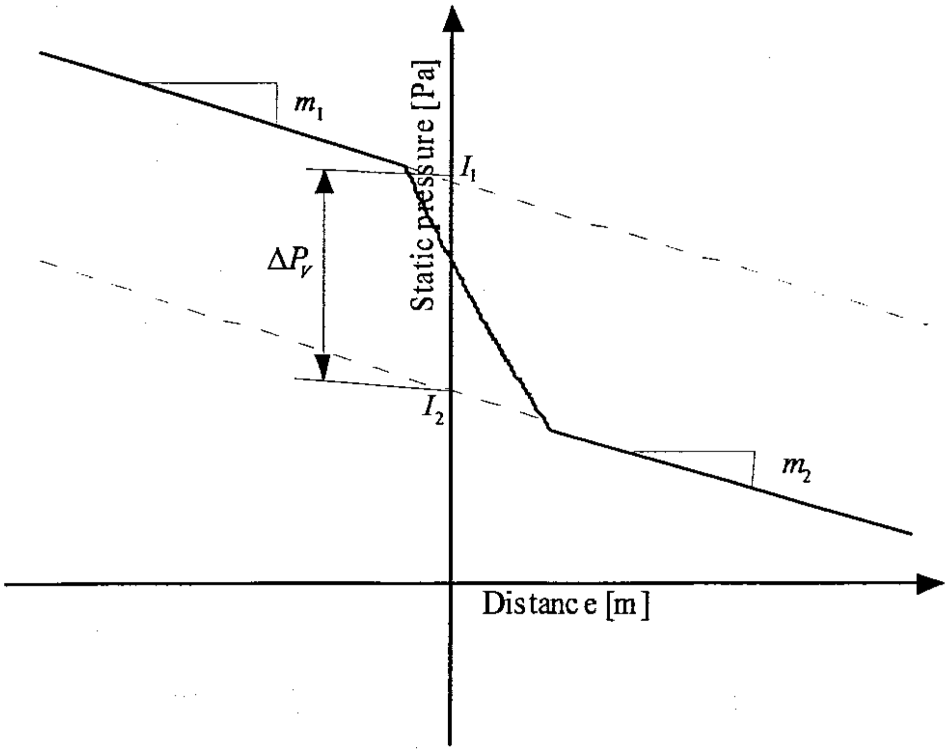

Figure 2. 10 Diagram illustrating the calculation of valve loss coefficient

4.4.2 Graphical presentation of the valve loss coefficient k_v versus Reynolds number

It is customary in fluid mechanics to represent experimental data of loss coefficient on a graph k_v versus Reynolds number (Edwards *et al.*, 1985; Turian *et al.*, 1997; Pienaar, 1998).

In this investigation, the Slatter Reynolds number (Re_3) is used to make such representation. It was very difficult to identify the transition by deviation for the diaphragm valves. The intersection method was therefore used to obtain the point of transition.

4.4.2.1 Diaphragm Valve of 40 millimetres nominal bore diameter

For the 40 millimetres diaphragm valve the loss coefficient in laminar flow $C_v = 1200$. In turbulent flow the loss coefficient is constant and an average of $k_v = 7.96$ (0.226 standard deviation) was calculated. The range of Reynolds numbers is between 1 and 100000.

The transition by intersection of the laminar and turbulent loci is calculated at $Re_3 = 150.75$. The loss coefficient data are presented in Figure 4.5.

4.4.2.2 Diaphragm valve of 50 millimetres nominal bore diameter

For the 50 millimetres diaphragm valve the loss coefficient in laminar flow $C_v = 946$. In turbulent flow the loss coefficient is constant and an average of $k_v = 2.53$ (0.209 standard deviation) was calculated. The range of Reynolds numbers is between 1 and 100000.

The transition by intersection of the laminar and turbulent loci is calculated at $Re_3 = 373.9$. The loss coefficient data are presented in Figure 4.6.

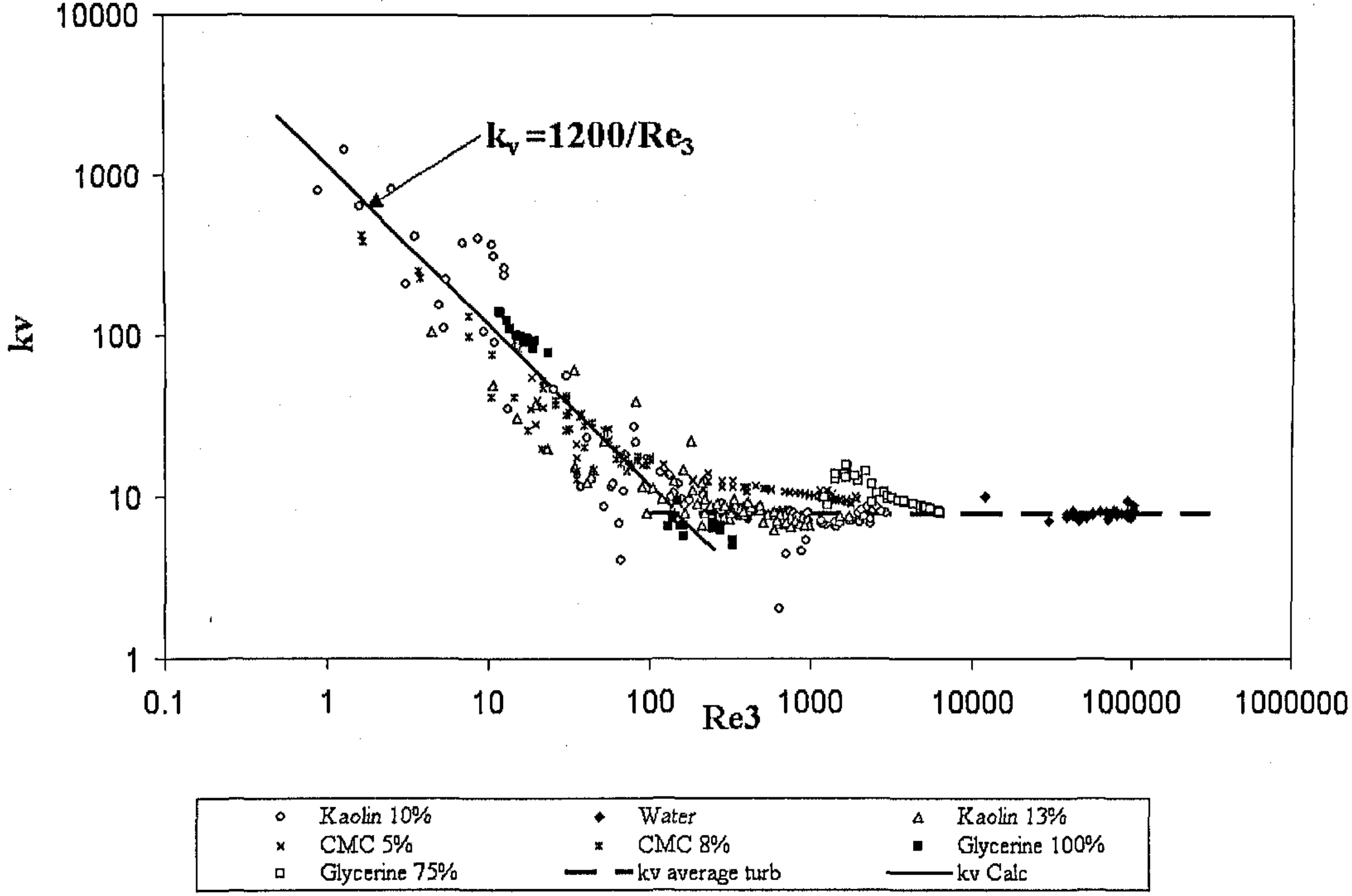

Figure 4. 5 Loss coefficient kv vs Reynolds number for 40 millimetres bore diameter diaphragm valve

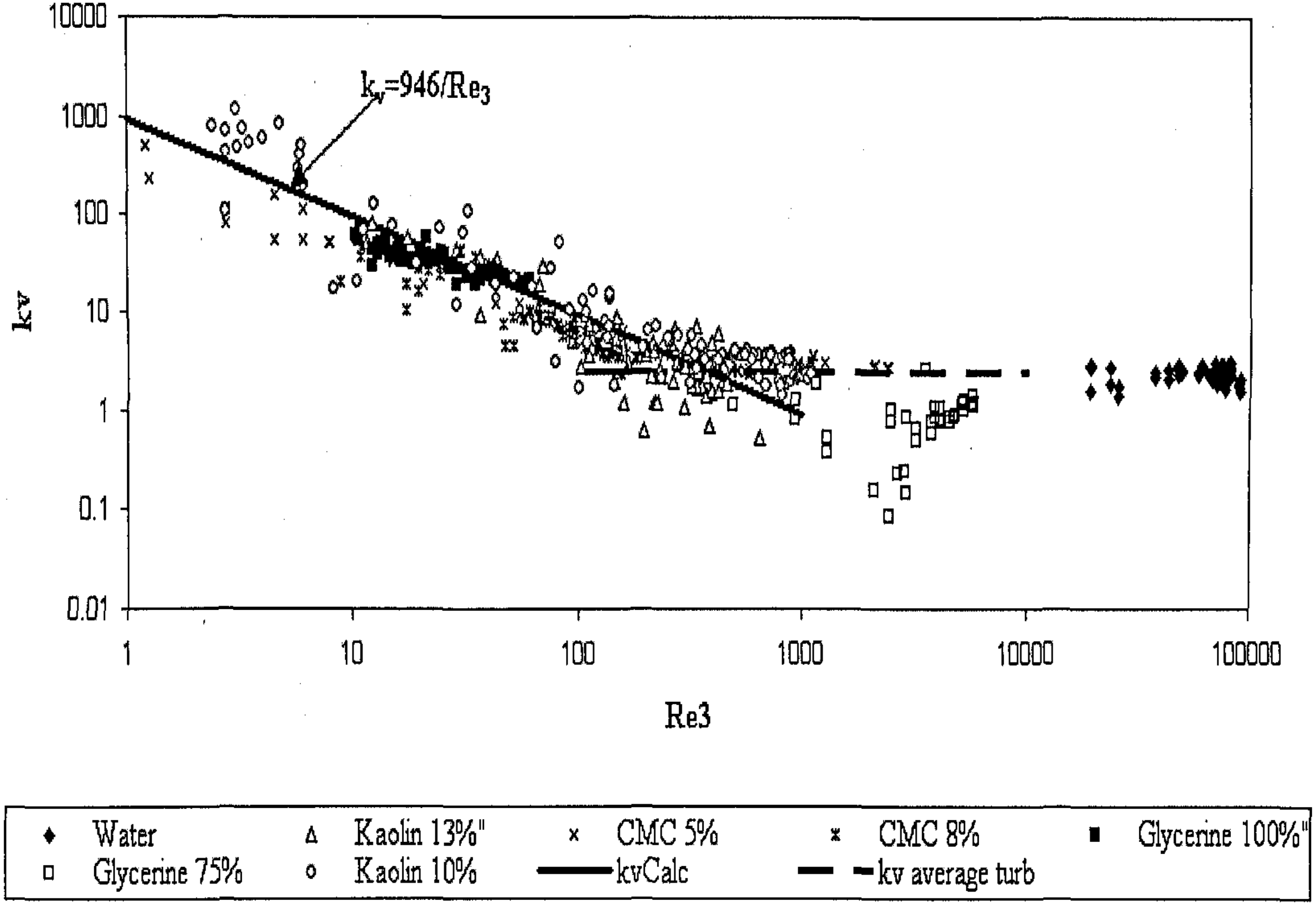

Figure 4. 6 Loss coefficient k_v vs. Reynolds number for 50 millimetres bore diameter diaphragm valve

4.4.2.3 Diaphragm valve of 65 millimetres nominal bore diameter

For the 65 millimetres diaphragm valve the loss coefficient in laminar flow $C_v = 555$. In turbulent flow the loss coefficient is constant and an average of $k_v = 1.21$(0.121 standard deviation) was calculated. The range of Reynolds numbers is between 1 and 100000. The intersection of the laminar and turbulent loci is calculated at $Re_3 = 633$. The loss coefficient data are presented in Figure 4.7.

4.4.2.4 Diaphragm valve of 80 millimetres nominal bore diameter

For the 80 millimetres diaphragm valve the loss coefficient in laminar flow $C_v = 515.14$. I turbulent flow the loss coefficient is constant and an average of $k_v = 2.54$ (0.116 standard deviation) was calculated. The range of Reynolds numbers is between 0.1 and 100000. The intersection of the laminar and turbulent loci is calculated at $Re_3 = 202.76$. The loss coefficient data are presented in Figure 4.8.

4.4.2.5 Diaphragm valve of 100 millimetres nominal bore diameter

For the 100 millimetres diaphragm valve the loss coefficient in laminar flow $C_v = 69$. In turbulent flow the loss coefficient is constant and an average of $k_v = 1.3$ (0.155 standard deviation) was calculated. The range of Reynolds numbers is between 0.05 and 100000. The intersection of the laminar and turbulent loci is calculated at $Re_3 = 53$. The loss coefficient data are presented in Figure 4.9.

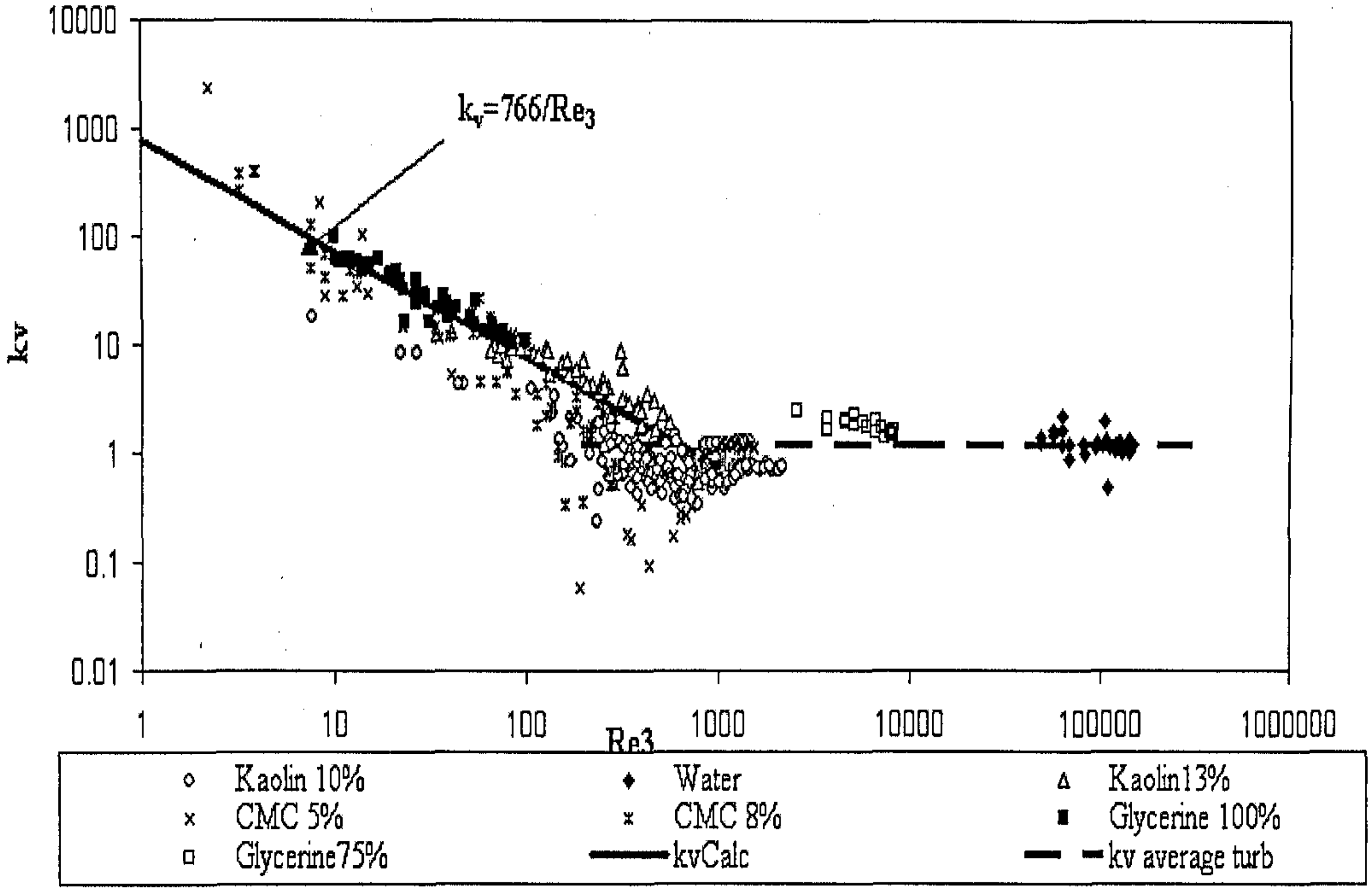

Figure 4. 7 Loss coefficient k_v vs. Reynolds number for 65 millimetres bore diameter diaphragm valve

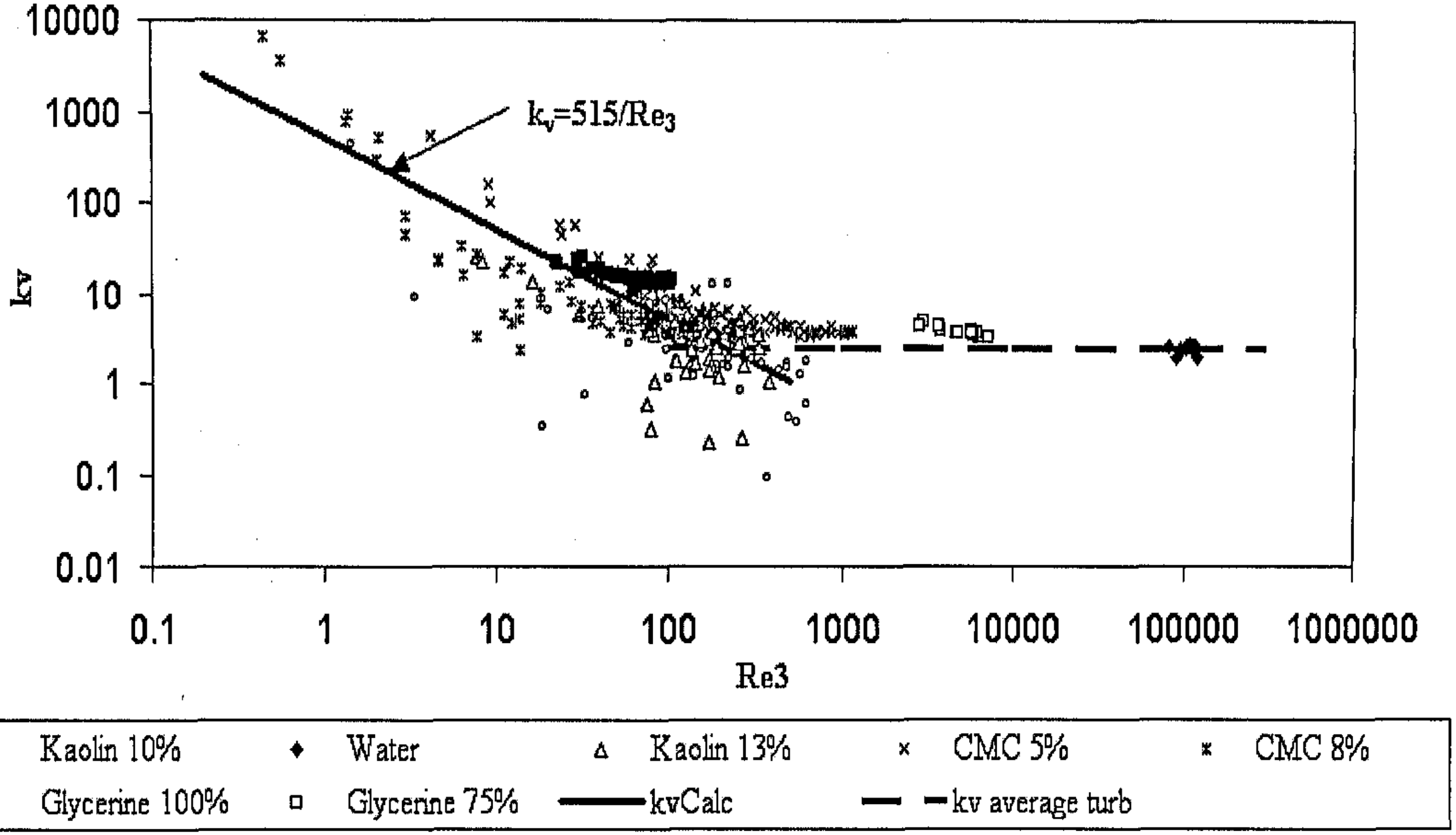

Figure 4. 8 Loss coefficient k_v vs. Reynolds number for 80 millimetres bore diameter diaphragm valve

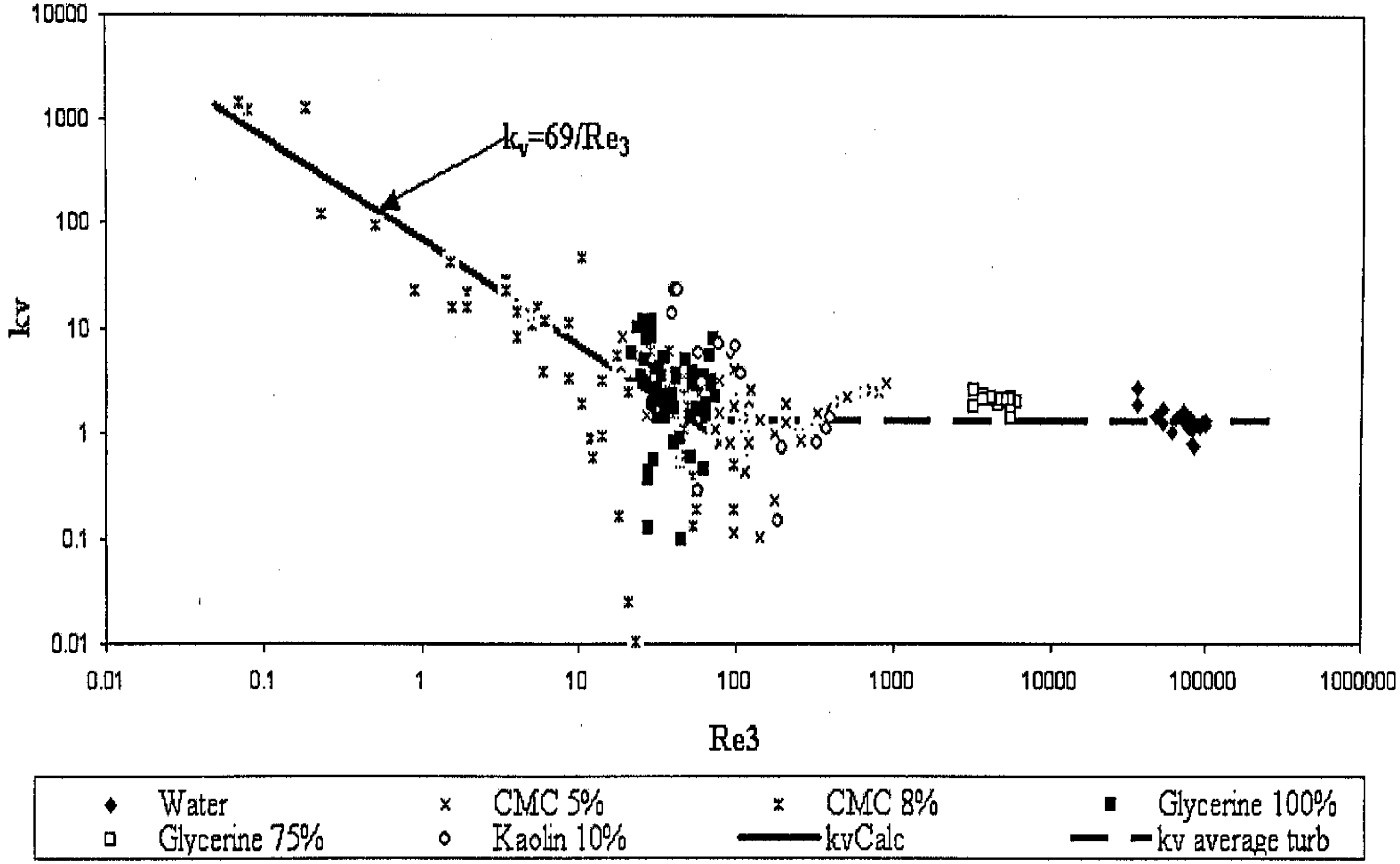

Figure 4. 9 Loss coefficient k_v vs Reynolds number for 100 millimetres bore diameters diaphragm valve

Table 4. 7 Summary of C_v and k_v values obtained in this work

Valve dimension [mm]	C_v	k_v
40	1200	7.96
50	946	2.53
65	555	1.21
80	515	2.54
100	69	1.30

4.5 EFFECT OF REYNOLDS NUMBER ON THE VALVE LOSS COEFFICIENT

In this analysis, other Reynolds numbers are used to predict the laminar loss coefficient and to predict the laminar-turbulent transition in valves for individual fluids of given characteristics. The Reynolds numbers used are the Newtonian Reynolds number and the Metzner and Reed generalised Reynolds number. The results are than compared to the results obtained using the Slatter Reynolds number.

The Newtonian Reynolds number is generally used when the fluid has Newtonian behaviour and the Metzner and Reed generalised Reynolds number is used for fluids exhibiting non-Newtonian behaviour especially pseudoplastic fluids.

In comparison with the Slatter Reynolds number (Re_3), the Newtonian Reynolds number gives the same result as Re_3 and the prediction of the laminar loss coefficient and the transition region, using the two Reynolds numbers is the same and that was experienced with water, 75 and 100% Glycerine. In this case the Slatter Reynolds number reverts to the Newtonian Reynolds number.

In the case of the Metzner and Reed generalised Reynolds number, this Reynolds number was used for pseudoplastic fluids and yield pseudoplastic fluids using relations (2.27) and (2.31) and 2.32) in section 2.3.7.2. For pseudoplastic fluids, the Metzner and Reed generalised Reynolds number predicts a lower loss coefficient than the Slatter Reynolds number and even the transition using the Metzner and Reed generalised Reynolds number is earlier than the transition predicted using the Slatter Reynolds number. This is illustrated on the Fig.4.10 for the loss coefficient of a 5% CMC solution in a diaphragm valve of 50 millimetres nominal bore diameter.

From Figure 4.10 the difference between the prediction of the laminar valve loss coefficient (C_v) and the transition from laminar to turbulent flow values, is 10.89% greater when the Slatter Reynolds number is used than when the Metzner and Reed generalised Reynolds number is used for this pseudoplastic material.

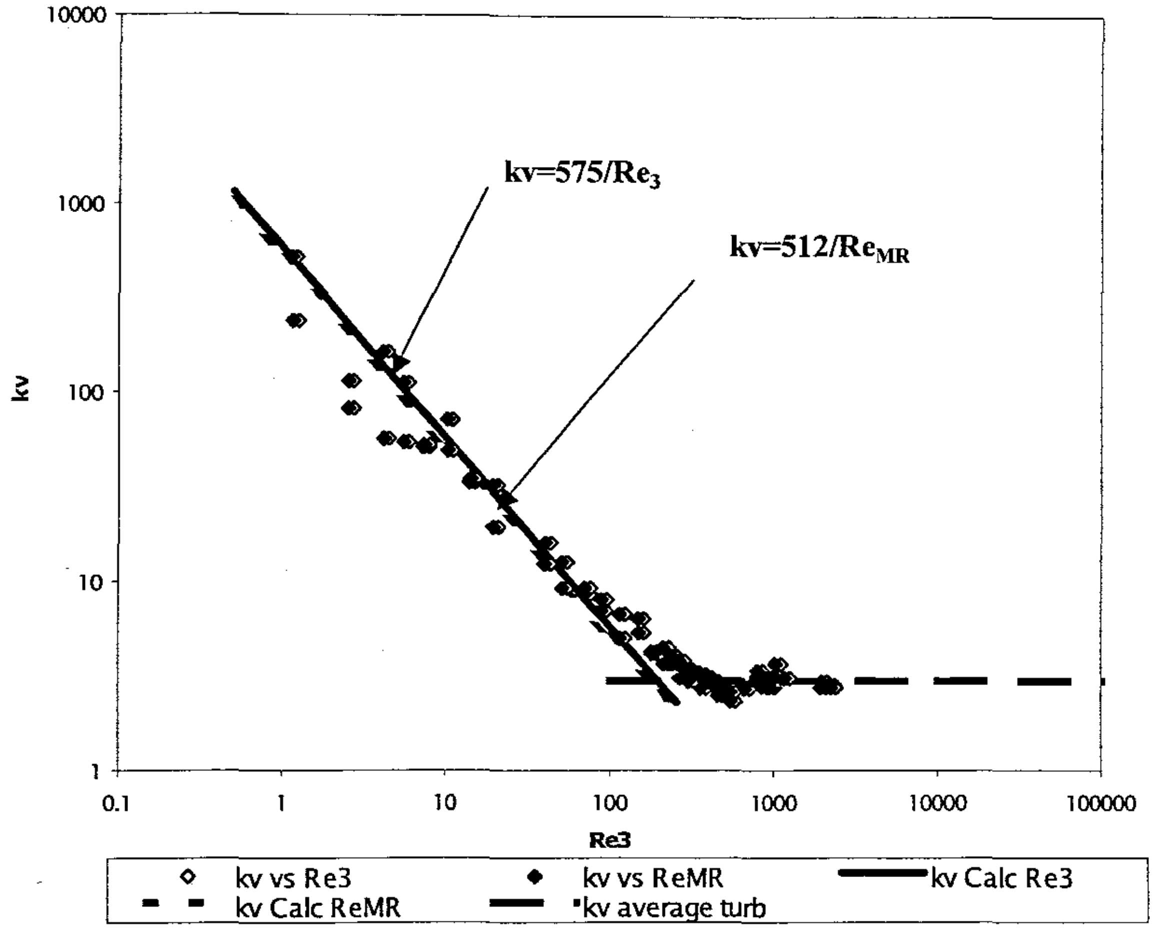

Figure 4. 10 Comparison of loss coefficient using Re_3 and Re_{MR} for a pseudoplastic fluid.

In the case of yield pseudoplastic fluids, the Slatter Reynolds number gives also a higher loss coefficient than the Metzner and Reed generalised Reynolds number. The prediction of the transition is earlier with the Metzner and Reed Reynolds number, which is illustrated on Figure 4.11.

Figure 4.11.shows the difference in the prediction of the laminar loss coefficient. In this case it is about 6 % greater using Slatter Reynolds number than when using the Metzner and Reed generalised Reynolds number.

The essence of this analysis is not to determine which Reynolds number better predicts the laminar loss coefficient or the transition, and is beyond the scope of this investigation and could be a subject of future investigations. This analysis showed that the Slatter Reynolds number can be used for design purposes for Newtonian, pseudoplastic and yield pseudoplastic fluids.

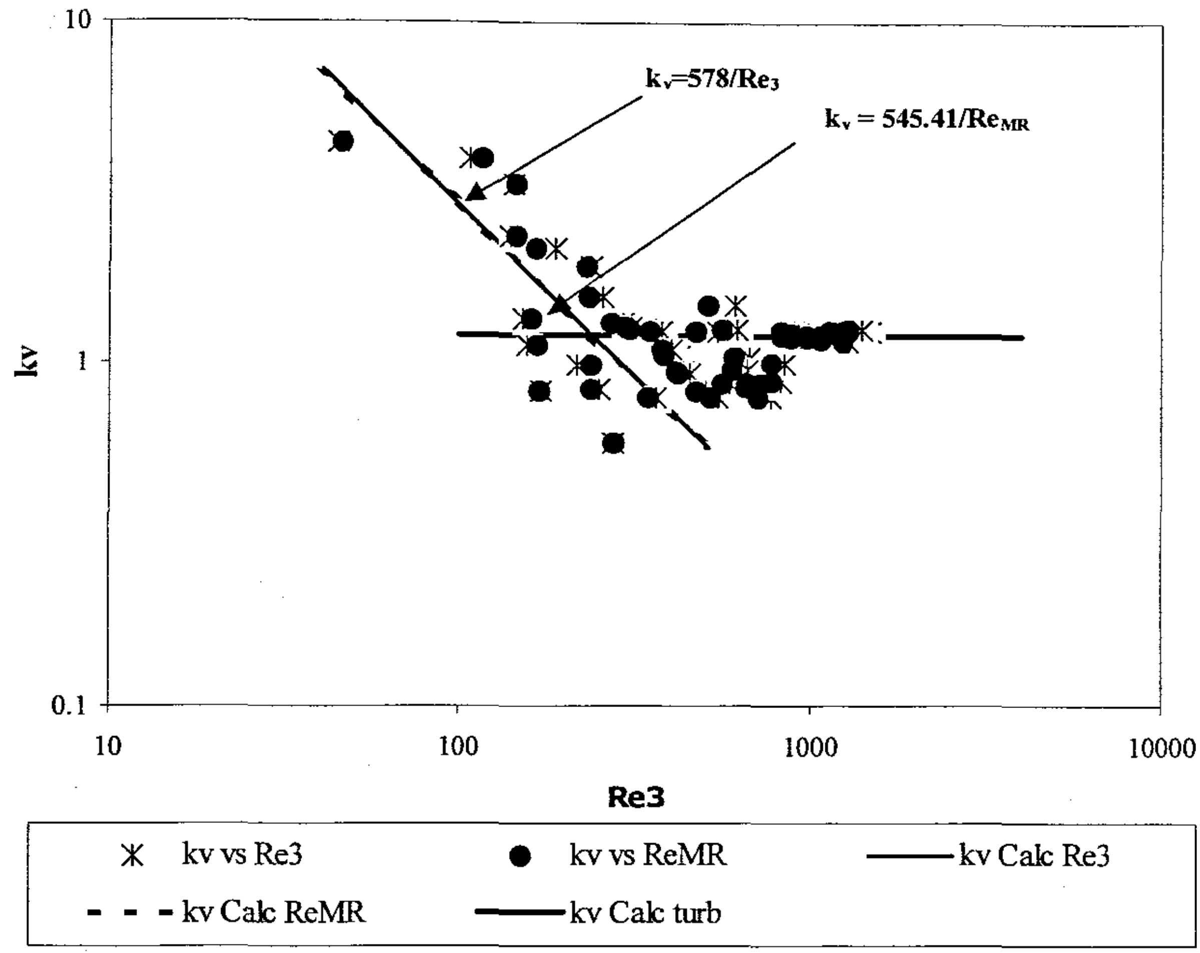

Figure 4. 11 Comparison of loss coefficient using Re_3 and Re_{MR} for a yield pseudoplastic fluid.

4.6 CONCLUSION

The rheological characterisation of all materials tested has been presented.

Flow in straight pipes has been analysed and compared to theoretical models for friction factors.

Loss coefficient values in laminar flow, transition and turbulent regimes have been calculated in diaphragm valves of 40, 50, 65, 80 and 100 millimetres nominal bore diameters.

The effect of the choice of the Reynolds number has been established and it has been shown that the Slatter Reynolds number is a very useful tool and can be used for design purpose when dealing with non-Newtonian material.

CHAPTER 5

CHAPTER 5
DISCUSSION AND EVALUATION OF RESULTS

5.1 INTRODUCTION

In order to evaluate, the objectives of this investigation, the subject of discussion are:

- The literature review
- The experimental test loop
- The experimental method
- Materials tested
- Rheological characterisation
- Loss coefficients
- Comparison with literature and originality of this work

5.2 THE LITERATURE REVIEW

An in-depth literature review has been done in this investigation from both a theoretical and practical engineering point of view to establish the need for the investigation. Thus giving to the reader a comprehensive overview of valves in general and diaphragm valves in particular.

It has been established after review of the open literature that data on non-Newtonian loss coefficients through diaphragm valves are scarce. Most of the data on non-Newtonian loss coefficients through valves are on gate and globe valves and were only relevant to this investigation by their methodology.

Some work on fluid flow through diaphragm valves was found in the literature, on qualitative and quantitative analysis of Newtonian loss coefficients in diaphragm valves (Hooper, 1981). The work of Hooper, (1981) using the two-K method defined a dimensionless factor K, as the excess head loss in a pipe fitting, expressed in velocity heads.

The drawback of Hooper's work is the fact that there is no valve dimension specification, assuming geometric similarity. This work investigated the assumption of geometric similarity by testing several sizes of valves from the same manufacturer.

5.3 EXPERIMENTAL TEST LOOP

The experimental test loop used is the new state-of-the-art valve test rig. The valve test rig was designed and built at the Cape Peninsula University of Technology. The valve test rig has 5 diaphragm valves ranging from 40 to 100 mm nominal bore diameter. It is fitted with multiple transducers. It can accommodate other types of valves as well as contraction and expansions with minor modifications. From a practical point of view, viscometry tests as well as tests for the determination of loss coefficients for many types and dimension of valves can be performed on the valve test rig.

The Valve test rig is a plant in miniature and experimental values obtained for loss coefficients on this test loop are reliable because it simulates what happens in industry when a fluid is being pumped from one point to another. For that reason values obtained for valve loss coefficients from this test loop can be used for design purposes for 100% open NATCO diaphragm valves.

The Valve test rig as it is presently built can perform beyond its present capabilities, but is limited by instrumentation capabilities.

5.4 PUMP AND INSTRUMENTATION

The main components of the valve test rig when running tests are the pump, the flow meters and the pressure transducers.

The pump used is a progressive cavity positive displacement (PD) pump and the main drawback was that the flow rate was pulsating and it could not deliver very high flow rates due to power limitations.

The difficulties experienced on the Valve test rig were most of the time due to the limitation of the instrumentation mentioned above: materials with low viscosities could not be tested within a very large range of Reynolds number in bigger pipes, due to very low pressure drops between tapping points even in small pipe diameters and could be tested only at very high flow rates, because of the limitation of the PPT and DP Cells ranges.

Materials with very high viscosity could not be tested in smaller pipe diameters due to the limitation of the pump power. In bigger pipe diameters where pressure drops between tapping points were very small, the PPT and DP Cells limitation was a problem but also the pump power not allowing to reach very high flow rates.

5.5 THE EXPERIMENTAL METHOD

The experimental method used is the hydraulic grade line approach. This method is expensive compared to the total pressure method because of the number of pressure transducers (in this case nine) is needed, compared to 1 differential pressure transducer in the case of the total pressure method. The approach was used because the Valve test rig was especially built to accommodate this method. The positive fact about this method is the fact that the frictional losses are actually measured in the straight pipes and need not to be estimated. In the calculation of the valve loss coefficient; it does use only the definition of loss coefficient given by Miller (1978)(Figure 2.4).

The difficulties observed at this point were the fact that with low viscosity materials like water, the two slopes of pressure gradients upstream and downstream the test valve in regions of fully developed flow were not always parallel.

In some cases with very viscous materials, especially in bigger pipes, the slope of the two pressure gradient upstream and downstream of the test valve were not always parallel and in some cases, the intercept of the pressure gradient downstream was bigger than that of the pressure drop gradient line upstream of the test valve. The difference in the upstream and downstream slopes may be due to the slight differences obtained in the actual internal diameter of the pipes during the manufacturing process.

5.6 MATERIALS TESTED

The materials tested were selected to represent different characteristics needed in this investigation. Water and glycerine were selected as Newtonian fluids and CMC and kaolin as non-Newtonian fluids. CMC presents pseudoplastic behaviour and kaolin yield pseudoplastic behaviour.

Water was used to obtain very high flow rates thus very high Slatter Reynolds numbers, Glycerine 100% was used to obtain valve loss coefficients in laminar flow for Newtonian fluid and Glycerine 75% to obtain data for loss coefficients in the transition region and the early turbulent flow for Newtonian fluids.

CMC and kaolin were used because of their well-known non-Newtonian rheological behaviour, being pseudoplastic and yield pseudoplastic materials respectively. High concentrations ensured that sufficient data could be obtained in laminar flow.

5.7 RHEOLOGICAL CHARACTERISATION

Rheological characterisation was done by tube viscometry test. Glycerine 75% and 100% were characterised as Newtonian fluids, CMC 5% and 8% were characterised as pseudoplastic fluids and kaolin 10 and 13% were characterised as yield pseudoplastic fluids.

Rheological characterisation is not easy and is beyond the scope of this work and is used in this investigation as a stepping-stone. Rheological characterisation is said to be a stepping-stone because, it is used in this case to determine rheological parameters which are used to verify some correlations in straight pipes (2.20) and (2.45) and not used for an in-depth study of rheological behaviour based on the physical or chemical basis of the slurries.

5.8 LOSS COEFFICIENTS

Loss coefficients obtained in this investigation confirmed the general qualitative trend given in the literature that in laminar flow the loss coefficient increases significantly with decreasing Reynolds number and in turbulent flow, the loss coefficient is constant. This is true for any type of fluid, both Newtonian or non-Newtonian.

The transition from laminar to turbulent flow by deviation, for all the valves sizes starts at Reynolds number between 10 and 100 and confirms the general theory that in fittings in general and valves in particular the transition occurs earlier than in straight pipes.

For all the diaphragm valves diameter, the transition region where there is transition by intersection, goes from 10 to 1000 Slatter Reynolds number and in that region the flow is very unstable and the value of the valve loss coefficient is fluctuating.
The transition by intersection for the different valves sizes is given in Table 5.1 below.

Table 5. 1 Transition by intersection for the different valves.

Valve nominal bore diameter [mm]	Transition Reynolds number
40	150.75
50	373.9
65	633
80	202.75
100	53

5.9 COMPARISON WITH LITERATURE AND ORIGINALITY OF THIS WORK

Values found in the literature on diaphragm valves in fully open position are as follows:
Hooper (1981): C_v=1000 and k_v=2
Miller (1978): k_v=0.8
Perry & Chilton (1973): k_v=2.3
From the literature, it can be seen that little data on non-Newtonian and Newtonian losses are found in the literature and these data are scattered.
The work of Hooper, Miller and Perry & Chilton do not specify the dimensions of the diaphragm valves tested. This work investigated and addressed this issue. Table 5.2 compares values of diaphragm valve loss coefficients from the literature to this work.
A comparison of values of the valve loss coefficients of this work to that from the literature in the turbulent region is given in Figure 5.1.

Table 5. 2 Comparison of loss coefficients of this work with literature.

Valve dimension [mm]	This work		Hooper		Miller		Perry & Chilton	
	C_v	k_v	C_v	k_v	C_v	k_v	C_v	k_v
40	1200	7.96	1000	2	-	0.8	-	2.3
50	946	2.53						
65	555	1.21						
80	515	2.54						
100	69	1.3						

It can be seen that the value of the valve loss coefficient given by Hooper in laminar flow is more or less equal to that found in this work for the valve dimension of 50 mm in laminar flow. And Perry & Chilton's value for turbulent flow coincides with the value found in this work for the valves of 50 and 80 mm nominal bore diameters in turbulent flow.

The value of the valve loss coefficient given by Miller in turbulent flow does not coincide with any loss coefficient value in this work and is under predicting the loss coefficient. This confirms the need that studies should be carried out with a range of diaphragm valves of different sizes and that the details of the valve should be supplied together with the loss coefficient details.

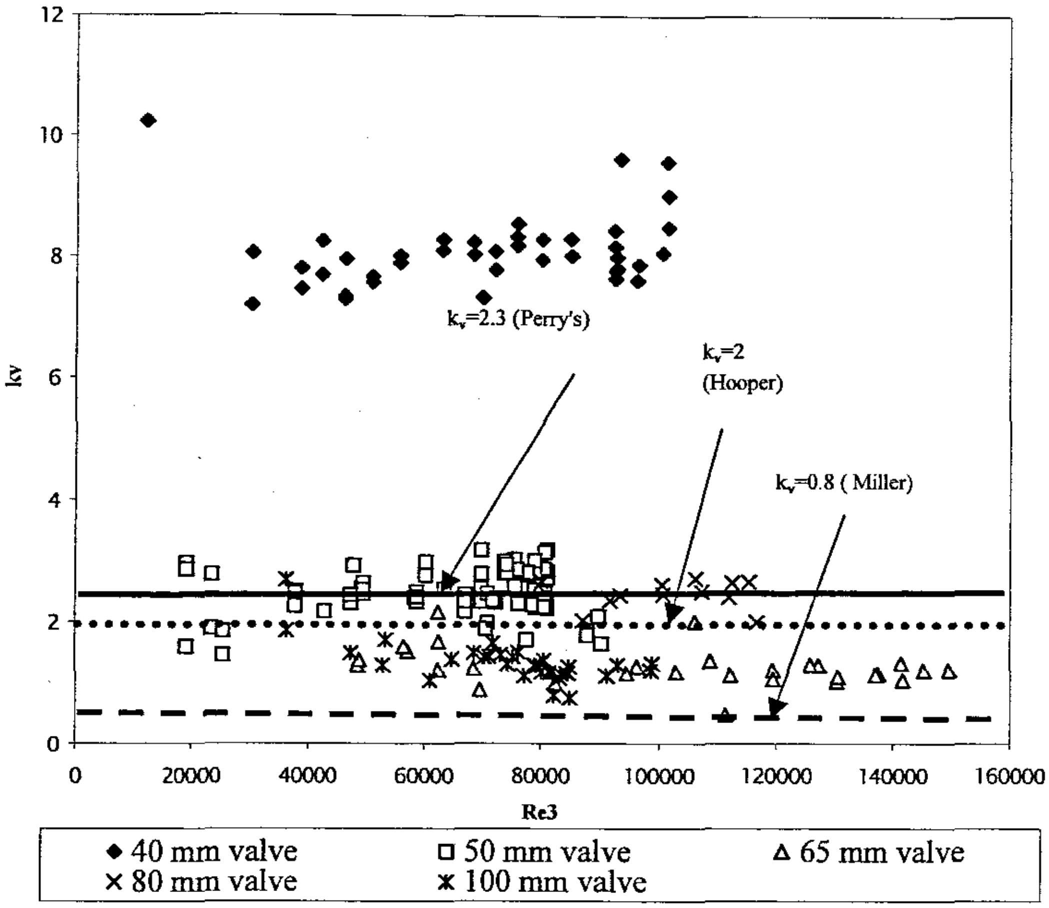

Figure 5. 1 Comparison of this work turbulent flow valve loss coefficients to valve loss coefficients found in the literature

5.10 SIMILARITIES ANALYSIS

Although geometric similarity was not achieved for the type of valves tested, a dynamic similarity analysis was done on experimental data obtained for the 5 valves sizes, to establish if any analytical relationship could be established between the size of the valve and the loss coefficients in laminar and turbulent flow regimes.

According to 2.7.4 two systems geometrically similar are dynamically similar if their Reynolds numbers are the same. Also Turian *et al.*, (1997) suggested that because it has been found using dimensional analysis that k_v for incompressible Newtonian fluids is a dimensionless function of Reynolds number (Re) and of dimensionless geometric ratios characteristics of the valve:

$$k_v = fn(Re, \text{ geometric ratios}) \quad \textbf{(2.62)}$$

Thus the valve loss coefficient k_v is the same for all sizes of a given type of valve provided dynamic similarity is enforced for instance equality of Reynolds number and geometric similarity are maintained. Around these two assumptions above mentioned will gravitate the similarity analysis.

As shown on Figure 5.2, for the laminar loss coefficient (Cv), there is a big variation of the laminar valve loss coefficient as a function of the valve dimension. This variation is almost linear, the laminar valve loss coefficient is a function of the valve size, and the laminar valve loss coefficient increases with the decrease of size and vice versa. Figure 5.3 gives diaphragm valve loss coefficients for CMC 8% in laminar flow. But for turbulent flow there is no big variation of valve loss coefficient with size, and the values of valve loss coefficients are random but close beside the 40 mm valve and follow the trend given on Figure 5.2. Figure 5.4 gives the values of different valve loss coefficient obtained in turbulent flow

Both in turbulent and laminar flows, dynamic similarity is not achieved because of lack of geometric similarities.

In conclusion, it has been established that dynamic similarity is not achieved with the diaphragm valves studied as opposed to other type of valves in the literature. In general, valves of different sizes and from different manufacturers, although apparently similar, are not always geometrically similar. For instance, in small sizes, one valve body may be offered with a variety of end connection sizes and in some cases a valve of one nominal size may be available with several seat sizes. Also in this specific case of diaphragm valves studied, dynamic similarity is not achieved as in other types of valves. This could be due to the fact that the internal lining of the valve is in rubber and is inserted manually compared to globe valves for example where the internal part of the valve is machined from metal to exact repeatable dimensions.

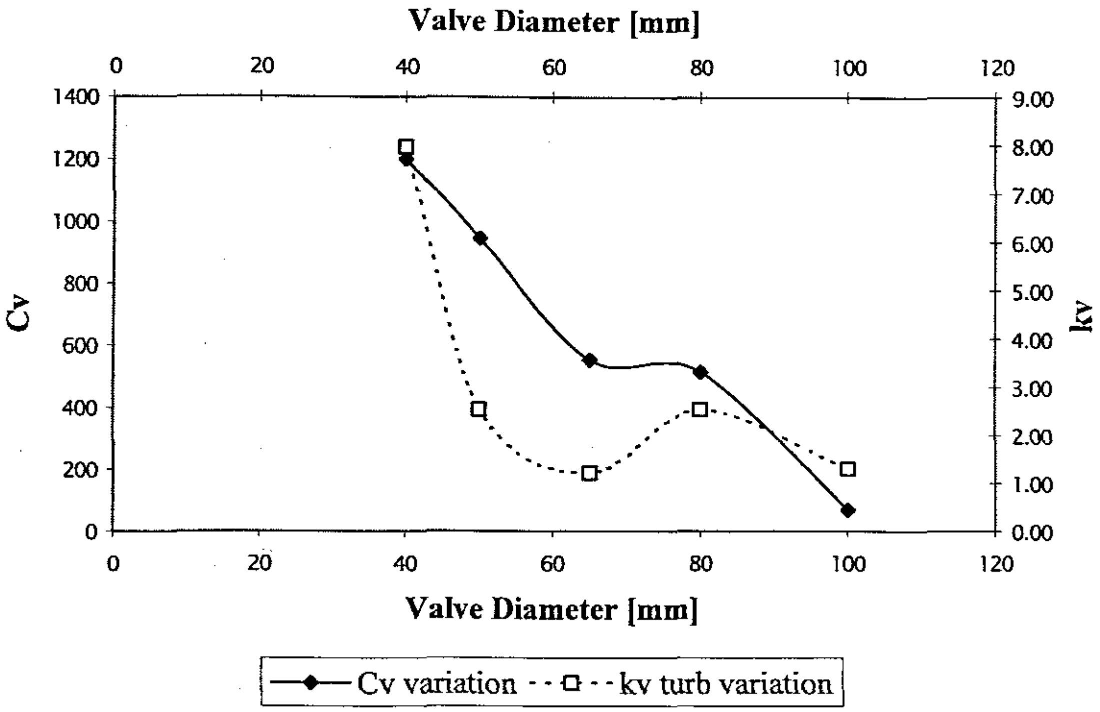

Figure 5. 2 Variation of loss coefficient in laminar and turbulent flow

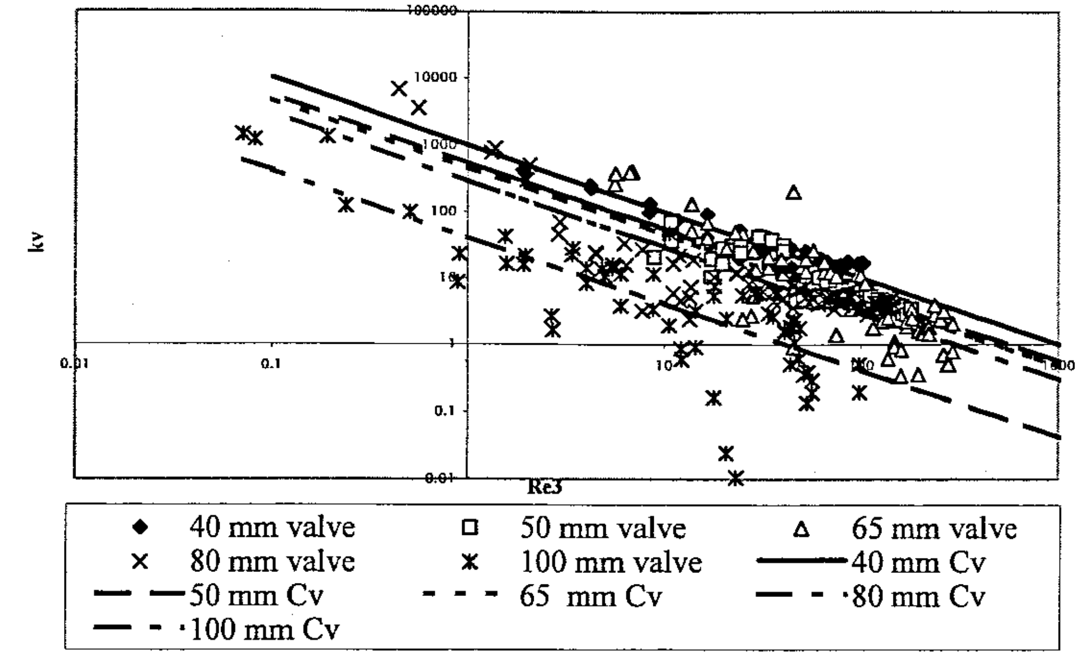

Figure 5. 3 Diaphragm valve loss coefficients for CMC 8% in laminar flow

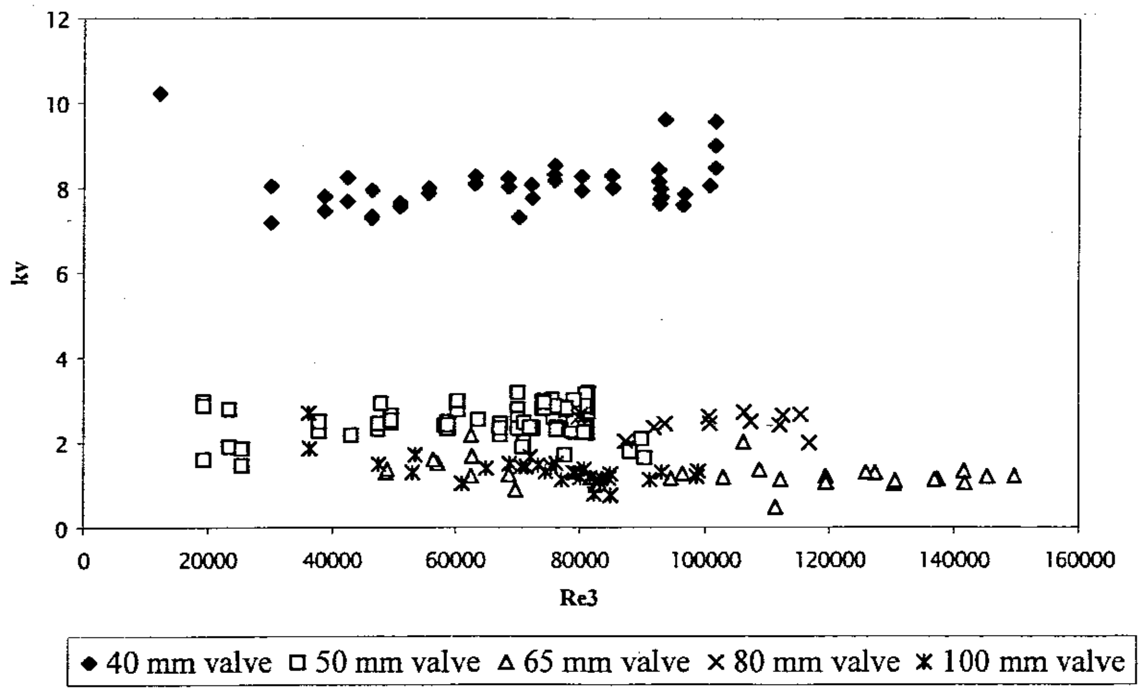

Figure 5. 4 Diaphragm valves loss coefficients for water in turbulent flow

5.11 CONCLUSION

It has been shown that there is lack of data on diaphragm valves in the literature and the available data in the literature are scattered.

The experimental test loop has also been discussed and proved to be reliable and accurate.

The experimental method has been discussed and evaluated.

The instrumentation has been described and evaluated.

Materials tested have been discussed and their use justified.

The diaphragm valve loss coefficients and the rheological characterisation has been discussed and evaluated.

A similarity analysis has been done and it has been established that dynamic similarity is not achieved with the diaphragm valves studied and possible reasons for this were given.

CHAPTER 6

CHAPTER 6
SUMMARY, CONTRIBUTIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The literature review, the experimental method, as well as the analysis of results and discussion and evaluation of results have been presented.

In this chapter the contributions of this work will be summarised and some recommendations proposed.

6.2 SUMMARY

This investigation was concerned with the evaluation of valve loss coefficients in diaphragm valves when non-Newtonian materials flow through the valve in laminar, transitional and turbulent flow. Qualitative and quantitative data on non-Newtonian losses in diaphragm valves is scarce.

An experimental test loop referred to as the Valve test rig was designed, built, commissioned and optimised. The Valve test rig was fitted with five diaphragm valves of 40, 50, 65, 80, and 100 millimetre nominal bore diameters. Various Newtonian (water and glycerine) and non-Newtonian fluids (CMC and kaolin slurries of various concentrations) were rheologically characterised and the valve loss coefficients were determined using the HGL approach.

The results were presented as plots of valve loss coefficient versus Reynolds number. Loss coefficients for laminar, transitional and turbulent flow were determined for all five valves.

6.3 CONTRIBUTIONS

The present investigation has confirmed the general theory on valve loss coefficients in laminar, transitional and turbulent flow and in particular:

- It has confirmed that the loss coefficient in laminar flow increases significantly with decreasing Reynolds number and is a hyperbolic function of the Reynolds number:

$$k_v = \frac{C_v}{Re} \tag{2.56}$$

- This investigation has also confirmed that in turbulent flow, the valve loss coefficient is essentially constant and is independent of the Reynolds number.

Further more this investigation has:

- Confirmed that the transition from turbulent flow to laminar flow occurs earlier in valves than in straight pipes.
- Highlighted the usefulness of the Slatter Reynolds number for both Newtonian and non-Newtonian fluids for the first time.
- Produced quantitative data on loss coefficients through diaphragm valves (Table 4.7) for use by slurries pipeline design engineers.
- Highlighted the need that studies should be carried out with a range of diaphragm valves to establish if geometric similarity is achieved and subsequently to establish dynamic similarity.
- Highlighted the need to investigate the internal details of the valve with the corresponding loss coefficient details and not to conclude at first sight that geometric and dynamic similarities are achieved.

Table 4.7 Summary of C_v and k_v values obtained

Valve dimension [mm]	C_v	k_v
40	1200	7.96
50	946	2.53
65	555	1.21
80	515	2.54
100	69	1.30

6.4 RECOMMENDATIONS

The following recommendations are suggested:

- Further experimental test work must be done on the determination of valve loss coefficients in general and diaphragm valve loss coefficients in particular.
- The determination of valve loss coefficients should be done for different valve openings (fully open, ¾ open, ½ open and ¼ open) for different types of materials. But for a refinement in the research, fluids of the same characteristics (Newtonian, pseudoplastic, yield pseudoplastic and Bingham plastic) should be tested and evaluated separately.
- Further study on geometrically similar valves in general and diaphragm valves in particular from other manufacturers should be done.
- The two experimental methods: the Hydraulic grade line approach and the Total pressure method should be done on the Valve test- rig, evaluated and then discussed.
- Further market research on the available fluid flow instrumentation should be done so that instruments with very large capabilities can be identified.

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APPENDICES

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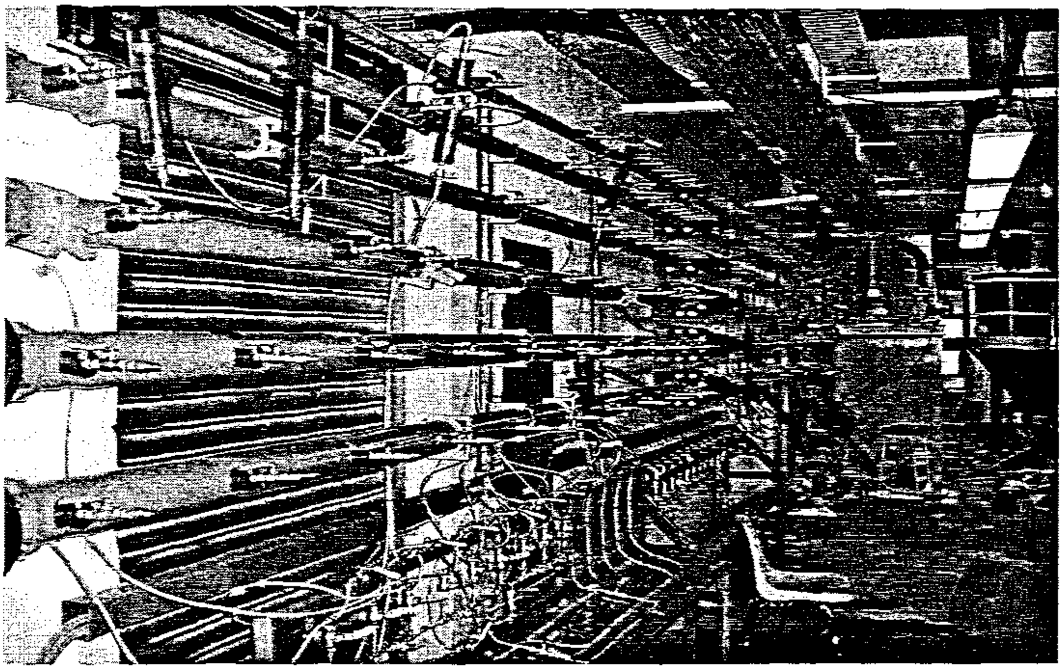
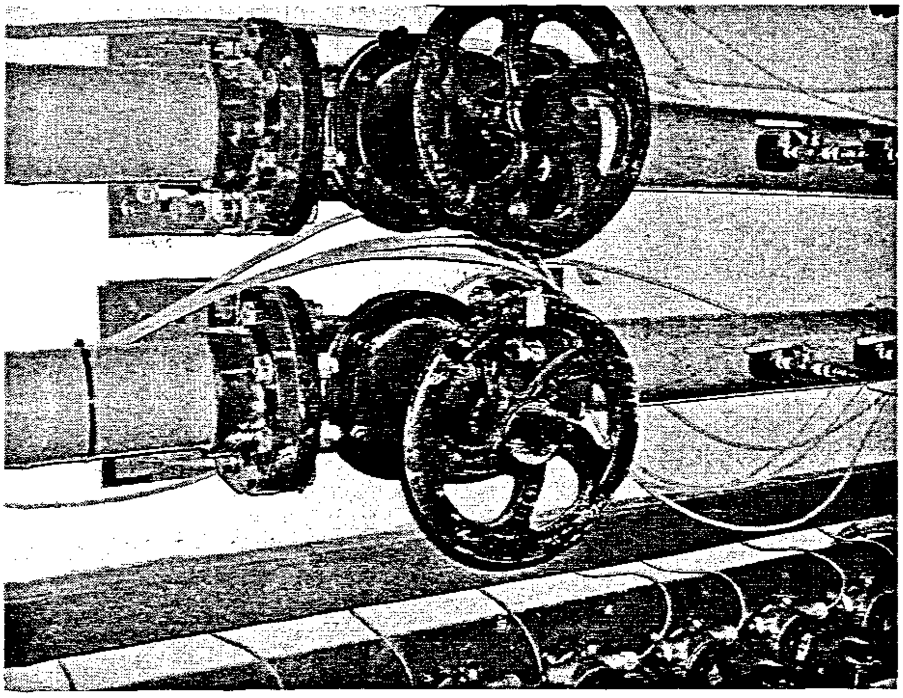
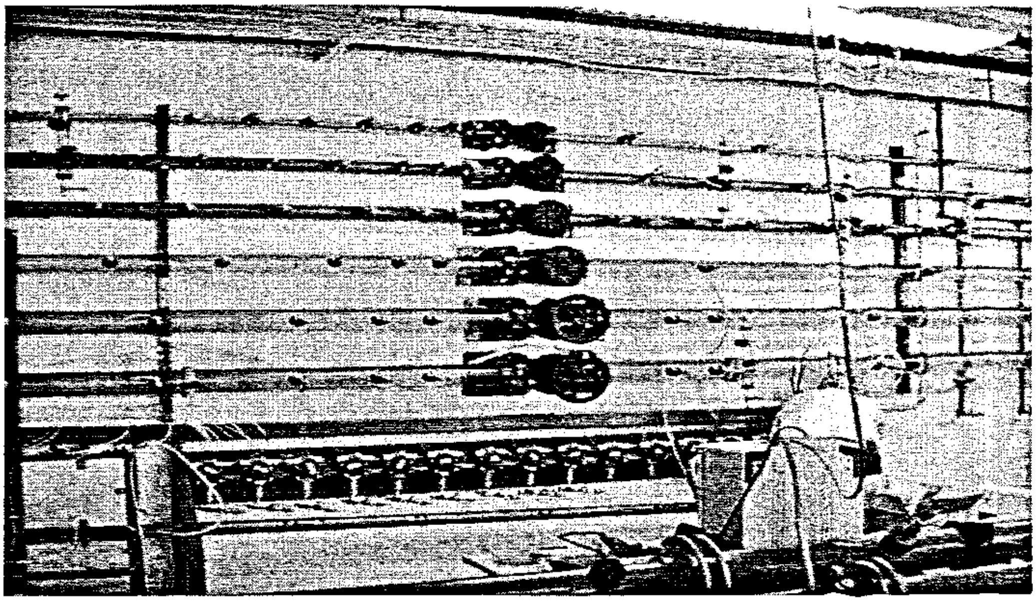
PHOTOGRAPHS OF THE EXPERIMENTAL TEST LOOP AND INSTRUMENTATION



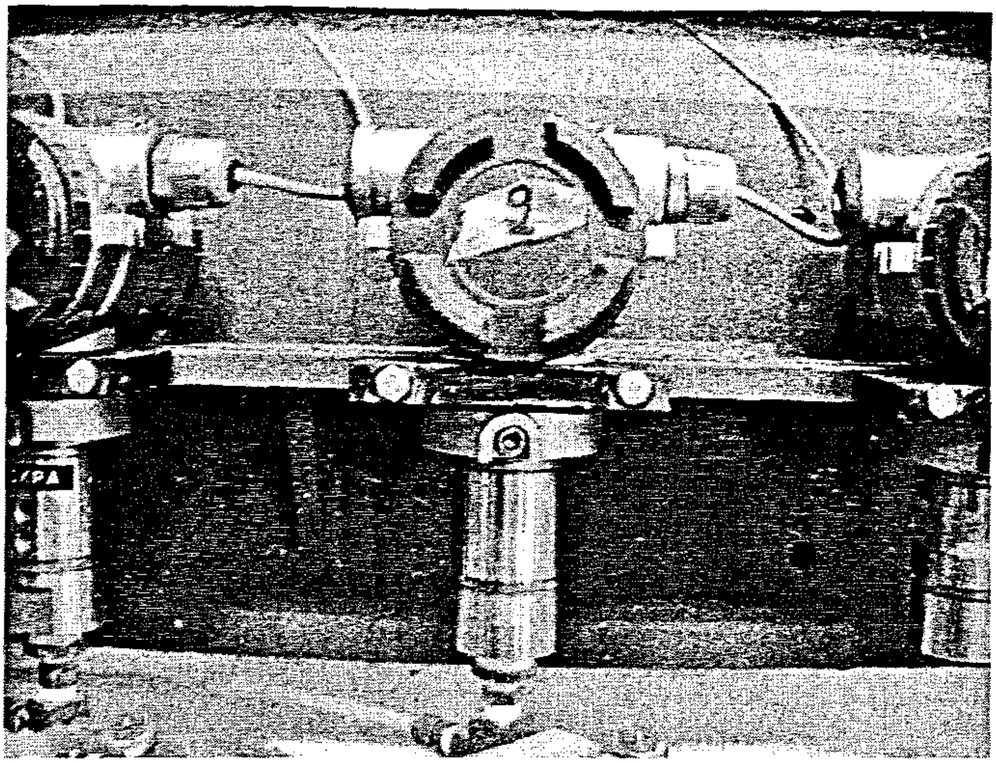
Photograph 1. Overview of the Valve test rig



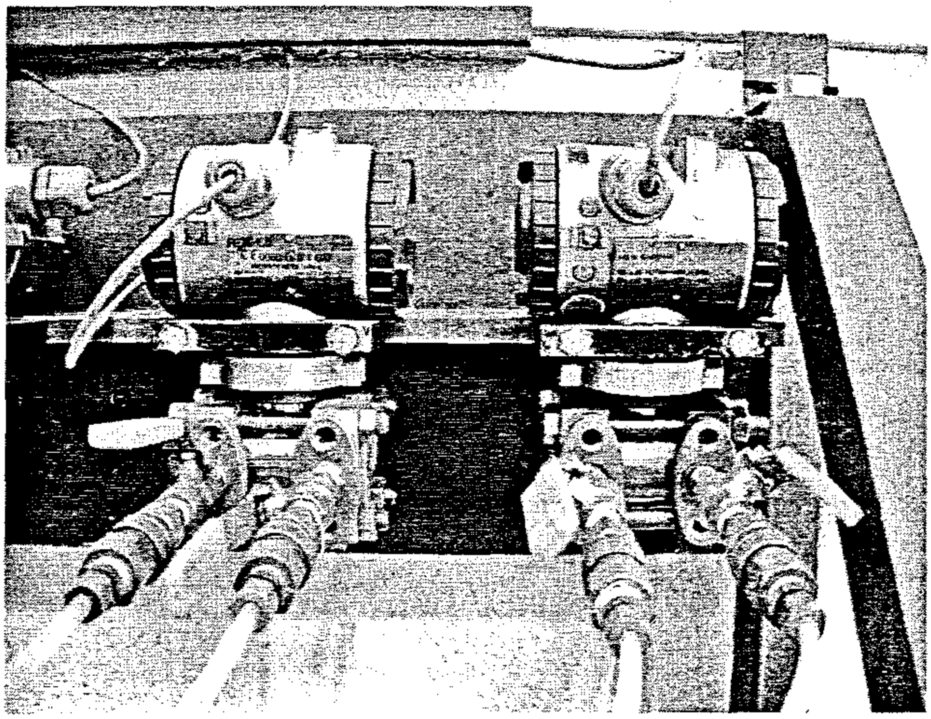
Photograph 2. Diaphragm valves connected to pipes



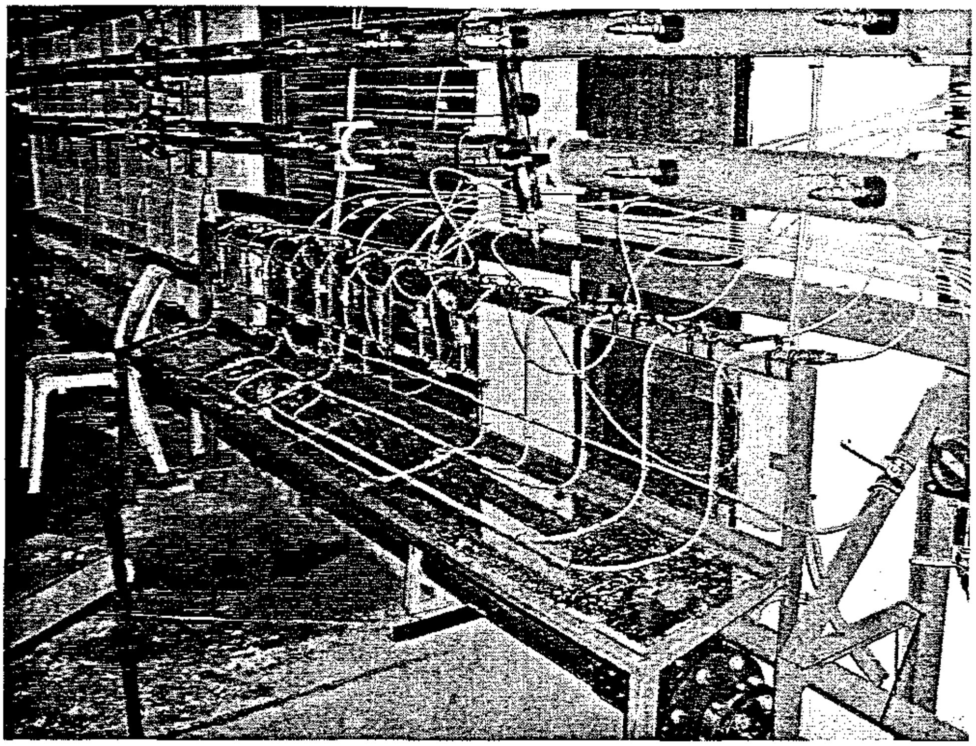
Photograph 3. Diaphragm valves, pipes, Point Pressure Transducers and Differential Pressure Cell



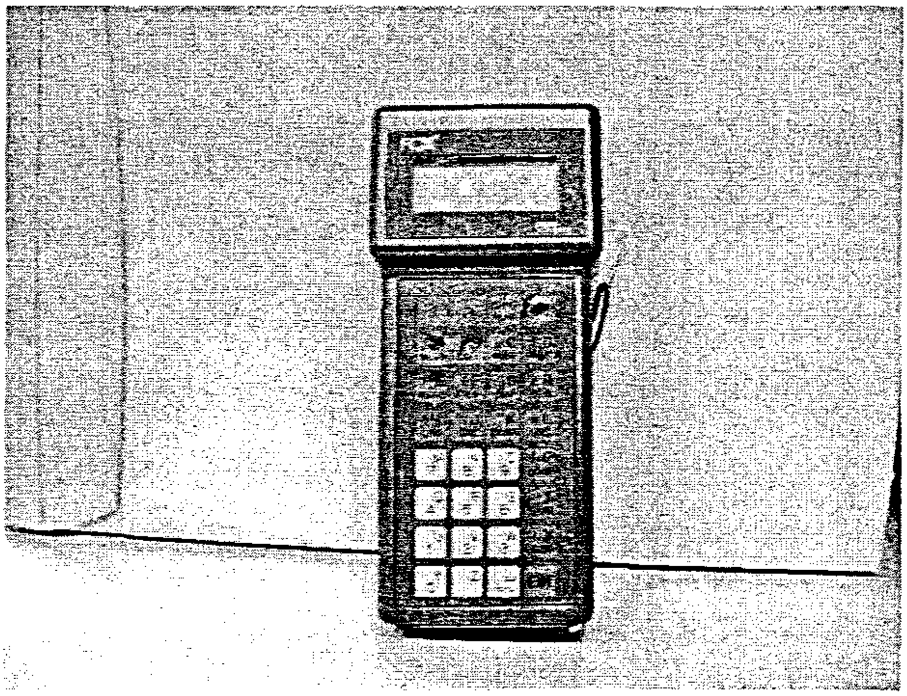
Photograph 4. Point Pressure Transducer



Photograph 5. Differential Pressure Cells



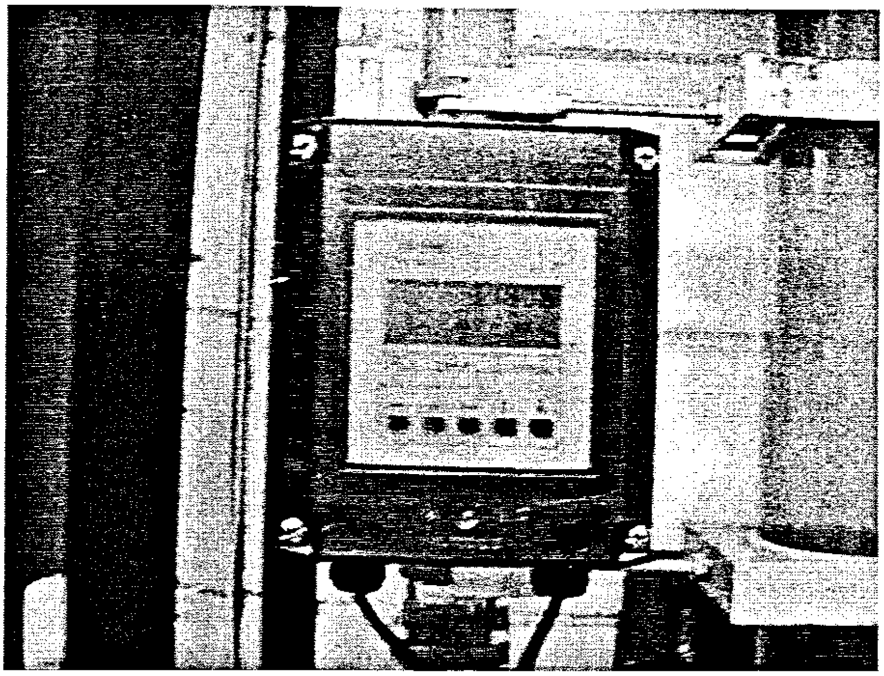
Photograph 6. Pressure Lines Board



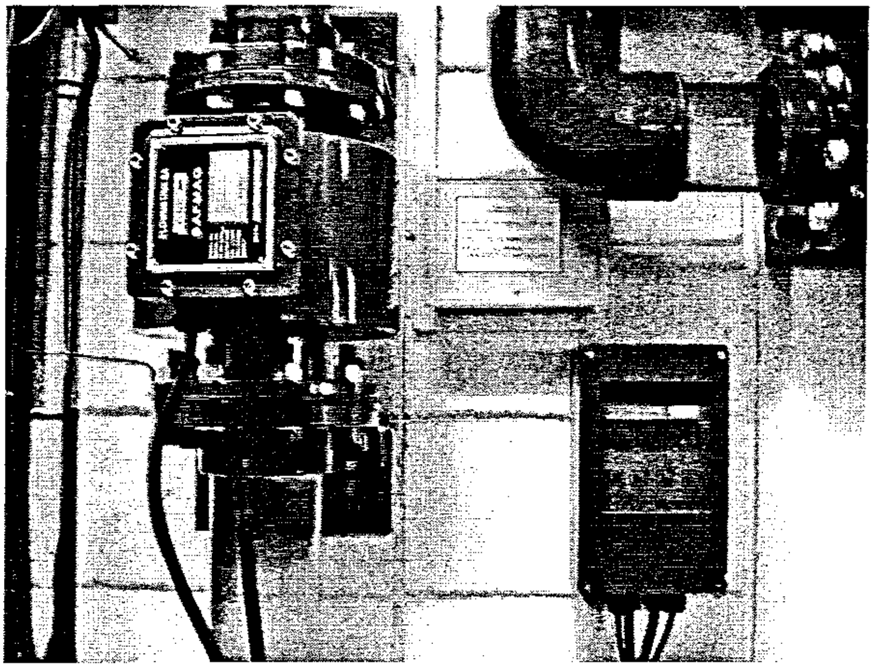
Photograph 7. Hand Held Communicator

Photograph 8. Data Acquisition Unit

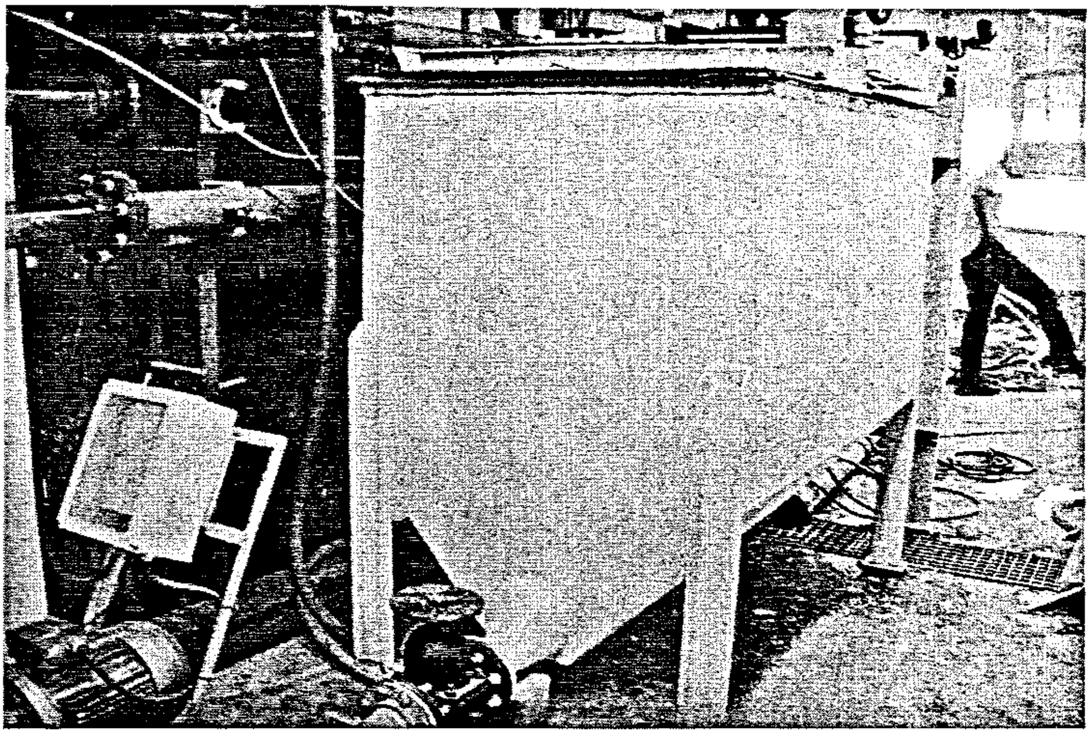
Photograph 9. PC and Data Acquisition Unit



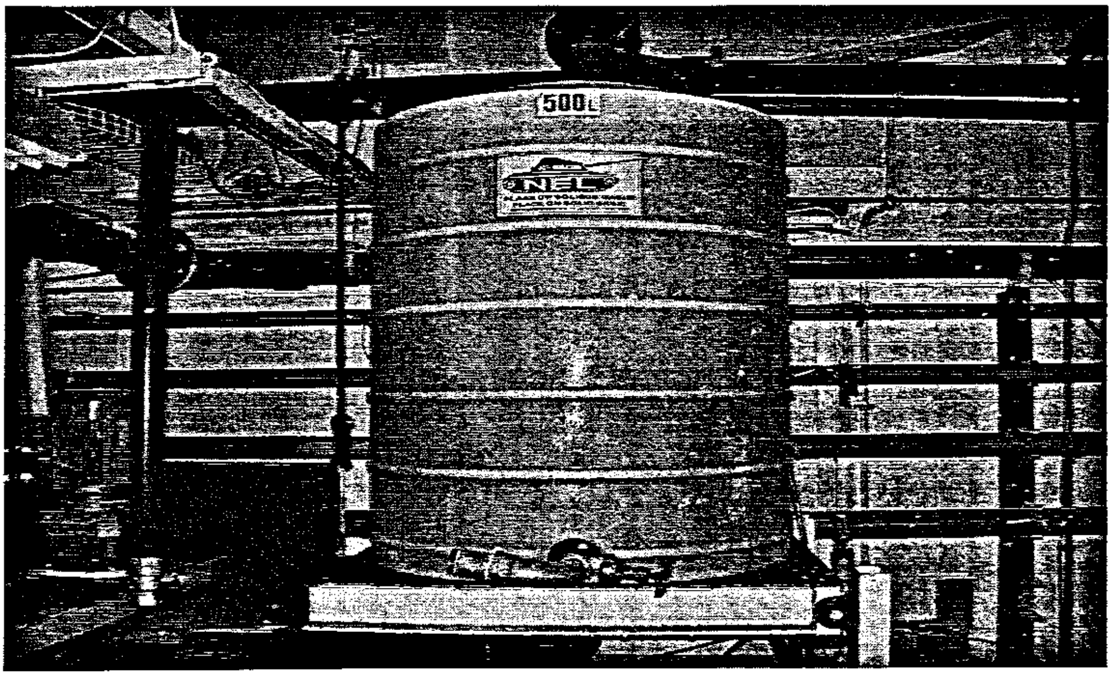
Photograph 10. Krohne magnetic flow meter



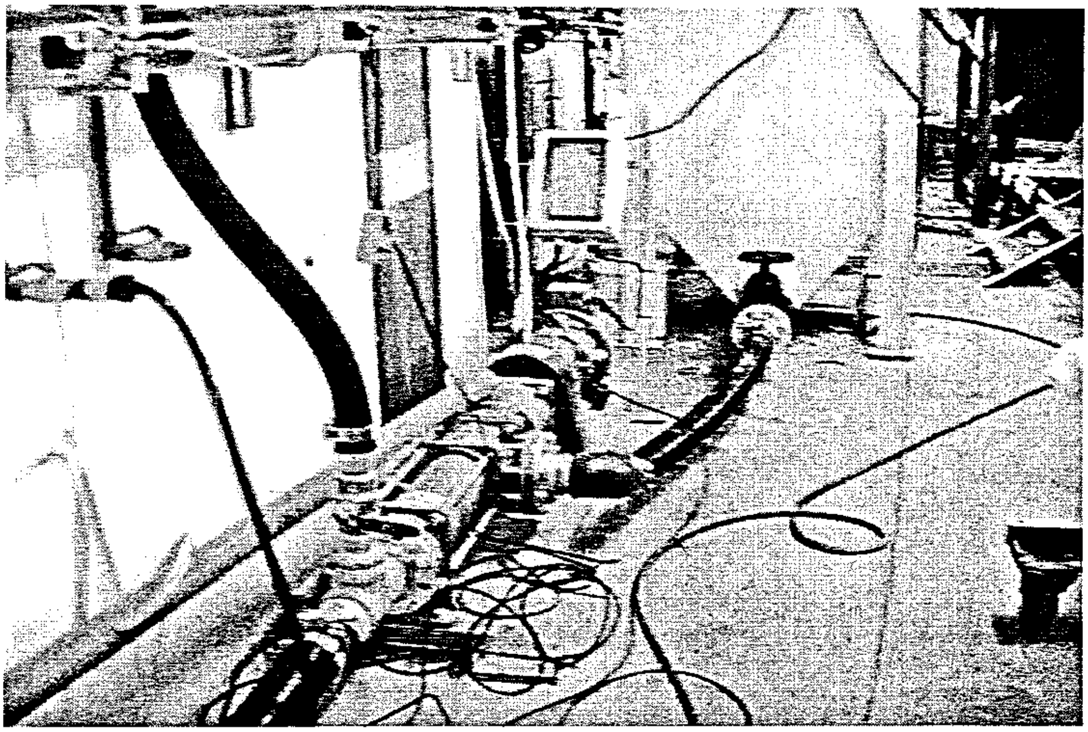
Photograph 11. Safmag magnetic flow meter



Photograph 12. Mixing tank



Photograph 13. Weigh tank with Load cell



Photograph 14. Orbit PD pump

APPENDIX 2
COMPARISON OF WATER TEST RESULTS WITH COLEBROOK & WHITE EQUATION

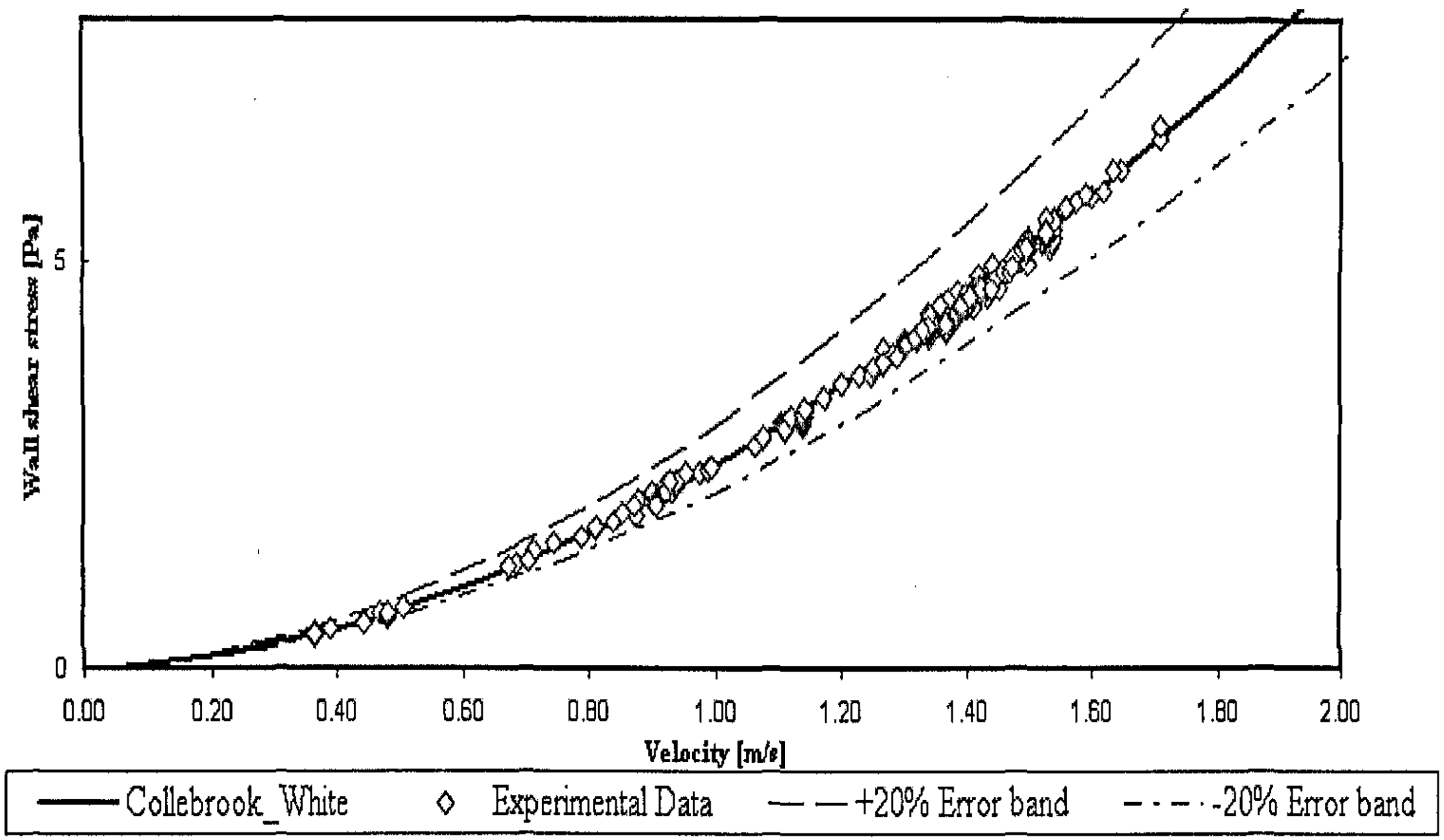


Figure 1 Comparison with Colebrook and White for water test, pipe of 52.08 mm

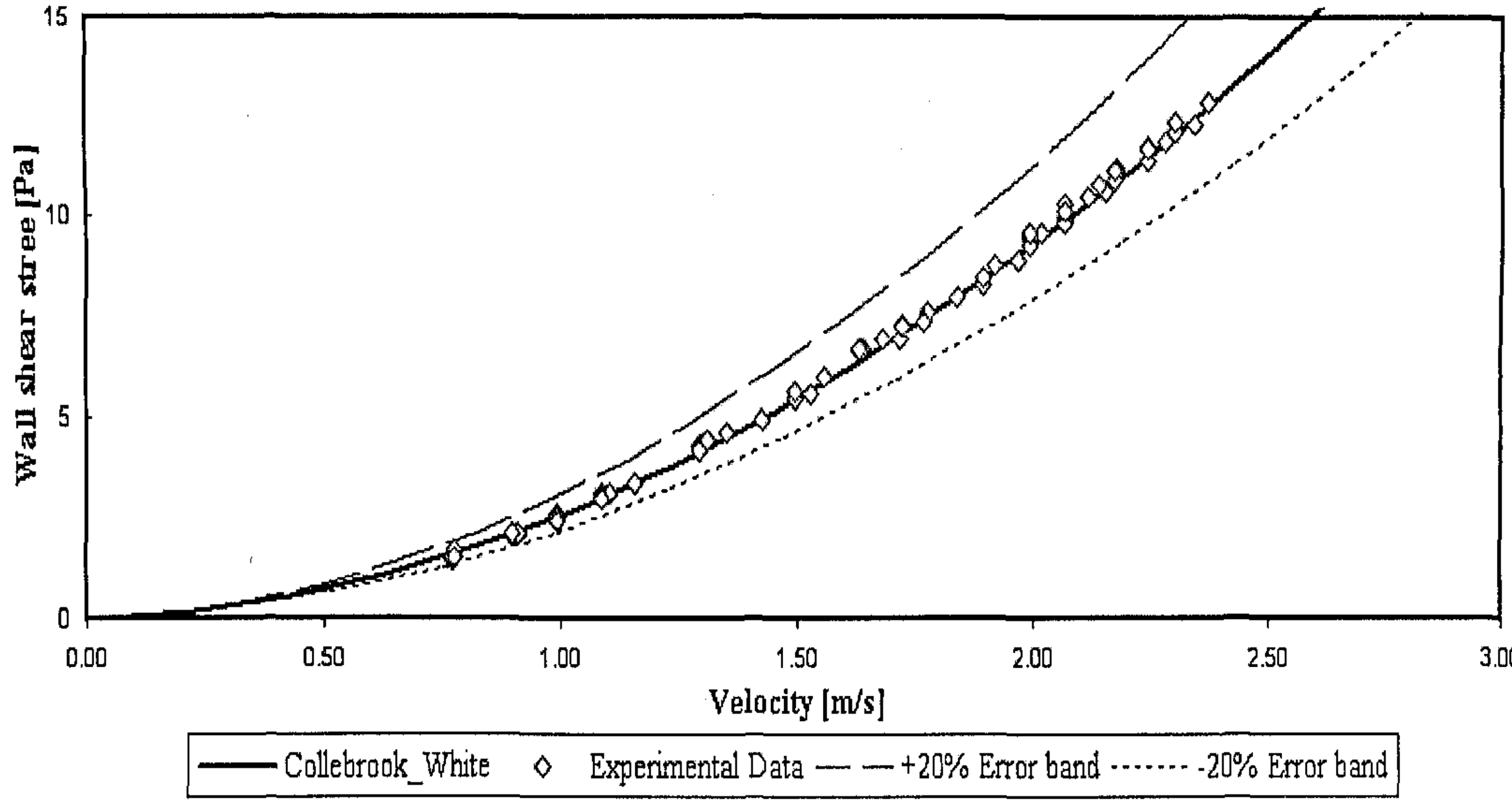


Figure 2 Comparison with Colebrook and White for water test, pipe of 63.08 mm

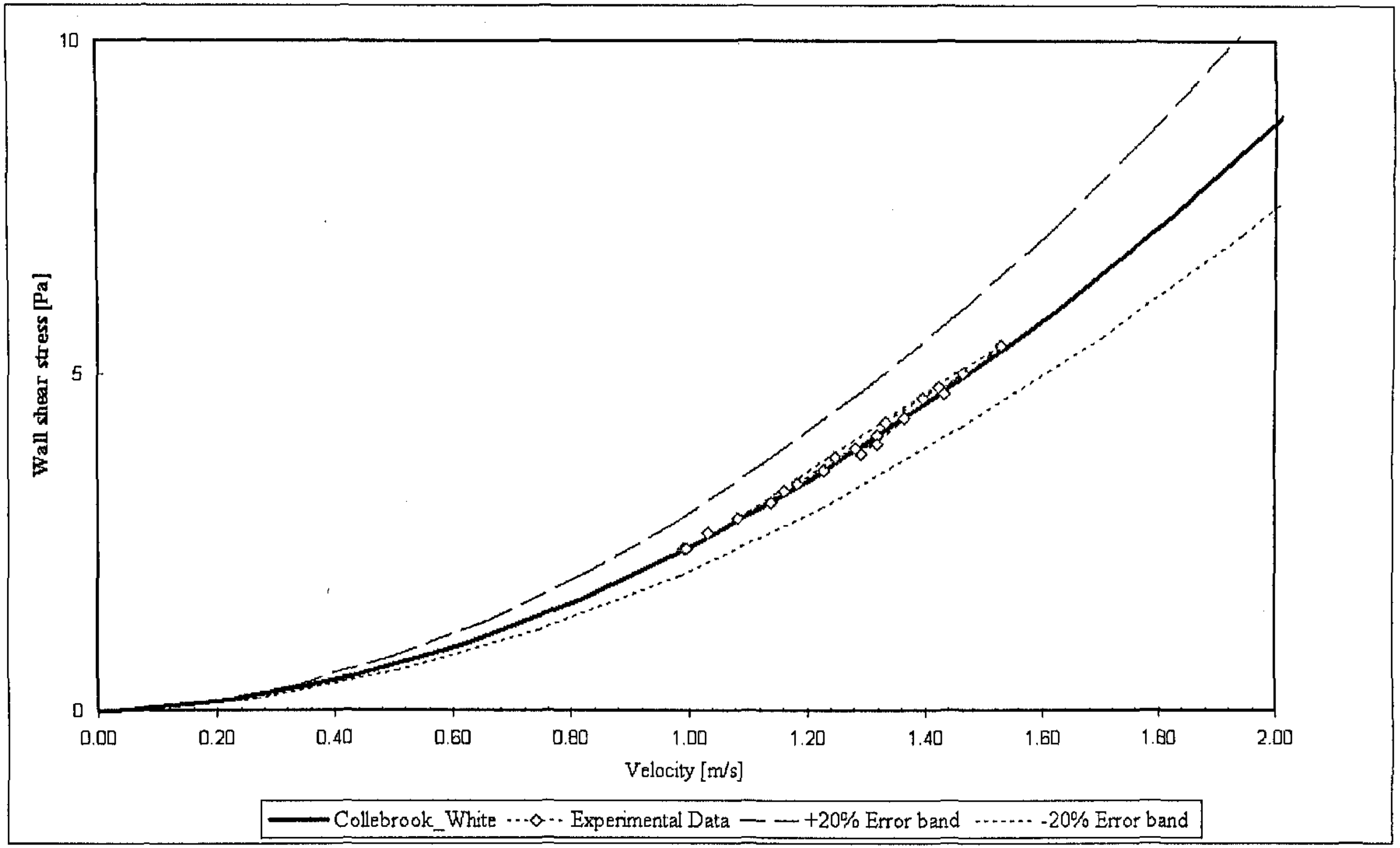


Figure 3 Comparison with Colebrook and White for water test, pipe of 80.43 mm

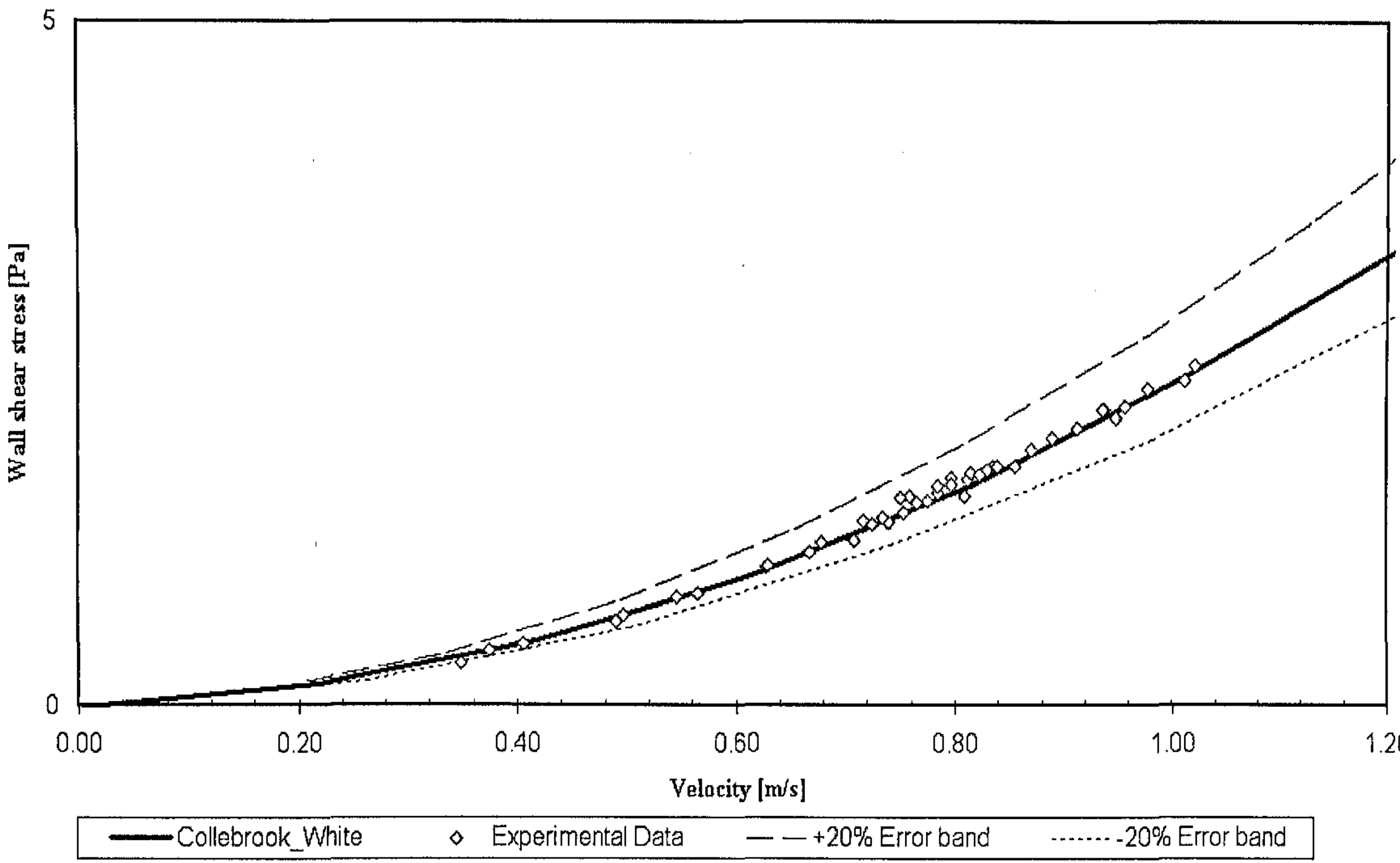


Figure 4 Comparison with Colebrook and White for water test, pipe of 97.17 mm

APPENDIX 3
RHEOGRAMS OF FLUIDS TESTED

GLYCERINE 100%

SLURRY PROPERTIES	
Date	22/11/2004
Slurry Relative Density	1270 kg/m^3
Volume Concentration	100%
Viscosity	0.842 Pa.s
Temperature	25.5°C

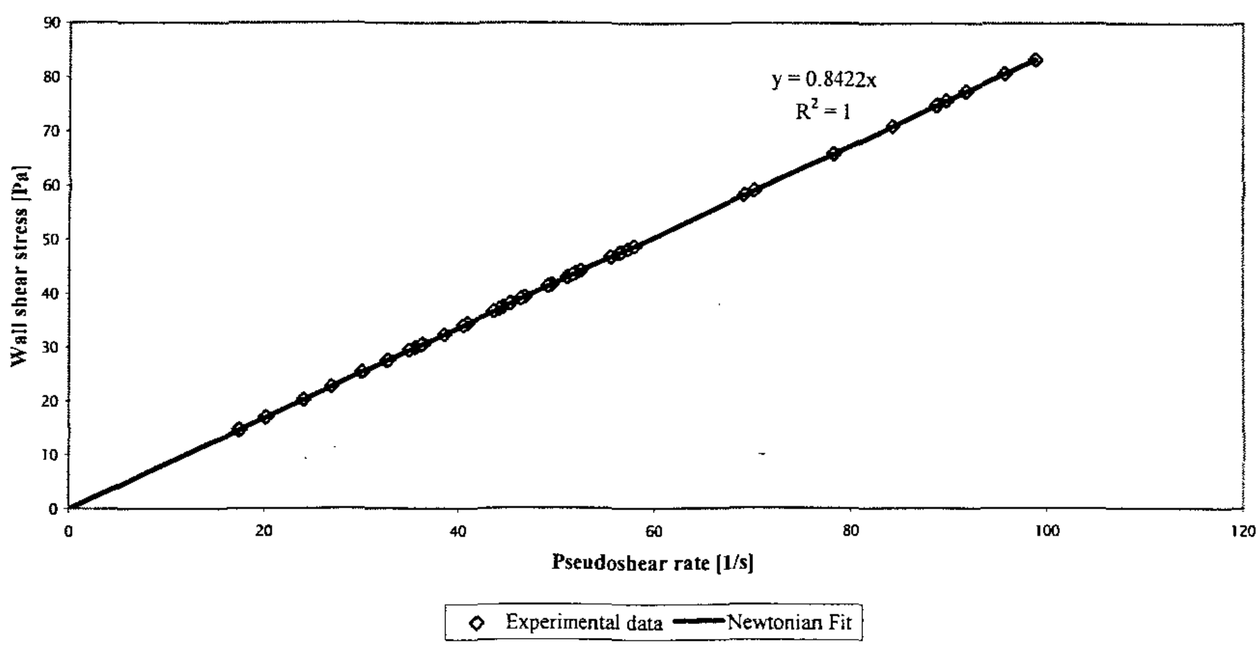


Figure 5 Rheogram Glycerine 100%

GLYCERINE 100%

SLURRY PROPERTIES	
Date	19/11/2004
Slurry Relative Density	1252.61 kg/m^3
Volume Concentration	100%
Viscosity	0.175 Pa.s
Temperature	27°C

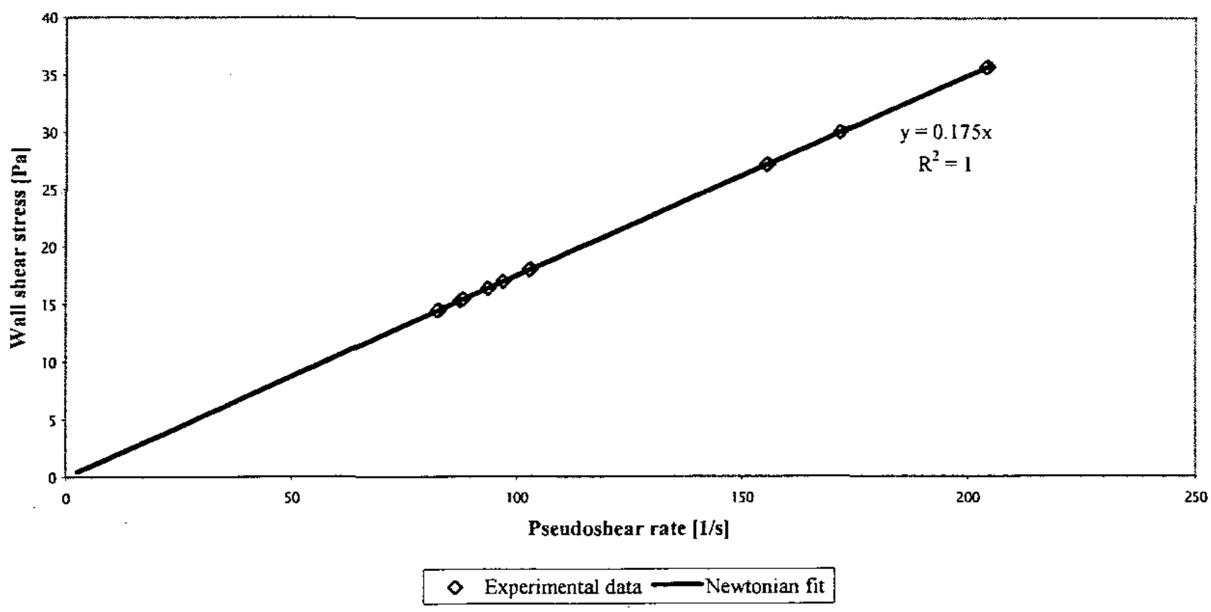


Figure 6 Rheogram Glycerine 100%

GLYCERINE 100%

SLURRY PROPERTIES	
Date	25/11/2004
Slurry Relative Density	1256 kg/m^3
Volume Concentration	100%
Viscosity	0.693 Pa.s
Temperature	22°C

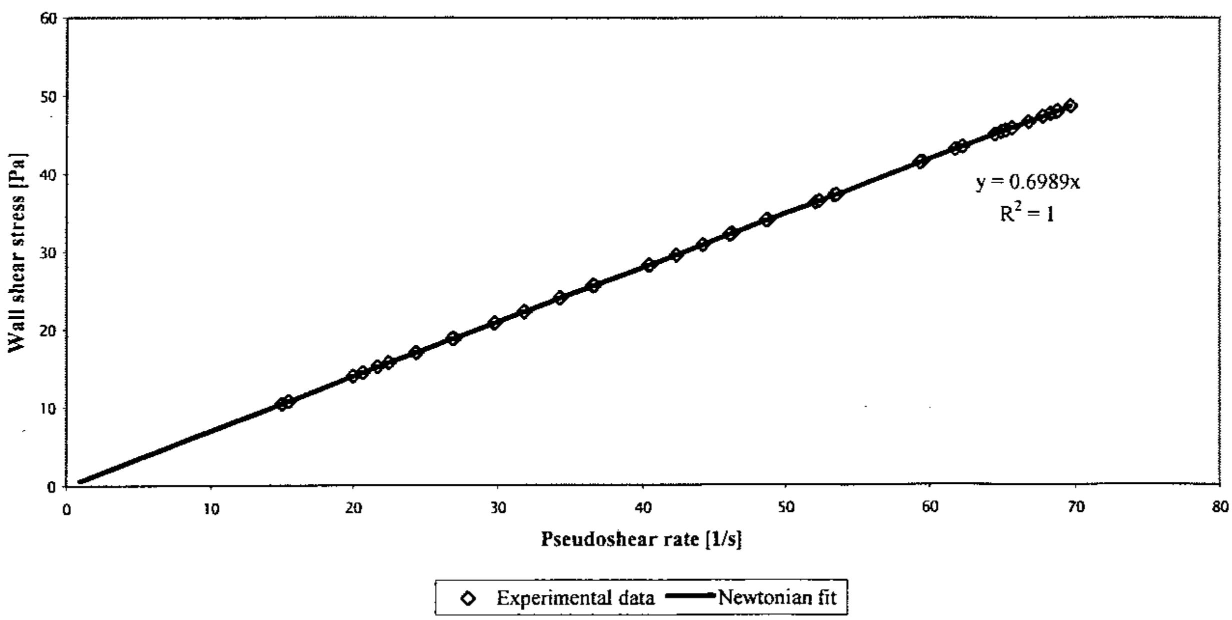


Figure 7 Rheogram Glycerine 100%

GLYCERINE 75%

SLURRY PROPERTIES	
Date	1/12/2004
Slurry Relative Density	1197.2 kg/m^3
Volume Concentration	75%
Viscosity	0.0196 Pa.s
Temperature	21°C

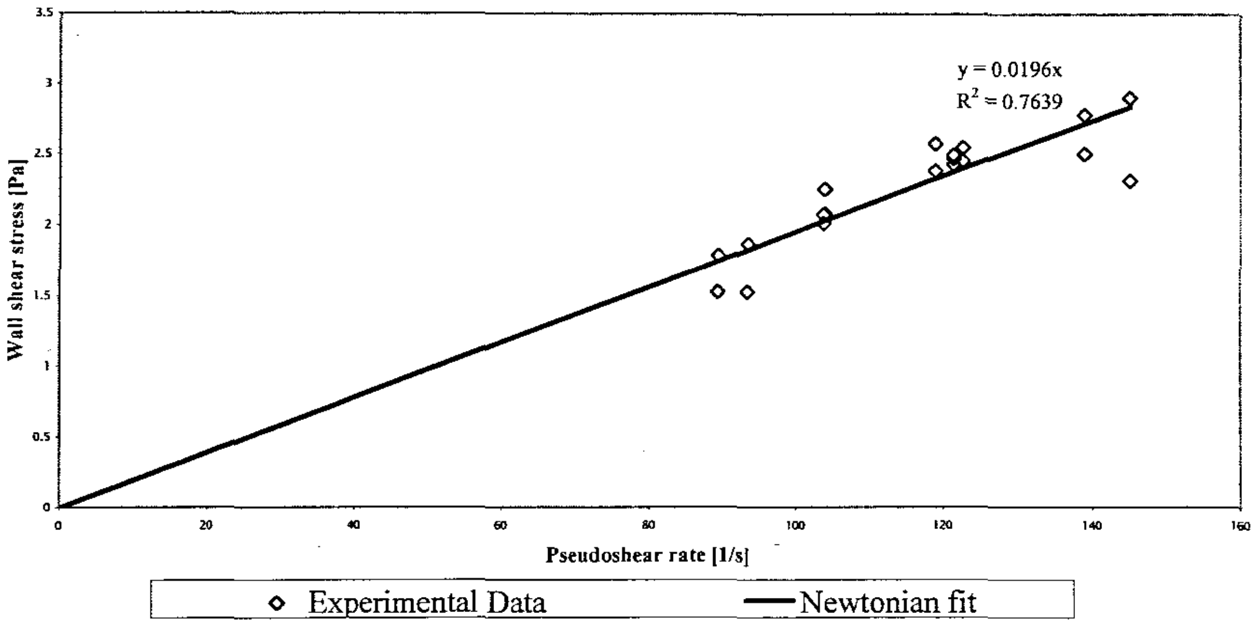


Figure 8 Rheogram Glycerine 75%

GLYCERINE 75%

SLURRY PROPERTIES	
Date	30/11/2004
Slurry Relative Density	1197.2 kg/m^3
Volume Concentration	75%
Viscosity	0.0184 Pa.s
Temperature	21°C

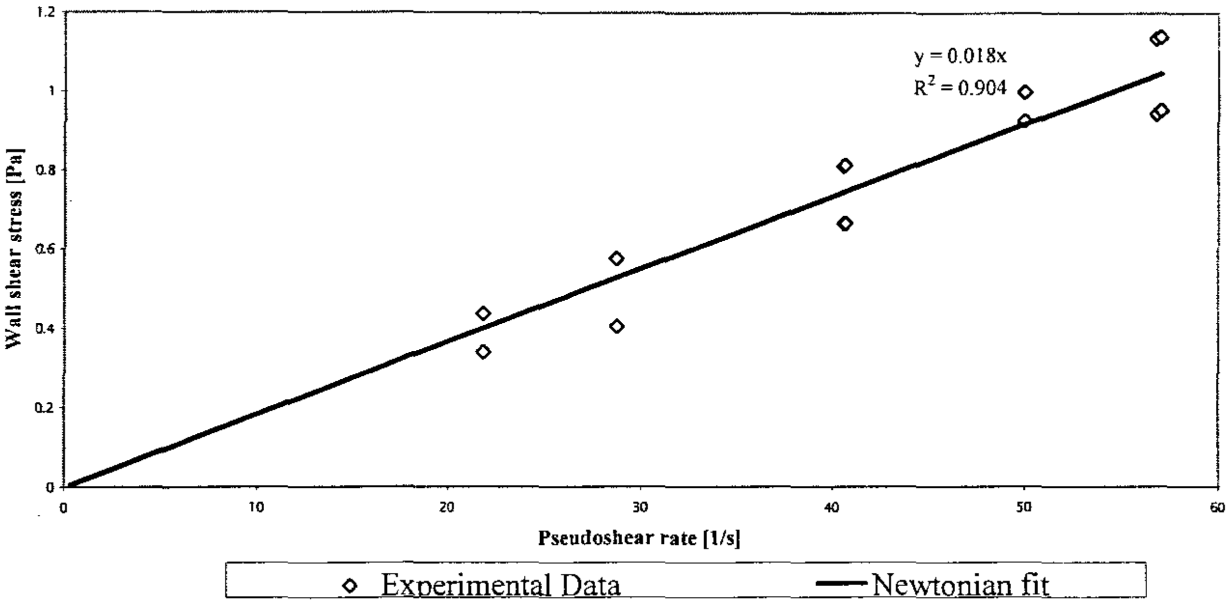


Figure 9 Rheogram Glycerine 75%

CMC 5%

SLURRY PROPERTIES	
Date	22/10/2004
Slurry Relative Density	1029 kg/m^3
Mass Concentration	5%
Fluid Consistency Index	0.304 Pa.s^n
Flow Behaviour Index	0.723

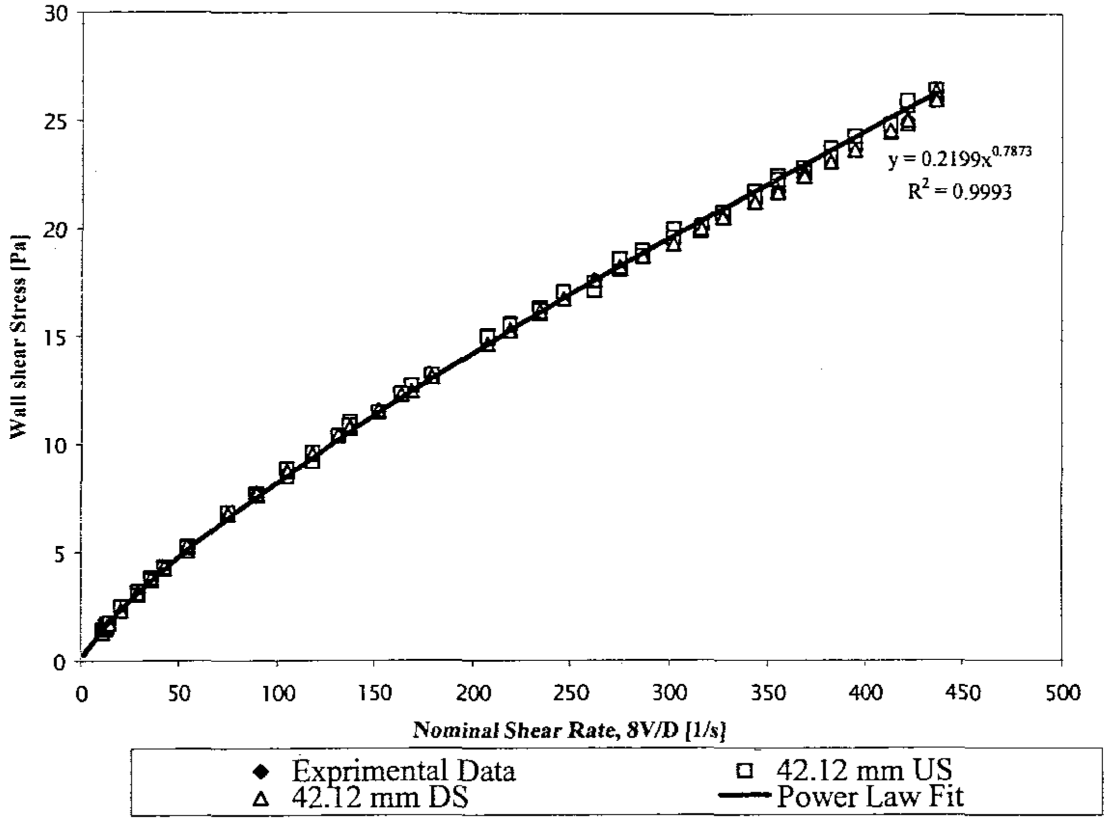


Figure 10 Rheogram CMC 5%

CMC 5%

SLURRY PROPERTIES	
Date	26/10/2004
Slurry Relative Density	1026.5 kg/m^3
Mass Concentration	5%
Fluid Consistency Index	0.472 $Pa.s^n$
Flow Behaviour Index	0.742

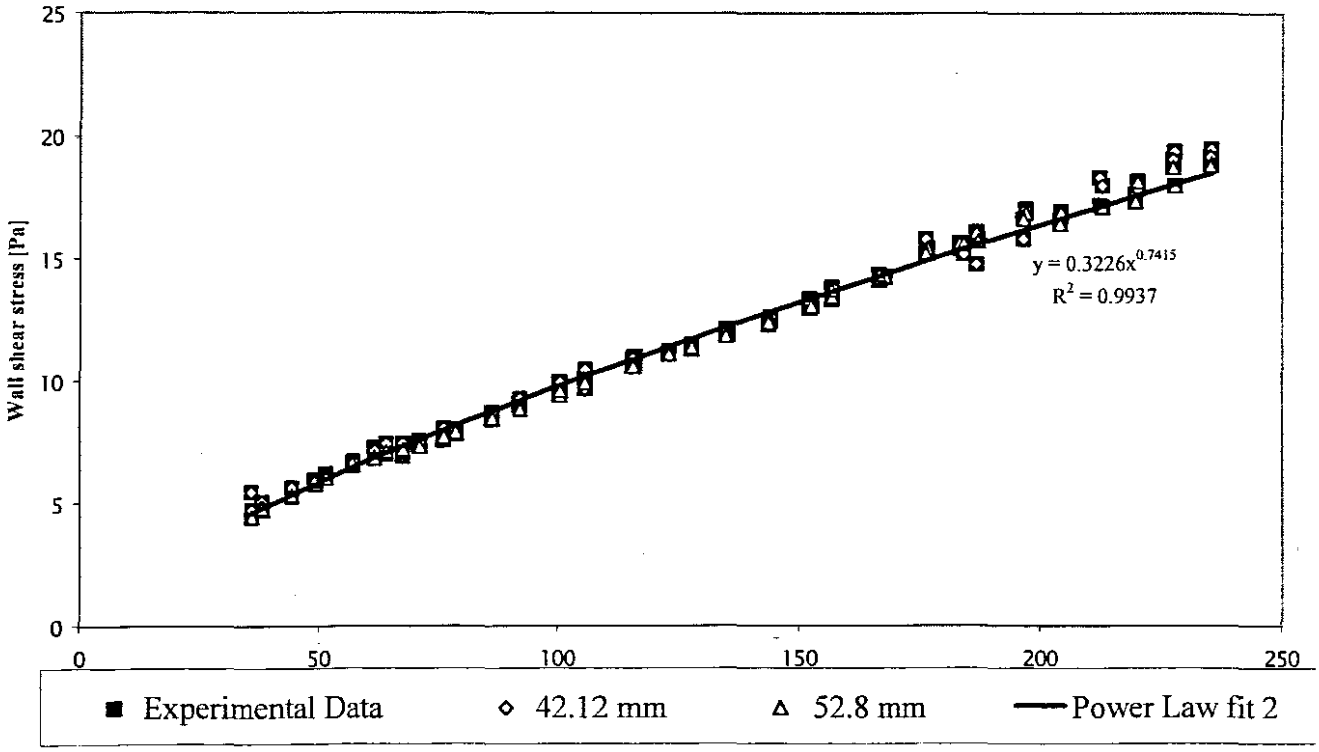


Figure 11 Rheogram CMC 5%

CMC 5%

SLURRY PROPERTIES	
Date	2/11/2004
Slurry Relative Density	1028.2 kg/m^3
Mass Concentration	5%
Fluid Consistency Index	1.095 $Pa.s^n$
Flow Behaviour Index	0.798

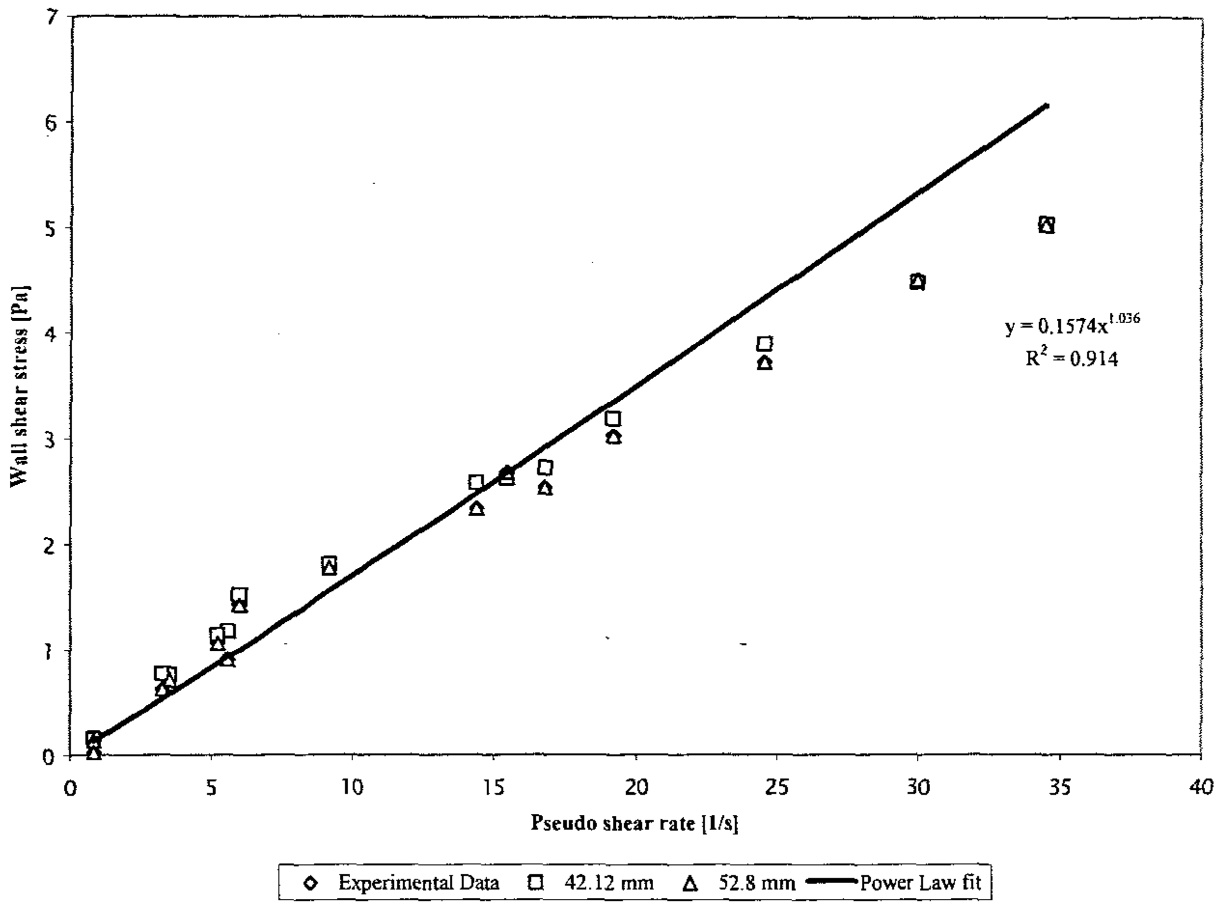


Figure 12 Rheogram CMC 5%

CMC 8%

SLURRY PROPERTIES	
Date	12/11/2004
Slurry Relative Density	1040 kg/m^3
Mass Concentration	8%
Fluid Consistency Index	5.908 Pa.s^n
Flow Behaviour Index	0.6147

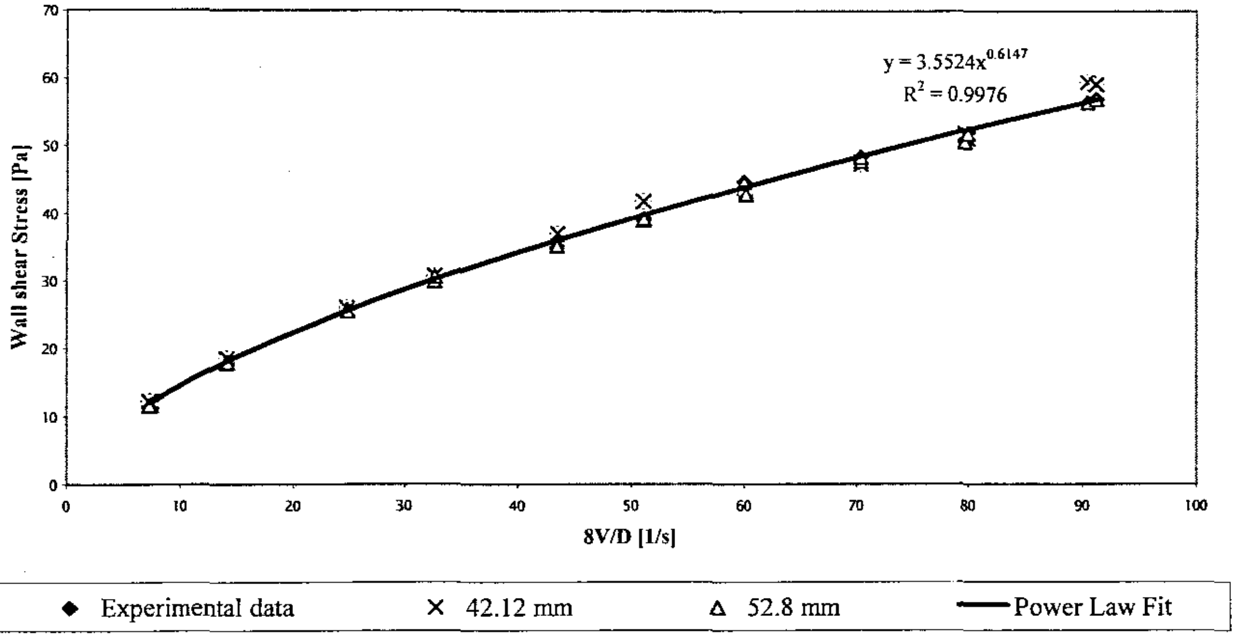


Figure 13 Rheogram CMC 8%

CMC 8%

SLURRY PROPERTIES	
Date	08/11/2004
Slurry Relative Density	1037.5 kg/m^3
Mass Concentration	8%
Fluid Consistency Index	8.68 $Pa.s^n$
Flow Behaviour Index	0.54

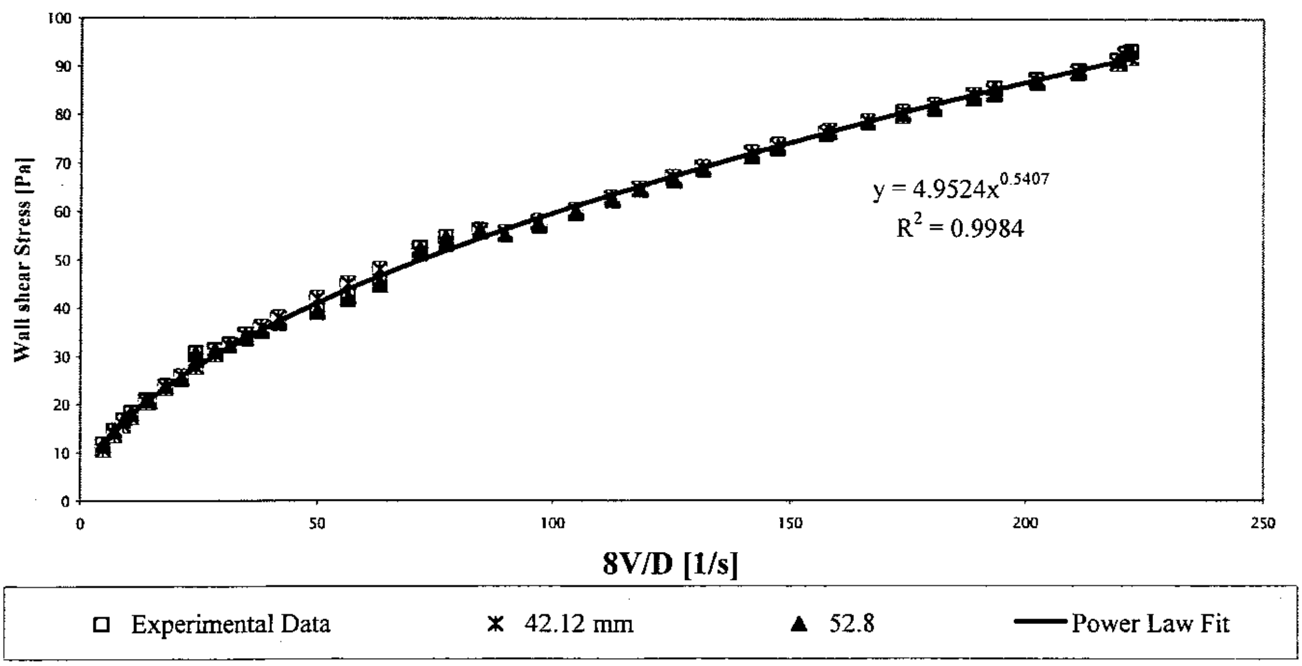


Figure 14 Rheogram CMC 8%

CMC 8%

SLURRY PROPERTIES	
Date	10/11/2004
Slurry Relative Density	1044 kg/m^3
Mass Concentration	8%
Fluid Consistency Index	10.29 Pa.s^n
Flow Behaviour Index	0.53

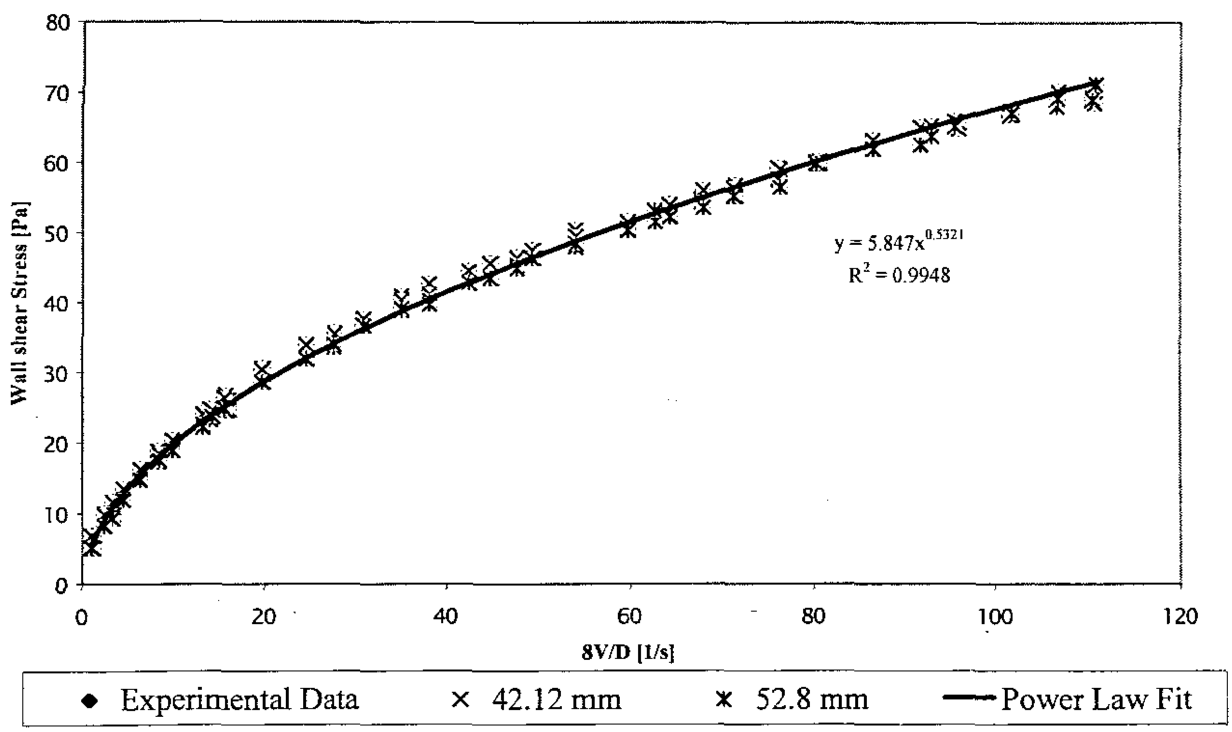


Figure 15 Rheogram CMC 8%

KAOLIN 10%

SLURRY PROPERTIES	
Date	20/08/2004
Slurry Relative Density	1163.4kg/m^3
Mass Concentration	10%
Yield stress	10 Pa
Fluid Consistency Index	3.15 Pa.s^n
Flow Behaviour Index	0.240

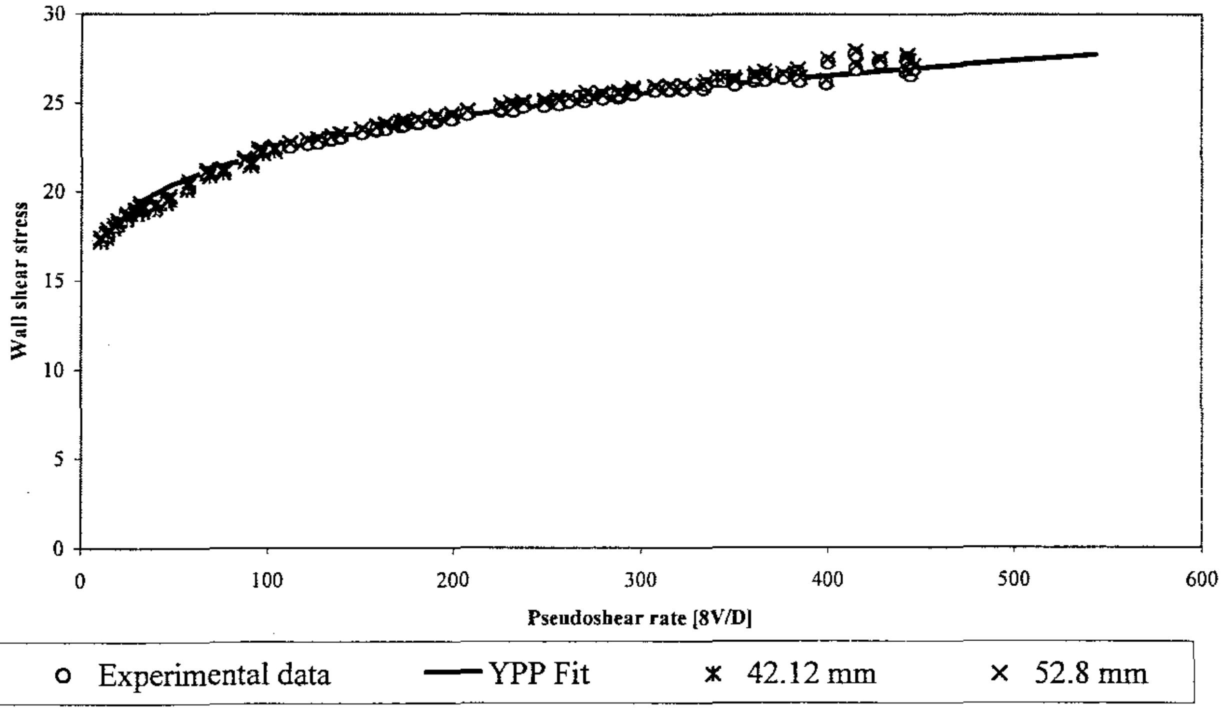


Figure 16 Rheogram kaolin 10%

KAOLIN 10%

SLURRY PROPERTIES	
Date	11/08/2004
Slurry Relative Density	1172.4kg/m^3
Mass Concentration	10%
Yield stress	10.7 Pa
Fluid Consistency Index	2.2 Pa.s^n
Flow Behaviour Index	0.32

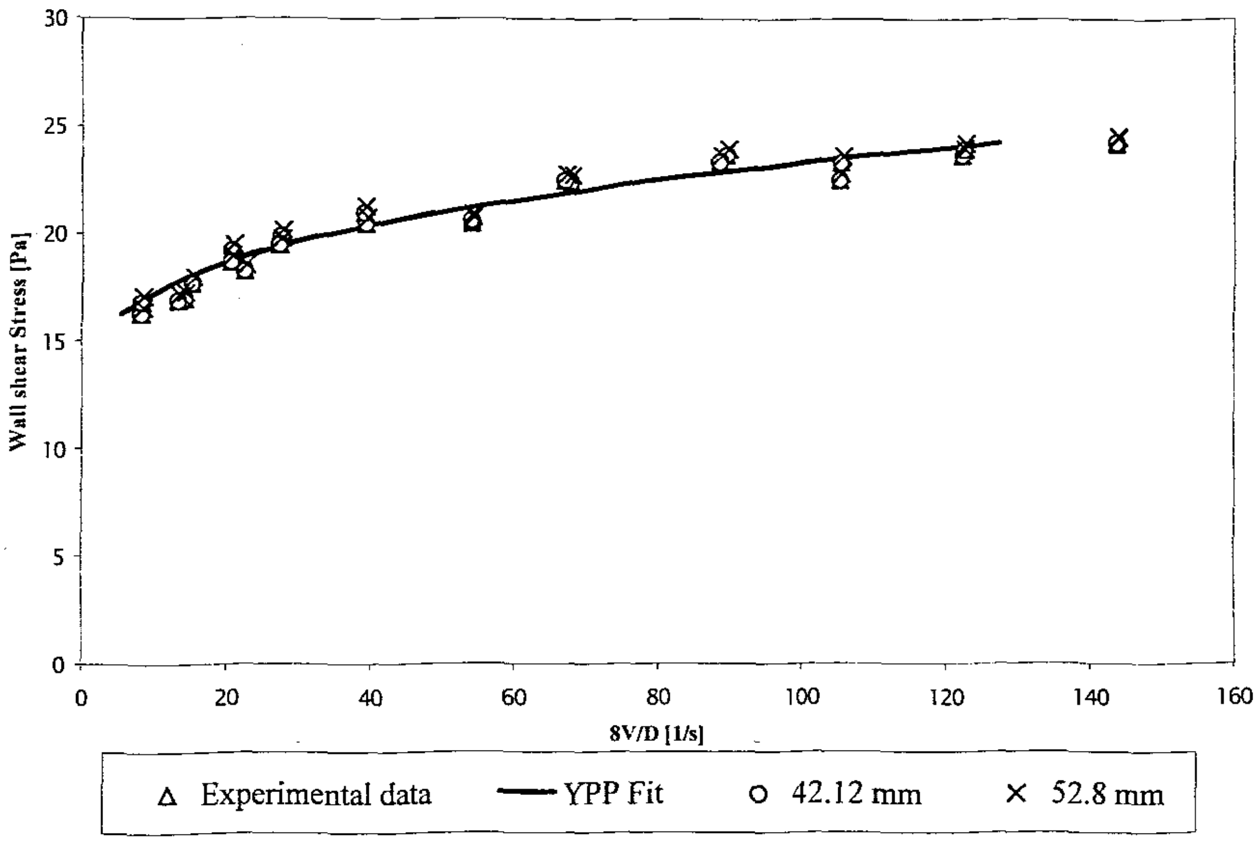


Figure 17 Rheogram kaolin 10%

KAOLIN 13%

SLURRY PROPERTIES	
Date	30/09/2004
Slurry Relative Density	1214 kg/m^3
Mass Concentration	13 %
Yield stress	35 Pa
Fluid Consistency Index	0.8 Pa.s^n
Flow Behaviour Index	0.5

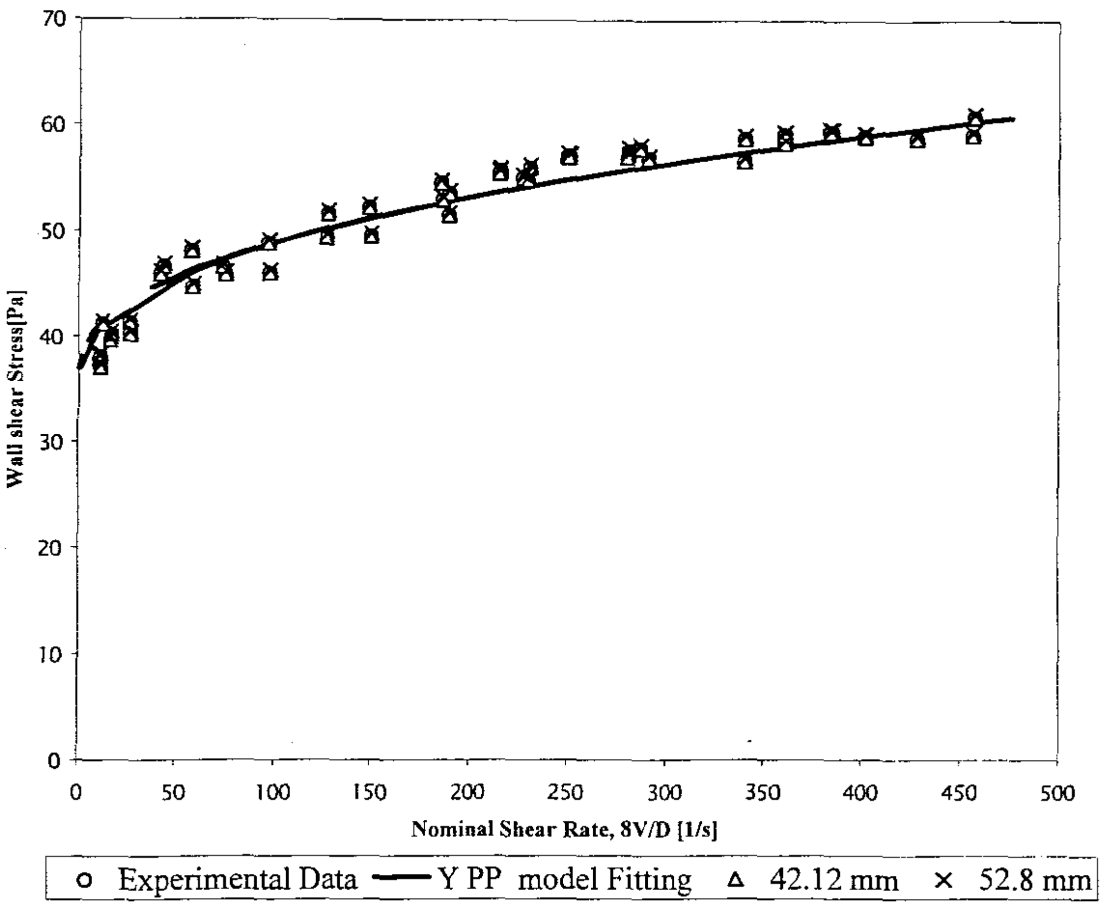


Figure 18 Rheogram kaolin 13%

KAOLIN 13%

SLURRY PROPERTIES	
Date	07/10/2004
Slurry Relative Density	1210.2 kg/m^3
Mass Concentration	13 %
Yield stress	35 Pa
Fluid Consistency Index	0.55Pa.s^n
Flow Behaviour Index	0.5

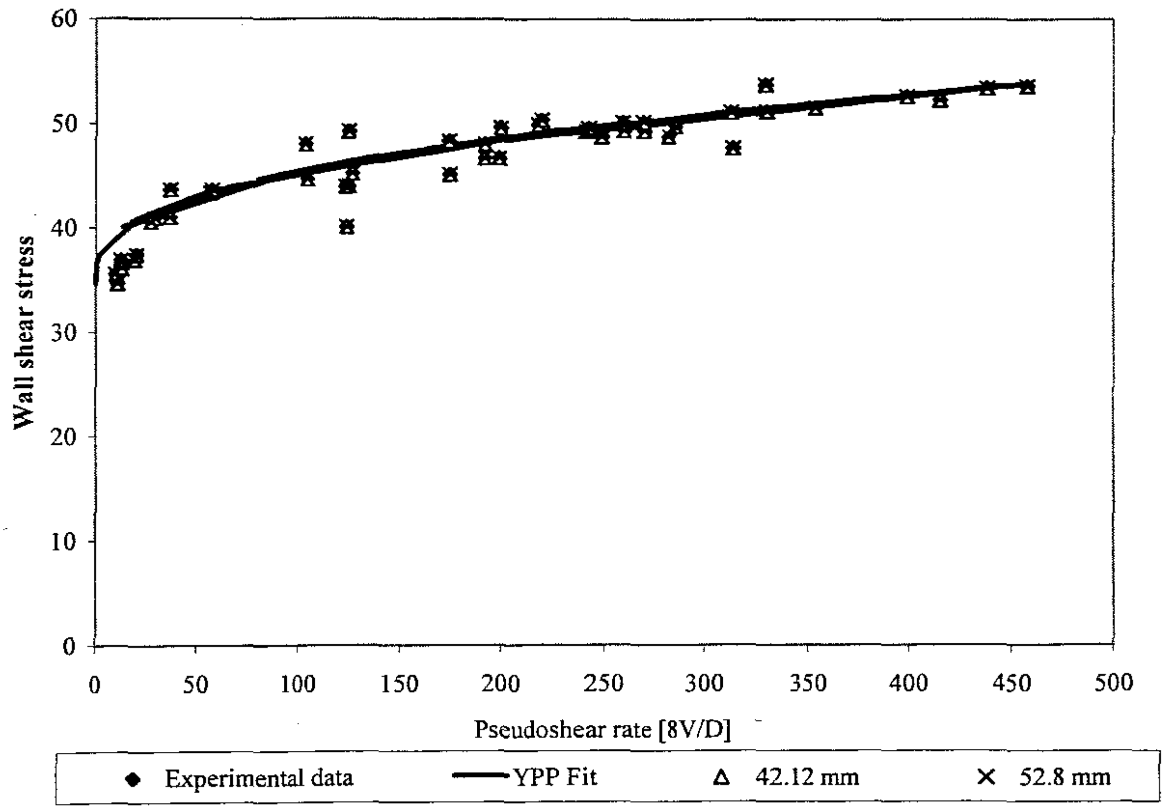


Figure 19 Rheogram kaolin 13%

APPENDIX 4
COMPARISON OF EXPERIMENTAL VALUES OF THE FRICTION FACTOR TO THE THEORETICAL VALUES FOR DIFFERENT FLUIDS IN STRAIGHT PIPE (f – Re GRAPHS)

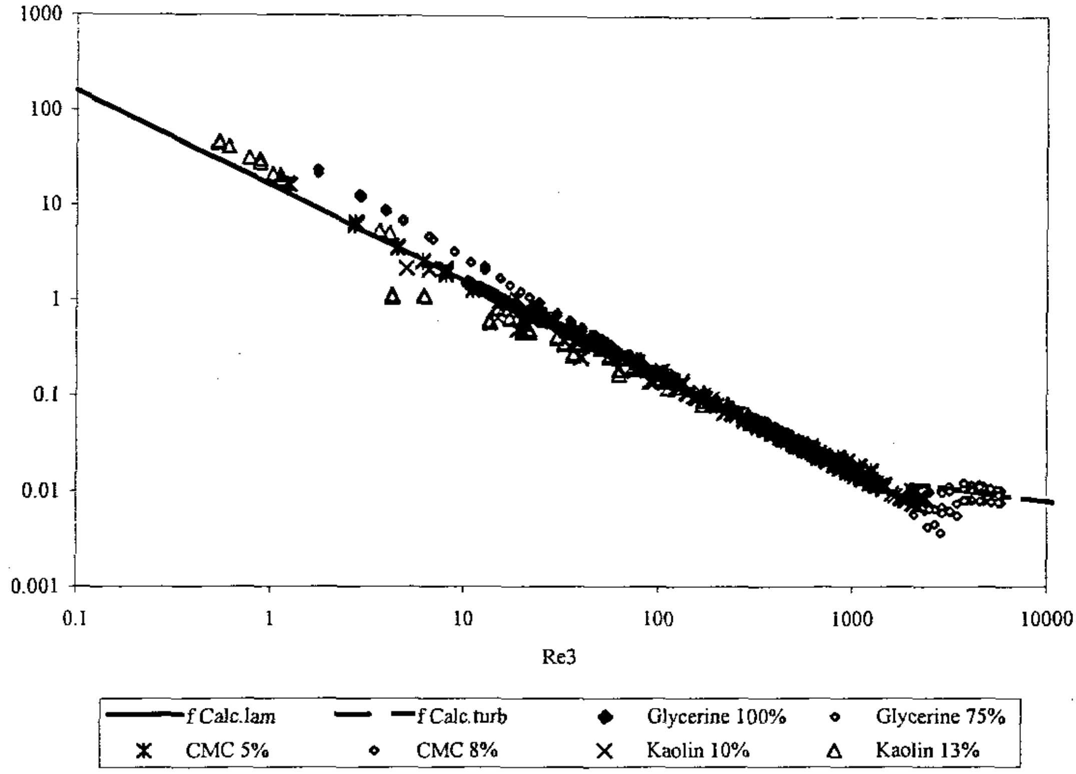


Figure 20 Comparison of experimental values of the friction factor with the theoretical line for different fluids in straight pipe of Diameter 52.8 mm ID pipe

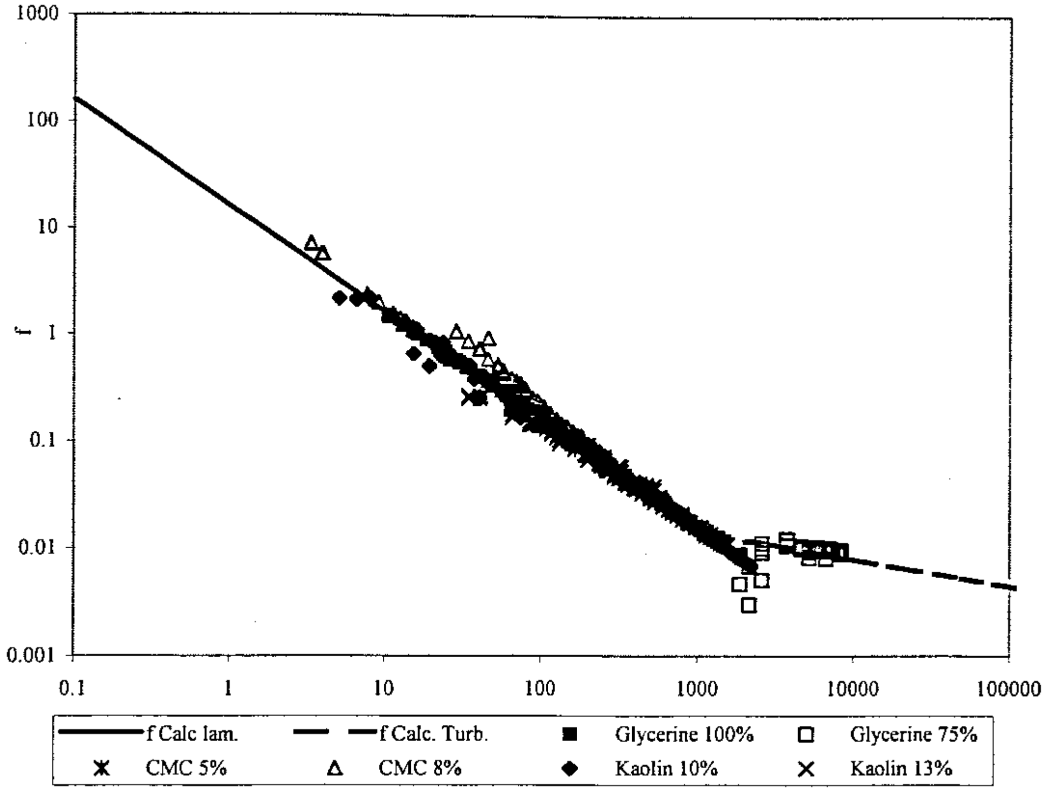


Figure 21 Comparison of experimental values of the friction factor with the theoretical line for different fluids in straight pipe of Diameter 63.08 mm ID pipe

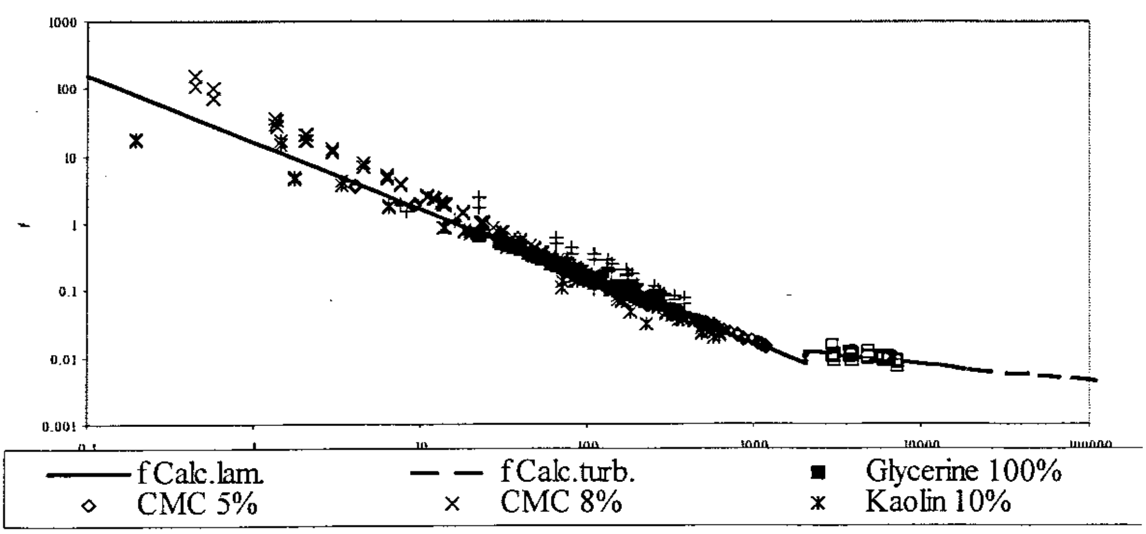


Figure 22 Comparison of experimental values of the friction factor with the theoretical line for different fluids in straight pipe of Diameter 80.43 mm ID pipe

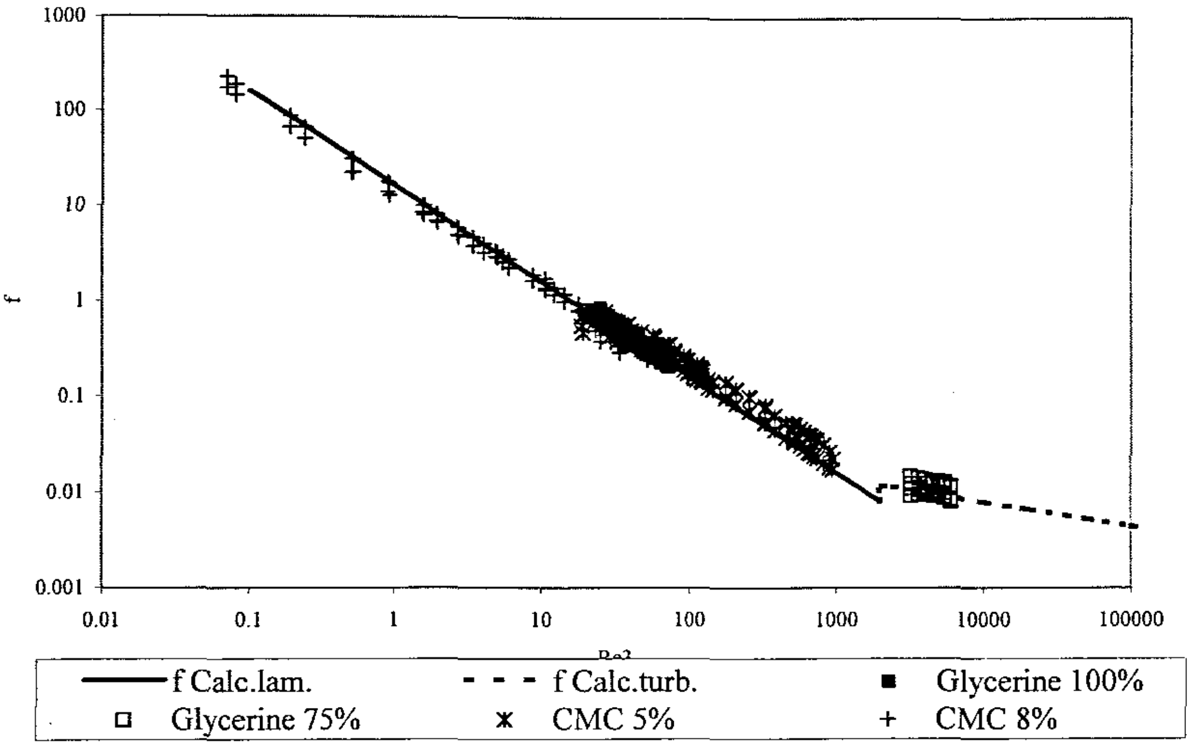


Figure 23 Comparison of experimental values of the friction factor with the theoretical line for different fluids in straight pipe of Diameter 97.17 mm ID pipe

APPENDIX 5
Calculation of the apparent fluid consistency index (K') and the apparent flow behaviour index (n') for a yield pseudoplastic fluid

It has been demonstrated that for the laminar flow of any given time independent fluid, 8V/D is some function of τ_o only. This may be expressed as (Metzner & Reed, 1955):

$$\tau_o = K'\left(\frac{8V}{D}\right)^{n'} \qquad \textbf{(2.23)}$$

To derive the relationship between K' and n' and the parameters characterising the Herschel – Bulkley model (τ_y, K and n). It must be proceeded as follows:

For a yield Pseudoplastic fluid:

$$\frac{32Q}{\pi D^3} = \frac{8V}{D} = \frac{4n}{K^{\frac{1}{n}}\tau_o^3}\left(\tau_o - \tau_y\right)^{\frac{1+n}{n}}\left[\frac{\left(\tau_o - \tau_y\right)^2}{1+3n} + \frac{2\tau_y\left(\tau_o - \tau_y\right)}{1+2n} + \frac{\tau_y^2}{1+n}\right] \qquad \textbf{(2.42)}$$

(2.42) In logarithmic form:

$$\mathrm{Log}\left(\frac{8V}{D}\right) = \mathrm{Log}4n - \frac{1}{n}\mathrm{Log}K - 3\mathrm{Log}\tau_o + \frac{1+n}{n}\mathrm{Log}\left(\tau_o - \tau_y\right) + \mathrm{Log}\left[\frac{\left(\tau_o - \tau_y\right)^2}{1+3n} + \frac{2\tau_y\left(\tau_o - \tau_y\right)}{1+2n} + \frac{\tau_y^2}{1+n}\right] \qquad \textbf{(1)}$$

Differentiating (1) with respect to d ($\mathrm{Log}\tau_o$):

$$\frac{d(\mathrm{Log}8V/D)}{d(\mathrm{Log}\tau_o)} = \frac{-3d(\mathrm{Log}\tau_o)}{d(\mathrm{Log}\tau_o)} + \frac{1+n}{n}\frac{d[\mathrm{Log}(\tau_o - \tau_y)]}{d(\mathrm{Log}\tau_o)} + \frac{d\left\{\mathrm{Log}\left[\frac{\left(\tau_o - \tau_y\right)^2}{1+3n} + \frac{2\tau_y\left(\tau_o - \tau_y\right)}{1+2n} + \frac{\tau_y^2}{1+n}\right]\right\}}{d(\mathrm{Log}\tau_o)} \qquad \textbf{(2)}$$

By definition:

$$n' = \frac{d(\mathrm{Log}\tau_o)}{d(\mathrm{Log}8V/D)} \qquad \textbf{(2.26)}$$

$$\frac{1}{n'} = -3 + \left(\frac{1+n}{n}\right)\frac{\frac{d(\tau_o-\tau_y)}{(\tau_o-\tau_y)}}{\frac{d\tau_o}{\tau_o}} + \frac{d\left[\frac{(\tau_o-\tau_y)^2}{1+3n}+\frac{2\tau_y(\tau_o-\tau_y)}{1+2n}+\frac{\tau_y^2}{1+n}\right]}{\frac{(\tau_o-\tau_y)^2}{1+3n}+\frac{2\tau_y(\tau_o-\tau_y)}{1+2n}+\frac{\tau_y^2}{1+n}}\frac{\tau_o}{d\tau_o}$$

$$\frac{1}{n'} = -3 + \frac{1+n}{n}\frac{\tau_o}{\tau_o-\tau_y} + \frac{d\left[\frac{(\tau_o-\tau_y)^2}{1+3n}\right]+d\left[\frac{2\tau_y(\tau_o-\tau_y)}{1+2n}\right]}{\left[\frac{(\tau_o-\tau_y)^2}{1+3n}+\frac{2\tau_y(\tau_o-\tau_y)}{1+2n}+\frac{\tau_y^2}{1+n}\right]}\frac{\tau_o}{d\tau_o}$$

$$\frac{1}{n'} = -3 + \frac{1+n}{n}\frac{\tau_o}{\tau_o-\tau_y} + \frac{2\tau_o(1+n)(\tau_o+2n\tau_o+n\tau_y)}{(1+n)(1+2n)(\tau_o-\tau_y)^2+2\tau_y(\tau_o-\tau_y)(1+n)(1+3n)+\tau_y^2(1+2n)(1+3n)}$$

$$n' = \frac{1}{-3 + \frac{1+n}{n}\frac{\tau_o}{\tau_o-\tau_y} + \frac{2\tau_o(1+n)(\tau_o+2n\tau_o+n\tau_y)}{(1+n)(1+2n)(\tau_o-\tau_y)^2+2\tau_y(\tau_o-\tau_y)(1+n)(1+3n)+\tau_y^2(1+2n)(1+3n)}}$$

Knowing that (2.23):

$$\tau_o = K'\left(\frac{8V}{D}\right)^{n'}$$

$$K' = \frac{\tau_o}{\left(\frac{8V}{D}\right)^{n'}} \qquad \textbf{(3)}$$

8V/D is obtained from (2.42) thus:

$$K' = \frac{\tau_o}{\left\{\frac{4n}{K^{\frac{1}{n}}\tau_o^3}(\tau_o-\tau_y)^{\frac{1+n}{n}}\left[\frac{(\tau_o-\tau_y)^2}{1+3n}+\frac{2\tau_y(\tau_o-\tau_y)}{1+2n}+\frac{\tau_y^2}{1+n}\right]\right\}^{n'}} \qquad \textbf{(4)}$$

APPENDIX 6
DIAPHRAGM VALVE LOSS COEFFICIENTS DATA

Table 1 HGL Test for water

		Axial distances	-6.258	-2.932	-1.88	-0.621	1.076	3.805	4.920	8.075	9.975	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
8/26/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		25472.420	25370.620	25333.680	25325.035	24925.531	24846.567	24783.211	24730.654	24677.408	0.399
Valve dimension[mm]:	40		29210.373	28652.701	28435.676	28450.006	26118.221	25733.986	25577.629	25110.270	24849.966	0.998
Valve position:	Open		31802.137	31042.955	30606.781	30541.863	26803.221	26724.543	25986.316	25305.529	24889.330	1.278
Pipe Diameter [mm]:	42.12		31951.068	30924.297	30864.596	30330.158	26836.107	26238.088	25961.523	25296.100	24887.135	1.278
Material Type:	Water		33121.191	32330.000	32065.957	31819.010	27247.459	26508.650	26134.914	25386.479	24880.201	1.399
Density[kg/m^3]:	998.168		32998.639	32141.556	31787.354	31313.516	27131.906	26484.983	26136.283	25387.555	24911.791	1.399
μ [Pa.s]	0.001		38311.313	37240.516	36669.765	35778.598	28746.055	27466.680	27029.223	25701.256	24931.076	1.845
			38735.848	36885.469	36935.902	36343.070	28711.830	27526.137	26971.115	25715.506	24903.078	1.843
			36659.160	35065.965	34925.863	34263.754	28106.793	27155.322	26625.824	25607.006	24925.410	1.589
			37095.117	35134.340	35114.160	34398.305	28081.170	27154.170	26708.029	25612.363	24925.164	1.650
			41795.906	40712.781	39990.180	39237.910	29597.057	28114.811	27555.818	25854.055	24923.592	2.088
			45225.105	43027.363	42869.066	41852.645	30217.834	28691.713	27854.230	25932.625	24833.764	2.262
			44769.449	43122.332	42179.859	41947.262	30277.939	28620.064	27804.045	25967.811	24830.666	2.263
			47583.648	45080.801	44148.457	43906.445	30794.482	29912.621	28119.379	26134.648	24818.797	2.390
			46923.473	44795.039	44453.102	43350.453	30741.254	28940.359	28168.750	26126.941	24824.646	2.365
			52360.129	50253.145	48877.172	47970.352	31985.020	29861.178	28795.201	26361.934	24770.211	2.654
			51918.176	49618.617	48367.438	47975.195	32031.621	29849.234	28808.674	26342.473	24814.520	2.655
			55729.840	52634.516	51701.715	50179.496	32893.340	30364.527	29215.449	26520.000	24754.729	2.821
			61368.316	57257.277	56084.102	54659.346	34125.266	31270.990	29894.441	26678.881	24630.789	3.066
			60953.195	57396.203	56491.238	55275.703	33902.891	31285.462	29979.996	26674.529	24705.589	3.071
			64498.652	59518.105	58428.637	57296.496	34913.445	31717.910	30236.510	26709.295	24585.334	3.189
			64253.145	59783.797	58895.379	57532.566	34742.504	31796.764	30268.424	26826.143	24697.736	3.198
			67896.047	63543.531	63131.363	59868.008	35533.965	32217.441	30877.365	26875.984	24602.736	3.095

Table 2 HGL Test for water

		Axial distances	-6.298	-4.568	-2.932	-0.421	1.076	3.805	6.046	8.075	9.975	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
9/9/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		48818.879	48029.887	46661.641	45076.102	30910.443	28692.355	27011.764	25694.109	24170.645	2.506
Valve dimension[mm]:	40		34063.238	33249.430	32965.410	32168.502	27196.666	26310.428	25627.730	25018.281	24423.135	1.531
Valve position:	Open		33968.191	33279.547	32828.633	32381.080	27144.697	26313.518	25598.357	25012.148	24433.264	1.531
Pipe Diameter [mm]:	42.12		49139.402	48055.477	46820.926	44174.340	30742.078	28693.281	27113.613	25592.291	24208.469	2.508
Material Type:	Water		60425.168	58722.496	56575.906	53984.008	33172.316	30516.070	28101.879	25877.477	23990.336	3.068
Density[kg/m^3]:	998.168		61345.613	58289.824	56938.938	54137.035	33406.348	30460.133	28077.633	25962.396	23949.918	3.059
μ [Pa.s]	0.001		60164.125	59055.547	56436.980	53964.434	33070.824	30481.990	27891.803	25937.291	24032.473	3.055
			71175.773	68906.813	66917.617	63522.059	35714.203	32180.941	28955.652	26236.887	23698.166	3.3545
			71477.359	68975.070	66304.720	63780.168	35790.270	32101.771	29025.914	26332.426	23700.271	3.3547
			66049.234	63758.023	62238.996	58991.887	34594.098	31331.447	28506.979	26124.986	23759.164	3.3239
			45422.516	44046.652	43031.746	41487.438	29831.701	28325.954	26881.223	25583.887	24334.379	2.3147
			45916.496	43945.051	43366.520	41468.195	29807.389	28344.037	26652.979	25499.396	24402.602	2.3108

Table 3 HGL Test for water

7/22/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	50
Valve position:	Open
Pipe Diameter [mm]:	52.8
Material Type:	Water
Density[kg/m³]:	1000
μ [Pa.s]	0.001

Axial distances	-6.574	-5.47	-3.526	-1.521	0.510	2.509	4.108	7.666	9.669	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	27027.016	26554.324	25816.590	24955.076	21959.906	21104.928	20095.535	18824.057	17947.473	3.364
	27020.516	26554.691	25764.768	24934.822	21952.357	21099.781	20107.975	18775.346	17983.203	3.366
	26981.307	26557.549	25789.709	24923.801	21915.744	21086.330	20062.646	18806.959	17949.723	3.362
	26506.496	26117.826	25334.639	24572.426	21734.582	20914.971	19923.252	18760.678	17956.504	3.261
	26521.672	26101.045	25340.967	24556.648	21765.219	20925.686	19950.834	18733.744	17951.438	3.263
	26567.320	26082.611	25366.219	24534.541	21741.629	20957.760	19942.316	18751.393	17922.045	3.262
	25304.740	24928.469	24333.531	23600.506	21217.691	20500.797	19703.016	18659.037	17959.084	3.001
	25317.482	24970.197	24357.303	23609.375	21178.895	20539.805	19741.775	18636.698	17958.053	2.958
	25316.420	24899.113	24352.377	23647.768	21239.559	20517.795	19727.799	18715.518	17937.951	2.996
	24403.859	24065.131	23574.258	22994.271	20833.078	20232.117	19514.537	18592.275	18000.740	2.782
	24439.379	24114.223	23507.195	22972.504	20845.736	20240.072	19537.439	18626.559	18008.959	2.780
	27846.451	27595.910	27312.287	26991.985	25904.426	25566.473	25159.928	24676.113	24356.564	1.970
	27830.469	27612.133	27325.232	26986.084	25878.635	25550.133	25153.826	24645.221	24345.732	1.969
	27345.834	27109.344	26883.025	26585.656	25719.340	25451.123	25110.818	24729.537	24421.635	1.782

Table 4 HGL Test for water

Valve Type:	Diaphragm
Valve dimension[mm]:	50
Valve position:	Open
Pipe Diameter [mm]:	52.9
Material Type:	Water
Density[kg/m³]:	1000
μ [Pa.s]	0.001

Axial distance										
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	25287.543	25206.590	25195.834	25117.148	24905.641	24832.602	24759.170	24666.902	24582.557	0.797
	25280.883	25240.174	25154.375	25100.252	24915.385	24836.932	24769.201	24659.703	24589.566	0.798
	25304.166	25259.662	25196.590	25160.748	24890.541	24838.635	24757.156	24650.322	24588.082	0.797
	25591.273	25510.336	25453.090	25352.723	25063.152	24976.426	24843.656	24688.123	24607.686	0.973
	25561.572	25540.199	25401.457	25328.768	25066.570	24915.320	24848.350	24702.492	24604.369	0.973
	25730.914	25654.764	25532.926	25466.627	25111.410	24997.900	24880.189	24689.635	24598.094	1.058
	25785.510	25623.826	25552.330	25460.682	25123.623	25026.400	24890.805	24702.322	24593.734	1.057
	26779.922	26643.826	26421.414	26336.012	25502.105	25291.355	25023.772	24706.602	24481.951	1.567
	26782.914	26639.496	26453.701	26236.633	25495.273	25313.969	25028.145	24695.260	24486.984	1.568
	26789.748	26641.051	26448.049	26234.828	25514.684	25290.740	25019.818	24686.242	24486.082	1.568
	27987.926	27844.738	27504.535	27163.465	25944.721	25567.852	25150.027	24636.850	24243.697	2.050
	28043.645	27805.596	27555.439	27134.113	25910.357	25573.904	25163.529	24603.994	24275.471	2.059
	28009.736	27849.109	27484.041	27154.143	25941.463	25588.602	25131.807	24625.678	24251.617	2.058
	28022.404	27867.656	27509.303	27111.463	25930.281	25576.387	25136.490	24612.121	24261.156	2.058
	29143.016	28926.994	28466.158	27943.697	26337.029	25871.166	25283.469	24559.748	24124.322	2.436
	29169.771	28880.465	28451.742	28004.854	26329.883	25786.361	25251.393	24568.793	24045.383	2.420
	29159.191	28857.178	28473.518	28025.049	26323.357	25857.871	25289.574	24469.393	24009.883	2.436
	29140.832	28842.348	28499.846	28020.549	26375.420	25843.520	25227.746	24602.721	24077.334	2.438
	28848.213	28429.404	28068.389	27504.611	25374.719	24426.160	23669.777	22532.055	22217.994	2.897
	29117.029	28710.252	27987.529	27193.594	25082.629	24631.717	23646.900	22789.604	22057.908	3.217
	29204.732	28654.451	28171.602	27307.092	25213.492	24575.691	23605.605	22845.195	22102.686	2.856
	28728.590	28814.127	28155.291	27183.895	25213.420	24137.381	23549.426	22917.299	22017.607	2.858
	28863.992	28351.467	27935.400	27494.818	25163.211	24463.129	23680.174	22717.977	22149.021	2.897
	26655.129	26192.092	25475.078	24622.025	21792.371	20964.791	19975.963	18747.293	17882.219	3.648
	26653.738	26151.832	25422.871	24598.205	21739.531	20938.152	19963.898	18761.744	17872.773	3.647
	26636.463	26133.242	25444.420	24647.824	21746.266	20950.463	19990.051	18743.020	17892.368	3.281
	26697.438	26246.164	25544.355	24688.066	21742.268	20961.365	19974.561	18704.824	17908.725	3.284
	26747.201	26219.059	25522.959	24721.766	21713.963	20936.258	19966.609	18732.340	17946.842	3.281
	27316.982	26773.133	26068.555	25198.525	21885.254	21051.895	19992.270	18695.477	17862.574	3.353
	27250.750	26736.332	26070.621	25167.201	21869.666	21048.754	20060.230	18739.285	17873.498	3.724
	27314.541	26626.877	26134.693	25164.520	21859.709	21003.330	20005.873	18722.988	17840.061	3.351
	27241.125	26798.119	26067.719	25169.102	21842.895	21021.799	19988.564	18738.174	17879.486	3.351
	26877.201	26399.189	25784.580	24881.930	21699.158	20898.346	19903.016	18713.373	17901.225	3.276
	26916.082	26432.125	25734.480	24940.451	21702.631	20896.170	19954.154	18699.466	17867.467	3.276
	26959.449	26471.270	25732.953	24919.025	21698.400	20910.939	19909.836	18698.375	17874.678	3.273
	27027.016	26554.324	25816.590	24955.076	21959.906	21104.988	20095.635	18824.057	17947.473	3.364
	27030.516	26554.691	25764.768	24934.822	21952.357	21099.781	20107.973	18775.346	17983.203	3.366
	26981.307	26557.549	25789.709	24923.801	21915.744	21086.330	20062.646	18806.959	17949.723	3.362
	26506.496	26117.826	25334.639	24572.426	21734.582	20914.571	19923.252	18760.678	17956.504	3.261
	26521.672	26101.045	25340.967	24556.648	21765.219	20925.686	19950.834	18730.744	17951.438	3.263
	26567.320	26082.611	25366.219	24534.541	21741.629	20957.760	19942.316	18751.393	17922.045	3.262
	25304.740	24888.469	24333.531	23600.506	21217.691	20500.797	19703.016	18659.037	17959.084	3.001
	25317.482	24970.197	24357.303	23609.375	21178.895	20539.805	19741.775	18636.688	17958.053	2.998
	25316.428	24899.113	24352.377	23647.768	21239.559	20517.795	19727.799	18715.518	17937.951	2.996
	24403.859	24065.131	23574.258	22994.271	20833.078	20232.117	19514.537	18592.275	18000.740	2.782
	24439.379	24114.223	23507.195	22972.504	20845.736	20240.072	19537.439	18626.559	18008.959	2.780
	27846.451	27595.910	27312.287	26991.885	25904.426	25566.473	25159.928	24676.113	24356.564	1.970
	27830.469	27612.133	27325.232	26986.084	25878.635	25550.133	25153.826	24645.221	24345.732	1.969
	27345.834	27109.344	26883.025	26585.656	25719.340	25451.123	25110.818	24729.537	24471.635	1.782
	22971.986	22298.451	21400.525	20673.412	17235.684	16438.914	15334.930	13990.175	12870.027	3.745
	22706.263	22340.500	21617.924	21141.396	17422.764	16400.949	15419.493	13887.534	13093.313	3.370
	23391.186	22847.582	22169.932	21184.250	17292.152	16390.324	15254.707	13883.954	12931.680	3.370
	23224.244	22783.232	22074.127	21079.736	17365.061	16478.965	15228.733	13998.975	12743.926	3.370
	22537.080	22101.307	21305.047	20391.676	16865.803	15989.448	14753.326	13859.982	12839.436	3.351
	22444.977	21898.033	21251.285	20278.891	16926.381	16124.182	15055.610	13804.682	13033.058	3.350
	22429.033	21992.670	21089.145	20429.637	16998.756	16102.568	15145.691	13711.912	12989.233	3.346
	22396.422	21863.727	21266.447	20154.771	16990.615	16106.790	15029.941	13739.907	12911.374	3.346
	22162.143	21597.895	20966.408	19970.467	16843.166	15930.409	14972.507	13743.753	13028.585	3.280
	21903.293	21619.508	20789.643	20197.025	16825.576	15868.709	15041.447	13919.804	12863.631	3.277
	21992.926	21665.340	20943.539	20072.473	16606.285	15942.404	14944.707	13588.503	13003.673	3.276
	21291.215	20739.537	20243.250	19557.830	16578.057	15553.185	14865.177	13655.750	13051.879	3.136
	21251.691	20893.557	20319.098	19530.186	16484.086	15811.451	14846.969	13707.096	13089.545	3.133
	21330.574	21015.986	20136.191	19295.279	16128.086	15856.821	14773.875	13700.261	12968.193	3.139
	21068.650	20741.480	20164.473	19324.609	16386.059	15713.844	14853.608	13866.763	13075.282	3.066
	21017.766	20718.230	20068.494	19142.096	16329.429	15632.257	14889.778	13805.004	13080.026	3.063
	20481.008	20104.688	19363.549	18853.811	16049.584	15431.547	14700.102	13794.312	13156.705	2.940
	20495.887	20138.895	19488.236	18909.236	16378.427	15493.838	15211.053	14110.018	13435.672	2.940
	26151.748	25664.809	25047.904	24257.826	21620.098	20850.385	19909.504	18785.623	18027.244	3.162
	26136.199	25700.160	25054.848	24304.467	21579.270	20816.016	19965.566	18954.387	18047.365	3.161
	26962.307	26484.873	25756.867	24916.135	21989.830	21131.779	20103.127	18885.787	18052.492	3.347
	26971.789	26512.693	25736.166	24931.672	22093.234	21098.266	20117.100	18866.141	18008.234	3.344

Table 5 HGL Test for water

		Axial distances	-6.574	-5.47	-3.526	-1.531	0.510	2.509	4.108	7.666	9.669	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
7/26/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		22971.986	22398.451	21400.525	20673.412	17235.684	16438.914	15334.930	13990.175	12870.027	3.745
Valve dimension[mm]:	50		22706.262	22340.500	21617.924	21141.996	17422.764	16400.949	15419.493	13687.534	13093.313	3.370
Valve position:	Open		23391.186	22847.582	22169.932	21184.250	17292.152	16390.224	15254.707	13883.954	12931.680	3.370
Pipe Diameter [mm]:	52.8		23324.244	22783.232	22074.127	21079.736	17365.061	16478.965	15328.732	13998.975	12743.926	3.370
Material Type:	Water		22537.080	22101.307	21305.047	20391.676	16865.803	15989.448	14753.326	13859.982	12839.436	3.351
Density[kg/m^3]:	1000		22444.977	21898.033	21251.285	20278.891	16926.381	16124.182	15055.616	13804.682	13033.058	3.350
m	0.001		22429.033	21992.670	21089.145	20439.637	16998.756	16102.568	15145.691	13711.912	12989.233	3.346
			22396.432	21863.727	21266.447	20154.771	16990.615	16106.790	15029.941	13739.907	12911.374	3.346
			22162.143	21597.895	20966.408	19970.467	16843.166	15930.409	14972.507	13742.753	13028.585	3.280
			21903.293	21619.508	20789.643	20197.035	16825.576	15868.709	15041.447	13919.804	12863.631	3.277
			21992.926	21665.340	20943.539	20072.473	16606.285	15942.404	14944.707	13588.503	13003.673	3.276
			21291.215	20739.537	20243.250	19557.830	16578.057	15553.185	14865.177	13655.750	13051.879	3.136
			21251.691	20893.557	20319.098	19530.186	16484.086	15811.451	14846.369	13707.096	13089.545	3.133
			21320.574	21015.986	20136.191	19295.279	16108.086	15856.821	14773.875	13700.261	12568.193	3.139
			21068.630	20741.480	20164.473	19324.609	16386.059	15713.844	14853.608	13866.763	13075.282	3.066
			21017.766	20718.230	20068.494	19142.096	16328.429	15632.257	14889.778	13805.004	13083.026	3.063
			20481.008	20104.688	19363.949	18853.811	16049.584	15431.947	14700.102	13794.312	13156.705	2.940
			20495.887	20138.895	19488.236	18909.236	16378.427	15493.838	15211.053	14110.018	13435.672	2.940
			26718.053	26310.732	25640.742	24909.453	21636.320	20852.295	19886.521	18741.174	17937.352	3.221
			26808.30273	26341.94141	25647.40625	24884.16797	21647.73438	20833.56445	19882.28906	18649.73047	17959.99805	3.225
			26741.37109	26300.63672	25654.13672	24877.44727	21629.27734	20871.21875	19896.16797	18731.13281	17936.69141	3.223
			26355.55469	26021.88086	25341.30469	24575.10547	21533.17383	20747.29297	19823.98633	18691.74023	17913.39648	3.148
			26369.13281	25985.13477	25333.45117	24599.20703	21526.4375	20760.6875	19828.25977	18750.77734	17961.75586	3.147
			26444.09766	26030.4375	25377.55664	24621.35742	21528.59961	20784.7207	19803.64648	18714.35156	17953.93359	3.150
			26084.16602	25692.66406	25064.23242	24415.64648	21401.00781	20644.50977	19746.75195	18661.30078	17965.52344	3.078
			26117.69336	25715.13672	25081.52734	24396.67188	21339.99219	20639.03125	19758.11133	18694.1875	17955.41797	3.081
			26092.64063	25745.56914	25123.01758	24444.96289	21353.76172	20647.46484	19758.06836	18685.5293	17962.32617	3.078
			23564.36719	23293.83203	22879.9375	22390.21094	20355.77734	19839.73242	19261.10742	18536.72852	17995.38867	2.777
			23561.37695	23315.17773	22865.55664	22382.7832	20362.59844	19856.3457	19243.78711	18519.17188	18025.24414	2.500
			23569.86469	23323.37891	22860.62305	22425.07617	20368.21484	19850.09375	19278.98438	18542.30078	17993.83008	2.499
			23576.95703	23329.35352	22907.86133	22399.89063	20380.89648	19853.29102	19257.29492	18543.04102	18010.91602	2.501
			21918.04297	21743.15625	21447.30664	21232.86133	19705.08594	22164.23828	25140.78516	24653.83984	24318.15039	2.033
			27910.4707	27798.75391	27493.98242	27178.32031	25868.09961	25588.85547	25167.89453	24660.60547	24310.15625	1.989

Table 6 HGL Test for water

		Axial distances	-6.574	-5.47	-3.526	-1.531	0.510	2.509	4.108	7.666	9.669	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
7/21/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		20226.084	20074.990	19559.703	19051.146	17129.670	16603.369	16020.906	15119.057	14564.322	2.929
Valve dimension[mm]:	50		20235.271	20090.053	19581.205	19085.551	17242.803	16602.684	15967.844	15152.481	14600.640	2.636
Valve position:	Open		20728.547	20304.441	19700.678	18966.889	16560.080	15876.600	15050.644	14006.127	13330.940	2.978
Pipe Diameter [mm]:	52.8		26151.748	25684.809	25047.904	24257.826	21620.098	20850.285	19909.504	18785.623	18027.244	3.162
Material Type:	Water		26136.199	25700.160	25054.848	24304.467	21579.270	20816.016	19965.566	18954.387	18047.365	3.161
Density[kg/m^3]:	1000		26962.307	26484.873	25756.867	24916.135	21989.830	21131.779	20103.127	18885.787	18052.492	3.347
m	0.001		26971.789	26512.693	25736.166	24931.672	22093.234	21098.266	20117.100	18866.141	18008.234	3.344

Table 7 HGL Test for water

		Axial distances	-6.9735	-4.8855	-2.885	-0.937	0.987	1.968	2.938	3.916	4.858	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
8/31/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		41743.605	40037.098	38688.945	36258.840	32203.672	31478.678	30592.266	29604.285	28941.893	7.409
Valve dimension[mm]:	65		41706.305	40197.570	38558.910	36925.316	32242.297	31522.492	30678.004	29785.744	29039.701	7.199
Valve position:	Open		40987.672	39539.586	38078.188	36529.176	31897.832	31377.508	30483.893	29536.664	28997.797	7.008
Pipe Diameter [mm]:	63.08		41080.441	39524.426	37895.039	36367.953	32032.348	31700.035	30576.904	29748.855	28976.885	7.016
Material Type:	Water		39565.695	38086.121	36914.457	35444.125	31303.635	30802.350	30101.164	29227.527	28655.979	6.812
Density $[kg/m^3]$:	1000		39558.242	38188.152	36721.555	35364.613	31211.939	30758.867	30027.340	29224.670	28667.064	6.787
μ [Pa.s]	0.001		37923.344	36675.936	35619.215	34240.406	30648.289	30162.900	29493.006	28822.725	28279.357	6.304
			38041.777	36804.984	35498.484	34246.598	30628.260	30063.072	29569.638	28757.279	28255.242	6.452
			36561.977	35401.859	34367.363	33155.020	30025.697	29579.658	29007.248	28378.848	27926.299	5.915
			36479.781	35479.707	34340.332	33022.316	30003.625	29597.076	29131.602	28419.928	27918.949	5.915
			35479.602	34159.922	33026.133	31999.111	29132.730	29030.529	28763.936	28057.697	27588.223	5.513
			35672.766	34432.129	33375.500	32523.559	25619.600	29029.394	28535.176	27790.983	27565.938	5.555
			33733.707	32927.967	32026.678	31276.553	28885.234	28465.205	28044.586	27569.033	27229.588	5.095
			35096.258	34261.836	33213.223	32535.182	29997.244	28932.900	28486.979	27919.258	27541.357	5.388
			38567.781	37216.410	35947.199	34592.730	30794.285	30305.174	29566.475	28888.584	28317.861	6.230
			38666.336	37300.941	35995.184	34738.254	30707.039	30314.645	29700.211	28830.471	28325.135	6.461
			32793.695	32050.721	31294.648	30653.000	28516.674	28250.781	27789.934	27341.633	27024.486	4.678
			32772.895	32056.834	31348.973	30621.859	28493.441	28208.954	27739.572	27362.500	27001.717	4.772
			30903.021	30373.441	29785.768	29247.875	27690.893	27388.500	27152.455	26742.232	26565.230	4.047
			30951.299	30406.459	29747.129	29271.129	27651.127	27458.299	27140.688	26803.064	26530.249	4.387
			30077.727	29174.379	28507.408	28496.010	26742.137	26976.352	26776.969	26574.789	26198.531	3.575
			28400.461	28297.152	28318.787	27432.230	26524.969	26244.025	26397.639	26226.047	25904.549	3.094

Table 8 HGL Test for water

		Axial distances	-6.9735	-4.8855	-2.885	-0.937	0.987	2.938	6.427	8.432	10.433	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
9/1/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		30167.082	29716.779	29233.262	28791.922	28043.443	27438.828	26762.660	26359.498	25962.713	3.448
Valve dimension[mm]:	65		30129.354	29659.977	29262.818	28868.684	27811.785	27413.387	26653.832	26331.473	25882.473	3.400
Valve position:	Open		29276.469	29071.492	28591.520	28346.387	27423.410	27072.646	26497.652	26185.646	25836.875	3.099
Pipe Diameter [mm]:	63.08		29405.838	29131.105	28735.424	28316.303	27230.699	27076.668	26479.938	26125.877	25860.398	3.105
Material Type:	Water		28657.969	28446.625	28118.432	27818.496	26966.361	26699.445	26260.459	25984.320	25713.879	2.840
Density $[kg/m^3]$:	1000		28704.150	28468.609	28156.422	27829.914	26990.305	26729.574	26272.986	25986.520	25728.561	2.806
μ [Pa.s]	0.001		27627.508	27502.379	27310.988	27108.141	26519.752	26245.023	25931.418	25742.059	25552.451	2.419
			27757.119	27511.926	27315.123	27088.592	26444.875	26236.230	25938.730	25748.168	25540.598	2.432

Table 9 HGL Test for water

		Axial distances	-6.413	-4.809	-3.61	-1.609	0.707	3.907	5.273	8.461	9.956	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
9/2/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		30067.029	29782.479	29574.584	29302.188	27260.092	26637.365	26427.219	25911.689	25660.918	5.905
Valve dimension[mm]:	80		30134.840	29864.680	29555.357	29304.650	27226.953	26632.123	26410.533	25897.572	25610.898	5.794
Valve position:	Open		30865.742	30597.066	30365.758	29931.531	27678.947	26910.557	26639.168	26024.574	25703.859	6.348
Pipe Diameter [mm]:	80.43		30862.248	30560.795	30272.602	29958.734	27595.387	26956.611	26593.119	26086.449	25686.193	6.358
Material Type:	Water		31424.305	31117.543	30854.982	30406.789	27819.652	27047.965	26717.828	26119.143	25792.777	6.710
Density[kg/m³]:	1000		31477.918	31156.646	30946.145	30436.697	27821.859	27043.674	26793.594	26091.391	25690.730	6.777
μ [Pa.s]	0.001		32205.871	31774.084	31485.051	31053.615	28121.430	27253.633	26953.383	26217.555	25834.980	7.071
			32217.982	31812.924	31622.941	31023.150	28156.633	27321.471	26964.361	26246.068	25832.391	7.106
			32475.205	32069.475	31815.406	31313.121	28296.713	27424.928	26976.645	26232.621	25890.000	7.287
			32638.033	32165.227	31784.451	31275.158	28203.762	27424.002	27157.240	26312.449	25887.314	7.374
			29623.381	29263.873	29035.773	28819.727	27172.277	26500.990	26267.943	25764.461	25551.248	5.509
			28846.039	28947.678	28505.668	28481.496	26527.369	26346.061	26204.563	25783.225	25548.650	5.034
			29465.943	29259.752	29125.084	28622.572	26929.625	26151.252	26367.354	25716.553	25492.707	5.060

Table 10 HGL Test for water

		Axial distances	-5.050	-3.042	-2.542	-0.699	0.700	2.502	4.499	5.010	9.511	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
			ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
9/3/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	166.251	225.988	322.437	906.748	1082.156	1150.776	1298.432	1746.347	5.887
Valve dimension[mm]:	100		0.000	151.729	171.305	287.916	764.557	929.632	1005.829	1184.832	1516.251	5.435
Valve position:	Open		0.000	166.251	225.988	322.437	906.748	1082.156	1150.776	1298.432	1746.347	5.887
Pipe Diameter [mm]:	97.17		0.000	151.729	171.305	287.916	764.557	929.632	1005.829	1184.832	1516.251	5.435
Material Type:	Water		0.000	155.790	193.248	310.004	884.501	1042.963	1133.930	1299.233	1703.375	6.049
Density[kg/m³]:	1000		0.000	154.829	190.267	315.252	872.469	1027.777	1109.162	1271.838	1666.576	6.231
μ [Pa.s]	0.001		0.000	191.250	244.539	438.661	1192.445	1460.317	1541.839	1795.409	2256.754	7.544
			0.000	200.328	255.964	416.425	1154.997	1419.388	1560.606	1761.222	2312.275	7.523
			0.000	161.388	228.687	336.323	1017.977	1161.300	1250.000	1406.000	1824.076	6.479
			0.000	168.149	238.525	334.903	1007.371	1166.319	1175.138	1256.300	1816.875	6.486
			0.000	133.181	167.850	278.615	771.873	989.247	1043.216	1184.969	1538.266	5.752
			0.000	130.200	165.772	284.277	809.638	966.235	1027.589	1228.711	1513.042	5.818
			0.000	113.453	138.128	247.796	695.706	830.520	956.820	1107.127	1384.777	5.487
			0.000	104.023	139.499	228.872	667.718	788.595	880.196	953.998	1258.127	5.235
			0.000	108.441	115.722	206.235	612.323	726.653	756.515	862.635	1117.548	4.950
			0.000	98.866	122.704	160.344	540.755	708.006	664.801	775.734	1045.117	4.654
			0.000	79.230	85.201	153.542	424.996	568.547	580.530	645.900	824.930	4.089
			0.000	67.545	91.088	152.964	452.389	518.824	504.992	623.558	785.434	4.052
			0.000	60.544	76.691	133.617	390.316	412.564	459.862	527.185	689.285	3.630
			0.000	56.954	52.685	79.169	236.871	234.558	340.440	308.430	436.598	2.771
			0.000	38.983	47.496	70.477	229.835	296.293	343.907	375.368	452.490	2.760

Table 11 HGL Test for Glycerine 100%

		Axial distances	-6.298	-4.568	-2.932	-0.832	1.076	2.685	6.046	8.075	9.975	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
Temperature	25.5°C		ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
22/11/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	5566.989	9585.270	15690.515	23742.049	28501.135	38159.688	43800.371	49239.543	0.261
Valve dimension[mm]:	40		0.000	4983.221	9419.583	15602.231	23642.201	28448.000	37998.805	43590.023	49172.621	0.257
Valve position:	Open		0.000	5515.025	10347.409	16923.379	25809.309	30951.914	41369.375	47604.586	53510.551	0.282
Pipe Diameter [mm]:	42.12		0.000	5491.529	10344.870	17047.236	25820.014	30912.096	41304.227	47422.051	53390.117	0.282
Material Type:	Glycerine 100%		0.000	5828.247	11000.604	18036.154	27402.451	32863.512	43817.535	50258.023	56723.906	0.300
Density[kg/m^3]:	1270		0.000	5982.000	11007.419	18059.191	27399.125	32822.184	43786.066	50248.770	56599.543	0.300
μ[Pa.s]	0.842		0.000	6673.835	11966.745	19469.695	29645.465	35474.223	47422.441	54393.203	61246.707	0.326
			0.000	6710.753	11863.936	19427.084	29640.412	35406.996	47223.574	54220.051	61057.480	0.323
			0.000	6774.523	12571.463	20449.879	31293.898	37350.426	49795.711	57142.480	64262.012	0.343
			0.000	7099.193	12463.105	20439.814	31208.539	37174.871	49527.965	56777.559	63906.957	0.340
			0.000	7190.658	13307.282	21631.725	33156.527	39615.176	52640.094	60378.613	67918.906	0.363
			0.000	7594.890	13205.260	21576.014	33000.770	39498.543	52569.395	60214.898	67776.984	0.360
			0.000	7650.565	13769.910	22444.498	34504.277	41249.148	54811.594	62865.793	70736.086	0.375
			0.000	8018.901	13725.224	22407.020	34395.828	41152.813	54555.891	62641.145	70381.875	0.374
			0.000	7697.799	14127.473	22957.148	35631.859	42414.891	56301.480	64577.105	72649.313	0.385
			0.000	8454.119	13997.710	23000.783	35447.520	42255.848	56221.844	64290.457	72408.047	0.381
			0.000	8219.145	13901.546	22749.313	35298.715	42070.578	55768.410	63860.148	71806.109	0.379
			0.000	8996.306	15164.017	24796.031	38606.984	46018.344	61144.184	70039.094	78797.016	0.413
			0.000	9473.310	15233.040	24857.230	38624.480	46034.227	61248.965	70216.859	79009.133	0.415
			0.000	8233.594	15422.583	25197.344	39054.863	46567.496	61929.258	70950.523	79807.992	0.420
			0.000	10634.353	18878.932	30747.998	48318.723	57480.684	76185.594	87238.867	98025.789	0.514
			0.000	8093.587	21051.492	34437.020	55386.746	65696.914	86796.414	99310.945	109195.539	0.574
			0.000	9487.057	23948.965	39205.816	63860.395	75443.719	99481.094	113765.445	125336.227	0.653
			0.000	15009.630	23901.480	39108.238	63717.313	75328.695	99271.688	113596.047	125082.000	0.651
			0.000	13462.658	25782.133	42385.000	69532.336	82165.641	108066.305	123478.672	136365.625	0.703
			0.000	-1099.775	4637.779	7829.043	11799.213	14298.604	19090.686	21860.547	22853.180	0.126
			0.000	-1099.750	4694.583	7852.646	11847.295	14395.796	19202.467	22012.713	23068.119	0.128
			0.000	-682.824	5416.985	9066.894	13636.618	16512.363	22030.691	25236.949	26678.525	0.148
			0.000	-608.189	5436.595	9077.637	13649.655	16540.662	22039.459	25249.984	26680.934	0.148
			0.000	3976.250	6448.511	10559.313	15769.153	19020.277	25005.852	28570.807	30327.303	0.176
			0.000	4013.628	6465.009	10552.603	15785.689	19059.777	25033.691	28596.877	30343.480	0.176
			0.000	4420.224	7233.161	11927.548	17749.289	21387.998	28163.527	32169.482	34385.684	0.197
			0.000	4356.388	7237.753	11827.337	17735.723	21388.523	28153.357	32131.301	34340.602	0.197
			0.000	4880.979	8075.320	13264.645	19962.768	24027.502	31709.748	36178.250	38611.098	0.220
			0.000	4934.398	8121.035	13294.069	20004.313	24048.416	31726.139	36240.820	39059.129	0.221
			0.000	5308.175	8789.071	14371.594	21752.809	26096.920	34502.449	39294.852	42319.188	0.239
			0.000	5478.600	8831.463	14398.267	21735.592	26114.082	34479.445	39335.191	42424.465	0.241
			0.000	5974.331	9779.966	15950.815	24158.256	28967.086	38349.938	43743.848	47284.508	0.266
			0.000	5390.845	9752.901	15932.161	24116.953	28944.080	38276.664	43705.336	47170.160	0.266
			0.000	6701.529	11720.472	19134.992	29321.816	35050.215	46279.902	52973.199	57268.250	0.319
			0.000	6666.170	11697.716	19112.732	29250.912	35000.930	46202.676	52746.070	57245.461	0.319
			0.000	7293.640	12184.369	19950.303	30681.930	36677.520	48393.055	55287.328	60195.574	0.332
			0.000	7540.765	12162.216	19915.396	30656.918	36543.832	48367.234	55155.090	59858.402	0.331
			0.000	14195.943	24194.750	39615.805	64716.520	76415.617	100420.734	114390.406	125608.914	0.659
			0.000	12279.644	22687.021	37055.285	60168.758	71257.430	93520.938	106681.484	117192.656	0.618
			0.000	12716.377	21030.049	34288.520	55268.956	65350.625	85975.281	98206.500	107854.281	0.573
			0.000	10737.938	18608.912	30346.734	48328.473	57333.883	75614.750	86307.086	94376.992	0.507
			0.000	9009.627	15582.549	25413.275	39897.375	47542.094	62742.781	71563.117	78219.008	0.425
			0.000	9011.606	14933.459	24423.033	38179.824	45543.484	60027.281	68694.555	75018.266	0.407
			0.000	6136.698	10881.965	17785.006	27313.488	32721.531	43224.582	49313.477	55459.500	0.297
			0.000	14585.301	24719.867	40311.500	66804.891	78696.914	103217.555	117787.586	129944.484	0.674
			0.000	13581.576	24738.664	40309.387	66714.484	78668.656	103048.859	117485.055	129493.148	0.674
			0.000	15401.742	26609.889	43353.367	72674.344	85542.805	111682.242	127276.500	140762.234	0.725

Table 12 HGL Test for Glycerine 100%

		Axial distances	-6.298	-4.568	-2.932	-0.832	1.076	2.685	6.046	8.075	9.975	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
Temperature	27°C		DP_1	DP_2	DP_3	DP_4	DP_5	DP_6	DP_7	DP_8	DP_9	
11/19/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	2701.912	4639.613	7562.665	11258.888	13494.032	17824.922	20629.561	23181.803	0.608
Valve dimension[mm]:	40		0.000	2689.120	4615.703	7558.782	11228.120	13474.951	17799.209	20594.480	23174.670	0.605
Valve position:	Open		0.000	2837.890	4898.820	8093.548	12056.617	14492.524	19155.373	22150.705	24907.111	0.642
Pipe Diameter [mm]:	42.12		0.000	2865.699	4938.461	8121.496	12065.771	14496.234	19165.799	22138.164	24899.484	0.648
Material Type:	Glycerine 100%		0.000	3136.670	5426.389	8941.302	13279.903	16012.077	21159.145	24445.010	27517.412	0.712
Density[kg/m^3]:	1252.61		0.000	3139.670	5241.507	8911.486	13329.260	15989.359	21154.861	24459.854	27485.264	0.687
μ[Pa.s]	0.175		0.000	3323.059	5775.890	9521.111	14276.807	17084.330	22526.881	26127.506	29370.926	0.757
			0.000	3323.769	5753.862	9486.066	14249.255	17054.199	22585.678	26056.953	29374.561	0.755
			0.000	4737.972	8701.843	14282.565	21939.021	26146.053	34904.375	40224.195	45179.805	1.141
			0.000	4709.354	8683.687	14276.526	21877.088	26168.637	34948.395	40256.242	45150.633	1.139
			0.000	5207.805	9597.317	15717.863	24248.941	28940.865	38677.512	44484.090	49856.867	1.259
			0.000	5222.186	9591.481	15740.182	24285.615	28912.393	38668.004	44514.859	49954.090	1.258
			0.000	6110.700	11430.271	18467.387	28940.484	34532.438	45756.316	52642.055	59154.473	1.499
			0.000	6118.117	11403.418	18615.623	29142.240	34585.785	45788.977	52764.977	59100.527	1.495

Table 13 HGL Test for Glycerine 100%

Temperature	20°C
23/11/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	50
Valve position:	Open
Pipe Diameter (mm]:	52.8
Material Type:	Glycerine 100%
Density[kg/m³]:	1256
μ[Pa.s]	0.342

Axial distances	-6.574	-3.526	-2.281	-1.031	1.257	3.012	5.666	7.666	9.669	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	0.000	4038.963	5565.966	7064.325	10374.470	12670.666	16324.454	18669.953	21348.076	0.294
	0.000	3963.846	5475.211	7017.866	10247.792	12424.918	16113.467	18565.668	21069.518	0.289
	0.000	4153.880	5727.493	7288.449	10827.706	13113.719	16923.090	19544.064	21965.338	0.302
	0.000	4183.377	5624.477	7290.179	10754.432	12960.359	16692.430	19226.385	21662.037	0.297
	0.000	4800.327	6518.601	8466.906	12426.967	14975.042	19428.496	22330.381	25523.781	0.344
	0.000	4825.163	6503.833	8347.495	12355.500	14903.502	19289.482	22366.105	25456.439	0.343
	0.000	5140.682	6820.737	8880.432	13053.696	15758.062	20392.086	23529.051	26692.414	0.360
	0.000	5004.987	6877.467	8808.673	13023.739	15845.328	20372.971	23475.314	26763.953	0.363
	0.000	5418.516	7242.665	9422.722	13875.647	16741.432	21676.176	24976.850	28346.146	0.382
	0.000	5475.104	7223.335	9393.858	13802.063	16681.057	21587.830	24876.303	28226.451	0.381
	0.000	5411.261	7171.865	9263.006	13669.472	16462.619	21429.439	24708.457	28029.031	0.378
	0.000	5275.455	7177.021	9266.750	13689.189	16479.900	21339.881	24634.166	27986.146	0.379
	0.000	5340.680	7068.031	9160.837	13514.771	16268.487	21091.732	24306.205	27526.277	0.373
	0.000	5691.316	7515.934	9738.557	14331.181	17286.842	22405.527	25770.266	29201.838	0.397
	0.000	5498.631	7476.108	9703.656	14332.205	17242.178	22371.898	25750.592	29201.838	0.394
	0.000	6120.768	7774.074	10173.103	14874.814	17984.432	23297.227	26731.939	30405.521	0.410
	0.000	6141.932	7716.983	10024.478	14788.330	17831.811	23105.781	26666.654	30225.275	0.407
	0.000	6207.924	8352.690	10834.347	15987.311	19427.760	25056.734	29981.393	32820.098	0.441
	0.000	6423.994	8337.889	10847.135	16052.313	19245.072	24912.695	28689.432	32538.809	0.440
	0.000	6328.762	8555.938	11124.570	16356.207	19787.188	25605.248	29465.641	33431.629	0.451
	0.000	6644.833	8481.570	11076.769	16294.454	19634.289	25425.887	29354.566	33251.453	0.447
	0.000	6700.190	8843.863	11559.823	17094.828	20625.428	26655.566	30790.816	34957.680	0.467
	0.000	6818.082	8839.486	11475.913	17044.658	20554.064	26556.686	30747.430	34861.984	0.466
	0.000	7228.000	9725.557	12776.191	18879.742	22794.352	29411.404	33925.066	38660.621	0.513
	0.000	7426.445	9754.355	12657.525	18829.719	22677.631	29324.287	33856.004	38484.262	0.515
	0.000	7634.915	10275.310	12892.419	19749.986	23794.082	30853.734	35624.625	40508.699	0.542
	0.000	7868.508	10207.794	13306.051	19808.213	23854.426	30829.848	35489.738	40327.066	0.539
	0.000	7964.173	10575.881	13770.797	20480.441	24665.258	31736.561	36694.617	41456.883	0.558
	0.000	8147.501	10485.794	13715.686	20259.994	24407.852	31670.072	36562.273	41299.668	0.553
	0.000	8282.777	11218.759	14547.674	21625.930	26275.047	33724.648	38894.887	43428.996	0.592
	0.000	8504.004	11196.928	14610.945	21660.838	26186.795	33801.797	38689.059	44202.484	0.591
	0.000	9348.888	12400.290	16106.403	24068.797	29056.957	37519.547	43100.266	49018.559	0.654
	0.000	48954.832	12434.740	15935.553	24087.137	28942.285	37489.254	43252.285	48972.656	0.656
	0.000	9847.197	13081.816	16958.668	25346.496	30529.801	39520.344	45537.160	51277.738	0.690
	0.000	9837.337	12862.604	17007.736	25330.359	30548.563	39645.094	45509.781	51813.289	0.679
	0.000	10390.727	14138.246	18380.615	27448.301	33139.852	42793.262	49301.074	56031.145	0.746
	0.000	10825.584	13546.846	17661.564	27467.699	33149.535	42741.250	49219.891	55893.609	0.715
	0.000	11201.236	15296.285	19677.803	29706.865	35853.016	46445.988	53456.391	60772.809	0.807
	0.000	11289.378	15279.431	19917.021	29735.545	35865.066	45888.516	53427.211	60480.324	0.806
	0.000	12793.220	17092.883	22079.975	33138.930	39961.258	51514.773	59413.180	67430.641	0.902
	0.000	12327.660	16917.193	22031.963	33118.090	39774.820	51358.148	59331.578	67244.375	0.892
	0.000	13449.519	17997.400	23465.525	35114.719	42420.613	54835.113	63195.875	71676.523	0.949
	0.000	13735.502	17963.203	23420.621	35081.547	42350.664	54642.477	63014.105	71309.320	0.948
	0.000	14166.266	18771.703	24297.268	36609.719	44214.742	57052.984	65580.469	74457.352	0.990
	0.000	13903.771	18591.529	24171.998	36308.516	43801.438	56428.016	65239.844	74146.359	0.981
	0.000	14458.427	19704.945	25437.973	38452.215	46219.359	59608.738	68723.844	78031.414	1.040
	0.000	14673.791	19657.639	25349.750	38354.242	46161.691	59629.715	68739.344	77936.031	1.037
	0.000	14256.986	19243.766	25013.057	38005.410	45605.203	58740.496	67720.219	76720.227	1.015
	0.000	13885.934	19144.695	24943.850	37775.598	45556.238	58655.695	67614.133	76663.602	1.010
	0.000	14856.896	20657.014	26852.383	40651.820	49079.887	63092.352	72860.219	82537.539	1.090
	0.000	15088.130	20619.781	26784.445	40775.293	48987.113	63130.516	72675.203	82214.391	1.088
	0.000	15934.602	21857.191	28395.924	43134.426	51924.148	66852.898	77065.422	87331.391	1.153
	0.000	15697.466	21744.643	28094.285	42952.949	51682.402	66698.867	76867.484	86954.258	1.147
	0.000	16284.456	22547.557	29210.850	44571.590	53652.750	68978.516	79469.141	90108.641	1.190
	0.000	16258.384	22471.773	29173.545	44451.129	53487.094	68945.211	79320.133	89880.586	1.186
	0.000	15846.840	22185.359	28886.107	44164.609	53102.223	68617.602	79070.148	89487.172	1.170
	0.000	16537.977	22328.801	28939.768	44214.816	53150.410	68343.336	78556.156	89327.438	1.178
	0.000	16816.402	22661.168	29748.873	45515.676	54687.688	70613.422	81310.258	91920.563	1.206
	0.000	17680.584	22795.414	29643.594	45448.906	54564.438	70399.477	80944.531	91754.414	1.203
	0.000	17188.689	23419.639	30393.188	46600.871	56013.273	72183.039	83278.203	94108.773	1.236
	0.000	17058.117	23484.287	30469.959	46604.547	56021.039	71973.641	82866.023	93969.375	1.239
	0.000	17415.855	23766.918	30883.021	47401.023	56919.797	73266.508	84370.328	95910.180	1.254
	0.000	17284.010	23826.729	30857.686	47396.582	56951.250	73298.227	84342.594	95628.320	1.257
	0.000	17499.689	24185.143	31297.713	48363.344	58068.480	74583.180	85990.391	97448.922	1.276
	0.000	17734.414	24155.252	31412.561	48179.914	57761.719	74293.922	85474.234	96835.508	1.274
	0.000	18329.316	24995.541	32384.072	50197.039	60224.750	77507.070	89141.430	101052.336	1.319
	0.000	18455.938	25108.449	32589.332	50173.613	60224.465	77456.586	89081.328	100937.547	1.325
	0.000	20300.654	28170.035	36544.613	56611.836	67854.398	87122.672	100271.805	113528.531	1.486
	0.000	20969.148	28120.783	36488.477	56329.988	67540.898	86797.820	99934.789	113158.070	1.484
	0.000	22430.186	30804.943	39967.074	62295.328	74468.656	95623.109	109928.813	124478.406	1.625
	0.000	22776.166	30779.367	39896.141	62079.113	74132.008	95394.695	109701.602	124179.016	1.624
	0.000	22860.398	32005.455	41609.012	64951.520	77437.602	99630.375	114623.461	129671.555	1.689
	0.000	22875.441	32013.439	41434.230	64857.973	77556.313	99509.383	114360.172	129319.656	1.689
	0.000	23242.842	32152.486	41706.699	65358.461	77820.320	99809.813	114734.211	129858.734	1.696
	0.000	23180.816	32071.592	41530.582	64943.500	77644.273	99656.758	114703.023	129746.648	1.692
	0.000	21583.615	29979.244	38844.156	59933.082	71765.594	91588.664	103551.070	119185.773	1.582

Table 14 HGL Test for Glycerine 100%

Temperature	22°C
24/11/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	65
Valve position:	Open
Pipe Diameter [mm]:	63.08
Material Type:	Glycerine 100%
Density[kg/m^3]:	1256
μ[Pa.s]	0.837

Axial distances	-6.974	-3.865	-2.885	-0.937	1.316	2.938	6.427	8.432	10.156	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	0.000	20275.893	29100.000	39436.613	54029.457	65969.867	84775.070	97192.781	109850.500	3.304
	0.000	5059.177	7440.000	9494.262	12800.566	15780.283	20316.057	23289.277	26397.352	0.845
	0.000	3129.810	3775.232	5468.532	7275.657	9017.188	11537.497	13230.517	14900.640	0.429
	0.000	2646.164	3106.708	4496.460	5949.710	7341.016	9437.029	10775.207	12159.499	0.353
	0.000	2439.037	3040.785	4499.357	5996.837	7317.140	9344.184	10689.679	12062.483	0.345
	0.000	2449.596	3071.134	4368.259	5899.713	7299.011	9367.891	10692.890	12057.821	0.349
	0.000	2979.486	3759.190	5411.548	7287.366	8953.211	11516.364	13113.791	14817.225	0.427
	0.000	2930.987	3771.875	5404.520	7244.253	8915.511	11485.133	13149.400	14821.925	0.428
	0.000	3580.359	4519.078	6513.801	8910.991	10901.148	13991.103	16040.411	18088.438	0.513
	0.000	3627.732	4406.903	6543.440	8785.081	10900.696	13880.282	15985.331	18060.070	0.500
	0.000	3849.634	4728.215	7112.583	9397.921	11707.043	15121.566	17172.475	19419.326	0.537
	0.000	3921.880	4653.249	7091.773	9485.891	11655.814	15169.381	17216.676	19421.713	0.528
	0.000	4415.916	5338.174	7843.668	10429.658	12789.294	16588.744	19009.396	21461.449	0.606
	0.000	4376.313	5296.515	7803.536	10611.175	12939.266	16643.787	18976.258	21416.299	0.601
	0.000	5247.938	6267.666	9374.106	12428.594	15336.307	19746.881	22615.525	25440.682	0.712
	0.000	5233.208	6327.830	9278.050	12180.164	15152.143	19680.184	22421.643	25454.713	0.718
	0.000	6337.402	7079.557	10749.202	14571.795	17793.027	22907.658	26133.584	29691.641	0.804
	0.000	6264.976	7020.866	10479.294	14257.800	17654.996	22974.041	26164.539	29579.891	0.797
	0.000	6956.387	8303.542	11891.241	16297.815	20012.799	25997.916	29677.789	33548.289	0.943
	0.000	7006.705	8284.465	11854.784	16460.260	19865.268	25839.266	29590.135	33542.742	0.941
	0.000	7283.042	8731.201	12714.366	17359.471	21582.979	27606.822	31599.170	35742.695	0.991
	0.000	7244.391	8649.556	12610.636	17523.607	21212.414	27314.512	31557.836	35392.008	0.982
	0.000	7973.750	9630.773	14195.621	19112.586	23868.170	30730.652	35154.574	39764.293	1.093
	0.000	8159.472	9550.260	14213.220	19241.117	23862.836	30682.217	35114.336	39808.953	1.084
	0.000	9658.786	11618.963	17162.166	23271.006	28602.771	36773.961	42227.121	47673.734	1.319
	0.000	9925.344	11782.281	16951.852	23171.455	28647.676	36636.422	42003.844	47593.422	1.338
	0.000	10704.304	13120.325	18832.967	25925.750	31961.328	40975.426	47047.184	53060.293	1.490
	0.000	10810.248	12877.014	18900.160	25685.834	31761.191	40917.199	46664.676	53046.402	1.462
	0.000	11180.000	13981.638	20375.027	27651.932	34150.176	43860.609	50458.652	57056.301	1.587
	0.000	11147.392	13795.490	20366.402	27431.879	33688.324	43391.012	50075.730	56567.543	1.566
	0.000	11775.579	14514.674	21259.506	28872.438	35748.551	46167.641	52781.160	55665.469	1.648
	0.000	12261.097	14511.179	21357.826	28971.006	35938.438	45937.113	52784.332	59814.355	1.648
	0.000	13443.971	15988.301	23534.238	32056.572	39703.781	50985.500	58247.051	65942.664	1.815
	0.000	13574.969	15984.414	23456.871	31932.924	39542.469	50885.039	58063.848	65798.625	1.815
	0.000	14232.327	17062.748	24978.963	34327.641	42378.148	54284.379	62309.242	70466.773	1.937
	0.000	14291.575	17086.943	25105.518	34455.059	42225.355	54344.375	62173.168	70376.547	1.940
	0.000	14063.241	17581.090	25671.596	35170.191	43344.527	55733.895	63706.719	72243.922	1.996
	0.000	14376.397	17674.039	25890.947	35358.500	43837.328	56269.543	64335.246	72742.047	2.007
	0.000	14351.772	17647.082	25759.596	35041.660	43292.172	55612.246	63526.289	71920.359	2.004
	0.000	14305.705	17647.750	25881.371	35396.859	43701.238	56151.793	64264.027	72655.039	2.004
	0.000	14919.608	18297.910	26901.873	37560.066	45539.809	58432.035	66877.781	75673.188	2.077
	0.000	14653.656	18333.656	26727.674	36911.324	45214.652	58145.414	66619.344	75245.617	2.081
	0.000	14523.118	17907.348	26289.344	36195.316	44653.840	57385.602	65648.336	74151.742	2.033
	0.000	15002.632	18520.697	27232.980	37354.730	46373.543	59618.559	68276.789	77105.414	2.103
	0.000	14990.723	18563.723	22688.528	37866.500	46339.363	59419.723	68000.867	72508.531	2.108

Table 15 HGL Test for Glycerine 100%

Temperature	22°C
25/11/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	80
Valve position:	Open
Pipe Diameter [mm]:	80.43
Material Type:	Glycerine 100%
Density[kg/m³]:	1256
μ[Pa.s]	0.693

Axial distances	-6.413	-4.909	-2.408	-1.209	0.707	3.827	5.897	8.381	9.876	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	0.000	1671.453	2777.906	3565.062	5453.058	7720.973	9131.263	10790.470	11874.359	1.028
	0.000	1740.062	2871.101	3638.578	5500.361	7741.151	9120.766	10775.314	11848.078	1.063
	0.000	1390.000	2071.829	2679.479	4017.902	5687.994	6706.264	7916.839	8720.358	0.767
	0.000	1384.222	2135.742	2722.665	4033.802	5711.486	6738.803	7932.701	8721.771	0.791
	0.000	1785.347	3015.064	3977.486	6038.278	8491.285	10080.295	11892.132	13105.949	1.116
	0.000	1898.999	3126.986	3989.890	6059.476	8521.841	10065.772	11895.381	13083.761	1.158
	0.000	2071.722	3384.105	4352.148	6627.557	9343.796	11045.188	13051.467	14342.765	1.253
	0.000	2093.449	3380.825	4348.895	6630.526	9341.890	11044.942	13040.663	14333.440	1.251
	0.000	2229.160	3747.569	4827.173	7386.098	10378.257	12264.143	14476.939	15917.958	1.387
	0.000	2291.077	3736.120	4820.109	7369.845	10372.460	12272.300	14482.491	15907.613	1.383
	0.000	2559.925	4135.230	5356.502	8237.902	11558.123	13641.490	16121.843	17719.512	1.531
	0.000	2597.157	4142.297	5357.419	8220.131	11558.300	13649.900	16097.356	17683.328	1.533
	0.000	2757.591	4431.462	5719.647	8837.786	12401.603	14634.756	17253.346	18567.393	1.640
	0.000	2700.677	4423.512	5723.959	8824.994	12375.988	14608.401	17252.395	18956.408	1.637
	0.000	2939.886	4781.776	6175.707	9593.718	13425.639	15834.163	18688.545	20527.504	1.770
	0.000	2910.140	4774.924	6165.954	9570.364	13410.380	15814.699	18665.896	20506.408	1.768
	0.000	3970.066	6433.847	8322.698	13261.714	18392.842	21651.518	25481.141	27950.543	2.382
	0.000	3889.275	6412.265	8314.112	13220.093	18300.059	21580.465	25407.625	27886.311	2.374
	0.000	3119.776	5084.692	6583.327	10280.999	14352.375	16964.570	20005.096	21964.631	1.882
	0.000	3163.941	5098.964	6600.638	10282.023	14360.359	16933.441	19975.912	21920.678	1.887
	0.000	3381.988	5615.567	7274.034	11457.052	15962.330	18819.260	22179.570	24333.410	2.079
	0.000	3550.436	5622.846	7275.837	11442.668	15943.895	18791.381	22148.477	24301.332	2.081
	0.000	3681.435	5883.361	7592.131	12041.251	16737.967	19715.260	23197.566	25477.820	2.178
	0.000	4572.984	5883.714	7606.089	12024.188	16711.650	19687.738	23168.803	25443.762	2.178
	0.000	3721.571	6146.520	7949.302	12665.437	17560.172	20679.553	24341.256	26687.188	2.275
	0.000	3909.088	6145.600	7930.011	12629.509	17495.100	20608.719	24247.666	26600.025	2.275
	0.000	4001.934	6440.814	8323.052	13342.263	18574.785	21690.725	25527.637	27987.951	2.384
	0.000	3864.751	6414.843	8300.614	13291.740	18393.475	21596.580	25402.881	27865.746	2.375
	0.000	4250.682	6784.591	8751.517	14074.690	19492.623	22891.904	26949.855	29525.486	2.511
	0.000	4525.113	6768.412	8731.907	14030.038	19398.293	22794.920	26798.006	29394.529	2.505
	0.000	4247.574	7239.729	9383.223	15161.681	20904.602	24636.852	28954.654	31686.924	2.680
	0.000	4421.072	7279.866	9360.229	15167.189	21041.709	24527.754	28877.352	31551.336	2.695
	0.000	4706.388	7422.873	9602.650	15569.021	21503.947	25229.346	29666.379	32565.229	2.748
	0.000	4581.958	7446.611	9584.917	15556.371	21468.582	25209.148	29659.031	32378.447	2.757
	0.000	4912.920	8279.063	10670.740	17587.766	24071.375	28393.203	33242.383	36345.180	3.065
	0.000	4829.505	8253.841	10656.114	17490.258	24043.121	28190.592	33150.074	36339.770	3.055
	0.000	5123.654	8591.443	11071.470	18484.625	25325.027	29939.820	33126.168	38396.859	3.180
	0.000	5397.909	8662.631	11171.697	18549.137	25397.414	29675.918	34780.340	38102.194	3.207
	0.000	5289.244	8973.592	11675.915	19631.918	26742.721	31427.117	36704.570	40124.004	3.322
	0.000	5835.774	9038.878	11577.844	19583.625	26622.355	31166.744	36569.691	39954.965	3.346
	0.000	5659.943	9078.343	11719.938	19908.611	26983.662	31538.369	36973.816	40373.109	3.361
	0.000	5337.495	9141.228	11790.273	20116.100	27161.971	31768.324	37252.801	40696.469	3.384
	0.000	5944.089	9298.614	11961.941	20452.039	27643.072	32348.246	37874.063	41409.859	3.442
	0.000	6043.818	9554.503	12207.151	21077.287	28429.324	33180.160	38931.242	42414.891	3.537
	0.000	6180.153	9505.357	12153.591	20975.432	28282.307	33010.945	38722.809	42249.973	3.519
	0.000	6027.255	9433.638	12220.615	21292.820	28663.852	33416.973	39157.020	42697.445	3.492
	0.000	6070.813	9697.330	12513.563	21902.594	29357.302	34181.629	40061.297	43688.309	3.590
	0.000	6669.704	9572.236	12542.104	21754.949	29173.688	34061.086	39830.215	43504.211	3.543

Table 16 HGL Test for Glycerine 75%

		Axial distance	-5.824	-4.72	-3.536	-1.031	1.257	3.012	5.666	7.666	9.669	
		Valve plane				0						
Temperature	21°C		Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
1/12/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		26674.872	26564.990	26598.711	26505.630	26497.145	26490.412	26252.354	26346.963	26149.012	0.315
Valve dimension[mm]:	40		26716.311	26586.412	26616.145	26492.908	26511.832	26479.541	26270.502	26353.912	26147.858	0.416
Valve position:	Open		27130.000	27050.000	26989.670	26861.680	26707.471	26628.873	26443.467	26333.602	26242.231	0.587
Pipe Diameter [mm]:	42.12		27150.000	27067.840	27008.379	26860.545	26705.900	26637.316	26437.963	26375.941	26236.066	0.588
Material Type:	Glycerine 75%		27539.000	27447.482	27341.330	27174.891	26946.344	26857.270	26584.770	26489.564	26258.441	0.820
Density[kg/m³]:	1197.2		27569.439	27478.496	27370.930	27172.145	26946.107	26838.191	26584.730	26524.596	26255.346	0.824
μ [Pa.s]	0.020		27583.160	27454.578	27409.162	27175.107	27020.379	26798.732	26568.336	26542.881	26287.258	0.722
			29185.252	28020.355	27865.463	27616.959	27270.422	27062.742	26743.332	26700.201	26359.314	1.327
			42027.215	41132.309	39630.715	37614.516	33443.742	32130.428	29639.523	28724.012	26432.371	3.309
			45488.609	44229.188	42504.347	40028.508	34947.660	33319.016	30299.402	28617.494	26386.316	3.681
			45535.734	44366.301	42493.965	40034.113	34935.609	33291.711	30316.654	28624.090	26381.973	3.691
			44580.402	43368.184	41591.344	39522.730	34536.922	32977.855	30139.662	28548.656	26434.477	3.578
			44279.217	43437.273	41699.180	39386.668	34549.793	33027.082	30141.842	28532.196	26382.828	3.585
			41940.348	40785.172	39416.176	37563.230	33341.438	32073.822	29571.645	28315.224	26428.320	3.264
			41909.586	40734.766	39408.377	37362.098	33320.398	32062.264	29595.854	28298.479	26440.152	3.285
			39703.262	38723.172	37498.383	35772.051	32315.125	31300.465	29179.836	28123.053	26459.471	3.002
			39677.980	38742.641	37501.199	35823.387	32333.988	31268.277	29193.816	28107.756	26456.119	3.011
			38681.926	37690.848	36579.238	35240.023	31913.441	30928.375	28941.924	28010.160	26481.326	2.874
			38618.336	37714.375	36601.516	35234.324	31877.178	30915.973	28953.206	28024.420	26458.398	2.877
			36663.684	35862.813	34927.488	33580.277	31038.281	30230.242	28563.553	27829.350	26478.902	2.613
			36614.284	35800.250	34910.902	33595.983	31026.439	30223.217	28551.258	27825.961	26475.971	2.615
			36472.324	35855.473	34936.145	33566.684	30970.729	30146.382	28579.205	27844.424	26473.191	2.608
			35304.227	34789.148	34099.914	32829.348	30483.594	29845.285	28342.219	27732.346	26483.605	2.465
			35504.660	34825.059	34036.492	32792.344	30482.525	29843.326	28341.250	27725.609	26461.176	2.469
			34730.387	34015.461	33407.383	32296.512	30093.434	29674.742	28215.596	27661.092	26468.879	2.375
			35138.020	34369.254	33613.715	32512.934	30340.613	29615.602	28245.154	27672.854	26489.234	2.400
			33013.680	32800.750	32418.904	31282.500	29321.725	28741.380	27842.504	27536.715	26456.943	2.209
			33513.367	32672.715	32123.227	31370.762	29416.006	28978.857	27967.156	27520.172	26473.904	2.207
			31897.182	31283.926	30887.025	29938.928	28782.830	28211.578	27601.205	27368.029	26642.768	2.026
			31686.102	31327.025	30777.545	30186.039	28932.262	28630.463	27609.648	27309.709	26630.508	2.029
			30829.736	30286.777	30062.984	29474.371	28572.863	28045.345	27431.203	27242.227	26543.240	1.845
			30768.105	30362.186	30041.660	29492.617	28422.113	28078.961	27343.298	27225.926	26564.271	1.852
			29856.230	29492.543	29305.391	28877.295	28073.328	27745.111	27168.150	27121.631	26516.973	1.587
			29848.600	29506.563	29308.529	28889.660	28058.066	27758.556	27140.949	27130.438	26513.869	1.589
			28868.490	28560.021	28432.086	28108.186	27553.719	27377.088	26872.209	26956.576	26410.381	1.811
			28850.627	28525.016	28441.398	28069.545	27570.010	27366.920	26893.375	26946.986	26356.869	1.696
			28420.713	28150.400	28032.082	27738.451	27341.861	27232.230	26768.609	26875.658	26367.641	1.6130
			28426.670	28127.826	28050.300	27758.869	27354.982	27193.922	26754.742	26866.932	26361.012	1.5596

Table 17 HGL Test for Glycerine 75%

		Axial distance	-6.298	-4.568	-2.922	-0.832	1.976	2.685	6.046	8.075	9.975	
		Valve plane				0						
Temperature	21°C		Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
30/11/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		29857.799	29520.000	29262.345	28828.600	27411.412	27063.949	26560.000	26301.660	25990.000	0.684
Valve dimension[mm]:	50		29847.811	29540.000	29278.119	28798.297	27426.205	27044.449	26560.000	26317.486	25990.000	0.654
Valve position:	Open		31798.041	31470.000	31134.383	30527.047	29071.508	27552.229	26950.000	26490.914	26110.000	0.762
Pipe Diameter [mm]:	52.8		31825.703	31450.000	31163.229	30539.703	28100.633	27590.014	26930.000	26560.000	26180.000	0.760
Material Type:	Glycerine 75%		33226.223	32820.000	32466.137	31780.646	28521.381	27939.159	27100.000	26582.594	26140.000	0.872
Density[kg/m³]:	1197.2		33238.340	32800.000	32462.133	31774.234	28538.311	27925.779	27120.000	26589.295	26200.000	0.891
μ[Pa.s]	0.018		34150.148	33760.000	33366.316	32537.184	28794.371	28176.268	27400.000	26900.000	26450.000	0.899
			34093.605	33710.000	33317.805	32524.672	28795.801	28129.840	27380.000	26930.000	26450.000	0.890
			35109.215	34630.000	34181.686	33276.047	29025.443	28370.000	27601.988	27090.000	26740.000	1.064
			35012.250	34510.000	34123.980	33294.273	29004.104	28259.396	27592.719	27090.000	26660.000	1.019
			37514.563	36930.000	36447.332	35427.410	29586.945	28764.930	27802.973	27270.000	26770.000	1.169
			39563.871	38770.164	37929.613	37182.379	29970.117	29154.924	28244.221	26927.811	26093.902	1.292
			39721.719	38678.297	38200.438	37021.367	30376.645	29023.488	27845.033	26938.395	26137.004	1.296
			41566.785	40517.176	39706.395	37802.172	30796.867	29305.217	28253.311	27034.395	25933.377	1.377
			45842.488	44347.234	43582.961	41701.473	32218.912	31105.975	28952.191	27313.914	25909.281	1.535
			45790.078	44456.203	43495.281	41558.137	32436.465	31112.676	28945.779	27359.264	25839.723	1.535
			47430.570	45809.356	44806.348	42962.055	32884.887	31585.301	29324.607	27444.811	25823.049	1.600
			47378.770	45972.816	44905.113	43075.246	32945.023	31597.918	29280.369	27459.498	25822.580	1.599
			49820.781	48120.609	47020.332	44884.340	33770.277	32312.203	29633.352	27595.639	25799.053	1.707
			49798.492	48042.117	46969.535	44952.105	33745.602	32279.516	29596.781	27632.789	25791.996	1.705
			53519.188	51519.082	50212.293	47690.266	34914.434	33240.805	30156.098	27682.309	25760.373	1.872
			53455.340	51536.203	50140.996	47821.824	34922.672	33274.703	30166.225	27760.689	25793.490	1.868
			57213.758	55036.867	53492.676	50832.785	36093.133	34228.582	30645.582	28039.461	25707.691	2.031
			57250.938	55045.472	53511.102	50900.945	36150.316	34184.898	30576.566	28040.389	25723.656	2.029
			64847.641	62259.266	60125.195	56807.332	38455.094	36154.668	31558.307	28413.875	25532.121	2.325
			64878.551	62163.051	60054.750	56656.098	38381.172	36169.852	31318.492	28444.064	25565.984	2.323
			71623.273	68605.047	65966.641	62224.516	40540.906	37874.539	32519.203	28740.865	25399.479	2.562
			71488.805	68602.023	65960.539	62318.051	40591.918	37950.441	32388.637	28655.930	25424.316	2.567
			75529.039	72354.766	69455.406	65504.949	41702.434	38950.297	32564.527	29070.049	25364.646	2.695
			75612.078	72302.539	69467.914	65574.047	41868.191	38875.609	32533.938	28897.295	25346.676	2.700
			78400.633	74822.320	71931.727	67677.141	42587.691	39546.543	33039.598	29112.182	25331.922	2.796
			78375.570	74788.172	71904.914	67672.602	42720.543	39549.719	33207.438	29094.180	25373.725	2.791
			82312.727	78806.602	75479.602	70774.836	43810.293	40488.836	33678.762	29334.133	25200.625	2.925
			81107.320	77001.109	72602.633	67470.125	34954.473	30961.133	22604.453	17467.848	12681.935	3.259
			81098.453	76897.953	72700.039	67254.039	34819.398	30857.822	22596.391	17397.055	12588.207	3.369
			86979.086	82133.859	77567.828	72013.047	36694.738	32565.801	23530.656	17948.174	12666.243	3.432
			98023.086	93346.555	89230.370	83508.336	49362.266	45063.195	36470.329	31144.186	25893.629	3.3726

Table 18 HGL Test for Glycerine 75%

		Axial distance	-6.9735	-4.8855	-2.885	-1.267	0.987	2.938	5.449	7.454	9.455	
		Valve plane				0						
Temperature	21°C		Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
2/12/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		59767.691	56264.306	52784.340	50041.902	42859.074	39454.297	34595.707	31262.930	27846.457	6.763
Valve dimension[mm]:	65		59527.414	56341.305	52798.633	49953.637	42824.809	39495.117	34525.191	31251.168	27867.426	6.724
Valve position:	Open		56381.945	53201.418	50201.641	47691.801	41241.082	38235.582	33837.508	30849.375	27840.473	6.418
Pipe Diameter [mm]:	63.08		56235.852	53191.336	50158.047	47681.176	41297.938	38222.316	33852.590	30913.262	27827.678	6.554
Material Type:	Glycerine 75%		52702.422	50021.262	47345.656	45136.340	39564.801	36933.035	33054.680	30403.818	27865.279	5.803
Density[kg/m³]:	1192.5		52808.266	50064.535	47213.652	45188.875	39616.918	36924.379	33073.967	30428.773	27800.516	6.021
μ[Pa.s]	0.020		48526.359	46268.551	43975.805	42163.320	37527.719	35309.129	32115.213	29955.641	27813.701	5.429
			48510.988	46329.402	44046.141	42472.758	37838.922	35610.828	32383.469	30270.951	28708.221	5.430
			44804.773	42897.785	40971.566	39486.699	35706.422	33808.664	31089.734	29332.699	27598.387	4.849
			44993.281	43282.926	41388.840	39667.301	36108.395	34249.004	31531.663	29708.217	28012.654	4.687
			40411.578	39041.336	37605.355	36456.422	33647.406	32252.129	30220.088	28889.672	27657.566	4.218
			40219.082	38938.535	37554.773	36442.305	33602.379	32278.332	30251.059	29139.705	27993.336	4.211
			38313.297	37208.527	36009.648	35134.613	32745.863	31513.332	29788.992	28614.787	27589.900	3.789
			38292.477	37183.105	35948.758	35049.895	32619.670	31437.672	29728.855	28608.189	27568.623	3.737
			35320.176	34422.383	33514.613	32896.656	31281.684	30424.457	29282.693	28368.951	27628.453	3.044
			35336.012	34471.945	33545.090	32942.027	31166.469	30528.775	29024.699	28184.512	27474.369	3.068
			30576.393	30464.453	29962.355	29662.260	28722.479	28312.738	27901.609	27537.744	27258.699	2.126

Table 19 HGL Test for Glycerine 75%

		Axial distances	-6.413	-4.309	-2.408	-1.209	0.707	3.907	5.977	8.461	9.956	
		Valve plane				0						
Temperature	21°C		Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
2/12/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		41904.098	41272.824	39656.591	39061.203	34253.738	32368.111	31229.143	29887.174	29126.168	7.223
Valve dimension[mm]:	80		41678.867	41154.820	39780.750	39078.914	34413.816	32446.385	31305.549	29890.227	29139.018	7.461
Valve position:	Open		40089.680	39385.059	38066.247	37453.555	33365.715	31658.379	30658.447	29468.102	28803.549	6.617
Pipe Diameter [mm]:	80.43		40197.367	39504.324	38251.602	37676.961	33518.480	31820.266	30754.143	29615.656	28954.314	6.460
Material Type:	Glycerine 75%		38714.121	38025.295	36991.294	36447.523	32714.457	31295.264	30454.082	29387.928	28822.656	6.159
Density[kg/m^3]:	1192.5		38680.539	38089.762	37024.539	36492.113	32960.602	31308.074	30426.922	29401.955	28822.854	5.952
μ[Pa.s]	0.020		38643.121	38040.027	37030.801	36574.406	32824.898	31343.984	30474.088	29400.027	28795.328	5.988
			35390.125	34927.230	34095.766	33818.367	31264.266	30156.377	29584.209	28852.643	28468.125	4.869
			35337.961	34913.191	34116.820	33762.043	31266.905	30193.727	29589.959	28854.885	28482.000	4.955
			32556.639	32316.168	31745.305	31587.018	29952.633	29260.363	28840.404	28376.658	28170.203	3.948
			32576.805	32324.402	31300.908	31531.652	29950.637	29218.379	28648.117	29373.066	28163.646	3.797
			30870.553	30880.592	30372.492	30201.002	29158.996	28646.527	28287.646	29144.195	27989.174	3.110
			30943.590	30747.211	30338.449	30236.916	29211.770	28628.525	28447.545	28108.494	28013.205	2.974

Table 20 HGL Test for Glycerine 75%

		Axial distances	-4.552	-3.042	-2.542	-1.040	0.700	2.502	3.501	5.010	9.511	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
Temperature	22°C		ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
3/12/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	276.453	432.411	771.364	2498.214	2897.197	3130.774	3609.340	4853.760	7.540
Valve dimension[mm]:	100		0.000	255.290	409.174	753.661	2438.135	2873.807	3086.486	3612.885	4881.392	7.540
Valve position:	Open		0.000	233.882	389.896	696.774	2246.870	2652.534	2872.708	3299.330	4428.136	6.937
Pipe Diameter [mm]:	97.17		0.000	236.959	409.113	693.378	2281.342	2696.066	2867.916	3310.240	4494.563	6.858
Material Type:	Glycerine 75%		0.000	220.947	374.752	658.789	2081.830	2504.758	2678.078	3085.014	4162.104	6.827
Density[kg/m^3]:	1192.5		0.000	209.477	369.720	651.164	2126.677	2530.482	2698.339	3103.326	4178.189	6.869
μ[Pa.s]	0.020		0.000	191.478	336.859	581.269	1885.795	2224.476	2391.745	2723.004	3733.051	6.192
			0.000	183.485	349.505	597.089	1917.093	2252.606	2409.153	2751.355	3749.029	6.305
			0.000	140.930	281.181	485.602	1564.886	1856.698	1967.843	2250.316	3139.907	5.842
			0.000	124.637	290.971	485.647	1565.122	1865.300	1988.191	2268.057	3098.029	5.833
			0.000	96.463	243.553	407.050	1314.905	1578.328	1707.234	1885.060	2648.394	5.316
			0.000	68.533	239.347	404.121	1327.027	1551.186	1669.582	1891.362	2631.722	5.128
			0.000	58.566	205.681	318.235	1053.036	1248.175	1354.297	1450.780	2006.882	4.655
			0.000	46.550	180.646	319.898	1064.380	1272.623	1299.388	1497.072	2102.426	4.619
			0.000	34.079	136.742	243.611	817.403	987.023	1018.565	1093.063	1669.821	4.068

Table 21 HGL Test for CMC 5%

22/10/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	40
Valve position:	Open
Pipe Diameter [mm]:	42.12
Material Type:	CMC 5%
Density[kg/m³]:	1029
τ_y:	0.000
K:	0.304
n:	0.723

Axial distances	-6.298	-4.568	-1.890	-0.621	1.076	2.685	6.046	8.075	9.975	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	26698.344	26675.074	26292.943	26118.396	25845.410	25650.309	25236.768	24969.262	24729.711	0.076
	26854.184	26613.984	26312.105	26170.121	25852.438	25651.254	25207.658	24964.855	24730.053	0.077
	27207.604	26937.695	26546.098	26386.156	26005.537	25785.918	25298.133	25024.541	24749.775	0.089
	27200.494	26887.434	26519.969	26359.994	25997.066	25799.051	25299.805	25019.545	24750.203	0.089
	27363.996	27042.090	26647.473	26446.975	26108.453	25860.189	25352.900	25045.861	24758.852	0.095
	27303.846	27059.627	26636.881	26483.596	26107.791	25853.850	25348.932	25047.793	24758.836	0.096
	27551.143	27265.441	26838.494	26613.529	26213.488	25972.914	25412.127	25080.910	24770.201	0.103
	27548.500	27259.533	26814.455	26615.871	26232.563	25940.611	25412.467	25074.447	24769.914	0.104
	28676.053	28229.412	27633.406	27332.232	26785.430	26453.607	25704.543	25250.994	24826.150	0.149
	28610.990	28200.180	27575.059	27361.217	26791.365	26449.229	25692.201	25248.730	24824.813	0.149
	30047.754	29504.283	28713.850	28302.863	27555.266	27059.211	26061.709	25451.211	24886.865	0.214
	29977.867	29491.262	28711.379	28275.350	27572.781	27054.648	26055.447	25459.352	24888.826	0.213
	31029.834	30367.047	29434.137	28987.699	28069.611	27500.105	26303.566	25597.549	24923.340	0.262
	31009.285	30369.986	29453.918	29045.137	28073.607	27504.588	26343.299	25606.270	24925.658	0.262
	32028.381	31310.232	30212.143	29636.504	28549.559	27919.434	26565.754	25728.543	24960.039	0.310
	32003.813	31331.980	30233.289	29636.678	28598.818	27937.664	26561.789	25740.689	24956.813	0.311
	33718.266	32846.148	31601.080	30856.096	29414.945	28653.336	26988.445	25962.262	25013.094	0.399
	33771.906	32919.367	31559.080	30901.703	29447.068	28643.109	26983.139	25957.004	25012.654	0.400
	33715.121	32875.535	31539.246	30915.441	29489.887	28662.580	26983.193	25958.816	25010.787	0.400
	36597.258	35452.773	33763.465	32899.121	30823.393	29742.580	27623.641	26309.406	25086.221	0.548
	36549.637	35493.676	33703.953	32955.320	30820.596	29774.160	27608.061	26308.920	25089.721	0.550
	38529.172	37300.242	35295.910	34432.113	31717.146	30480.287	28037.898	26530.393	25139.885	0.653
	38583.434	37334.527	35397.781	34412.961	31671.156	30510.479	28015.500	26534.076	25139.139	0.654
	40608.625	39154.727	36893.324	35805.781	32597.336	31270.213	28466.969	26759.729	25183.889	0.765
	40497.262	39137.219	36933.031	35827.941	32606.824	31219.439	28440.842	26762.025	25184.090	0.765
	42239.750	40705.074	38207.914	37097.703	33306.395	31818.971	28728.765	26879.438	25163.832	0.860
	42192.234	40712.598	38330.363	36566.328	33297.441	31809.172	28735.734	26888.098	25178.910	0.860
	44117.191	42432.184	39757.012	38483.301	34025.480	32420.824	29089.977	27079.818	25209.924	0.961
	44146.859	42402.809	39783.855	38490.066	33987.023	32394.266	29093.680	27098.096	25205.859	0.960
	45057.695	43140.047	40427.492	39129.258	34335.516	32686.613	29278.982	27166.469	25232.453	1.006
	45001.148	43206.070	40438.672	39070.363	34367.453	32706.404	29236.018	27165.084	25231.213	1.003
	47003.395	45124.145	42192.340	40706.418	35087.512	33353.949	29590.506	27345.857	25271.922	1.113
	49375.891	47259.191	44040.473	42492.043	35876.008	33563.246	29935.076	27554.430	25279.723	1.237
	48664.027	46585.504	43485.125	41954.395	35660.406	33794.766	29886.602	27519.285	25301.717	1.199
	50795.613	48622.215	45269.797	43616.055	36496.568	34440.816	30243.150	27714.170	25345.246	1.310
	50799.668	48653.652	45253.258	43725.979	36458.992	34461.500	30237.514	27708.885	25346.424	1.312
	54943.008	52466.105	48632.684	46929.785	37859.426	35598.914	30890.301	28066.014	25426.105	1.520
	54988.879	52484.328	48710.688	46919.160	37884.133	35623.730	30906.809	28075.398	25430.807	1.520
	56672.652	54056.551	50129.344	48271.797	38468.434	36184.250	31197.084	28250.102	25466.141	1.607
	56677.074	54105.414	50161.500	48267.082	38542.902	36141.688	31165.365	28234.986	25466.357	1.606
	58834.023	56087.777	51973.984	50091.383	39146.719	36684.426	31486.695	28393.867	25494.262	1.718
	58780.449	56110.629	51979.551	50037.336	39246.641	36768.848	31537.531	28411.873	25498.289	1.718
	60682.488	57851.598	53634.430	51680.995	39911.008	37305.203	31792.480	28573.889	25533.941	1.809
	60828.953	58046.246	53663.809	51640.895	39814.277	37215.582	31823.789	28585.441	25570.658	1.808
	62991.773	60181.496	55645.660	53488.246	40703.035	37834.570	32166.326	28776.088	25600.777	1.921
	62956.914	60147.270	55762.516	53493.480	40632.676	37835.754	32165.367	28751.744	25581.529	1.920
	64894.844	61953.266	57285.727	54984.992	41094.957	38312.367	32451.416	28926.818	25664.084	2.016
	65133.648	62055.258	57324.578	55118.820	41178.332	38303.633	32441.357	28905.641	25626.914	2.015
	66804.477	63626.953	58827.613	56641.609	41940.668	32802.957	32625.127	29012.898	25632.043	2.099
	66699.531	63632.313	58825.012	56517.230	41706.211	38722.816	32579.490	29109.107	25574.076	2.099
	69164.195	65801.758	60761.020	58412.238	42376.102	39189.281	32897.438	29179.879	25688.404	2.214
	69009.047	65728.313	60776.742	58366.113	42324.164	39164.441	32914.551	29156.068	25698.283	2.214
	71146.695	67820.688	62741.199	60237.461	42961.844	39686.535	33202.469	29355.301	25766.225	2.316
	71165.836	67746.648	62703.086	60229.785	42926.699	39684.113	33216.707	29350.887	25733.320	2.318
	72793.984	69509.906	64093.664	61602.848	43397.883	40101.699	33452.617	29440.996	25763.900	2.397
	72792.695	69477.141	64061.824	61669.871	43428.539	40064.086	33489.828	29470.020	25809.533	2.397
	75282.891	71747.508	66129.250	63838.156	44112.848	40618.336	33749.176	29657.629	25796.742	2.514
	75347.352	71686.453	66323.047	63720.664	44126.852	40663.371	33757.445	29633.494	25813.881	2.515
	77326.047	73589.203	67882.570	65398.113	44693.363	41047.867	33960.676	29758.516	25806.758	2.601
	77260.945	73522.641	67896.055	65295.273	44668.668	41045.969	33944.840	29779.619	25831.670	2.601
	79521.672	75807.844	69924.344	67284.789	45274.645	41581.770	34262.648	29894.047	25799.270	2.698
	79502.453	75777.125	69993.930	67206.016	45279.063	41580.770	34210.320	29881.248	25815.770	2.698
	82038.594	78269.773	72074.352	69310.602	45914.098	42008.184	34519.633	29992.301	25859.439	2.800
	81975.633	78023.727	72170.031	69453.945	45997.992	42030.746	34552.570	30078.141	25906.672	2.801
	84416.992	80248.422	74329.852	71377.008	46596.344	42507.258	34798.082	30228.496	25951.701	2.892
	84435.269	80474.820	74219.477	71546.492	46585.816	42540.664	34792.563	30183.758	25940.535	2.891
	87507.219	83273.734	77058.383	74027.227	47336.563	43143.430	35095.625	30367.025	25936.803	3.030
	87460.055	83295.516	77010.758	73910.156	47163.535	42891.793	34816.055	30035.641	25625.385	3.030
	88830.586	84514.250	78024.328	75179.484	47641.324	43422.738	35266.211	30358.154	25972.301	3.094
	88720.969	84276.547	77818.797	74960.992	47416.137	43105.645	35264.816	30119.848	25908.209	3.095
	91557.055	87237.016	80624.258	77327.219	48225.020	43538.797	35519.090	30270.029	25653.398	3.202
	91358.813	87063.484	80247.984	77470.016	48245.844	43615.086	35524.977	30371.627	25816.057	3.201

Table 22 HGL Test for CMC 5%

		Axial distances	-6.298	-4.568	-1.880	-0.621	1.076	2.685	6.046	8.075	9.975	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
3/11/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		94431.250	89592.133	82189.953	78753.734	50847.938	46126.570	36708.602	31168.785	25928.309	2.824
Valve dimension[mm]:	40		94980.516	90108.367	82574.934	79447.734	51640.359	47011.277	37706.436	32180.232	25850.531	2.829
Valve position:	Open		100674.727	95595.367	87849.516	84161.609	52343.051	47386.297	37292.762	31495.744	25975.053	3.068
Pipe Diameter [mm]:	42.12		100650.664	95574.883	87794.375	83886.758	52525.246	47482.332	37587.680	31786.748	26323.258	3.056
Material Type:	CMC 5%		105011.438	99823.914	91660.219	87838.156	53983.324	48736.348	38344.129	32319.408	26798.307	3.375
Density[kg/m³]:	1024		104796.359	99571.977	91519.828	87932.391	53911.504	48590.090	38370.855	32386.852	26756.240	3.257
τ_y:	0.000		135605.266	128944.813	118201.734	113941.211	60882.371	54026.313	41154.129	32785.105	26989.836	4.293
K:	0.304		136168.984	129020.922	118125.727	113663.398	60306.371	53306.766	40590.324	33137.785	26367.896	4.237
n:	0.770											

Table 23 HGL Test for CMC 5%

		Axial distances	-6.574	-3.526	-2.281	-1.031	1.257	3.012	5.666	7.666	9.669	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
3/11/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		49898.738	45832.191	44061.473	42076.699	37496.988	35020.086	31020.949	28355.338	25677.211	2.680
Valve dimension[mm]:	50		50721.063	46868.793	45121.691	43045.219	38427.789	35989.758	31984.834	29163.408	26600.000	2.707
Valve position:	Open		51816.496	47488.504	45784.352	43443.590	38391.043	35791.633	31494.070	28600.451	25694.605	2.917
Pipe Diameter [mm]:	52.8		51769.969	47465.547	45504.504	43373.965	38343.625	35774.793	31441.914	28578.883	25711.717	2.931
Material Type:	CMC 5%		54584.313	50078.590	47747.121	45400.742	39443.523	36665.938	31984.877	28954.084	25795.102	3.242
Density[kg/m³]:	1024		54390.816	49933.023	47622.027	45472.754	39626.039	36705.426	32044.082	28915.432	26344.865	3.277
τ_y:	0.000		57771.035	52700.602	50223.922	47678.039	41081.230	37480.199	32549.225	29267.031	25834.775	3.611
K:	0.442		70943.359	63877.953	61098.965	57774.672	46801.313	42016.453	35150.531	30691.564	26273.561	5.247
n:	0.670		70589.688	64059.105	61504.676	57929.777	46711.762	42208.602	35227.277	30869.020	26420.436	5.306
			75184.406	67847.602	64810.598	61115.641	48573.840	43370.832	35890.980	31100.307	26491.123	5.863
			74849.148	67780.273	64864.297	61453.160	48585.137	43437.605	36009.434	31244.781	26527.492	5.779

Table 24 HGL Test for CMC 5%

25/10/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	50
Valve position:	Open
Pipe Diameter [mm]:	52.8
Material Type:	CMC 5%
Density[kg/m^3]:	1025.5
τ_y:	0.000
K:	0.442
n:	0.670

Axial distances	-6.574	-3.526	-2.281	-1.031	1.257	3.012	5.666	7.666	9.669	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	25572.230	25406.410	25352.396	25280.555	25166.916	25052.729	24908.631	24804.740	24697.107	0.020
	25582.297	25390.279	25356.100	25273.531	25152.576	25066.998	24904.234	24805.299	24691.854	0.020
	25846.807	25633.965	25540.885	25468.254	25342.932	25205.813	24999.434	24883.762	24741.225	0.036
	25851.652	25650.010	25556.758	25468.684	25320.664	25206.525	25005.895	24871.281	24735.676	0.036
	26110.889	25856.922	25747.998	25647.008	25467.504	25325.750	25089.625	24929.508	24771.002	0.053
	26115.750	25853.365	25769.164	25633.799	25433.684	25328.723	25083.430	24923.391	24769.117	0.053
	26278.934	26003.629	25886.799	25783.734	25572.078	25408.002	25153.434	24975.371	24798.836	0.066
	26270.240	25997.178	25897.869	25753.316	25563.453	25408.762	25145.287	24978.904	24798.848	0.066
	26489.488	26164.109	26041.698	25902.365	25684.365	25501.238	25206.275	25014.025	24814.123	0.081
	26462.250	26179.152	26015.064	25916.020	25654.652	25499.379	25204.900	25013.826	24812.408	0.081
	26758.180	26411.715	26288.260	26100.049	25837.072	25632.656	25298.078	25065.293	24837.242	0.103
	26768.479	26399.598	26267.834	26083.514	25826.949	25637.949	25292.234	25068.799	24837.404	0.104
	27121.559	26712.426	26521.475	26306.334	26019.439	25783.688	25396.816	25140.369	24867.887	0.131
	27105.150	26672.541	26534.250	26346.424	26025.549	25790.580	25400.150	25133.068	24867.260	0.130
	27533.393	27084.408	26826.584	26612.193	26246.924	25971.828	25513.568	25206.646	24897.090	0.166
	27566.773	27062.857	26853.240	26606.840	26240.537	25979.133	25525.039	25211.484	24894.158	0.166
	28871.654	28144.447	27862.363	27529.662	26983.961	26587.227	25906.699	25444.047	24986.172	0.289
	28861.951	28169.127	27868.439	27561.484	26980.227	26580.033	25905.375	25445.330	24987.227	0.289
	29467.035	28618.025	28301.371	27934.918	27301.299	26833.645	26064.984	25545.209	25016.775	0.348
	29448.021	28622.596	28322.137	27928.938	27292.641	26827.980	26063.266	25545.309	25017.025	0.347
	30359.160	29370.336	28980.971	28506.484	27775.238	27223.637	26306.666	25692.398	25066.471	0.441
	30308.783	29385.014	28983.725	28499.732	27762.295	27233.174	26318.566	25692.551	25062.977	0.442
	31053.391	29957.137	29522.270	29018.939	28160.400	27547.354	26511.432	25806.967	25106.490	0.521
	31046.607	29957.035	29554.410	29003.063	28162.480	27535.168	26515.154	25811.053	25106.811	0.523
	32002.467	30737.092	30239.332	29645.260	28663.896	27950.170	26779.355	25959.313	25151.850	0.631
	31978.668	30768.953	30255.537	29646.369	28672.467	27948.078	26770.586	25960.459	25152.047	0.631
	33073.195	31676.541	31130.488	30384.922	29200.922	28444.279	27056.771	26144.184	25200.416	0.766
	33067.855	31667.529	31096.521	30404.488	29239.424	28413.074	27065.604	26124.033	25194.992	0.766
	33980.113	32416.895	31764.207	30967.279	29704.254	28811.689	27312.914	26279.406	25243.049	0.876
	34011.445	32408.273	31798.088	31019.992	29727.834	28812.193	27320.914	26281.582	25244.338	0.877
	34292.438	32549.670	31971.264	31179.234	29867.494	28920.166	27368.273	26323.721	25251.324	0.911
	34208.672	32628.556	31961.889	31148.188	29852.055	28934.371	27385.711	26326.443	25255.184	0.910
	34837.102	33145.219	32438.408	31639.838	30181.441	29185.299	27529.104	26397.975	25275.775	0.995
	34887.195	33176.164	32411.582	31595.313	30170.979	29189.252	27536.719	26402.572	25275.676	0.993
	35635.836	33791.703	32973.082	32097.871	30518.789	29500.063	27704.682	26526.801	25324.273	1.086
	35544.164	33709.508	32998.973	32123.164	30500.670	29461.240	27741.855	26535.725	25323.912	1.088
	36311.137	34283.238	33519.551	32564.547	30841.246	29780.918	27908.006	26631.727	25339.461	1.181
	36224.078	34289.988	33514.092	32571.244	30852.377	29770.684	27896.369	26616.715	25345.965	1.175
	37065.648	34960.273	34085.145	33076.785	31260.355	30109.955	28121.283	26757.400	25394.555	1.288
	36996.715	34957.422	34045.941	33099.988	31257.816	30073.654	28068.311	26735.271	25387.500	1.282
	37574.109	35473.840	34594.563	33527.848	31573.910	30344.641	28276.557	26858.775	25399.189	1.368
	37594.539	35466.715	34584.102	33515.953	31560.779	30329.643	28281.098	26844.184	25407.908	1.368
	38314.789	36084.941	35172.902	34028.844	31945.148	30653.205	28476.158	26959.844	25454.516	1.475
	38397.715	36066.652	35140.066	34072.918	31959.039	30663.225	28466.443	26969.084	25436.760	1.475
	39078.094	36651.094	35673.320	34481.570	32318.373	30948.072	28607.916	27071.928	25484.338	1.572
	39103.387	36671.395	35707.523	34486.023	32319.252	30933.705	28639.480	27062.412	25478.172	1.572
	39873.281	37348.422	36313.410	35020.613	32722.410	31287.564	28827.576	27181.969	25517.961	1.687
	39829.195	37337.305	36282.871	35019.820	32707.217	31294.428	28839.037	27177.863	25511.342	1.688
	40396.395	37739.418	36711.031	35461.590	32587.633	31520.010	28976.854	27279.330	25555.301	1.769
	40442.820	37763.863	36680.297	35405.285	32975.906	31508.717	28971.641	27272.201	25537.564	1.770
	40739.832	38130.137	36979.770	35711.348	33130.645	31657.197	29056.496	27284.002	25520.143	1.843
	40770.098	38085.285	36950.441	35688.027	33137.352	31627.646	29043.777	27277.162	25524.205	1.845
	41530.852	38816.754	37578.867	36296.539	33505.840	31967.982	29244.152	27356.473	25547.244	1.959
	41594.746	38773.152	37637.945	36240.898	33518.145	31940.924	29241.582	27395.191	25542.598	1.960
	42073.875	39096.387	37956.852	36522.516	33690.008	32077.055	29352.416	27460.502	25564.135	2.021
	41999.418	39145.648	37959.059	36511.172	33663.473	32107.973	29341.217	27459.828	25570.410	2.021
	44536.660	41271.055	39958.180	38430.113	34954.543	33001.426	29904.600	27833.162	25698.457	2.345
	44513.711	41207.816	40009.863	38461.664	34979.180	33046.340	29933.473	27793.236	25685.338	2.349
	47548.895	44232.406	42720.258	40954.539	36516.313	34258.797	30661.371	28253.846	25803.648	2.831
	47943.938	44261.457	42729.914	40935.215	36548.430	34252.383	30643.693	28245.854	25785.828	2.832
	49452.816	45617.840	44086.102	42124.039	37214.938	34842.031	31013.822	28433.619	25851.523	3.067
	49563.969	45704.773	44046.605	42099.402	37215.480	34898.785	31037.674	28470.979	25870.775	3.066

Table 25 HGL Test for CMC 5%

26/10/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	65
Valve position:	Open
Pipe Diameter [mm]:	63.08
Material Type:	CMC 5%
Density[kg/m³]:	1026.5
τ_y:	0.000
K:	0.472
n:	0.670

Axial distances	-6.9735	-3.865	-2.585	-0.937	0.987	2.938	6.427	8.432	10.433	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	31692.811	30508.297	30147.828	29331.268	28509.654	27772.527	26692.645	25957.689	25225.496	1.210
	33169.605	31786.350	31382.209	30436.537	29399.416	28464.742	27145.305	26259.094	25349.676	1.664
	33977.035	32467.561	32020.305	31016.035	29778.367	28846.705	27376.268	26375.949	25420.221	1.870
	34059.527	32525.563	31974.818	30959.424	29810.881	28820.082	27357.158	26397.365	25398.832	1.871
	34175.020	32595.139	32154.383	31113.314	29868.990	28923.174	27443.428	26442.529	25435.873	1.932
	34860.504	33207.223	32667.760	31642.408	30238.234	29185.760	27603.238	26577.139	25462.684	2.110
	35579.457	33691.352	33178.277	32091.217	30639.984	29500.422	27815.443	26701.979	25573.646	2.262
	36718.797	34856.695	34213.563	32880.285	31300.221	30080.453	28214.170	26931.547	25695.422	2.602
	37675.762	35576.273	34825.273	33519.785	31754.189	30461.457	28472.299	27114.965	25780.873	2.842
	38220.895	36011.973	35335.398	33979.715	32079.627	30679.949	28634.779	27221.836	25817.523	3.014
	38262.270	36020.023	35356.863	33919.289	32077.633	30680.371	28632.287	27239.449	25812.529	3.020
	38574.633	36285.559	35595.918	34199.918	32289.916	30814.191	28724.543	27313.982	25857.342	3.136
	38578.730	36314.184	35628.715	34209.320	32271.990	30839.291	28725.217	27305.254	25834.846	3.134
	39210.168	36968.148	36220.969	34758.223	32676.990	31129.357	28941.893	27453.297	25923.676	3.327
	39339.004	36920.027	36195.480	34778.719	32662.588	31124.441	28934.797	27452.090	25925.316	3.317
	40300.508	37829.227	37030.137	35426.121	33204.930	31511.441	29156.100	27590.830	25988.064	3.546
	40236.156	37823.164	37050.285	35517.883	33158.984	31509.186	29159.840	27602.742	26008.162	3.534
	41261.043	38735.004	37859.996	36344.461	33820.117	31879.178	29478.432	27813.414	26084.201	3.740
	41341.242	38679.613	37889.078	36202.906	33765.398	31977.494	29417.572	27765.188	26098.041	3.750
	41916.680	39178.160	38326.551	36570.004	34080.379	32150.605	29565.625	27851.412	26152.148	3.853
	41750.625	39162.367	39299.500	36625.434	34076.988	32182.049	29596.781	27812.029	26108.266	3.849
	43062.223	40145.867	39375.324	37455.348	34629.961	32555.295	29863.250	28085.189	26234.885	4.125
	42990.352	40134.809	39331.664	37529.828	34612.492	32566.631	29862.785	28035.295	26214.277	4.094
	44108.719	41168.668	40169.566	38188.637	35180.195	32936.793	30260.723	28233.885	26339.549	4.352
	44101.859	41074.238	40002.445	38139.082	35190.203	33046.441	30163.658	28245.648	26291.283	4.341
	44837.930	41654.441	40846.172	38872.898	35517.172	33247.758	30331.480	28397.836	26359.939	4.520
	44753.477	41587.824	40815.121	38712.371	35621.762	33193.375	30343.857	28341.002	26378.367	4.541
	44876.527	42092.273	41047.121	39056.164	35638.777	33421.965	30475.867	28442.287	26387.748	4.606
	45142.434	42063.438	41039.984	38955.422	35824.098	33473.398	30396.869	28433.729	26402.607	4.613
	46223.277	42734.125	41906.629	39670.027	36282.492	33832.949	30760.189	28613.068	26469.238	4.858
	46073.375	42796.836	41973.316	39795.824	36280.605	33790.956	30691.428	28587.439	26464.141	4.842
	46650.691	43159.977	42351.543	40105.977	36558.125	34015.363	30744.609	28715.240	26567.520	5.030
	46641.602	43269.030	42296.469	40171.172	36613.883	33932.078	30862.530	28674.314	26560.314	5.035
	47565.281	43967.008	42814.969	40796.367	37003.797	34212.953	30991.143	28877.829	26621.944	5.233
	47428.355	43972.145	42764.492	40865.305	36982.590	34282.289	30989.447	28812.773	26639.641	5.246
	48126.633	44706.129	43553.363	41312.023	37532.676	34519.734	31160.725	29054.861	26753.135	5.415
	48208.559	44618.719	43576.637	41288.129	37384.375	34573.785	31305.574	28976.217	26689.682	5.428
	49174.617	45495.309	44152.590	42034.820	37823.281	34849.559	31353.584	29125.160	26782.512	5.616
	49038.188	45446.332	44099.047	42034.457	37851.867	34906.484	31484.910	29101.025	26727.611	5.607
	49774.180	46062.574	44725.426	42611.379	38123.176	35215.445	31609.750	29221.160	26809.922	5.802
	49652.840	45975.172	44681.746	42368.227	38347.938	35142.797	31586.258	29252.244	26807.211	5.796

Table 26 HGL Test for CMC 5%

		Axial distanc	-6.413	-4.809	-3.610	-1.209	0.707	3.907	5.977	8.461	9.956	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
			ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
2/11/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	210.676	383.828	741.644	1134.375	1594.970	1913.038	2295.481	2521.203	0.854
Valve dimension[mm]:	80		0.000	200.252	374.021	708.487	1108.861	1543.748	1839.723	2189.153	2382.088	0.844
Valve position:	Open		0.000	188.313	351.214	685.276	1066.989	1470.111	1764.034	2120.873	2262.915	0.752
Pipe Diameter [mm]:	80.43		0.000	194.937	350.583	674.793	1040.676	1503.520	1805.494	2082.978	2285.143	0.769
Material Type:	CMC 5%		0.000	174.903	312.362	621.418	918.824	1303.283	1564.121	1860.006	2028.218	0.680
Density[kg/m³]:	1028.2		0.000	172.258	311.387	614.596	921.271	1315.270	1577.196	1880.051	2053.565	0.685
τ_y:	0.000		0.000	155.171	279.143	554.955	823.111	1191.315	1431.425	1694.611	1841.401	0.604
K:	1.095		0.000	178.803	302.976	581.941	866.817	1211.120	1447.390	1695.554	1890.029	0.594
n:	0.798		0.000	151.048	267.302	511.618	778.533	1044.587	1276.399	1511.427	1660.033	0.502
			0.000	152.213	271.994	512.334	762.613	1065.879	1272.719	1513.934	1655.210	0.500
			0.000	130.875	223.847	434.867	633.268	911.096	1100.849	1285.684	1432.643	0.421
			0.000	135.684	225.076	425.234	629.429	904.475	1057.996	1258.648	1437.430	0.430
			0.000	111.631	185.738	367.986	529.640	773.068	889.509	1073.243	1160.642	0.335
			0.000	112.685	189.276	358.218	527.664	756.672	920.863	1058.853	1163.624	0.326
			0.000	88.894	162.800	316.433	459.039	633.914	772.390	921.628	992.023	0.284
			0.000	91.085	161.453	320.541	453.055	652.307	767.846	960.420	975.801	0.278
			0.000	52.376	83.095	172.050	245.031	348.930	416.477	488.840	543.224	0.129
			0.000	60.847	82.149	162.680	232.375	346.115	416.723	497.318	532.530	0.124
			0.000	31.598	42.599	98.721	120.502	192.633	235.180	280.299	293.508	0.065

Table 27 HGL Test for CMC 5%

27/10/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	80
Valve position:	Open
Pipe Diameter [mm]:	80.43
Material Type:	CMC 5%
Density[kg/m^3]:	1027
τ_y:	0.000
K:	0.558
n:	0.610

Axial distance	-6.413	-4.809	-3.61	-1.209	0.707	3.907	5.977	8.461	9.956	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	27502.922	27282.613	27106.949	26750.643	26415.480	25936.727	25659.563	25321.863	25110.432	0.842
	27481.211	27268.818	27110.078	26767.068	26404.744	25950.771	25674.428	25323.211	25128.074	0.842
	27492.051	27262.439	27148.297	26781.969	26395.875	25970.666	25667.943	25324.852	25136.313	0.842
	27675.352	27404.889	27241.447	26881.574	26489.916	25999.506	25701.523	25364.969	25140.695	0.914
	27624.910	27412.949	27246.898	26886.064	26480.854	26015.258	25706.654	25359.510	25129.969	0.905
	27991.055	27699.590	27528.658	27142.486	26673.039	26172.465	25804.436	25443.535	25190.289	1.069
	27982.070	27691.611	27522.344	27121.879	26679.236	26168.266	25817.412	25434.662	25186.758	1.069
	28159.383	27878.121	27693.074	27265.648	26767.615	26243.730	25867.211	25478.084	25207.113	1.135
	28140.377	27884.742	27669.578	27243.576	26746.895	26229.717	25875.336	25462.428	25213.777	1.136
	28482.105	28152.859	27927.738	27477.080	26921.898	26381.260	25982.033	25539.393	25259.510	1.232
	28420.502	28126.328	27923.990	27470.699	26959.395	26368.930	25977.646	25536.186	25255.762	1.232
	28631.078	28348.664	28144.299	27628.225	27071.047	26461.824	26018.076	25593.725	25295.084	1.365
	28658.666	28347.496	28098.492	27645.439	27079.316	26464.178	26039.826	25585.877	25271.102	1.366
	28404.459	28093.707	27898.326	27452.336	26940.861	26325.004	25963.207	25536.686	25256.660	1.267
	28758.766	28466.879	28204.863	27722.373	27129.113	26503.531	26084.344	25608.621	25297.834	1.416
	28766.857	28440.750	28199.699	27720.197	27124.264	26489.340	26075.715	25607.877	25308.422	1.415
	29022.420	28671.859	28459.574	27939.824	27294.348	26621.596	26187.900	25667.621	25333.555	1.505
	29032.791	28677.984	28455.504	27923.111	27290.139	26625.734	26176.781	25676.070	25318.945	1.506
	29207.471	28829.605	28623.553	28060.350	27359.824	26693.355	26221.908	25701.703	25379.834	1.638
	29205.760	28857.576	28575.961	28009.514	27357.162	26703.520	26248.686	25718.992	25377.945	1.632
	29420.295	29010.049	28749.463	28230.102	27482.918	26788.389	26314.350	25759.379	25406.818	1.722
	29402.145	29022.570	28787.639	28220.654	27485.848	26794.199	26304.973	25758.771	25416.764	1.724
	29699.301	29357.686	29117.100	28515.393	27704.363	26939.320	26432.549	25857.520	25443.396	1.873
	29740.479	29332.162	29089.332	28480.139	27682.766	26958.434	26430.057	25838.871	25453.949	1.884
	29818.580	29385.033	29053.076	28518.219	27678.844	26950.803	26421.508	25839.584	25475.586	1.910
	29772.813	29351.375	29069.154	28506.340	27703.295	26971.980	26434.160	25835.809	25476.195	1.903
	30013.188	29589.547	29296.660	28662.836	27809.385	27046.947	26504.883	25844.934	25512.803	1.997
	29999.424	29563.553	29247.211	28634.609	27809.996	27009.588	26500.965	25879.541	25506.897	1.977
	30554.000	30101.660	29772.564	29121.771	28113.420	27232.180	26661.490	25972.557	25551.766	2.207
	30514.438	30100.848	29803.148	29136.068	28119.061	27220.418	26634.533	25997.686	25545.668	2.203
	30806.777	30346.242	29993.260	29316.088	28236.842	27280.979	26733.422	26026.137	25642.771	2.380
	30812.729	30332.697	29955.002	29315.703	28225.615	27310.600	26723.082	26047.945	25635.854	2.374
	31426.021	30893.439	30478.750	29754.668	28550.080	27538.961	26919.008	26128.014	25706.584	2.649
	31336.930	30874.873	30475.041	29781.582	28553.643	27554.141	26901.291	26115.037	25726.119	2.645
	31888.586	31407.842	30969.691	30191.498	28814.229	27768.463	27093.861	26252.209	25764.551	2.928
	31930.584	31376.039	31058.061	30254.342	28845.572	27757.879	27073.656	26309.994	25794.307	2.925
	32175.166	31599.301	31214.879	30404.953	29015.574	27850.131	27120.527	26275.209	25823.080	3.082
	32181.158	31549.828	31236.559	30417.396	29032.902	27877.584	27202.447	26354.377	25845.078	3.085
	32566.947	31955.398	31561.588	30725.961	29224.291	28045.441	27285.504	26389.270	25914.836	3.276
	32595.070	32013.861	31581.736	30724.227	29152.426	28010.617	27268.992	26401.863	25889.100	3.273
	32774.023	32269.463	31748.313	30926.451	29276.727	28096.742	27345.926	26466.990	25927.311	3.393
	32818.469	32254.561	31737.193	30881.027	29295.049	28113.281	27352.410	26480.283	25913.350	3.401
	33473.398	32802.152	32264.898	31375.902	29663.406	28339.721	27530.838	26581.600	25997.615	3.715
	33454.941	32776.980	32320.182	31380.174	29614.781	28351.096	27497.148	26570.977	26047.240	3.713
	33720.793	33036.539	32598.066	31695.773	29797.373	28489.055	27631.785	26658.811	26045.885	3.863
	33645.012	33019.883	32543.742	31615.848	29842.111	28434.289	27640.098	26680.379	26067.596	3.852
	34148.648	33478.355	32968.453	32076.816	30107.650	28617.703	27804.037	26759.840	26116.174	4.067
	34138.441	33463.668	32981.176	32051.109	30126.326	28623.092	27778.371	26774.773	26134.250	4.071
	34882.703	34123.195	33642.836	32625.051	30494.646	28908.955	27977.076	26951.121	26271.648	4.302
	34839.219	34150.676	33622.211	32586.305	30469.088	28931.982	28030.979	26947.416	26227.904	4.326
	35709.242	34976.828	34408.730	33314.020	30906.990	29260.475	28251.461	27125.482	26431.379	4.697
	35758.191	34972.652	34380.391	33314.297	30968.398	29250.605	28253.240	27105.623	26426.104	4.680
	36350.801	35623.473	34991.398	33830.664	31281.893	29439.396	28378.156	27250.785	26540.205	4.988
	36357.359	35552.000	34993.754	33799.730	31286.568	29483.383	28483.852	27236.193	26516.002	4.987
	37142.301	36327.449	35732.387	34511.434	31702.258	29762.654	28721.055	27446.596	26648.688	5.377
	37227.273	36350.305	35736.332	34546.012	31656.203	29759.727	28696.770	27431.520	26682.268	5.382
	37919.387	37022.613	36377.934	35188.035	32029.971	29996.896	28942.250	27588.650	26790.316	5.657
	37841.602	37048.543	36400.781	35106.395	32072.928	30000.066	28889.496	27573.113	26760.979	5.663
	38401.953	37552.426	36888.234	35552.105	32299.369	30254.125	29076.990	27710.070	26888.563	5.888
	38385.195	37575.848	36910.188	35586.230	32327.213	30168.258	29076.709	27726.689	26893.518	5.897
	38979.594	38112.414	37401.457	36047.801	32622.340	30421.678	29241.229	27857.332	26977.613	6.159
	38780.711	38103.648	37371.406	36060.559	32637.957	30410.156	29251.918	27815.305	26987.381	6.164

Table 28 HGL Test for CMC 5%

		Axial distances	-5.050	-3.544	-2.542	-1.040	0.700	2.502	4.499	5.010	9.511	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
			ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
28/10/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	102.535	165.250	275.906	419.955	548.394	681.907	765.099	1084.386	0.894
Valve dimension[mm]:	100		0.000	102.477	167.267	275.362	420.517	557.267	676.241	755.895	1084.208	0.893
Valve position:	Open		0.000	118.339	191.556	310.531	485.369	619.811	787.789	853.818	1251.013	1.066
Pipe Diameter [mm]:	97.17		0.000	128.741	213.650	352.760	546.521	696.819	886.457	963.285	1396.475	1.210
Material Type:	CMC 5%		0.000	128.971	210.842	342.402	546.846	698.908	864.265	951.949	1377.450	1.208
Density[kg/m^3]:	1027		0.000	121.589	207.133	334.262	520.702	663.932	834.340	924.633	1312.828	1.150
τ_y:	0.000		0.000	142.086	229.381	375.404	584.728	749.985	954.723	1031.219	1497.783	1.296
K:	1.130		0.000	143.414	228.647	367.114	572.258	745.131	944.152	1041.763	1485.917	1.295
n:	0.784		0.000	142.261	234.860	391.406	616.330	797.442	992.111	1096.014	1587.266	1.407
			0.000	160.311	255.322	410.354	660.320	836.236	1047.745	1166.888	1663.756	1.489
			0.000	165.853	252.828	408.578	656.605	840.371	1037.124	1147.681	1661.142	1.488

Table 29 HGL Test for CMC 5%

		Axial distances	-5.050	-3.544	-2.542	-1.040	0.700	2.502	3.501	5.010	9.511	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
			ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
29/10/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	98.489	170.603	276.091	430.921	551.000	628.109	757.319	1109.421	0.906
Valve dimension[mm]:	100		0.000	134.929	170.664	281.391	429.507	555.619	624.457	758.485	1083.705	0.907
Valve position:	Open		0.000	126.688	191.298	307.182	486.504	620.677	715.396	873.426	1217.240	1.021
Pipe Diameter [mm]:	97.17		0.000	123.044	192.391	310.432	484.639	620.232	695.497	850.780	1227.846	1.022
Material Type:	CMC 5%		0.000	128.849	199.672	324.765	507.333	648.708	736.527	926.528	1284.225	1.082
Density[kg/m^3]:	1025		0.000	123.708	199.089	327.838	507.179	658.642	721.722	897.186	1274.813	1.081
τ_y:	0.000		0.000	137.103	229.148	365.454	555.907	731.012	808.365	995.505	1418.905	1.225
K:	1.130		0.000	139.557	222.908	353.996	554.164	712.984	807.179	1000.890	1443.822	1.224
n:	0.784		0.000	148.645	233.312	380.485	593.109	751.451	860.351	1046.648	1484.951	1.307
			0.000	158.048	231.350	368.004	579.896	742.546	843.747	1035.643	1487.777	1.279
			0.000	188.085	294.215	479.532	776.828	962.295	1095.550	1340.807	1937.244	1.766
			0.000	195.677	304.494	482.071	763.748	992.291	1098.561	1328.497	1931.379	1.764
			0.000	204.190	334.004	537.467	879.126	1105.383	1258.501	1517.005	2168.075	2.012
			0.000	202.689	329.470	535.158	875.185	1104.055	1235.718	1507.782	2172.986	2.011
			0.000	236.143	381.646	610.817	1028.317	1274.916	1433.380	1747.589	2524.356	2.376
			0.000	237.597	388.238	609.884	1024.949	1279.020	1422.933	1765.537	2516.700	2.398
			0.000	271.117	432.639	701.131	1217.100	1503.365	1689.248	2049.081	2951.815	2.912
			0.000	265.325	438.843	702.841	1218.713	1490.393	1685.360	2063.641	2917.908	2.913
			0.000	291.079	477.078	754.387	1363.955	1691.413	1897.108	2308.652	3244.860	3.310
			0.000	278.474	473.629	763.903	1363.058	1681.995	1873.825	2275.931	3221.728	3.314
			0.000	329.484	527.897	838.081	1578.903	1976.916	2205.958	2631.538	3721.350	3.827
			0.000	332.531	531.171	846.406	1601.568	1953.343	2198.468	2650.681	3727.784	3.827
			0.000	362.175	584.896	945.482	1829.970	2259.777	2513.863	3037.891	4271.024	4.235
			0.000	367.631	576.817	944.905	1830.072	2261.113	2526.994	3045.917	4253.732	4.237
			0.000	387.675	614.297	999.737	1944.804	2445.865	2711.832	3275.841	4570.851	4.556
			0.000	370.789	615.873	996.950	1938.448	2443.285	2712.990	3275.374	4564.630	4.567
			0.000	406.670	638.322	1032.802	2032.368	2574.109	2866.618	3449.408	4790.168	4.808
			0.000	371.088	638.375	1036.972	2034.954	2568.233	2861.415	3445.366	4790.384	4.800
			0.000	389.512	656.983	1070.949	2130.121	2722.267	3016.665	3630.063	5014.363	5.071
			0.000	420.647	650.961	1073.200	2145.352	2720.018	3023.776	3617.119	5018.768	5.067
			0.000	416.691	667.612	1090.093	2204.469	2804.788	3107.121	3714.316	5139.146	5.215
			0.000	427.543	670.670	1090.405	2195.655	2800.765	3104.359	3706.624	5145.146	5.201
			0.000	425.173	693.426	1123.104	2299.924	2938.461	3248.359	3903.363	5380.161	5.466
			0.000	434.208	687.021	1125.428	2297.009	2924.122	3253.068	3889.631	5364.341	5.455
			0.000	417.686	706.941	1149.422	2395.335	3061.396	3385.590	4043.592	5562.834	5.684
			0.000	410.723	708.197	1145.301	2394.229	3060.848	3372.094	4044.719	5560.375	5.668
			0.000	514.037	815.750	1329.617	3025.583	3847.391	4229.673	5038.436	6336.378	7.002
			0.000	444.338	753.773	1211.888	2642.435	3371.800	3685.494	4449.771	6065.713	6.225
			0.000	479.768	783.543	1299.527	2881.954	3645.342	4040.137	4795.899	6336.359	6.711
			0.000	276.499	469.154	745.474	1297.487	1613.284	1835.425	2206.917	3187.416	2.949
			0.000	356.762	594.415	964.502	1862.578	2275.586	2555.064	3062.461	4321.327	4.178
			0.000	104.999	166.437	275.096	426.224	549.702	623.952	767.494	1122.640	0.855
			0.000	98.240	160.174	264.386	413.171	534.466	604.397	741.671	1079.605	0.836
			0.000	76.405	134.362	223.790	347.080	447.287	513.157	621.986	916.427	0.694
			0.000	86.813	132.580	217.908	336.933	440.295	501.585	618.268	897.936	0.705
			0.000	69.658	105.126	181.150	279.882	360.921	412.109	500.909	737.976	0.593
			0.000	76.770	109.855	184.962	283.918	365.994	415.583	507.330	744.860	0.595
			0.000	58.784	89.297	153.111	237.476	311.189	348.609	428.140	632.366	0.504
			0.000	64.691	90.216	157.185	233.398	307.304	347.476	423.541	607.599	0.521
			0.000	56.607	73.229	128.033	194.719	274.612	294.129	349.204	524.867	0.442
			0.000	64.306	69.630	118.231	181.953	240.836	272.176	332.102	482.816	0.374
			0.000	54.244	65.395	115.636	170.626	221.537	255.760	311.076	451.527	0.397
			0.000	44.786	35.776	73.084	94.086	130.306	150.434	182.380	258.490	0.281
			0.000	40.189	40.658	66.602	93.736	125.674	154.281	175.745	254.765	0.277

Table 30 HGL Test for CMC 8%

		Axial distances	-6.298	-4.568	-1.880	-0.621	1.076	2.685	6.046	8.075	9.975	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
			ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
5/11/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	8924.903	23055.250	29874.957	41359.867	49256.215	66567.391	77040.828	86878.234	0.533
Valve dimension[mm]:	40		0.000	9482.671	23168.468	29725.975	41198.242	49378.445	66675.938	76555.172	86308.023	0.535
Valve position:	Open		0.000	9570.536	23455.355	30031.564	41650.379	49885.871	67319.375	77929.445	87870.156	0.552
Pipe Diameter [mm]:	42.12		0.000	9490.130	23279.416	30224.139	41952.652	49908.977	67397.133	78118.359	87815.875	0.554
Material Type:	CMC 8%		0.000	10604.855	25321.201	32567.010	45130.598	53746.855	72998.242	84485.258	94737.977	0.633
Density[kg/m³]:	1040		0.000	10220.763	25205.965	32499.236	44582.301	54250.262	72705.586	84468.742	94361.359	0.635
τ_y:	0.000		0.000	10456.512	25933.129	33461.770	45570.895	55829.961	74341.273	86066.773	97018.086	0.665
K:	5.252		0.000	10207.088	25075.070	33357.727	46123.723	54799.730	74437.258	85802.656	97307.750	0.668
n:	0.799		0.000	10949.592	27296.820	34913.734	48344.965	57579.809	78059.000	90401.525	100888.844	0.732
			0.000	10779.941	26731.486	34381.125	47940.887	58168.313	77976.297	89553.633	102271.844	0.733
			0.000	11581.232	28995.340	37268.910	52225.652	62570.863	84766.313	97959.547	109795.250	0.840
			0.000	12150.376	28706.217	37261.996	52310.469	62732.773	84362.719	97417.078	109618.008	0.841
			0.000	12327.234	29750.031	38234.266	54007.410	64964.129	87321.578	100552.641	113529.883	0.971
			0.000	12493.315	29673.580	38221.445	54200.406	64895.371	87236.680	100891.438	113061.172	0.972
			0.000	12313.487	30538.561	39289.895	55756.219	67083.172	90088.898	103654.641	116928.828	1.024
			0.000	12099.822	30550.258	39284.180	55624.840	66990.961	89756.820	103630.375	116764.250	1.027
			0.000	12913.728	31973.793	41085.762	58823.016	70313.094	94553.133	108799.797	122920.008	1.114
			0.000	12398.740	32451.123	41662.387	58717.813	70161.711	94447.109	108832.336	122008.063	1.164
			0.000	12455.340	32260.346	41562.410	60898.715	72568.329	97402.102	112556.773	126356.477	1.247
			0.000	12466.927	32338.922	41580.035	61055.574	72887.750	97669.250	112257.555	126514.414	1.251
			0.000	13288.417	34187.316	44056.461	65449.652	77822.586	104393.578	120290.133	134923.969	1.391
			0.000	13283.230	34105.207	44105.898	65492.117	77756.984	104295.359	119999.578	135163.156	1.393
			0.000	13477.780	34933.910	45097.570	67015.914	80087.359	107196.570	123451.672	138398.656	1.452
			0.000	13369.990	34661.414	45019.791	66996.758	79876.234	107141.281	123298.570	138260.703	1.449

Table 31 HGL Test for CMC 8%

		Axial distances	-6.298	-4.568	-1.880	-0.621	1.076	2.685	6.046	8.075	9.975	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
			ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
12/11/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	9052.295	24980.283	31600.000	42948.566	51672.480	69691.523	80269.336	90778.977	0.663
Valve dimension[mm]:	40		0.000	8201.023	24830.242	32000.000	42384.992	51057.902	69341.594	80367.734	90599.813	0.669
Valve position:	Open		0.000	8158.912	21759.227	28751.963	39252.902	46759.352	63785.363	73545.688	82664.234	0.584
Pipe Diameter [mm]:	42.12		0.000	8655.667	21450.564	28323.252	39229.941	46507.953	63475.523	73223.578	82826.367	0.586
Material Type:	CMC 8%		0.000	8482.380	20032.082	26954.879	36393.762	43583.609	58943.707	68070.055	76752.164	0.516
Density[kg/m³]:	1040		0.000	8077.688	19849.189	25723.986	36414.887	43545.695	58835.602	68066.977	76880.156	0.516
τ_y:	0.000		0.000	7578.319	18401.211	23536.119	33054.254	39357.168	52956.484	61729.863	69630.469	0.439
K:	5.908		0.000	7737.510	18213.965	23924.770	32240.732	39501.984	53383.898	62048.145	69393.633	0.441
n:	0.799		0.000	6968.901	17555.828	21005.813	29475.494	35418.406	48397.867	56032.586	62956.969	0.374
			0.000	6854.186	17536.330	21628.547	30163.764	35741.629	48112.051	55956.465	62762.914	0.374
			0.000	5869.261	15557.994	19238.074	26598.789	32236.182	43833.121	50666.176	57179.742	0.319
			0.000	5843.367	14810.656	19563.098	27059.549	32451.623	43919.504	50720.766	57071.578	0.319
			0.000	5002.443	12881.254	16476.469	22544.160	27045.561	36808.621	42405.176	47994.938	0.239
			0.000	5077.586	12917.047	16477.355	22547.377	27060.010	36694.254	42464.492	48123.613	0.240
			0.000	4480.250	10938.357	14019.441	19253.334	23198.408	31314.383	36231.039	40921.734	0.182
			0.000	4532.675	10827.637	14036.925	19233.057	23122.133	31355.932	36245.035	40883.926	0.183
			0.000	3265.865	7755.351	9924.280	13590.688	16353.843	22097.002	25528.969	28769.244	0.103
			0.000	3291.164	7769.907	9958.375	13585.854	16341.796	22097.248	25616.447	28804.963	0.104
			0.000	2314.849	5142.093	6478.434	8858.673	10648.303	14361.526	16602.979	18694.791	0.054
			0.000	2248.228	5133.373	6506.737	8845.138	10646.116	14371.770	16632.799	18718.678	0.053

Table 32 HGL Test for CMC 8%

8/11/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	50
Valve position:	Open
Pipe Diameter [mm]:	52.8
Material Type:	CMC 8%
Density[kg/m³]:	1037.5
τ_y:	0.000
K:	5.252
n:	0.799

Axial distances	-6.574	-3.526	-2.281	-1.031	1.257	3.012	5.666	7.666	9.669	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	0.000	20605.293	27726.764	37637.359	52186.258	63573.742	82219.867	95354.914	108365.445	2.390
	0.000	5476.409	7609.682	10535.610	13822.907	17113.934	22015.395	25724.490	29225.084	0.259
	0.000	6062.583	8382.579	11584.163	15254.948	18847.945	24453.424	28299.582	32114.061	0.307
	0.000	6087.419	8387.658	11641.576	15248.552	18788.592	24250.145	28224.643	32009.867	0.307
	0.000	7750.865	10465.762	14928.514	19207.941	23577.096	30504.686	35466.457	40308.988	0.453
	0.000	7739.520	10460.180	14889.371	19218.082	23636.656	30310.809	35492.633	40172.762	0.452
	0.000	8258.329	11190.489	15779.969	20493.475	25216.984	32563.188	37721.398	42786.762	0.504
	0.000	8166.892	11142.940	15830.169	20475.070	25144.803	32405.037	37867.988	42868.863	0.504
	0.000	8846.511	11699.691	16641.416	21517.723	26418.408	34387.840	39748.188	45074.387	0.552
	0.000	8852.911	11722.693	16634.602	21524.260	26470.090	34297.262	39834.559	45040.863	0.551
	0.000	9579.515	12316.499	17383.531	22746.557	27884.262	36417.711	41861.254	47592.754	0.604
	0.000	9801.194	12362.030	17408.719	22756.736	27898.066	36326.566	41909.543	47509.414	0.603
	0.000	10723.841	13665.977	19113.400	25218.398	30902.807	40852.734	46429.176	52695.066	0.721
	0.000	10314.030	13634.922	19073.271	25194.098	30924.711	40710.105	46384.023	52683.477	0.722
	0.000	11645.781	14645.813	20448.436	27178.039	33196.836	43968.184	49842.172	56632.977	0.817
	0.000	10779.481	14636.629	20467.826	27126.143	33162.566	43718.625	49845.563	56559.133	0.819
	0.000	12235.168	15610.143	21828.615	29101.721	35364.922	46900.250	53041.746	60474.563	0.917
	0.000	12403.229	15617.632	21830.561	28904.412	35413.633	46646.863	53154.961	60394.855	0.917
	0.000	11841.747	16668.518	22960.084	31691.170	37830.285	48719.992	56662.750	64508.574	1.036
	0.000	12037.824	16655.480	22981.881	31667.813	37854.941	48596.273	56861.508	64525.488	1.038
	0.000	12303.140	17319.553	23861.529	32808.148	39325.547	50681.016	59162.355	66970.156	1.116
	0.000	12362.598	17290.900	23828.494	32763.152	39365.332	50582.727	59141.910	67189.406	1.117
	0.000	12897.330	18141.156	24884.223	34393.703	41368.133	53308.395	61950.453	70363.438	1.219
	0.000	12981.381	18163.336	24943.082	34402.758	41294.582	53265.023	62000.055	70295.227	1.221
	0.000	12951.105	18029.338	24562.725	34080.379	41085.086	53282.219	61631.328	70048.969	1.297
	0.000	12872.146	18105.861	24663.869	34131.637	41089.469	53360.855	61663.898	70116.281	1.298
	0.000	13432.384	18872.563	25799.879	35683.516	42956.762	55739.543	64444.793	73046.906	1.403
	0.000	13375.255	18777.922	25719.184	35468.750	42758.633	55542.441	64203.445	73064.703	1.398
	0.000	14184.034	19613.869	26944.098	37174.840	44775.543	58012.195	67182.945	76267.391	1.514
	0.000	14049.575	19601.930	26856.135	37110.398	44698.992	58060.039	67047.703	76159.875	1.514
	0.000	14827.614	20413.848	27950.143	38609.215	46616.348	60406.105	69920.164	79317.266	1.622
	0.000	14824.115	20460.701	27976.959	38493.223	46639.277	60530.449	70018.664	79618.969	1.620
	0.000	15548.244	21009.557	28750.801	39734.895	48058.637	62351.586	72106.508	81930.203	1.706
	0.000	15732.734	21076.469	28878.445	39686.070	48122.711	62295.797	72083.906	81903.719	1.703
	0.000	15833.845	21746.443	29943.914	41301.188	49658.852	64705.977	74540.945	84854.500	1.810
	0.000	15872.385	21871.076	29930.949	41068.758	49651.293	64520.977	74747.516	84834.148	1.806
	0.000	16321.656	22494.025	30740.934	42380.375	51188.648	66642.141	76831.188	87464.859	1.898
	0.000	16676.215	22426.299	30633.639	42447.316	51233.586	66472.063	77032.547	87457.063	1.896
	0.000	16971.104	23504.074	32090.949	44413.461	53653.555	69642.984	80428.695	91282.703	2.046
	0.000	18207.814	23405.086	32025.877	44347.293	53605.012	69639.484	80508.313	91473.383	2.046
	0.000	17427.197	24016.863	32810.879	45344.410	54914.609	71208.219	82357.609	93517.633	2.128
	0.000	17677.922	23916.881	32636.348	45147.340	54683.316	71053.336	82187.297	93234.422	2.125
	0.000	18620.182	24927.992	33998.332	47090.379	57163.922	74134.945	85754.672	97369.195	2.282
	0.000	18225.840	24957.273	34034.406	47148.320	57089.988	74027.625	85649.258	97225.734	2.285
	0.000	18814.555	24803.105	33844.617	46837.926	56728.043	73667.336	85230.961	96723.391	2.272
	0.000	19343.225	25606.943	34961.043	48343.730	58628.402	76009.242	87827.117	99803.477	2.404
	0.000	19434.539	25579.604	34864.035	48178.648	58584.625	75998.156	87904.461	99809.648	2.403
	0.000	19567.836	26225.158	35718.453	49406.738	59921.434	77856.922	89902.461	102172.672	2.514
	0.000	20674.822	25945.322	35699.195	49269.953	59899.449	77925.539	89918.500	102238.445	2.513
	0.000	20003.150	26660.127	36286.777	50412.160	61233.434	79573.188	91769.375	104217.891	2.612
	0.000	19853.678	26691.109	36363.934	50384.605	61229.328	79371.594	91709.031	104155.273	2.610
	0.000	20261.543	27301.232	37276.297	51626.652	62781.785	81249.211	94259.555	106814.188	2.731
	0.000	20747.768	27357.330	37120.359	51512.465	62590.328	81232.789	94518.906	106533.813	2.731
	0.000	20318.457	27620.709	37659.582	52073.910	63398.156	82289.672	95069.492	107855.930	2.793
	0.000	21725.848	27581.635	37532.887	52181.031	63503.715	82266.609	95178.336	108258.445	2.795
	0.000	21035.102	28336.930	38555.695	53398.770	64946.855	84211.586	97396.008	110716.898	2.919
	0.000	20414.979	28245.002	38499.309	53363.352	65214.105	84299.695	97365.281	110618.695	2.923
	0.000	21677.025	28943.834	39420.121	54675.504	66465.070	86229.805	99528.352	113308.531	3.049
	0.000	22046.338	28942.564	39297.883	54634.949	66466.172	86200.539	99624.773	113142.078	3.047
	0.000	20978.328	29526.016	40248.969	55919.332	68134.695	88302.422	102095.813	116025.242	3.173
	0.000	21093.182	29539.479	40204.906	55864.496	68141.797	88394.641	102209.148	116143.125	3.167
	0.000	21286.496	29936.219	40866.746	56823.680	69313.664	89739.922	103745.727	118038.422	3.208
	0.000	21440.146	30038.244	40985.426	56715.105	69162.406	89662.367	103890.953	117842.563	3.192

Table 33 HGL Test for CMC 8%

		Axial distances	-6.974	-3.865	-2.885	-0.937	0.987	2.938	6.427	8.432	10.433	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
			ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
9/11/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		0.000	7652.967	9658.114	14524.323	18977.877	23460.123	30436.504	34720.316	39494.379	0.800
Valve dimension[mm]:	65		0.000	7334.447	9537.080	14470.827	18975.234	23254.727	30302.996	34636.758	39512.758	0.800
Valve position:	Open		0.000	7999.683	9989.782	15385.593	20141.250	25158.373	32335.600	37535.641	42167.617	0.926
Pipe Diameter (mm):	*63.08*		*0.000*	*7554.899*	*10191.791*	14674.006	20296.627	24941.949	32178.883	37374.191	42128.699	0.928
Material Type:	CMC 8%		0.000	8554.097	10965.667	16258.208	23240.588	27751.104	35245.375	40354.023	46114.117	1.053
Density[kg/m^3]:	1037.5		0.000	8480.470	11530.149	16882.217	23588.758	28637.742	36716.625	42253.332	47907.508	1.071
τ_y:	0.000		0.000	8716.008	11308.776	16326.356	22568.010	28542.291	30742.838	42151.871	48046.617	1.183
K:	5.252		0.000	9069.192	10996.116	16304.350	22875.473	28383.910	36725.102	42230.520	47592.648	1.183
n:	0.790		0.000	10302.869	12800.000	18500.000	25844.422	31172.434	39910.863	45800.637	51691.586	1.334
			0.000	9649.424	12118.228	18930.609	25005.656	30451.832	39203.660	45256.434	51676.246	1.335
			0.000	9923.541	13543.530	18922.203	24654.730	31296.611	40035.152	46261.109	52568.906	1.433
			0.000	10377.018	11643.161	17445.184	24966.225	30924.043	40450.090	46472.453	52343.121	1.431
			0.000	10482.264	14050.884	20950.098	28331.029	33834.449	42969.801	49677.223	55993.480	1.587
			0.000	10882.395	14562.153	20832.029	28153.041	33702.203	43219.363	49578.090	56206.727	1.587
			0.000	10633.650	13799.799	20641.217	27731.215	34735.012	44294.945	50769.398	57566.020	1.681
			0.000	10709.887	14044.871	21023.691	28205.152	34126.305	44091.012	51244.250	57840.707	1.682
			0.000	10612.736	13703.315	19656.645	28510.420	35836.949	45004.480	52289.805	59528.141	1.770
			0.000	10873.777	13670.957	21276.215	28588.816	35635.574	45654.559	53134.266	59619.902	1.773
			0.000	11293.798	14404.271	21935.100	28764.152	36464.449	46891.402	54244.254	61324.148	1.873
			0.000	*11073.453*	*14400.070*	*22000.520*	*30023.205*	*36546.520*	*47565.445*	*54503.602*	*61205.977*	*1.876*
			0.000	10704.304	13366.499	22839.012	29361.385	36008.113	46577.137	53785.086	60720.176	2.037
			0.000	12009.379	15177.537	21999.330	30750.297	37469.418	47990.563	54998.559	63198.977	2.172
			0.000	13121.910	15509.029	22780.293	30678.184	36928.672	48631.801	56122.863	63616.348	2.258
			0.000	11611.120	16633.146	21985.963	29962.012	38368.137	48707.277	56183.008	63726.781	2.258
			0.000	11947.200	15696.167	22514.449	31341.197	38083.137	49452.813	57102.594	65079.789	2.350
			0.000	12206.868	16612.311	21145.607	30649.428	39218.660	49839.938	57036.672	64885.590	2.349
			0.000	12320.313	16411.256	25053.162	33506.109	40497.426	52216.676	60043.555	68117.633	2.537
			0.000	12226.973	15848.758	24459.395	32970.344	40503.043	52243.840	60202.750	68253.336	2.540
			0.000	12991.690	17284.611	24799.008	34709.711	42650.820	54642.125	63047.480	71004.898	2.764
			0.000	13506.683	16960.684	24746.088	34422.031	42745.602	54137.414	63442.879	70874.109	2.766
			0.000	*14306.660*	*17510.041*	*25866.930*	*35948.406*	*43040.133*	*56491.230*	*65047.754*	*73402.758*	*2.936*
			0.000	14117.474	17292.063	26581.164	35754.305	44391.598	56864.270	64534.074	73223.859	2.930
			0.000	14241.090	17512.412	27360.086	36945.164	45468.277	58917.844	67699.453	76938.906	3.129
			0.000	13531.299	18515.959	26911.309	37908.328	46677.965	59521.680	67898.148	77360.773	3.120
			0.000	14406.320	19065.137	27335.285	37630.191	45536.055	59138.082	67842.781	77430.414	3.118
			0.000	14253.241	18893.799	27957.029	39255.379	48424.215	62660.918	71502.602	81268.789	3.356
			0.000	14148.417	19377.164	27990.107	38458.656	48308.438	62475.871	71600.828	81149.797	3.350
			0.000	16027.370	19977.006	29092.256	40267.867	49269.953	63806.082	74124.703	82914.594	3.541
			0.000	15724.432	20183.754	27218.848	40896.633	49700.426	64009.406	73770.773	83226.633	3.533
			0.000	17096.170	20500.973	31060.021	41427.418	51652.328	65594.961	75572.688	85595.141	3.725
			0.000	15448.370	20086.525	31409.664	41455.480	50783.074	65696.742	75561.906	86274.492	3.733
			0.000	16426.090	21716.408	32095.434	42264.281	53019.691	69373.180	78495.422	89550.344	3.980
			0.000	16597.477	20479.061	30532.143	43398.092	53270.180	69400.000	78505.445	89411.789	3.985
			0.000	17092.883	22422.133	32379.092	44124.164	54663.105	70746.031	80095.633	91709.414	4.164
			0.000	17023.037	20837.117	31769.021	43995.656	54800.438	69480.711	80623.414	91054.844	4.162
			0.000	17605.258	21855.779	33847.348	45999.613	55766.285	72148.531	82637.844	94481.180	4.387
			0.000	17421.623	22343.391	33166.203	45887.340	56353.016	72337.070	82800.953	94309.789	4.400
			0.000	18189.590	23368.307	34217.840	46385.895	58210.840	73972.477	85392.352	97060.586	4.648
			0.000	17711.205	23274.260	34046.738	46480.973	57400.520	73280.180	85678.273	97133.484	4.641
			0.000	17957.908	23876.223	36049.344	47673.027	59384.500	75782.398	88017.414	99651.109	4.892
			0.000	18273.143	23986.270	35377.320	47969.539	58898.277	75807.977	87789.602	99463.445	4.895
			0.000	18506.135	24279.254	36306.750	49157.426	61472.008	78067.258	89426.000	101419.531	5.043
			0.000	18585.344	24593.635	35691.215	48054.117	60926.770	77002.109	90320.789	101743.781	5.042
			0.000	18893.369	25474.457	36322.184	49450.938	62385.492	80218.719	91573.664	102871.063	5.261
			0.000	19407.264	24765.383	37001.273	49993.332	62375.609	79264.523	91902.977	102737.609	5.272
			0.000	19244.113	24530.236	37074.371	51096.965	63546.219	81788.125	93474.195	105603.219	5.485
			0.000	19583.662	25633.750	37689.930	52136.297	62617.363	80133.117	93479.328	105025.414	5.483

Table 34 HGL Test for CMC 8%

10/11/2004	
Valve Type:	Diaphragm
Valve diame	80
Valve positio	Open
Pipe Diamete	80.43
Material Typ	CM 8%
Density(kg/m	1044
τ_y:	0.000
K:	7.400
n:	0.790

Axial distance	-6.413	-4.809	-3.610	-1.209	0.707	3.907	5.977	8.461	9.956	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	(l/s)
	0.000	1047.862	1626.475	2769.068	3860.231	5286.199	6426.680	7585.735	8385.050	0.169
	0.000	1068.208	1617.539	2942.654	4034.258	5585.365	6682.142	7832.224	8509.299	0.164
	0.000	1178.998	1886.460	3313.521	4711.050	6642.854	7865.220	9365.738	10243.511	0.227
	0.000	1249.372	1876.040	3320.519	4695.085	6623.360	7876.385	9380.537	10235.101	0.224
	0.000	1374.822	2268.823	4005.717	5729.082	8070.482	9562.445	11388.370	12479.892	0.322
	0.000	1420.652	2262.746	4015.040	5726.396	8065.076	9580.535	11371.902	12504.339	0.322
	0.000	1538.789	2635.387	4600.217	6593.786	9403.078	11065.926	13244.828	14489.451	0.422
	0.000	1710.031	2568.654	4586.021	6673.590	9327.552	11140.186	13246.342	14603.061	0.430
	0.000	1721.615	2811.570	5080.268	7303.604	10303.747	12245.769	14566.113	15984.414	0.502
	0.000	1740.837	2837.649	5062.040	7266.897	10278.455	12194.437	14513.051	15940.395	0.503
	0.000	2101.959	3359.980	6024.638	8514.528	12237.746	14444.657	17251.121	18920.154	0.676
	0.000	2038.833	3349.483	5959.985	8607.232	12234.040	14484.682	17194.736	18881.932	0.676
	0.000	2116.412	3449.081	6188.705	8965.818	12756.475	15108.545	17945.783	19711.936	0.715
	0.000	2070.344	3420.463	6135.747	8878.275	12641.909	14970.629	17908.936	19656.963	0.727
	0.000	2251.861	3643.278	6726.898	9598.975	13511.379	16025.325	19084.746	20914.279	0.818
	0.000	2274.609	3729.160	6633.811	9456.010	13375.826	16014.229	19047.227	20883.289	0.801
	0.000	1013.481	1399.838	2372.615	3329.808	4654.527	5496.475	6508.606	7130.171	0.120
	0.000	1016.489	1374.577	2379.011	3316.487	4650.989	5497.500	6510.014	7129.680	0.116
	0.000	716.512	956.394	1579.912	2156.936	2996.410	3531.429	4164.516	4531.938	0.058
	0.000	794.237	953.815	1578.254	2160.504	2996.943	3525.701	4164.692	4544.086	0.047
	0.000	2271.613	3624.700	6544.606	9355.809	13303.013	15811.449	18954.656	20706.652	0.792
	0.000	2237.128	3675.465	6568.594	9431.239	13361.691	15882.207	18954.814	20792.182	0.792
	0.000	2623.485	4265.940	7659.608	11025.333	15606.785	18539.221	22070.402	24215.166	1.007
	0.000	2550.495	4235.101	7623.009	10989.900	15562.379	18475.686	22024.791	24139.105	1.004
	0.000	2917.204	4733.974	8576.500	12325.009	17498.027	20837.082	24805.504	27177.230	1.252
	0.000	2950.234	4724.720	8583.421	12348.433	17365.445	20799.426	24806.498	27106.000	1.250
	0.000	2972.706	4972.938	8948.403	12965.056	18424.318	21950.389	26057.309	28593.018	1.404
	0.000	3074.100	4939.417	8991.191	12967.669	18373.510	21864.934	26036.506	28591.260	1.407
	0.000	3184.357	5228.754	9581.311	13923.415	19658.486	23322.063	27861.111	30584.561	1.567
	0.000	3098.371	5248.790	9591.523	13776.099	19610.082	23240.484	27674.131	30490.875	1.571
	0.000	3419.327	5707.703	10169.749	14830.864	21085.305	24994.303	29775.754	32693.406	1.789
	0.000	3417.071	5625.183	10282.230	14784.650	21006.238	25008.402	29774.648	32748.564	1.788
	0.000	3573.749	5946.844	10708.682	15414.990	21904.080	26036.781	31089.127	34012.391	1.939
	0.000	3673.696	5735.543	10671.446	15378.813	21850.020	26113.916	30863.979	33975.902	1.940
	0.000	3639.323	6086.007	11293.195	16348.937	23161.418	27474.268	32777.738	35966.309	2.160
	0.000	3759.225	6202.629	11237.766	16337.311	23094.830	27379.215	32704.150	35858.633	2.159
	0.000	3686.591	6363.262	11570.282	16816.648	23952.004	28228.293	33702.703	36839.246	2.281
	0.000	3728.983	6364.993	11510.363	16779.059	23788.434	28303.504	33628.867	36920.020	2.275
	0.000	3943.182	6492.917	11737.525	17327.748	24451.375	29076.064	34781.074	38051.516	2.430
	0.000	4012.182	6468.546	11851.251	17427.619	24526.199	29217.457	34659.480	38102.496	2.427
	0.000	3929.895	6619.219	12073.894	17706.713	24895.068	29763.072	35277.273	38948.625	2.520
	0.000	3985.565	6628.973	12150.806	17663.158	25014.930	29605.053	35419.965	38777.090	2.515
	0.000	4563.304	7030.408	12671.867	18664.266	26373.365	31235.561	37181.793	40723.082	2.758
	0.000	4238.918	6901.144	12708.362	18399.059	26156.236	31245.740	37086.578	40832.516	2.762
	0.000	4342.327	7194.368	13200.452	19343.320	27355.389	32536.691	38794.172	42558.184	3.045
	0.000	4351.051	7187.335	13193.914	19430.902	27475.152	32591.242	38862.504	42553.352	3.045
	0.000	4283.712	7412.732	13548.545	19949.527	28103.295	33514.164	39941.883	43723.359	3.198
	0.000	4279.972	7417.152	13589.030	19920.410	28036.137	33489.855	39891.473	44002.309	3.195
	0.000	4482.613	7545.146	13717.842	20184.355	28436.297	33930.082	40568.477	44351.496	3.276
	0.000	4444.676	7523.841	13743.379	20318.285	28693.463	33993.359	40478.176	44337.441	3.278
	0.000	4517.164	7639.715	14317.330	20819.637	29130.229	34895.932	41611.941	45661.625	3.455
	0.000	4628.625	7819.689	14172.167	20880.887	29489.275	34958.746	41686.805	45567.762	3.465
	0.000	4639.333	7927.540	14557.664	21457.627	30345.814	36064.563	42855.578	47010.820	3.645
	0.000	4682.432	7870.311	14457.690	21589.977	30236.510	36129.254	42837.777	47076.957	3.634
	0.000	4889.002	8267.971	14902.830	22307.350	31515.502	37344.730	44486.383	48774.949	3.884
	0.000	4981.142	8233.355	15043.961	22623.324	31460.861	37604.508	44510.793	48798.805	3.894
	0.000	5133.618	8402.855	15403.714	23000.818	32383.929	38416.949	45799.125	50273.852	4.113
	0.000	5274.757	8380.350	15533.089	23068.824	32450.525	38469.105	45844.316	50320.914	4.094
	0.000	5308.002	8778.892	16080.226	24122.746	33745.949	40092.352	47837.469	52371.988	4.414
	0.000	5832.593	8824.753	15946.150	24080.738	33895.500	40149.902	47772.574	52424.551	4.416
	0.000	6139.952	9085.050	16485.861	25052.629	35219.047	41846.734	49692.555	54250.969	4.690
	0.000	5191.660	9109.919	16455.625	25031.854	35064.273	41657.770	49451.469	54296.043	4.752
	0.000	5423.738	9049.582	16810.961	25418.463	35548.664	42341.086	50275.227	55350.074	4.905
	0.000	5317.287	9200.467	16852.967	25579.633	35822.707	42194.047	50289.781	55106.555	4.883
	0.000	5497.994	9412.302	17455.428	26381.311	36559.801	43782.047	52213.324	57012.707	5.188
	0.000	5596.741	9331.749	17327.891	26216.043	36846.070	43888.441	51985.527	57177.164	5.201
	0.000	5702.578	9634.096	17841.992	27539.426	37950.055	45171.973	53459.754	58643.164	5.451
	0.000	5561.869	9786.507	17959.109	27270.535	38008.266	44994.891	53292.570	58697.746	5.450
	0.000	5528.170	9563.508	18226.998	27811.590	38716.398	45777.602	54479.086	59873.809	5.661
	0.000	5676.476	9674.475	18089.646	27969.441	38710.301	45979.645	54470.773	59636.676	5.643

Table 35 HGL Test for CMC 8%

		Axial distances	-5.050	-3.544	-2.542	-1.040	0.700	2.502	3.501	5.010	9.511	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
11/11/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		69481.531	66460.930	64388.535	61284.051	56806.621	53075.520	51034.984	46640.152	36419.172	5.788
Valve dimension[mm]:	100		69420.781	66297.664	64194.289	61138.926	56549.098	52891.461	50860.023	46684.281	36354.047	5.807
Valve position:	Open		29026.340	28800.000	28659.557	28415.795	28084.693	27795.838	27625.549	27290.426	26490.412	0.051
Pipe Diameter [mm]:	97.17		29029.117	28783.010	28669.715	28428.803	28092.932	27802.188	27630.512	27289.826	26489.803	0.046
Material Type:	CM 8%		30638.344	30330.000	30127.967	29784.500	29294.193	28864.998	28617.238	28143.156	27007.697	0.089
Density[kg/m³]:	1040		30657.197	30292.623	30135.668	29784.184	29311.135	28878.254	28666.656	28155.461	27014.326	0.104
τ_y:	0.000		32210.004	31765.779	31550.861	31125.219	30488.301	29955.506	29651.254	29004.352	27509.414	0.174
K:	6.434		33835.301	33230.992	33014.609	32492.398	31727.070	31049.648	30674.131	29905.742	28081.023	0.256
n:	0.503		33867.316	33265.363	33010.582	32460.498	31679.977	31001.887	30630.678	29865.031	28006.662	0.252
			35615.133	35006.480	34561.344	33889.617	32965.387	32159.521	31721.262	30802.855	28557.277	0.368
			35605.719	34884.848	34506.602	33845.074	32925.953	32119.443	31673.984	30763.189	28548.902	0.364
			36562.625	35788.172	35371.305	34636.234	33625.727	32750.563	32263.795	31250.951	28826.037	0.428
			36650.426	35849.977	35443.488	34683.039	33672.320	32787.820	32290.852	31268.637	28831.773	0.422
			38049.645	37196.727	36709.738	35870.734	34716.906	33716.906	33156.918	32019.273	29267.791	0.527
			38011.105	37286.977	36693.438	35873.188	34749.914	33765.105	33221.871	32069.932	29301.721	0.532
			39229.883	38413.395	37785.598	36841.359	35605.758	34496.715	33887.094	32626.514	29627.797	0.621
			39137.559	38304.020	37728.516	36817.219	35566.434	34505.516	33872.770	32634.002	29640.596	0.618
			40118.457	39120.633	38599.305	37597.086	36268.883	35092.430	34451.473	33165.977	29947.631	0.693
			40197.938	39213.242	38676.863	37684.859	36327.551	35176.020	34501.203	33165.906	29944.994	0.693
			41497.953	40430.055	39724.289	38683.531	37227.387	35974.820	35282.152	33825.715	30363.533	0.784
			41514.133	40430.262	39743.965	38705.746	37251.234	35983.063	35277.477	33831.633	30362.607	0.800
			41934.176	40853.906	40145.152	39117.773	37631.055	36319.930	35603.828	34110.895	30523.906	0.847
			42013.574	40799.613	40206.570	39144.332	37648.531	36313.914	35589.461	34073.605	30478.039	0.850
			42472.066	41347.949	40686.391	39508.969	37935.461	36620.508	35910.480	34339.395	30642.869	0.902
			42417.070	41218.363	40640.828	39588.293	38034.273	36693.625	35939.645	34415.887	30696.654	0.903
			45031.996	43687.352	42847.344	41608.070	39821.859	38269.023	37433.402	35669.457	31431.973	1.162
			45010.395	43681.723	42851.832	41575.852	39817.691	38282.379	37367.262	35655.801	31422.740	1.157
			46196.578	44780.816	43983.160	42607.824	40717.941	39108.723	38863.305	36316.359	31792.729	1.316
			46206.422	44816.859	43913.461	42579.168	40704.313	39046.688	38112.309	36162.008	31805.311	1.315
			47497.051	46017.262	45105.320	43632.547	41680.297	39932.551	38922.195	36968.465	32189.285	1.445
			47490.609	46034.559	45112.621	43638.121	41651.523	39908.414	38953.934	36953.824	32191.248	1.448
			48842.832	47342.230	46334.535	44782.953	42663.402	40816.973	39780.543	37686.109	32605.336	1.611
			48805.621	47211.051	46286.273	44762.668	42618.152	40815.508	39787.961	37668.461	32605.693	1.611
			46974.879	45420.727	44324.887	42578.090	40136.273	38299.500	37185.398	35071.965	29585.873	1.860
			47064.648	45485.691	44321.602	42663.465	40425.695	38318.168	37286.520	35048.395	29577.777	1.864
			47969.566	46340.313	45218.328	43474.285	41084.730	38965.230	37856.031	35467.797	29793.525	2.056
			47915.918	46272.121	45136.230	43437.313	41017.953	38922.203	37834.004	35445.914	29723.045	2.057
			48513.445	46671.621	45727.809	43851.516	41389.227	39383.703	38189.953	35814.477	29919.963	2.223
			49028.313	47402.875	46265.234	44458.984	41961.129	39750.313	38542.043	36075.672	30155.637	2.339
			50705.594	48967.145	47818.984	45959.406	43208.949	40859.852	39590.508	36972.074	30714.234	2.572
			52180.914	50456.340	49043.895	47052.426	44351.645	41937.707	40513.605	37794.656	31170.000	2.863
			52679.711	50836.711	49592.840	47538.367	44702.961	42214.051	40938.707	38019.484	31275.439	2.965
			53311.777	51502.398	50127.027	47938.164	44948.219	42627.965	41165.789	38220.754	31573.211	3.082
			53552.551	51356.598	49878.668	48062.500	45083.500	42552.742	41213.633	38367.480	31354.439	3.082
			54273.031	51906.723	50685.957	48670.051	45793.895	43174.199	41772.375	38378.500	31679.084	3.249
			54374.246	51929.633	50728.836	48571.949	45729.164	43183.145	41704.324	38614.520	31846.422	3.249
			54958.402	52776.820	51527.246	49281.234	45773.332	43585.324	42240.066	39221.250	31832.156	3.410
			54933.066	52784.977	51317.891	49364.016	46185.641	43466.191	42148.027	39286.352	31983.348	3.402
			55232.895	53012.059	51592.418	49346.270	46115.371	43763.496	42382.383	39281.008	32029.258	3.472
			55289.184	52943.586	51689.551	49505.082	46195.789	43899.168	42059.410	39301.465	32110.680	3.469
			55296.961	53490.816	51803.617	49699.012	46269.695	43950.035	42486.293	39257.844	32094.357	3.521
			55502.781	53351.035	51892.809	49624.996	46630.344	43836.535	42489.227	39254.414	32133.393	3.523
			55947.816	53697.133	52258.738	50051.242	46934.699	44269.414	42610.117	39714.094	32349.457	3.648
			55907.246	53864.867	52246.977	50110.375	46800.672	44207.301	42664.434	39721.719	32220.689	3.637
			56752.180	54508.016	53094.543	50722.711	47525.574	44789.691	43350.438	40007.191	32447.770	3.785
			57544.184	55259.777	53694.320	51268.578	48040.254	45175.055	43712.445	40475.613	32750.322	3.874
			57488.777	55164.270	53654.004	51396.453	48028.637	45190.066	43711.488	40480.598	32720.010	3.905
			58210.148	55780.090	54228.766	51835.102	48446.539	45697.605	44080.195	40784.531	32982.887	4.033
			58199.742	55790.500	54247.363	51844.836	48440.977	45608.461	44006.840	40866.055	32977.934	4.029

Table 36 HGL Test for kaolin 10%

		Axial distances	-6.298	-4.568	-2.932	-0.832	1.076	3.805	6.046	8.075	9.975	
		Valve plane				0						
			Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
11/8/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		53930.070	51269.910	48722.129	45307.727	41754.621	35732.453	33769.602	30494.576	27805.361	0.058
Valve dimension[mm]:	40		54061.180	51072.031	48685.918	45097.340	41767.777	35777.719	33668.457	30446.734	27463.924	0.059
Valve position:	Open		34599.463	51792.863	49157.930	45697.426	42313.410	35644.434	34064.234	30331.143	27870.170	0.095
Pipe Diameter [mm]:	42.12		55622.563	52701.164	49963.438	46401.230	42897.176	36979.313	34402.105	30847.775	27656.740	0.110
Material Type:	Kaolin 10%		57165.129	54307.938	51329.924	47689.979	43869.758	38664.380	34883.137	31262.400	27805.922	0.165
Density[kg/m³]:	1172.4		57563.648	54436.484	51420.633	47603.934	43973.887	38199.105	34953.715	31265.857	27820.193	0.152
τ_y:	10.700		57582.215	54637.637	51607.707	47859.566	44036.633	37783.055	34952.469	31226.430	27971.799	0.151
K:	2.2		58739.586	55688.973	52380.238	48489.633	44692.836	39892.797	35297.652	31504.658	27921.072	0.202
n:	0.32		58825.082	55918.441	52604.172	48454.738	44700.570	38502.508	35329.313	31511.434	27908.771	0.301
			60419.859	57277.426	53872.238	49759.676	45693.023	40446.445	35821.527	31818.357	28019.072	0.298
			60588.375	57092.836	53876.313	49944.793	45730.512	39028.941	35840.605	31775.301	28235.203	0.286
			61817.094	58412.734	55225.547	50923.063	46299.348	39239.730	36164.609	31937.104	28170.215	0.396
			62107.629	59413.664	55934.445	51560.438	47011.496	39087.113	36230.605	32067.578	28100.207	0.497
			62182.023	59406.285	55993.563	51586.285	46986.789	38832.891	36347.844	32079.836	28348.742	0.491
			64410.523	60451.707	56853.613	52344.879	47426.258	38963.559	36537.590	32134.953	28119.025	0.655
			64435.488	60651.648	56974.332	52654.090	47411.145	38554.063	36554.813	32103.939	28394.723	0.648
			65591.938	61633.395	58141.957	53437.918	47663.738	38893.434	36707.570	32215.981	28326.713	0.773
			65390.527	61654.746	58202.980	53356.473	47731.660	38904.441	36694.617	32121.012	28322.254	0.772
			66772.352	62893.164	59297.477	54275.922	48021.191	39562.797	36853.688	32211.217	28077.350	0.997
			66802.086	62834.926	59157.926	54401.504	47962.684	40244.148	36787.059	32141.693	28169.184	0.898
			68219.384	64258.391	60489.537	55648.805	48310.215	39739.570	36902.836	32148.650	28035.682	1.054
			68126.648	64345.151	60375.941	55593.371	48214.785	39066.578	36924.617	32241.939	28039.498	1.053
			56967.246	53963.039	51133.332	47494.695	43811.301	38910.465	34996.781	31618.875	28338.400	1.290
			56935.777	52894.730	51136.541	47398.066	43796.355	38651.133	34785.887	31495.895	28454.006	1.292
			57145.520	54107.527	51263.125	47537.695	43805.090	38471.211	34619.207	31376.967	28376.082	1.432
			57087.207	54078.648	51190.195	47512.625	43682.070	38433.883	34669.715	31264.289	28596.746	1.436

Table 37 HGL Test for kaolin 10%

		Axial distances	-6.298	-4.568	-2.932	-0.832	1.076	3.805	6.046	8.075	9.975	
		Valve plane				0						
			Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
5/8/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		64018.656	57048.957	54980.289	52034.031	45719.609	40170.211	37903.094	31545.375	27630.219	1.125
Valve dimension[mm]:	40		63965.039	57204.211	55072.477	51946.824	45733.004	40026.262	37921.809	31557.176	27645.332	1.121
Valve position:	Open		65742.813	58814.984	56480.621	53868.477	46127.398	40344.457	38119.832	31582.943	27621.561	1.280
Pipe Diameter [mm]:	42.12		66070.477	58866.391	56561.496	53831.750	46183.680	40283.852	38198.359	31615.990	27635.922	1.278
Material Type:	Kaolin 10%		65769.859	58843.004	56620.543	53938.082	46223.563	40247.887	38199.824	31650.184	27649.471	1.274
Density[kg/m³]:	1172.4		70158.453	62765.617	60430.023	57536.301	46992.348	41092.277	38645.320	31729.102	27569.049	1.668
τ_y:	10.700		70052.156	62693.387	60388.074	57546.598	46997.766	40975.176	38648.852	31754.734	27559.463	1.671
K:	2.2		69899.727	62687.578	60407.500	57447.785	46924.363	40902.742	38609.309	31628.502	27537.609	1.672
n:	0.32		73938.219	66403.648	63925.184	61100.211	47542.285	41438.711	38976.430	31836.430	27499.426	2.090
			74067.906	66335.734	63869.141	61085.570	47395.859	41282.359	38936.895	31834.014	27533.080	2.094
			78336.438	70544.945	68016.156	65283.945	47713.836	41627.930	39150.316	31840.674	27501.887	2.587
			78308.313	70668.742	68131.008	65418.051	47878.668	41663.996	39119.445	31869.268	27521.879	2.588
			87126.133	79362.523	76492.828	74064.273	48317.168	41667.746	39168.715	31582.049	27328.740	3.133
			87347.023	79156.586	76679.227	73736.211	48525.328	41993.141	39195.273	31592.576	27098.529	3.148
			89664.969	81126.938	79828.570	76696.352	48381.234	41500.266	39144.586	31252.523	26757.273	3.305
			89898.875	82274.445	79856.906	76579.195	48320.059	41772.453	38886.191	31301.145	26841.113	3.304

Table 38 HGL Test for kaolin 10%

		Axial distances	-6.298	-2.932	-1.88	-0.621	1.076	3.805	4.920	8.075	9.975	
		Valve plane				0						
			Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
12/8/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		64018.656	57048.957	54980.289	52034.031	45719.609	40170.211	37903.094	31545.375	27630.219	1.125
Valve dimension[mm]:	40		63965.039	57204.211	55072.477	51946.824	45733.004	40026.262	37921.809	31557.176	27645.332	1.121
Valve position:	Open		65742.813	58814.984	56480.621	53868.477	46127.398	40344.457	38119.832	31582.943	27621.561	1.280
Pipe Diameter [mm]:	42.12		66070.477	58866.391	56561.496	53831.750	46183.680	40283.852	38198.359	31615.990	27635.922	1.278
Material Type:	Kaolin 10%		65769.859	58843.004	56620.543	53938.082	46223.563	40247.887	38199.824	31650.184	27649.471	1.274
Density[kg/m³]:	1172.4		70158.453	62765.617	60430.023	57536.301	46992.348	41092.277	38645.320	31729.102	27569.049	1.668
τ_y:	10.700		70052.156	62693.387	60388.074	57546.598	46997.766	40975.176	38648.852	31754.734	27559.463	1.671
K:	2.2		69899.727	62687.578	60407.500	57447.785	46924.363	40902.742	38609.309	31628.502	27537.609	1.672
n:	0.32		73938.219	66403.648	63925.184	61100.211	47542.285	41438.711	38976.430	31836.430	27499.426	2.090
			74067.906	66335.734	63869.141	61085.570	47395.859	41282.359	38936.895	31834.014	27533.080	2.094
			78336.438	70544.945	68016.156	65283.945	47713.836	41627.930	39150.316	31840.674	27501.887	2.587
			78308.313	70668.742	68131.008	65418.051	47878.668	41663.996	39119.445	31869.268	27521.879	2.588
			87126.133	79362.523	76492.828	74064.273	48317.168	41667.746	39168.715	31582.049	27328.740	3.133
			87347.023	79156.586	76679.227	73736.211	48525.328	41993.141	39195.273	31592.576	27098.529	3.148
			89664.969	81126.938	79828.570	76696.352	48381.234	41500.266	39144.586	31252.523	26757.273	3.305
			89898.875	82274.445	79856.906	76579.195	48320.059	41772.453	38886.191	31301.145	26841.113	3.304

Table 39 HGL Test for kaolin 10%

6/8/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	40
Valve position:	Open
Pipe Diameter [mm]:	42.12
Material Type:	Kaolin 10%
Density[kg/m³]:	1168.2
τ_y:	10.700
K:	2.2
n:	0.32

Axial distance	-6.299	-4.568	-2.932	-1.580	1.076	3.805	6.046	8.075	9.975	
Valve plane				0						
	Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	67330.789	63211.430	59395.278	56948.234	49725.443	43485.730	38334.535	33668.117	29153.726	0.321
	68206.086	64072.082	60433.457	57757.043	49944.457	43556.586	38245.906	33555.102	29038.994	0.609
	67766.484	63758.172	60029.541	57472.957	49666.750	43434.383	38100.953	33318.176	29095.279	0.630
	67642.688	63656.035	59937.496	57404.762	49679.250	43496.414	38048.563	33371.965	29080.521	0.630
	71616.758	67236.766	63394.125	60891.484	50756.387	44150.473	38598.500	33677.637	29017.336	1.024
	71585.563	67282.539	63396.402	60837.293	50723.437	44139.633	38558.301	33669.109	28957.668	1.021
	71419.953	67330.063	63344.539	60843.484	50720.621	44084.824	38468.344	33633.625	28940.035	1.023
	76584.055	72266.672	68019.656	65299.699	51530.336	44672.258	38980.953	33817.473	28757.369	1.538
	78586.257	72223.188	68043.659	65373.977	51630.805	44709.723	39017.805	33872.027	29754.352	1.536
	76423.484	71997.094	67952.734	65128.914	51498.344	44660.707	38975.918	33830.539	28755.969	1.536
	80700.016	76096.554	71929.617	69139.633	51337.913	44488.363	38921.141	33661.480	28716.639	2.024
	80442.945	75958.259	71855.023	69010.109	51407.938	44569.559	38777.531	33617.859	28798.971	2.032
	80244.188	75805.977	71726.875	69094.609	51334.934	44495.461	38786.238	33605.477	28811.852	2.032
	84565.531	80421.758	76239.234	73653.602	51665.539	44881.953	38904.203	33730.133	28709.939	2.578
	84792.328	80119.422	75975.133	73562.398	51710.258	44788.238	38864.004	33659.387	28617.457	2.575
	84710.641	80524.164	76178.141	73301.844	51806.633	44760.715	38987.258	33566.473	28718.963	2.571
	88815.172	83943.125	79365.430	76445.906	53487.863	43940.297	39806.055	34212.820	28964.719	2.490
	88706.953	84024.984	79319.531	76114.977	53424.746	43982.910	39750.551	34172.363	28931.938	2.492
	88453.719	83715.086	79066.477	76313.508	53345.535	43939.223	39696.930	34190.871	28935.818	2.489
	93894.555	89115.945	84323.016	81045.313	52903.750	46163.020	39845.270	34054.188	28739.125	3.007
	93679.664	89162.500	84072.570	81059.852	53789.781	46252.438	39768.832	34086.828	28719.334	3.006
	93353.438	88351.328	84108.016	80901.711	53929.199	46070.102	39756.859	34022.914	29685.887	3.004
	105209.969	99806.813	95624.797	93579.594	54285.852	46329.484	39760.094	33904.738	28348.889	3.584
	105735.375	99848.227	96419.703	92558.023	54226.008	45931.516	39625.648	33661.949	28151.652	3.584
	104805.883	101175.361	94977.555	91735.742	54305.617	46056.820	39525.715	33791.426	28394.096	3.574
	115751.719	110525.219	106948.219	102738.688	54637.754	46044.988	39265.895	33277.688	27625.973	4.044
	116249.023	111304.906	105760.000	101604.109	54500.148	45843.094	39098.922	33297.656	28012.465	4.029
	116017.977	111373.328	105089.656	102530.344	54560.094	46115.012	39682.074	33525.016	28241.697	4.033
	125693.695	119950.727	114672.742	109192.258	55104.824	46127.996	39308.648	33073.961	27217.816	4.352
	126373.688	120262.859	115818.906	112275.906	54603.512	46662.215	40008.074	33144.641	27402.211	4.357
	126062.891	121331.461	115225.375	113207.516	54910.895	46778.594	39085.137	34158.512	27271.617	4.349

Table 40 HGL Test for kaolin 10%

13/8/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	40
Valve position:	Open
Pipe Diameter [mm]:	42.12
Material Type:	Kaolin 10%
Density[kg/m³]:	1162.7
τ_y:	10.700
K:	2.2
n:	0.32

Axial distance	-6.298	-2.932	-1.58	-0.621	1.076	3.805	4.920	8.075	9.975	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	54105.391	48599.574	46872.361	44942.590	41952.605	37395.184	35574.105	30386.486	27356.222	0.075
	54800.309	49212.516	47430.539	45322.910	42547.746	37872.508	36019.066	30432.797	27612.958	0.130
	61795.559	54896.250	52728.801	50122.926	46134.945	40076.719	38219.184	31533.258	27764.438	0.543
	61830.813	54916.582	52754.824	50314.715	46022.336	40417.641	38239.613	31498.496	27892.195	0.540
	67811.492	60271.172	57736.531	54978.008	47685.770	41542.410	39130.078	31958.393	27906.418	1.170
	67682.914	60095.340	57920.551	55045.285	47583.430	41538.672	39153.484	31958.102	27790.887	1.172
	71264.367	63474.551	61080.914	58259.098	48251.828	41984.375	39371.238	32063.869	27682.834	1.523
	71326.211	63412.566	61015.156	58098.645	48254.992	41956.366	39410.090	32074.275	27695.412	1.523
	76572.438	68786.359	65749.789	62645.660	48898.234	42451.509	39720.363	32134.305	27549.660	2.021
	76340.719	68191.359	65709.936	62742.477	48898.449	42364.309	39777.438	32139.596	27550.404	2.021
	80951.406	72497.391	69891.555	66921.352	49642.008	42868.590	40146.215	32293.760	27574.188	2.497
	81335.438	72899.250	70218.445	66926.250	49696.836	42881.203	40123.859	32318.053	27603.516	2.495
	90774.297	81561.789	78992.922	76409.555	50173.082	42913.930	40146.750	31976.707	27043.490	3.162
	90802.750	82342.758	79249.492	75930.984	50025.473	42927.332	40136.203	31787.918	27011.303	3.164
	53596.508	48486.500	46561.617	44088.395	41788.418	37159.730	35510.078	30101.982	27361.354	0.094
	52076.934	46807.695	45322.586	43034.922	40266.176	36200.504	34780.012	29655.342	27181.379	0.078
	52064.320	46878.348	45084.711	43158.898	40254.715	36106.250	34610.820	29651.180	27420.467	0.077
	52537.078	47153.980	45218.565	43219.938	40409.402	36491.000	34763.672	29619.271	27378.018	0.084
	53829.078	48265.844	46342.742	44317.637	41494.320	36979.375	35353.262	29759.588	27394.904	0.128
	53876.379	48200.633	46486.355	44415.539	41424.805	36931.820	35304.031	29755.980	27451.590	0.127
	56132.547	49733.754	47906.578	45707.270	42449.441	37614.445	35867.086	29950.693	27412.619	0.227
	56297.387	49972.141	47969.707	45805.355	42529.148	37592.418	35998.531	30092.822	27617.133	0.226
	58088.137	51877.602	49599.121	47242.219	43375.184	38296.285	36563.051	30307.566	27562.305	0.329
	57909.105	51678.395	49598.695	47666.391	43444.730	38475.396	36458.953	30391.516	27681.123	0.334
	59969.965	53552.867	51383.375	48389.613	44446.230	38901.832	37121.008	30373.373	27727.891	0.544
	59994.117	53289.648	51320.594	48298.086	44093.375	38976.258	36994.430	30322.645	27767.111	0.546
	61342.469	54717.242	52760.500	50141.176	46086.641	40084.590	37663.398	31508.584	27702.336	0.704
	61328.234	54599.227	52604.734	49974.309	45001.621	40049.941	37709.027	31464.555	27730.596	0.704
	55130.766	49629.246	47705.707	45217.863	41794.082	37229.914	35265.676	30076.566	27362.465	0.141
	55038.145	49510.535	47602.074	44844.988	41495.387	37352.297	35154.992	29929.373	27484.889	0.152
	55401.520	49620.012	47583.680	45126.527	41965.512	37306.273	35026.551	29769.490	27445.209	0.192
	55376.633	49628.012	47439.549	45000.445	41895.426	37196.906	34818.293	29663.621	27620.098	0.201
	56248.906	50017.234	47979.340	45381.520	42308.297	37523.508	35006.234	29692.961	27443.352	0.247
	56346.297	50250.234	48064.676	45287.602	42236.051	37503.051	34950.980	29946.523	27549.328	0.250

Table 41 HGL Test for kaolin 10%

		Axial distances	-6.574	-3.526	-2.281	-0.780	1.257	3.012	5.666	7.666	9.669	
		Valve plane				0						
			Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
16/8/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		46953.879	43436.777	42155.305	40400.300	37910.504	35768.303	32409.520	29600.240	27772.025	0.093
Valve dimension[mm]:	50		46986.363	43540.656	42129.727	40418.622	37813.035	35768.923	32386.387	29629.787	29033.932	0.092
Valve position:	Open		47354.598	43946.336	42587.422	40807.742	38224.758	36117.980	32570.262	29840.082	28013.363	0.107
Pipe Diameter [mm]:	52.8		46336.523	43398.664	41938.590	40185.105	37741.215	35652.437	32284.813	29914.760	27755.668	0.082
Material Type:	Kaolin 10%		47357.336	44084.367	42528.754	40729.379	38273.051	36079.770	32433.676	29730.715	27811.525	0.108
Density[kg/m^3]:	1172.4		48011.316	44398.133	42811.430	41137.738	38479.266	36304.172	32638.236	29708.361	27875.873	0.123
τ_y:	10.700		47910.328	44351.035	42959.086	41101.230	38503.734	36246.922	32616.604	29777.729	28125.906	0.123
K:	2.2		48415.063	44629.453	43144.613	41316.533	38602.131	36374.434	32626.273	29742.225	27894.797	0.135
n:	0.32		48269.867	44693.012	43140.016	41225.852	38620.047	36506.301	32773.313	29794.555	28059.461	0.131
			49022.500	45204.637	43729.545	41800.320	38999.980	36736.188	32898.188	30065.195	28051.046	0.165
			49081.688	45303.664	43853.500	41797.609	39075.164	36747.238	32878.969	29881.074	28134.342	0.163
			49937.020	45976.953	44356.855	42791.512	39489.301	37328.496	33194.531	30105.896	28008.520	0.203
			49963.223	46041.012	44319.813	42438.695	39478.523	37232.090	33188.680	30045.342	28304.682	0.205
			51409.250	47134.723	45359.094	43393.680	40273.871	37839.137	33671.422	30414.330	28166.010	0.328
			51426.750	47141.746	45457.523	43262.785	40301.188	37835.676	33468.793	30218.732	28236.238	0.326
			52286.512	47826.262	46237.605	43942.230	40919.835	38238.043	33669.180	30398.252	28224.330	0.477
			52517.266	47942.762	46135.480	43987.535	40915.539	38266.590	33558.348	30546.475	28241.367	0.433
			52680.711	48296.348	46462.379	44234.016	41120.129	38550.926	33652.391	30526.365	28282.152	0.513
			52744.664	48362.195	46535.199	44383.336	41133.129	38471.113	33309.738	30647.047	28559.023	0.509
			52744.664	48362.195	46535.199	44383.336	41130.129	38471.113	33309.738	30647.047	28559.023	0.717
			53112.840	48722.098	46795.754	44664.656	41273.586	38034.477	34324.109	29963.783	28320.047	0.720
			52713.508	48599.070	46732.936	43696.906	40952.684	37662.324	34261.508	29940.818	28562.909	0.716
			52958.664	48841.734	46946.719	43944.406	41182.219	38060.555	34316.590	31321.326	28290.441	0.885
			52922.551	48866.410	47016.164	44021.016	41038.992	37688.027	34240.402	31163.469	28418.148	0.883
			52721.668	48966.402	47103.180	44130.633	41164.109	37711.125	34289.699	31087.756	28279.475	0.950
			54760.277	50154.668	48204.559	45393.129	42258.219	39372.359	34859.785	31690.705	28353.369	1.054
			54539.543	50043.398	48090.234	45134.309	42058.117	39409.301	34791.910	31638.053	28525.480	1.052
			54811.512	50078.590	48089.414	45479.016	42059.977	39448.914	34733.129	31572.213	28382.393	1.119

Table 42 HGL Test for kaolin 10%

		Axial distances	-6.574	-5.47	-3.526	-1.531	1.257	4.013	5.666	7.666	9.669	
		Valve plane				0						
			Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
6/6/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		54764.754	53184.254	50256.605	47736.535	43239.727	38665.750	35477.152	32367.916	29269.664	0.245
Valve dimension[mm]:	50		57480.039	55550.652	52386.398	49341.579	44354.074	39617.723	36256.145	32888.598	29497.893	0.522
Valve position:	Open		57605.242	55720.000	52435.516	49478.434	44272.355	39630.508	36273.191	32905.262	29492.162	0.521
Pipe Diameter [mm]:	52.8		57362.852	55757.078	52550.930	49498.309	44294.621	39612.258	36300.652	32905.074	29491.619	0.518
Material Type:	Kaolin 10%		58623.578	56807.426	53414.730	50132.234	44872.051	40066.914	36616.492	33120.641	29547.365	0.725
Density[kg/m^3]:	1168.2		58410.492	56799.648	53488.230	49956.938	44920.387	40132.738	36615.023	33110.957	29571.627	0.725
τ_y:	10.700		58162.207	56864.289	53456.809	49891.516	44910.703	40218.355	36615.023	33110.957	29571.627	0.722
K:	2.2		59624.063	57713.379	54226.180	50616.289	45428.898	40579.352	36890.391	33277.578	29658.133	1.025
n:	0.32		59070.844	57713.699	54270.852	50693.156	45424.184	40474.785	36841.523	33283.938	29631.613	1.018
			59295.719	57723.961	54261.027	50594.621	45449.629	40505.910	36853.727	33309.820	29646.516	1.027

Table 43 HGL Test for kaolin 10%

		Axial distances	-6.298	-4.568	-2.932	-1.980	1.976	3.805	6.046	8.075	9.975	
		Valve plane				0						
			Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
3/8/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		67638.727	64809.859	60985.395	56476.680	48281.398	44625.586	38388.055	35669.000	29839.068	3.355
Valve dimension[mm]:	40		67684.523	65437.648	61128.527	56992.148	45662.461	45140.477	38576.363	34520.938	29825.758	3.355
Valve position:	Open		67584.813	65602.492	61004.414	56981.203	46665.484	45030.215	38499.758	34519.922	29765.553	3.355
Pipe Diameter [mm]:	42.12		61575.590	59491.555	55790.133	51981.922	46532.082	43447.578	37544.543	34102.484	29856.406	1.258
Material Type:	Kaolin 10%		61316.344	59404.684	55813.746	52067.492	46393.727	43551.832	37562.961	34061.746	29909.029	1.268
Density[kg/m^3]:	1168.2		61784.160	60045.309	56295.699	52441.504	46757.684	43734.219	37618.273	34030.582	29911.193	1.585
τ_y:	10.700		62411.422	60018.926	56249.855	52281.754	46723.418	43653.859	37622.746	33930.934	29904.820	1.590
K:	2.2		62045.199	59853.426	56151.582	52319.727	46761.246	43301.125	37711.805	33713.516	29870.854	1.590
n:	0.32		62754.590	60410.523	56871.530	52840.648	46788.777	43385.469	37716.480	33578.637	29717.654	2.125
			62437.445	60160.723	56829.480	52427.582	46565.121	43084.160	37655.020	33336.020	29948.441	2.124
			62343.297	60045.559	56177.133	51935.320	46761.609	43103.848 –	37419.023	33334.613	29941.170	2.127
			63140.434	60469.473	56948.484	52984.086	46570.477	43029.281	37281.918	33215.895	30019.434	2.577
			62543.129	60037.920	56548.541	52235.840	46178.160	42775.910	37104.371	32769.582	29618.188	2.579
			63401.035	60763.742	57199.387	52752.270	46510.983	42974.560	37118.719	32896.121	29839.107	2.796
			63257.059	60550.699	57143.156	52563.523	46446.773	42801.502	36989.852	32698.662	29837.410	2.791
			63277.281	60529.691	57070.621	52600.117	46140.320	42615.152	36845.414	32731.447	29989.393	2.790
			64231.672	61497.598	57916.305	53233.301	46353.316	42754.859	36725.656	32653.934	29962.803	3.057
			64081.047	61416.348	57882.328	53142.539	46435.777	42728.473	36819.316	32586.420	29823.061	3.057

Table 44 HGL Test for kaolin 10%

13/8/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	50
Valve position:	Open
Pipe Diameter [mm]:	52.9
Material Type:	Kaolin 10%
Density[kg/m³]:	1167.5
τ_y:	10.700
K:	2.2
n:	0.32

Axial distance	-6.574	-5.47	-3.526	-1.531	1.257	3.012	5.666	7.666	9.669	
Valve plane				0						
	Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	67638.727	64809.859	60985.395	56476.680	48281.398	44625.586	38388.055	33669.000	29839.068	3.353
	67684.523	65437.648	61128.527	56992.148	46662.461	45140.477	38576.363	34520.938	29825.758	3.355
	67584.813	65602.492	61004.414	56981.303	46661.484	45030.215	38499.758	34319.922	29765.553	3.355
	61575.590	59491.555	55790.133	51581.922	46532.282	43447.578	37544.543	34102.484	29856.406	1.258
	61316.344	59404.684	55813.746	52067.492	46393.727	43551.932	37562.961	34061.746	29909.029	1.268
	61784.160	60045.309	56291.699	52441.504	46757.684	43734.219	37618.273	34030.582	29911.193	1.585
	62411.422	60018.926	56249.855	52281.754	46723.418	43653.859	37632.746	33930.934	29904.830	1.590
	62045.199	59853.426	56151.582	52319.727	46761.246	43001.125	37711.805	33713.516	29870.854	1.590
	62754.590	60410.523	56871.530	52940.648	46788.777	43385.469	37716.480	33578.637	29717.654	2.125
	62437.445	60160.723	56829.480	52427.582	46565.121	43084.160	37655.020	33336.020	29948.441	2.124
	62343.297	60045.559	56177.133	51935.320	46761.609	43103.848	37419.023	33334.613	29941.170	2.127
	63140.434	60468.473	56948.484	52584.086	46570.477	43029.281	37281.918	33219.895	30019.434	2.577
	62543.129	60037.820	56548.341	52235.840	46178.160	42775.910	37104.371	32769.582	29618.188	2.579
	63401.035	60763.742	57199.387	52752.270	46510.883	42974.660	37118.719	32896.121	29839.107	2.796
	63257.059	60550.699	57143.156	52563.523	46446.773	42801.602	36989.852	32698.662	29897.410	2.791
	63277.281	60529.691	57070.621	52608.117	46140.820	43615.152	36845.414	32731.447	29989.353	2.790
	64231.672	61497.538	57916.305	53223.301	46353.316	42754.859	36925.656	32653.934	29982.803	3.057
	64081.047	61416.948	57882.328	53142.539	46433.777	42728.473	36819.316	32586.420	29823.061	3.057

Table 45 HGL Test for kaolin 10%

HGL Test for kaolin 10%

17/8/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	50
Valve position:	Open
Pipe Diameter [mm]:	52.8
Material Type:	Kaolin 10%
Density[kg/m³]:	1163.4
τ_y:	10.700
K:	2.2
n:	0.32

Axial distance	-6.574	-3.526	-2.281	-0.780	1.257	3.012	5.666	7.666	9.669	
Valve plane				0						
	Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	54881.121	50357.070	48153.648	45248.984	41978.668	39118.207	34571.254	31766.709	28480.246	1.341
	54645.133	50291.652	48116.645	45274.535	42009.207	39091.355	34589.504	31589.645	28499.456	1.342
	54597.188	50437.875	48255.574	45564.188	42074.988	39087.406	34626.688	31624.828	28173.703	1.432
	54742.809	50356.952	48217.552	45578.898	41998.453	39306.281	34669.211	31607.365	28434.580	1.434
	54892.457	50515.992	48343.402	45676.180	42295.152	39194.113	34663.828	31561.201	28456.454	1.510
	54769.574	50724.738	48288.551	45899.703	42284.102	39398.246	34689.457	31564.910	28416.430	1.511
	55061.469	50729.397	48448.752	45767.980	42315.902	39441.387	34559.918	31582.234	28399.643	1.624
	55115.039	50658.391	48486.902	45935.637	42365.379	39348.242	34788.242	31527.188	28433.082	1.625
	55088.738	50778.246	48511.129	45932.539	42258.117	39405.602	34688.195	31573.141	28397.506	1.714
	55153.793	50787.801	48318.316	46011.500	42386.871	39391.152	34716.055	31540.590	28402.492	1.713
	55618.914	50999.078	48534.340	46227.164	42421.195	39416.254	34834.691	31532.781	28367.316	1.812
	55284.031	50877.344	48459.801	46237.922	42499.051	39311.484	34777.926	31567.760	28427.392	1.810
	55500.426	51066.566	48973.949	46256.363	42440.176	39467.266	34773.516	31554.822	28293.000	1.922
	55424.430	50968.820	48725.380	46171.160	42538.480	39317.719	34773.949	31478.570	28311.985	1.921
	55486.953	51060.047	48915.344	46451.957	42491.426	39335.797	34656.094	31429.480	28290.035	2.032
	55462.789	51182.816	48999.613	46318.391	42554.273	39366.398	34730.480	31428.729	28052.377	2.031
	55426.527	51707.133	49222.543	46603.965	42743.781	39413.824	34773.234	31463.416	28267.225	2.139
	55525.738	51354.027	49183.852	46422.973	42714.125	39247.987	34841.457	31357.793	28348.029	2.138
	55846.641	51599.438	49512.703	46517.129	42411.504	39323.891	34807.922	31274.018	28243.512	2.248
	55989.598	51437.313	49310.797	46483.516	42663.008	39354.305	34834.801	31360.820	28439.430	2.253
	55669.328	51636.289	49570.031	46618.473	42442.027	39251.703	34765.570	31340.607	28228.928	2.348
	55653.508	51364.234	49535.055	46555.414	42457.246	39275.488	34814.875	31390.695	28426.318	2.348
	55660.277	51743.844	49666.035	46613.578	42482.738	39244.580	34846.918	31330.805	28267.105	2.417
	56008.926	51512.844	49574.281	46657.645	42454.895	39209.291	34827.777	31359.793	28250.422	2.408
	55993.199	51913.816	49863.672	46891.387	42547.613	39080.090	34975.141	31290.309	28266.456	2.526
	56183.141	51836.465	49826.094	46924.395	42565.293	39058.563	34941.070	31301.537	28448.053	2.529
	56577.902	52352.180	50183.242	47173.980	42582.582	38977.436	34809.656	31330.344	28259.301	2.626
	56471.703	52364.328	50210.195	47340.305	42593.133	38990.473	34925.523	31300.506	28462.531	2.626
	56805.641	52497.543	50862.340	47633.273	42726.570	39021.602	34897.617	31322.043	28239.518	2.720
	57085.426	52762.598	50609.559	47619.141	42830.410	38872.105	34980.465	31308.520	28472.582	2.722
	57500.000	52931.492	50877.957	47838.023	42635.844	39062.598	34914.566	31300.506	28274.596	2.801
	57700.000	52730.652	50887.543	47567.031	42630.711	38974.313	34907.906	31291.092	28422.922	2.804
	58865.500	53571.530	51295.926	48626.945	43676.723	40664.715	35405.457	31830.410	28422.922	2.913
	58804.971	53409.746	51299.426	48606.102	43637.719	40627.645	35327.426	31831.328	28250.141	2.931
	59041.145	53759.410	51484.434	48844.375	43739.832	40649.496	35350.879	31855.787	28253.102	3.029
	59055.836	53690.738	51444.465	48472.910	43648.992	40630.492	35340.457	31814.549	28256.199	3.017
	58595.188	53191.871	50902.520	48551.344	43424.875	40443.656	35112.281	31742.109	27961.744	3.012
	58589.102	53169.516	50792.258	48419.297	43428.477	40412.043	35074.457	31537.602	28197.551	3.009
	58726.445	53533.023	51060.188	48617.477	43409.613	40427.395	35071.289	31526.154	28196.168	3.117
	58787.363	53555.445	51178.762	48652.910	43403.164	40430.836	35029.223	31491.180	28225.008	3.122
	58873.520	53538.867	51327.766	48780.703	43446.441	40445.270	35037.957	31585.654	28188.930	3.171
	58881.977	53538.867	51326.586	48753.898	43405.301	40414.824	34961.668	31495.287	28176.389	3.186
	59209.184	53863.434	51568.234	48946.719	43510.457	40486.430	34563.773	31634.744	28187.891	3.287
	59168.301	52891.961	51591.625	49029.816	43493.395	40459.980	34990.539	31528.828	28240.156	3.296
	59368.281	54066.484	51906.012	49140.074	43581.621	40473.676	35112.211	31638.201	28162.727	3.354
	59400.469	54077.371	51920.414	49269.938	43553.531	40535.488	35028.719	31627.543	28182.904	3.355

Table 46 HGL Test for kaolin 10%

		Axial distances	-6.9735	-4.8855	-2.985	-0.937	0.987	1.968	2.938	3.916	4.858	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
19/8/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	(l/s)
Valve Type:	Diaphragm		53339.273	50428.012	47540.574	44807.098	41684.324	40325.168	38549.512	37581.371	36134.055	2.398
Valve dimension(mm):	65		53376.672	50463.227	47638.924	44778.609	41732.879	40319.936	38538.238	37553.102	36239.859	2.392
Valve position:	Open		53664.875	50621.793	47857.527	44918.848	41807.500	40449.332	39026.438	37681.293	36259.574	2.574
Pipe Diameter (mm):	63.08		53668.941	50704.145	47716.539	44922.914	41838.190	40498.855	39069.723	37610.559	36290.633	2.591
Material Type:	Kaolin 10%		53844.789	50917.137	48024.395	45128.566	42002.309	40586.219	39122.193	37704.961	36344.309	2.742
Density(kg/m³)	1163.4		53868.076	52889.341	47937.375	45081.363	41937.250	40555.211	39080.555	37653.766	36368.766	2.710
τ_y	10.700		54140.281	51123.848	48213.270	45257.934	41978.629	40639.723	39191.285	37849.691	36457.527	2.944
K	2.2		54216.983	51205.340	48216.457	45267.977	42009.145	40601.273	39281.219	37837.436	36462.199	2.940
n	0.32		54286.336	51310.969	48358.555	45448.680	42108.422	40756.477	39294.945	37806.504	36485.805	3.108
			54413.242	51312.109	48421.569	45464.375	42125.820	40715.410	39268.023	37908.180	36472.395	2.971
			54620.473	51521.367	48547.102	45608.383	42256.691	40840.930	39399.785	37925.371	36598.805	3.247
			54588.477	51520.617	48568.294	45739.324	42240.688	40813.125	39387.520	37955.133	36551.930	3.258
			54909.004	51770.254	48808.477	45837.465	42358.891	41015.105	39508.156	38067.328	36642.684	3.469
			54902.613	51643.805	48959.156	45844.727	42327.230	40955.609	39471.012	38069.211	36649.133	3.474
			55158.277	52013.227	49300.200	46083.117	42463.590	40995.168	39526.473	38117.191	36646.254	3.631
			55190.617	52077.121	49006.953	46289.766	42476.496	41036.949	39578.492	38101.289	36669.527	3.652
			55460.402	52197.926	49379.207	46278.391	42939.027	41354.289	39595.750	38192.305	36760.824	3.803
			55450.809	52314.355	49244.164	46268.668	42455.605	41075.633	39676.129	38188.313	36767.523	3.796
			55496.363	52422.730	49379.344	46288.480	42593.207	41240.500	39786.953	38213.582	36944.152	3.970
			55550.516	52305.938	49417.309	46357.641	42585.430	41161.941	39750.000	38207.738	36857.031	3.954
			55663.469	52517.047	49482.898	46514.230	42705.602	41252.594	39739.723	38265.273	36813.012	4.154
			55720.512	52578.891	49490.316	46506.715	42613.633	41190.875	39754.199	38273.266	36825.594	4.147
			55852.063	52676.652	49638.508	46687.270	42710.379	41305.523	39842.926	38338.242	36865.199	4.313
			55898.906	52711.232	49627.437	46662.817	42736.938	41292.527	39794.191	38253.324	36885.199	4.351
			56662.316	53437.496	50299.852	47275.031	43016.594	41511.957	40048.012	38515.492	36992.461	4.537
			56589.766	53503.730	50310.770	47236.891	42952.219	41494.281	40053.570	38510.387	37021.410	4.550
			57148.305	53935.133	50810.941	47726.340	43173.598	41682.308	40126.262	38609.918	37128.496	4.712
			57160.848	53912.453	50753.969	47690.832	43147.465	41625.648	40116.195	38601.473	37159.051	4.722
			57513.738	54236.918	51091.305	48019.418	43323.359	41763.965	40242.289	38712.684	37216.828	4.863
			57541.289	54258.215	51082.688	47961.547	43338.070	41599.109	40216.977	38696.586	37221.684	4.873
			58049.445	54779.953	51545.567	48473.809	43576.953	41949.941	40418.570	38871.047	37385.984	5.176
			58128.730	54719.535	51527.281	48416.727	43495.492	41925.336	40391.508	38833.609	37400.242	5.175
			58585.445	55133.684	51969.633	48847.504	43662.031	42127.457	40553.535	39033.113	37512.320	5.425
			58584.059	55193.715	51991.129	48895.523	43699.012	42136.971	40536.922	39026.398	37494.672	5.424
			58727.660	55440.582	52182.422	49138.922	43806.453	42148.207	40606.723	39068.188	37541.121	5.579
			58685.918	55382.898	52223.353	49039.582	43713.770	42198.828	40653.094	39043.984	37563.941	5.589
			59237.914	55854.965	52661.676	49448.652	44071.352	42358.180	40743.074	39208.039	37665.758	5.877
			59355.801	55819.199	52667.533	49512.633	44001.301	42355.152	40765.141	39209.063	37669.027	5.882
			59062.996	55740.301	52691.369	49496.590	42930.898	42272.590	40735.379	39157.695	37617.879	6.004
			59190.902	55681.523	52646.168	49454.281	43949.828	42282.996	40670.523	39091.070	37661.301	5.999
			56668.980	53773.660	50816.492	47878.629	44907.258	43387.695	41886.738	40550.570	39159.340	2.378
			54172.004	51053.273	48142.313	45360.703	42246.102	40834.402	39274.266	37861.957	36491.289	2.408
			53631.371	50558.766	47805.766	44960.375	41936.887	40524.871	39107.184	37700.000	36308.277	1.981
			53345.793	50305.371	47564.785	44546.555	41911.715	40452.508	38997.063	37671.348	36291.840	1.941
			53153.086	50352.926	47474.953	44770.512	41746.637	40312.934	38845.480	37608.352	36255.477	1.839
			53282.168	50203.605	47557.289	44746.348	41747.344	40357.473	38885.262	37557.375	36210.277	1.844
			53135.609	50239.031	47272.430	44658.898	41674.629	40336.584	38879.285	37498.133	36173.223	1.636
			53126.770	50025.359	47478.559	44392.574	41771.723	40274.660	38909.871	37546.645	36217.121	1.629
			52626.957	49552.602	46850.008	44293.652	41382.313	39940.781	38606.348	37264.246	35963.523	1.621
			53030.883	50025.008	47307.133	44626.000	41616.984	40244.930	38926.766	37392.652	36207.387	2.002
			52998.484	49938.984	47367.156	44730.156	41628.488	40299.145	38857.109	37592.914	36221.402	1.976
			51982.039	49045.566	46292.539	43594.266	40885.023	39663.547	38241.496	36923.449	35701.730	1.191
			51900.273	49046.773	46229.270	43676.250	40887.301	39511.508	38236.293	36893.145	35706.965	1.180
			50876.168	48117.125	45449.531	42916.641	40389.371	39053.724	37762.637	36482.910	35285.273	0.833
			48898.094	46449.453	44069.465	41698.762	39315.766	38168.418	36968.621	35837.539	34662.699	0.382
			50874.242	48153.336	45646.109	43023.734	40638.336	39215.324	37861.707	36634.910	35371.945	0.988
			50154.012	47791.715	45034.027	42626.035	40068.191	38829.949	37530.996	36249.949	35094.457	0.734

Table 47 HGL Test for kaolin 10%

		Axial distances	-6.413	-4.809	-3.61	-1.609	0.707	3.907	5.273	8.461	9.956	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
17/9/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	(l/s)
Valve Type:	Diaphragm		51083.430	49028.816	47573.480	45139.668	41751.281	37802.164	36215.008	32067.404	30313.838	2.762
Valve dimension(mm):	80		50744.781	48783.129	47316.535	44796.117	41542.621	37443.012	35723.008	32021.381	30176.058	2.809
Valve position:	Open		51011.816	49077.801	47454.340	45044.191	41686.668	37610.313	35995.063	32069.178	30139.055	3.271
Pipe Diameter (mm):	80.43		51032.848	49061.469	47540.750	45079.477	41534.668	37573.457	36017.176	32004.230	30172.066	3.274
Material Type:	Kaolin 10%		51671.332	49655.449	48074.238	45569.715	41893.320	37777.008	36231.422	32233.949	30271.238	3.853
Density(kg/m³)	1167.6		51924.586	50198.324	48455.953	45544.457	41754.867	38077.488	36340.109	32061.768	30253.305	4.452
τ_y	10.000		51145.457	49997.344	48408.219	45896.465	41640.645	38193.547	36494.855	32119.479	30253.197	4.426
K	1.568		52376.918	50523.758	48892.566	46248.156	41445.734	38197.859	36713.277	33232.496	30673.240	5.133
n	0.500		52958.516	50889.766	48869.762	46737.824	41348.383	38401.418	36625.215	32229.570	30375.634	5.779
			52930.699	50456.637	49419.770	47162.645	41658.656	38037.262	36606.750	32403.287	30350.164	5.807
			53485.355	51401.445	49752.645	47083.039	41238.262	38468.109	36634.664	32459.252	30550.117	6.341
			53369.895	51375.563	49630.672	47099.973	41221.469	38477.848	36675.227	32333.631	30508.367	6.321
			54383.516	52262.672	50705.738	47871.188	42852.090	38641.465	36857.742	32577.215	30579.054	7.210
			55339.590	52277.848	50644.609	47981.508	42855.852	38624.684	36860.965	32592.607	30602.947	7.228

Table 48 HGL Test for kaolin 10%

16/9/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	80
Valve position:	Open
Pipe Diameter [mm]:	80.43
Material Type:	Kaolin 10%
Density[kg/m³]:	1166
τ_y:	10.000
K:	1.568
n:	0.5

Axial distances	-6.413	-4.909	-3.61	-1.609	0.707	3.907	5.273	8.461	9.956	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	43660.926	42751.316	41702.758	40103.156	38188.154	35599.703	34455.613	31860.359	30544.722	0.306
	48447.293	45168.645	44023.477	42159.434	39989.574	36956.703	35705.469	33627.869	31076.953	0.450
	48854.703	47247.445	46102.465	43574.956	41579.168	38271.160	36773.160	33401.816	31805.566	1.100
	48833.781	47186.988	46020.762	43540.160	41536.891	38257.035	36764.141	33353.695	31796.461	1.098
	49607.383	47961.934	46703.309	44152.445	42007.719	38622.688	37158.785	33620.203	32029.719	1.442
	49448.398	47848.113	46665.527	44055.548	41963.934	38582.578	37106.242	33540.105	32025.512	1.446
	50072.309	48407.039	47192.840	44591.316	42292.898	38885.884	37417.777	33851.625	32232.389	1.880
	49927.262	48476.230	47221.281	44630.883	42349.684	38957.172	37790.367	33868.773	32243.906	1.855
	44723.348	43451.582	41881.023	39767.316	37586.750	33999.438	32555.713	29262.891	27873.648	6.452
	44911.828	45140.367	41937.668	40085.797	37525.336	34158.394	32567.664	29452.939	27945.566	6.037
	44475.625	43350.902	42263.133	40169.992	37568.438	34370.367	32736.207	29032.686	27628.154	6.209
	45586.285	44026.148	42375.852	40728.238	38408.194	35304.855	33853.836	30766.504	29300.365	3.353
	44069.387	43885.020	42926.979	41180.043	38288.156	35106.504	33771.277	30517.678	29065.307	2.871
	43698.145	43788.336	42703.434	40672.313	37951.680	34986.977	33597.160	30529.326	29006.453	3.195

Table 49 HGL Test for kaolin 13%

30/9/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	40
Valve position:	Open
Pipe Diameter [mm]:	42.12
Material Type:	Kaolin 13%
Density[kg/m³]:	1214
τ_y:	35.000
K:	0.99
n:	0.5

Axial distances	-6.303	-2.937	-1.885	-0.625	1.076	3.805	6.046	8.075	9.975	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	0.000	14030.533	19278.629	24218.346	33758.066	44624.875	55186.039	63453.160	72375.461	0.305
	0.000	13725.393	20191.059	26326.980	34108.418	47954.582	57102.695	66364.336	75021.781	0.423
	0.000	15619.612	18768.127	26196.924	34842.871	46722.188	57735.680	66284.781	74971.070	0.428
	0.000	14813.058	19260.689	26667.922	36487.031	48300.457	58665.172	67927.289	75070.375	0.549
	0.000	12913.122	19556.307	23993.697	35894.953	48193.016	58655.426	68334.492	77214.578	0.539
	0.000	15211.420	20489.603	26931.869	35805.258	50018.672	60294.473	69904.273	79121.273	0.706
	0.000	15362.381	19312.055	26646.385	36365.500	49560.523	60278.574	69563.734	78945.188	0.711
	0.000	15578.240	20715.270	28197.979	37978.285	50675.605	62024.656	71850.336	81172.305	0.927
	0.000	16570.094	21636.711	27159.457	38588.758	51253.297	61283.516	71803.008	80965.000	0.932
	0.000	16752.389	20775.469	27546.904	39660.316	51993.469	64598.906	74352.141	82817.148	1.095
	0.000	15874.967	21911.182	27546.908	41444.836	53544.039	64288.820	74893.273	83830.750	1.089
	0.000	17319.020	21608.551	30053.572	44643.875	58218.445	69572.641	79316.695	89298.273	1.384
	0.000	16358.048	22477.395	28775.670	44393.687	58205.867	69354.977	79744.039	89509.906	1.386
	0.000	17618.291	23058.934	30658.785	46145.762	59242.902	70974.266	80697.203	90903.266	1.666
	0.000	15148.819	23087.898	26513.900	45913.730	59648.402	69918.609	80504.836	90539.969	1.664
	0.000	16396.205	22210.725	29169.412	42593.613	56938.980	67983.539	78662.313	88644.414	1.361
	0.000	17289.063	22879.742	29226.883	42598.992	56856.383	68313.984	78877.539	88566.633	1.356
	0.000	17858.621	23366.219	29640.369	45606.590	60089.375	71476.172	82211.789	92153.602	1.581
	0.000	18161.956	23282.180	29705.135	45645.586	59663.809	71780.781	82171.148	92236.680	1.576
	0.000	18039.727	23029.467	30017.254	47646.055	61671.605	73279.258	84207.578	94223.016	1.683
	0.000	18093.146	23504.957	29767.313	47261.266	61540.535	73757.564	84316.584	94510.031	1.692
	0.000	18177.121	23972.465	30288.547	49327.750	64138.965	75754.102	86274.367	96920.570	1.831
	0.000	17750.205	23917.139	30460.672	49492.805	63676.973	75973.625	86549.039	96678.211	1.836
	0.000	18310.697	24165.676	30645.018	51137.488	65573.969	77858.727	88523.875	99208.844	2.054
	0.000	18415.131	23939.498	30644.729	50842.430	65625.406	77728.891	88428.719	98894.016	2.051
	0.000	18483.773	23882.258	30598.986	52157.113	66454.219	78998.000	89917.164	100338.930	2.128
	0.000	18665.754	24283.053	30755.660	50989.707	65979.469	78314.609	89497.641	99642.641	2.095
	0.000	19120.893	24668.822	32060.881	56191.074	71241.172	83119.148	94375.719	105247.492	2.491
	0.000	18939.828	23778.084	31282.449	56236.047	71001.781	83353.320	94644.234	105168.602	2.491
	0.000	19366.391	24496.199	32589.539	56898.219	72429.781	85616.836	96253.609	107080.227	2.637
	0.000	18961.668	24826.426	32088.363	58007.207	72794.328	85091.586	96336.664	107011.492	2.637
	0.000	19943.234	24930.293	31477.928	59578.564	75113.656	87156.766	98767.695	109177.102	2.815
	0.000	19777.713	24936.371	31359.326	58742.121	75514.383	87465.742	98659.602	109508.172	2.807
	0.000	19961.816	24782.268	32950.922	61869.758	76348.984	89042.148	100649.375	111065.734	2.938
	0.000	19850.428	24759.766	31354.102	61304.051	76234.219	89186.102	100883.844	111170.836	2.942
	0.000	20069.572	24681.469	32470.516	64712.375	78697.383	91811.805	103241.219	114198.414	3.136
	0.000	19881.307	24690.551	32396.365	64263.328	79193.500	92059.633	102995.836	113849.930	3.136
	0.000	20126.240	24801.133	32649.031	66825.391	82476.250	94411.508	106744.867	116997.172	3.342
	0.000	17736.432	25522.465	32273.980	66604.258	81736.086	94255.422	106646.938	117125.211	3.351

Table 50 HGL Test for kaolin 13%

7/10/2004	
Valve Type:	Diaphragm
Valve dimension[mm]:	40
Valve position:	Open
Pipe Diameter [mm]:	42.12
Material Type:	Kaolin 13%
Density[kg/m³]:	1208.6
τ_y:	35.000
K:	0.5999
n:	0.5

Axial distances	-6.298	-4.568	-1.880	-0.621	1.076	3.805	6.046	8.075	9.975	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	ΔP_1	ΔP_2	ΔP_3	ΔP_4	ΔP_5	ΔP_6	ΔP_7	ΔP_8	ΔP_9	
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	0.000	5542.124	17030.213	20363.252	28332.160	39306.746	46902.676	55246.871	62484.598	0.200
	0.000	6231.734	18325.750	22583.799	29803.416	39221.570	49264.121	57038.422	64625.895	0.273
	0.000	6419.931	17215.117	22988.203	29317.193	40362.406	49586.129	57335.332	64629.293	0.269
	0.000	8396.567	18195.914	23105.037	30949.795	41959.113	52293.020	60224.223	67866.256	0.414
	0.000	8179.369	18316.387	24087.598	31244.336	43098.707	51958.953	60541.090	68265.586	0.421
	0.000	8615.957	20158.587	25505.154	32596.107	45187.695	55155.207	64275.645	72754.766	0.761
	0.000	7395.993	18757.072	25351.654	33304.625	45529.387	55237.742	64275.645	72903.258	0.767
	0.000	9284.545	18999.820	23963.383	33982.051	47115.754	57242.453	65832.898	74550.547	0.932
	0.000	7424.554	16826.857	27350.547	35772.438	48371.016	56789.125	66914.805	74808.492	0.910
	0.000	5360.247	18478.191	24990.811	35952.750	46937.207	56670.055	65827.594	74486.359	0.919
	0.000	6624.445	19451.979	26671.393	34823.051	47435.617	57612.805	66675.445	74381.750	0.906
	0.000	5598.433	20671.674	23018.131	36151.793	47921.133	57733.457	66750.805	75065.039	0.918
	0.000	8951.542	20289.430	27179.773	39007.793	52219.223	62556.489	71723.828	80249.844	1.273
	0.000	7116.113	18951.346	26175.654	39257.043	52578.613	62077.539	71567.367	80037.867	1.277
	0.000	6690.265	19620.219	25398.336	39208.465	51327.922	61581.625	70846.477	79594.125	1.407
	0.000	8089.132	20184.351	25501.100	38764.734	51647.043	61602.680	70712.563	79293.852	1.407
	0.000	7555.214	19619.414	25844.139	39788.566	51649.473	62162.293	71510.164	80421.750	1.459
	0.000	7810.715	20824.502	26109.564	39790.191	52111.473	62198.191	71504.516	80404.266	1.463
	0.000	8532.830	20959.004	26464.237	41465.227	53498.320	63900.250	73424.297	82235.633	1.600
	0.000	8084.540	21136.771	26229.467	41387.707	53704.324	64003.207	73189.727	82158.039	1.614
	0.000	7979.620	20676.871	26599.994	42808.211	55436.246	65994.250	75666.023	84472.281	1.771
	0.000	8422.251	20796.314	26661.221	42758.770	55665.355	66518.242	75839.000	84867.109	1.778
	0.000	8574.374	20707.646	26475.285	45392.102	58276.555	68857.375	78247.063	87477.016	1.973
	0.000	8493.227	21054.109	26545.098	45546.238	58118.289	68776.055	78489.797	87518.805	1.968
	0.000	7676.997	20682.066	26534.277	43814.676	56472.117	67075.148	76540.664	85711.602	1.824
	0.000	8411.968	20457.797	26944.342	43500.047	56592.375	67133.313	76799.047	85473.531	1.824
	0.000	8066.354	21027.049	25707.957	44882.695	57335.363	67472.852	77247.258	86402.891	1.897
	0.000	8194.977	20706.740	27001.262	44662.281	57544.297	67644.617	77253.945	86460.198	1.901
	0.000	9337.569	20883.926	26393.893	46342.473	59424.137	69919.430	79817.063	88621.453	2.089
	0.000	9226.250	20483.390	26670.256	45881.680	58968.430	69843.156	79488.234	88489.680	2.065
	0.000	9224.232	21451.945	27563.299	48779.555	61970.066	72998.672	82770.789	91832.297	2.290
	0.000	8419.565	20014.422	27435.691	49179.648	62074.426	73039.094	82896.313	92204.727	2.299
	0.000	9662.534	22549.430	28562.457	51027.645	63190.527	74149.109	83924.742	93167.414	2.411
	0.000	8554.377	21491.545	27439.904	50135.008	63383.457	74163.711	83690.492	93132.852	2.415
	0.000	8533.578	21623.180	28307.359	52004.172	64870.551	75850.047	85854.578	95265.742	2.591
	0.000	8466.902	22086.832	29582.791	53592.160	69065.602	79305.047	89852.305	99489.906	2.926
	0.000	8832.101	21937.391	28647.246	56673.598	70560.430	80864.594	91955.414	100860.703	3.043
	0.000	8847.854	22411.674	28203.771	59096.539	72896.391	85355.141	94383.547	103936.289	3.213
	0.000	8583.632	22486.506	28833.467	61656.164	77265.805	88164.867	97963.430	107276.133	3.355

Table 51 HGL Test for kaolin 13%

		Axial distances	-6.5744	-3.5264	-1.5314	-0.527	1.257	4.013	5.666	7.666	9.669	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
28/9/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		97969.195	86275.289	78638.016	74498.781	67423.109	56683.703	48698.172	41283.039	33478.215	0.614
Valve dimension[mm]:	50		97654.836	86178.008	78603.125	74328.023	67372.492	56628.766	48524.500	41211.094	34074.457	0.616
Valve position:	Open		99135.477	87291.813	79585.789	75250.742	68107.906	57323.016	49223.598	41611.168	33684.758	0.743
Pipe Diameter [mm]:	52.8		99255.922	87143.234	79621.914	75400.686	68095.391	57283.945	48987.176	41611.781	34549.219	0.749
Material Type:	Kaolin 13%		100165.172	88066.063	80363.070	75936.906	68731.219	57753.684	49375.180	41877.297	33850.971	0.874
Density[kg/m^3]:	1214		99739.465	88097.844	80263.594	75515.820	66676.672	57589.449	48988.887	41860.527	34114.883	0.875
τ_y:	30.000		100763.633	88839.750	80857.250	76368.383	68988.016	58003.430	49136.496	42017.484	34001.781	0.988
K:	1.500		100635.039	88242.641	80842.914	76289.273	68911.594	57825.297	49315.930	41929.074	34629.188	0.989
n:	0.590		101016.203	88654.414	80831.286	76619.922	69138.805	58045.398	48848.254	41949.727	33936.508	1.075
			100915.316	88841.695	80902.344	76588.797	68844.469	57928.719	49016.580	41939.531	34487.445	1.085
			101639.078	89057.664	81651.492	77226.219	69472.836	58420.290	49404.617	42209.168	34083.227	1.300
			101584.352	88878.055	81628.914	77198.563	69263.766	58372.563	48999.789	42214.734	34956.781	1.302
			101554.727	89431.578	81254.719	77155.242	69336.656	58223.164	50347.871	42157.543	33945.484	1.564
			101519.477	89395.297	81360.141	77115.492	69281.648	58217.031	50267.648	42083.980	34163.328	1.561
			102172.680	89798.773	81900.070	77235.086	69423.930	58374.531	50296.676	42150.461	33203.012	1.651
			102119.672	89885.828	81867.156	77343.922	69501.313	58354.484	50252.797	42236.047	34493.565	1.650
			102262.891	90018.031	81913.383	77339.078	69512.258	58442.180	50305.410	42185.355	33367.777	1.708
			102331.617	89996.953	81952.070	77461.453	69389.156	58462.746	50418.664	42216.250	34383.352	1.700
			103236.555	90872.063	82533.719	78249.570	70206.195	58957.258	50214.586	42383.375	33807.289	1.998
			103290.664	90841.539	82587.727	78170.078	70076.930	58990.313	49961.875	42293.254	34405.953	1.979
			102873.680	90369.695	82102.656	77582.633	69541.063	58626.137	50374.676	42517.387	32907.734	2.351
			101869.922	90332.992	82145.031	77139.867	69399.039	58559.965	50166.563	42409.473	34097.957	2.347
			102024.328	90931.391	82878.500	78369.227	70125.258	58808.750	50460.098	42541.699	34450.336	2.561
			102540.172	91339.711	83222.531	77910.172	70725.109	59045.344	50178.715	42567.645	34776.340	2.564
			101679.031	90545.438	81924.797	77558.141	68646.688	56859.836	48289.434	43107.500	31792.807	2.862
			100836.352	89845.195	82621.578	78333.936	66550.938	56641.246	47903.227	39932.379	32339.693	2.848
			102511.391	90470.438	81521.016	77212.273	66703.508	56661.063	48428.180	39836.500	44489.645	3.036
			101602.313	90259.969	81703.711	76841.547	68371.313	56671.652	47959.766	39703.746	31721.936	3.048
			102074.594	90767.742	82313.305	77603.789	68779.234	56422.086	47369.137	39557.987	31514.211	3.281
			101636.477	90684.539	82237.156	77769.594	68460.578	56514.730	47458.699	39451.082	32434.869	3.284

Table 52 HGL Test for kaolin 13%

		Axial distances	-6.9735	-4.8855	-2.885	-0.937	0.987	2.938	3.916	8.432	10.156	
		Valve plane				0						
			Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
27/9/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		97630.273	89567.539	82107.141	74592.539	66703.922	59459.363	55579.426	38322.031	33813.914	5.003
Valve dimension[mm]:	50		109131.320	100774.258	92718.500	84822.914	76485.102	68780.789	64802.445	45069.535	41466.336	5.360
Valve position:	Open		108463.063	100012.125	92227.977	84007.586	75670.672	67998.773	63933.484	43953.566	40355.867	5.193
Pipe Diameter [mm]:	52.8		109446.703	101104.055	93126.039	85136.336	76784.867	68996.125	64501.410	45302.980	41462.590	3.965
Material Type:	Kaolin 13%		109513.477	101125.273	93169.797	85127.008	76743.117	69011.086	64681.418	45086.461	41518.664	3.945
Density[kg/m^3]:	1209.9		109716.078	101290.477	93458.352	85329.063	76990.211	69187.961	64514.520	45354.141	41525.254	4.087
τ_y:	30.000		109802.531	101388.945	93411.336	85247.313	76885.133	69114.313	65627.984	45835.566	41431.938	4.075
K:	1.200		110165.102	101933.945	93679.055	85673.984	77083.156	69227.141	65259.941	45645.141	41543.230	4.291
n:	0.610		110669.555	102174.695	93987.406	86015.211	77254.602	69605.305	65318.523	45464.156	41515.813	4.251
			111071.125	102689.305	94568.789	86507.219	77751.422	69863.891	65807.539	49825.520	41839.715	4.596
			111451.352	102834.609	94651.703	86505.195	77776.516	69885.898	65828.078	49846.227	41863.137	4.614
			111695.328	103120.641	95199.148	87052.305	78021.742	70291.531	65962.469	50015.348	41968.867	4.891
			112193.430	103382.602	95200.570	87547.125	78100.867	70259.477	66199.313	49429.426	42187.602	4.881
			112691.789	103662.102	95877.570	88109.461	78855.625	70576.648	66933.445	49822.703	42254.824	5.080
			112840.406	104094.063	96143.891	87813.648	78651.094	70824.961	66719.773	48142.707	42240.469	5.045
			113811.289	105396.227	96694.211	88904.047	79332.406	71140.125	67029.125	50608.125	42450.363	5.202
			113902.734	104638.297	96704.430	88619.227	79254.234	71335.758	66897.766	50159.672	42354.438	5.206
			113946.383	105070.656	96777.172	88634.063	79412.836	71378.508	67433.875	49421.340	42588.684	5.280
			113913.000	105940.047	96957.781	88768.742	79371.898	71099.914	67093.820	49313.328	42478.277	5.158
			104143.502	96698.180	89196.047	81740.602	74084.586	66567.633	62871.141	48075.035	40678.051	2.298
			100343.102	92212.438	84447.766	76887.320	68698.414	61094.584	57287.801	41542.730	34633.273	3.846
			104453.273	95830.719	87842.641	79822.602	71151.070	63422.434	59290.380	42039.488	35122.082	5.418
			105419.227	97186.102	88910.578	80745.945	71934.688	63781.098	59693.578	42239.473	35759.500	5.804
			107704.305	95340.875	90759.859	82272.336	72833.320	65087.901	60880.906	39180.789	35546.797	7.053

Table 53 HGL Test for kaolin 13%

		Axial distances	-5.47	-3.526	-2.281	-0.780	1.257	4.013	5.666	7.666	9.669	
		Valve plane				0						
			Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
8/10/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		88071.320	81509.391	77017.648	71449.463	63696.895	53817.527	46683.668	35418.422	31974.428	1.759
Valve dimension[mm]:	50		89542.445	83899.430	78261.219	72630.641	64717.926	54637.102	47292.793	35794.797	32348.572	2.174
Valve position:	Open		89995.648	83173.070	78363.719	73138.875	64299.059	54064.074	46474.063	38910.258	31173.996	2.594
Pipe Diameter (mm):	53.5		91527.570	84594.344	79933.555	73972.266	64985.742	54413.387	46733.324	38934.711	30929.766	3.077
Material Type:	Kaolin 13%		93216.133	85795.641	80826.344	74705.664	64999.582	54360.898	46762.168	38876.396	30886.273	3.354
Density[kg/m³]:	1210.2		90638.805	83298.805	78662.258	72369.836	64356.168	54173.324	46451.855	38842.707	31234.021	2.848
τ_y:	30.000		89402.195	82745.891	78115.563	71964.625	64001.363	53726.852	46312.004	38766.238	31349.701	2.644
K:	1.200		88491.609	81975.961	77441.344	71905.227	63556.656	53476.555	46193.977	38813.965	31456.893	2.327
n:	0.610		87639.750	81741.719	77147.539	71664.008	63980.375	54117.105	46673.227	39461.883	32273.426	1.957
			85975.625	80210.914	75765.000	69962.391	62815.918	53340.016	46207.660	39074.422	32070.539	1.525
			84916.352	78235.414	73951.945	68413.906	61422.328	52144.027	45424.469	38557.879	31700.543	1.039
			81808.555	75970.977	71778.547	66869.781	59863.586	50996.301	44475.641	37881.887	31241.549	0.691

Table 54 HGL Test for kaolin 13%

		Axial distances	-6.9735	-4.8855	-2.885	-0.937	0.987	2.938	3.916	8.432	10.156	
		Valve plane				0						
			Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8	Pos 9	Average Flow rate
23/9/2004			Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm		96407.047	88689.016	81997.844	74975.180	67657.070	60712.578	57240.664	43108.996	36269.594	1.839
Valve dimension[mm]:	65		96225.883	88768.625	81652.953	74985.875	67580.133	60729.789	57289.086	43215.082	36264.855	1.844
Valve position:	Open		96379.844	89520.055	82170.344	75237.383	67928.891	60799.383	57429.891	43116.840	36316.617	2.018
Pipe Diameter (mm):	63.08		96287.414	89312.078	82156.016	75171.930	67907.992	60944.820	57605.250	43135.523	36351.445	2.011
Material Type:	Kaolin 13%		96977.727	89583.609	83550.500	75501.352	68170.391	61125.203	57593.582	43327.664	36457.352	2.177
Density[kg/m³]:	1219.9		96843.555	89820.867	82489.797	75509.406	68256.555	61126.512	57852.133	43420.594	36482.273	2.177
τ_y:	35.000		96675.648	89593.766	81947.125	75445.164	68199.984	61003.113	57635.285	43650.348	36517.668	2.255
K:	1.500		96523.750	89570.078	82116.563	75332.516	68428.602	60926.887	57219.531	43644.609	36587.918	2.246
n:	0.500		97165.852	90133.867	82425.695	75836.336	68522.164	61237.266	57650.172	43821.023	36675.555	2.429
			97312.648	90170.391	82569.992	75854.484	66697.992	61185.117	57407.074	43825.238	36688.492	2.416
			97561.039	90218.578	83205.609	76262.891	68691.969	61601.281	57761.418	43974.754	36869.543	2.568
			97715.664	90539.391	83096.094	76068.906	68958.367	61760.516	57998.156	44057.633	36885.516	2.555
			98131.953	90707.555	83528.398	76390.703	68771.133	61975.371	57561.184	44184.137	37039.367	2.703
			98360.664	90390.641	83564.469	76315.875	69111.008	61956.582	58156.762	44249.734	37021.305	2.708
			97312.469	89997.602	82817.664	75397.609	68419.961	61525.418	57608.727	43706.313	36524.938	2.808
			97453.750	90221.289	83096.516	75671.313	68345.938	61372.992	57588.945	43620.723	36559.449	2.804
			97573.477	90095.966	82830.898	75432.656	68292.281	61544.953	57821.488	43642.863	36507.293	3.031
			97708.305	89888.609	82573.453	75811.625	68134.039	61376.305	57794.672	43595.691	36396.359	3.005
			97513.727	90328.734	83082.039	76164.141	68418.969	61512.590	57871.523	43838.965	36508.855	3.072
			98109.016	90440.992	83442.773	76298.016	68433.906	61532.230	57875.734	43808.344	36579.566	3.077
			96187.141	88330.977	81301.031	73799.867	66724.047	58915.348	55501.605	40868.547	33825.461	3.419
			96219.648	83648.102	81236.797	73943.672	66341.906	59215.957	55539.289	41076.129	33817.941	3.408
			96199.781	88559.227	81411.602	73867.570	66248.398	59088.773	55235.961	41007.082	33724.648	3.543
			96421.805	88625.898	81161.117	73556.430	66224.617	59228.793	54989.281	41038.668	34247.215	3.526
			96465.500	88658.961	81478.513	73544.672	66480.500	59148.340	54462.043	40787.703	33685.715	3.988
			96516.164	88933.180	81437.891	73923.203	66399.977	59092.621	55573.414	40285.570	34483.313	3.951
			97567.852	90063.844	82258.852	74890.250	66863.930	59613.328	55468.277	41150.172	33530.254	4.872
			98342.219	90122.898	82791.859	74965.906	67010.938	59802.094	55606.449	40920.238	33893.867	4.845

Table 55 HGL Test for kaolin 13%

	Axial distances	-6.9735	-4.8855	-2.885	-0.937	0.987	2.938	3.916	8.432	10.156	
	Valve plane				0						
		Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
27/9/2004		Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm	97630.273	89567.539	82107.141	74592.539	66703.922	59459.363	55579.426	38722.031	33813.914	5.003
Valve dimension[mm]:	65	109131.320	100774.258	92719.500	84822.914	76485.102	58780.789	64802.445	45069.535	41466.336	5.360
Valve position:	Open	108463.063	100012.125	92227.977	84007.586	75670.672	67988.773	63933.484	43953.566	40355.867	5.193
Pipe Diameter [mm]:	63.08	109446.703	101104.055	93126.039	85136.336	76784.867	68996.125	64501.410	45302.980	41462.590	3.965
Material Type:	Kaolin 13%	105513.477	101125.273	93169.797	85127.008	76743.117	69011.086	64681.418	45086.461	41318.664	3.945
Density[kg/m³]:	1209.9	105716.078	101290.477	93458.352	85529.063	76990.211	69187.961	64514.520	45354.141	41525.254	4.087
τ_y:	35.000	109832.531	101388.945	93411.336	85247.313	76885.133	69114.313	65627.984	45835.566	41431.938	4.075
K:	1.900	110165.102	101953.945	93679.055	85673.984	77083.156	69227.141	65359.941	45645.141	41543.230	4.241
n:	0.500	110669.555	102174.695	93987.406	86015.211	77254.602	69605.305	65318.523	45464.156	41515.813	4.251
		111071.125	102689.305	94568.789	86507.219	77751.422	69862.891	65807.539	49825.520	41839.715	4.396
		111451.352	102834.609	94651.703	86505.195	77776.516	69885.898	65828.079	49846.227	41863.137	4.614
		111695.328	103120.641	95199.148	87752.305	78021.742	70291.531	65562.469	50015.348	41968.867	4.891
		112193.430	103382.602	95200.570	87547.125	78100.867	70259.477	66199.313	49429.426	42187.602	4.881
		112691.789	103662.102	95877.570	88109.461	78855.625	70576.648	66933.445	49822.703	42254.824	5.080
		112840.406	104054.063	96143.891	87813.648	78651.094	70824.961	66719.773	48142.707	42240.449	5.045
		112811.289	105396.227	96654.211	88904.047	79332.406	71140.125	67029.125	50638.125	42450.363	5.202
		113902.734	104638.297	96704.430	88618.227	79254.234	71335.758	66897.766	50159.672	42354.438	5.206
		113946.383	105070.656	96777.172	88634.063	79412.836	71378.508	67433.875	49421.840	42588.684	5.283
		113913.000	105940.047	96937.781	88768.742	79371.898	71099.914	67093.820	49313.328	42478.277	5.158
		104143.602	96698.180	89196.047	81740.602	74084.566	66567.633	62871.141	48079.035	40678.051	2.298
		100343.102	92212.438	84447.766	76887.320	68699.414	61094.684	57287.801	41542.730	34633.273	3.846
		104453.273	95830.719	87942.641	79922.602	71151.070	63422.434	59290.883	42039.488	35122.082	5.418
		105419.227	97186.102	88910.578	80745.945	71934.688	63781.098	59693.578	42239.473	35759.500	5.804
		107704.305	99340.875	90759.859	82272.336	72833.320	65087.801	60862.906	39183.789	35546.797	7.053

Table 56 HGL Test for kaolin 13%

	Axial distances	-6.012	-4.809	-3.61	-1.509	0.707	3.907	5.273	8.461	9.956	
	Valve plane				0						
		Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
8/10/2004		Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
Valve Type:	Diaphragm	67986.422	65264.262	62754.563	58483.891	53172.305	46371.793	43473.105	36856.363	33595.180	0.179
Valve dimension[mm]:	80	67823.906	65347.965	62823.574	58505.633	53305.375	46381.914	43460.813	36776.898	33561.453	0.272
Valve position:	Open	67946.594	65766.438	63173.043	58782.945	53458.273	46614.340	43670.734	36990.820	33708.781	0.946
Pipe Diameter [mm]:	80.43	68344.000	65988.703	63452.590	59099.180	53647.270	46766.238	43825.492	37123.402	33819.684	1.090
Material Type:	Kaolin 13%	68497.539	66242.148	63637.367	59119.922	53790.684	46899.398	43951.074	37278.863	33862.602	1.275
Density[kg/m³]:	1210.2	69060.531	66870.344	64233.602	59340.121	54301.402	47360.699	44332.441	37406.227	34102.586	1.559
τ_y:	29.000	68325.141	65957.969	63399.313	58423.086	53299.066	46423.695	43298.781	36427.410	33045.449	1.827
K:	1.500	68127.227	66357.766	63643.848	58589.805	53519.836	46434.457	43409.582	36591.883	33134.066	2.089
n:	0.500	68195.750	66547.906	63920.727	58926.426	53699.348	46596.941	43476.242	36627.324	33143.484	2.318
		68567.766	66951.094	64325.723	59324.652	53872.996	46675.191	43593.770	36598.805	33230.852	2.596
		68836.484	67221.203	64496.402	59188.801	53832.996	46898.164	43806.422	36640.477	33137.063	2.788
		69281.008	67523.781	64938.480	59636.395	54196.387	47007.113	43870.836	36645.109	33309.531	3.088
		70753.633	68203.445	65493.910	60644.844	54528.672	47471.738	44417.953	37037.031	33777.012	3.352
		71390.469	69014.227	66205.984	61362.223	55109.691	48035.020	44557.234	37640.965	34182.223	3.509
		71454.008	68753.023	66064.383	61151.793	54643.453	47568.355	44340.813	37026.578	33549.691	3.803
		71151.180	69112.469	66372.992	61653.895	54849.566	47660.078	44456.988	37118.270	33621.750	4.093
		72049.547	69724.086	66589.578	61654.715	55114.684	47719.355	44609.020	37196.539	33741.402	4.334
		72941.820	70034.711	67069.336	62340.371	55040.035	47858.242	44588.352	37009.938	33604.836	4.462
		73163.656	69740.125	67359.016	62754.254	55364.320	48010.738	45003.559	37217.727	33754.922	4.808
		73303.234	70195.766	67670.561	63039.895	55389.145	47962.398	44719.863	37452.211	33780.762	5.075
		74200.125	71547.336	68498.258	63571.832	55202.488	48221.848	45074.242	37322.742	33689.789	5.526

Table 57 HGL Test for kaolin 13%

27/9/2004	
Valve Type:	Diaphragm
Valve dimension(mm):	80
Valve position:	Open
Pipe Diameter (mm):	80.43
Material Type:	Kaolin 13%
Density[kg/m³]:	1209
Ty:	29.000
K:	1.590
n:	0.500

Axial distance	-6.413	-4.809	-3.51	-1.609	0.707	3.907	5.272	8.461	9.956	
Valve plane				0						
	Pod 1	Pod 2	Pod 3	Pod 4	Pod 5	Pod 6	Pod 7	Pod 8	Pod 9	Average Flow rate
	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	[l/s]
	72457.813	69113.299	66253.563	61237.816	55159.840	47819.263	44674.121	37186.746	33550.070	2.879
	72174.680	68932.477	66101.563	60990.555	55203.664	47719.426	44473.176	36661.152	33475.219	2.845
	72031.648	69150.047	66391.633	61547.781	55318.602	47785.359	44387.578	36326.344	33522.023	3.030
	72082.273	69312.164	66395.945	61084.383	55210.434	47538.949	44596.621	36437.004	33964.273	3.054
	72201.305	69456.930	66723.375	61970.875	55500.781	47459.051	44750.945	36499.063	34008.375	3.361
	72397.727	69917.656	67080.383	61445.250	55961.539	47632.047	44582.469	36759.223	33887.055	3.349
	73616.211	70854.445	67704.275	63112.484	56261.488	48226.406	44948.859	37354.828	34292.309	3.708
	74111.928	71315.445	68023.703	63253.676	56331.641	48654.730	45595.555	37185.453	35110.207	3.705
	75410.727	71672.883	68478.758	63925.512	56611.227	49311.906	46347.758	38326.344	34739.043	3.925
	74801.227	71634.594	68673.391	63973.160	56511.207	49450.391	45956.637	38301.637	34549.188	3.950
	72284.156	68335.711	65647.656	61049.332	53870.498	47198.004	44475.840	37075.984	34075.500	4.188
	72213.242	68816.234	65953.406	61232.875	54113.273	47247.801	44399.031	37010.609	33646.356	4.189
	73202.828	69416.758	66715.531	62039.668	55097.363	48095.977	44817.703	37428.395	34001.633	4.301
	73195.602	65669.078	66806.730	61873.664	54954.941	47956.453	44669.914	37579.828	34000.133	4.286
	73154.242	69614.125	67056.609	62050.113	55320.441	47294.156	44656.086	37313.584	33898.528	4.495
	72805.891	69430.477	67014.477	62256.191	55047.066	48021.723	44872.539	37291.082	33734.488	4.502
	73563.500	70119.633	67424.813	62318.949	55627.617	48065.285	44923.945	37613.922	33946.234	4.668
	73119.453	70302.898	67166.294	62678.242	55176.031	48189.297	44986.652	37583.188	33945.293	4.680
	74329.547	70893.969	67571.156	62980.020	55690.330	48261.801	45006.469	37642.469	34028.965	4.856
	73328.430	70493.230	67597.991	62790.426	55475.648	48012.331	44782.426	37636.484	34040.992	4.868
	74566.125	70499.180	67989.266	63054.645	55471.555	48276.883	44933.707	37411.584	33841.859	5.209
	74471.250	70986.203	67672.070	63229.473	55384.074	48198.395	45076.734	37547.000	34154.773	5.210
	75140.813	71699.195	68486.273	63946.926	55871.141	48542.148	45260.070	37781.926	34099.133	5.544
	75166.953	71622.406	68270.320	63778.953	55526.320	48328.328	44990.215	37630.746	34078.449	5.536
	75449.586	71277.844	68561.563	63654.324	55509.773	48258.047	45233.289	37630.391	34049.758	5.703
	75104.477	71718.836	68720.133	63620.176	55625.449	48423.121	45270.160	37704.992	34031.035	5.677
	73161.945	70414.305	67664.945	62993.336	54712.324	47941.586	45003.285	37280.414	33971.508	5.115
	74429.766	70848.922	68030.273	63290.113	55640.426	48189.125	45104.191	37716.551	34010.121	5.084
	73563.992	70597.953	67601.031	63006.816	55467.539	48305.578	44866.414	37616.168	34210.203	4.735
	73882.859	70672.156	67649.656	62826.926	55622.543	48254.965	44819.215	37568.781	34219.773	4.757
	73846.820	70252.223	67214.461	62494.727	55706.480	48023.730	45137.902	37670.035	34146.465	4.413
	74137.461	70118.781	67222.216	62538.258	55340.898	48293.379	44972.563	37726.922	34152.566	4.411
	72599.383	69162.695	66158.742	61728.578	54967.602	47660.582	44715.934	37337.145	33757.379	3.998
	72302.773	67317.586	66344.308	61761.020	55043.969	47810.605	44726.277	37298.500	33798.160	3.978
	70755.742	67418.555	64638.281	60096.223	53843.906	46854.066	43807.516	36643.180	33112.244	3.383
	69498.141	66304.969	63647.379	59120.566	53387.574	46255.719	43259.188	36359.070	32930.957	2.487