THE RANGE OF APPLICABILITY OF MODELS FOR THE FLOW OF HIGH CONCENTRATION BACKFILL SLURRIES IN PIPELINES

by

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BSc (Civil Engineering)

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DECLARATION

I, Peter Edward Goosen, declare that this thesis is essentially my own work and has not been submitted for a degree at another university.

Signed by candidate

Signature Removed

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APRIL 1992

ABSTRACT

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Two models recently developed at the University of Cape Town are intended to model the flow of high concentration backfill slurries. These models are the Cooke model for dense phase flow of cyclone classified tailings and the Paterson model for stabilised flow of high concentration full plant tailings.

These two materials (cyclone classified tailings and full plant tailings) form the extremes, in terms of particle size distribution, of tailings materials used as backfill in South African gold mines. The purpose of this dissertation is to investigate the possibility of applying these models in the region, in terms of particle size distribution, between full plant tailings and cyclone classified tailings.

Measured pressure gradient data has been collected for materials with particle size distributions ranging from full plant tailings to cyclone classified tailings. The calculated model predictions are then compared with the measured data in order to determine the range of applicability of the models.

Three intermediate materials were made up by mixing full plant tailings and cyclone classified tailings in ratios of 1 to 2, 1 to 1 and 2 to 1. These, together with the cyclone classified tailings and two full plant tailings materials, provided the range of materials in terms of particle size distribution.

The six materials are characterised in terms of relevant solid and particle properties. Measured pressure gradient data is then presented covering two pipe diameters (40 mm and 80 mm nominal bore), a range of solids concentrations (35% to 52% by volume) and a range of flow velocities (0.5 to 4.5 m/s).

The models of Cooke and Paterson are reviewed. Model predictions are then calculated for comparison with the measured data. The range, in terms of solids concentration and particle size distribution, over which each model is in acceptable agreement with the measured data is then presented and reported as the range of applicability of the model.

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TABLE OF CONTENTS

Detailed chapter contents:

Page

Chapter 1 : Introduction

Page

Chapter 2 : Experimental investigation

Page

Chapter 3 : Literature review

Page

Chapter 4 : Model evaluation

NOMENCLATURE

		units
C	Solids concentration	
d_{50}	particle diameter such that 50% of solids by mass are smaller than d_{50}	m
D	Pipe internal diameter	m
g	Acceleration due to gravity	m/s^2
h	Thickness of boundary fluid shear layer	m
i	Hydraulic gradient	
K	Fluid consistency index	$Pa.s^n$
Kr	Coefficient of lateral interparticle stress	
L	Length along pipe axis	m
n	Flow behaviour index	
P	Fluid pressure	Pa
r	Radial displacement from pipe axis	m
S	Relative density	
Sf	Particle shape factor	
δ	Internal angle of friction	radians
μ	Dynamic coefficient of viscosity	$N.s/m^2$
μ_s	Coefficient of sliding friction	
ν	Kinematic coefficient of viscosity	m^2/s
ρ	Density	Kg/m^3
σ	Normal stress	Pa
τ	Shear stress	Pa
φ	Angle defining pipeline slope	radians

Subscripts

b	Settled bed
f	Fine fraction
l	Liquid phase
m	Mixture
s	Solid phase
v	Viscous
w	Water
0	Pipe wall

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CHAPTER 1

Introduction

1. BACKGROUND

Backfilling of mined out areas with waste material (tailings) has become common practice in South African gold mines.

Backfill provides an alternative to timber supports for controling stope convergence and rock bursts. Additional advantages of backfilling are, reduced fire hazard, reduced ventilation costs and increased ore extraction.

Backfill is prepared at the surface from where it is transported underground and placed in paddocks as a slurry.

It is advantageous to place backfill at a high solids concentration as shrinkage and water run off after placement are reduced. A significant limitation to the transport of high concentration backfill slurries however, is a lack of knowledge of the flow behaviour of such slurries.

The design of reticulation systems for the distribution of backfill slurry underground requires a knowledge of the relationship between the pressure gradient and mean flow velocity in the pipeline. The measurement and prediction of pressure gradients for backfill slurries has thus been the subject of research at the University of Cape Town for a number of years.

As a result of this research, two mathematical models have been developed to model the flow of high concentration backfill slurries. These two models have, however, been developed for two distinctly different backfill materials as described below.

The Paterson model for stabilised flow of high concentration full plant tailings.

Paterson (1991) has developed a method for determining the rheology (and thus modeling the flow) of high concentration full plant tailings slurries.

Full plant tailings is the milled waste product remaining after the gold extraction process. The milling of the ore during this process results in finely divided, angular particles generally falling into the size range one micron to four hundred microns, as shown in Figure 1.1.

The Cooke model for dense phase flow of high concentration cyclone classified tailings.

Cooke (1991) has developed a model for the flow of high concentration cyclone classified tailings.

Cyclone classified tailings is produced by removing most of the fine fraction from full plant tailings by means of hydro–cyclones. The resulting material generally falls into the size range one hundred microns to four hundred microns, as shown in Figure 1.1.

The models of Cooke and Paterson have thus each been developed for extremes of the spectrum, in terms of particle size distributions, of possible gold tailings slurries.

2. THE OBJECT AND SCOPE OF THE INVESTIGATION

As each model has been developed specifically for materials at opposite extremes of the spectrum of possible tailings slurries, it is felt that a valuable contribution can be made to the industry by investigateing the range within the spectrum of possible tailings slurries over which each model can be used.

The object of this investigation is thus to determine the range, in terms of particle size distribution and solids concentration, over which the models of Cooke and Paterson are applicable.

3. METHODOLOGY

A data base of pressure gradient measurements covering a range of flow velocities, solids concentrations and materials (in terms of particle size distribution) has been built up.

These measured data are compared to calculated model predictions. The degree to which each data set and corresponding model prediction agree is determined. Conclusions are then drawn as to the range of applicability of each model based on the range over which agreement between the measured data and the model predictions is achieved.

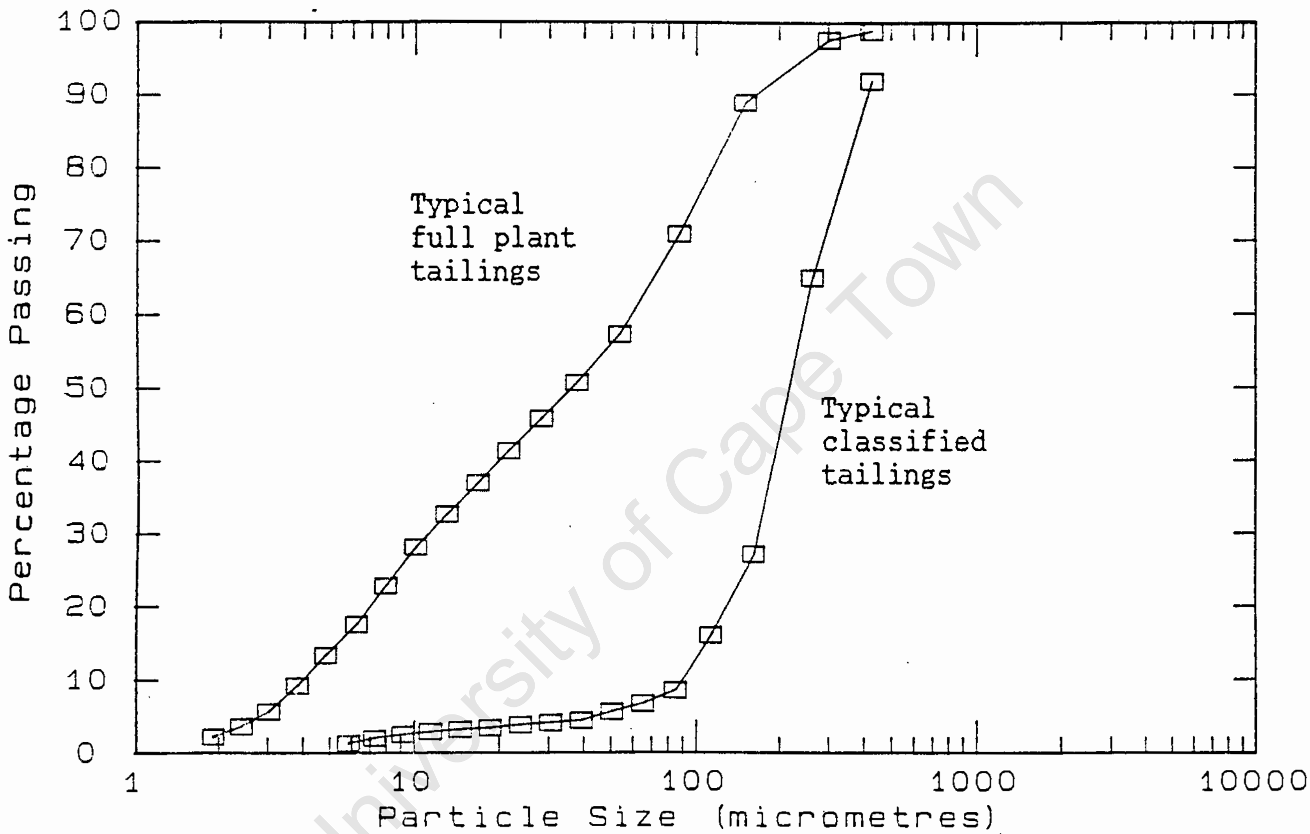


Figure 1.1 : Particle size distribution of typical full plant and cyclone classified tailings

CHAPTER 2

Experimental investigation

1. INTRODUCTION

The purpose of the experimental investigation is to build up a data base of pressure gradient data for high concentration tailings slurries which is used to evaluate the models. In compiling the data base, an attempt was made to cover as wide a range as possible in terms of solids concentration and material particle size distribution.

Pressure gradient data has been collected for six distinctly different materials (in terms of particle size distribution). Full plant tailings and cyclone classified tailings were available as "parent" materials and thus set the two extremes in terms of particle size distribution.

Three "intermediate" materials were produced by mixing the two parent materials (material 1 and material 5) in various ratios, as indicated in Table 2.1. Note that material 5 and 5A are two separate batches of full plant tailings and have significantly differant particle size distributions.

Material description	Mix ratio (CCT to FPT)	Material number	d_{50} [microns]	% −10 microns
CCT	–	1	211	3
Mix	2:1	2	162	9
Mix	1:1	3	128	13
Mix	1:2	4	81	19
FPT	–	5	56	22
FPT	–	5A	36	28

CCT – Cyclone classified tailings
FPT – Full plant tailings

Table 2.1 : Material descriptions, mix ratios, numbering, d_{50} and % −10 microns.

The six materials tested have been numbered 1 to 5 and 5A, as shown in Table 2.1. The materials are referred to by these numbers in the remainder of this document.

The five materials have been characterised in terms of relevant solids and material properties. This is presented in section 2 of this chapter.

The pipeline test facility used to collect the pressure gradient data is described in section 3, the experimental procedure is described in section 4 and the experimental results are presented in section 5. An analysis of the expected errors associated with the experimental data is presented in section 6.

2.2.3 Freely settled concentration ($C_{b\ FREE}$)

The freely settled concentration is defined as the concentration of the particle matrix formed when the particles settle through water to form a bed. This is determined using the procedure as described below:

(i) A one litre measuring cylinder is filled to 75% of its volume with de-aired water.

(ii) Oven dried solids are slowly poured into the measuring cylinder until the water level reaches the one litre mark. The volume of solids added is determined by weighing the measuring cylinder before and after the solids have been added, knowing the solids density.

(iii) After 24 hours the volume of the settled particle matrix is recorded.

(iv) The freely settled concentration is calculated as follows:

$$C_{b\ FREE} = \frac{\text{Volume of solids}}{\text{Volume of settled matrix}} \qquad (2.1)$$

Where :

$$\text{Volume of solids} = \frac{\text{Mass of solids}}{S_s}$$

It has been noted that, particularly for materials with a high fines content, the settled matrix formed in the cylinder comprises two distinct layers. A lower layer is formed consisting of course particles which settle almost immediately. An upper layer is formed consisting of fine particles which settle over a period of hours. The measured freely settled concentration is thus not a true measure of the freely settled concentration as may occur in a pipeline. In the case of slurry flow in a pipeline the fine particles would be in suspension in the carrier fluid and thus occupy the interstices between the coarse particles. However, the test as described above, is considered a valuable method of characterising these materials as it is easy to perform and gives repeatable results.

2.2.4 Submerged internal angle of friction (δ)

The submerged internal angle of friction is the submerged angle of repose (maximum slope at which the particle matrix remains stable) of the settled particle matrix. This is measured using the apparatus and method as developed by Cooke (1991).

The apparatus is a rectangular perspex box with a central opening in its base, as shown in Figure 2.2.

The test procedure is described below:

(i) The hole in the base of the box is plugged and the box half filled with de-aired water.

(ii) An oven dried sample of known mass (and thus volume) is poured into the box, taking care to ensure that the sample is evenly distributed.

(iii) The concentration of the settled particle matrix is varied by vibrating the box to compact the sample. The concentration is determined by measuring the height of the settled matrix, knowing the geometry of the box and the volume of solids.

(iv) The box is submerged in water and the plug in the opening removed. The solids pour out, forming a V-shape in the box, as shown in Figure 2.2 The angle that the V forms with the base of the box is measured and reported as the submerged internal angle of friction.

2.2.5 Coefficient of sliding friction (μ_s)

The coefficient of sliding friction is determined using a "tilting tube" apparatus as developed by Wilson et al (1972). This consists of a length of clear PVC tube which can be tilted about a central pivot point, as shown in Figure 2.3.

The test procedure involves placing a test sample at one end of the tube which is filled with water, ensuring that the sample forms a shallow bed (about 1 tenth of the tube diameter). The tube is then progressively tilted until the sample slides down the slope. The slope at which sliding occurs is noted and the coefficient of sliding friction is taken to be the tangent of the angle to the horizontal.

It is noted that what is measured is in fact the coefficient of static friction as the particles are initially at rest. However, as no simple procedure is available for measuring the coefficient of sliding friction directly, it is assumed to be equal to the measured coefficient of static friction.

2.2.6 Particle shape factor (Sf)

The particle shape factor is defined as the ratio of the particle settling velocity to the settling velocity of an equivalent sphere (a sphere of the same mass and volume as the particle).

The terminal settling velocity of the particles is measured by timing the particles settling over a known distance. The terminal settling velocity of an equivalent sphere is calculated.

The particle shape factor has been determined for particles in one size band only, this being 212 to 300 microns, with the representative particle diameter calculated as the geometric mean, d.

$$d = \sqrt{d_1 \, d_2} \qquad (2.2)$$

Where : d_1 = lower limit of size band

d_2 = upper limit of size band

This particular size band (212 to 300 microns) has been chosen as it is used by Cooke (1991) as an input for his model.

2.3 Material characterisation test results

The measured solid and particle properties for the six materials are summarised in Table 2.2 below.

Material :	1	2	3	4	5	5A
d_{50} [microns]	217	155	126	90	58	36
% −10 microns	3	9	13	19	22	28
S_s	2.73	2.74	2.74	2.74	2.74	2.73
$C_{b\ FREE}$ [%]	48.9	46.2	47.3	46.6	43.7	43.2
μ_s	0.54	0.53	0.57	0.55	0.56	0.55
tan δ (50%)	0.52	–	–	–	–	–
Sf	0.82	0.84	0.87	0.81	0.80	0.83

S_s – Solids relative density
$C_{b\ FREE}$ – Freely settled concentration
μ_s – Coefficient of sliding friction
δ (50%) – Internal angle of friction at C_v = 50%
Sf – Shape factor

Table 2.2 : Measured solid and particle properties.

The measured particle size distributions for the six materials have been plotted together for comparison in Figure 2.4. It is felt that the range of interest, in terms of particle size distribution, is suitably covered by these six materials.

The variation of internal angle of friction with solids concentration for material 1 is presented in Figure 2.5. The relationship between solids concentration and internal angle of friction, determined by linear regression for the first three points only (see Figure 2.5), is given by the equation below:

$$\tan \delta = 0.948\, C_v + 0.049 \qquad (2.3)$$

The internal angle of friction could not be measured for materials 2 to 5 and 5A. In the case of these materials the solids did not flow out of the hole in the base of the apparatus on removal of the plug. This behaviour was also observed by Cooke (1991) for classified tailings with a relatively high fines content. This is attributed to these materials exhibiting a yield stress as a result of the higher fines content.

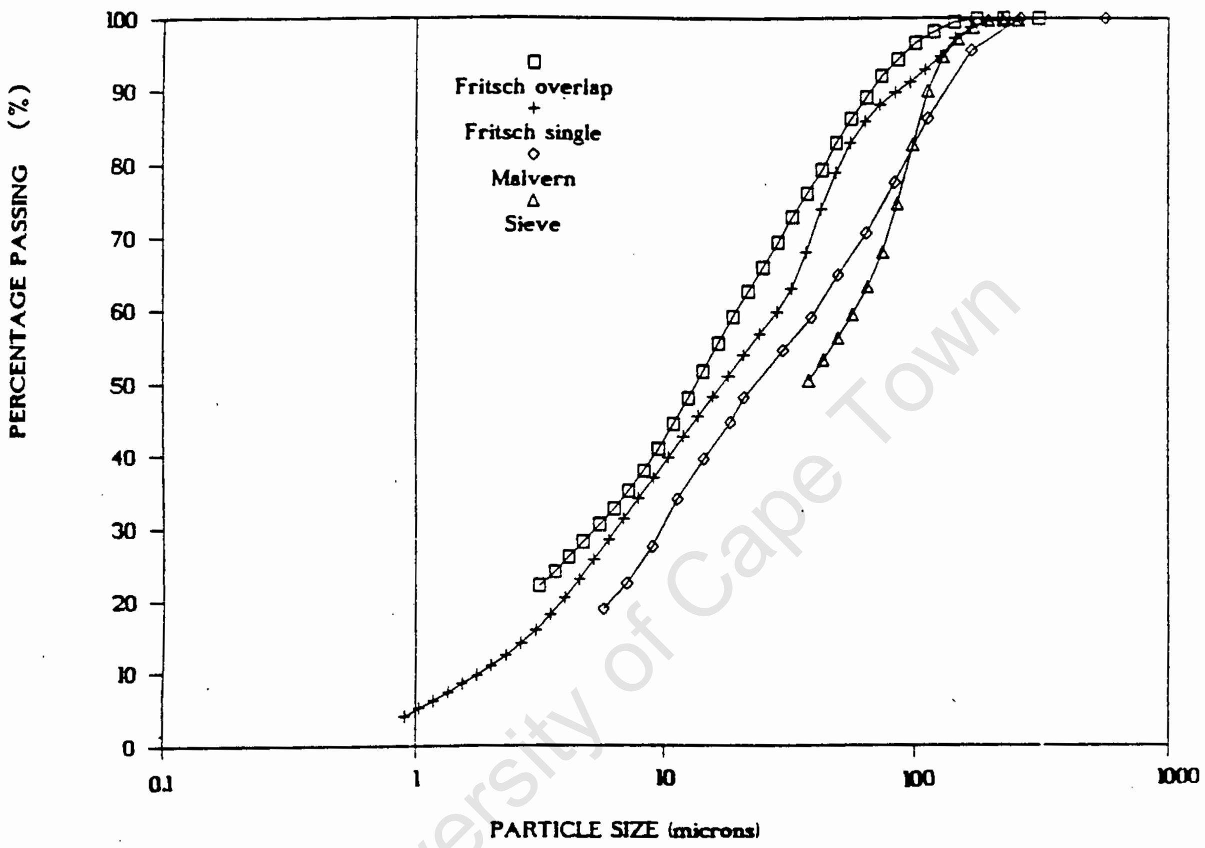


Figure 2.1 : Comparison of various techniques for the measurement of particle size distribution of a typical full plant tailings

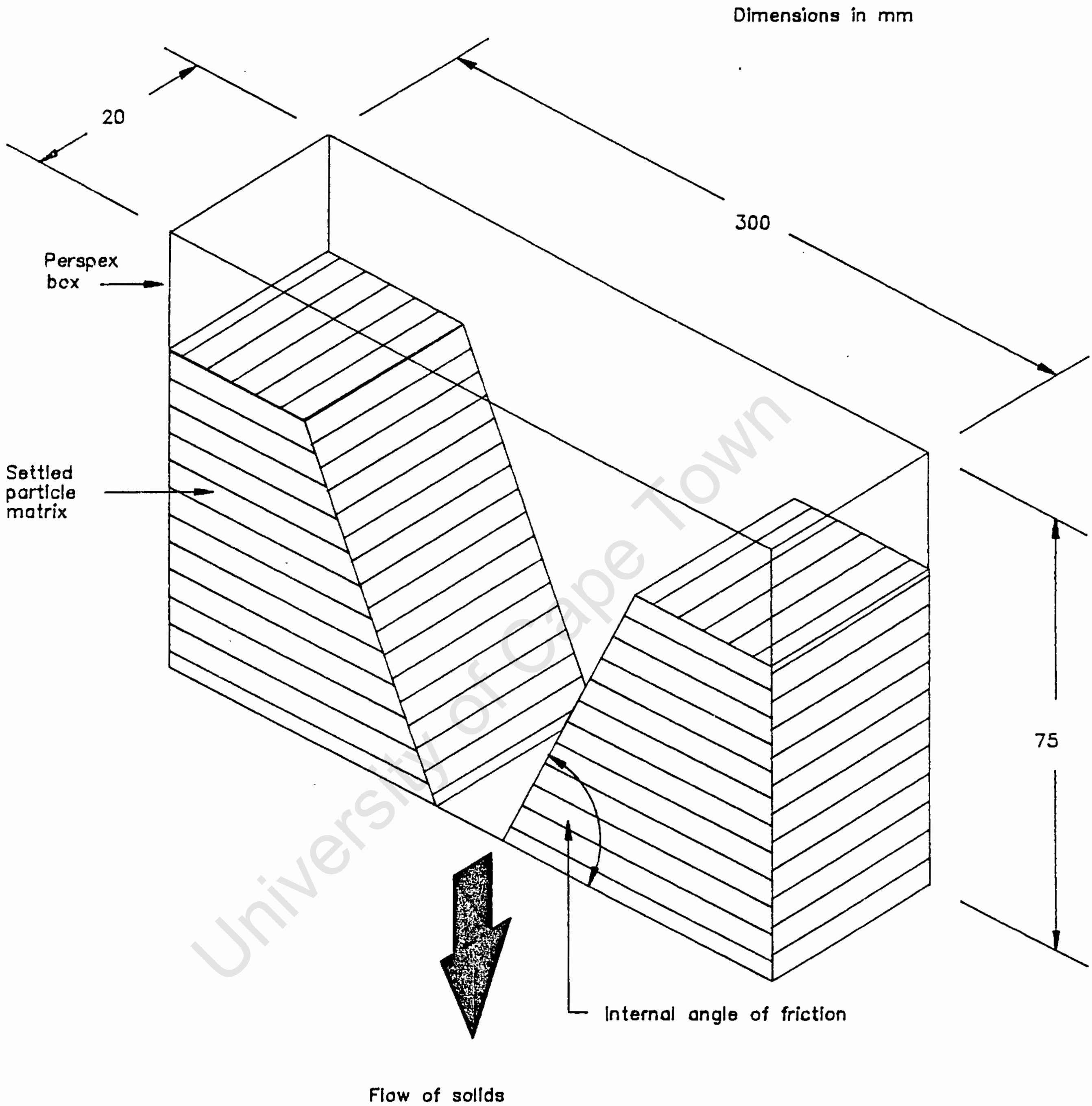


Figure 2.2 : Apparatus for measurement of the internal angle of friction.

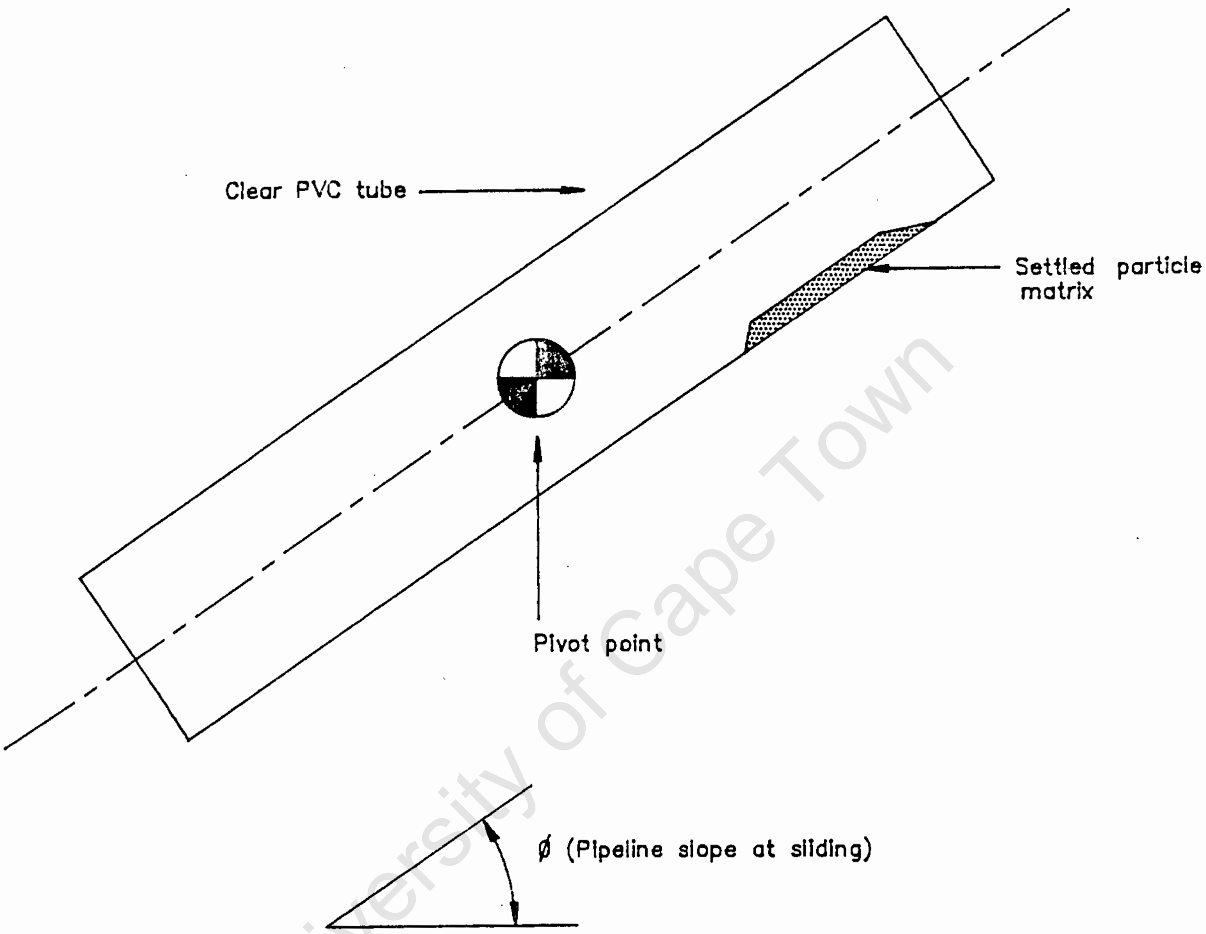


Figure 2.3 : Apparatus for measurement of the coefficient of sliding friction.

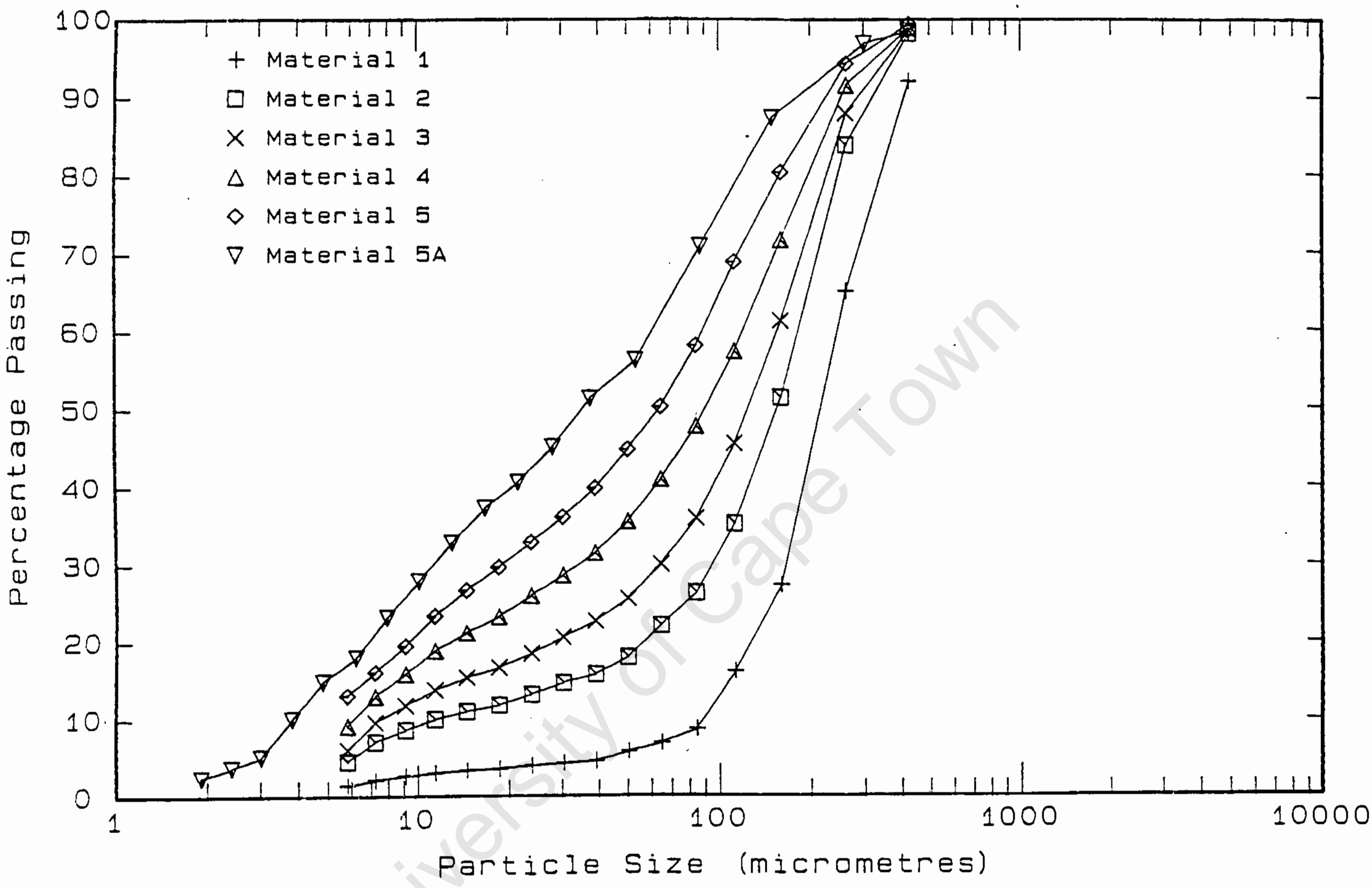


Figure 2.4 : Measured particle size distribution for the six materials

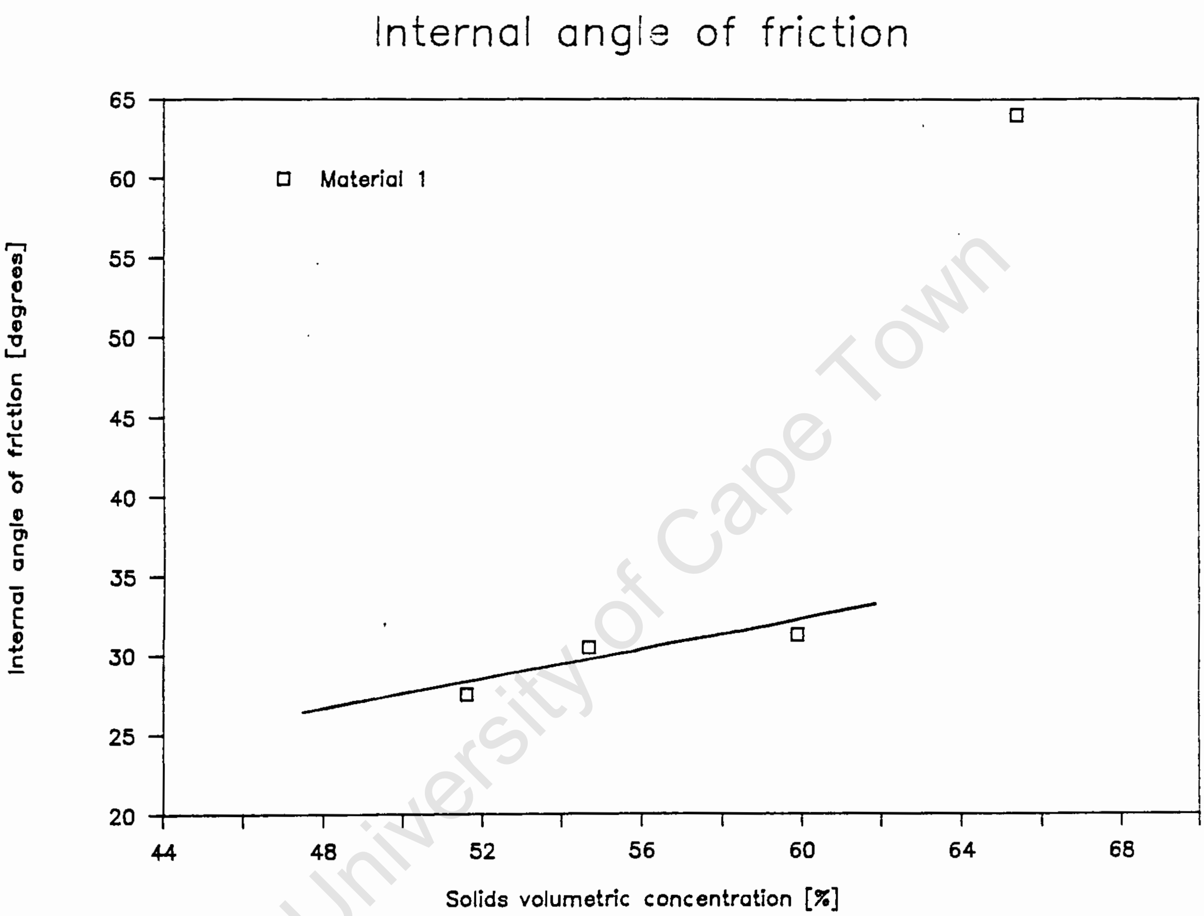


Figure 2.5 : Measured internal angle of friction for material 1

3. EXPERIMENTAL APPARATUS

3.1 Introduction

The experimentally measured pressure gradient data has been collected using a pipeline test rig constructed by the author specifically for work with high concentration backfill slurries. The test rig is described in section 3.2 and the instrumentation thereof in section 3.3. The instrument control and data capture equipment is described in section 3.4.

This test facility was used by Cooke (1991) to collect data for the development of his model, however at that time pressure gradient measurements could not be made for vertical upward flow. The test facility differs significantly from that used by Paterson (1991) in that the slurry is pumped through a closed pipe loop, as opposed to being driven by a gravity head. This allows for higher flow rates and higher solids concentrations than were achieved by Paterson.

3.2 The pipeline test rig

The pipeline test rig consists of two pipe loops, these being an 80 mm nominal bore and a 40 mm nominal bore loop. The layout of the test rig is shown in Figure 2.6. The test rig as a whole is described below, followed by more detailed descriptions of the various elements in the respective subsections.

3.2.1 General description

The slurry is pumped from the sump through the pipe loop (80 mm nominal bore or 40 mm nominal bore as selected by the operator) and back into the sump thus forming a re-circulating system. Each pipe loop consists of a vertical riser, a vertical down-comer and a horizontal leg. The riser, the down-comer and the horizontal leg each include a test section which has been fitted with pressure tappings to facilitate the measurement of pressure gradients. Each loop includes a heat exchanger to reduce heat build up in the re-circulating slurry. A section of clear PVC piping has been included in the horizontal leg of each loop to facilitate visual observation of the slurry during testing.

3.2.2 The sump

The sump is circular in plan with a conical base leading to a central outlet. The sump is fitted with a mechanical stirrer to ensure that the slurry remains consistently mixed during testing.

3.2.3 The pump and pump drive

A Warman 3/2 rubber lined, solids handling pump is used. The pump is installed at the level of the sump outlet to provide a positive inlet pressure.

The pump is driven by means of a variable speed hydraulic drive. This allows for precise control of the pump speed (and hence slurry flow rate) and sufficient power to achieve high pump speeds at high solids concentrations.

3.2.4 The test sections

Each test section consists of a length of seamless steel pipe. Pressure measurements are made via static pressure tappings located in the pipe wall. The tappings have been drilled to a diameter of 3 mm. Great care was taken to ensure that the tappings are cleanly drilled and free of burrs.

Each tapping is fitted with a solids trap to collect any solid material which may flow out through the tapping. A pressure tapping and solids trap is shown in Figure 2.7. Each solids trap and tapping can be flushed with mains water. This is done periodically during the course of the tests to remove any solids which may have collected in the solids trap or in the tapping.

3.2.5 The heat exchangers

The heat exchangers have been formed by enclosing a section of the pipe loop in a jacket formed by a length of larger diameter pipe. Tap water flowing through the space between the two pipes serves as the cooling medium.

3.3 Instrumentation

3.3.1 General description

The instrumentation of the test rig allows for the following measurements to be made:

Horizontal pressure differential
Vertical up pressure differential
Vertical down pressure differential
Slurry flow rate
Slurry temperature
Slurry relative density

The individual instruments used are described below in the respective subsections.

3.3.2 Pressure differentials

The pressure differential between tappings is measured by means of differential pressure transducers. The transducers are connected in parallel with air over water manometers. This allows for confirmation of the transducer readings and calibration of the transducers. Connection between the transducers and the pressure tappings is via flexible 8 mm hose.

Pressure gradients are calculated from the measured pressure differentials as described below (and see Figure 2.8).

The **measured** head differential is dH. (mm of water)

The **actual** head differential is H1 – H2. (mm of water)

From Figure 2.8:

$$H1 = dH + H2 + L \sin \varphi \text{ (mm of water)}$$

Thus :

$$H1 - H2 = dH + L \sin \varphi \text{ (mm of water)} \qquad (2.4)$$

The head differential is converted to a pressure differential by multiplying by the specific weight of water. This pressure differential (P1 – P2) includes a component due to the self weight of the slurry (except in the case of horizontal flow). For purposes of analysis, the weight component is later removed (knowing the density of the slurry) revealing the pressure gradient due to friction only.

The pressure gradient is defined as:

$$\frac{P_1 - P_2}{L} \qquad (2.5)$$

The differential pressure transducers are calibrated prior to use as described below.

(i) A head difference is set up manually on the manometer.

(ii) The head difference and the transducer output are noted.

(iii) The process is repeated from step (i) with a new head difference until a suitable range has been covered. These data are then used to derive a calibration equation.

The calibration equation relating transducer output to head differential is of the form shown below.

$$dH = A\,v + B \qquad (2.6)$$

Where :

dH = The head difference on the transducer (mm water).
v = The transducer output (volts).
A = The slope of the calibration curve.
B = The vertical intercept of the calibration curve.

3.3.3 Slurry flow rate

The slurry flow rate in the pipe loops is measured by means of a magnetic flow meter. The magnetic flow meter consists of a detection head in the pipe loop and a remote signal converter. The signal converter provides a current output proportional to the mean fluid velocity through the detection head.

Slurry flow rate is converted to velocity, knowing the internal diameter of the test section as shown in equation 2.4 below.

$$V_m = \frac{4 Q_m}{\pi D^2} \tag{2.7}$$

The flow meter is calibrated prior to testing as described below.

(i) Water is continuously supplied to the sump from an external supply.

(ii) The pump speed is set.

(iii) The flow from the pipe loop outlet is diverted into a 100 litre calibration tank. The diversion period is timed and the flow meter output noted.

(iv) The flow rate is determined by weighing the collected water, knowing the diversion period from step (iii).

(v) The process is repeated from step (ii) with a new pump speed until a suitable range has been covered. These data are then used to derive a calibration equation.

The calibration equation relating flow meter output to slurry flow rate is of the form shown below.

$$Q_m = A\, i + B \tag{2.8}$$

Where :

Q_m = Slurry flow rate
i = Flow meter output (miliamps)
A = Slope of calibration curve
B = Vertical intercept of calibration curve

3.3.4 Slurry temperature

The slurry temperature is monitored by means of a temperature probe in the sump. The temperature probe provides a voltage output proportional to the slurry temperature. The calibration of the temperature probe was checked against a mercury thermometer.

3.3.5 Slurry relative density

The slurry relative density is measured by massing a sample of known volume (about 30 litres). The procedure is as follows.

The volume of the sample tank (in which the slurry is collected) is determined by measuring its empty mass, (Me), and mass when full of water, (Mf).

The sample tank volume is then Mf – Me.

A sample is collected by diverting the slurry flow into the sample tank (the tank is not completely filled at this stage but a volume of about one litre is left to allow for accurate determination of the slurry volume, as described below).

The tank containing the sample is massed (M1).

The sample tank is then carefully topped up with water and massed again (M2).

The relative density is then determined by means of the following calculation:

$$S_m = \frac{\text{Mass of slurry}}{\text{Volume of slurry } \rho_w} \tag{2.9}$$

ρ_w assumed to be 1000 Kg/m3

Thus :

$$S_m = \frac{M1 - Me}{(Mf - Me) - (M2 - M1)}$$

The delivered solids volumetric concentration (C_{vd}) is determined using the equation shown below.

$$C_{vd} = \frac{S_m - S_w}{S_s - S_w} \tag{2.10}$$

S_w assumed to be 1

3.4 Data capture

3.4.1 General description

The output from the instruments are monitored by means of a data acquisition unit which converts the analogue output to digital signals. The digital signals are then read by a computer and converted to appropriate units of pressure, velocity and temperature. A hard copy of the data is printed out using a line printer.

3.4.2 Hardware

The data acquisition unit used is a Hewlet Packard 3497A. The digital outputs from the data acquisition unit are read by means of a Hewlet Packard HP86 personal computer. Communication between these instruments is made particularly easy by virtue of their compatibility. The layout of the instrumentation and hardware is shown in Figure 2.9.

3.4.3 Software

A program written in HP BASIC is used to read the data from the data acquisition unit. A data point is the average of 10 readings, recorded over a three second period. The four instruments (three differential pressure transducers and the magnetic flow meter) are read sequentially – i.e. 10 sets of four readings are recorded over the three second period. The temperature probe is read once at the start of each data set to determine the associated slurry temperature.

The program allows for viewing all the data collected at any time in the form of a graph. This feature proved to be particularly useful for identifying problems during a test such as a transducer over range or a blocked pressure tapping.

Pipe loop dimensions [m]

	a	b	c	d	e	f	g	h	i
40 mm loop	1.0	0.5	1.5	4.5	1.0	0.5	2.0	1.0	0.5
80 mm loop	2.0	1.0	0.5	3.5	1.5	0.5	2.5	1.5	1.5

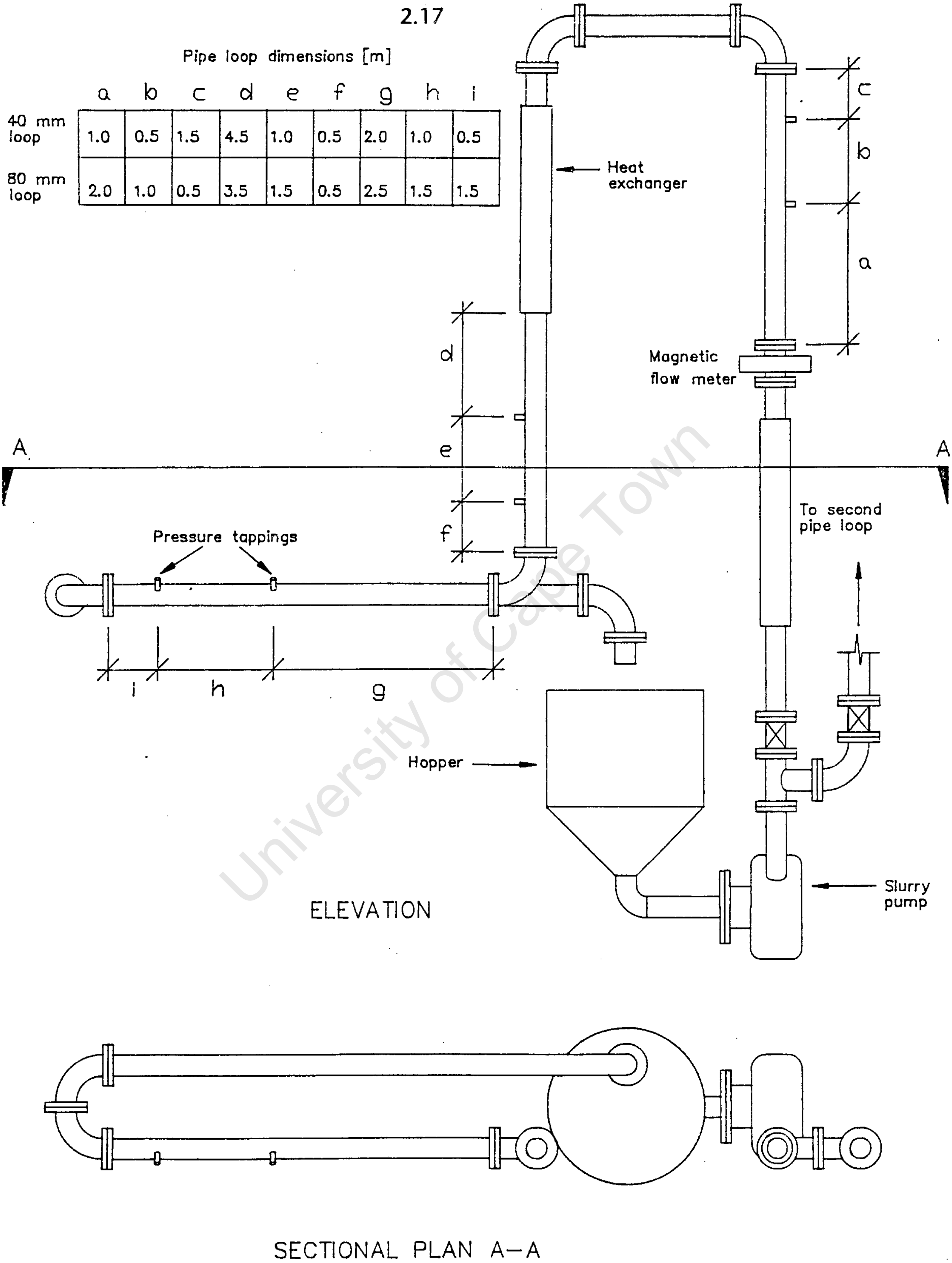


Figure 2.6 : Schematic of the pipeline test rig.

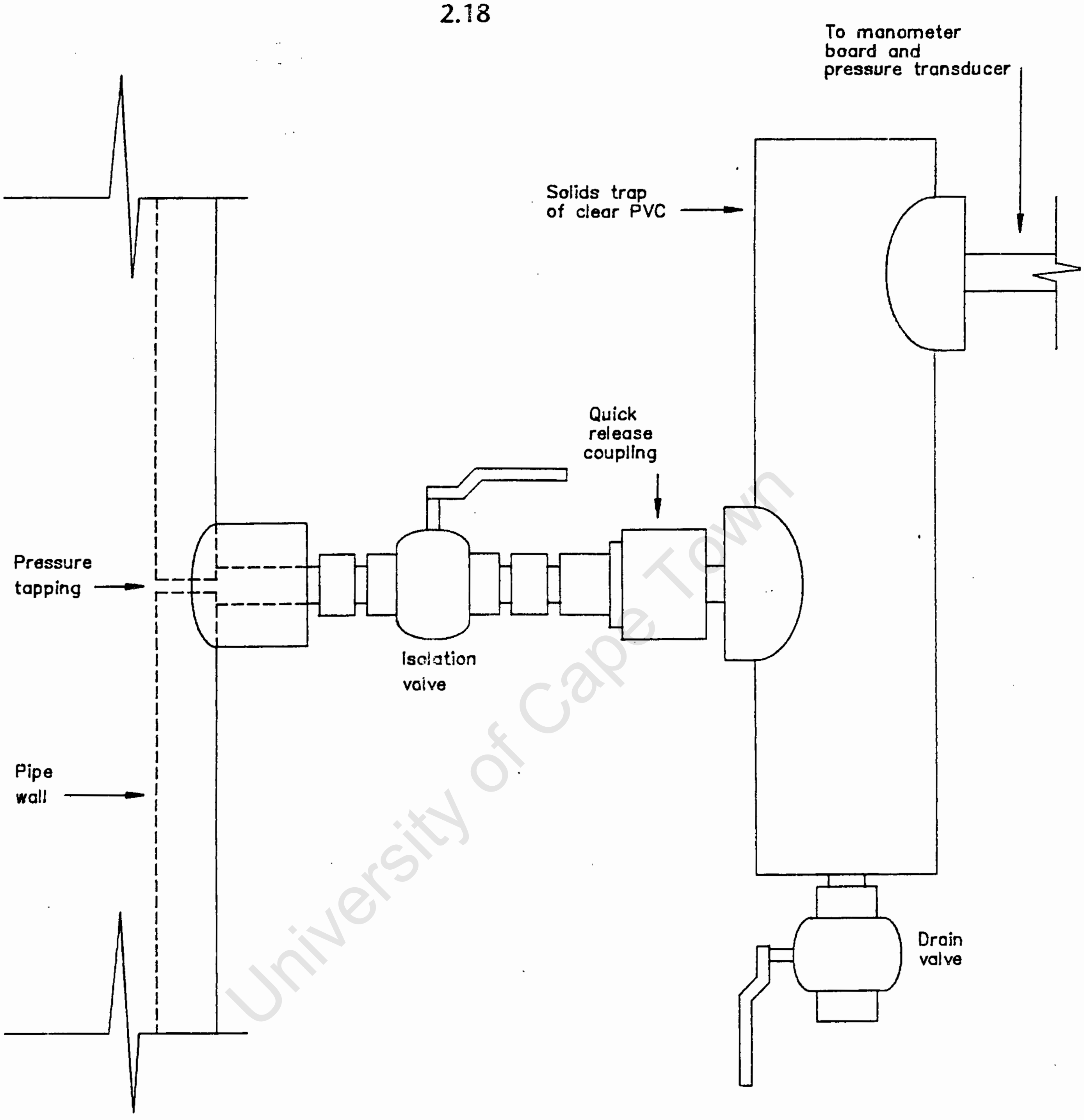
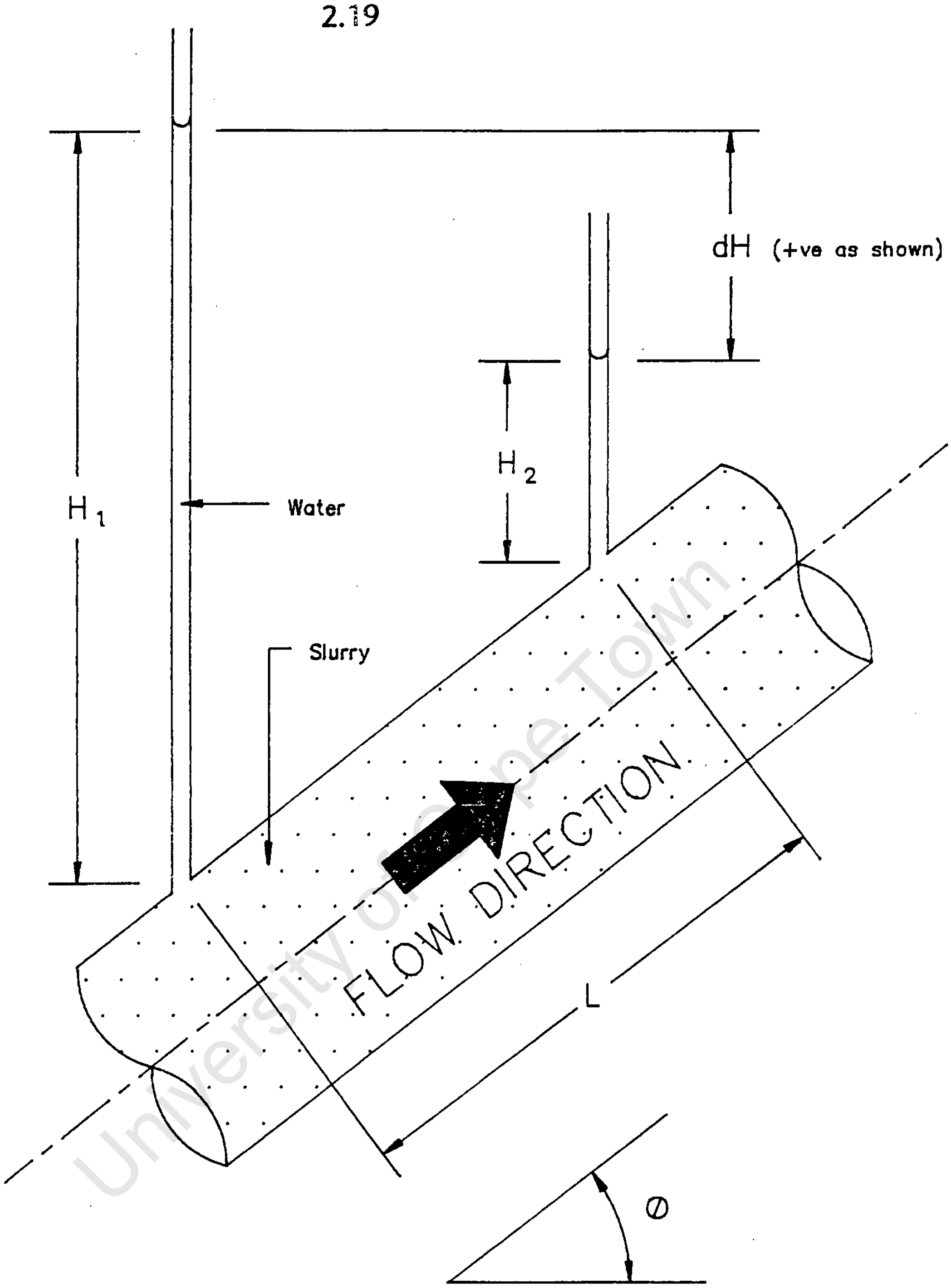


Figure 2.7 : Pressure tapping and solids trap.



Note: The pressure gradient is defined as:

$$\frac{DP}{L} = \left(\frac{H_1 - H_2}{L}\right) w$$

Figure 2.8 : Definition sketch for pressure gradient measurement.

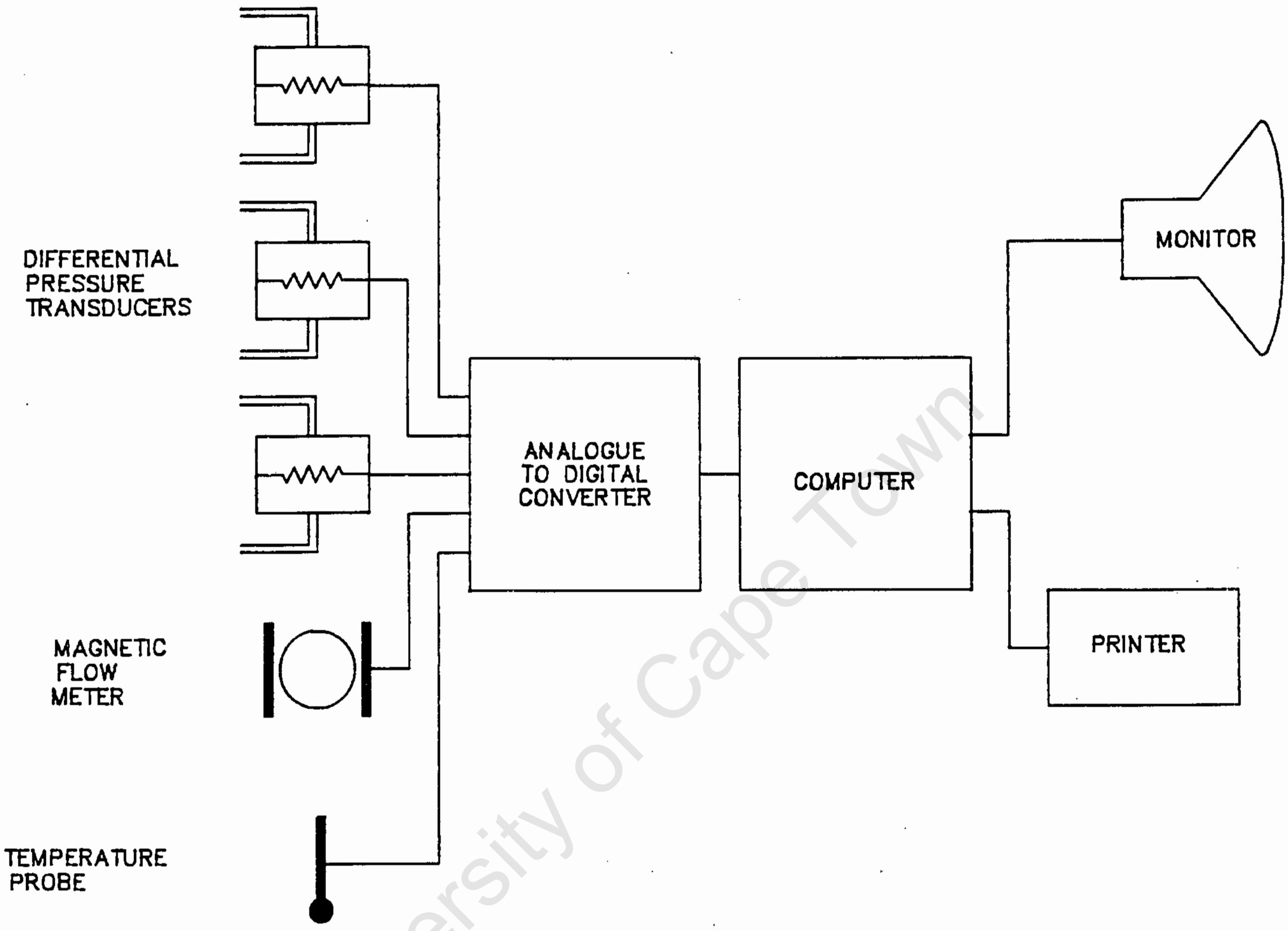


Figure 2.9 : Schematic of test rig instrumentation.

4. EXPERIMENTAL PROCEDURE

4.1 Introduction

Described in this section is the experimental procedure followed when operating the pipeline test rig.

4.2 Preliminary investigation

The tests to be run in the pipeline test rig were expected to take two to three hours to complete. The possibility that some degree of particle degradation may occur during that time was thus considered.

This was investigated by visual inspection of solid particles collected from the test rig after being circulated for four hours at a mean mixture velocity of 2 m/s. Examination of these samples under an electron microscope, however, revealed no noticeable signs of degradation. It is thus concluded that no significant particle degradation is likely to occur during the course of a test.

Micrographs of a "fresh" sample and a sample after four hours are presented in Figures 2.10 and 2.11.

4.3 Test rig operating procedure

The rig is loaded with dry solid material and water via the hopper. During the initial loading of the rig, sufficient water is run in to fill the pipeline, yet leaving space in the hopper for solid material to be added. With the water circulating and the stirrer running, the solid material is loaded into the hopper until the slurry relative density (as estimated by eye) is about 1.70 (40% by volume).

The slurry is circulated through the rig at a constant mixture velocity of 3 m/s for an initial two hour period. During this period the horizontal pressure gradient is monitored to ensure that stability of the system has been achieved before begining the test. The test being the measurement of pressure gradient data for horizontal, vertical up and vertical down flow over a range of flow velocities for a particular slurry.

A typical example of the horizontal pressure gradient during the initial two hour period is presented in Figure 2.12. There is no noticable trend in pressure gradient with time. It is thus concluded that stability of the system has been achieved by the end of the two hour period.

The test is begun at a mixture velocity of about 3.5 m/sec. After the velocity has been set, the pressure tappings and pods are flushed. The valves isolating the differential pressure transducers from the pods are opened, and data capture is begun.

Four to eight data points are read at the selected velocity (depending on the stability of the readings). An observation is made of the mixture flow behaviour in the clear horizontal section.

The velocity is then reduced by about 0.5 m/s and another set of data points read and the flow observation made. This process is continued until a full velocity range has been covered (about 3.5 m/s to 1 m/s).

The slurry relative density is measured by sampling the slurry from the pipeline outlet. A small sample (about 1 litre) is collected from the pipeline outlet for particle size distribution analysis.

The solids concentration is then increased. This is done by dumping some slurry from the system and adding fresh, dry solid material.

A number of tests are performed until a range of solids concentration has been covered. This completes the testing of a material in the chosen pipe diameter. The slurry is then dumped and the rig flushed with clear water.

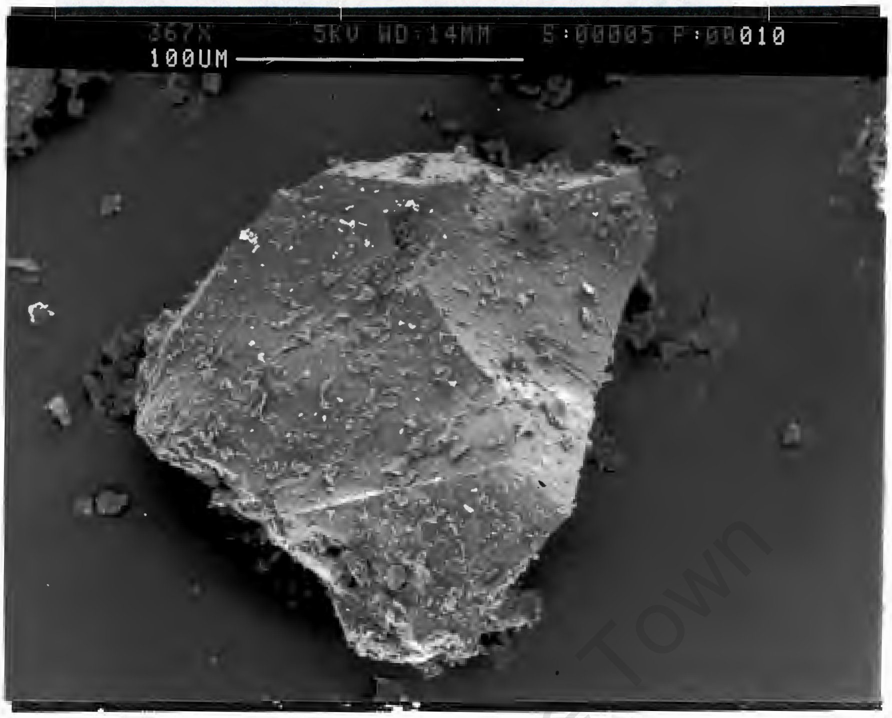


Figure 2.10 : Micrograph of "fresh sample".

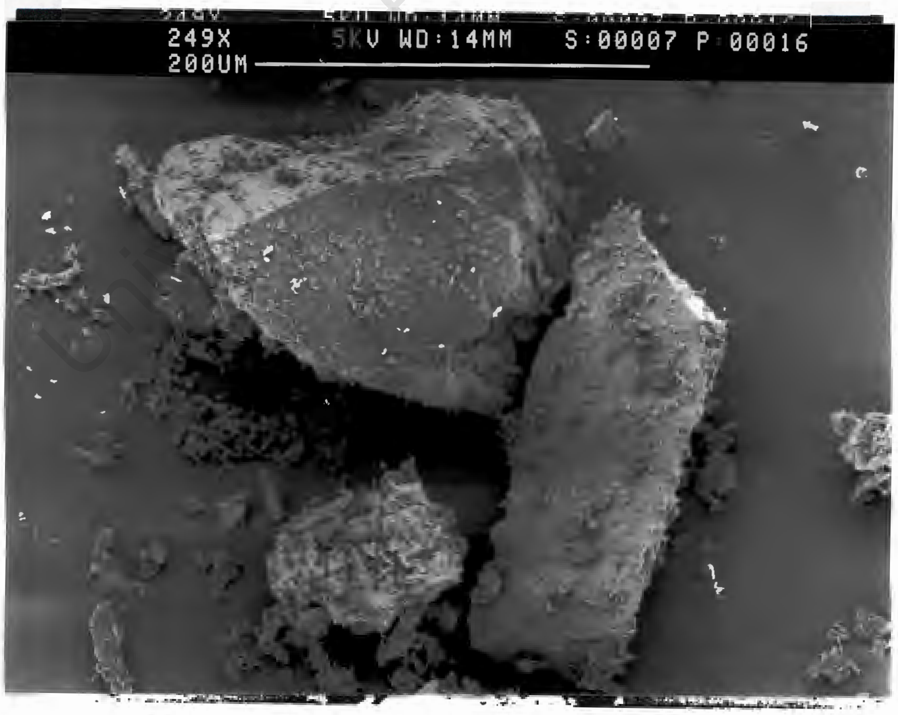


Figure 2.11 : Micrograph of sample after four hours at 2 m/s.

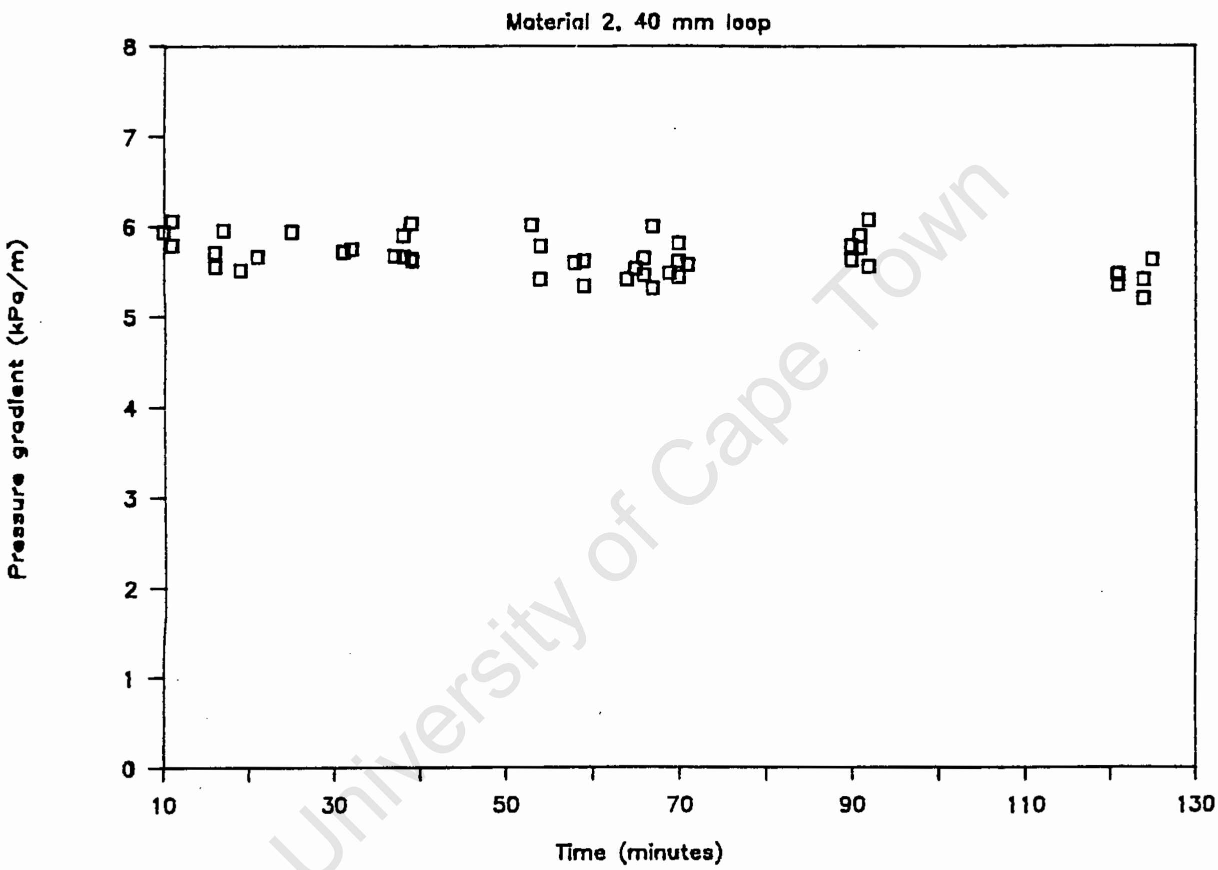


Figure 2.12 : Variation of horizontal pressure gradient with time during initial two hour period.

5. EXPERIMENTAL RESULTS

5.1 Introduction

The test results are presented in full in Appendix A. The results for each test being presented in the following format:

(i) A plot of measured pressure gradient versus mean mixture velocity data.

(ii) A plot of the particle size distribution of the sample taken at the end of the test.

(iii) The test results in tabular form, including:

Test parameters.

Velocity, pressure gradient, temperature data.

Particle size distribution.

Flow observations (horizontal only).

Note that the pressure gradient data presented in appendix A are as defined in Figure 2.8 and section 3.3.2 of this chapter.

The results of the tests are presented and discussed in section 5.2 below.

5.2 Discussion of results

The test results as presented in Appendix A are first discussed in section 5.2.1, refering to plots of measured pressure gradient versus velocity data presented in Figures 2.13 and 2.14.

The effect of solids concentration on pressure gradient is discussed in section 5.2.2, refering to plots of pressure gradient as a function of solids concentration presented in Figures 2.15 to 2.21.

The effect of particle size distribution on pressure gradient is discussed in section 5.2.3, refering to plots of pressure gradient as a function of % –10 microns presented in Figures 2.22 and 2.23.

5.2.1 General discussion

The results discussed here are presented in full in Appendix A.

At low solids concentrations (typically less than 45% by volume) the plots of pressure gradient versus mean mixture velocity generally show a transition from laminar to turbulent flow, as seen in Figure 2.13. This transition is indicated by a change of slope in the relationship between pressure gradient and mean mixture velocity. An increase in slope indicating the onset of turbulent flow.

The transition becomes more distinct and occurs at a higher velocity with increasing fines content and increasing solids concentration. The transition is also more distinct in the case of vertical flow than for horizontal flow. In the case of horizontal flow, the tendency for a bed to form on the pipe invert at low velocities masks the effect.

At higher concentrations (typically greater than 45% by volume) the flow over the full velocity range is laminar, as seen in Figure 2.14.

The trends described here have also been reported by Sauermann (1982) in work with seven gold slimes slurries with d_{50} particle sizes ranging from 28 to 200 microns.

5.2.2 The effect of solids concentration

The test results for each material have been summarised in Figures 2.15 to 2.21 which show pressure gradient as a function of solids concentration, with mean mixture velocity as parameter.

The data for horizontal flow only is presented. The trends seen in these plots are, however, also followed by the data for vertical up and vertical down flow.

The general shape of the trend curves drawn through the data points is similar for all materials, as discussed below.

At a mean mixture velocity of 1.5 m/s:

At a mean mixture velocity of 1.5 m/s, solids concentration appears to have little effect on pressure gradient at concentrations below 40% by volume. This is seen in Figures 2.16 to 2.19 (Materials 2 to 5 in the 40 mm N.B. pipeline) for which data is shown in this concentration range. For solids concentrations greater than 40% by volume, the pressure gradient increases with solids concentration. The rate of increase also increasing with solids concentration.

At a mean mixture velocity of 3.5 m/s:

At a mean mixture velocity of 3.5 m/s, the pressure gradient initially increases with increasing solids concentration, reaching a local maximum. This is seen in Figures 2.16 to 2.21 for materials 2 to 5 in the 40 mm N.B. loop and material 1 and 5A in the 80 mm loop.

The local maximum is not seen in Figure 2.15 for material 1 in the 40 mm N.B. loop as the data points do not extend to the range where the local maximum is expected to occur. However, based on the trend shown in Figure 2.15, a local maximum is expected to occur as the pressure gradient will tend to that for water as the solids concentration tends to zero.

With a further increase in solids concentration beyond the local maximum, a local minimum pressure gradient is reached. This is seen in Figures 2.15 to 2.21, for all materials and in both pipe diameters.

Beyond the local minimum, the pressure gradient continues to increases with increasing solids concentration.

The solids concentration at which the local maximum and minimum occur varies for each material, generally decreasing with increasing fines content.

The occurance of the local maximum, as described above, is attributed to the change from turbulent to laminar flow, due to increased dampening of turbulence, as the solids concentration increases. This reduction in turbulence results in a decrease in pressure gradient with increasing solids concentration in the region between the local maximum and local minimum.

The increase in pressure gradient with increasing solids concentration beyond the local minimum, is attributed to the greatly increased solids phase shear stress at the pipe wall as the solids concentration is increased beyond the point where interparticle contact forces solids against the pipe wall. This sharp increase in pressure gradient with increased solids concentration has been referred to by Cooke (1991) and Paterson (1991) as indicating the onset of high concentration flow.

At a mean mixture velocity of 2.5 m/s:

At a mean mixture velocity of 2.5 m/s, the trend curves drawn through the data points lie between those for 1.5 m/s and 3.5 m/s. The shape of these curves is generally similar to that for 3.5 m/s, however, the difference between the local maximum and the local minimum is not as pronounced.

5.2.3 The effect of particle size distribution

The effect of particle size distribution on pressure gradient is shown in Figures 2.22 and 2.23. Here pressure gradient has been plotted as a function of % –10 microns, with solids concentration as parameter.

In the 40 mm N.B. loop at 1.5 m/s:

In the case of the 40 mm loop at a mean mixture velocity of 1.5 m/s, as shown in Figure 2.22, pressure gradient increases with increasing fines content (% –10 microns). This increase is gradual up to a value of about 20% –10 microns, at which point it becomes sharply steeper. Increasing solids concentration results in an overall more rapid increase in pressure gradient with increasing fines content. It has been noted that flow is laminar for all points on this plot (Figure 2.22).

In the 40 mm N.B. loop at 3.5 m/s:

In the case of the 40 mm N.B. loop at a mean mixture velocity of 3.5 m/s, as shown in Figure 2.23, the trend curve for a solids concentrations of 42% by volume appears to have an unusual shape. This is as a result of the flow regime being turbulent at 3.5 m/s for this concentration, whereas at solids concentrations of 46% and 50% by volume the flow regime is laminar at the same velocity.

For solids concentrations of 46% and 50% by volume, there is again a sharp increase in pressure gradient at about 20% –10 microns, as seen at 1.5 m/s.

In the 80 mm N.B. loop:

Data from the 80 mm N.B. loop is available for two materials only (Materials 1 and 5A).

It is assumed that the trends identified for the 40 mm loop will also be followed in the 80 mm loop.

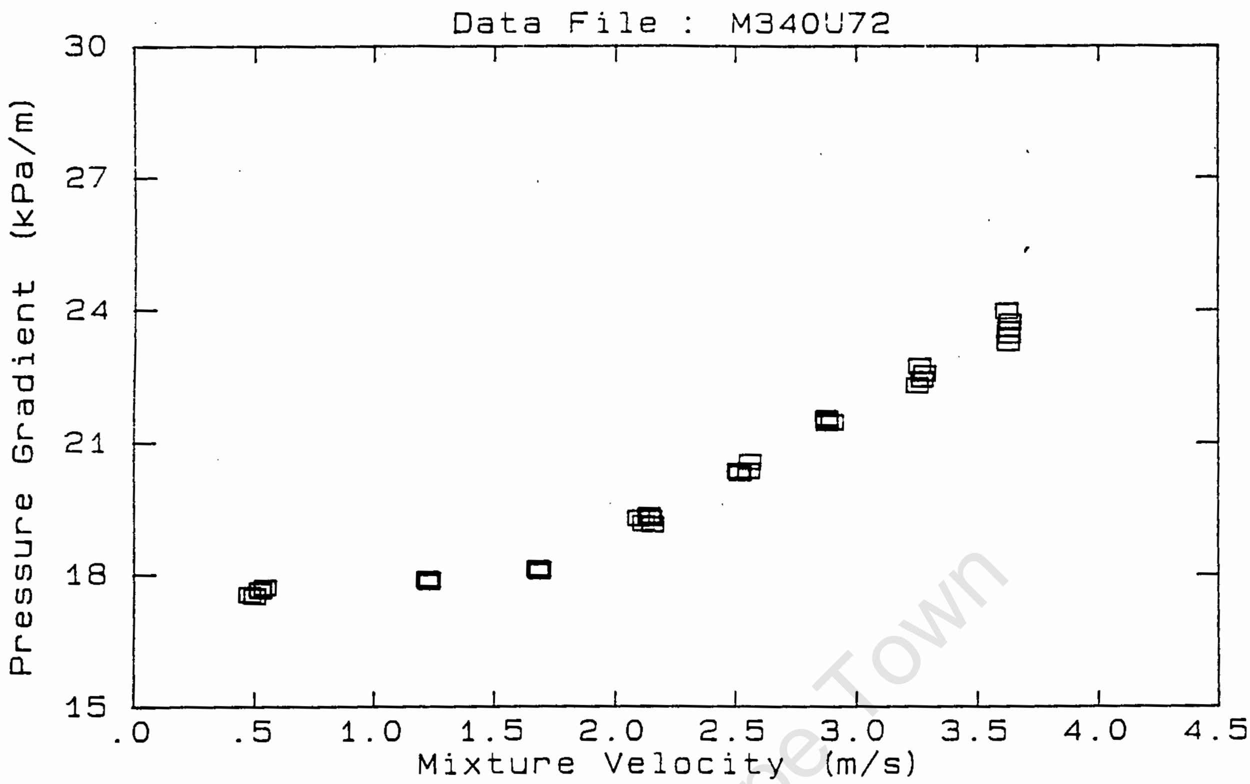


Figure 2.13 : Plot of measured pressure gradient data for Material 3, Cv = 41.4%

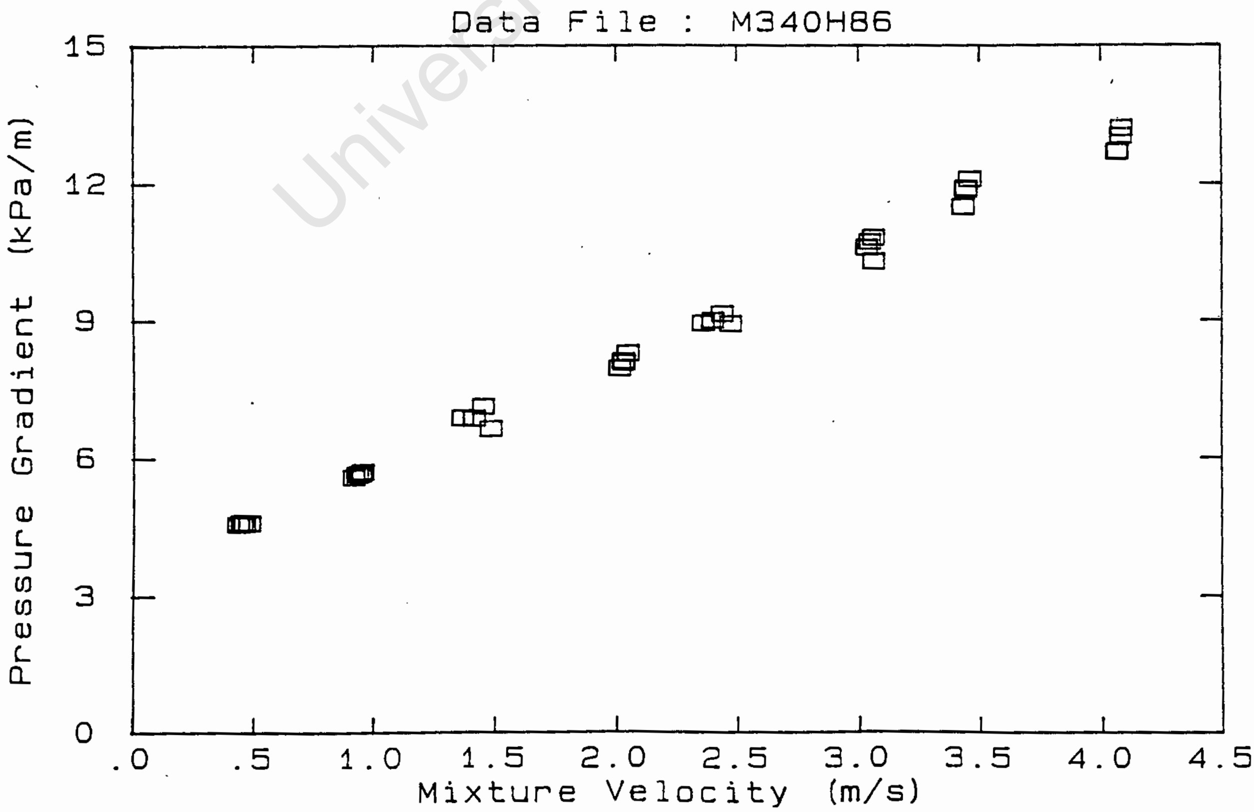
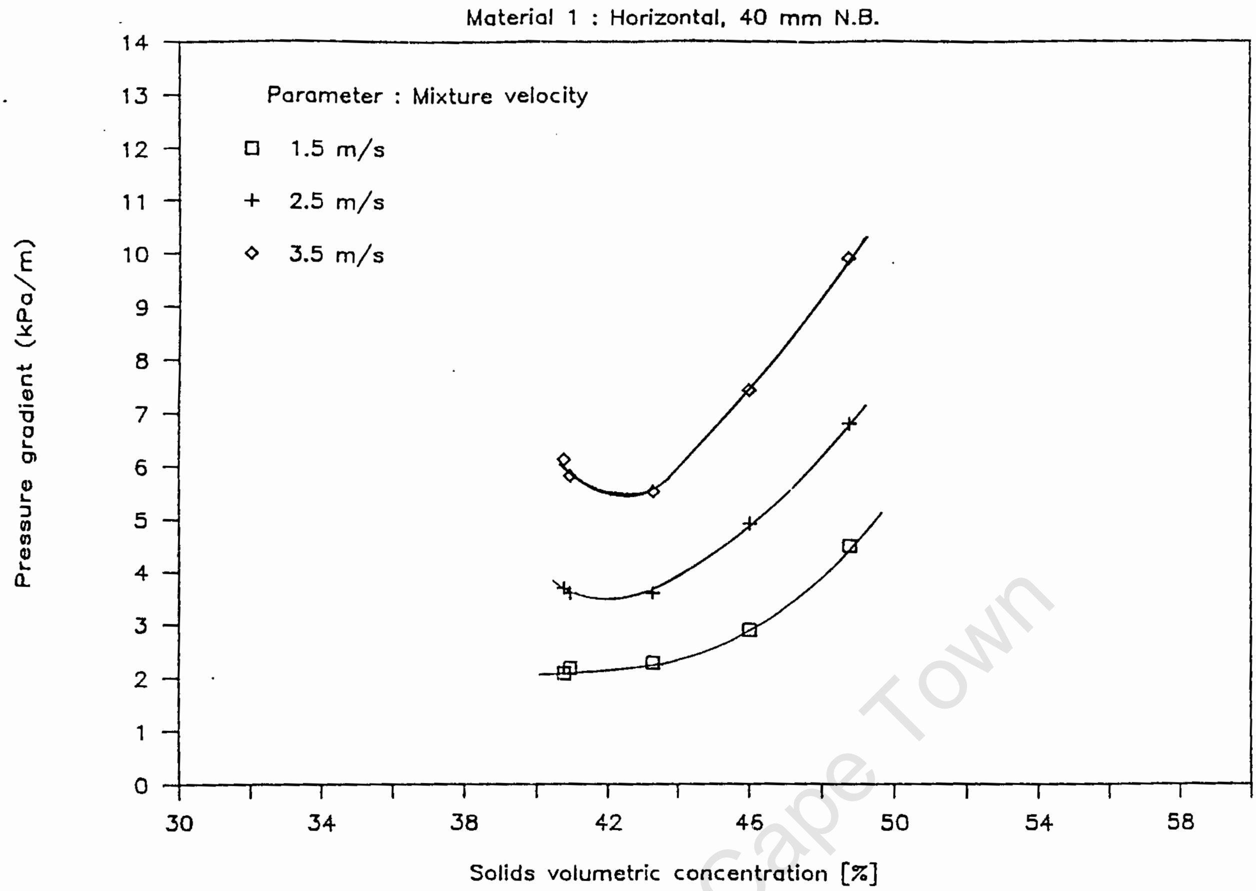
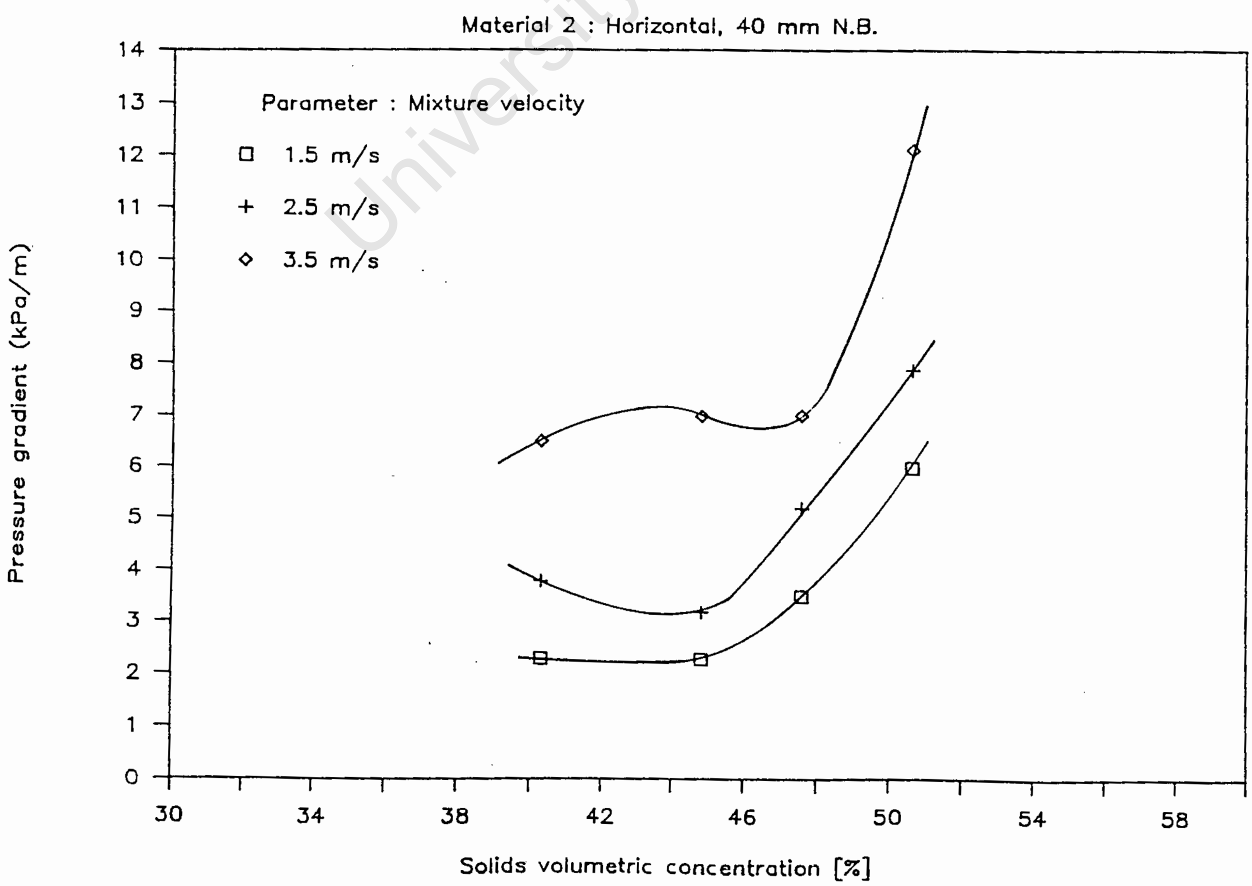


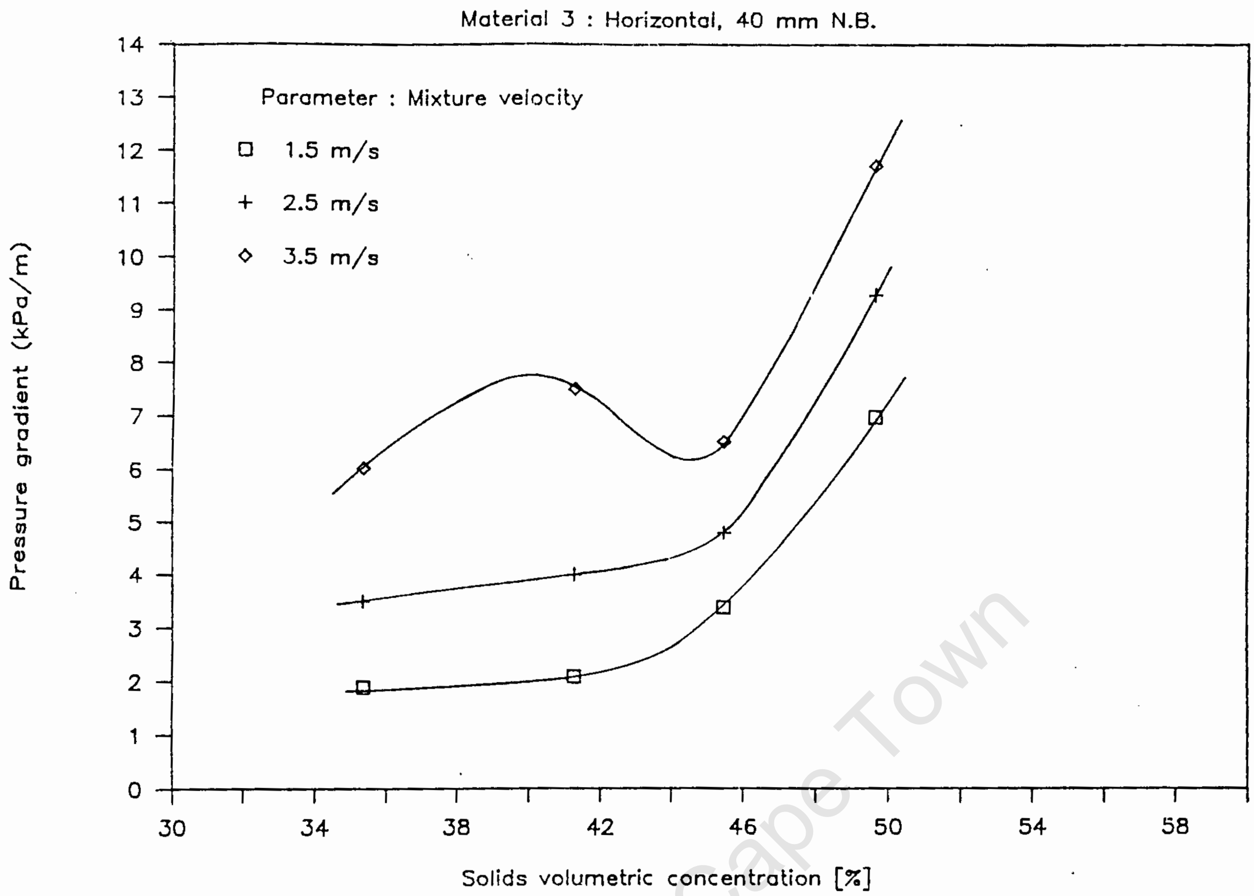
Figure 2.14 : Plot of measured pressure gradient data for Material 3, Cv = 49.4%



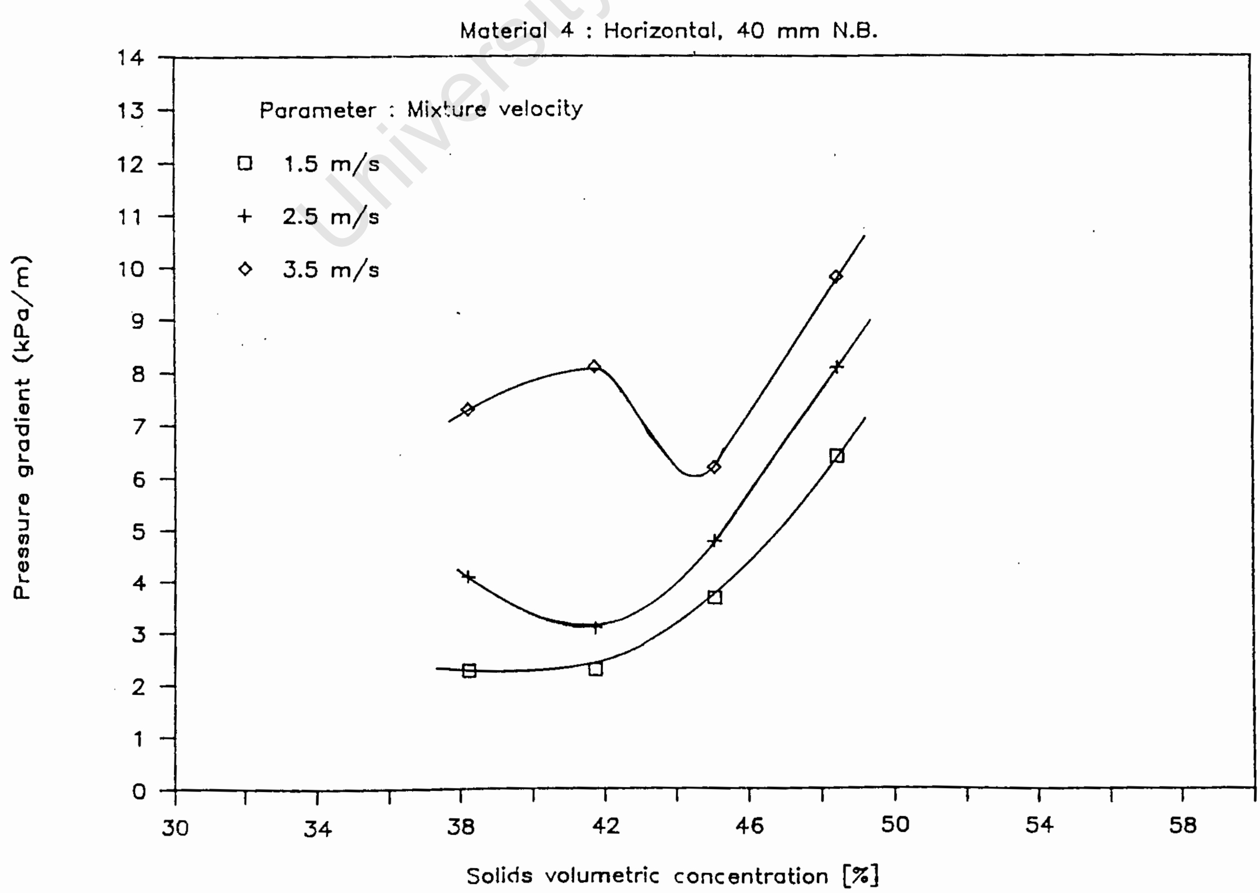
<u>Figure 2.15</u> : Pressure gradient as a function of solids concentration.



<u>Figure 2.16</u> : Pressure gradient as a function of solids concentration.



<u>Figure 2.17</u> : Pressure gradient as a function of solids concentration.



<u>Figure 2.18</u> : Pressure gradient as a function of solids concentration.

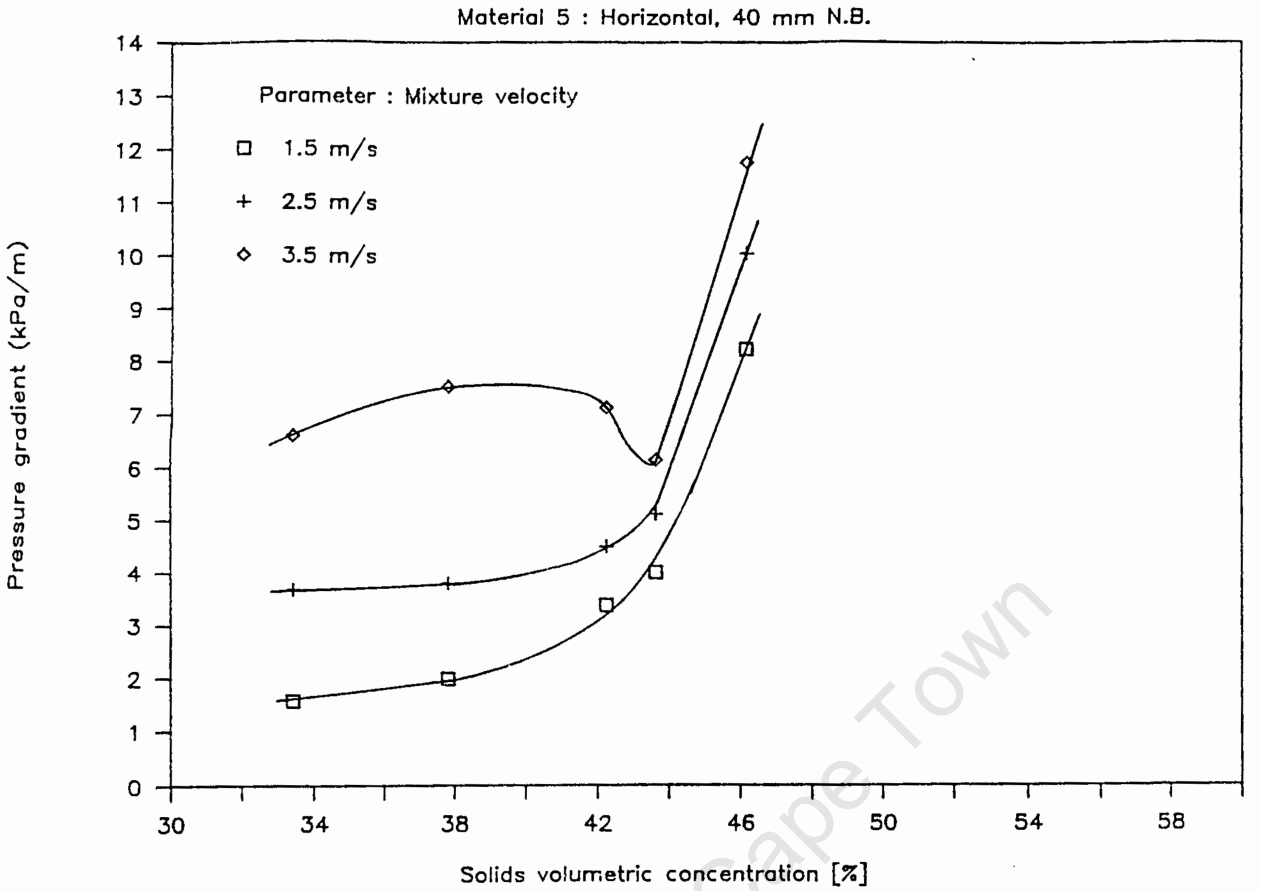


Figure 2.19 : Pressure gradient as a function of solids concentration.

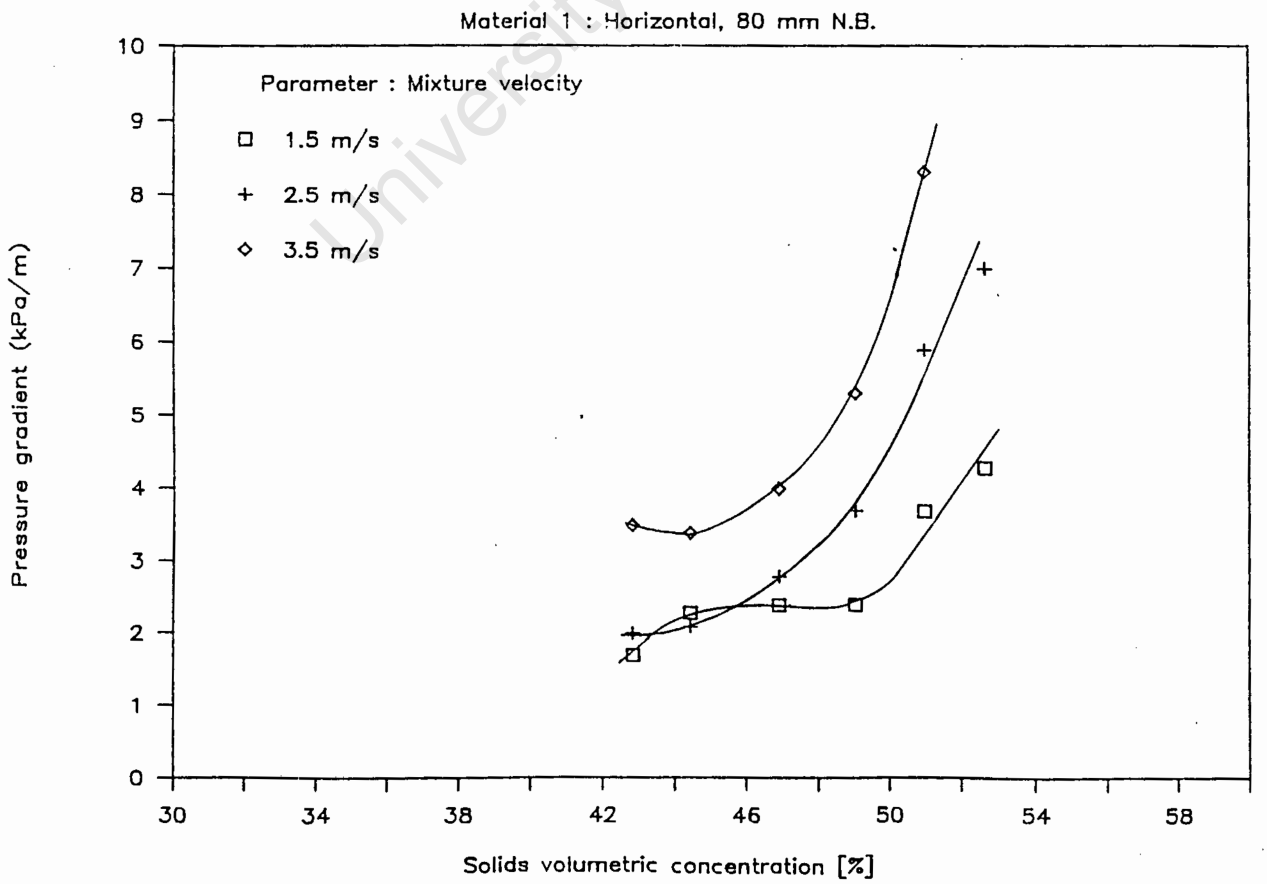


Figure 2.20 : Pressure gradient as a function of solids concentration.

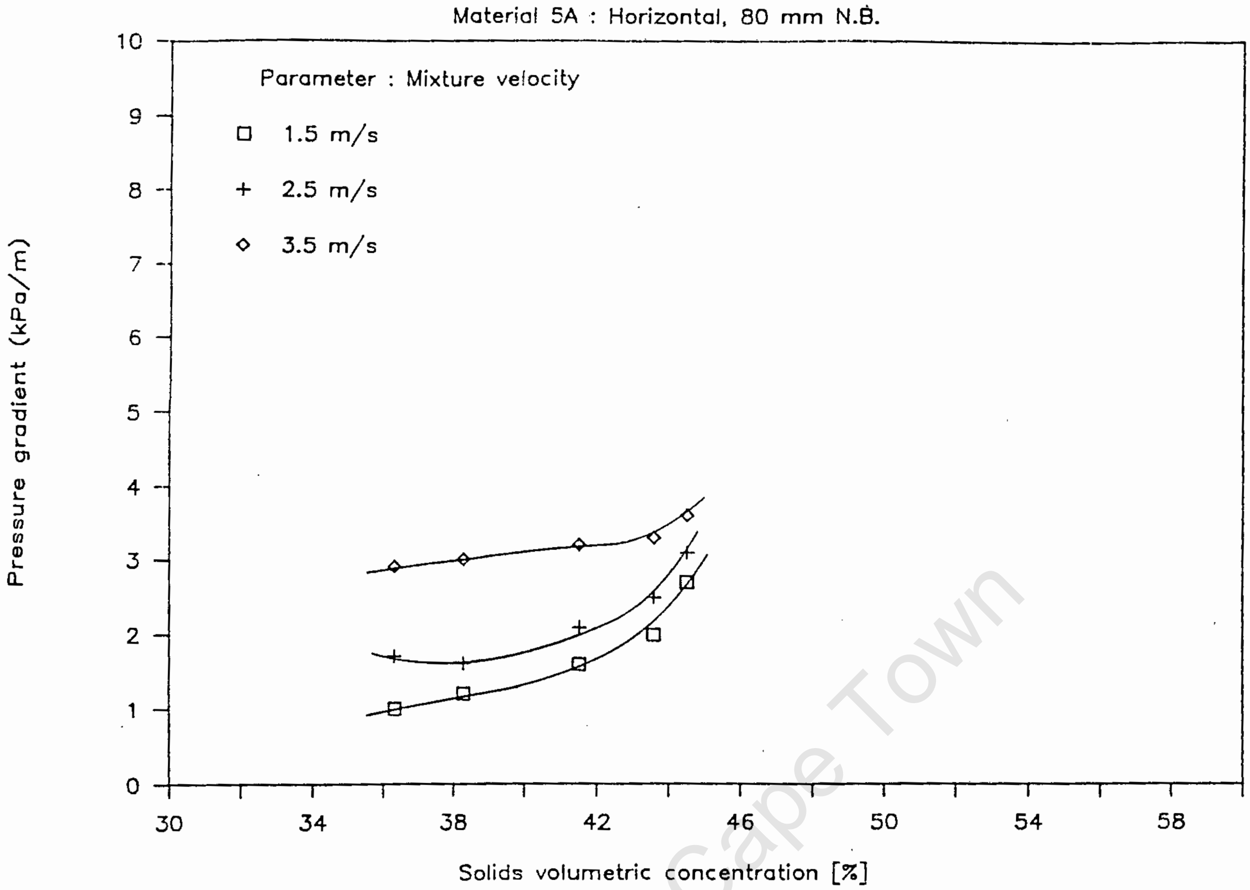


Figure 2.21 : Pressure gradient as a function of solids concentration.

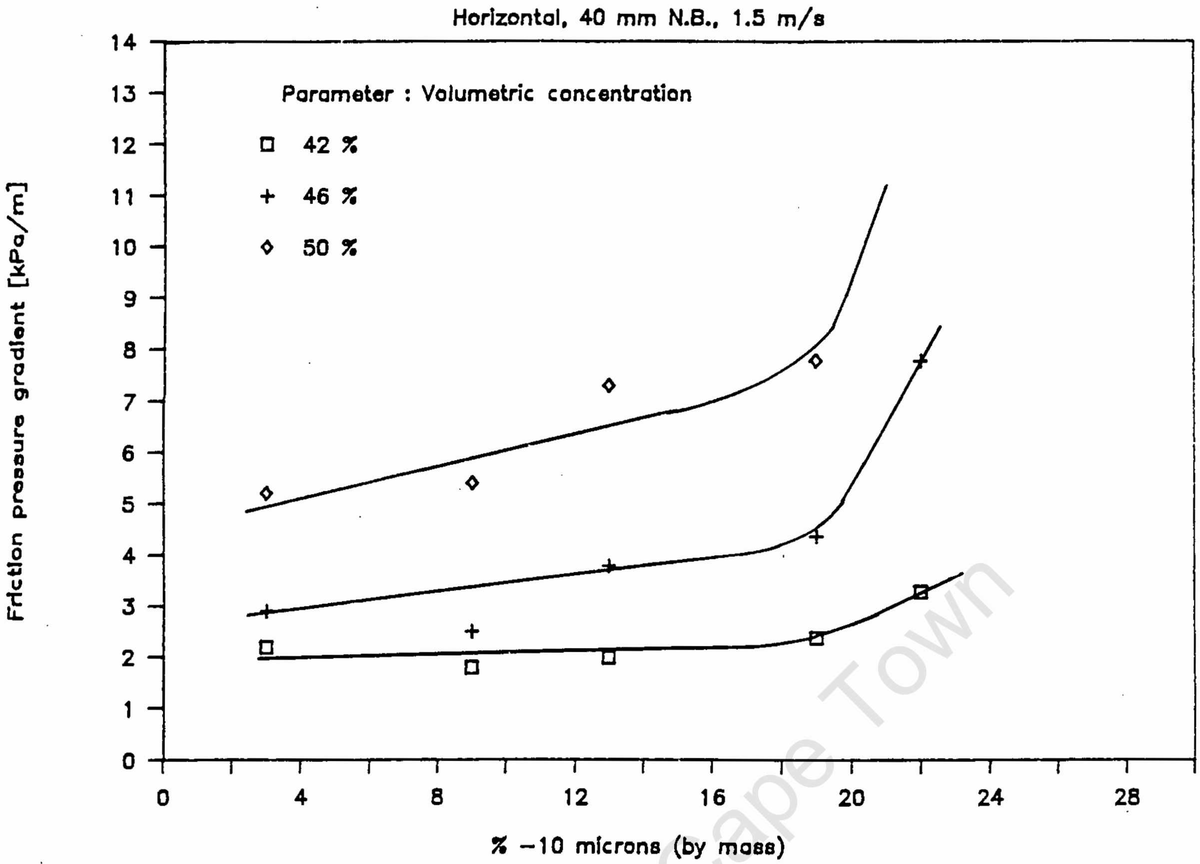


Figure 2.22 : Pressure gradient as a function of % -10 microns.

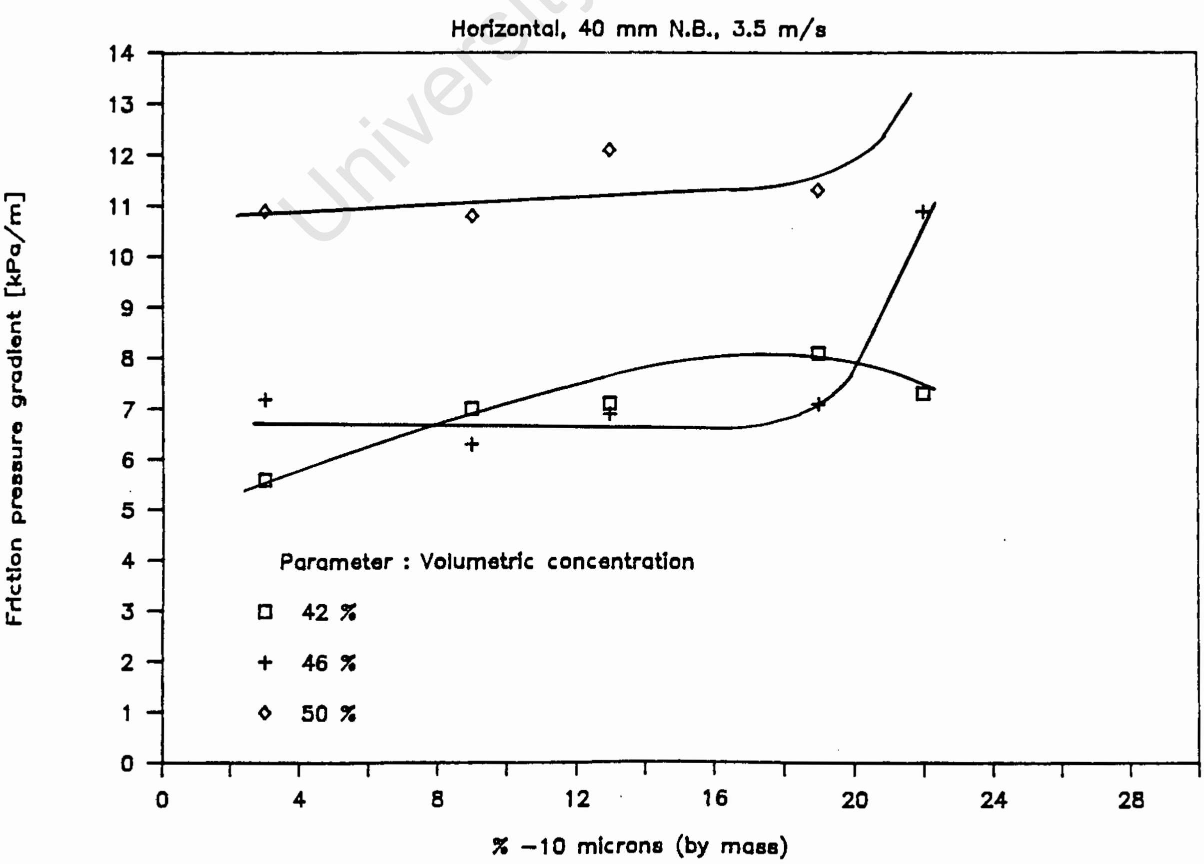


Figure 2.23 : Pressure gradient as a function of % -10 microns.

6. ANALYSIS OF ERRORS IN EXPERIMENTAL RESULTS

6.1 Introduction

An analysis of the expected maximum error associated with each measured quantity is presented here.

The error in a quantity, X, being a function of several measured quantities, will be the sum of the errors contributed by each.

If X is given by:

$$X = fn(a, b, c, ... n)$$

Then the error, ΔX, in X due to an error, Δn, in n is given by (Brinkworth (1968)):

$$\frac{(\Delta X)_n}{X} = \frac{\delta X}{\delta n} \cdot \frac{\Delta n}{X}$$

$$= \frac{\delta X}{\delta n} \cdot \frac{n}{x} \cdot \frac{\Delta n}{n} \qquad (2.11)$$

The maximum error expected in X is given by:

$$\left[\frac{\Delta X}{X}\right]^2 = \sum\left[\frac{X}{n} \cdot \frac{n}{X} \cdot \frac{\Delta n}{n}\right]^2 \qquad (2.12)$$

For purposes of error analysis, the measured quantities have been divided into two categories. These being primary measured quantities (quantities that are measured directly) and derived quantities (quantities derived from a combination of primary measured quantities).

6.2 Primary measured quantities

The primary measured quantities are:

Solids relative density, S_s.
Mixture relative density, S_m.
Mixture flow rate, Q_m.
Pressure differential, dP.
Pipe diameter, D.
Pipe length, L.
Slurry temperature, t.

An evaluation of the maximum expected error associated with each of these measurements is presented below.

Solids relative density, Ss.

The maximum error associated with the measured solids relative density is estimated from the degree of variation in the solids relative density test results, as presented in Table 2.3. The value of solids relative density for each material being taken as the average of three measurements. The maximum error expected is estimated as ± 0.01.

Material	Measured values			Average
1	2.723	2.730	2.732	2.73
2	2.728	2.738	2.749	2.74
3	2.750	2.749	2.725	2.74
4	2.743	2.745	2.738	2.74
5	2.750	2.745	2.722	2.74
5A	2.730	2.725	2.736	2.73

Table 2.3 : The results of the solids relative density tests.

Mixture relative density, Sm

The mixture relative density is calculated from equation 2.6:

$$S_m = \frac{M_m}{V_m \rho_w} \qquad (\rho w \text{ assumed to be } 1\,000 \text{ Kg/m}^3)$$

The errors associated with a typical mixture relative density test and the resultant maximum expected error, calculated using the procedure as set out in equation 2.9, are presented in Table 2.4 below.

Variable	Measured value	Expected value	% Error
M_m (Kg)	53.84	± 0.1	0.19
V_m (m^3)	30 E −3	± 0.1 E −3	0.33
ρ_w (Kg/m^3)	1 000 (assumed)	−2	0.20
S_m	1.8 (assumed)	± 0.008 (max)	0.44

Table 2.4 : Analysis of errors in determination of mixture relative density for a typical slurry.

Mixture flow rate, Q_m

The maximum error expected in the measurement of mixture flow rate is the sum of transducer errors and calibration errors.

The maximum expected transducer error is taken to be the rated accuracy of 1% of the output.

The maximum expected calibration error is estimated from the calibration curves and associated residuals as determined by linear regression. The calibration curves are shown in Figures 2.24 and 2.25. The estimated errors and total error for typical values of mixture flow rate are shown in Table 2.5 and Table 2.6 below.

Variable	Measured value	Expected error	% Error
Transducer ouput (mA)	5.766	± 0.132 (1% of ouput)	1.00
Calibration Q_m (Kg/s)	12.798	± 0.05 (estimated from calibration)	0.51
Q_m	Total maximum error: ± 0.059		1.5

Table 2.5 : Analysis of errors in mixture flow rate for a typical flow rate in the 40 mm N.B. loop.

Variable	Measured value	Expected error	% Error
Transducer ouput (mA)	5.766	± 0.132 (1% of ouput)	1.00
Calibration Q_m (Kg/s)	12.798	± 0.05 (estimated from calibration)	0.39
Q_m	Total maximum error: ± 0.233		1.82

Table 2.6 : Analysis of errors in mixture flow rate for a typical flow rate in the 80 mm N.B. loop.

Pipe length, L

The pipe length between tappings is used in the calculation of the pressure gradients from the measured pressure differentials. The pipe length is measured using a steel tape. The maximum error in L is estimated as 0.002 m.

Pipe diameter, D

The pipe diameters used in this work are those given in the manufacturers specifications. The expected error in pipe diameter is taken to be the tolerance specified by the manufacturers. These values are given in Table 2.7 below.

Nominal bore	Internal diameter	Tolerance	% Error
40 mm	40.9 mm	± 0.4 mm	0.98
80 mm	73.7 mm	± 0.8 mm	1.09

Table 2.7 : Specified pipe internal diameter and tolerance.

Pressure differentials, dP

The maximum error expected in the differential pressure measurement is the sum of the transducer error and the calibration error.

The maximum transducer error is 0.1% of the transducer range (2m water head) i.e. 2 mm water head.

The maximum calibration error is estimated from the calibration curves and associated residuals, as shown in Figure 2.26. The maximum calibration error is estimated as 3 mm water head.

The maximum total error expected is thus 5 mm water head.

Slurry temperature, t

The maximum transducer error is 1% of the transducer range (100°C) i.e. 1°C.

The maximum calibration error is estimated from the calibration curve, as shown in Figure 2.27. This value is estimated as 1°C.

The maximum total error expected is thus 2°C.

6.3 Derived quantities

The derived quantities are:

Solids volumetric concentration, C_v.
Mean mixture velocity, V_m.
Pressure gradient, dP/dL.

These quantities are derived from combinations of the primary measured quantities. The maximum error expected for each is thus calculated using the procedure as set out in equation 2.12.

Solids volumetric concentration, C_v

The solids volumetric concentration is calculated from equation 2.7:

$$C_v = \frac{S_m - S_w}{S_s - S_w} \qquad (S_w \text{ assumed to be } 1)$$

The errors associated with the calculation of C_v for typical values of S_m and S_s are presented in Table 2.8.

Variable	Measured value	Expected value	% Error
S_s	2.74	± 0.01	0.37
S_m	1.8	± 0.008	0.44
S_w	1.000	± 0.002	0.20
C_v	0.460	± 0.0053 (max)	1.15

Table 2.8 : Analysis of errors in a typical calculation of solids concentration.

Mean mixture velocity, V_m

The mean mixture velocity is calculated from equation 2.4:

$$V_m = \frac{4Q_m}{\pi D^2}$$

The errors associated with the calculation of V_m for typical values of Q_m in the two pipe loops are presented in Tables 2.9 and 2.10 below.

Variable	Measured value	Expected value	% Error
Q_m (m^3/s)	3.941 E −3	± 0.059 E −3	1.50
D (m)	0.0409	± 0.0004	0.98
V_m (m/s)	3.000	± 0.074	2.47

Table 2.9 : Analysis of errors in a typical calculation of mean mixture velocity in the 40 mm N.B. pipe loop.

Variable	Measured value	Expected value	% Error
Q_m (m^3/s)	12.798 E −3	± 0.233 E −3	1.82
D (m)	0.0737	± 0.0008	1.09
V_m (m/s)	3.000	± 0.065	2.17

Table 2.10 : Analysis of errors in a typical calculation of mean mixture velocity in the 80 mm N.B. pipe loop.

Pressure gradient, dP/dL

The hydraulic gradient is calculated from:

$$i_m = \frac{dh}{L}$$

The errors associated with the calculation of hydraulic gradient for typical values of dh and L are presented in Table 2.10 below:

Variable	Measured value	Expected value	% Error
dh (m)	0.500	± 0.005	1.00
L	1.000	± 0.002	0.20
i_m	0.500	± 0.010 (max)	2.00

Table 2.10 : Analysis of errors in a typical calculation of hydraulic gradient.

The pressure gradient is calculated from:

$$dP/dL = \rho_w \, g \, i_m$$

The errors associated with the calculation of dP/dL for a typical value of i_m are presented in table 2.11.

Variable	Measured value	Expected value	% Error
i_m	0.500	± 0.010	2.00
ρw (Kg/m^3)	1 000 (assumed)	−2	0.20
dP/dL (Pa/m)	4 905	± 99 (max)	2.02

Table 2.11 : Analysis of errors in a typical calculation of pressure gradient.

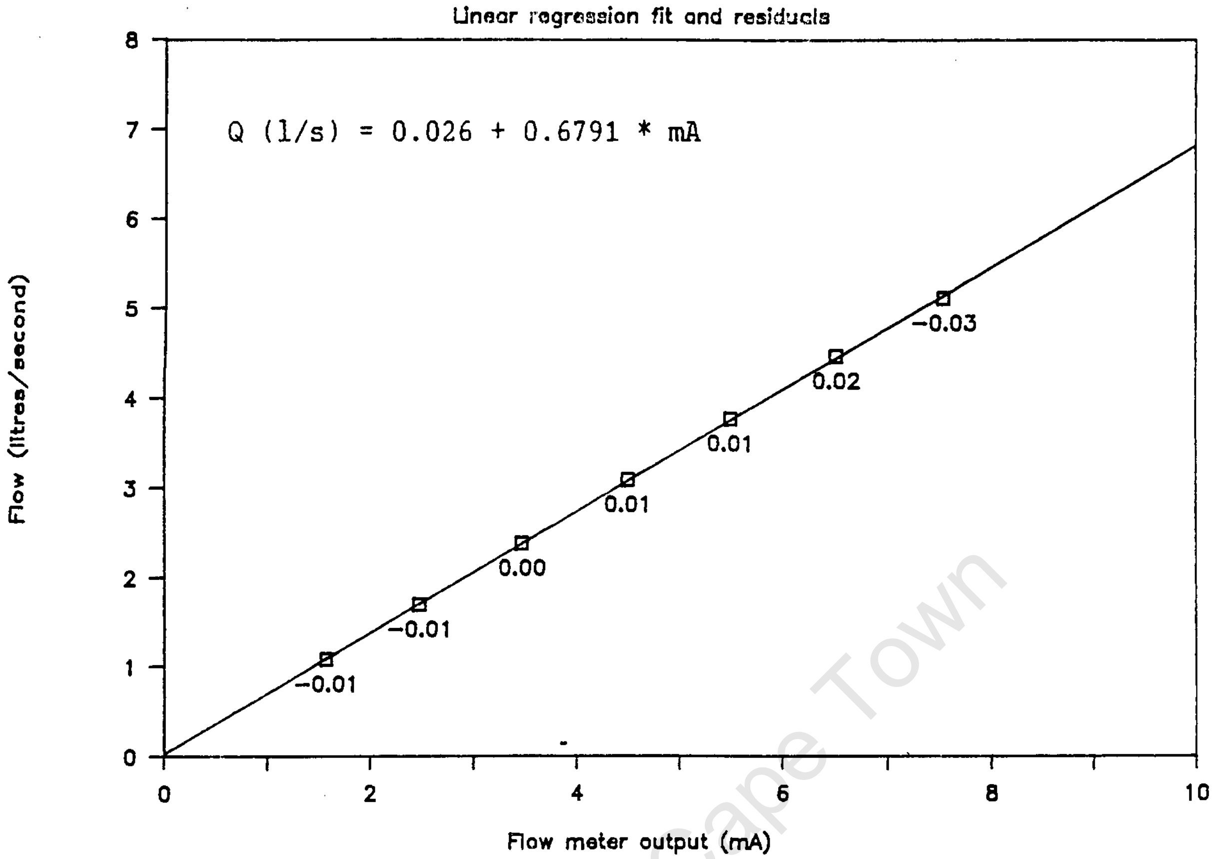


Figure 2.24 : 40 mm N.B. flow meter - calibration curve.

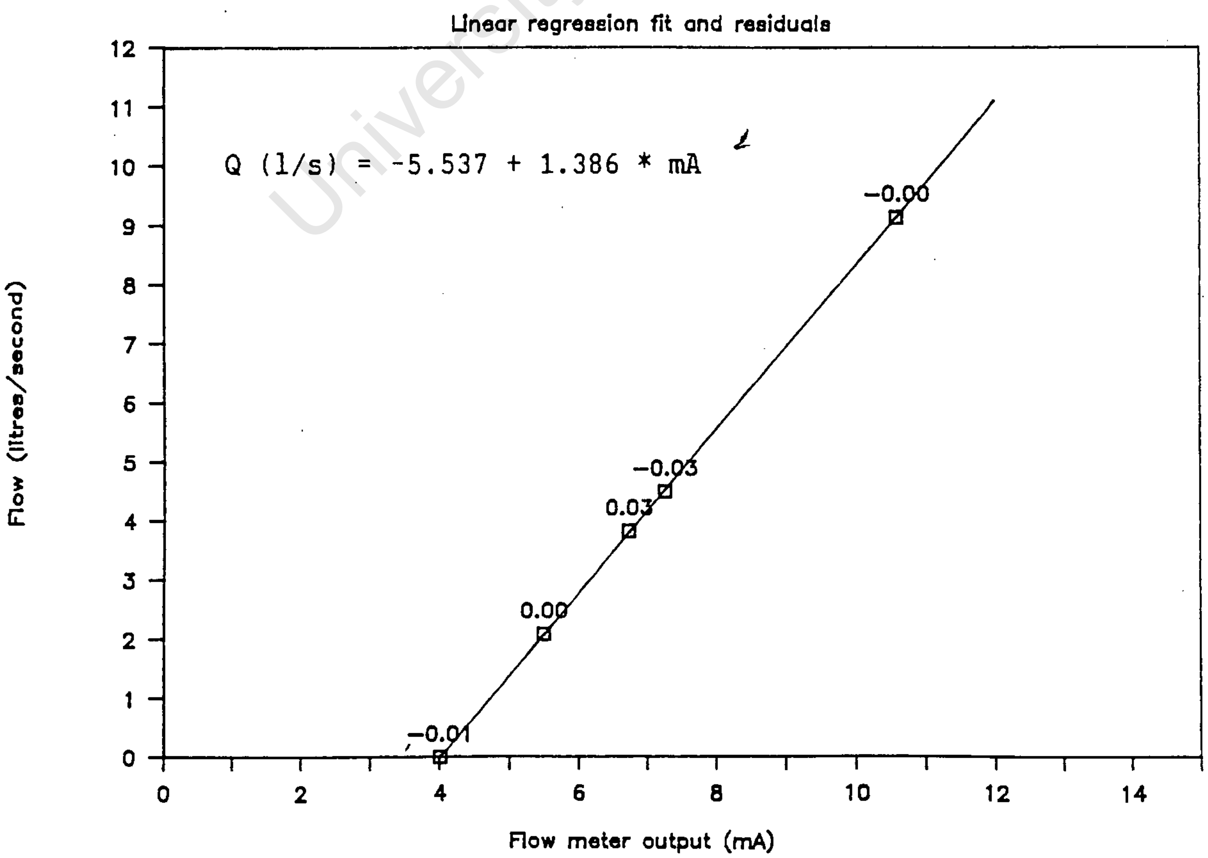


Figure 2.25 : 80 mm N.B. flow meter - calibration curve.

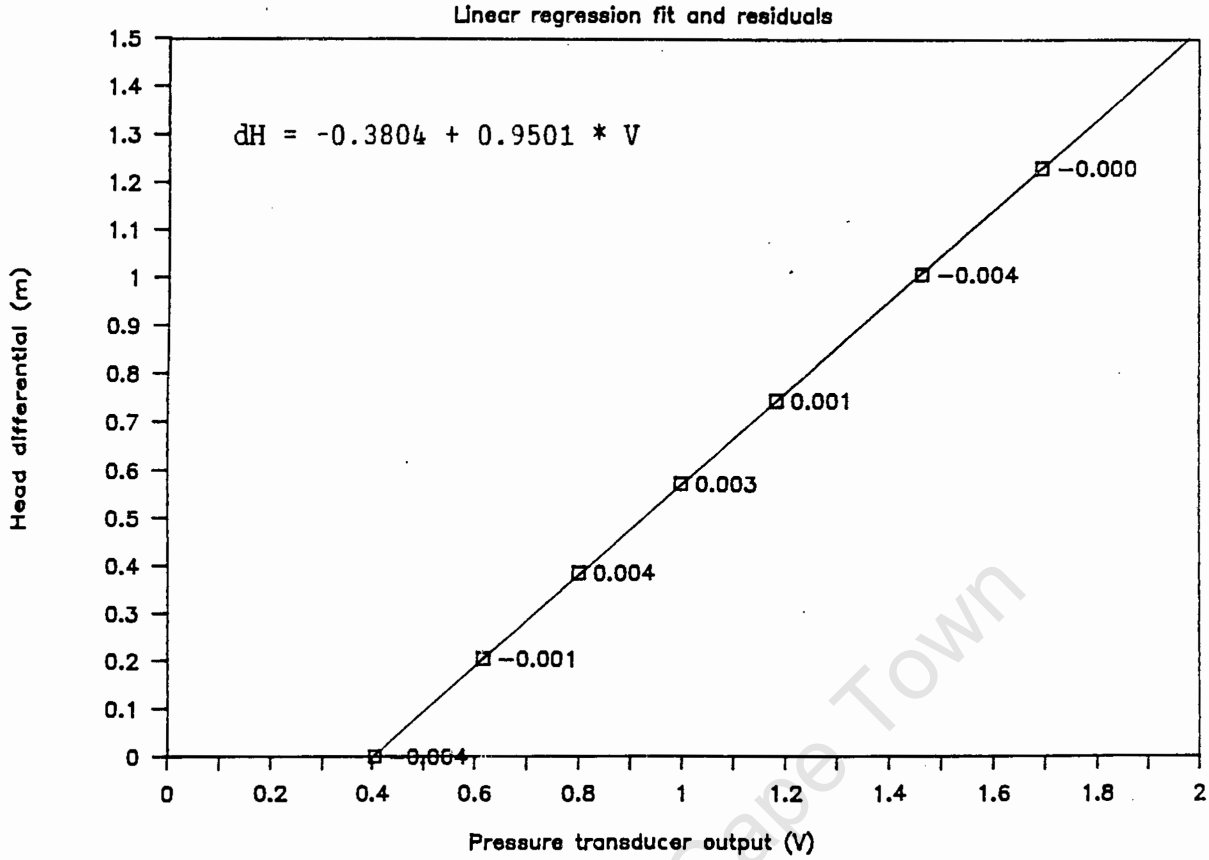


Figure 2.26 : Differential pressure transducers - typical calibration curve.

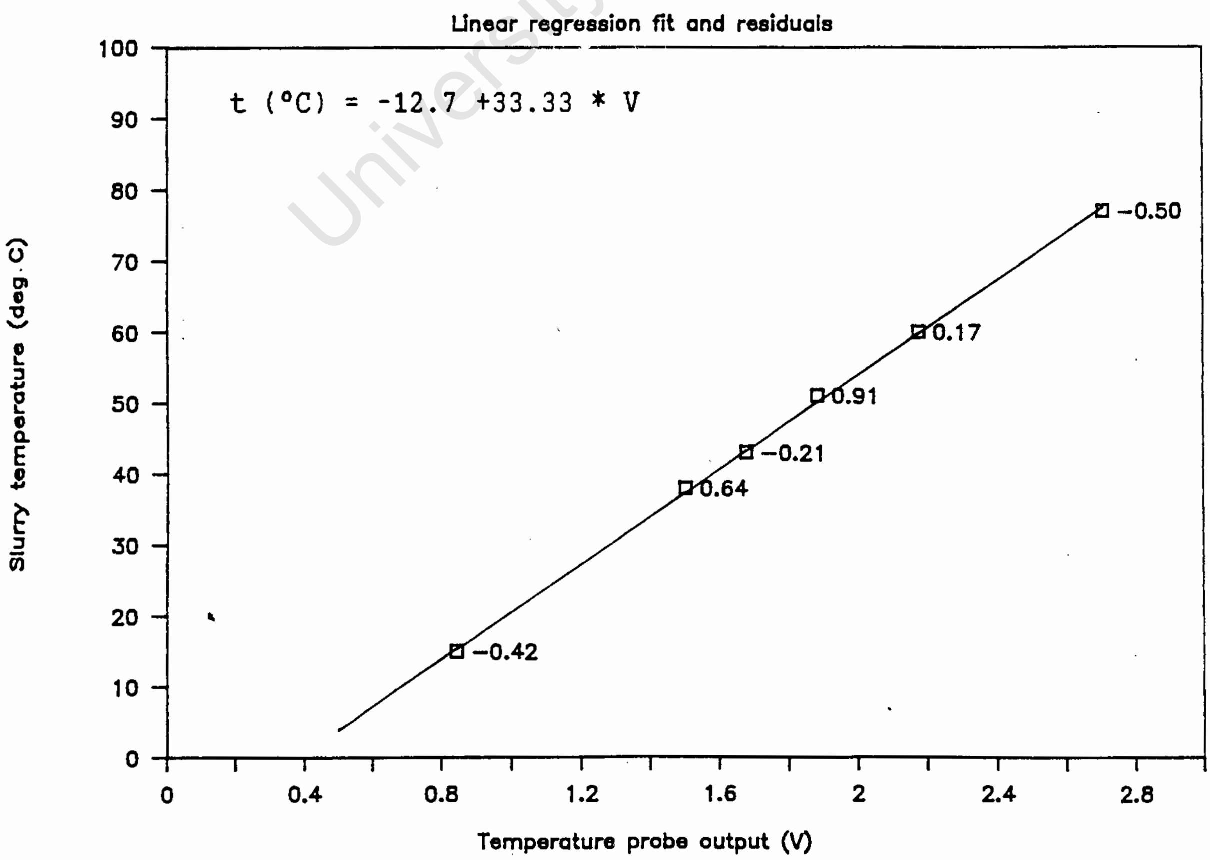


Figure 2.27 : Temperature probe - calibration curve.

CHAPTER 3

Literature review

1. INTRODUCTION

The purpose of this review is:

(i) To discuss, in general, models existing prior to those developed by Cooke and Paterson, showing the need for the development of models for high concentration tailings slurries.

(ii) To present the models developed by Cooke and Paterson specifically for high concentration cyclone classified tailings slurries and high concentration full plant tailings slurries respectively.

The discussion of existing models is presented in section 2 of this chapter. The models of Paterson and Cooke are presented in sections 3 and 4 respectively.

2. EXISTING MODELS

Models describing the flow of solid-liquid mixtures in pipelines can be broadly classed as either rheological, empirical or mechanistic. These three classes of models are discussed under separate headings below. In each case Paterson and/or Cooke have shown that these models are not applicable to high concentration gold tailings slurries.

The models referred to in the following sections are listed below in Table 3.1. The models investigated by Cooke and Paterson are as indicated.

Model/Author		Model type
+	Durand	Empirical
+	Newitt et al	Empirical
+	Wasp et al	Semi-empirical
+	Wilson	Mechanistic
+*	Lazarus	Mechanistic
+*	Streat dense phase (sliding bed)	Mechanistic
*	Streat dense phase (vertical flow)	Mechanistic
*	Wilson et al dense phase (vertical flow)	Mechanistic

Table 3.1 : Existing models investigated by Cooke and Paterson.

* – Investigated by Cooke
\+ – Investigated by Paterson

2.1 Rheological models

A rheological model is a mathematical description of the relationship between applied shear stress and the resultant rate of shear strain for a particular fluid.

Homogeneous suspensions, which behave as a single phase fluid, can generally be rheologically characterised in terms of one of a number of rheological models.

The rheology of full plant tailings, which forms a practically homogeneous suspension, was investigated by Neill (1988). Neill found that at "low" concentrations (Cv <30%) full plant tailings can be characterised using the yield pseudoplastic model. At "high" concentrations (Cv >30%), however, Neill found that full plant tailings exhibit anomalous behaviour and was not able to rheologically characterise these slurries.

Cooke (1991) has shown that cyclone classified tailings form a hetrogeneous suspension at "low" concentrations and dense phase mixtures at "high" concentrations. Rheological modelling is thus not applicable to cyclone classified tailings slurries because:

(i) The flow of hetrogeneous suspensions (eg low concentration cyclone classified tailings) is predominantly a turbulent phenomenon (Wasp (1978)).

(ii) The resistance to flow of dense phase mixtures (eg high concentration cyclone classified tailings) is predominantly in the form of particle-particle and particle-pipe wall mechanical friction (Wilson et al (1979), Streat (1986)).

2.2 Empirical models

The general form of most empirical models is that of the Durand type correlation, as shown in equation 3.1:

$$\Phi = K\psi^{m} \tag{3.1}$$

Where:

Φ = head loss parameter.

$$= \frac{i_m - i_w}{C_v \, i_w}$$

ψ = flow regime parameter.

$$= \frac{V_m^2 \, C_D}{g \, D}$$

C_D = drag coefficient of representative particle.

K and m are experimentally derived constants specific to a particular slurry.

The mixture head loss, i_m, is thus related to the head loss for water, i_w, by means of K and m, determined from measured data.

Values of K and m determined for a particular slurry are truly applicable to that slurry only. When considering using an empirical model, it is thus essential to ensure that the slurry in question is comparable to the slurry on which the model is based.

Existing well known empirical models have all been developed for low concentration slurries. These models are thus not expected to be applicable to high concentration slurries. This has been shown to be the case by Paterson (1991) who evaluated the models as indicated in Table 3.1, on the previous page.

2.3 Mechanistic models

Mechanistic models are based on the physical behaviour of the slurry in a pipeline. If this is correctly modelled then the model should be applicable to any slurry which behaves in the same manner.

A number of mechanistic models exist. These can be sub-divided into "low" concentration and "high" concentration models, as defined below, based on the solids concentration range for which they have been developed.

"High" concentration is generally considered to be a solids concentration such that the predominant mechanism of particle support is interparticle contact. In contrast, in the case of "low" concentrations the predominant mechanism of particle support is turbulence.

Low solids concentrations

Mechanistic models developed for low concentration slurries typically treat the slurry as a hetrogeneous suspension of coarse solids in a vehicle. The vehicle consisting of the fluid (generally water) and those fine particles which are homogeneously suspended in the fluid and contribute to its rheology.

Cooke (1991) and Paterson (1991) have shown that the Lazarus mechanistic model is applicable to low concentration cyclone classified tailings and full plant tailings slurries.

In the case of cyclone classified tailings, Cooke has shown that the Lazarus model accurately predicts pressure gradients for solids concentrations less than 40% by volume (S_m about 1.68). Beyond this point, however, error in the model prediction (under prediction) increases significantly.

In the case of full plant tailings, Paterson has shown that the Lazarus model closely predicts pressure gradients for full plant tailings up to solids concentrations of about 38% by volume (S_s about 1.65). Again, beyond this point the error in the model prediction (under prediction) increases significantly.

The poor correlation of the Lazarus model at high solids concentrations is typical of all mechanistic models developed for low concentration slurries. This is attributed to the fact that interparticle stresses, which have been identified as contributing significantly to the wall shear stress at high solids concentrations are not considered. These models are thus not applicable to high concentration slurries.

High solids concentrations

Mechanistic models developed for high concentration slurries, as listed in Table 3.1, are all "dense phase flow" models.

Cooke evaluated the three dense phase models (the Streat dense phase sliding bed model, the Streat model for dense phase vertical flow and the Wilson, Brown and Streat model for dense phase vertical flow). All these models are shown to give a poor correlation with measured data when applied to cyclone classified tailings slurries.

Paterson applied the Streat dense phase sliding bed model to full plant tailings slurries and found it give a very poor correlation with measured data.

It is thus concluded that these existing models for high concentration slurries are not applicable to high concentration full plant or cyclone classified tailings slurries. This serves to highlight the fact that models developed for a particular slurry type (in terms of physical properties) can not be applied blindly to other slurries.

2.4 Conclusions

Both Cooke and Paterson arrived at the conclusion that existing models are not applicable to high concentration mineral tailings slurries (cyclone classified tailings and full plant tailings respectively). A need was thus identified for the development of models applicable to these slurries.

The models developed by Cooke and Paterson (for cyclone classified tailings and full plant tailings respectively) are now reviewed in detail in the following two sections of this chapter.

3. THE PATERSON MODEL

3.1 Introduction

Paterson has developed a technique which allows for modeling the flow of "high concentration, stabilized flow, full plant mineral tailings slurries". Definitions of these terms are given below.

"High concentration", as applicable to full plant tailings, has been defined by Paterson (1991) as a solids concentration greater than the "freely settled bed packing concentration", $C_{b\ FREE}$. This being the concentration of the particle matrix formed when the material is allowed to settle freely through water. The procedure for determination of $C_{b\ FREE}$ has been described in Chapter 2.

"**Stabilized flow**" is a flow regime that is said to exist when larger particles in the slurry are supported by the yield stress of the vehicle. The vehicle consisting of the carrier fluid (usually water) and those fine particles which contribute to its rheology.

Stabilized flow typically occurs in slurries with a wide particle size range, a high percentage of fines and at high solids concentrations.

Full plant tailings have been shown to exhibit "anomalous" behaviour at high concentrations (Neill (1988)). The onset of anomalous behaviour occuring at a solids concentration approximately equal to $C_{b\ FREE}$ (Paterson (1991)).

The "anomalous" behaviour referred to above is a pipe diameter dependance on a shear diagram. In other words, the laminar flow region for varying pipe diameters are not coincident for such slurries, as would be expected for "normal" fluid behaviour. An example of anomalous behaviour is shown in Figure 3.1, for full plant tailings at a solids concentration of 43.3% by volume. Note that the trend curves drawn through the data points for the two pipe diameters shown, are not coincident in the laminar flow region.

A pseudo shear diagram for **low** concentration full plant tailings which does **not** exhibit anomalous behaviour, is shown for comparison in Figure 3.2. In this case, for a solids concentration of 29.5% by volume, the behaviour is as expected. Note that the trend curves drawn through the data points for the two pipe diameters shown are coincident in the laminar flow region.

As a result of the anomalous behaviour of full plant tailings at high concentrations, these slurries can not be rheologically characterised using traditional rheological models (which do not allow for diameter dependant rheology).

Various mechanisms were identified by Paterson which might explain anomalous behaviour in these slurries:

(i) The presence of a slip velocity at the pipe wall.

(ii) The particle size to pipe diameter ratio causing a reduction in in situ concentration.

(iii) The presence of a particle lean zone at the pipe wall due to migration of solids towards the pipe centre line.

These mechanisms were all investigated by Paterson. However, none were found to explain the anomalous behaviour of high concentration full plant tailings slurries.

Paterson has approached the problem of modeling these slurries by first presenting a mechanism to explain the anomalous behaviour. A technique is then presented for modelling the flow of high concentration full plant tailings slurries.

3.2 Description of the model

Paterson accounts for the anomalous behaviour of high concentration full plant tailings slurries through evaluating the two wall shear stress components which exist for such slurries. These components being:

(i) A viscous wall shear stress component (τ_v)

(ii) A solids wall shear stress component (τ_s)

Paterson presents a novel technique for extracting the viscous wall shear stress component (τ_v) from the pseudo shear diagram (as obtained from tube viscometer or pipeline tests). Having isolated the viscous wall shear stress component, the rheological parameters for this component (τ_y, K and n) are determined using a yield pseudoplastic approximation.

The solids wall shear stress component (τ_s) is attributed to mechanical sliding friction between the solid phase and the pipe wall, associated with a dispersive stress at high solids concentrations.

The technique for evaluating the viscous wall shear stress component, τ_v is described in detail in section 3.3. The evaluation of the solids wall shear stress component, τ_s is described in section 3.4.

3.3 Evaluation of the viscous wall shear stress component (τ_v)

The technique for evaluating the viscous wall shear stress component is presented by means of two examples.

The technique is first applied to **low** concentration full plant tailings (Example 1) and then to **high** concentration full plant tailings (Example 2).

Example 1 – low concentration full plant tailings

The procedure is set out in a step by step form below:

1. A pseudo-shear diagram is plotted for pressure gradient data collected from pipeline tests or a tube viscometer, as shown in Figure 3.2 (for full plant tailings at a solids concentration of 29.5% by volume and for pipe diameters of 4.2 mm, 13.4 mm and 28.4 mm).

2. From the pseudo shear diagram (Figure 3.2), the pressure gradient, dP/L, is determined for values of constant pseudo shear rate for the three pipe diameters in the laminar flow region; and plotted against 1/D, as shown in Figure 3.3.

3. Lines are drawn through the points of equal pseudo shear rate and the intercept of these lines on the pressure gradient axis (at 1/D = 0) is noted (Figure 3.3).

4. The zero intercept of these lines in this case indicates that as D tends to infinity, dP/L tends to zero.

Noting that for **viscous flow**, the relationship between wall shear stress (τ_0) and pressure gradient (dP/L) is as shown in equation 3.2:

$$\frac{dP}{L} = \frac{4\,\tau_0}{D} \qquad (3.2)$$

For a constant wall shear rate (τ_0), as D tends to infinity so the pressure gradient (dP/L) tends to zero. Thus, looking at the results of step 4 above, it is concluded that the wall shear stress is entirely viscous in this case (low concentration), as would be expected where anomalous behaviour does **not** occur.

<u>Example 2</u> – **high concentration full plant tailings**

The procedure as set out in Example 1 above is again followed.

1. The pseudo shear diagram is shown in Figure 3.4, in this case for full plant tailings at a solids concentration of 43.3% by volume.

2. Pressure gradient has been plotted against 1/D for various values of pseudo shear rate in Figure 3.5.

3. Lines are drawn through the points of equal pseudo shear rate (Figure 3.5) These lines now have non-zero intercepts on the pressure gradient axis.

4. Thus, in this case, as D tends to infinity, the pressure gradient does not tend to zero (as in example 1 for entirely viscous wall shear stress). The pressure gradient at 1/D = 0 for a particular pseudo shear rate is taken to be the non-viscous or solid component of the total wall shear stress.

5. The intercept pressure gradient (at 1/D = 0) is plotted against pseudo shear rate in Figure 3.6. The line drawn through these points is taken to represent the relationship between pseudo shear rate and the solid component of the total measured pressure gradient.

6. The solid component of the measured pressure gradients is now removed from the original pressure gradient data (using the relationship identified in step 5 above) and the "corrected" or viscous component pseudo shear diagram is plotted, as shown in Figure 3.7. Note that the laminar flow region of these curves are now co-incident.

Paterson has shown that the yield pseudoplastic approximation can be used to determine the rheological parameters (τ_y, K and n) for the viscous portion of the wall shear stress, as isolated in the procedure set out above.

Using an optimization program based on the minimum error solution of equation 3.3 for a yield pseudoplastic slurry, Paterson has determined τ_y, K and n from a set of pressure gradient data for a particular full plant tailings.

$$\frac{8V}{D} = \frac{4n}{K^{1/n}\tau^3}(\tau - \tau y)^{(n+1)/n}\left[\frac{(\tau - \tau y)^2}{3n+1} + \frac{2\tau y(\tau - \tau y)}{2n+1} + \frac{\tau y^2}{n+1}\right] \qquad (3.3)$$

Best fit equations for τ_y, K and n as a function of solids concentration (for the full plant tailings used by Paterson) are presented in Table 3.2. The particle size distribution and solids relative density of the full plant tailings used by Paterson are presented in Table 3.3.

3.4 Evaluation of the solids wall shear stress component (τ_s)

Paterson postulates that at high concentrations (above the freely settled concentration) a dispersive stress (σ_d) exists as a result of the pressure gradient applied to the particle matrix. This dispersive stress results in a normal force between the pipe wall and those solid particles in contact with it. The solids wall shear stress component is related to the dispersive stress by the coefficient of sliding friction between the solid particles and the pipe wall (μ_s) as shown in equation 3.4:

$$\tau_s = \mu_s \sigma_d \qquad (3.4)$$

The dispersive stress, σ_d, is related to the applied pressure gradient as shown in equation 3.5:

$$\sigma_d = Kr\left|\frac{dP}{dL}\right| \qquad (3.5)$$

where:

$\frac{dP}{dL}$ = total pressure gradient due to the wall shear stress only

Kr = dispersive stress coefficient

In his analysis Paterson uses the coefficient of sliding friction, as measured using a "tilting tube" apparatus developed by Wilson et al (1972).

Using measured values of μ_s and measured pressure gradient data, the dispersive stress coefficient, Kr, is calculated. Kr is found to be a function of both solids concentration and pipe diameter.

Paterson presents the following relation for Kr, based on data for the particular full plant tailings material on which this work is based:

$$Kr = a + b\,S_m \tag{3.6}$$

where:

$$a = 0{,}0091534042 - 1{,}83476486\,D$$
$$b = 0{,}0077853195 + 1{,}26903739\,D$$

Paterson then develops a relation for the calculation of τ_s in terms of τ_v:

Combining equations 3.4 and 3.5:

$$\tau_s = \mu_s\,Kr\left|\frac{dP}{dL}\right| \tag{3.7}$$

noting that:

$$\frac{dP}{dL} = \frac{4\tau_0}{D} \tag{3.8}$$

and:

$$\tau_0 = \tau_v + \tau_s \tag{3.9}$$

Combining equations 3.7, 3.8 and 3.9:

$$\tau_s = \frac{4\mu_s\,Kr\,(\tau_v + \tau_s)}{D} \tag{3.10}$$

Rearranging gives:

$$\tau_s = \frac{4\mu_s\,Kr\,\tau_v}{D - 4\,\mu_s\,Kr} \tag{3.11}$$

Thus, having evaluated the viscous wall shear stress component as set out in section 3.3, the solids wall shear stress component can be determined from equation 3.11.

3.5 Turbulent flow of full plant tailings slurries

The technique set out above is applicable to the laminar flow region only.

In the case of turbulent flow, Paterson found that the Torrance (1963) relation for smooth wall pipes is applicable. The method of Hanks (1974) being used to determine the laminar to turbulent transition velocity. This was, however, established for turbulent flow at low concentrations only.

At high concentrations the flow was observed to be laminar for the full range of flow velocities covered, the technique developed by Paterson thus being applicable.

3.6 Summary of the procedure

Set out below is a summary of the procedure developed by Paterson to model high concentration full plant tailings slurries.

Data required

A set of pressure gradient data is required covering a range of solids concentrations, a range of mixture velocities and at least two pipe diameters.

The viscous wall shear stress component (τ_v)

The rheological parameters of the viscous wall shear stress component (τ_y, K and n) are determined for each solids concentration for which data is available, using the procedure as set out in section 3.3.

Equations are then determined relating τ_y, K and n to solids concentration based on these results.

The viscous wall shear stress component can now be calculated using the yield pseudoplastic approximation.

The solids wall shear stress component (τ_s)

The coefficient of sliding friction, μ_s is determined using a tilting tube apparatus.

Using the measured value of μ_s and measured pressure gradient data, the dispersive stress coefficient, Kr is determined as a function of solids concentration and pipe diameter.

The solids wall shear stress component is then calculated using equation 3.11, giving τ_s as a function of τ_v.

3.7 Conclusions

Paterson has presented a mechanism which accounts for the anomalous behaviour of high concentration full plant tailings slurries. This mechanism being the existance of both a viscous and solids friction wall shear stress component.

A novel technique is presented for isolating the two wall shear stress components from measured pressure gradient versus velocity data.

Rheological parameters can then be determined for the viscous wall shear stress component. The solids wall shear stress component is then related to the viscous wall shear stress component.

It is noted that the rheological parameters (τ_y, K and n) as presented in Table 3.2 have been determined for one particular full plant tailings material. These parameters are thus applicable only to the particular full plant tailings material on which this work is based. The same being true for the values presented for the dispersive stress coefficient, Kr.

It is thus reasonable to expect that a change in the material characteristics of the tailings (particle size distribution for example) will effect the rheological parameters and the dispersive stress coefficient.

However, the mechanism presented for explaining the anomalous behaviour of these slurries and the technique for analysing the slurries is expected to be applicable to any high concentration tailings slurry exhibiting anomalous behaviour due to the existance of both a viscous and mechanical friction wall shear stress component.

Parameter	Best fit equation	Range
τ_y	$7298.63\ C_v^{7.334254}$	$C_v > 21\%$
K	$99.3284\ C_v^{7.262278}$	$C_v > 21\%$
n	$4.4793 - 16.9757\ C_v + 19.4468\ C_v^2$	$32.9\% < C_v < 54.4\%$

Table 3.2 : τ_y, K and n as a function of solids concentration as determined for the full plant tailings material used by Paterson

Material : Chamber of Mines Full Plant
S_s : 2.72 to 2.74
d_{50} : 21.7 microns
% −10 microns : 30.9

Sieve size [microns]	% Passing	% Retained
564.0	100.0	0.0
262.0	100.0	0.0
168.0	95.5	4.5
113.0	86.2	9.3
84.0	77.4	8.8
65.0	70.5	6.9
50.0	64.8	5.7
39.0	59.0	5.8
30.0	54.5	4.5
21.0	49.6	4.9
11.0	33.9	15.7
6.0	18.8	15.1
Pan	0.0	18.8

Table 3.3 : Solids density and particle size distribution of full plant talings material used by Paterson

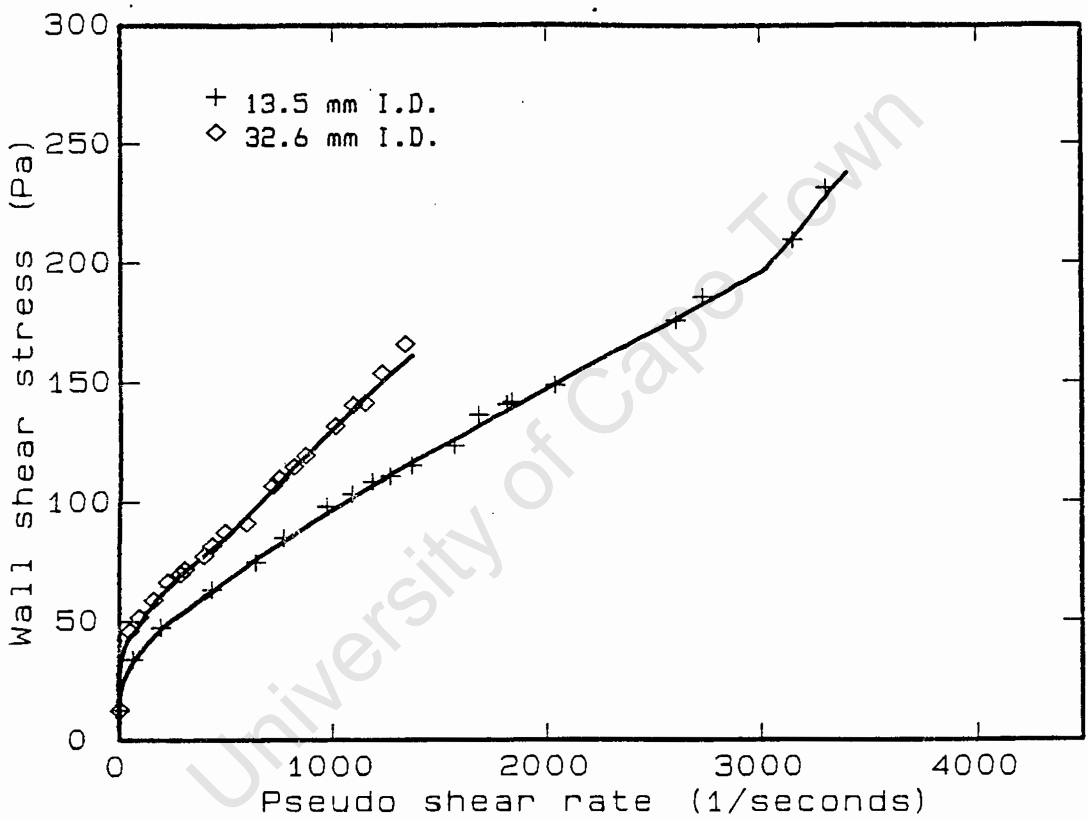


Figure 3.1 : Pseudo shear diagram for high concentration full plant tailings (Cv = 43.3%)

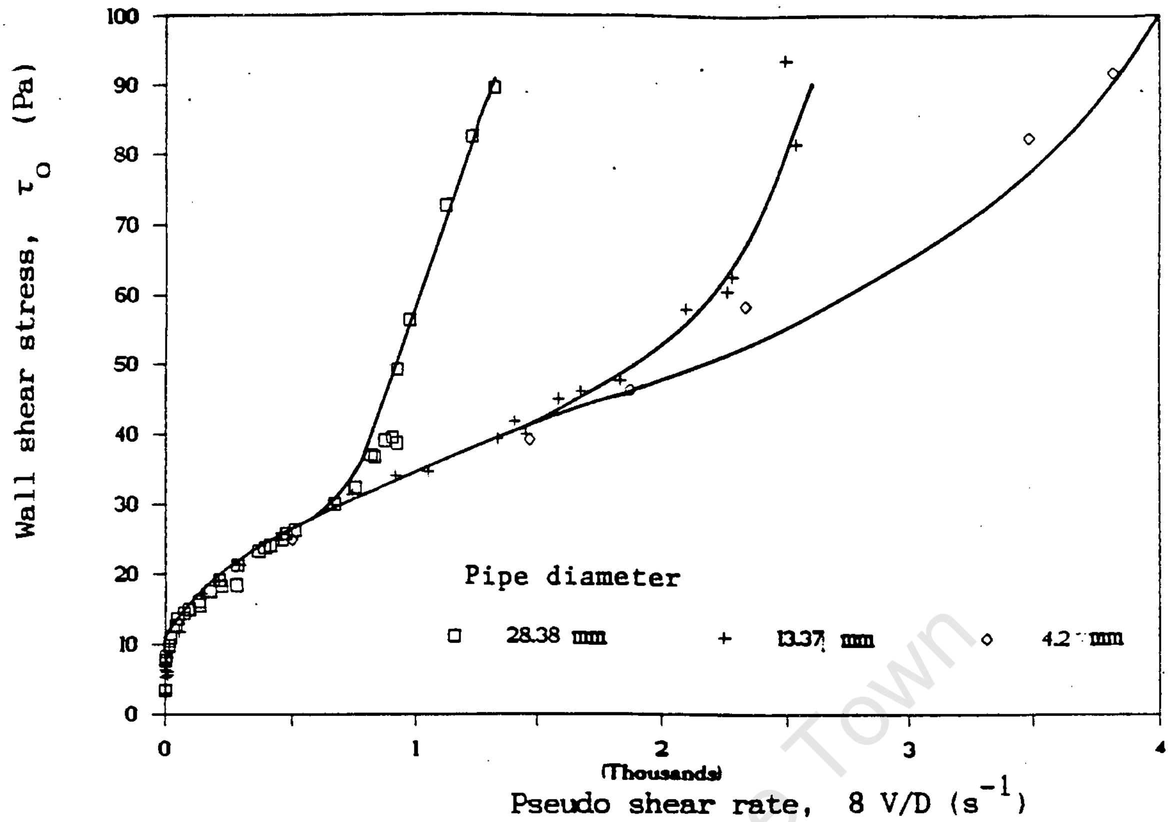


Figure 3.2 : Pseudo shear diagram for low concentration full plant tailings (Cv = 29.5%)

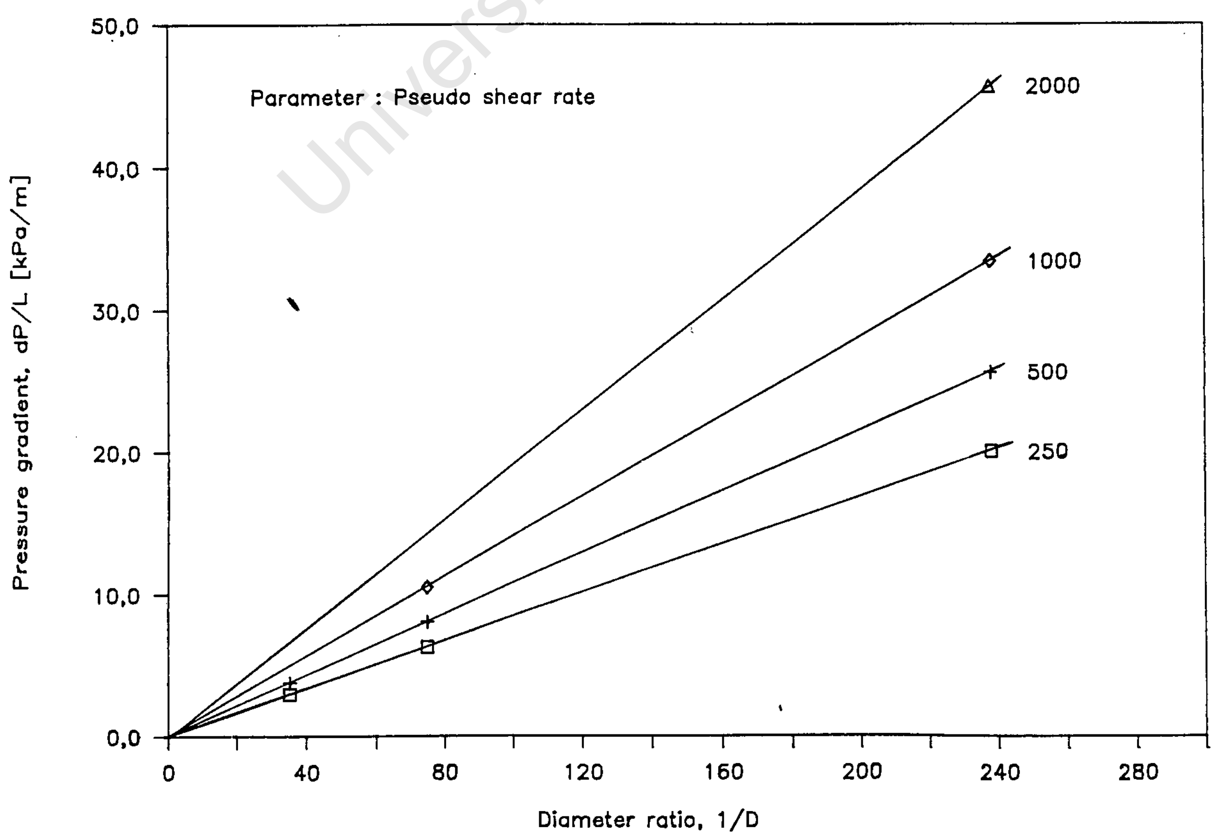


Figure 3.3 : Pressure gradient versus diameter ratio for low concentration full plant tailings

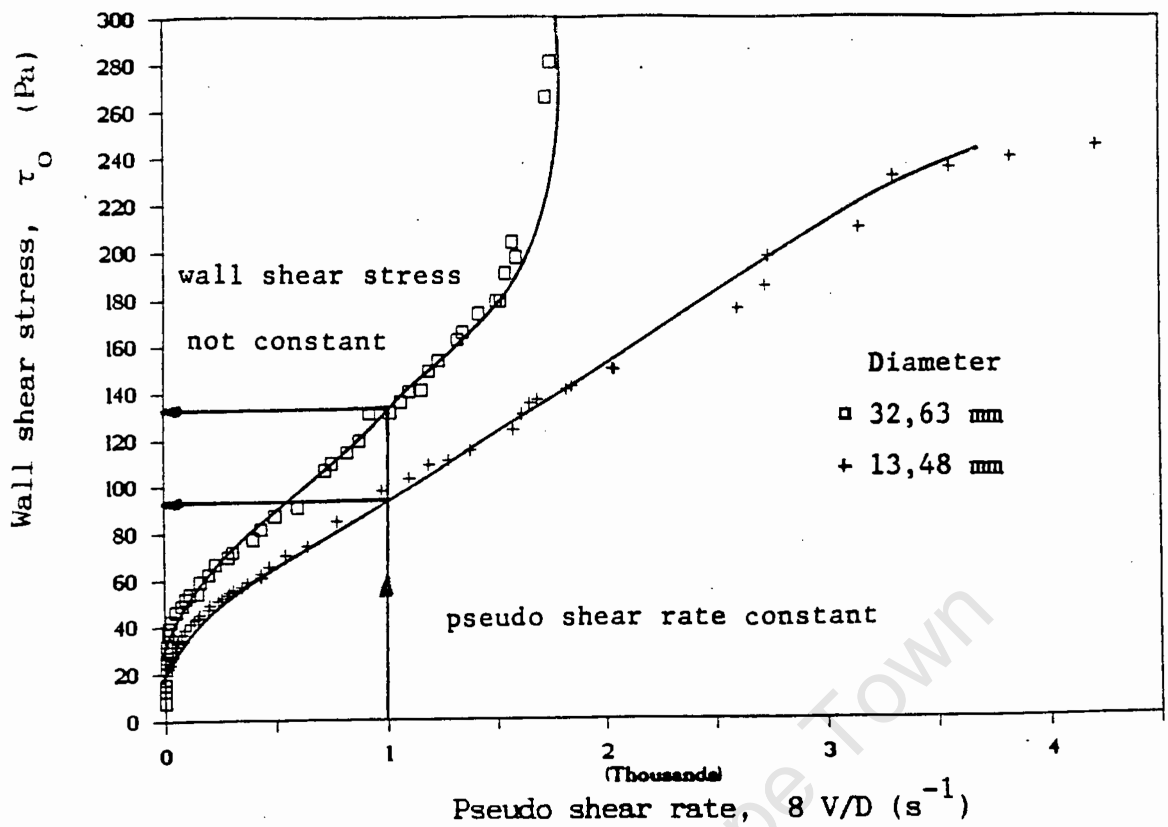


Figure 3.4 : Pseudo shear diagram for high concentration full plant tailings (Cv = 43.3%)

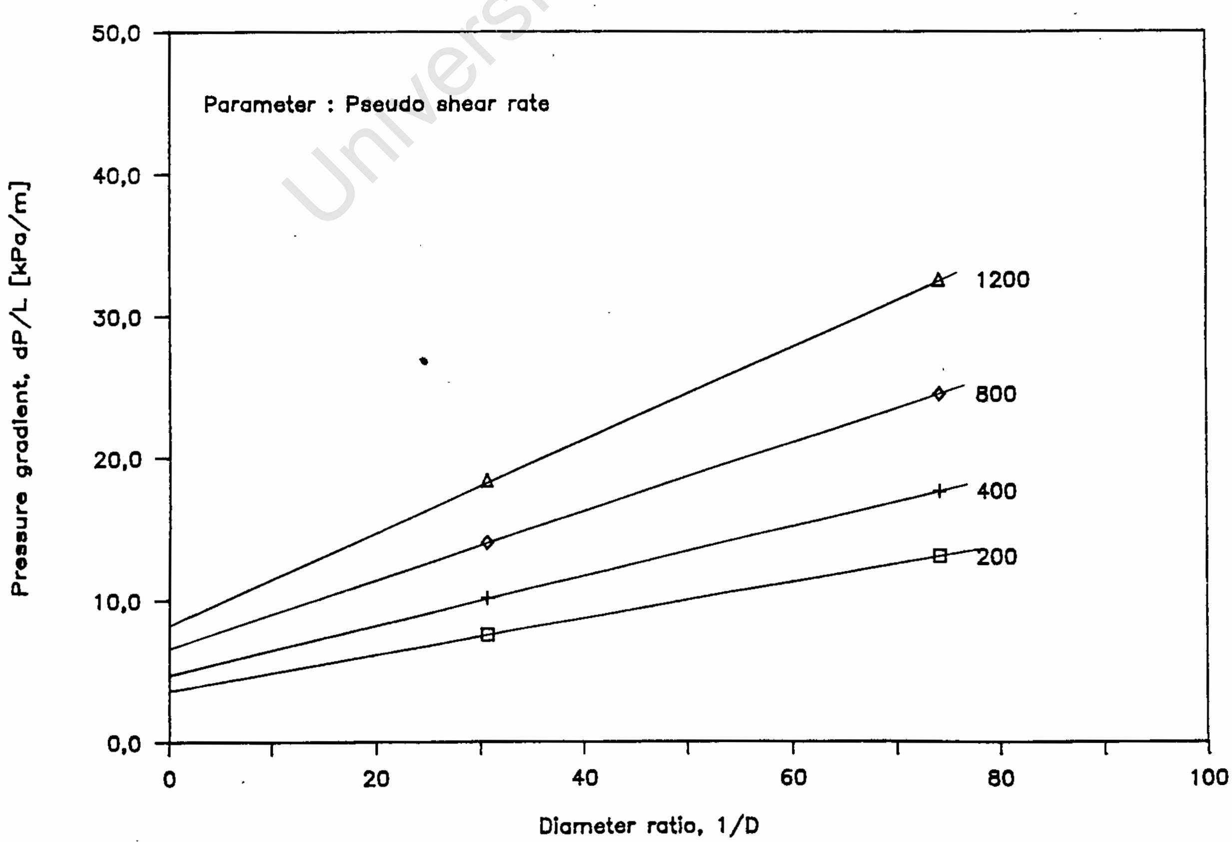


Figure 3.5 : Pressure gradient versus diameter ratio for high concentration full plant tailings

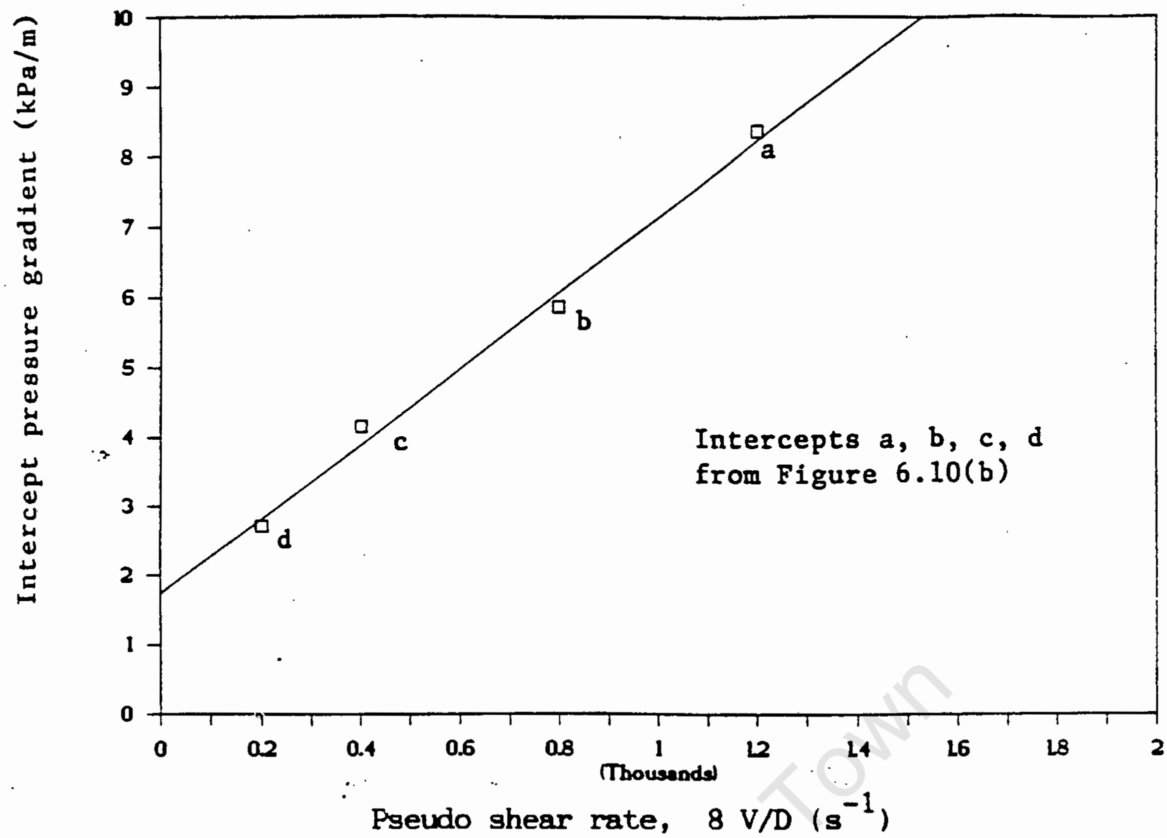


Figure 3.6 : Pressure gradient due to solids wall shear stress versus pseudo shear rate

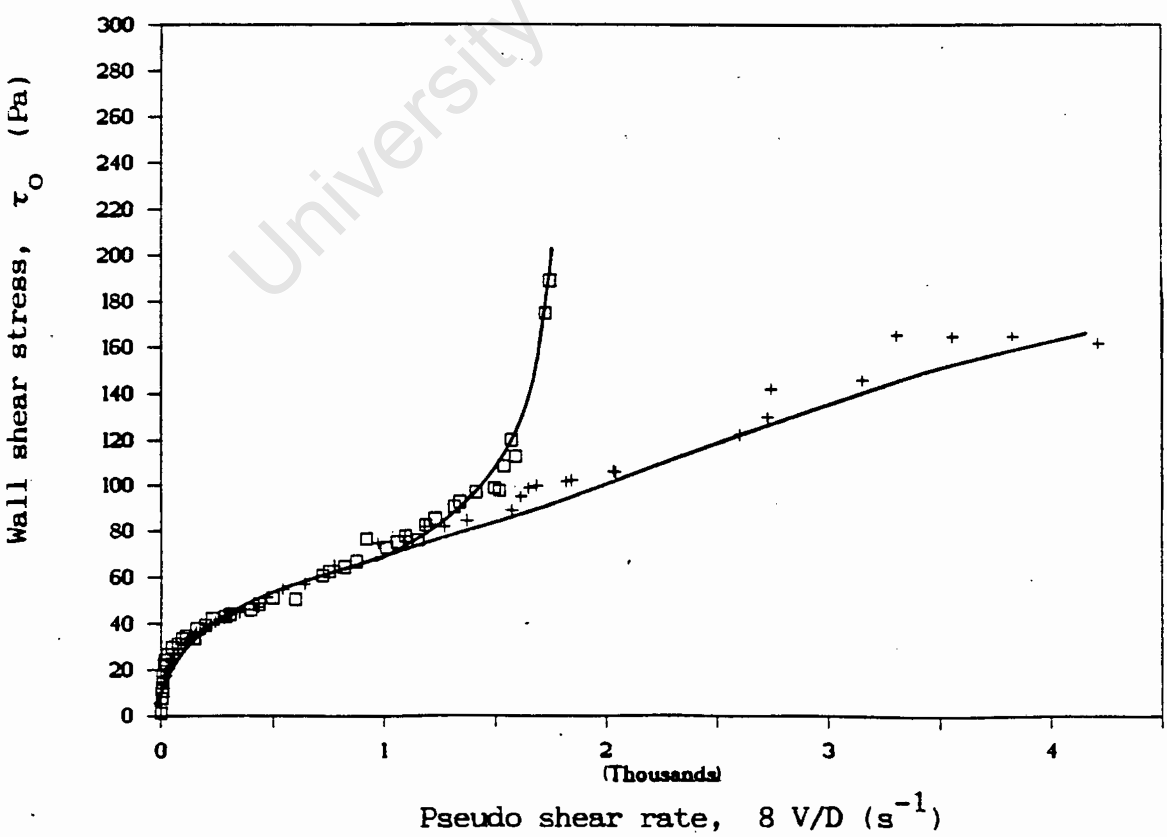


Figure 3.7 : Corrected pseudo shear diagram representing viscous wall shear stress component only

4. THE COOKE MODEL

4.1 Introduction

The Cooke model has been developed specifically to describe the dense phase flow of cyclone classified tailings slurries. The term dense phase flow is defined below:

"Dense phase" flow, by definition (Cooke 1991), exists when the dominant mechanism supporting the particles in the mixture is interparticle contact. This results in a uniform solids concentration across the pipe cross section.

4.2 Description of the model

For two phase (solid-liquid) mixtures, the total shear stress at any point is the sum of two components, These being:

A solids shear stress component (τ_s).

A liquid shear stress component (τ_l).

Cooke evaluates these two shear stress components across the pipe cross section, assuming an applied pressure gradient. These shear stresses are then substituted into the differential equation describing the velocity distribution in the pipe, yielding a mean mixture velocity. In this way a curve can be built up of pressure gradient versus mixture velocity.

4.3 Evaluation of the shear stress distribution

The shear stress distribution in a pipe conveying a dense phase mixture is found to be linear. This is the result of the constant solids concentration across the pipe cross section which, by definition, exists for dense phase flow.

The shear stress at any radius, r, is given by equation 3.12:

$$\tau_m = \frac{r}{2}\left[\frac{dP}{dx} - \rho_m g \sin\varphi\right] \tag{3.12}$$

Where:

$$\rho_m = \rho_l + C\,(\rho_s - \rho_l)$$

4.4 Evaluation of the solid phase shear stress component (τ_s)

The solid phase axial shear stress at any point is associated with a normal stress (normal to the pipe wall), the relationship being given by equation 3.13 below, and see Figure 3.8.

$$\tau_{skx} \leq \tau_{sk} \tan\delta \tag{3.13}$$

Where:

τ_{skx} = Solid phase shear stress.

τ_{sk} = Solid phase normal stress.

k = y or z direction in Figure 3.8

δ = internal angle of friction of the solid matrix.

When the applied shear stress is greater than $\tau_{sk} \tan \delta$ then the solid matrix will shear and τ_{skx} will be equal to $\tau_{sk} \tan \delta$ (i.e. the solid phase shear stress equals the "failure" shear stress).

When the applied shear stress is less than $\tau_{sk} \tan \delta$ then the solid matrix will not shear and τ_{skx} will equal the applied shear stress (i.e. the solid phase shear stress equals the applied shear stress).

In order to evaluate the solid phase shear stress, τ_{skx}, the solid phase normal stress, τ_{sk}, must first be determined, as described below.

The solid phase normal stress, τ_{sk}, at any point is the sum of two components, these being:

(i) A normal stress due to an applied axial stress.

(ii) A normal stress due to the self weight of the solids.

These two components are evaluated separately below:

Solid phase normal stress due to applied axial stress

Cooke postulates that the entire pressure gradient force is transferred to the particle matrix as an interparticle stress. There is thus an applied solid phase axial stress due to the pressure gradient along the pipeline.

In inclined pipelines there is an additional solid phase axial stress due to the component of the submerged weight of the solids acting in the direction of the pipe axis.

The net solid phase (interparticle) axial stress is thus the sum of these two components and is given by equation 3.14:

$$\frac{d\tau_{sx}}{dx} = \left|\frac{dP}{dx} - (S_m - S_l)\, g \sin \varphi\right| - (S_m - S_l)\, g \sin \varphi| \qquad (3.14)$$

The applied solid phase axial stress results in a solid phase normal stress acting in the plane at right angles to it. The relationship between these stresses is given in equation 3.15 below, and see Figure 3.9.

$$\tau_{sk} = Kr\, \tau_{sx} \qquad (3.15)$$

Where:

Kr = coefficient of lateral interparticle stress

k = y or z direction

Kr is a function of particle properties and solids concentration, however, as dense phase mixtures are assumed to be homogeneous, Kr is taken as constant across the pipe cross section. The value of Kr is determined for a specific material by matching the model output to measured data.

Thus, combining equations 3.14 and 3.15, the normal stress due to the applied axial stress (pressure gradient and weight component acting along the pipe axis) is given by equation 3.16:

$$\frac{d\tau_{sk}}{dx} = Kr \left| \frac{dP}{dx} - (S_m - S_l)\, \rho\, g \sin \varphi \right| \qquad (3.16)$$

Solid phase normal stress due to self weight of solids

The particle matrix is assumed to experience a hydrostatic type solid phase normal stress distribution due to the submerged weight of the solids, after Wilson (1970).

Assuming a homogeneous mixture, the solid phase normal stress due to self weight of the solids is given by equation 3.17:

$$\tau_{sk} = \rho\, g\, (S_s - S_l)\, C \left(\frac{D}{2} - y \right) \cos \varphi \qquad (3.17)$$

Where:

D = pipe diameter.
y = displacement from x axis (pipe centre line).

Total solid phase normal stress

The total solid phase normal stress is the sum of the components due to axial stress and self weight. Thus, combining equations 3.16 and 3.17:

$$\tau_s = Kr \left| \frac{dP}{dx} - (S_m - S_l)\, \rho\, g \sin \varphi \right| + \rho\, g\, (S_s - S_l)\, C \left(\frac{D}{2} - y \right) \cos \varphi \qquad (3.18)$$

The solid phase shear stress

The solid phase shear stress at any point in the solids matrix can now be evaluated by substituting τ_s from equation 3.18 into equation 3.13.

4.5 Evaluation of the liquid phase shear stress component (τ_l)

In dense phase flow it is assumed that turbulence will be completely dampened by the solids matrix. The liquid phase shear stress will thus be entirely viscous.

The mixture viscosity (μ_m) is determined using the correlation of Landel et al as shown in equation 3.19:

$$\frac{\mu_m}{\mu} = \left[1 - \frac{C}{C_{max}}\right]^m \qquad (3.19)$$

Where:

μ = dynamic coefficient of viscosity for water
C = concentration of solids in mixture
C_{max} = maximum possible concentration of solids
m = experimental coefficient (–2,5 used)

Cooke defines a transition particle diameter, d_t, below which particles combine with the fluid (usually water) to form the vehicle. The transition particle diameter is defined as that for which the settling velocity is 1 mm/s.

The settling velocity is calculated assuming the particle to be settling through a mixture of the fluid and all particles smaller than d_t. The value of d_t is found by iterative solution of equation 3.20:

$$d_t = \sqrt{\frac{0.018\, V_{mf}}{g\, Sf\, (S_s - S_{mf})}} \qquad (3.20)$$

The viscosity of the vehicle portion (μ_{mv}) is determined using the Landel relation for the fine fraction only (i.e. those particles smaller than d_t), as shown in equation 3.21 below:

$$\frac{\mu_{mv}}{\mu} = \left[1 - \frac{C_f}{C_{f\,max}}\right]^m \qquad (3.21)$$

Where:

C_f = concentration of fine fraction
$C_{f\,max}$ = maximum possible concentration of fine fraction

The concentration of the fine fraction is calculated using equation 3.22 below, and see figure 3.10.

$$C_f = \frac{P_f\, C_m}{1 - P_c\, C_m} \qquad (3.22)$$

Having determined μ_m and μ_{mv}, the velocity gradient of the liquid phase can be directly related to the liquid phase shear stress.

4.6 Solid – liquid shear stress relationship

The shear stress distribution, as given by equation 3.12, is shown in Figure 3.11a.

Note that where the applied shear stress is greater than the solids failure shear stress, the solids matrix will be sheared (failed) and the solid phase shear stress component will equal the failure shear stress at that point (in the sheared annulus in Figure 3.11a).

Where the applied shear stress is less than the solids failure shear stress, the solids matrix will not shear and the solid phase shear stress will equal the applied shear stress (in the un-sheared core in Figure 3.11a).

Thus, in the un-sheared zone, the shear stress consists of the solid phase shear stress component only. The liquid phase shear stress component is zero in this region as there is no shearing of the fluid.

In the sheared zone, the shear stress consists of the solid phase shear stress component, equal to the local solids failure shear stress, and the liquid phase shear stress component, making up the differance between the total shear stress and the solids failure shear stress.

Cooke has identified three possible flow regimes based on the relationship between the applied shear stress distribution and the solids failure stress distribution. The three flow regimes are:

(i) An un-sheared core and sheared annulus – Figure 3.11a.

(ii) A sliding bed – Figure 3.11b.

(iii) An un-sheared plug – Figure 3.11c.

4.7 Boundary conditions at the pipe wall

The conditions at the pipe wall are now evaluated:

Solid phase shear stress at the pipe wall

The solid phase shear stress at the pipe wall, τ_{0s}, is attributed to mechanical sliding friction between solid particles and the pipe wall. τ_{0s} is thus related to the local solid phase normal stress, τ_s, by the coefficient of sliding friction between the solid particle matrix and the pipe wall, as shown in equation 3.23.

$$\tau_{0s} = \mu_s \, \tau_s$$

Where:

μ_s = coefficient of sliding friction

Fluid shear stress at the pipe wall

The fluid shear stress at the pipe wall, τ_{0l}, is assumed to make up the differance between the total shear stress at the pipe wall and the calculated solid phase shear stress at the pipe wall, as shown in equation 3.24, and see Figure 3.12.

$$\tau_{0l} = \tau_0 - \tau_{0s} \qquad (3.24)$$

Where:

$$\tau_0 = \frac{D}{4}\frac{dP}{dx}$$

As shown in Figure 3.12, there is a zone of thickness h at the pipe wall in which the fluid shear stress is assigned the value τ_{0l}

It is assumed that the fluid at the pipe wall is stationary and the fluid at a distance h from the wall is moving at the velocity of the solids matrix. Thus, τ_{0l} is related to the velocity of the granular matrix at distance h from the pipe wall by the dynamic coefficient of viscosity of the vehicle, μ_{mv}, as shown in equation 3.25:

$$\tau_{0l} = \frac{v\,\mu_{mv}}{h} \qquad (3.25)$$

Cooke presents a relationship between h, solids concentration and the d_{50} particle size. The boundary fluid shear layer thickness, h, can thus be determined. Knowing μ_{mv} and τ_{0l} (from equation 3.24) the velocity of the solids matrix at a distance h from the pipe wall can be determined (from equation 3.25), providing boundary conditions for solution of the velocity distribution in the pipe.

4.8 Summary of the solution procedure

The solution procedure is set out bellow in a number of steps.

1. An applied pressure gradient is assumed, from which an applied shear stress distribution is determined.

2. The solid phase failure shear stress is evaluated and superimposed on the applied shear stress distribution, from which the flow regime is determined (sheared annulus, sliding bed or un-sheared plug).

3. The boundary conditions at the pipe wall are determined for the flow regime as identified in 2 above.

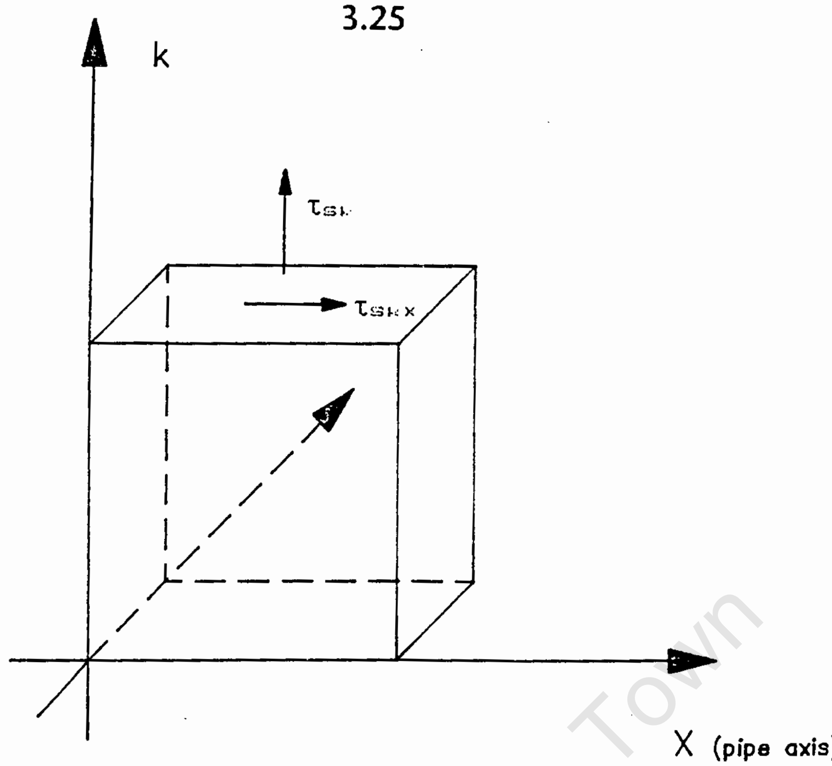
4. The velocity distribution is determined across the pipe cross section, using the boundary conditions from step 3. In the sheared zone, the velocity distribution is determined by solution of the differential equation describing the velocity distribution in a pipe.

Cooke has produced a computer program which performs the solution procedure as set out above. The input required by the program being the slurry properties, particle size distribution and pipeline parameters. The output is in the form of curve of pressure gradient versus mean mixture velocity.

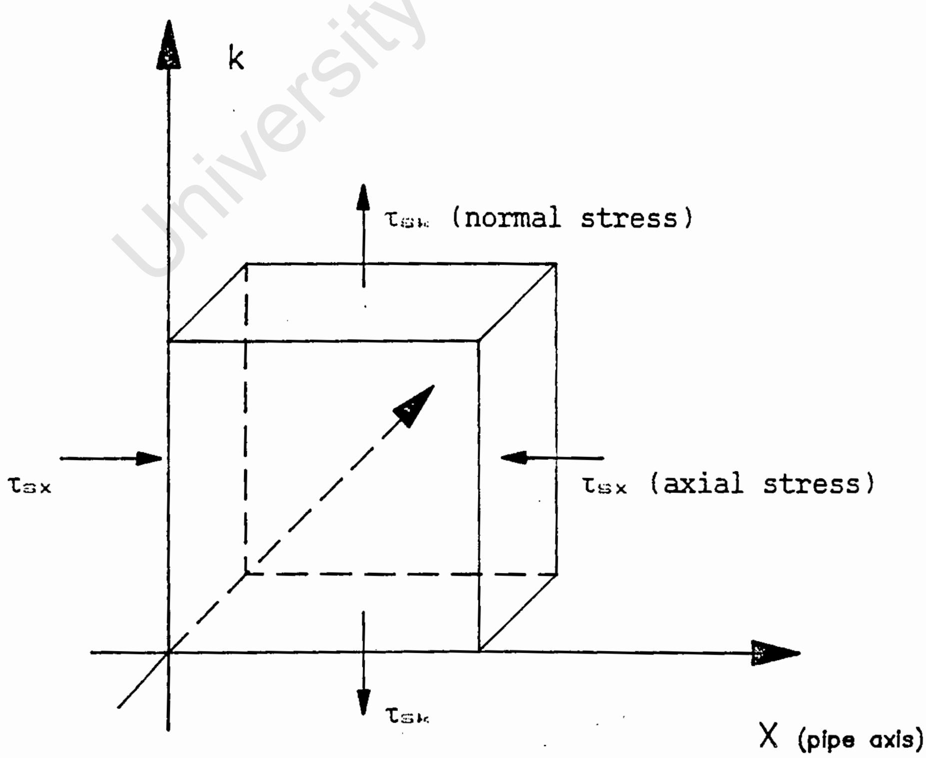
4.9 Conclusions

The mechanistic model developed by Cooke for the dense phase flow of high concentration cyclone classified tailings slurries has been presented.

The input required by the model are measured solids, slurry and pipeline properties. It is noted however that the coefficient of lateral interparticle stress, Kr, is determined by fitting the model output to measured pressure gradient data.



<u>Figure 3.8</u> : Solid phase normal and shear stress relationship.



<u>Figure 3.9</u> : solid phase axial normal stress relationship.

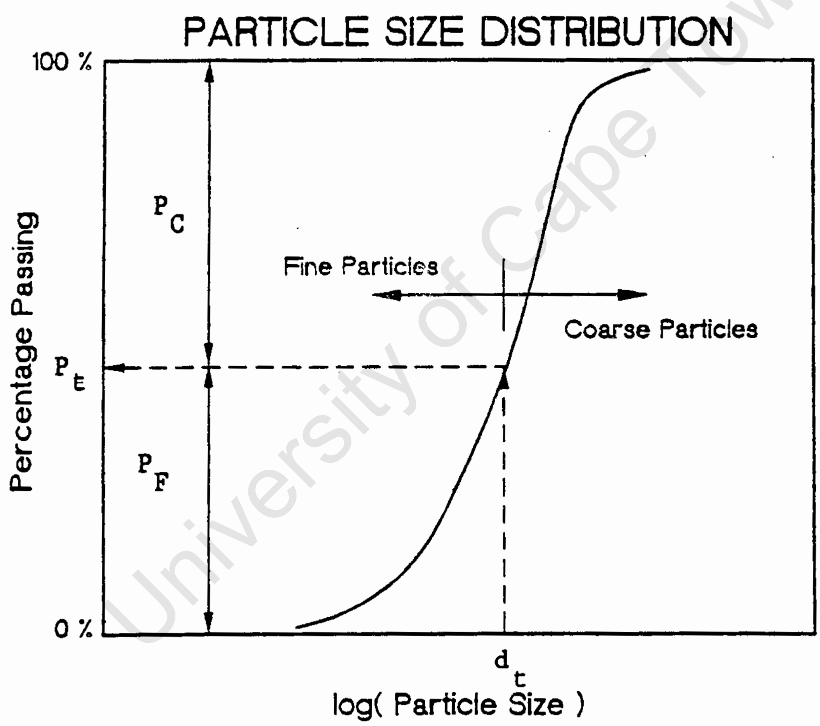


Figure 3.10 : Particle size distribution split into fine and coarse fractions.

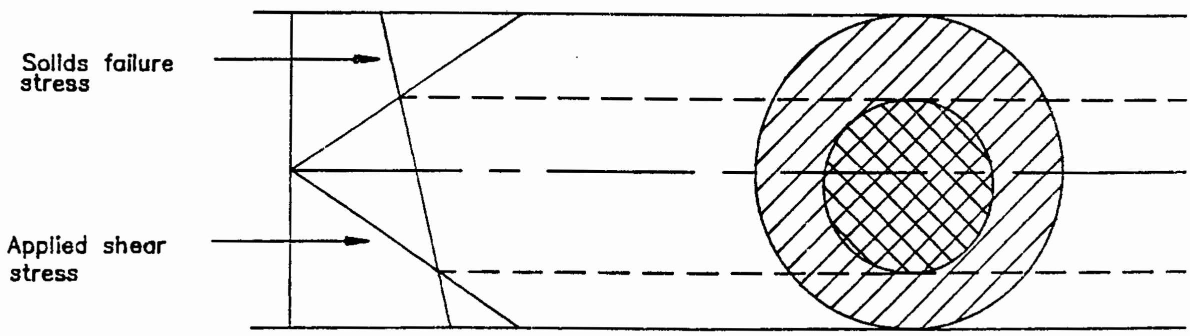


Figure 3.11a : Un-sheared core and sheared annulus.

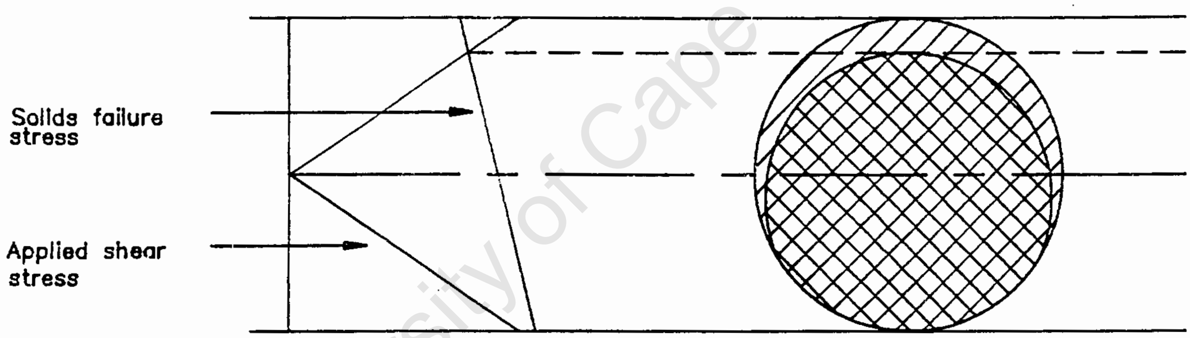


Figure 3.11b : Sliding bed.

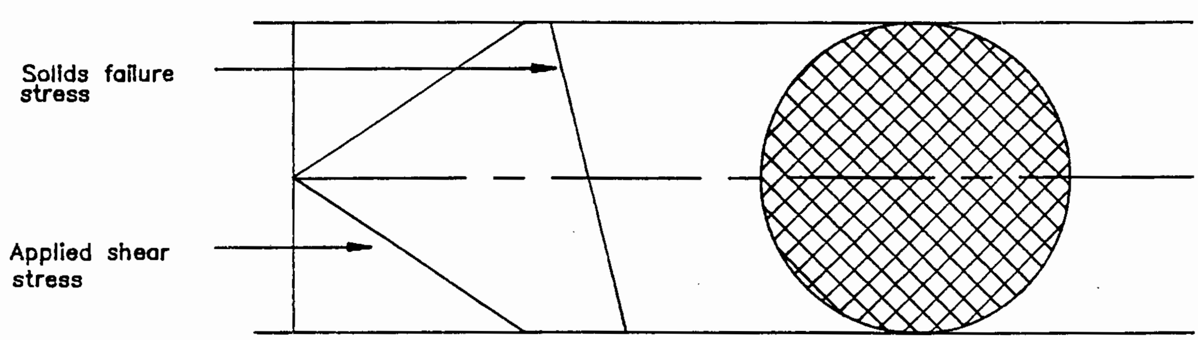


Figure 3.11c : Un-sheared plug.

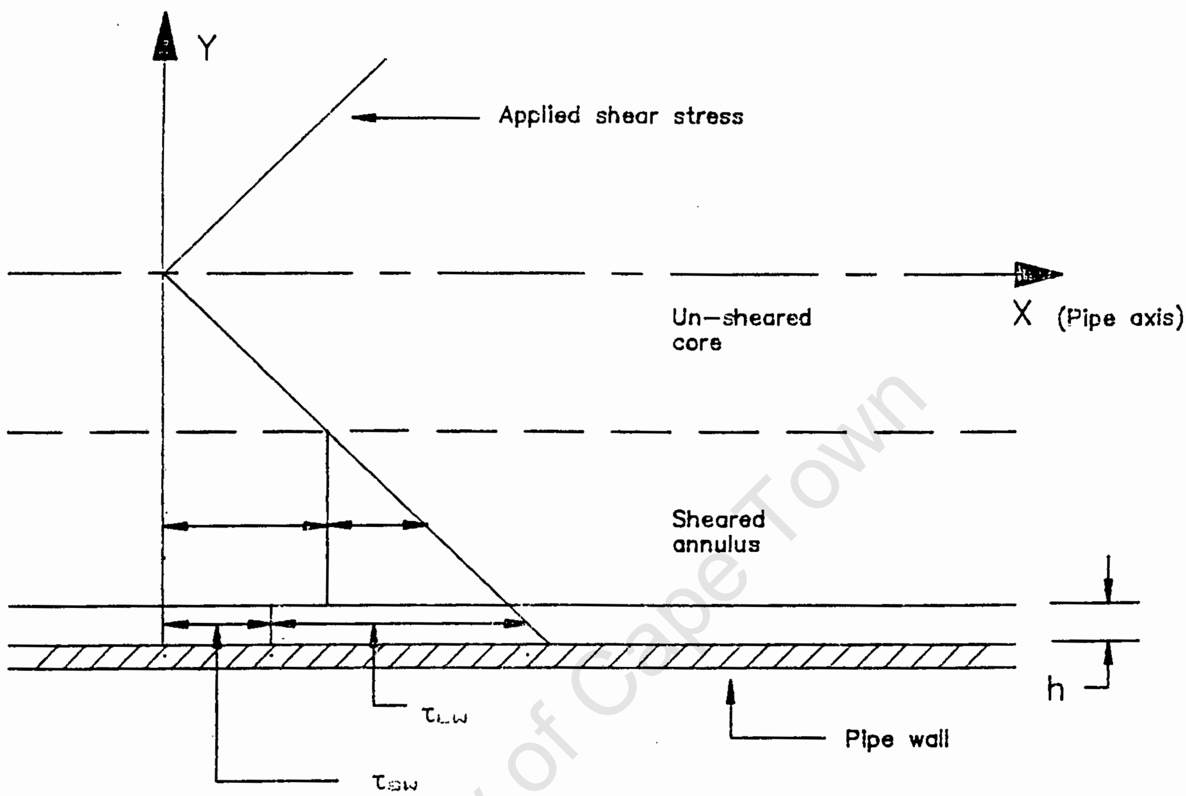


Figure 3.12 : boundary conditions at the pipe wall.

CHAPTER 4

Model Evaluation

1. INTRODUCTION

The Paterson and Cooke models, which were reviewed in Chapter 3, are now compared with the experimentally measured data as presented in Chapter 2.

The comparison of the model predictions with the measured data is done on the basis of a log standard error analysis. The log standard error analysis is discussed in section 2 of this chapter.

Each model is then discussed in a separate section, the Paterson model in section 3 and the Cooke model in section 4 of this chapter.

The range, in terms of particle size distribution and solids concentration, over which each model is in acceptable agreement with the measured data is determined. This is then reported as the range of applicability of the model.

2. LOG STANDARD ERROR ANALYSIS

The degree of agreement between the model pressure gradient predictions and the measured pressure gradient data is evaluated on the basis of the log standard error, as defined in equation 4.1:

$$S^2 = \frac{\Sigma\,[\log(\text{observed}) - \log(\text{predicted})\,]^2}{n-1} \qquad (4.1)$$

Where:

S = log standard error
n = number of data points

The log standard error is related to the average percentage error, e, as follows:

$$\%\ \text{error, e, above} = 100\ (10^S - 1) \qquad (4.2)$$

$$\%\ \text{error, e, below} = 100\ (1 - 10^{-S})$$

The model predictions, in the form of five points with velocity and pressure gradient ordinates, are calculated over the range covered by the measured data. These points are then joined by straight lines.

The model prediction at any intermediate point, as required in equation 4.1, is determined by linear interpolation between the two neighbouring model prediction points.

3. EVALUATION OF THE PATERSON MODEL

3.1 Calculation of model predictions

Paterson has coded the calculations required to produce pressure gradient predictions, based on the rheological parameters that he measured for full plant tailings, into a computer program.

These predictions are thus based on the rheological parameters as presented in Table 3.2, and values of Kr as given by equation 3.6 in Chapter 3. The work presented here is thus not an evaluation of the technique developed by Paterson, but is intended to determine the range of applicability of the actual rheological parameters and Kr values which Paterson reported for the particular full plant tailings material on which his work is based.

The input required by the computer program are:

(i) Pipe internal diameter, D

(ii) Solids volumetric concentration, C_v

(iii) Solids relative density, S_s

(iv) Coefficient of sliding friction, μ_s

(v) Flow orientation (up / down / horizontal)

The program output is a set of pressure gradient predictions, calculated over the velocity range 0 to 4.5 m/s at 0.5 m/s intervals.

A model prediction is calculated for comparison with each set of measured data. In each case the appropriate pipeline, slurry and solids properties are used as input.

3.2 Comparison with measured data

Three plots, each showing a set of measured data and corresponding model prediction, are presented in Figures 4.1 to 4.3.

Figure 4.1 shows the data and model prediction for Material 5 in the 40 mm N.B. horizontal pipeline for a low solids concentration of 37.9% by volume. In this case there is good agreement between the model prediction and the measured data. The calculated log standard error in this case is 0.1081, which corresponds to an average error of +28.3% and −22.0%. It is noted that this is not in the solids concentration range of interest in this work but is presented in order to give an idea of the degree of error associated with such values of log standard error.

Figures 4.2 and 4.3 show the data and model prediction for Materials 5 and 1, respectively, in the 40 mm N.B. horizontal pipeline for a solids concentration of 46% by volume which is in the high concentration region of interest. In this case, the log standard error for Material 5 (Figure 4.2) is 0.2961, and that for Material 1 is 0.6540. These correspond to average errors of +98% and +350% respectively. In both cases the error is an over prediction.

These plots have been presented in order to give an idea of the degree of error represented by these values of log standard error.

The values of log standard error calculated for all the measured data sets are presented in Figures 4.4 and 4.5. The trend, as described below, is seen in both plots (i.e. for both pipe diameters). Note that each point on these plots is the average of the log standard error for the three flow orientations (horizontal, vertical up and vertical down).

The log standard error decreases with increasing fines content, being highest for Materials 1, 2 and 3 and lowest for Materials 5 (the 40 mm N.B. pipeline, Figure 4.4) and 5A (the 80 mm N.B. pipeline, Figure 4.5). This is to be expected as Material 5 and Material 5A are closest in terms of particle size distribution to the full plant tailings material used by Paterson.

In all cases the log standard error increases with increasing solids concentration. The error at high concentrations being an over prediction.

3.3 Range of applicability

Figures 4.4 and 4.5 show that there is generally very poor correlation between the model and the measured data for solids concentrations greater than 40% by volume, this being the high concentration region of interest in this work.

Typical log standard error values for Materials 1 to 4 at a solids volumetric concentration of 48% are 0.7, which corresponds to an over prediction of 400%. In the case of Materials 5 and 5A typical log standard error values at a solids volumetric concentration of 48% are 0.4, which corresponds to an over prediction of 150%.

To investigate the poor correlation between the model prediction and measured data, the particle size distribution of the full plant tailings material used by Paterson and Materials 5 and 5A have been plotted together in Figure 4.6 for comparison. From this plot it can be seen that there is a differance between the particle size distribution of Patersons' full plant tailings material and Materials 5 and 5A. This small differance, relative to the range of possible particle size distribution for gold tailings slurries, however, results in a significant differance in pipeline pressure gradient.

Based on this it is concluded that the rheological parameters used in the Paterson model prediction are applicable only to the full plant tailings material from which they were derived.

The range of applicability of the Paterson model is thus estimated to be a narrow band, in terms of material % –10 microns, arround the value of 30.9 % –10 microns. This being the value measured for the full plant tailings material used by Paterson.

The width of the band in terms of % –10 microns, has been estimated as 0.7% arround 30.9%. This is based on the trends seen in Figures 2.22 and 2.23 in Chapter 2. These indicate that pipeline pressure gradients become increasingly sensitive to fines content (% –10 microns) in the full plant tailings region of the particle size distribution spectrum, hence the relatively narrow band width of 1.4% –10 microns.

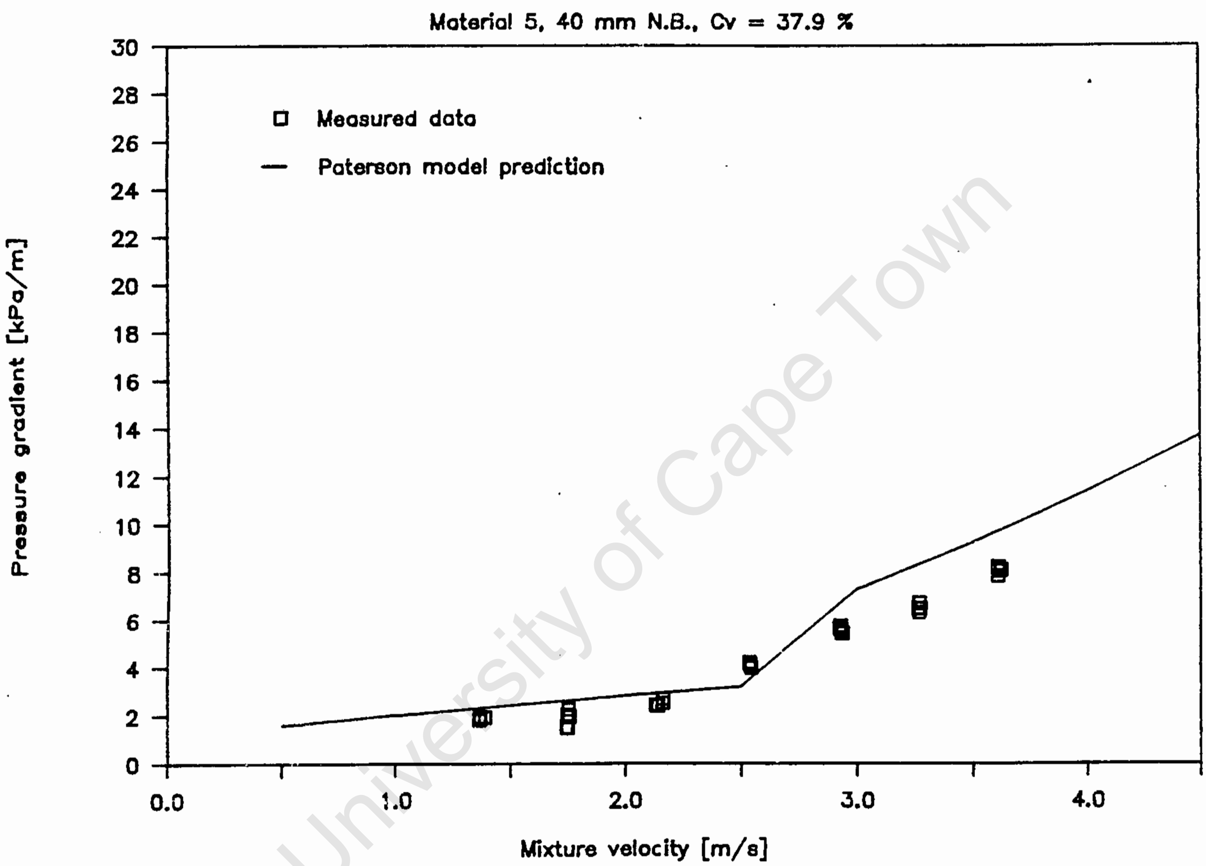


Figure 4.1 : Measured data and Paterson model prediction, log standard error = 0.1081.

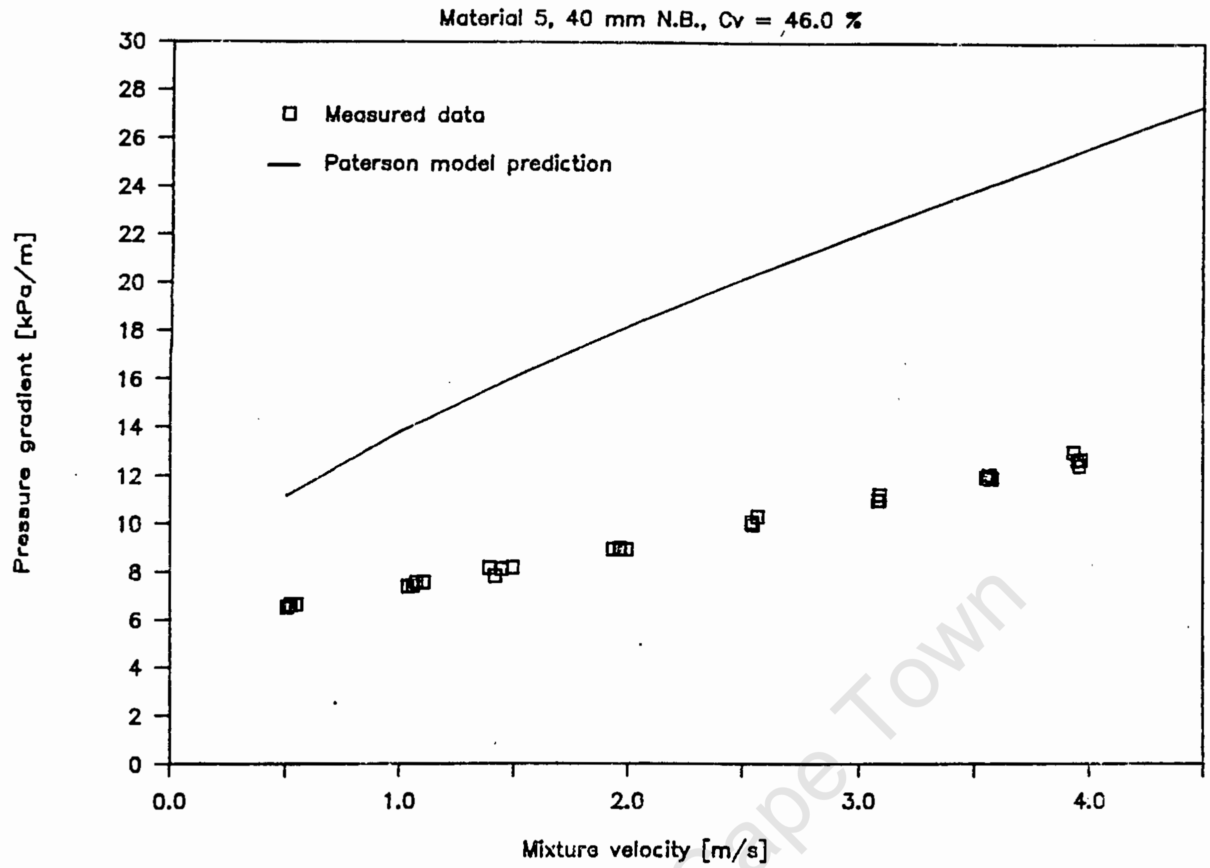


Figure 4.2 : Measured data and Paterson model prediction, log standard error = 0.2961.

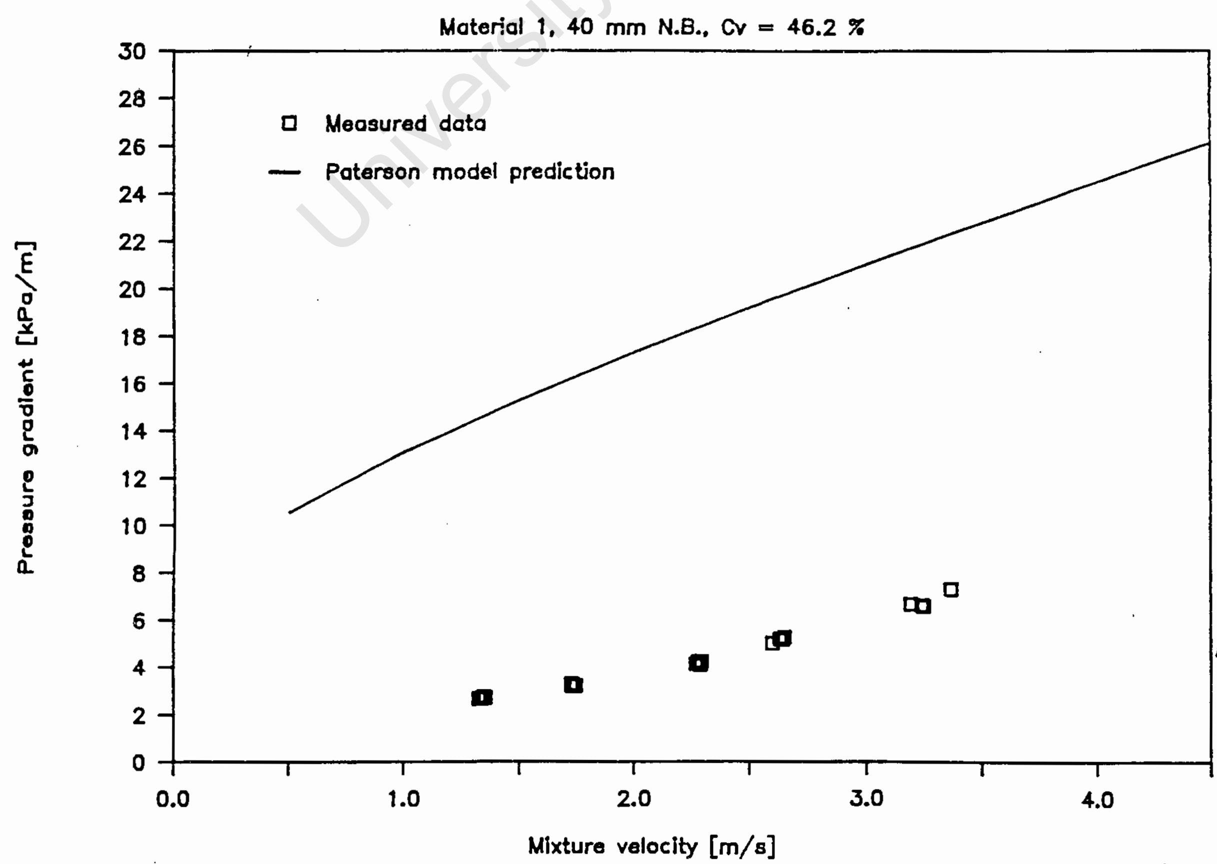


Figure 4.3 : Measured data and Paterson model prediction, log standard error = 0.6540.

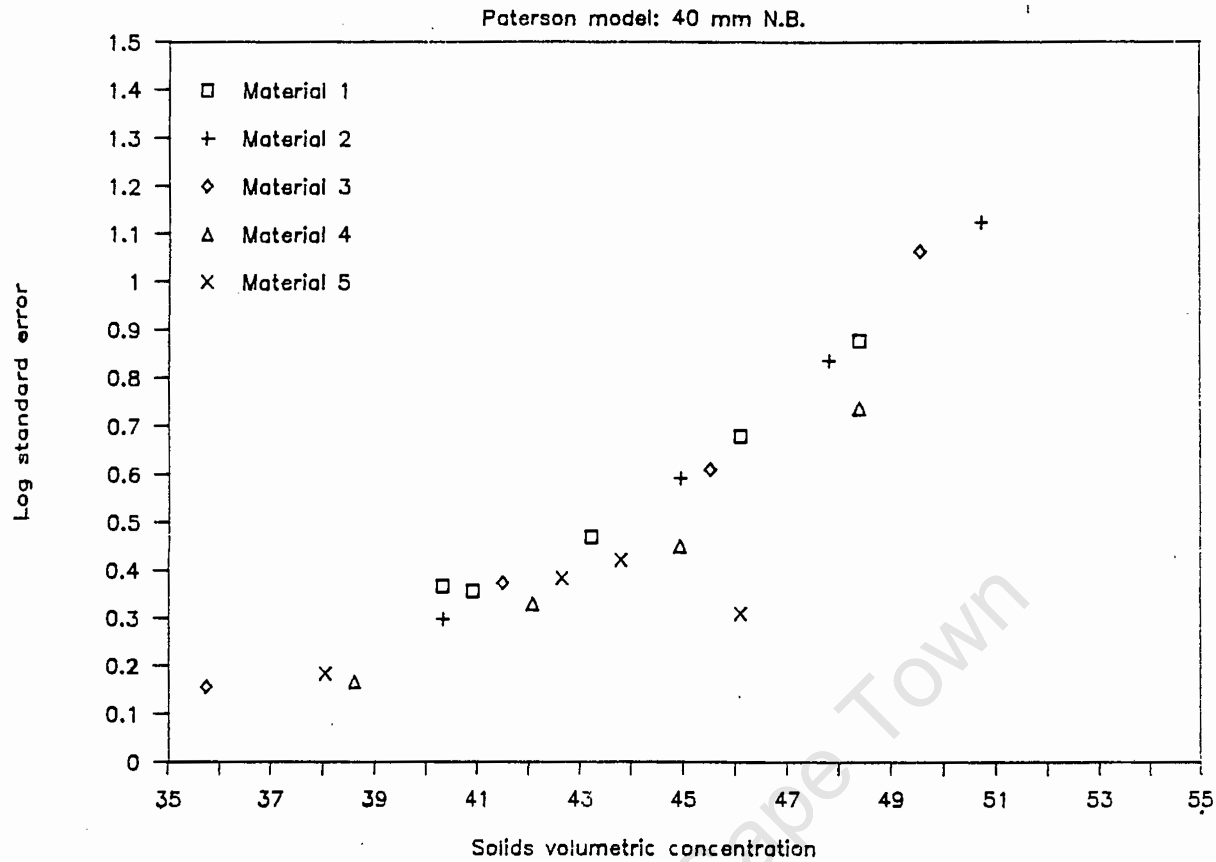


Figure 4.4 : Log standard error for Paterson model prediction as a function of solids concentration.

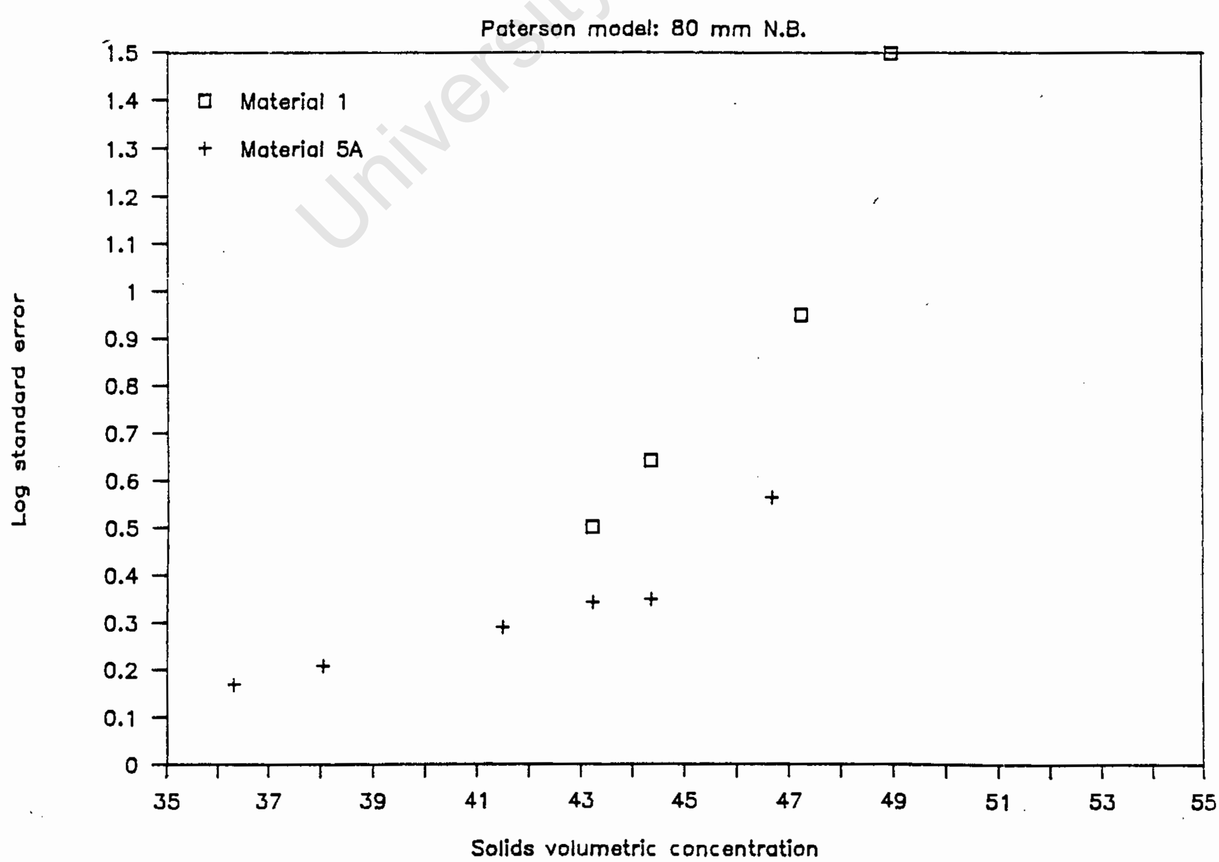


Figure 4.5 : Log standard error for Paterson model prediction as a function of solids concentration.

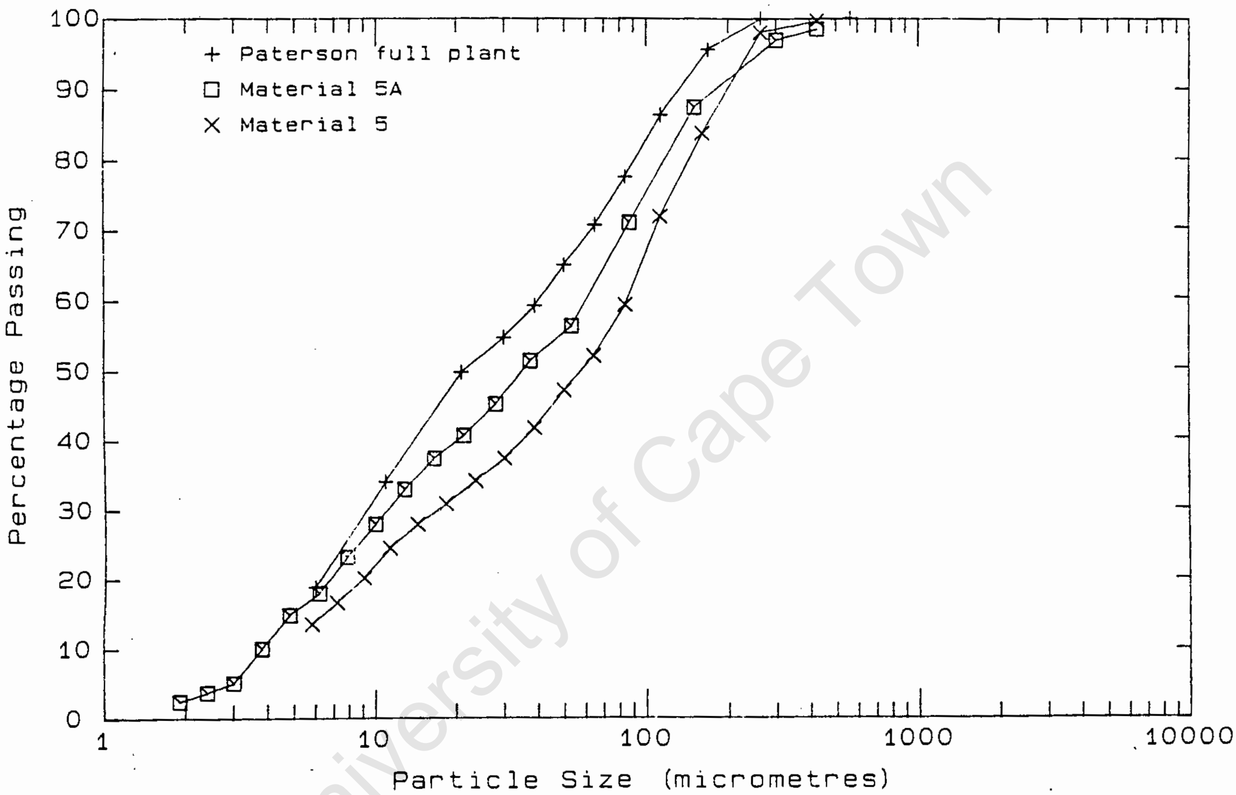


Figure 4.6 : Particle size distribution of Paterson full plant tailings, Material 5A and Material 5.

4. EVALUATION OF THE THE COOKE MODEL

4.1 Calculation of model predictions

Cooke has coded the calculations required for the Cooke model into a computer program which was used for this work. The input parameters required by the computer program are:

(i) **pipeline properties:**

* Pipe internal diameter, D
* Flow orientation (up, down, horizontal)

(ii) **Slurry properties:**

* Mean slurry temperature, t
* Solids concentration, C

(iii) **Solids properties:**

* Solids relative density, S_s

Coefficient of sliding friction, μ_s

Internal angle of friction, δ

Particle shape factor, Sf

* Particle size distribution

Maximum possible solids concentration, C_{max}

Coefficient of lateral interparticle stress, Kr

The model is evaluated by comparing the model predictions (pressure gradient versus mixture velocity curves) with measured pressure gradient data. A model prediction is calculated for comparison with each data set included in Appendix A, as described below.

Each data set is stored in the form of an ASCII file. The input parameters marked with an asterisk in the list above are read from the ASCII file by the program. The input data marked with a hash in the list above are entered by the operator.

The values used for each of the input parameters are determined as described below.

Pipe internal diameter

The internal diameter of the test sections in which the data were measured is taken to be as specified by the pipe manufacturers.

Flow orientation

This is defined by the angle of the pipeline to the horizontal, upwards flow being positive. The measured data sets are for either horizontal, vertical up or vertical down flow.

Slurry temperature

This is taken to be the average of the measured temperature data in each data file.

Solids concentration

The values asociated with each measured data set as measured at the end of each test are used.

Solids relative density

The values as determined for each material by means of the test described in Section 2.2.2 of Chapter 2 are used.

Internal angle of friction

The relationship between internal angle of friction and solids concentration for Material 1, as reported in Section 2.2.4 of Chapter 2 was used in all cases. This was done as no data is available for Materials 2 to 5.

Coefficient of sliding friction

Cooke developed and built a "Rotating disk" apparatus for measuring the coefficient of sliding friction. This apparatus measures the coefficient of sliding friction, as opposed to the coefficient of static friction, which is obtained from the tilting tube apparatus as described in Section 2.2.5 of Chapter 2.

Cooke assumed there to be a relationship between the coefficient of sliding friction and solids concentration. As the coefficient of sliding friction was measured at one concentration only, the assumption was made that the relationship is linear and has the same slope as the relationship between the internal angle of friction and solids concentration.

For the purposes of this evaluation, the coefficient of sliding friction for all materials has been taken to be the same as that reported by Cooke for "Blyvooruitsig" cyclone classified tailings at the one concentration at which it was measured. This was done as the Blyvooruitsig material is closest in terms of particle size distribution to Material 1, this being the only material for which the relationship between the internal angle of friction and solids concentration is known.

Thus, for all materials in this evaluation, the slope of the relationship between the coefficient of sliding friction and solids concentration has been taken to be the same as that for the internal angle of friction measured for Material 1. The vertical intercept at the concentration at which Cooke measured the coefficient of sliding friction is set by the value reported by Cooke for Blyvooruitsig cyclone classified tailings.

Particle shape factor

The values determined as described in Section 2.2.6 of Chapter 2 were used.

Particle size distribution

The particle size distribution associated with each data set, measured as described in Section 2.2.1 of Chapter 2 was used. Each ASCII file of measured data includes the particle size distribution of the sample taken after the test.

Maximum possible solids concentration

An attempt was made to measure the maximum possible solids concentration, however, no reliable results were obtained. An estimated value of 70% was thus used.

Coefficient of lateral interparticle stress

The coefficient of lateral interparticle stress, Kr, is determined by matching the model output to the measured data, as described below.

Cooke has shown Kr to be a function of material characteristics and solids concentration. The relationship between Kr and solids concentration is thus required for each material.

The value of Kr giving the overall best fit for the three flow orientations for a particular solids concentration and material was determined by trial over a range of values. The best fit Kr value was taken as that giving the minimum sum of log standard error for the three flow orientations. An example of a plot of Kr versus log standard error used to determine the "best fit" Kr value is given in Figure 4.7.

The Kr values thus determined for all six materials are presented in Figures 4.8 to 4.13.

4.2 Comparison with measured data

In the case of Material 1, Kr values are available from data for both pipe diameters, giving sufficient points to determine the relationship between Kr and solids concentration. A trend curve has thus been drawn through the plot of Kr versus solids concentration, as shown in Figure 4.8. This curve is then taken to give the relationship between Kr and solids concentration for Material 1. The model predictions for Material 1 were then recalculated using Kr values read from the curve in Figure 4.8.

To graphically show the degree of agreement between the model predictions and measured data, the data and model prediction have been plotted on the same set of axes in Figures 4.10 (Material 1 in the 40 mm pipeline) and 4.11 (Material 1 in the 80 mm pipeline). Each of these figures shows the results for two solids concentrations (one high and one low concentration).

The log standard error for all the model predictions for Material 1 are plotted against solids concentration in Figure 4.17. Note that each of these points is the average of the log standard error for the three flow orrientations.

In the case of Materials 2 to 5 and 5A, insufficient data is available to fit curves to the plots of Kr versus solids concentration shown in Figure 4.9. Model predictions were thus calculated using the "best fit" Kr value in each case. For each material, the data and model predictions are plotted on the same set of axes in Figures 4.12 to 4.16. Each figure shows the results for a high and a low solids concentration.

The log standard error for all predictions for Materials 2 to 5 and 5A are plotted against solids concentration in Figure 4.18. Again, these values are the average of the log standard error calculated for the three flow orrientations.

The plots showing the measured data and model predictions, Figures 4.10 to 4.16, all show an improvement in the model fit with increasing solids concentration. This is confirmed by the plots of log standard error versus solids concentration, Figures 4.17 and 4.18, which show a decrease in log standard error with increasing solids concentration for all materials.

4.3 Range of applicability

The range of applicability of the model is determined from Figure 4.19 which shows the distribution of measured data in terms of solids concentration and % –10 microns. Each point on Figure 4.19 represents one set of measured data (horizontal, up and down shown as one point) with the corresponding solids concentration and % –10 microns ordinates.

This Figure is thus a combination of the results shown in Figures 4.17 and 4.18 with the material names replaced by the % –10 microns ordinates. The symbols used for the points in Figure 4.19 indicate the log standard error range in which the model prediction lies for each data set. Based on these, estimated log standard error contours have been drawn.

In determining the range of applicability of the Cooke model, a log standard error of 0.12 is taken to be the limit of acceptable agreement. This corresponds to an average percentage error of +32% and –24%.

Although these values may seem high, they are a significant improvement on the dense phase models of Wilson and Streat which are typically out by 100% to 200%.

Thus, taking the 0.12 log standard error contour to represent the limit of applicability of the Cooke model, from Figure 4.19, the range of applicability is the region to the right of this contour. For practical purposes this is the region to the right of the line between the points on Figure 4.19 with the following coordinates:

C_v = 49% , -10 microns = 3%

and

C_v = 44% , -10 microns = 28%

There is uncertainty as to the upper bound, in terms of solids concentration, of the range of applicability of the model. As agreement between the model and measured data is shown to improve with increasing solids concentration, it is assumed that the range of applicability of the model extends beyond the range covered by the measured data.

It is, however, reasonable to expect that there is an upper bound beyond which the model will cease to be applicable. An absolute limit for this upper bound will be the maximum solids concentration at which flow is possible. This has been estimated, based on experience and observation during the experimental work carried out for purposes of this thesis, as being the line between the points with the following coordinates:

C_v = 57% , -10 microns = 3%

and

C_v = 50% , -10 microns = 28%

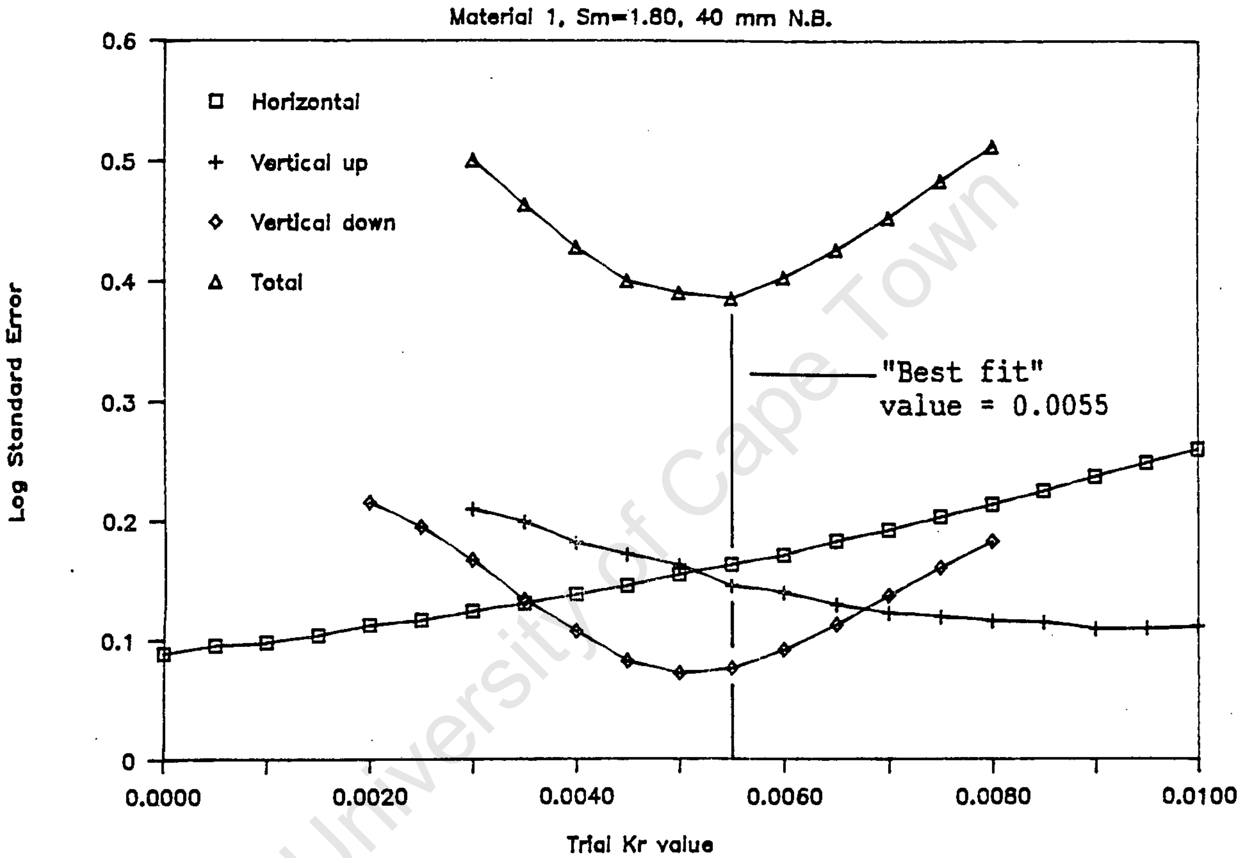


Figure 4.7 : Determination of the "best fit" Kr values for the Cooke model.

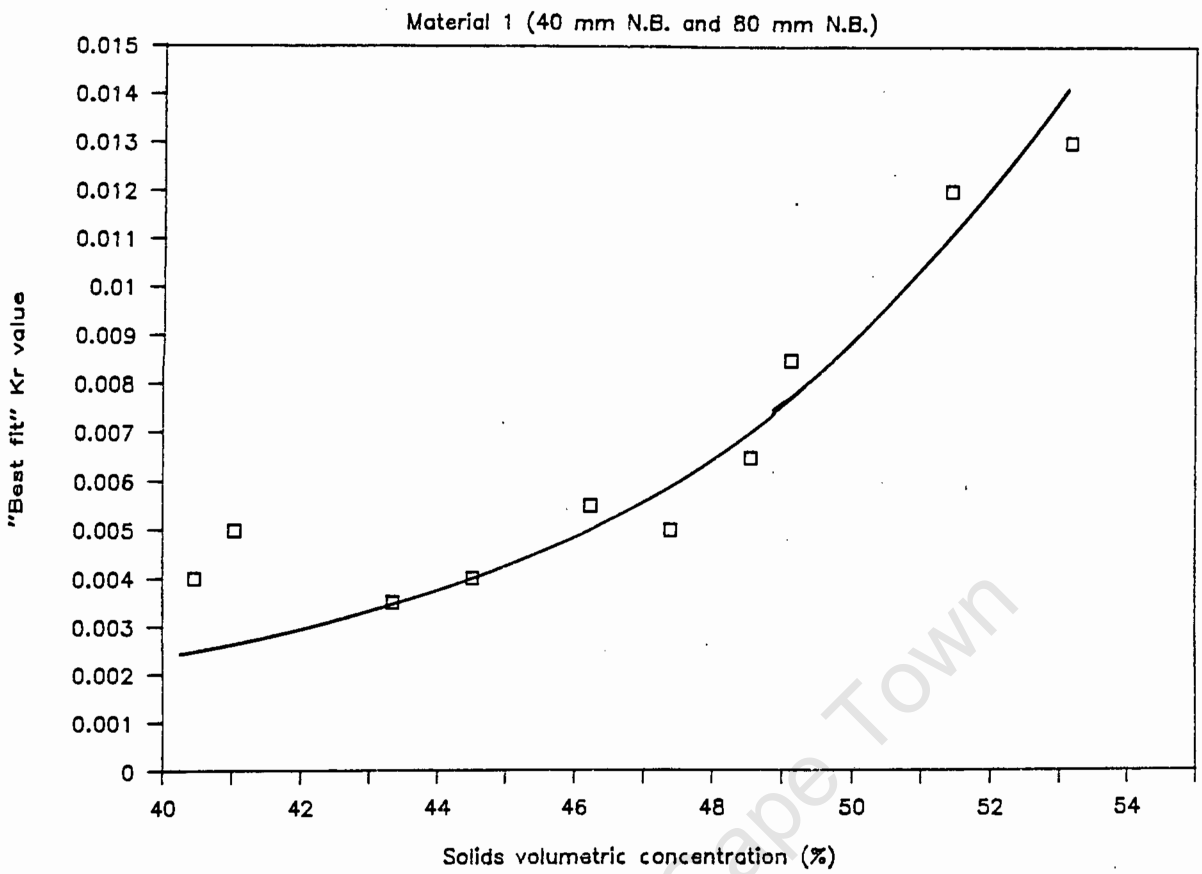


Figure 4.8 : "Best fit" Kr values as a function of solids concentration for Material 1.

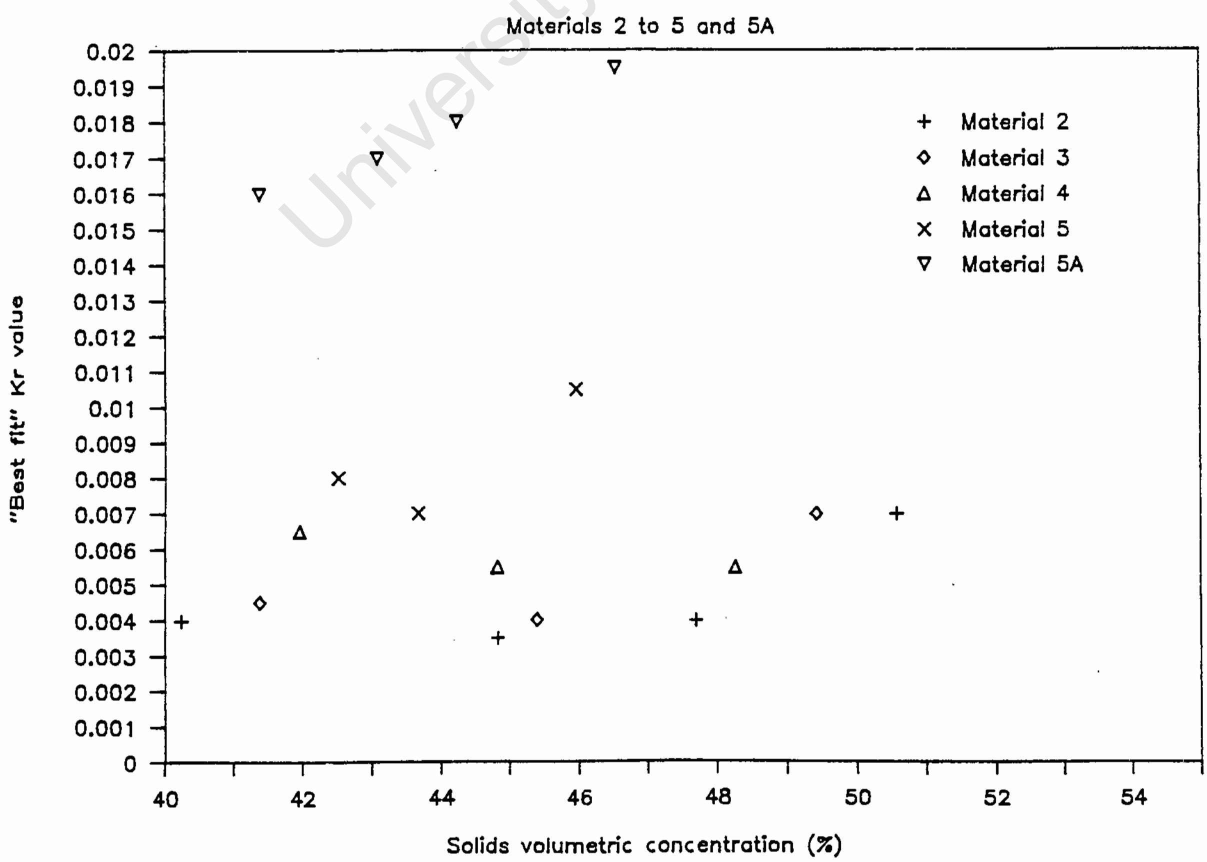


Figure 4.9 : "Best fit" Kr values for Materials 2 to 5 and 5A as a function of solids concentration.

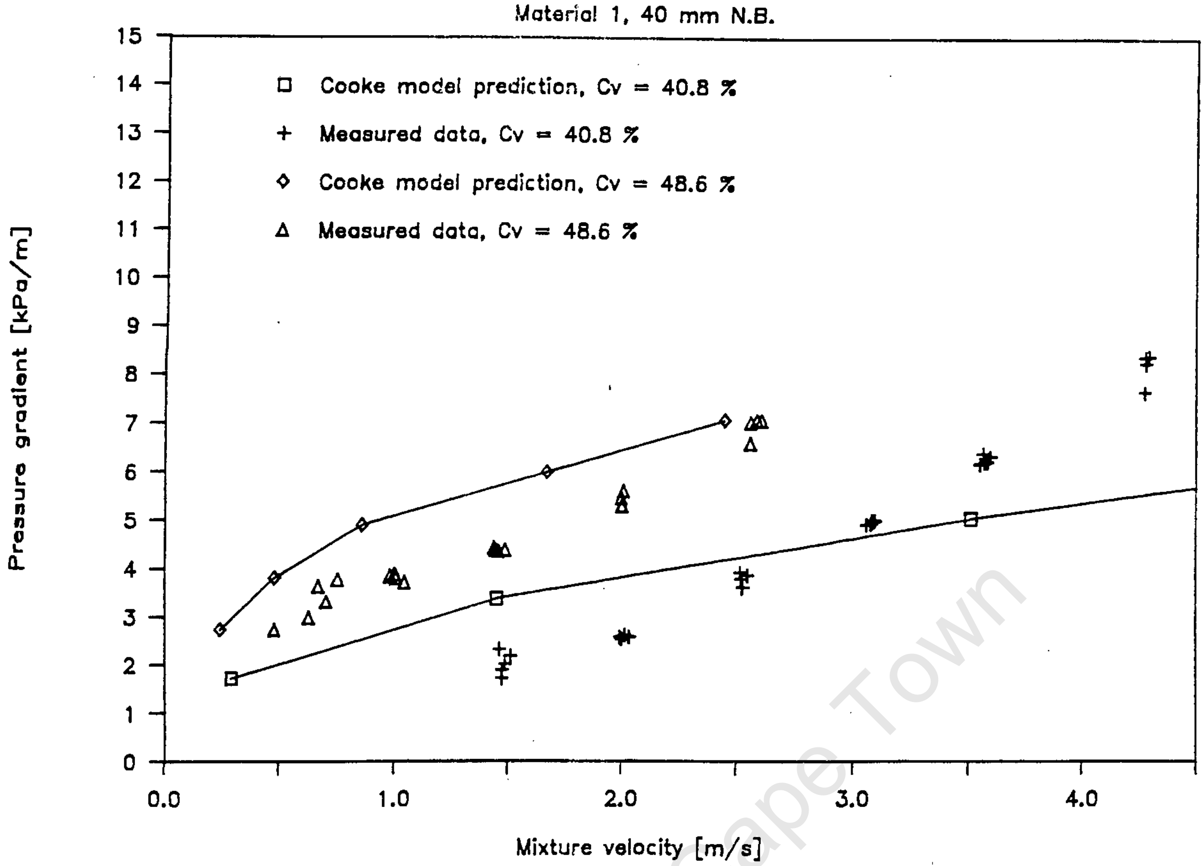


Figure 4.10 : Measured data and Cooke model prediction

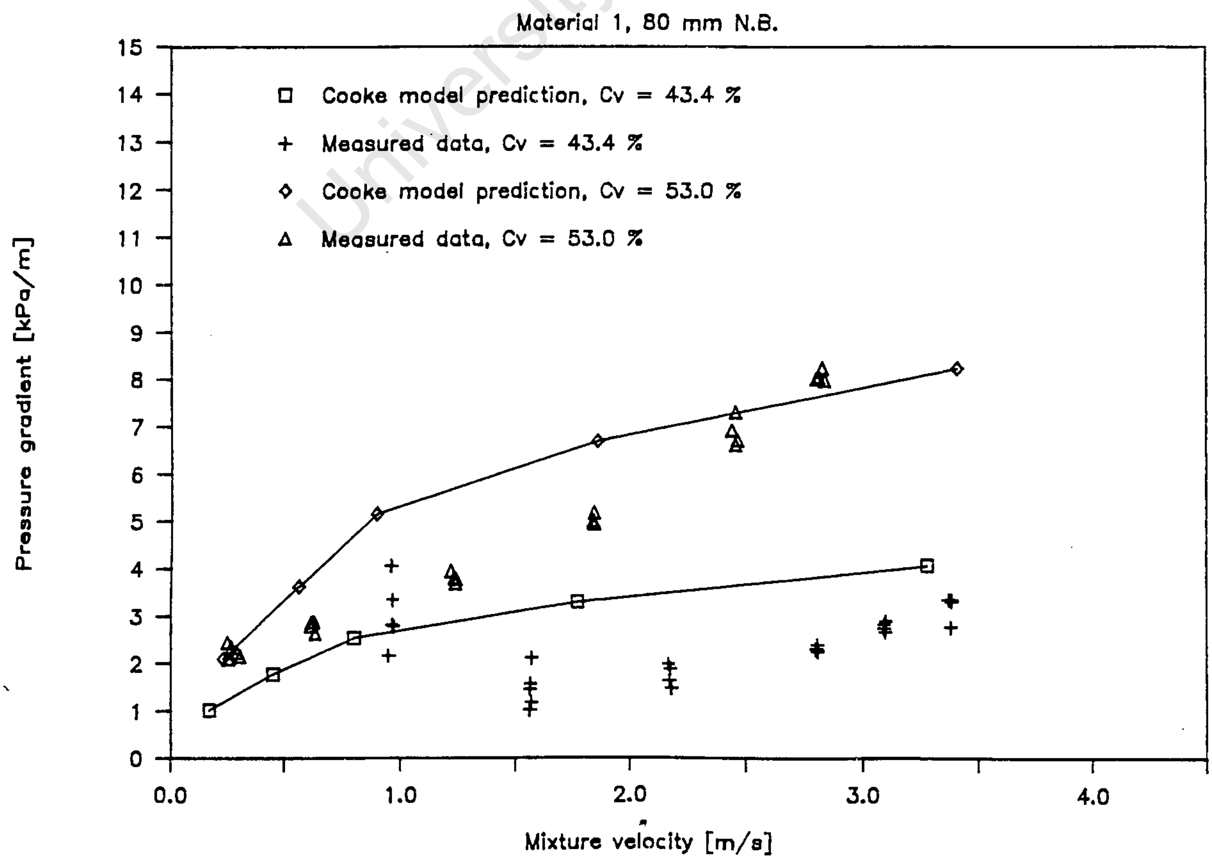


Figure 4.11 : Measured data and Cooke model prediction

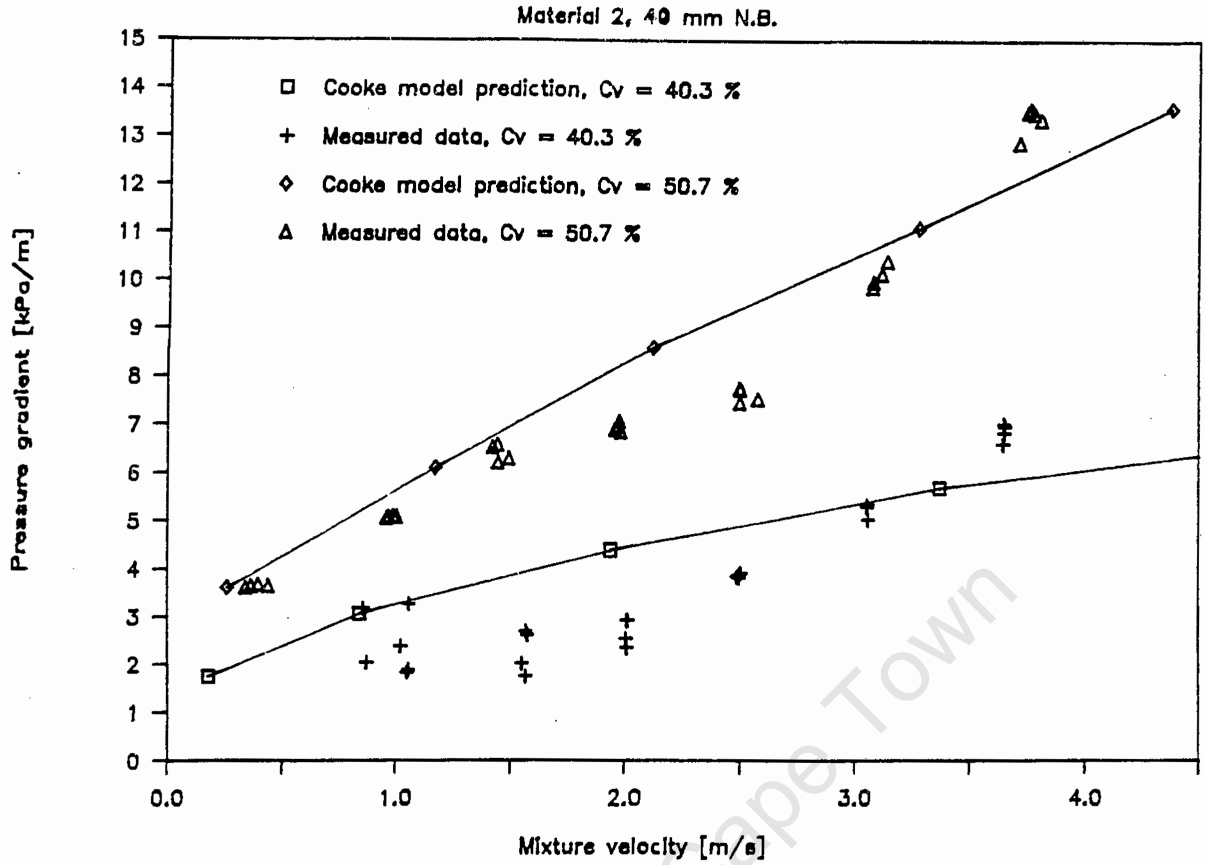


Figure 4.12 : Measured data and Cooke model prediction

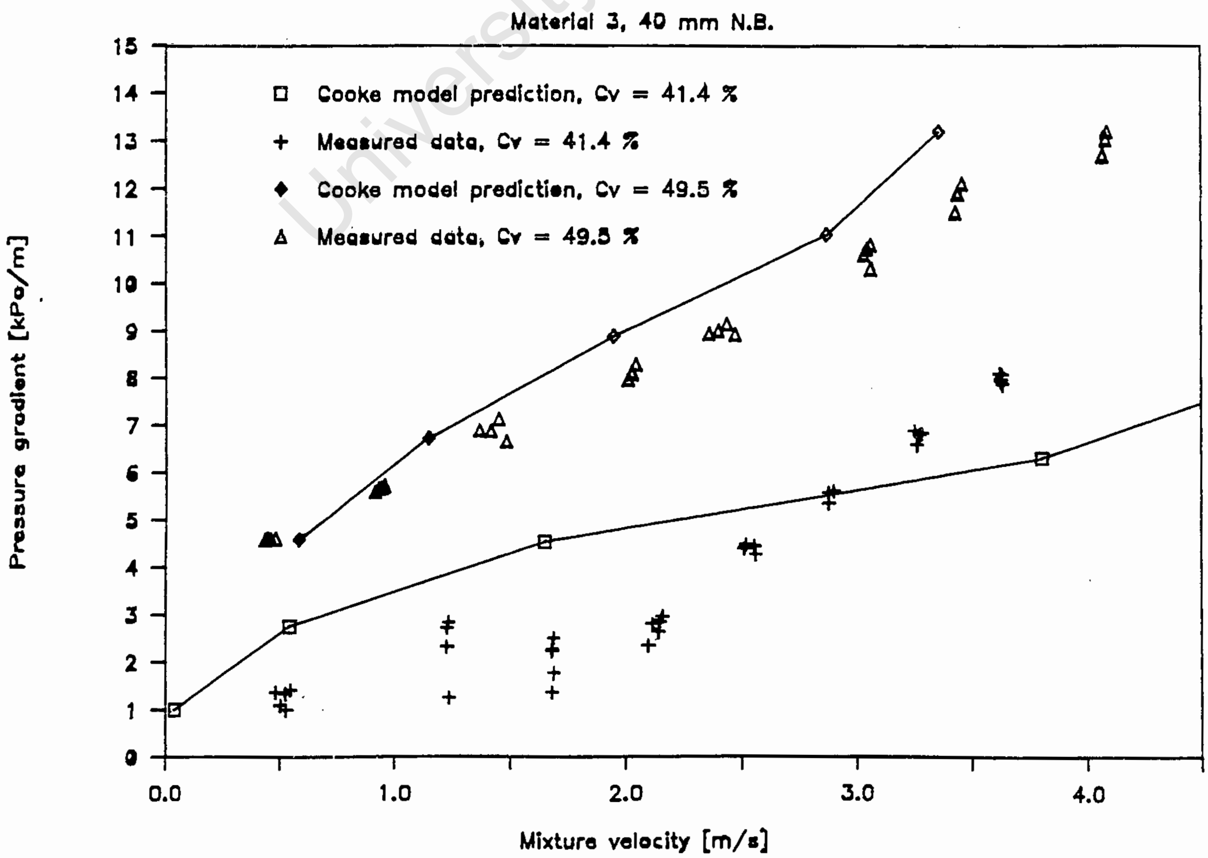


Figure 4.13 : Measured data and Cooke model prediction

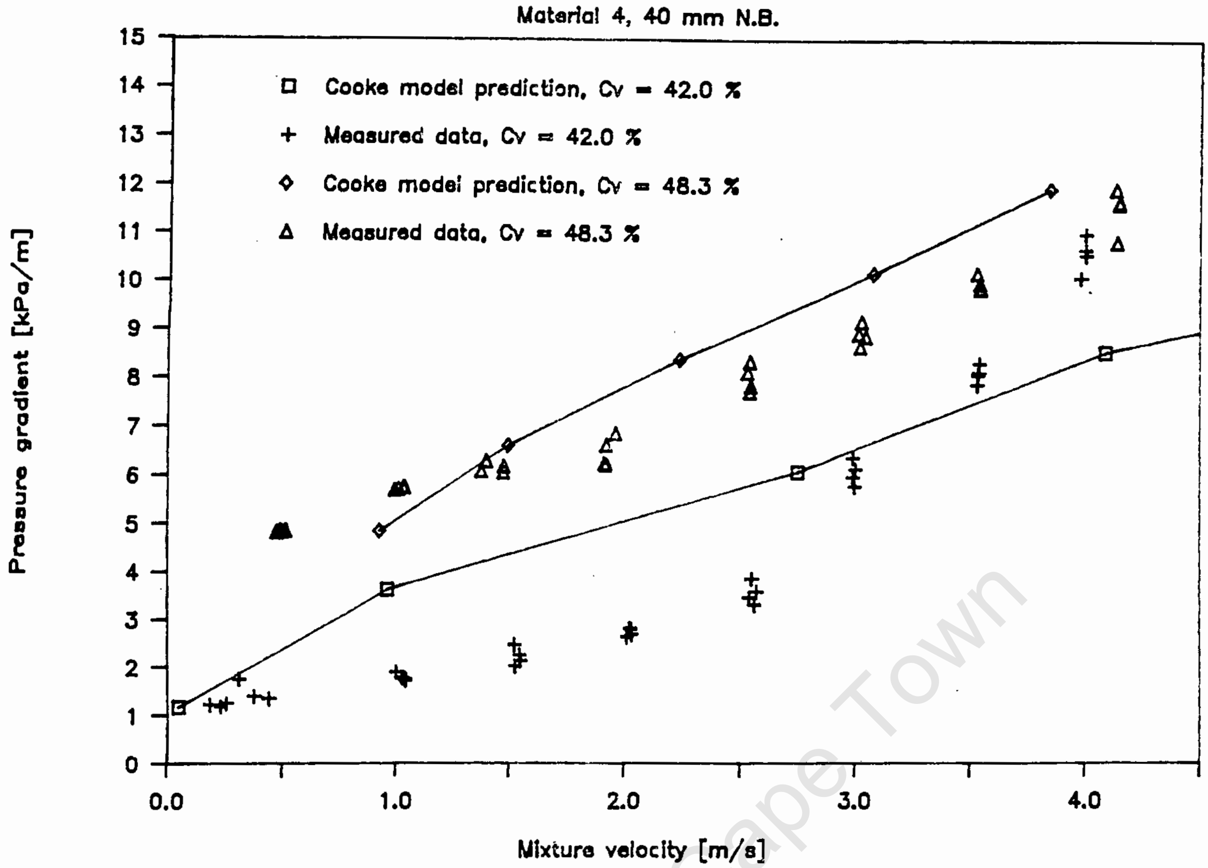


Figure 4.14 : Measured data and Cooke model prediction

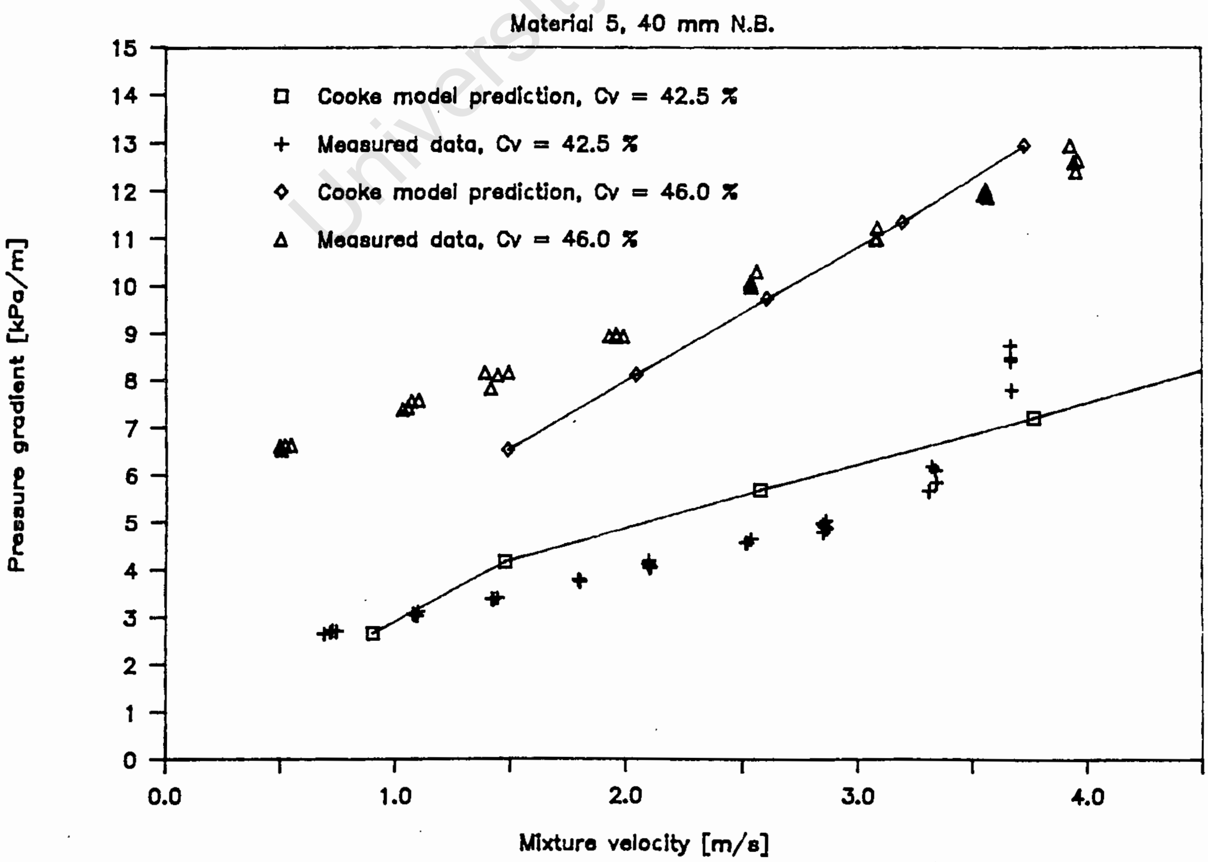


Figure 4.15 : Measured data and Cooke model prediction

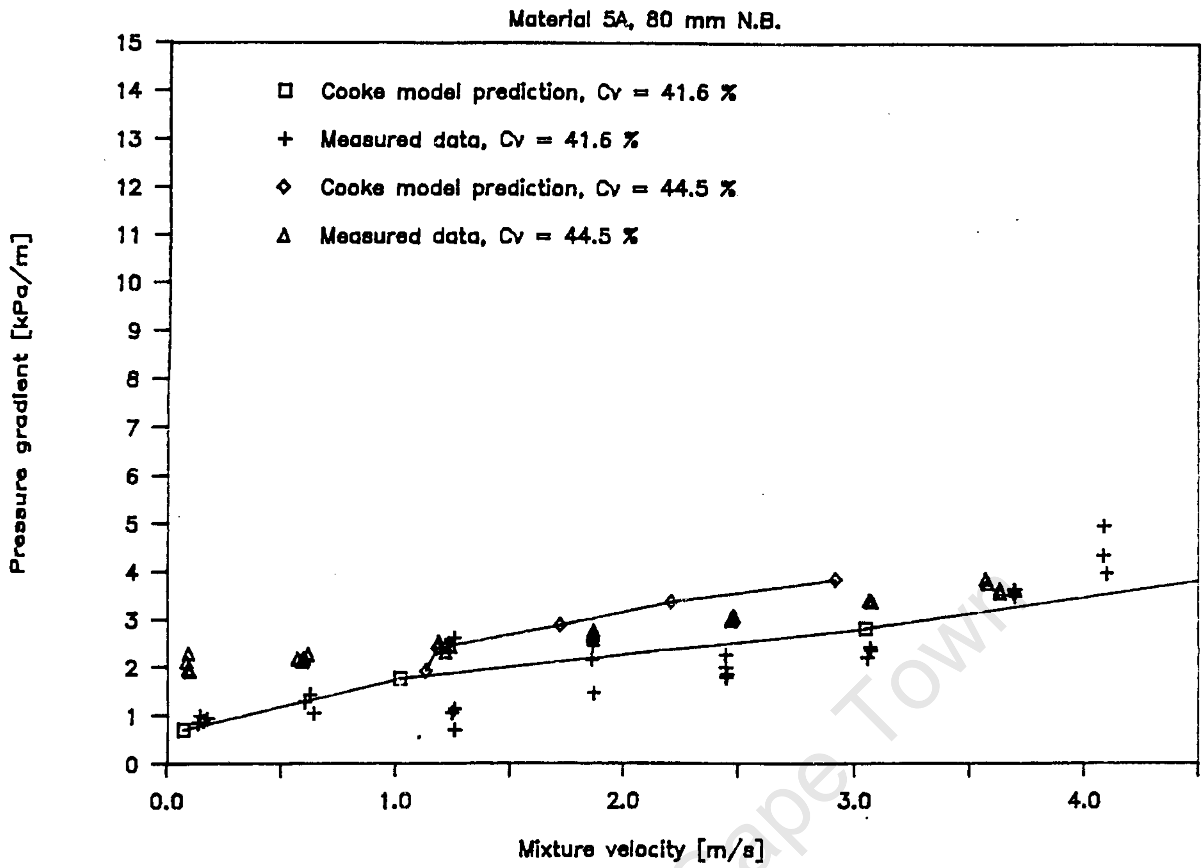
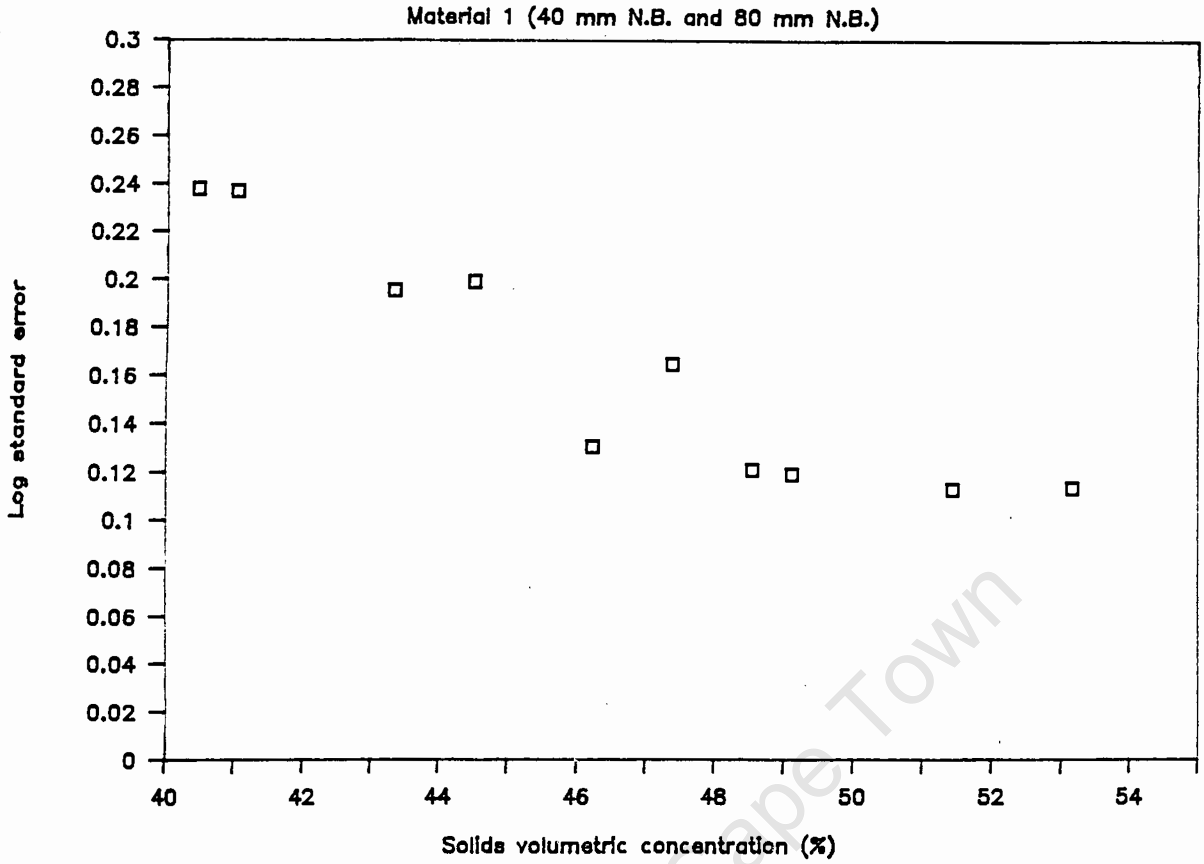
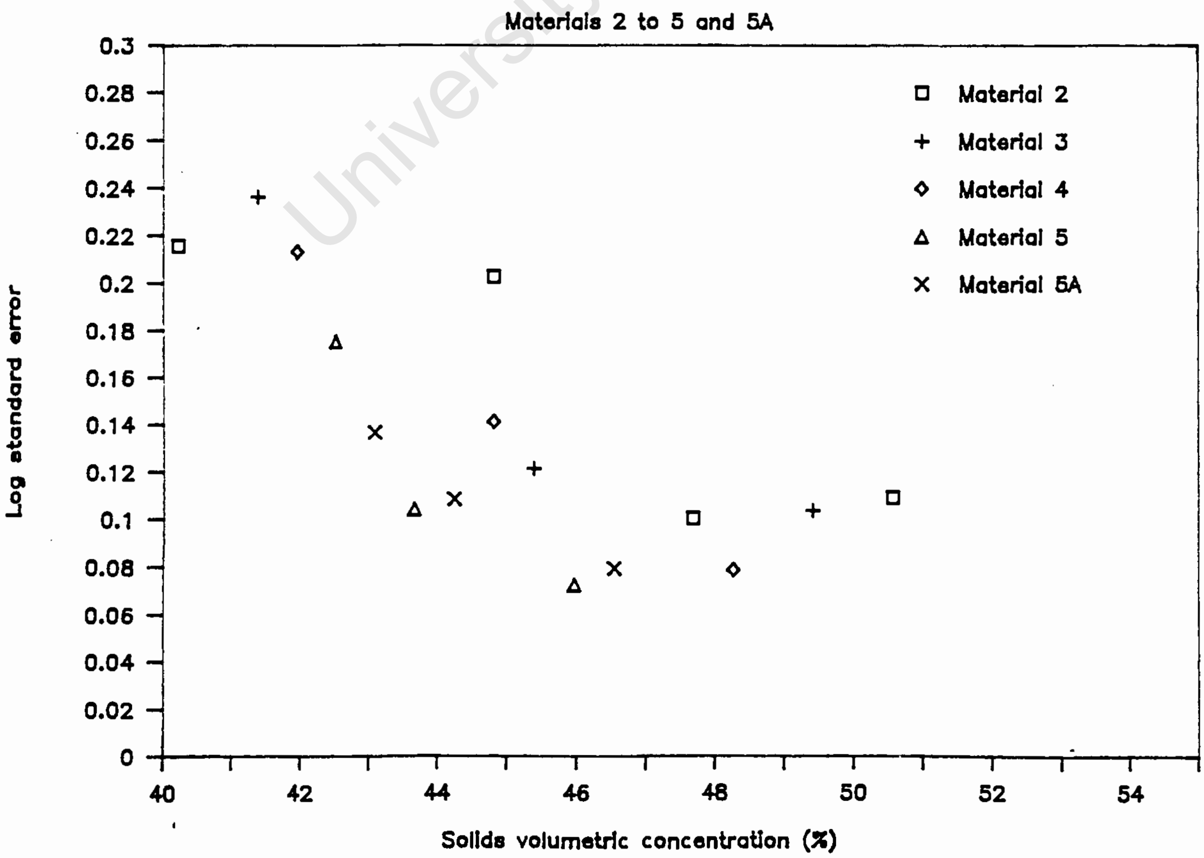


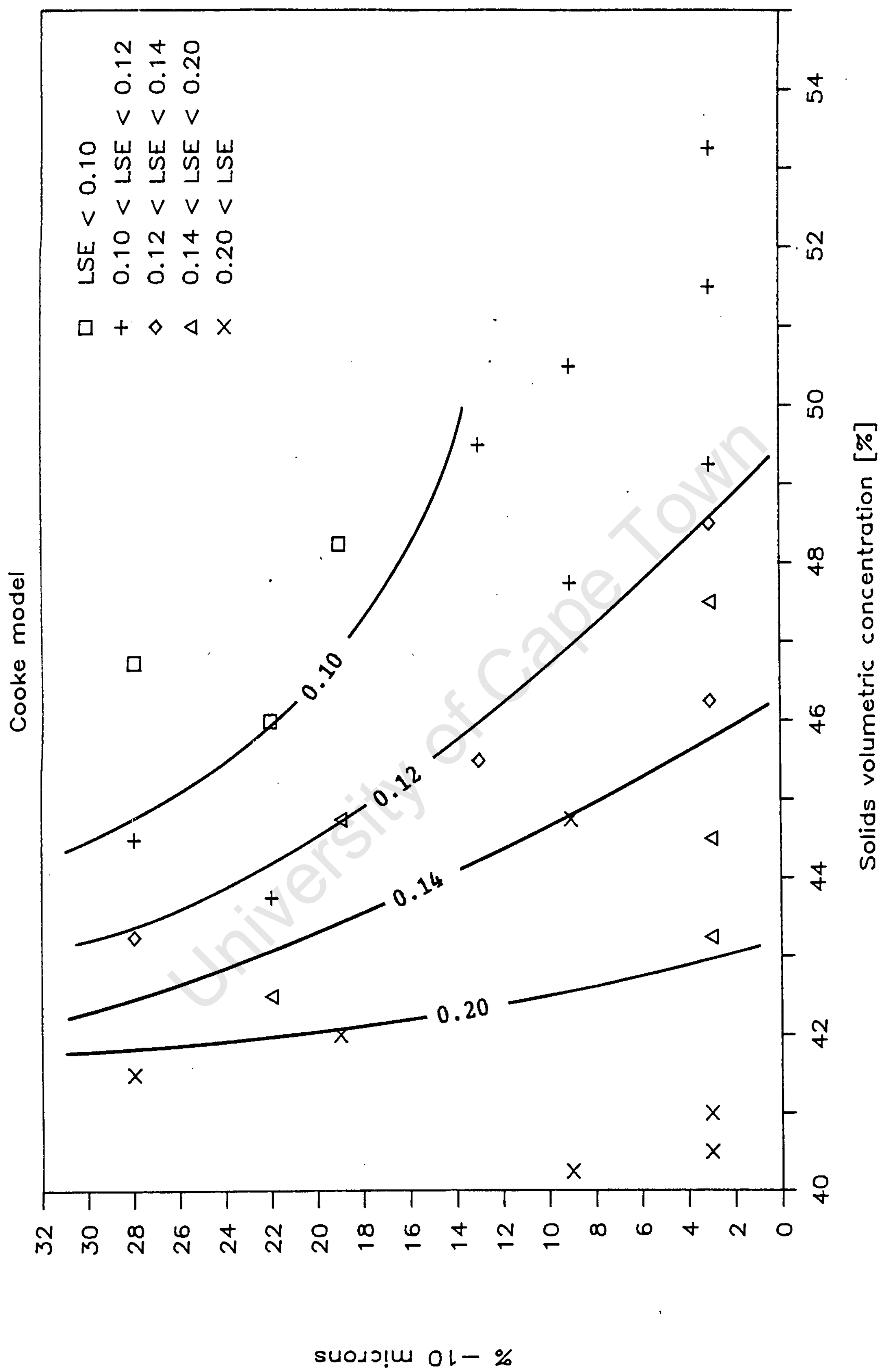
Figure 4.16 : Measured data and Cooke model prediction



<u>Figure 4.17</u> : Log standard error for Cooke model as a function of solids concentration.



<u>Figure 4.18</u> : Log standard error for Cooke model as a function of solids concentration.



<u>Figure 4.19</u> : Log standard error for Cooke model as a function of solids concentration and % -10 microns.

5. CHAPTER SUMMARY

5.1 The Paterson model

It was shown in Section 3.4 of this chapter, that, in the high solids concentration range, the Patertson model is applicable only to the full plant tailings material on which it is based.

The range of applicability of the Paterson model is thus as indicated in Figure 4.20, this being a band of width 1.4% around a value of 30.9% –10 microns.

5.2 The Cooke model

It was shown in Section 4.4 of this chapter that the range of applicability of the Cooke model is bounded by the solid lines in Figure 4.20. The left hand line (lower limit in terms of solids concentration) is approximately the 0.12 log standard error contour in Figure 4.19. The right hand line (upper limit in terms of solids concentration) has been estimated based on experience and observation.

The dashed line in Figure 4.20 indicates the upper limit, in terms of solids concentration, of the measured data.

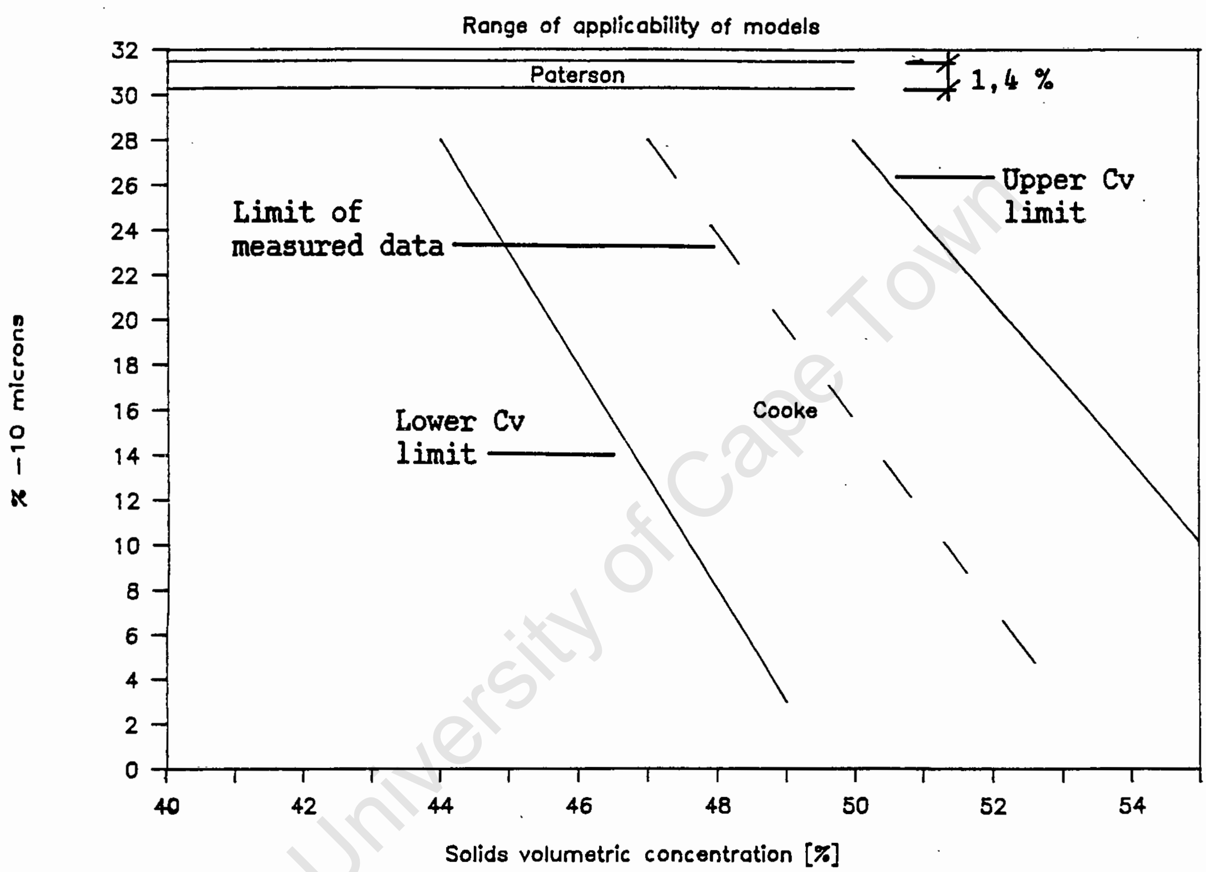


Figure 4.20 : The range of applicability of the Cooke and Paterson models.

CHAPTER 5

Conclusions

1. EXPERIMENTAL INVESTIGATION

1. Six distinctly different materials (in terms of particle size distribution) have been used in this work. These materials span the spectrum of possible particle size distribution for tailings backfill slurries.

2. The six materials have been characterised in terms of solid and particle characteristics relevant to the hydraulic transport by pipeline of such materials.

3. Measured pressure gradient data have been collected for solid-water mixtures (slurries) of these materials over a range of high solids concentrations (typically C_v = 40% to 50%) and over a mean mixture velocity range of 0 to 4.5 m/s.

   The pressure gradient data were measured in a 40 mm N.B. pipeline (five materials) and in an 80 mm N.B. pipeline (two materials).

4. The measured pressure gradient data has been presented in full in Appendix A. The data has also been presented in the form of plots showing trends in pressure gradient as a function of solids concentration and particle size distribution.

   The following observations are made based on these plots:

   The variation of pressure gradient with increasing solids concentration shows a distinct local maximum followed by a local minimum. The decrease in pressure gradient between the local maximum and local minimum is attributed to the onset of laminar flow with increasing solids concentration in the region of the onset of high concentration flow.

   The variation of pressure gradient as a function of fines content (particle size distribution) shows an insensitivity to fines content over the range 0 to 20% –10 microns. In the case of materials with a fines content greater than 20% –10 microns, there is a sharp increase in pressure gradient with increasing fines content. It is noted that this range, %–10 microns greater than 20%, is the range in which typical full plant tailings materials fall.

2. LITERATURE REVIEW

1. It is shown that models existing before those developed by Paterson and Cooke are not applicable to high concentration backfill tailings slurries.

2. The Paterson model is reviewed, presenting by way of two examples, the technique developed by Paterson for rheological characterisation of high concentration full plant tailings slurries. The rheological parameters thus determined by Paterson for the full plant tailings material on which his work is based are presented.

3. The Cooke model is reviewed, presenting the solution procedure by which a mean mixture velocity is calculated based on the material, slurry and pipeline properties and an assumed pressure gradient.

3. MODEL EVALUATION

1. The rheological parameters which Paterson determined for full plant tailings are shown to be applicable only to the full plant tailings material on which the model is based.

   The range of applicability of the Paterson model, in terms of material fines content and solids concentration, is thus reported as:

   30.2% < –10 microns < 31.6%

   and

   Cv < 50%

2. Although the Cooke model was developed for the dense phase flow of cyclone classified tailings, it has been found to be applicable over the full range of material fines content covered in this investigation. The range of applicability of the model, in terms of solids concentration and material fines content (% –10 microns), is bounded by the lines defined by the following points:

   Lower solids concentration limit:

   Cv = 49% , –10 microns = 3%

   and

   Cv = 44% , –10 microns = 28%

   Upper solids concentration limit:

   Cv = 57% , –10 microns = 3%

   and

   Cv = 50% , –10 microns = 28%

Appendix A

APPENDIX A

TEST RESULTS

DATA FILE : M140H70

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.71
Solids Volumetric Concentration (%)	40.75
Solids Mass Concentration (%)	65.25
Mean Slurry Temperature (°C)	24.7
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.276	8.367	24.2
4.274	7.649	24.4
4.293	8.404	24.5
4.280	8.246	24.5
3.593	6.329	24.8
3.078	4.945	24.8
3.059	4.927	24.8
3.563	6.410	24.8
3.583	6.233	24.8
3.550	6.198	24.8
3.571	6.225	24.9
3.083	5.015	24.9
3.078	4.957	24.9
3.089	4.996	24.9
3.095	5.018	24.9
2.523	3.623	24.9
2.512	3.944	24.9
2.516	3.802	24.9
2.544	3.886	24.8
2.032	2.588	24.8
1.999	2.546	24.8
2.011	2.627	24.7
1.992	2.586	24.7
1.474	1.885	24.6
1.487	2.026	24.6
1.460	2.332	24.6
1.473	1.718	24.6
1.511	2.192	24.6

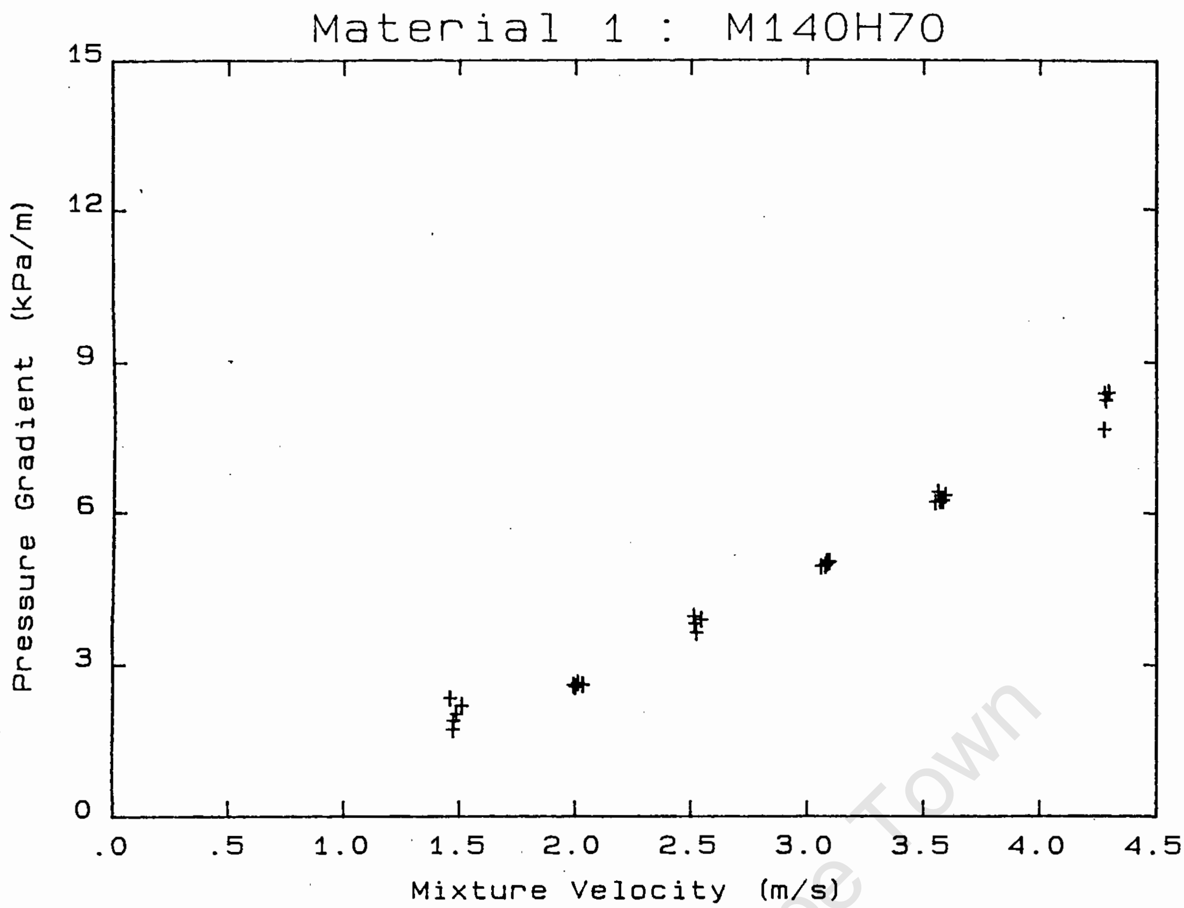
Particle Size Distribution
Sieve and Malvern Size Analysis *

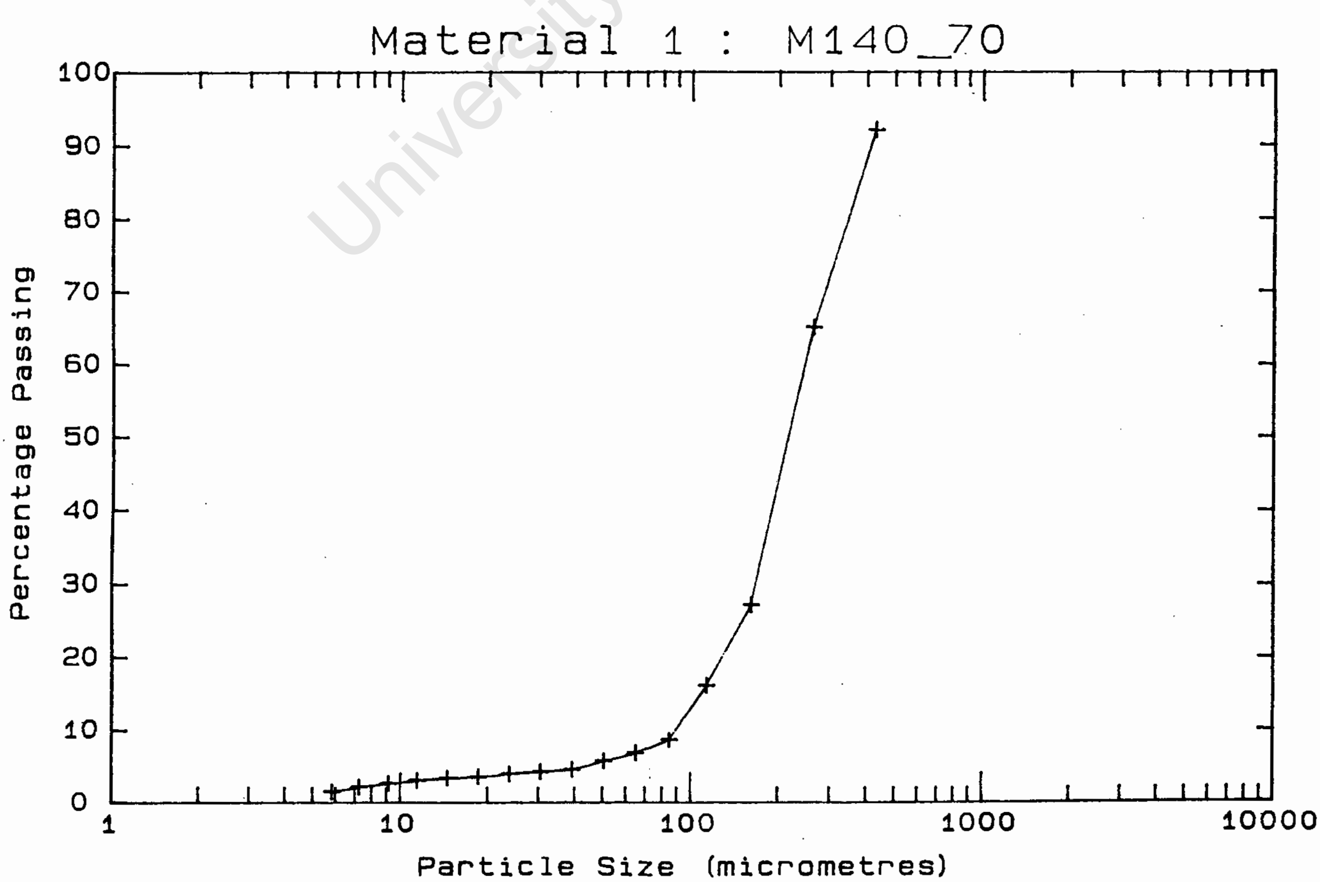
Size (µm)	% Passing	% Retained
425.0	92.0	8.0
261.6	65.0	27.0
160.4	27.2	37.8
112.8	16.1	11.1
84.3	8.6	7.5
64.6	6.8	1.8
50.2	5.7	1.1
39.0	4.5	1.2
30.3	4.2	.3
23.7	3.9	.3
18.5	3.5	.4
14.5	3.3	.2
11.4	3.0	.3
9.1	2.6	.4
7.2	2.1	.5
5.8	1.4	.7
Pan	- .1	1.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
1.16	Stationary bed
1.58	Sliding bed
1.99	Asymetric
2.44	Appears homogeneous
2.82	Appears homogeneous
3.38	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 1 : M140H70
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M140_70
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140D70

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.71
Solids Volumetric Concentration (%)	40.75
Solids Mass Concentration (%)	65.25
Mean Slurry Temperature (°C)	24.7
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.276	- 8.558	24.2
4.274	- 7.913	24.4
4.293	- 8.317	24.5
4.280	- 8.418	24.5
3.593	-10.559	24.8
3.078	-11.911	24.8
3.059	-11.544	24.8
3.563	-10.471	24.8
3.583	-10.509	24.8
3.550	-10.649	24.8
3.571	-10.468	24.9
3.083	-11.672	24.9
3.078	-11.711	24.9
3.089	-11.572	24.9
3.095	-11.732	24.9
2.523	-12.895	24.9
2.512	-12.869	24.9
2.516	-13.053	24.9
2.544	-13.127	24.8
2.032	-14.097	24.8
1.999	-14.116	24.8
2.011	-14.137	24.7
1.992	-14.221	24.7
1.474	-15.420	24.6
1.487	-15.939	24.6
1.460	-15.650	24.6
1.473	-15.451	24.6
1.511	-15.227	24.6

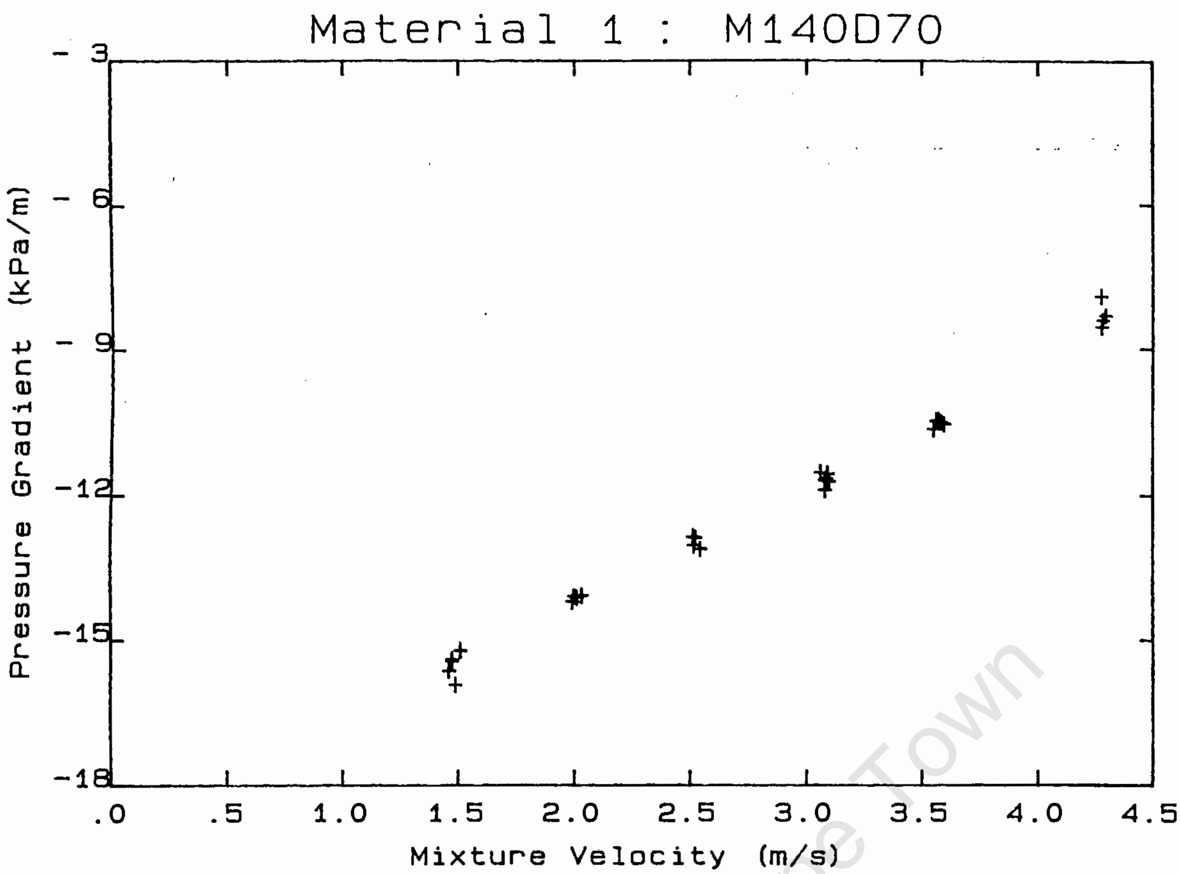
Particle Size Distribution
Sieve and Malvern Size Analysis *

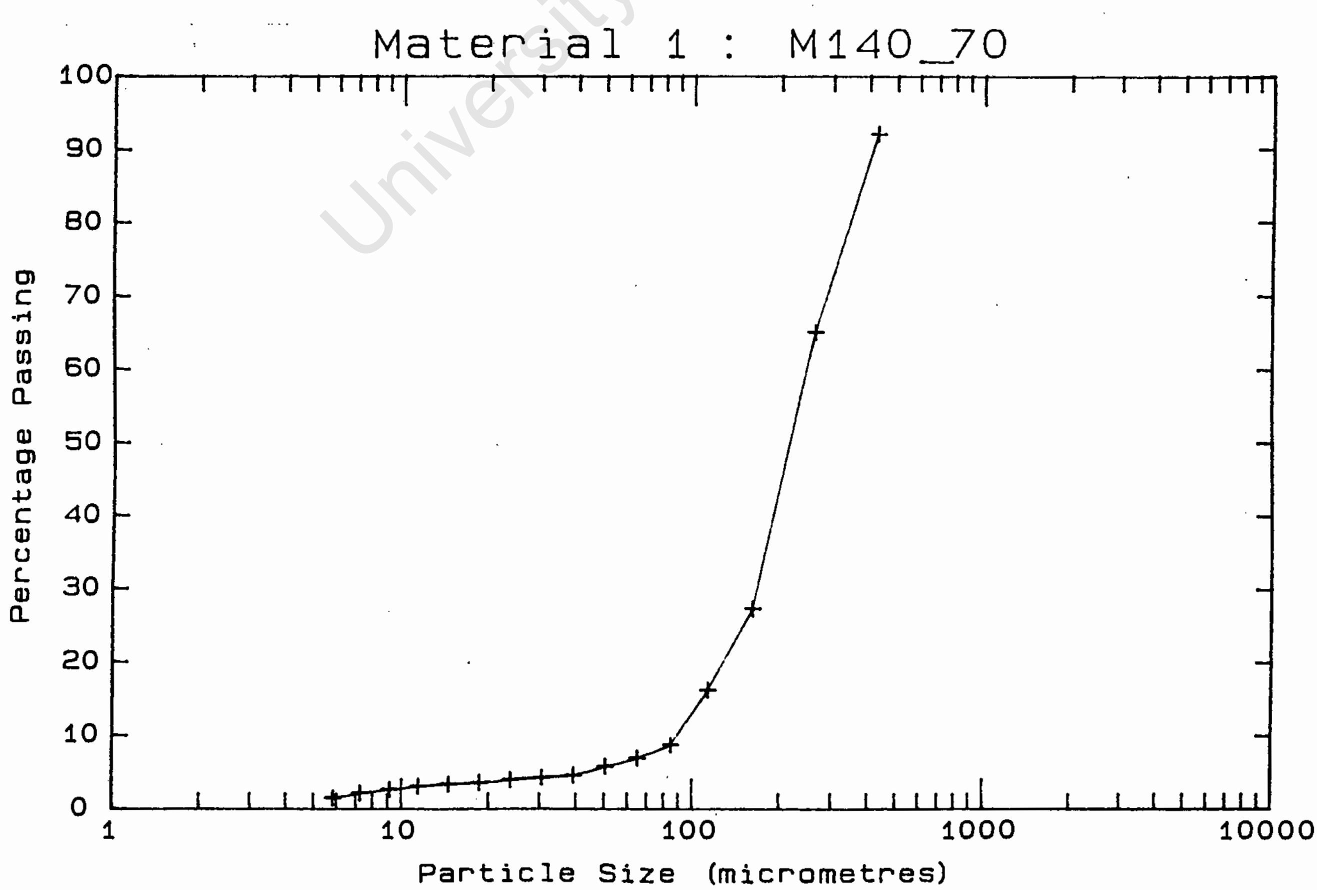
Size (μm)	% Passing	% Retained
425.0	92.0	8.0
261.6	65.0	27.0
160.4	27.2	37.8
112.8	16.1	11.1
84.3	8.6	7.5
64.6	6.8	1.8
50.2	5.7	1.1
39.0	4.5	1.2
30.3	4.2	.3
23.7	3.9	.3
18.5	3.5	.4
14.5	3.3	.2
11.4	3.0	.3
9.1	2.6	.4
7.2	2.1	.5
5.8	1.4	.7
Pan	- .1	1.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = .0 mm)

* -425 μm Malvern Particle Size Analyser


Material 1 : M140D70
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M140_70
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140U70

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.71
Solids Volumetric Concentration (%)	40.75
Solids Mass Concentration (%)	65.25
Mean Slurry Temperature (°C)	24.8
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.593	21.254	24.8
3.078	19.680	24.8
3.059	20.093	24.8
3.563	21.343	24.8
3.583	21.490	24.8
3.550	21.151	24.8
3.571	21.265	24.9
3.083	20.075	24.9
3.078	19.813	24.9
3.089	20.103	24.9
3.095	19.892	24.9
2.523	19.280	24.9
2.512	18.542	24.9
2.516	18.638	24.9
2.544	18.564	24.8
2.032	17.564	24.8
1.999	17.545	24.8
2.011	17.537	24.7
1.992	17.653	24.7
1.474	17.451	24.6
1.487	17.586	24.6
1.460	17.378	24.6
1.473	17.475	24.6
1.511	17.473	24.6

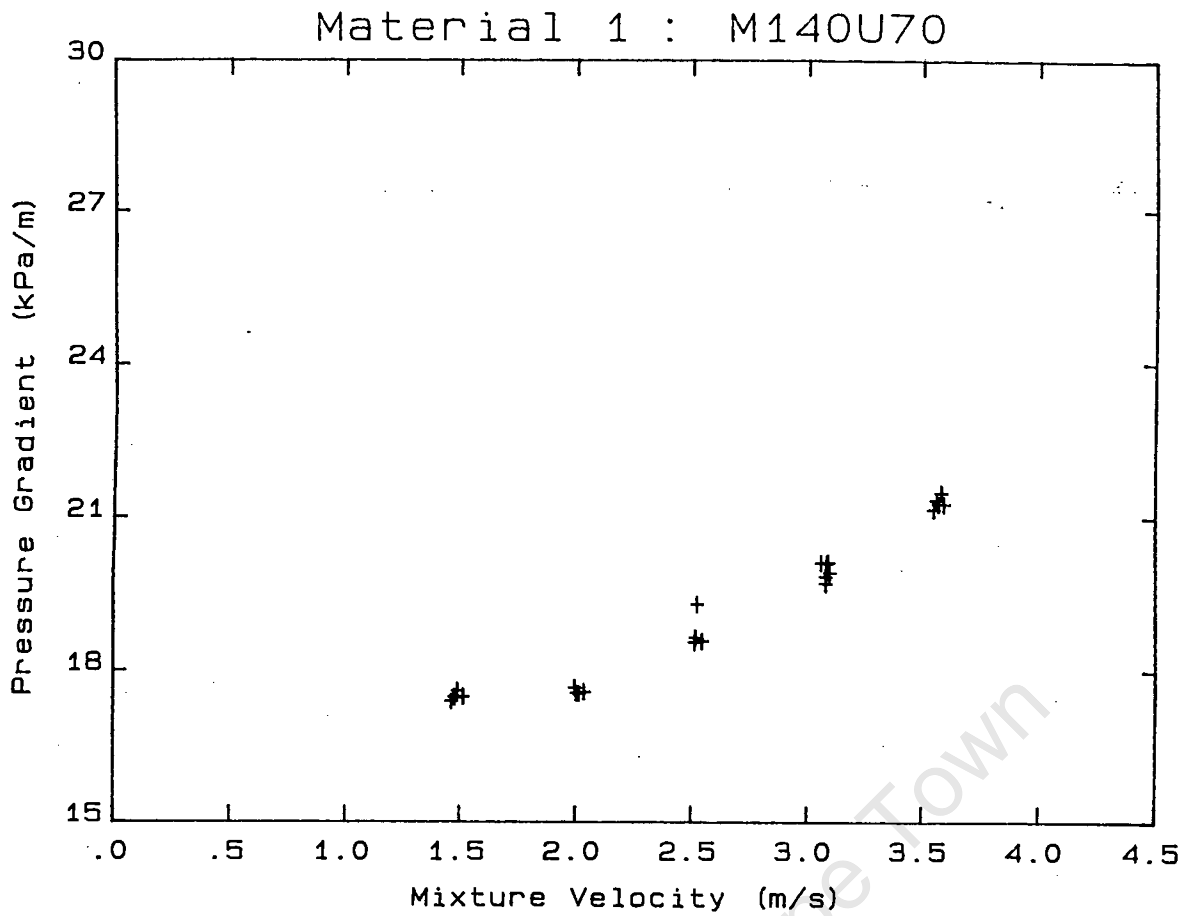
Particle Size Distribution
Sieve and Malvern Size Analysis *

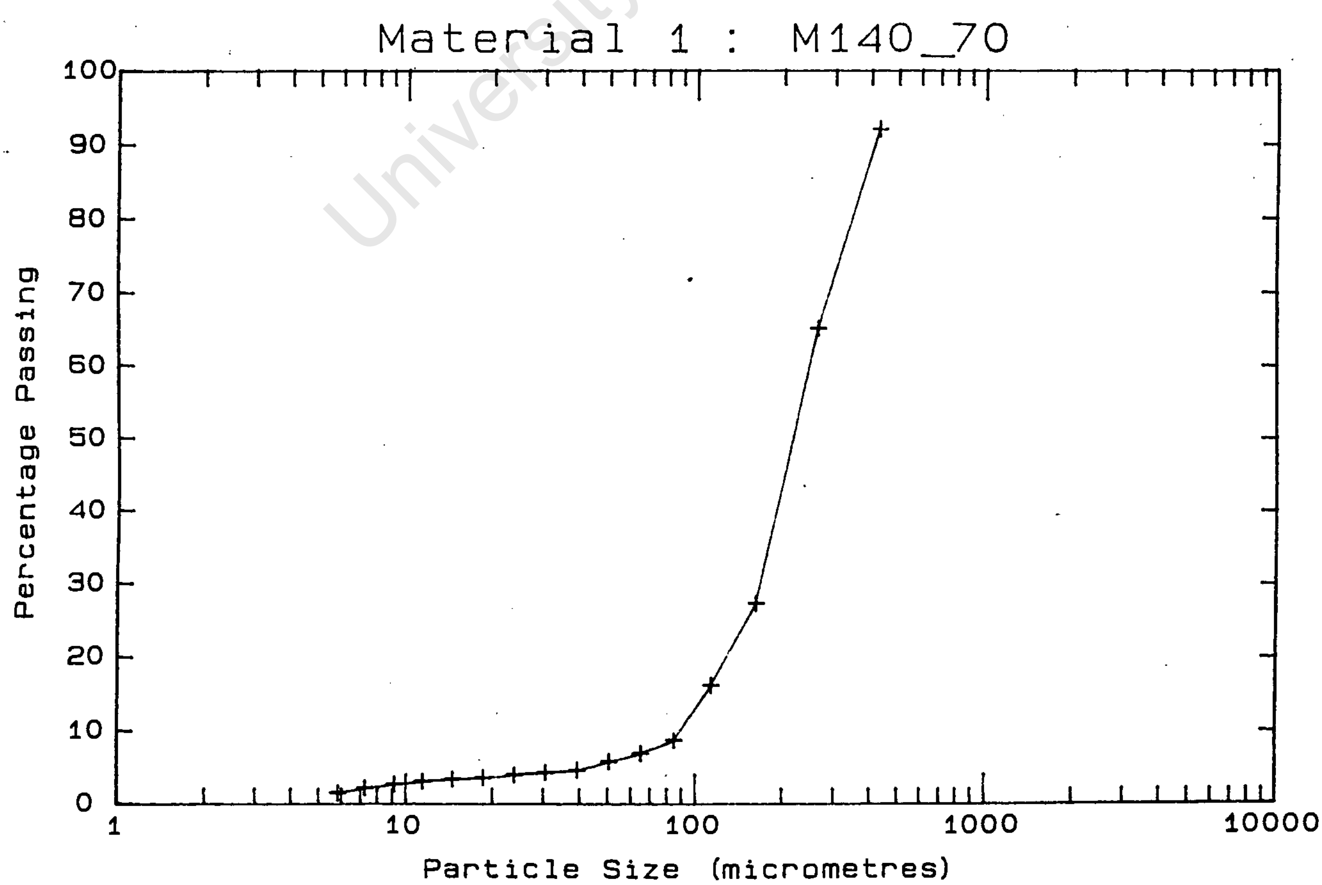
Size (µm)	% Passing	% Retained
425.0	92.0	8.0
261.6	65.0	27.0
160.4	27.2	37.8
112.8	16.1	11.1
84.3	8.6	7.5
64.6	6.8	1.8
50.2	5.7	1.1
39.0	4.5	1.2
30.3	4.2	.3
23.7	3.9	.3
18.5	3.5	.4
14.5	3.3	.2
11.4	3.0	.3
9.1	2.6	.4
7.2	2.1	.5
5.8	1.4	.7
Pan	- .1	1.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M140U70
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M140_70
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140H71

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.71
Solids Volumetric Concentration (%)	40.92
Solids Mass Concentration (%)	65.41
Mean Slurry Temperature (°C)	25.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.184	7.959	24.7
4.219	7.849	24.8
4.226	7.800	24.9
4.234	7.687	25.1
3.570	6.004	25.3
3.544	5.897	25.4
3.545	5.912	25.4
3.529	5.832	25.4
3.079	4.846	25.4
3.099	4.912	25.4
3.099	4.855	25.4
3.073	4.884	25.3
2.507	3.719	25.3
2.540	3.615	25.3
2.572	3.487	25.3
2.526	3.752	25.2
2.423	3.372	25.2
2.032	2.746	25.1
2.046	2.720	25.1
2.029	2.640	25.1
2.005	2.605	25.1
1.529	2.620	25.0
1.477	2.122	25.0
1.502	2.476	24.9
1.463	1.448	24.9

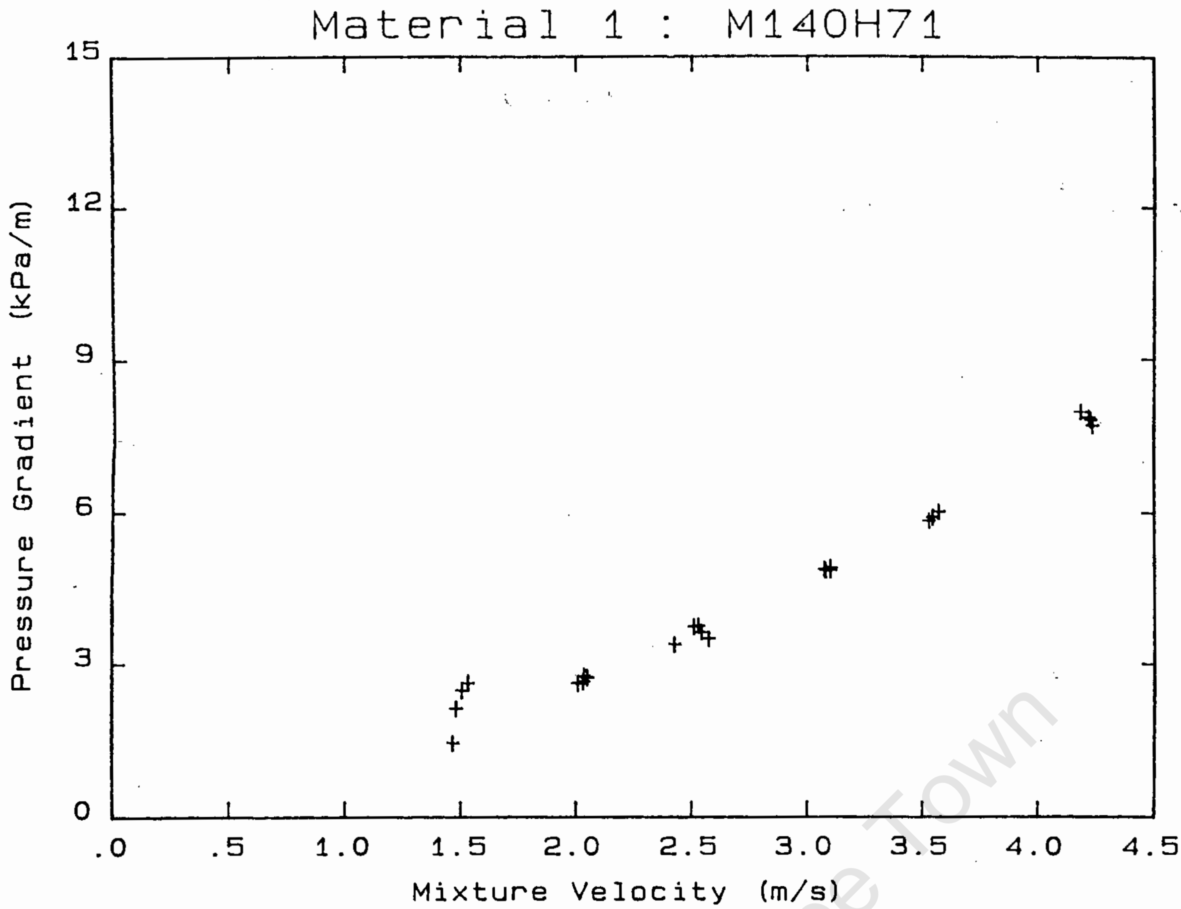
Particle Size Distribution
Sieve and Malvern Size Analysis *

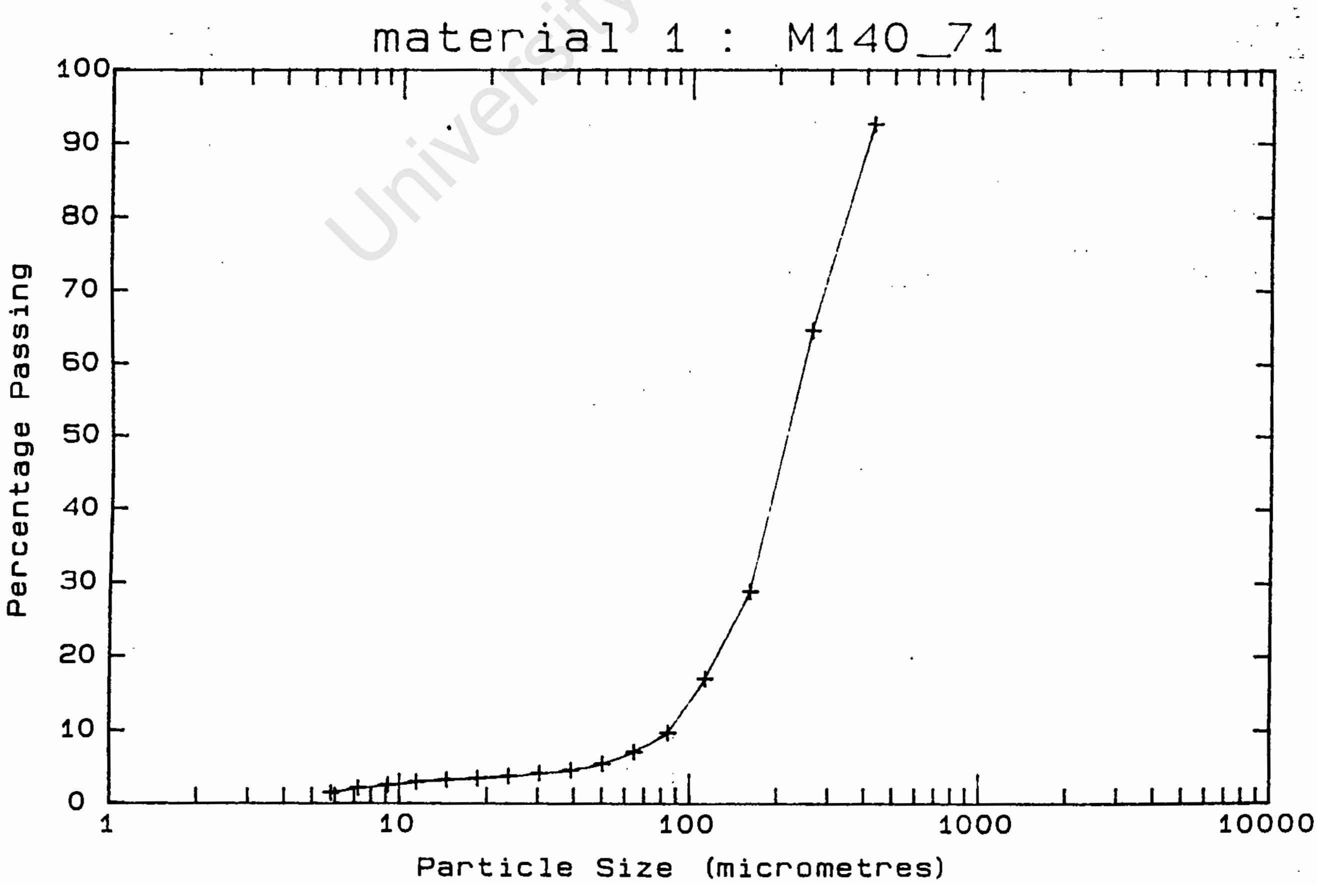
Size (μm)	% Passing	% Retained
425.0	92.5	7.5
261.6	64.5	28.0
160.4	28.8	35.7
112.8	16.9	11.9
84.3	9.6	7.3
64.6	7.0	2.6
50.2	5.4	1.6
39.0	4.5	.9
30.3	4.1	.4
23.7	3.7	.4
18.5	3.4	.3
14.5	3.2	.2
11.4	2.9	.3
9.1	2.5	.4
7.3	2.1	.4
5.8	1.4	.7
Pan	- .1	1.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
1.19	35% Stationary bed
1.61	Sliding bed
2.01	Sliding particles
2.44	Asymetric
2.81	Appears homogeneous
3.34	Appears homogeneous

* -425 μm Malvern Particle Size Analyser


Material 1 : M140H71
Pressure Gradient (kPa/m)
0
3
6
9
12
15
Mixture Velocity (m/s)
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


material 1 : M140_71
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
Particle Size (micrometres)
1
10
100
1000
10000

DATA FILE : M140D71

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.71
Solids Volumetric Concentration (%)	40.92
Solids Mass Concentration (%)	65.41
Mean Slurry Temperature (°C)	25.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.184	- 8.645	24.7
4.219	- 8.341	24.8
4.226	- 8.712	24.9
4.234	- 8.472	25.1
3.570	-10.617	25.3
3.544	-10.376	25.4
3.545	-10.474	25.4
3.529	-10.602	25.4
3.079	-11.479	25.4
3.099	-11.610	25.4
3.099	-11.544	25.4
3.073	-11.630	25.3
2.507	-12.860	25.3
2.540	-12.676	25.3
2.572	-12.556	25.3
2.526	-12.859	25.2
2.423	-13.209	25.2
2.032	-14.031	25.1
2.046	-14.206	25.1
2.029	-14.158	25.1
2.005	-14.183	25.1
1.529	-15.238	25.0
1.477	-15.565	25.0
1.502	-15.369	24.9
1.463	-15.133	24.9

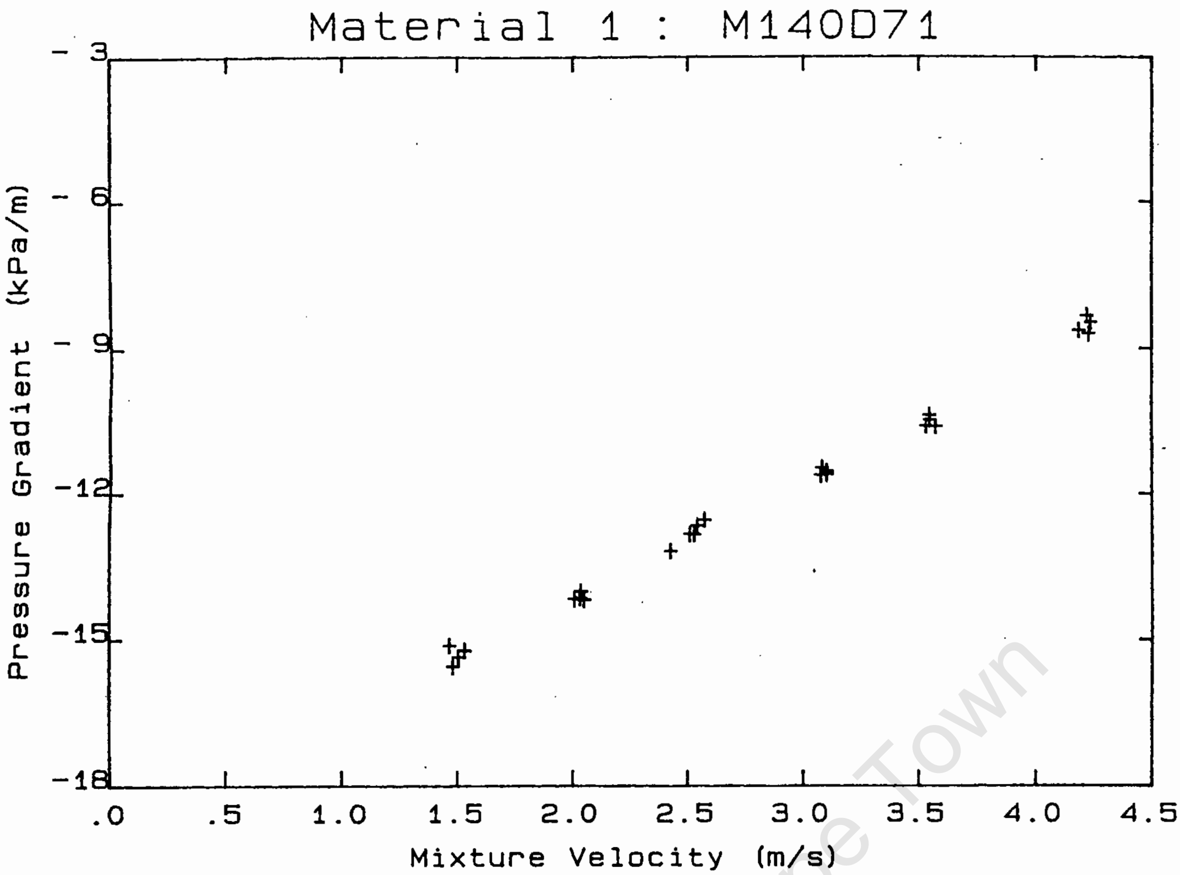
Particle Size Distribution
Sieve and Malvern Size Analysis *

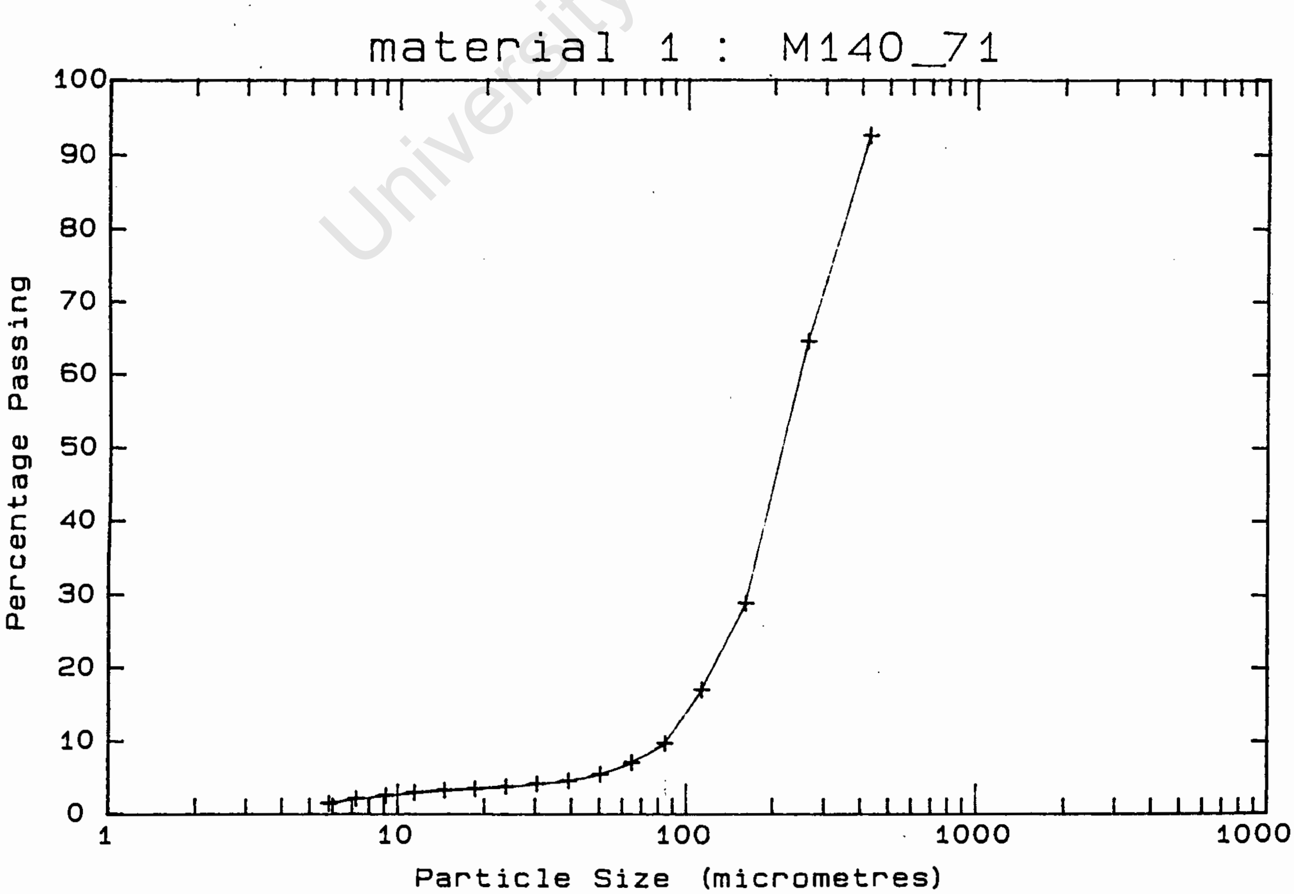
Size (μm)	% Passing	% Retained
425.0	92.5	7.5
261.6	64.5	28.0
160.4	28.8	35.7
112.8	16.9	11.9
84.3	9.6	7.3
64.6	7.0	2.6
50.2	5.4	1.6
39.0	4.5	.9
30.3	4.1	.4
23.7	3.7	.4
18.5	3.4	.3
14.5	3.2	.2
11.4	2.9	.3
9.1	2.5	.4
7.3	2.1	.4
5.8	1.4	.7
Pan	– .1	1.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = .0 mm)

* -425 μm Malvern Particle Size Analyser


Material 1 : M140D71
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


material 1 : M140_71
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140U71

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.71
Solids Volumetric Concentration (%)	40.92
Solids Mass Concentration (%)	65.41
Mean Slurry Temperature (°C)	25.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.184	22.811	24.7
4.219	22.714	24.8
4.226	22.618	24.9
4.234	22.316	25.1
3.570	21.122	25.3
3.544	21.261	25.4
3.545	21.139	25.4
3.529	21.378	25.4
3.079	20.063	25.4
3.099	20.244	25.4
3.099	20.139	25.4
3.073	19.684	25.3
2.507	18.937	25.3
2.540	19.284	25.3
2.572	19.397	25.3
2.526	18.969	25.2
2.423	18.550	25.2
2.032	17.679	25.1
2.046	17.611	25.1
2.029	17.597	25.1
2.005	17.626	25.1
1.529	17.626	25.0
1.477	17.601	25.0
1.502	17.655	24.9
1.463	17.742	24.9

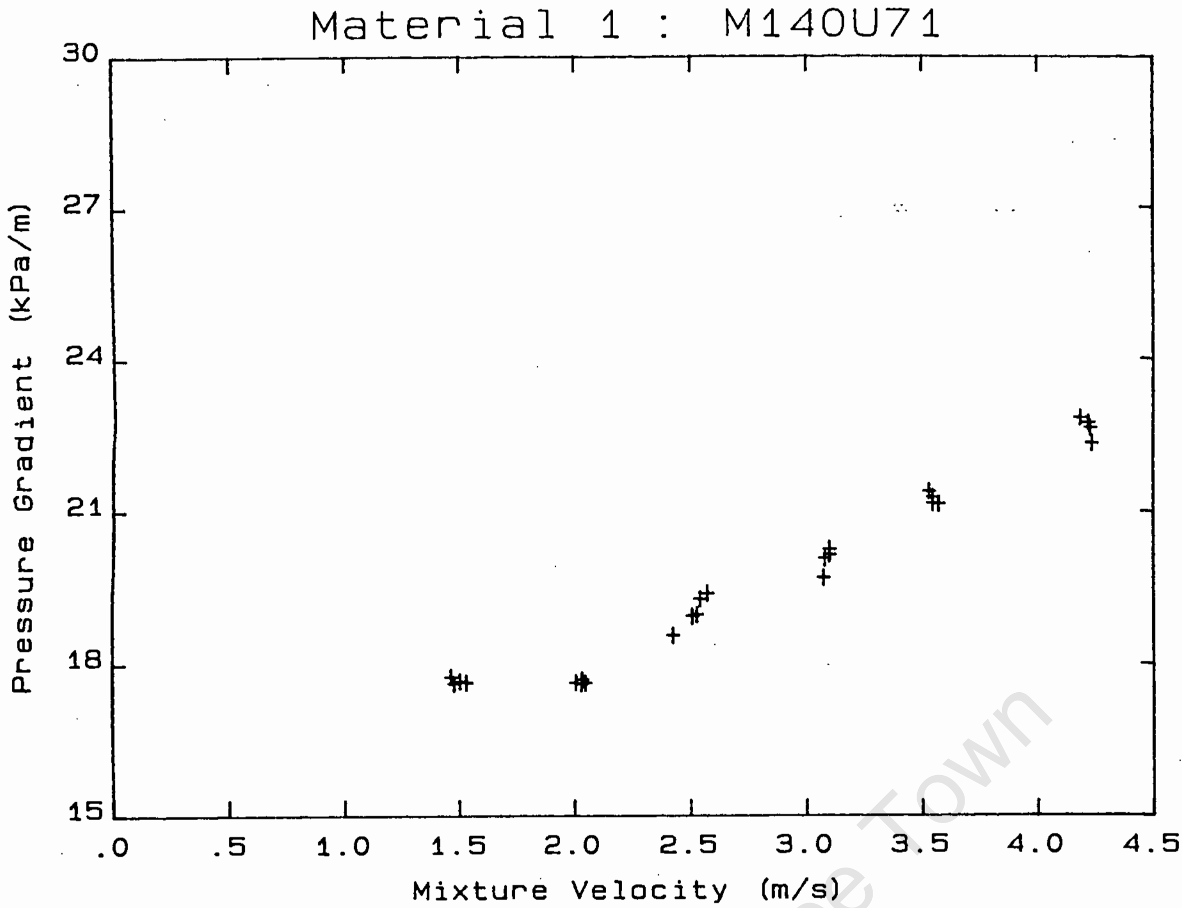
Particle Size Distribution
Sieve and Malvern Size Analysis *

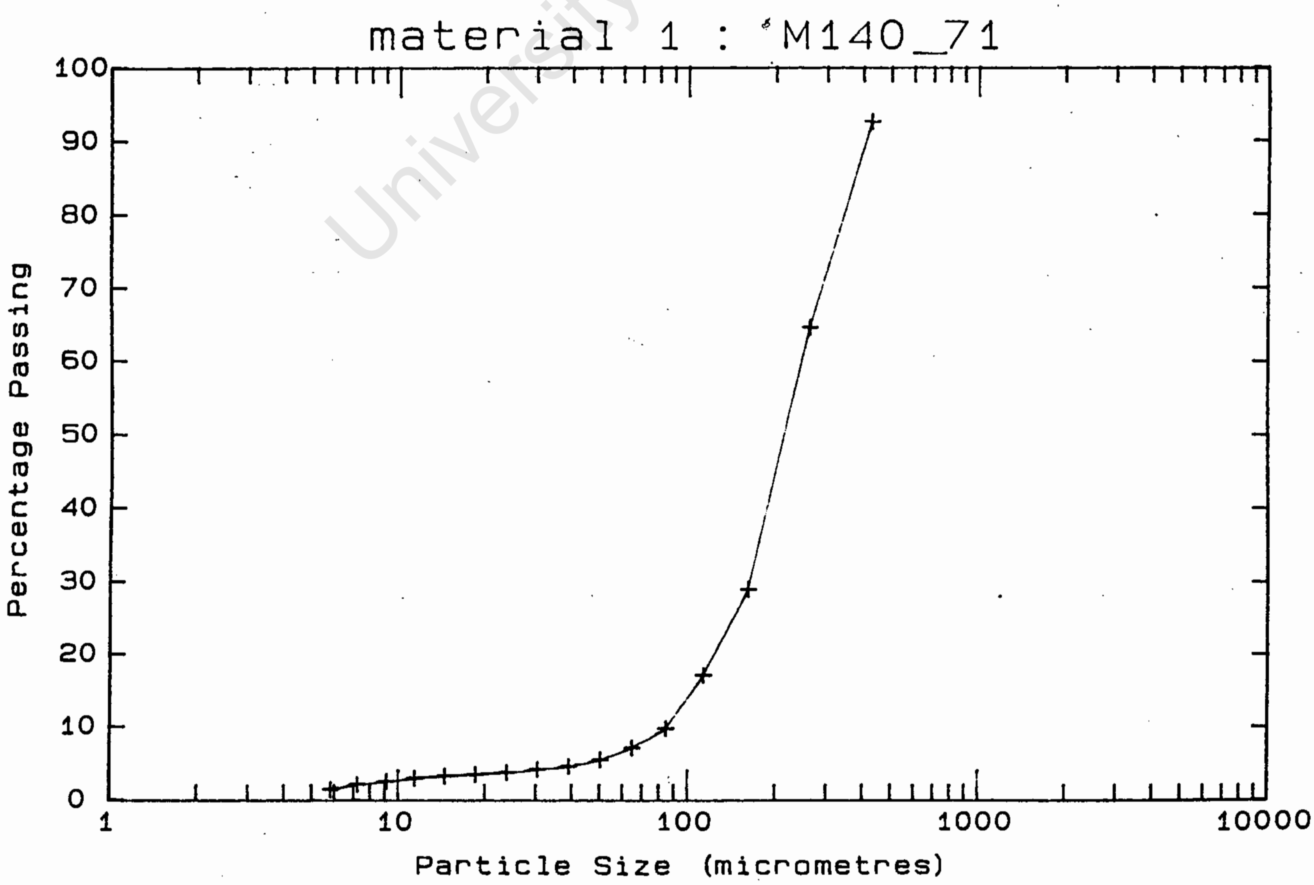
Size (µm)	% Passing	% Retained
425.0	92.5	7.5
261.6	64.5	28.0
160.4	28.8	35.7
112.8	16.9	11.9
84.3	9.6	7.3
64.6	7.0	2.6
50.2	5.4	1.6
39.0	4.5	.9
30.3	4.1	.4
23.7	3.7	.4
18.5	3.4	.3
14.5	3.2	.2
11.4	2.9	.3
9.1	2.5	.4
7.3	2.1	.4
5.8	1.4	.7
Pan	- .1	1.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = .0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M140U71
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


material 1 : M140_71
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140H75

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.75
Solids Volumetric Concentration (%)	43.29
Solids Mass Concentration (%)	67.58
Mean Slurry Temperature (°C)	25.9
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.113	6.651	24.9
4.121	6.557	25.1
4.137	7.133	25.2
4.153	6.787	25.4
4.130	6.413	25.5
3.555	5.481	26.1
3.553	5.718	26.1
3.554	5.731	26.2
3.555	5.488	26.2
3.558	5.681	26.3
3.024	4.087	26.3
3.016	4.405	26.3
3.019	4.409	26.3
3.020	4.367	26.3
2.513	3.614	26.2
2.505	3.816	26.2
2.527	3.497	26.2
2.534	3.482	26.1
2.487	3.713	26.1
1.986	2.883	26.0
1.985	2.875	26.0
2.009	2.773	26.0
2.006	2.902	25.9
1.457	2.562	25.9
1.445	1.920	25.8
1.451	2.245	25.8
1.449	2.321	25.7

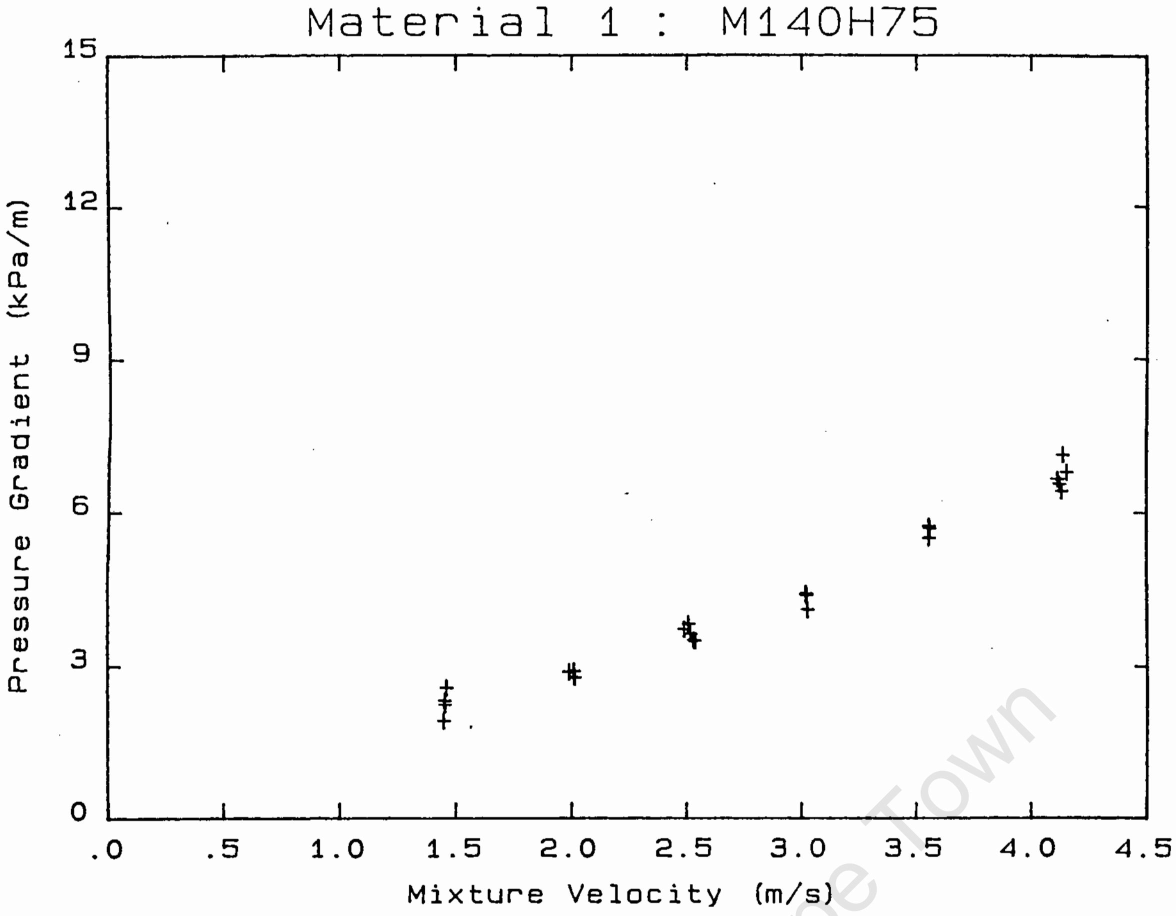
Particle Size Distribution
Sieve and Malvern Size Analysis *

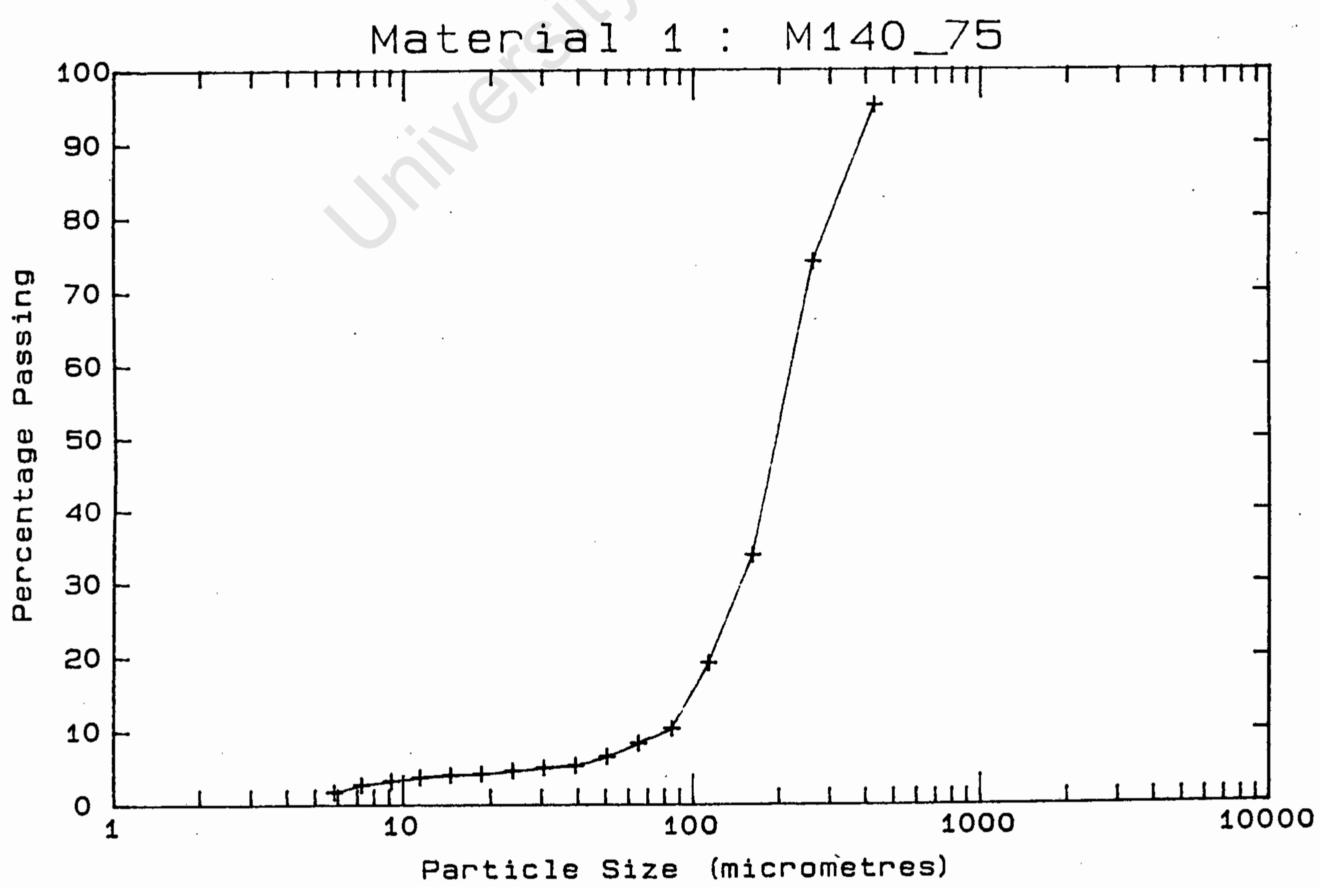
Size (µm)	% Passing	% Retained
425.0	95.1	4.9
261.6	74.0	21.1
160.4	33.8	40.2
112.8	19.2	14.6
84.3	10.3	8.9
64.6	8.3	2.0
50.2	6.5	1.8
39.0	5.3	1.2
30.3	5.0	.3
23.7	4.6	.4
18.5	4.2	.4
14.5	4.0	.2
11.4	3.7	.3
9.1	3.2	.5
7.2	2.7	.5
5.8	1.7	1.0
Pan	- .1	1.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
1.15	Sliding particles
1.58	Sliding particles
1.99	Sliding particles
2.39	Appears homogeneous
2.81	Appears homogeneous
3.27	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 1 : M140H75
Pressure Gradient (kPa/m)
Mixture Velocity (m/s)
15
12
9
6
3
0
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Material 1 : M140_75
Percentage Passing
Particle Size (micrometres)
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000

DATA FILE : M140D75

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.75
Solids Volumetric Concentration (%)	43.29
Solids Mass Concentration (%)	67.58
Mean Slurry Temperature (°C)	25.9
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.113	- 8.543	24.9
4.121	- 8.278	25.1
4.137	- 8.101	25.2
4.153	- 8.676	25.4
4.130	- 8.559	25.5
3.555	-11.747	26.1
3.553	-11.942	26.1
3.554	-11.691	26.2
3.555	-12.327	26.2
3.558	-11.808	26.3
3.024	-13.258	26.3
3.016	-13.281	26.3
3.019	-13.616	26.3
3.020	-13.471	26.3
2.513	-14.216	26.2
2.505	-14.000	26.2
2.527	-14.137	26.2
2.534	-14.048	26.1
2.487	-14.187	26.1
1.986	-14.724	26.0
1.985	-14.761	26.0
2.009	-14.777	26.0
2.006	-14.705	25.9
1.457	-15.153	25.9
1.445	-15.128	25.8
1.451	-14.999	25.8
1.449	-15.051	25.7

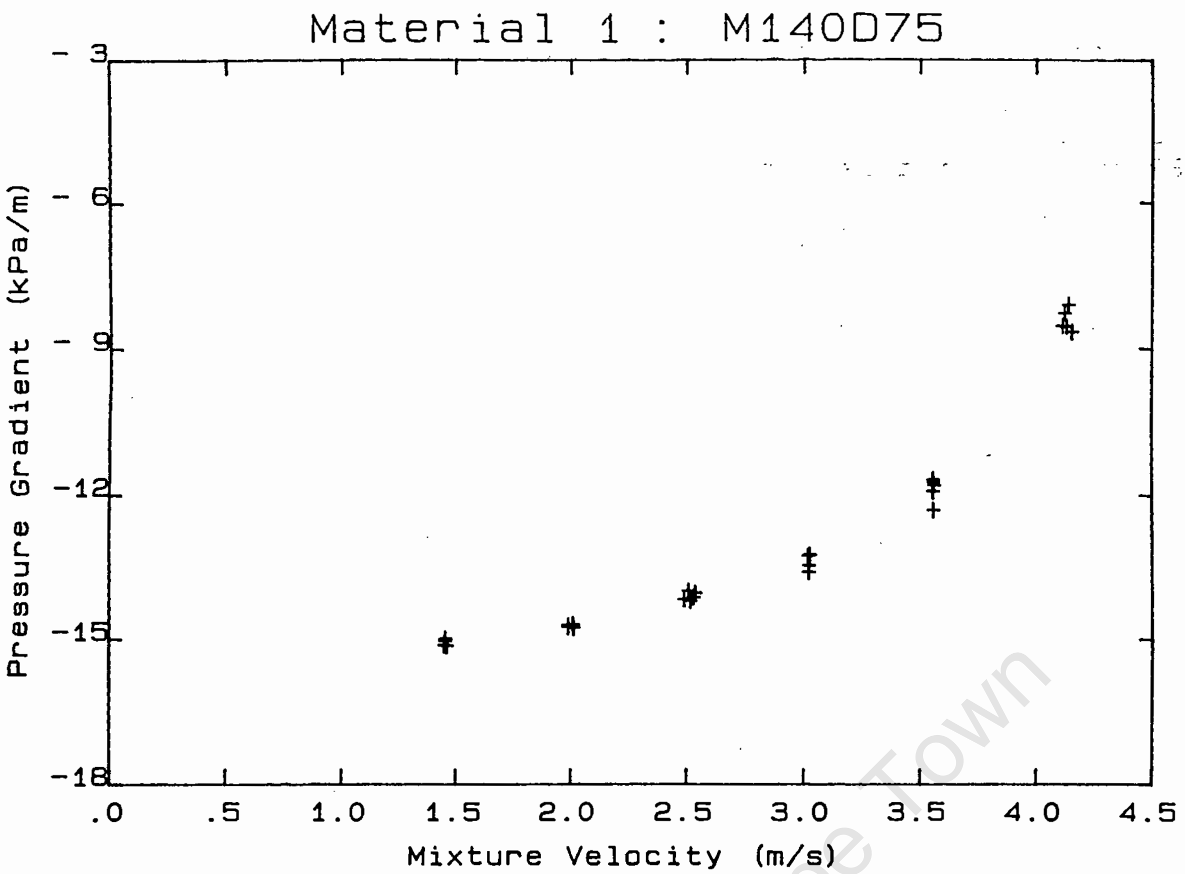
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	95.1	4.9
261.6	74.0	21.1
160.4	33.8	40.2
112.8	19.2	14.6
84.3	10.3	8.9
64.6	8.3	2.0
50.2	6.5	1.8
39.0	5.3	1.2
30.3	5.0	.3
23.7	4.6	.4
18.5	4.2	.4
14.5	4.0	.2
11.4	3.7	.3
9.1	3.2	.5
7.2	2.7	.5
5.8	1.7	1.0
Pan	- .1	1.8

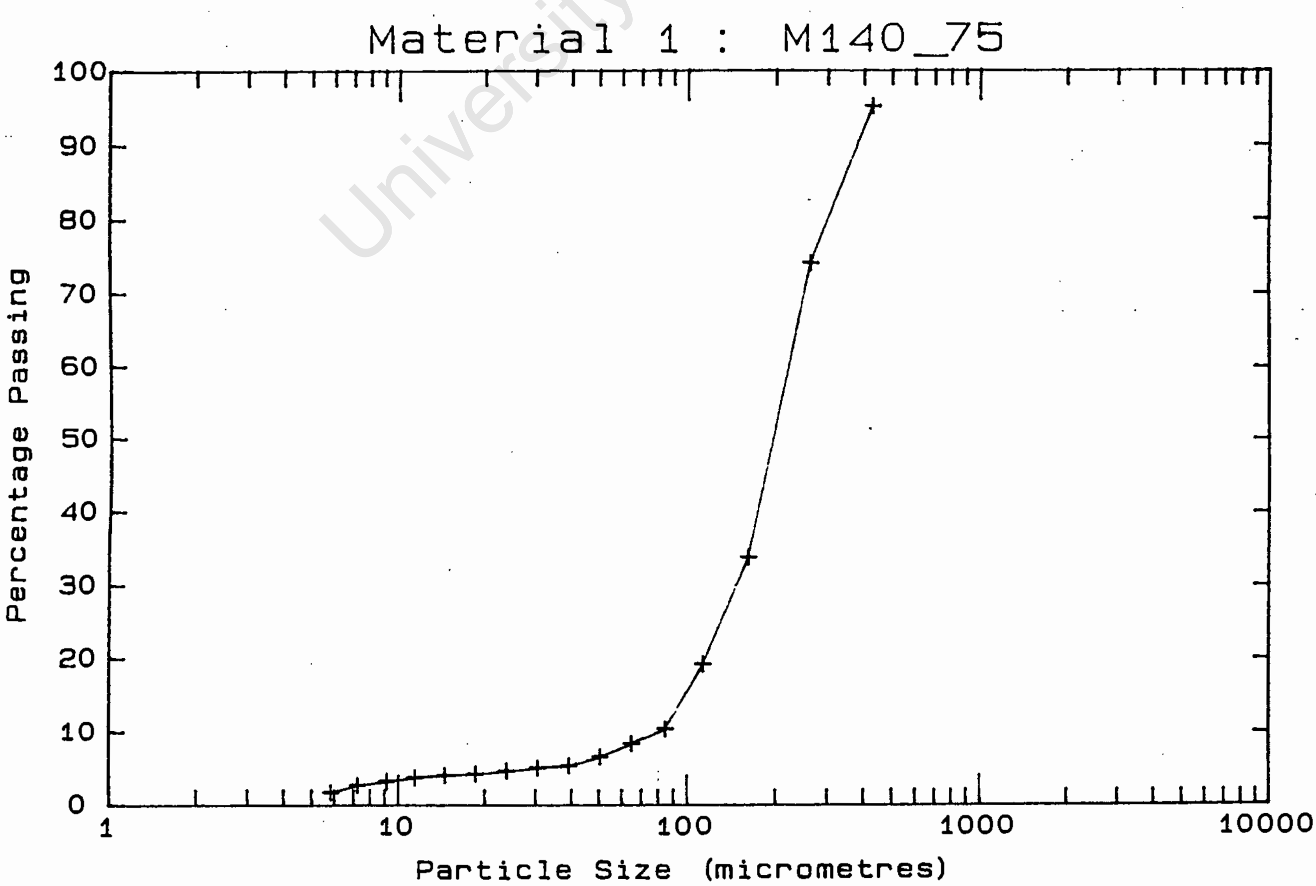
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser



Material 1 : M140D75
Pressure Gradient (kPa/m)
- 3
- 6
- 9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 1 : M140_75
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140U75

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.75
Solids Volumetric Concentration (%)	43.29
Solids Mass Concentration (%)	67.58
Mean Slurry Temperature (°C)	25.9
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.113	21.127	24.9
4.121	21.361	25.1
4.137	20.712	25.2
4.153	21.198	25.4
4.130	21.237	25.5
3.555	20.793	26.1
3.553	20.353	26.1
3.554	20.025	26.2
3.555	20.231	26.2
3.558	20.119	26.3
3.024	20.070	26.3
3.016	19.673	26.3
3.019	19.695	26.3
3.020	19.830	26.3
2.513	19.212	26.2
2.505	19.149	26.2
2.527	19.321	26.2
2.534	19.513	26.1
2.487	19.043	26.1
1.986	18.919	26.0
1.985	18.860	26.0
2.009	18.643	26.0
2.006	18.892	25.9
1.457	18.435	25.9
1.445	18.590	25.8
1.451	18.631	25.8
1.449	18.438	25.7

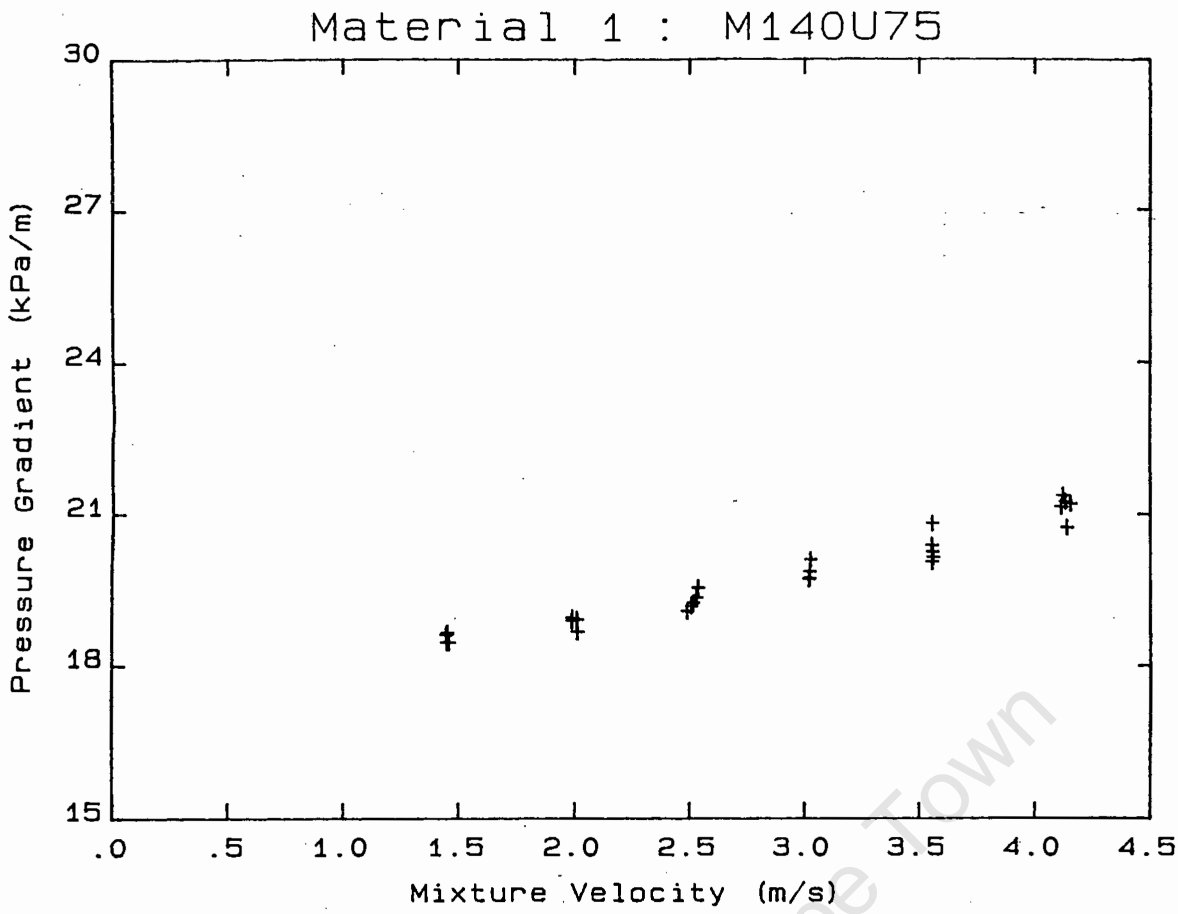
Particle Size Distribution
Sieve and Malvern Size Analysis *

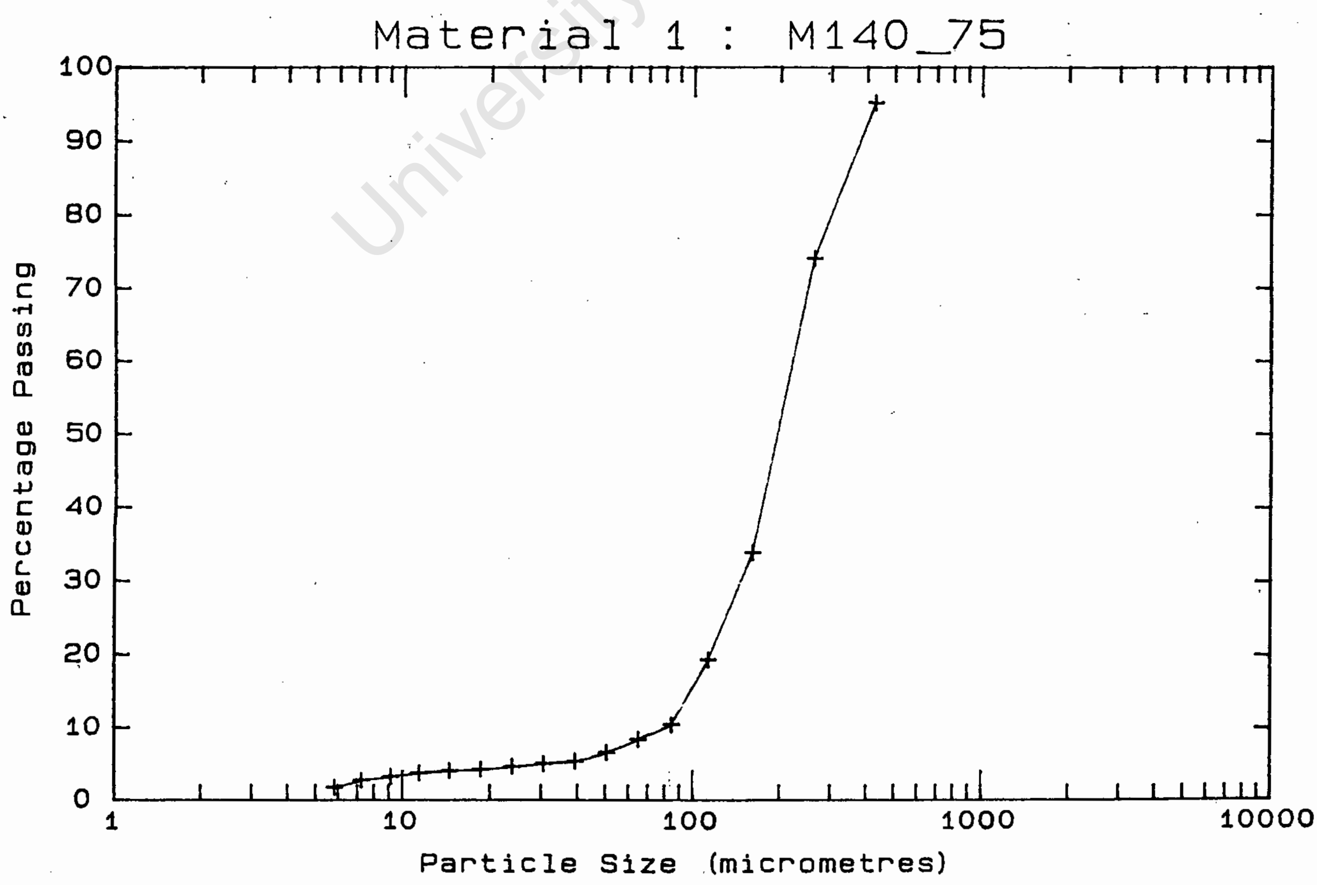
Size (µm)	% Passing	% Retained
425.0	95.1	4.9
261.6	74.0	21.1
160.4	33.8	40.2
112.8	19.2	14.6
84.3	10.3	8.9
64.6	8.3	2.0
50.2	6.5	1.8
39.0	5.3	1.2
30.3	5.0	.3
23.7	4.6	.4
18.5	4.2	.4
14.5	4.0	.2
11.4	3.7	.3
9.1	3.2	.5
7.2	2.7	.5
5.8	1.7	1.0
Pan	- .1	1.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M140U75
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M140_75
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140H80

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.80
Solids Volumetric Concentration (%)	46.24
Solids Mass Concentration (%)	70.13
Mean Slurry Temperature (°C)	26.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.193	6.712	25.6
3.240	6.657	25.8
3.249	6.619	25.8
3.366	7.344	26.0
2.598	5.024	26.2
2.641	5.166	26.3
2.630	5.201	26.3
2.649	5.293	26.3
2.289	4.240	26.4
2.266	4.154	26.4
2.277	4.250	26.4
2.287	4.098	26.3
1.746	3.213	26.3
1.739	3.260	26.3
1.727	3.327	26.3
1.728	3.221	26.3
1.336	2.686	26.2
1.323	2.670	26.2
1.351	2.711	26.1
1.344	2.769	26.1

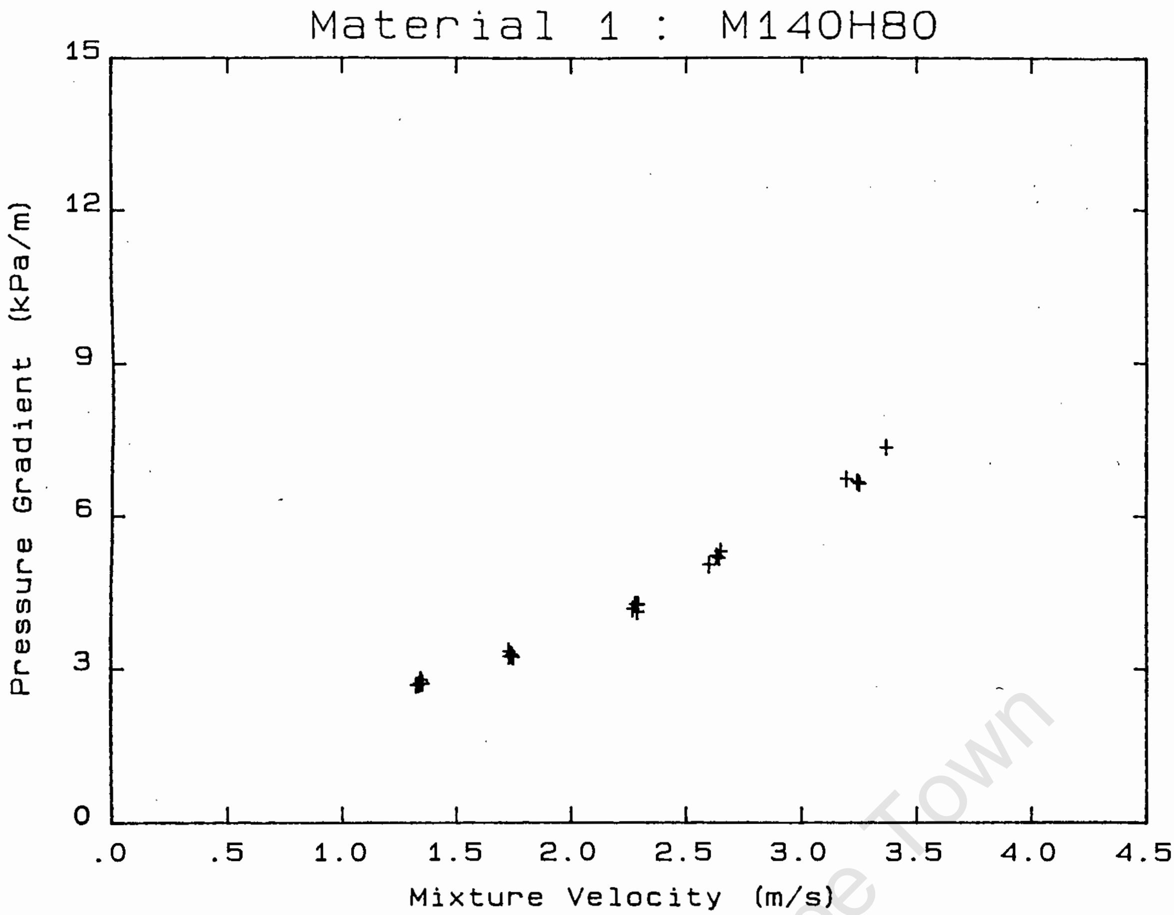
Particle Size Distribution
Sieve and Malvern Size Analysis *

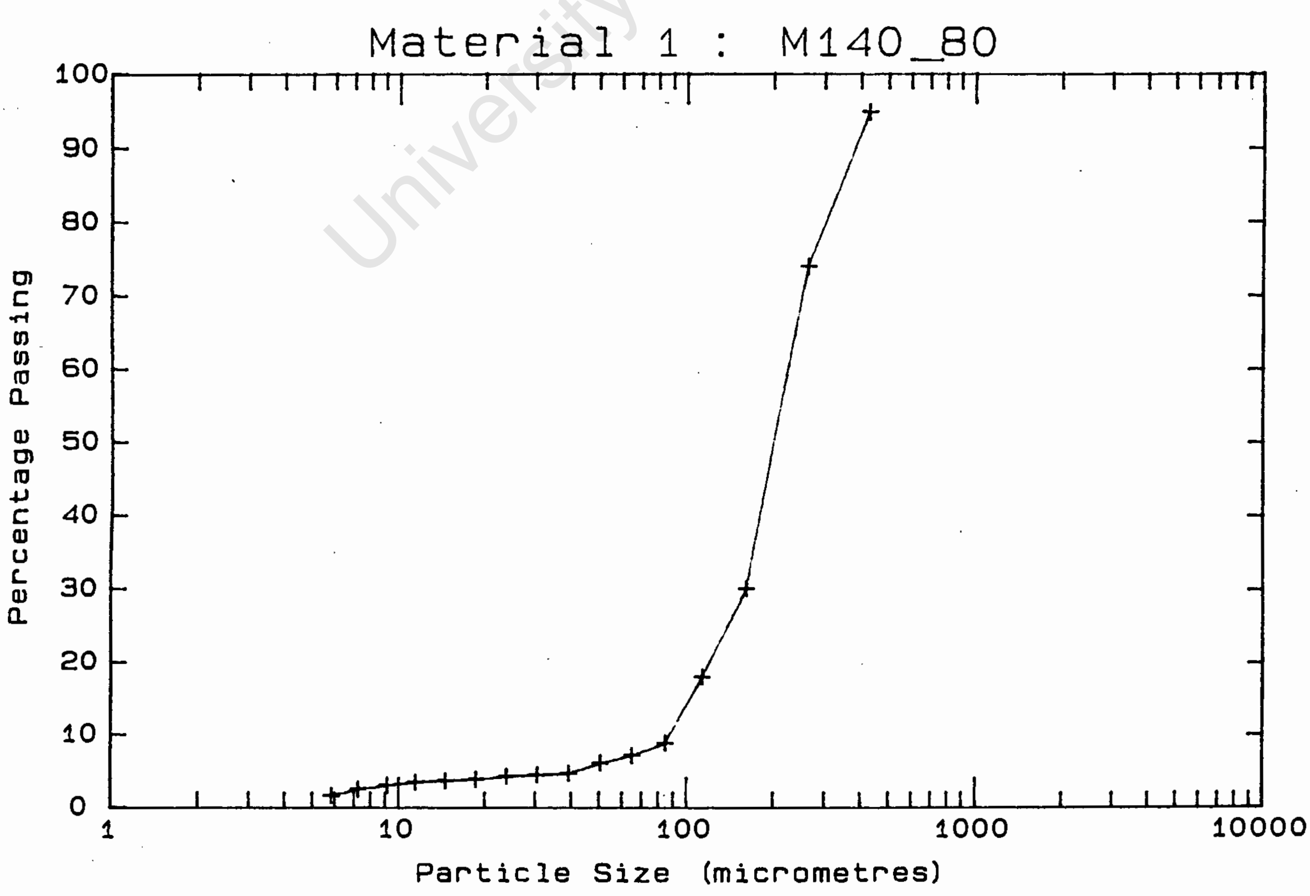
Size (μm)	% Passing	% Retained
425.0	94.8	5.2
261.6	73.9	20.9
160.4	30.0	43.9
112.8	17.9	12.1
84.3	8.7	9.2
64.6	7.0	1.7
50.2	6.0	1.0
39.0	4.6	1.4
30.3	4.4	.2
23.7	4.2	.2
18.5	3.8	.4
14.5	3.6	.2
11.4	3.4	.2
9.1	3.0	.4
7.2	2.5	.5
5.8	1.6	.9
Pan	- .0	1.6

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
1.06	Sliding particles
1.38	Sliding particles
1.80	Appears homogeneous
2.09	Appears homogeneous
2.57	Appears homogeneous

* -425 μm Malvern Particle Size Analyser


Material 1 : M140H80
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M140_80
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140D80

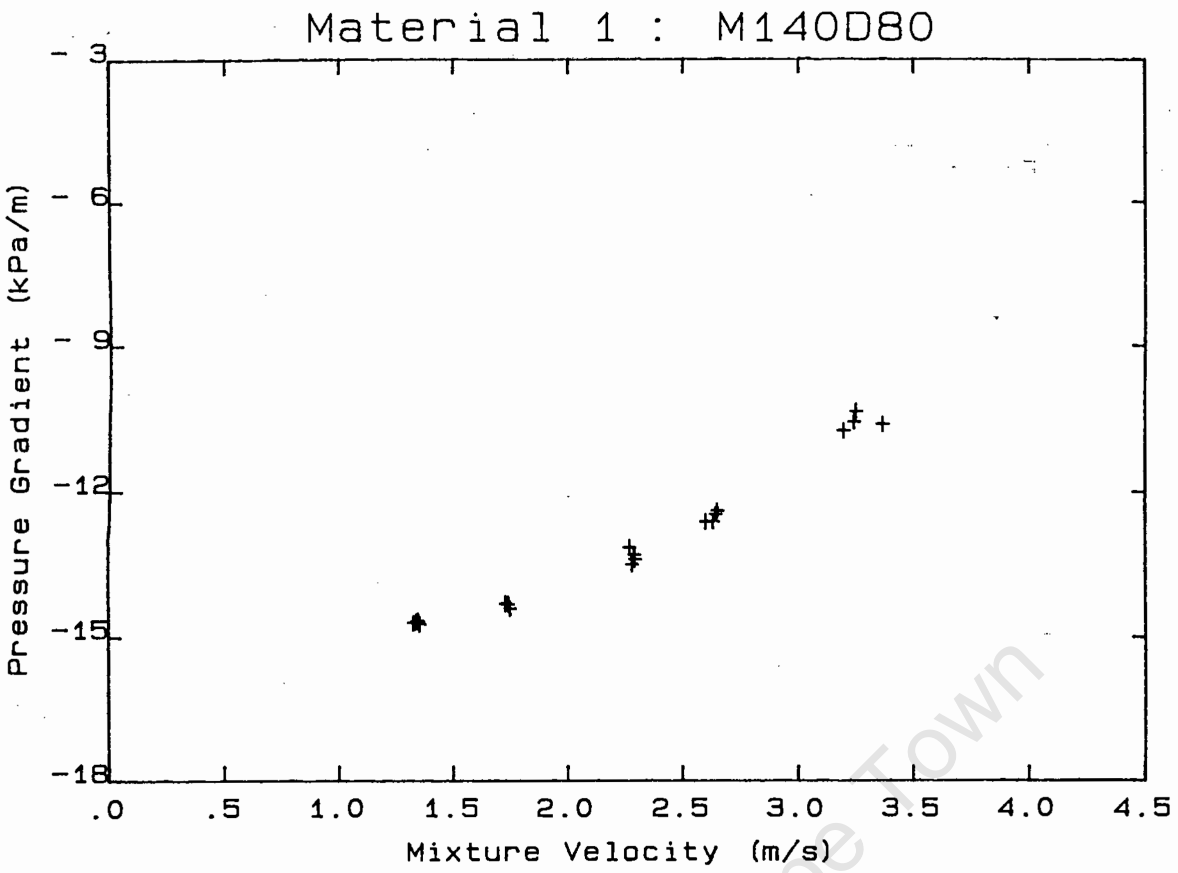
Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.80
Solids Volumetric Concentration (%)	46.24
Solids Mass Concentration (%)	70.13
Mean Slurry Temperature (°C)	26.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

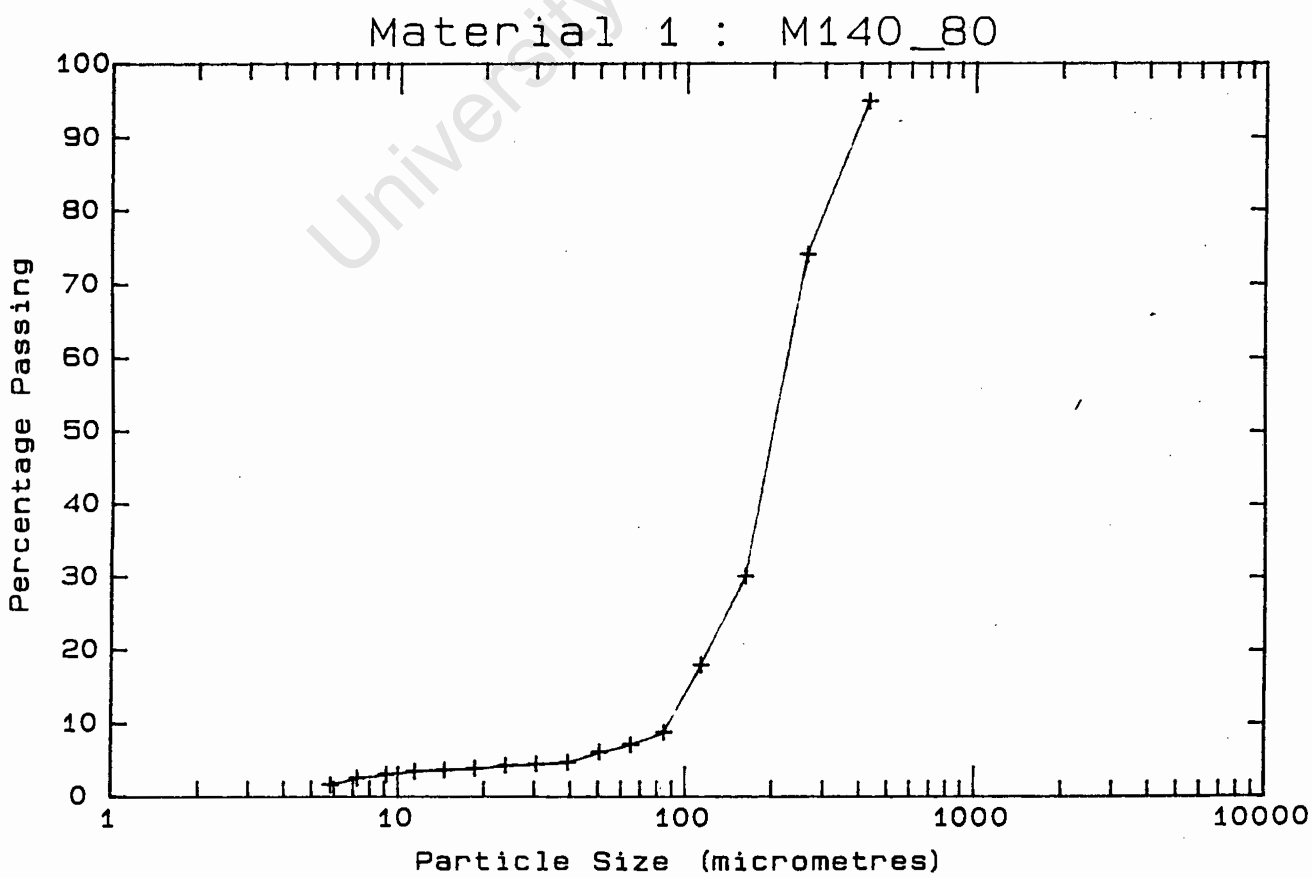
Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)	Particle Size Distribution Sieve and Malvern Size Analysis * Size (µm)	% Passing	% Retained
3.193	-10.751	25.6	425.0	94.8	5.2
3.240	-10.565	25.8	261.6	73.9	20.9
3.249	-10.350	25.8	160.4	30.0	43.9
3.366	-10.620	26.0	112.8	17.9	12.1
2.598	-12.637	26.2	84.3	8.7	9.2
2.641	-12.477	26.3	64.6	7.0	1.7
2.630	-12.630	26.3	50.2	6.0	1.0
2.649	-12.404	26.3	39.0	4.6	1.4
2.289	-13.420	26.4	30.3	4.4	.2
2.266	-13.164	26.4	23.7	4.2	.2
2.277	-13.515	26.4	18.5	3.8	.4
2.287	-13.316	26.3	14.5	3.6	.2
1.746	-14.427	26.3	11.4	3.4	.2
1.739	-14.330	26.3	9.1	3.0	.4
1.727	-14.317	26.3	7.2	2.5	.5
1.728	-14.330	26.3	5.8	1.6	.9
1.336	-14.692	26.2	Pan	- .0	1.6
1.323	-14.719	26.2			
1.351	-14.740	26.1			
1.344	-14.672	26.1			

OBSERVED FLOW BEHAVIOUR

Velocity	Observation

* -425 µm Malvern Particle Size Analyser


Material 1 : M140D80
Pressure Gradient (kPa/m)
- 3
- 6
- 9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)

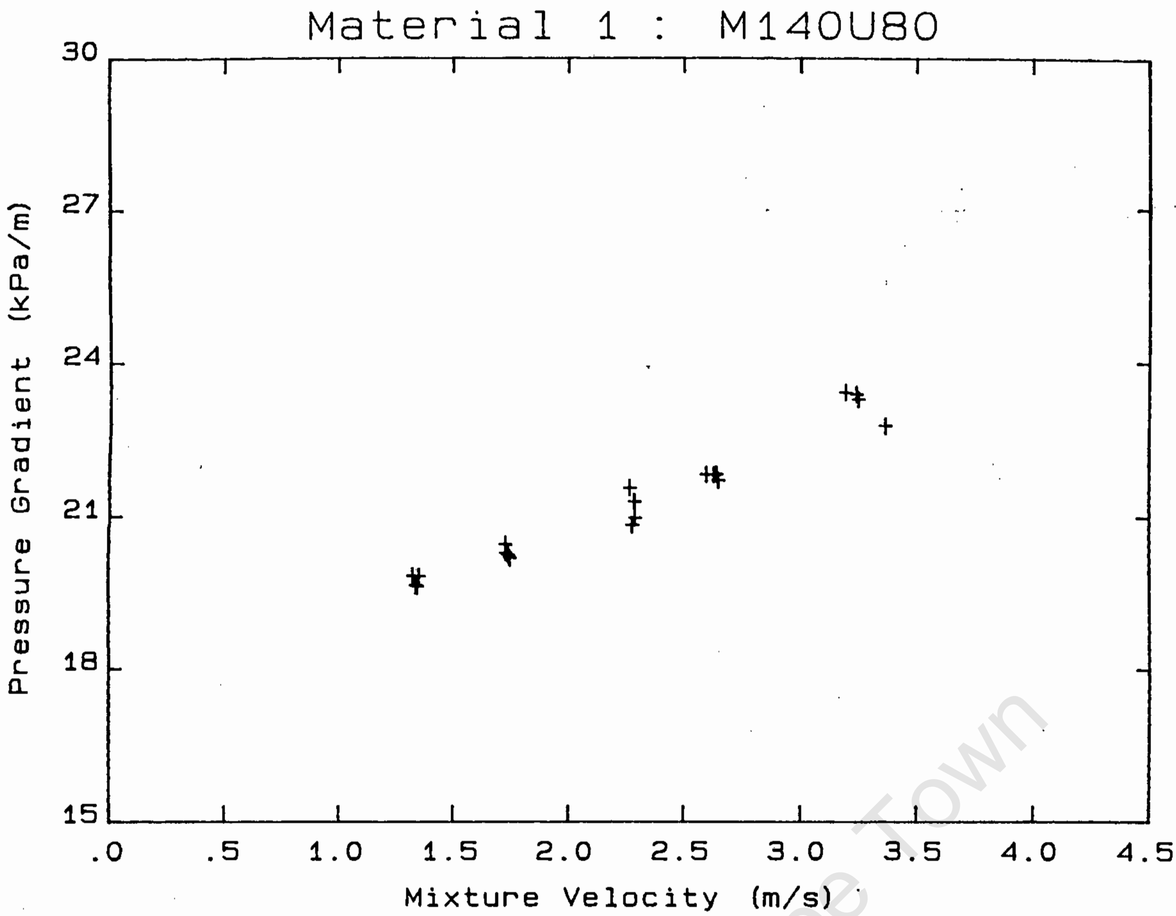

Material 1 : M140_80
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

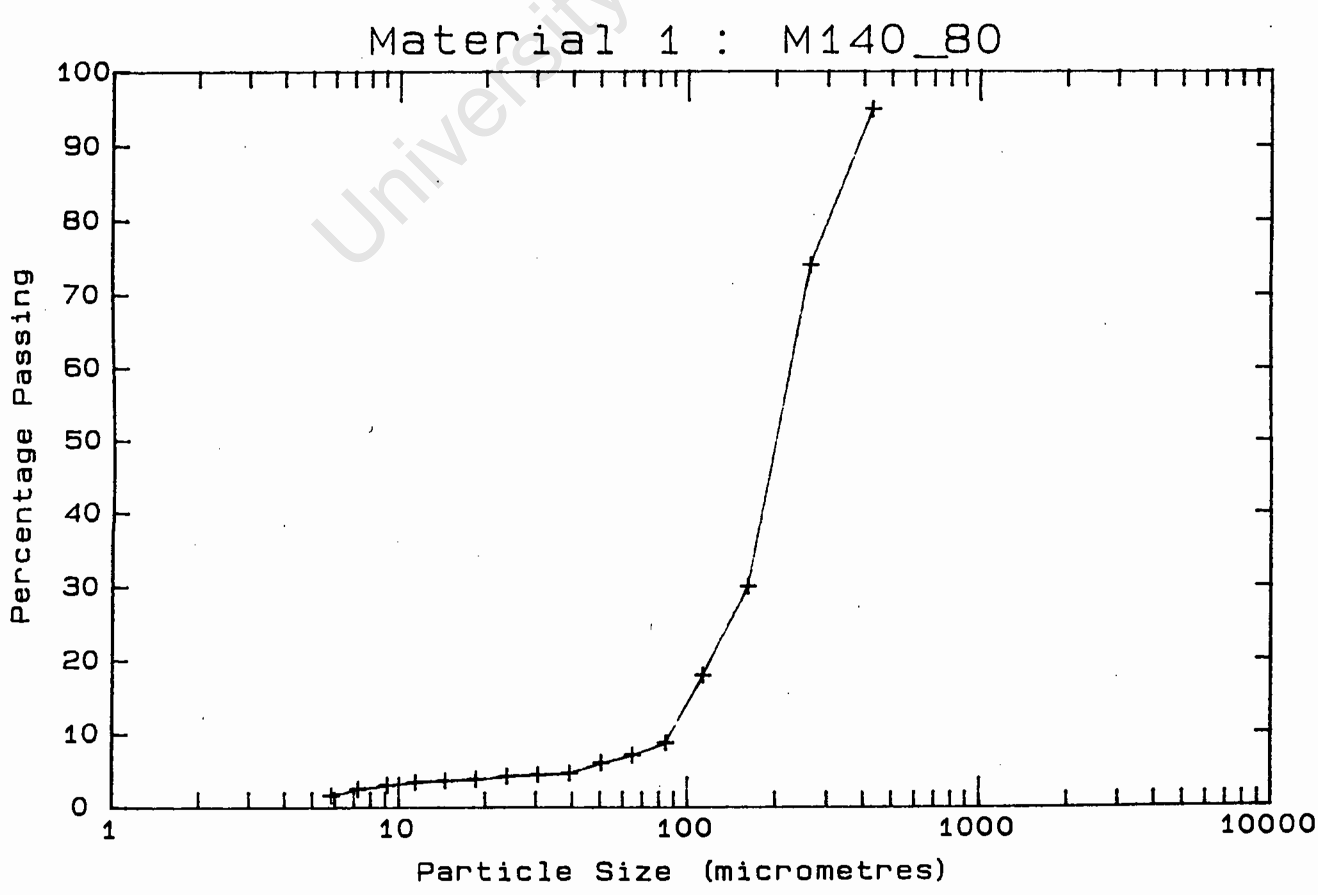
DATA FILE : M140U80

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.80
Solids Volumetric Concentration (%)	46.24
Solids Mass Concentration (%)	70.13
Mean Slurry Temperature (°C)	26.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)	Particle Size Distribution Sieve and Malvern Size Analysis * Size (µm)	% Passing	% Retained
3.193	23.416	25.6	425.0	94.8	5.2
3.240	23.384	25.8	261.6	73.9	20.9
3.249	23.286	25.8	160.4	30.0	43.9
3.366	22.771	26.0	112.8	17.9	12.1
2.598	21.820	26.2	84.3	8.7	9.2
2.641	21.830	26.3	64.6	7.0	1.7
2.630	21.812	26.3	50.2	6.0	1.0
2.649	21.709	26.3	39.0	4.6	1.4
2.289	20.964	26.4	30.3	4.4	.2
2.266	21.562	26.4	23.7	4.2	.2
2.277	20.829	26.4	18.5	3.8	.4
2.287	21.297	26.3	14.5	3.6	.2
1.746	20.179	26.3	11.4	3.4	.2
1.739	20.241	26.3	9.1	3.0	.4
1.727	20.455	26.3	7.2	2.5	.5
1.728	20.275	26.3	5.8	1.6	.9
1.336	19.636	26.2	Pan	- .0	1.6
1.323	19.833	26.2			
1.351	19.823	26.1	OBSERVED FLOW BEHAVIOUR		
1.344	19.629	26.1	Velocity	Observation	

* -425 µm Malvern Particle Size Analyser


Material 1 : M140U80
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M140_80
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140H84

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.84
Solids Volumetric Concentration (%)	48.55
Solids Mass Concentration (%)	72.04
Mean Slurry Temperature (°C)	27.5
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
2.560	6.598	26.6
2.561	7.034	27.0
2.590	7.090	27.1
2.608	7.075	27.4
2.004	5.600	27.7
1.996	5.464	27.8
2.001	5.298	27.8
1.997	5.293	27.8
1.485	4.385	27.8
1.443	4.387	27.8
1.437	4.433	27.8
1.455	4.360	27.8
1.042	3.720	27.7
1.006	3.805	27.7
.979	3.848	27.7
1.001	3.888	27.6
.626	2.980	27.5
.478	2.742	27.4
.672	3.646	27.4
.756	3.784	27.3
.705	3.325	27.3

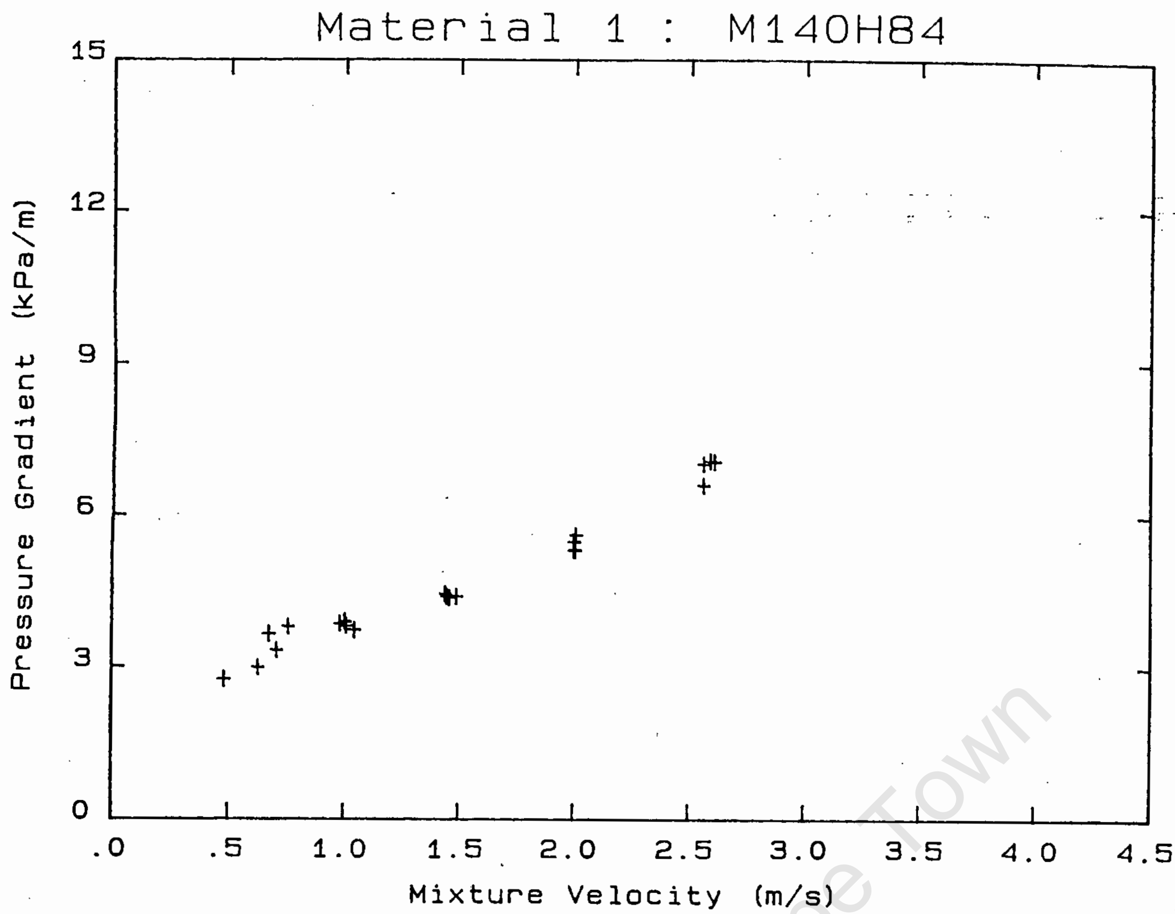
Particle Size Distribution
Sieve and Malvern Size Analysis *

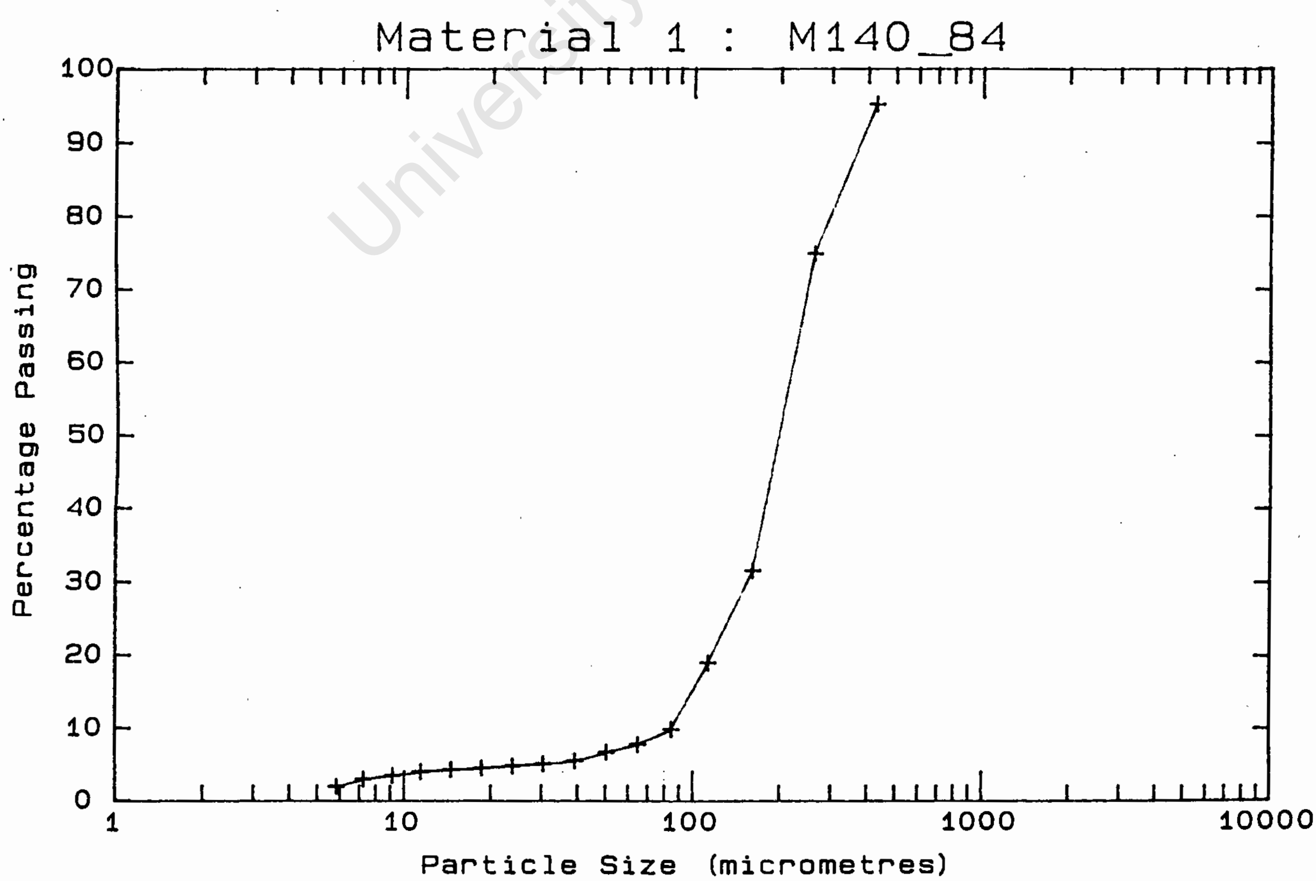
Size (µm)	% Passing	% Retained
425.0	95.1	4.9
261.6	74.8	20.3
160.4	31.5	43.3
112.8	18.9	12.6
84.3	9.8	9.1
64.6	7.7	2.1
50.2	6.6	1.1
39.0	5.4	1.2
30.3	5.0	.4
23.7	4.7	.3
18.5	4.4	.3
14.5	4.2	.2
11.4	3.9	.3
9.1	3.4	.5
7.2	2.9	.5
5.8	1.9	1.0
Pan	.0	1.9

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.51	Appears homogeneous
.79	Appears homogeneous
1.15	Appears homogeneous
1.58	Appears homogeneous
2.04	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 1 : M140H84
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M140_84
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140D84

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.84
Solids Volumetric Concentration (%)	48.55
Solids Mass Concentration (%)	72.04
Mean Slurry Temperature (°C)	27.5
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
2.560	-10.618	26.6
2.561	-10.675	27.0
2.590	-10.717	27.1
2.608	-10.651	27.4
2.004	-12.220	27.7
1.996	-12.263	27.8
2.001	-12.385	27.8
1.997	-12.076	27.8
1.485	-13.577	27.8
1.443	-13.605	27.8
1.437	-13.480	27.8
1.455	-13.653	27.8
1.042	-14.350	27.7
1.006	-14.289	27.7
.979	-14.356	27.7
1.001	-14.198	27.6
.626	-15.429	27.5
.478	-15.070	27.4
.672	-13.779	27.4
.756	-13.835	27.3
.705	-13.831	27.3

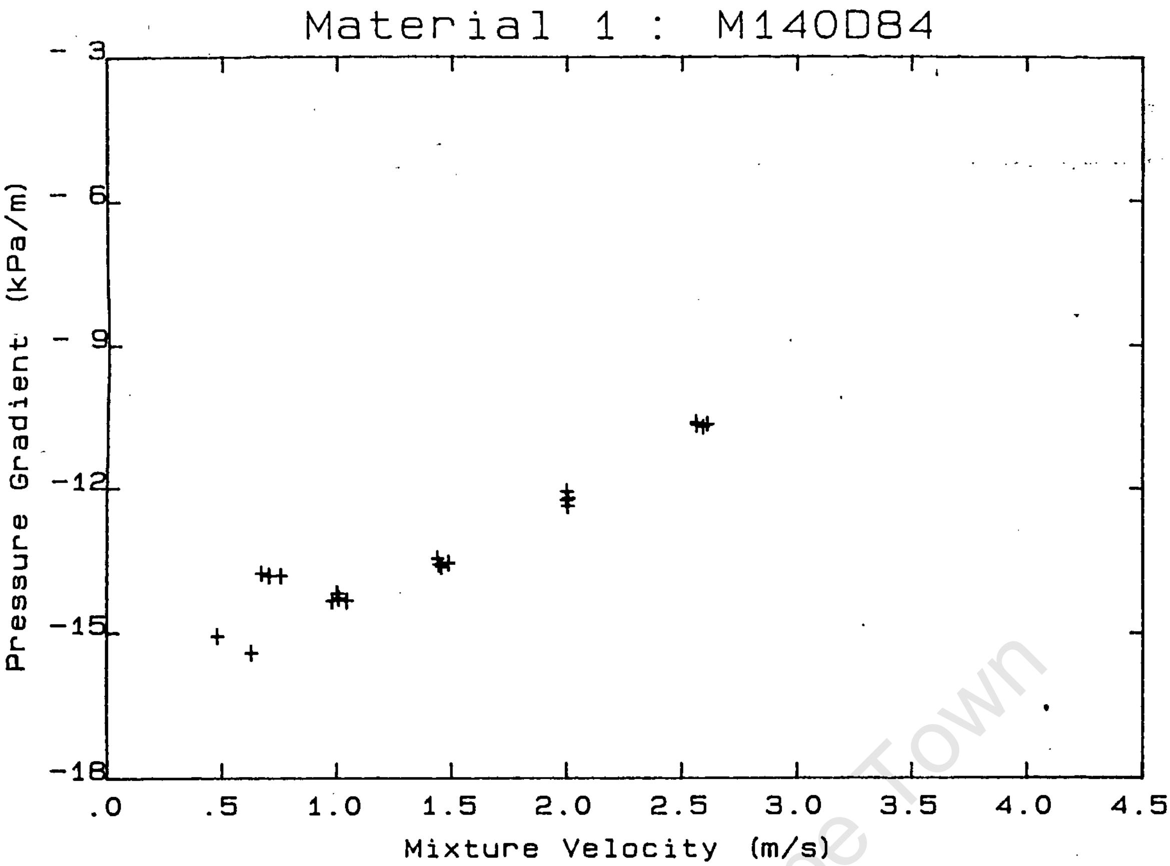
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	95.1	4.9
261.6	74.8	20.3
160.4	31.5	43.3
112.8	18.9	12.6
84.3	9.8	9.1
64.6	7.7	2.1
50.2	6.6	1.1
39.0	5.4	1.2
30.3	5.0	.4
23.7	4.7	.3
18.5	4.4	.3
14.5	4.2	.2
11.4	3.9	.3
9.1	3.4	.5
7.2	2.9	.5
5.8	1.9	1.0
Pan	.0	1.9

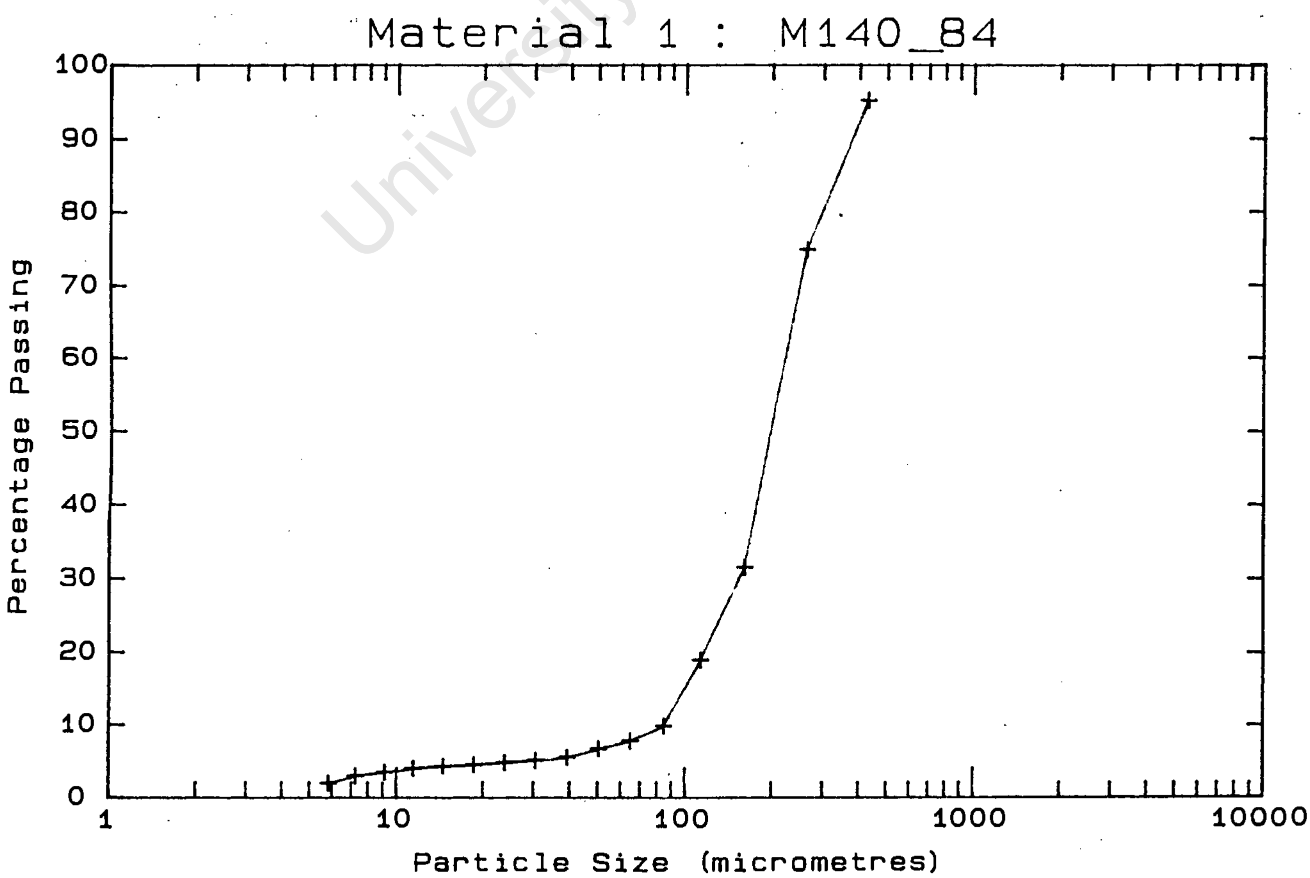
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser



Material 1 : M140D84
Pressure Gradient (kPa/m)
3
6
9
12
15
18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 1 : M140_84
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M140U84

Test Facility	UCT 40mm NB
Test Date	23/04/91
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.84
Solids Volumetric Concentration (%)	48.55
Solids Mass Concentration (%)	72.04
Mean Slurry Temperature (°C)	27.5
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
2.560	24.512	26.6
2.561	24.718	27.0
2.590	25.379	27.1
2.608	24.133	27.4
2.004	23.302	27.7
1.996	23.439	27.8
2.001	23.336	27.8
1.997	23.627	27.8
1.485	22.069	27.8
1.443	22.279	27.8
1.437	22.374	27.8
1.455	22.101	27.8
1.042	21.376	27.7
1.006	21.510	27.7
.979	21.725	27.7
1.001	21.435	27.6
.626	20.696	27.5
.478	20.885	27.4
.672	21.875	27.4
.756	20.872	27.3
.705	20.989	27.3

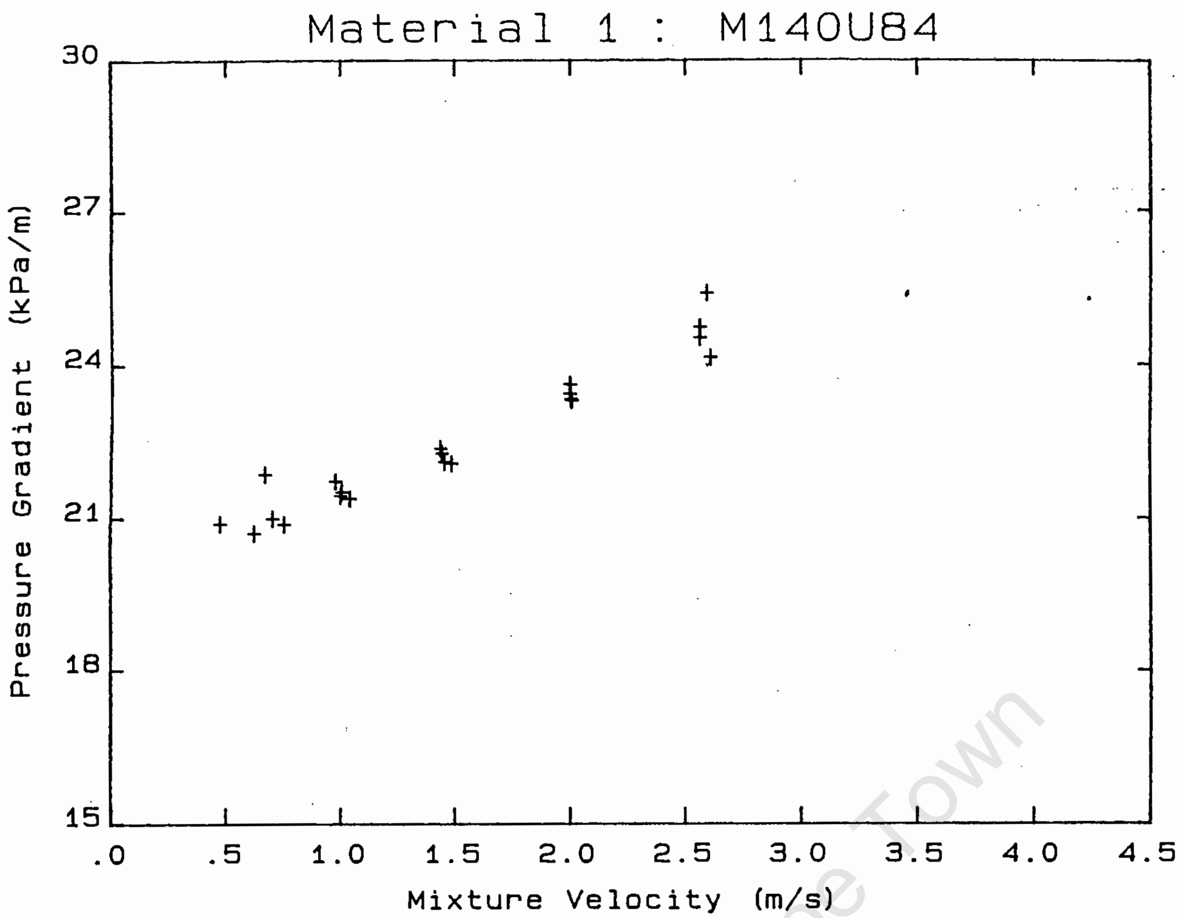
Particle Size Distribution
Sieve and Malvern Size Analysis *

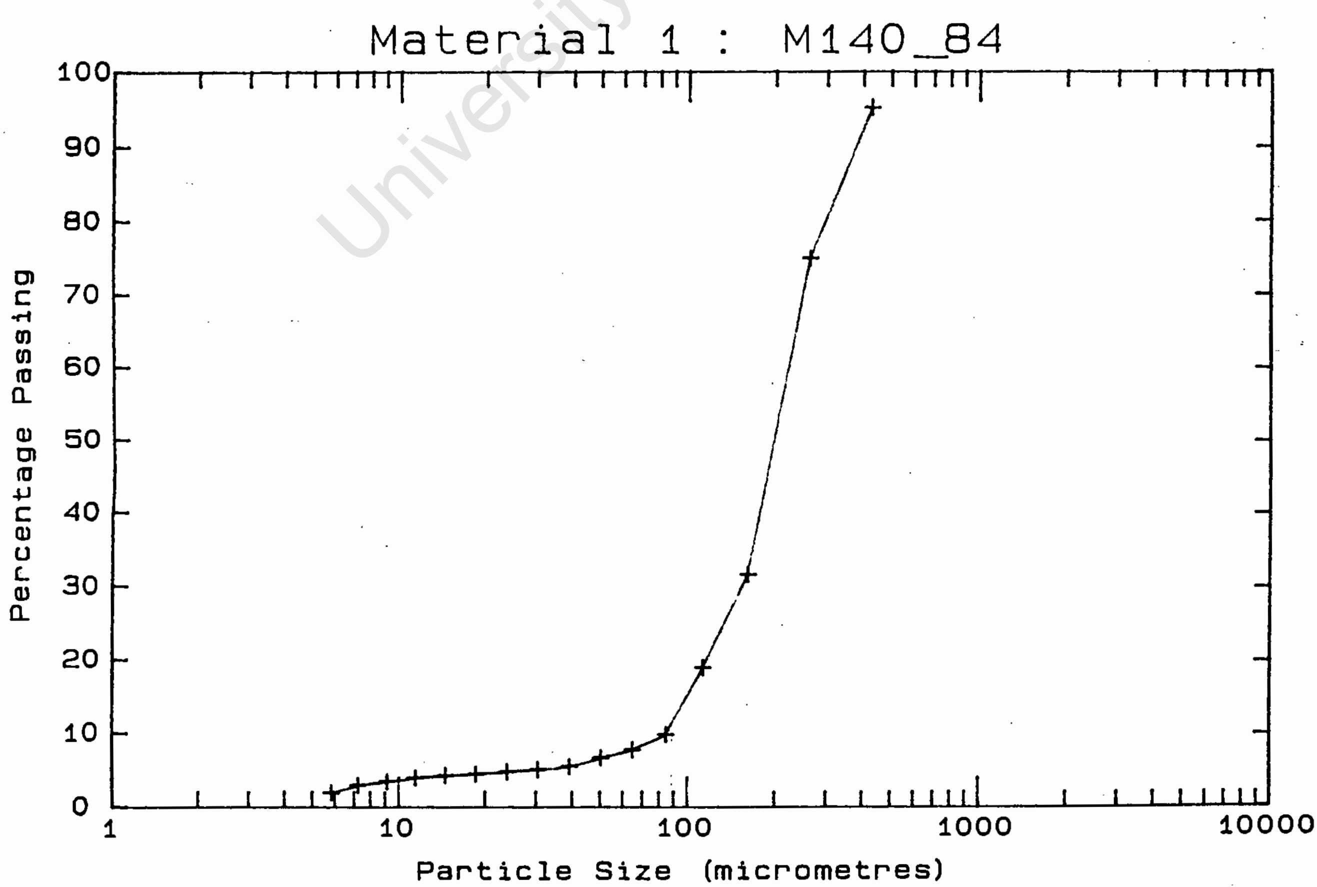
Size (µm)	% Passing	% Retained
425.0	95.1	4.9
261.6	74.8	20.3
160.4	31.5	43.3
112.8	18.9	12.6
84.3	9.8	9.1
64.6	7.7	2.1
50.2	6.6	1.1
39.0	5.4	1.2
30.3	5.0	.4
23.7	4.7	.3
18.5	4.4	.3
14.5	4.2	.2
11.4	3.9	.3
9.1	3.4	.5
7.2	2.9	.5
5.8	1.9	1.0
Pan	.0	1.9

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* −425 µm Malvern Particle Size Analyser


Material 1 : M140U84
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M140_84
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M240H70

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	Material 2
Material Relative Density	2.74
Slurry Relative Density	1.70
Solids Volumetric Concentration (%)	40.23
Solids Mass Concentration (%)	64.84
Mean Slurry Temperature (°C)	24.4
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.644	6.613	24.7
3.646	7.046	24.7
3.652	6.987	24.8
3.651	6.845	24.9
3.053	5.374	24.9
3.052	5.332	24.9
3.054	5.059	24.9
3.052	5.332	24.8
2.485	3.870	24.7
2.495	3.920	24.7
2.502	3.940	24.6
2.496	3.855	24.6
2.007	2.934	24.4
2.002	2.552	24.4
2.010	2.947	24.3
2.006	2.370	24.3
1.567	1.762	24.1
1.547	2.039	24.1
1.565	2.719	24.1
1.571	2.643	24.0
.869	2.065	24.0
.853	3.205	23.9
1.022	2.399	23.9
1.048	1.842	23.9
1.055	1.904	23.8
1.057	3.291	23.8

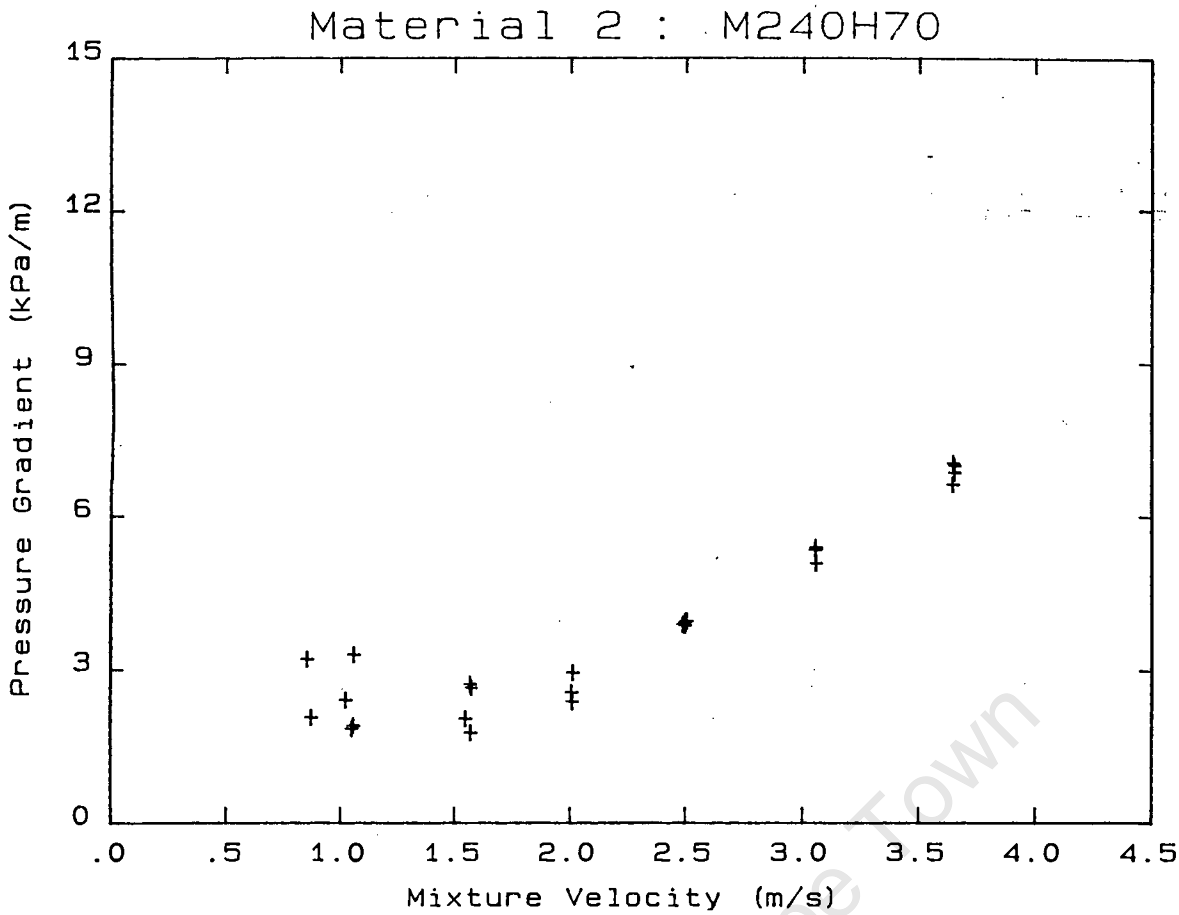
Particle Size Distribution
Sieve and Malvern Size Analysis *

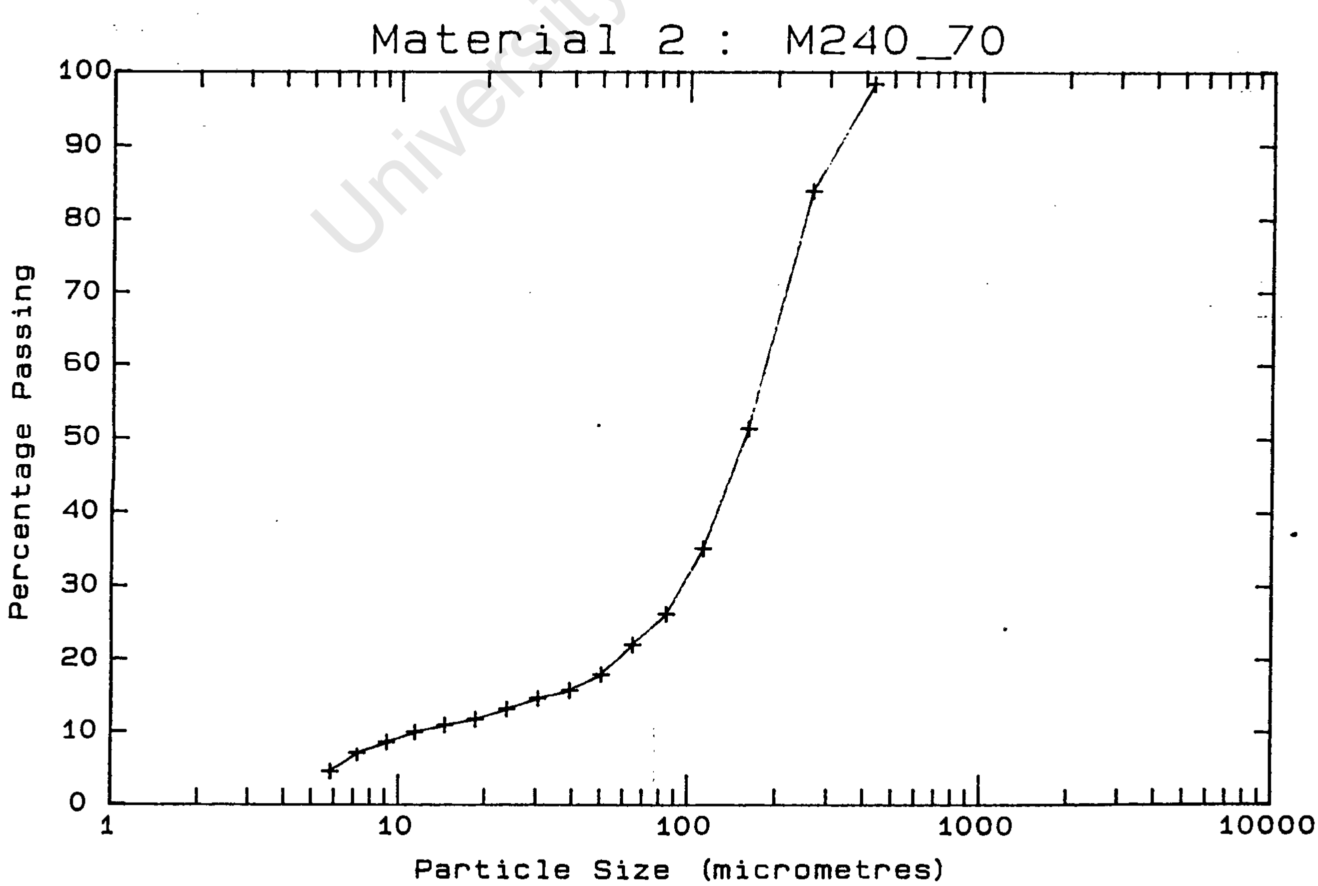
Size (µm)	% Passing	% Retained
425.0	98.2	1.8
261.6	83.8	14.4
160.4	51.3	32.5
112.8	35.1	16.2
84.3	26.2	8.9
64.6	22.0	4.2
50.2	17.9	4.1
39.0	15.7	2.2
30.3	14.6	1.1
23.7	13.1	1.5
18.5	11.7	1.4
14.5	10.9	.8
11.4	9.9	1.0
9.1	8.5	1.4
7.2	7.0	1.5
5.8	4.5	2.5
Pan	- .0	4.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.79	35% Stationary bed
1.23	Sliding particles
1.58	Sliding particles
1.98	Asymetric
2.41	Appears homogeneous
2.89	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 2 : M240H70
Pressure Gradient (kPa/m)
Mixture Velocity (m/s)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Material 2 : M240_70
Percentage Passing
Particle Size (micrometres)
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000

DATA FILE : M240D70

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	Material 2
Material Relative Density	2.74
Slurry Relative Density	1.70
Solids Volumetric Concentration (%)	40.23
Solids Mass Concentration (%)	64.84
Mean Slurry Temperature (°C)	24.4
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.644	- 9.284	24.7
3.646	- 9.493	24.7
3.652	- 9.620	24.8
3.651	- 9.421	24.9
3.053	-11.236	24.9
3.052	-11.663	24.9
3.054	-11.427	24.9
3.052	-11.389	24.8
2.485	-12.551	24.7
2.495	-12.716	24.7
2.502	-12.610	24.6
2.496	-12.569	24.6
2.007	-13.645	24.4
2.002	-13.958	24.4
2.010	-13.968	24.3
2.006	-14.054	24.3
1.567	-15.491	24.1
1.547	-15.065	24.1
1.565	-14.807	24.1
1.571	-14.533	24.0
.869	-15.704	24.0
.853	-15.686	23.9
1.022	-15.754	23.9
1.048	-15.905	23.9
1.055	-15.693	23.8
1.057	-15.337	23.8

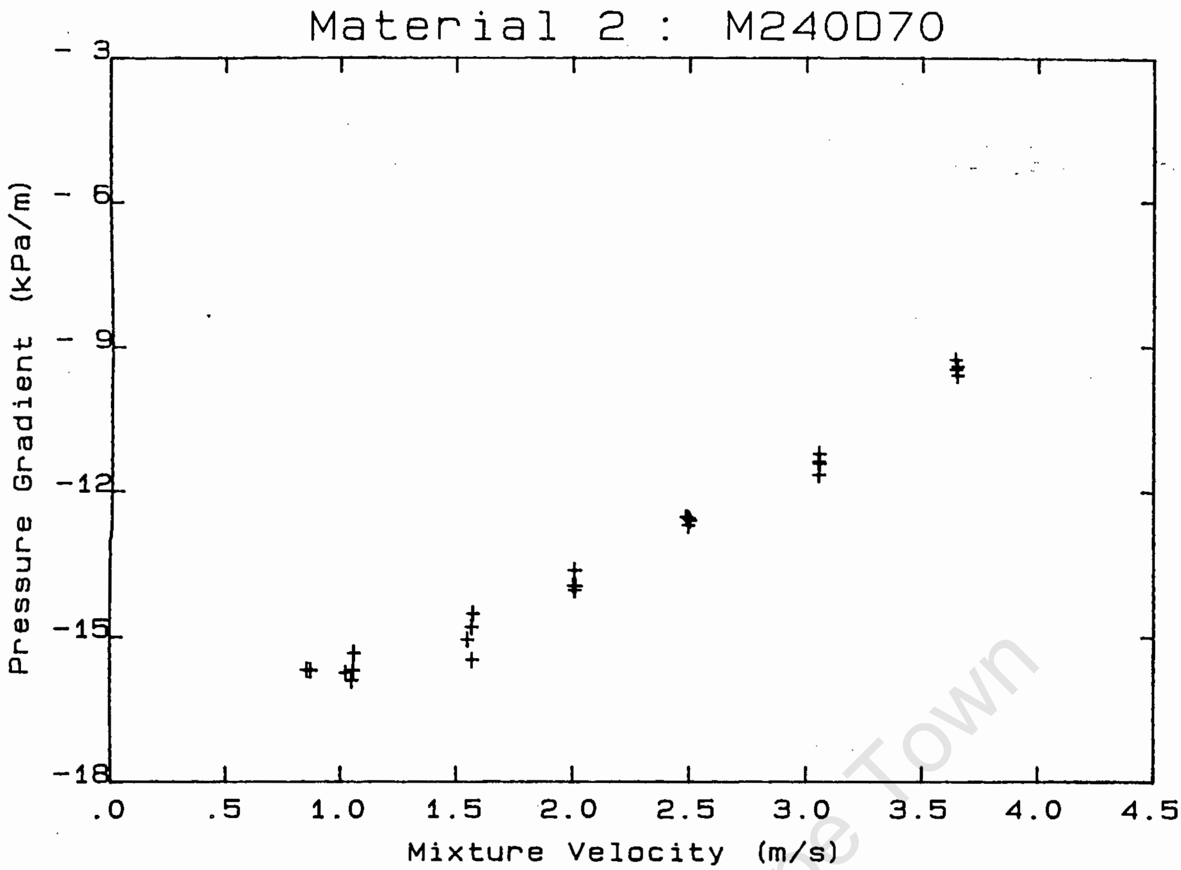
Particle Size Distribution
Sieve and Malvern Size Analysis *

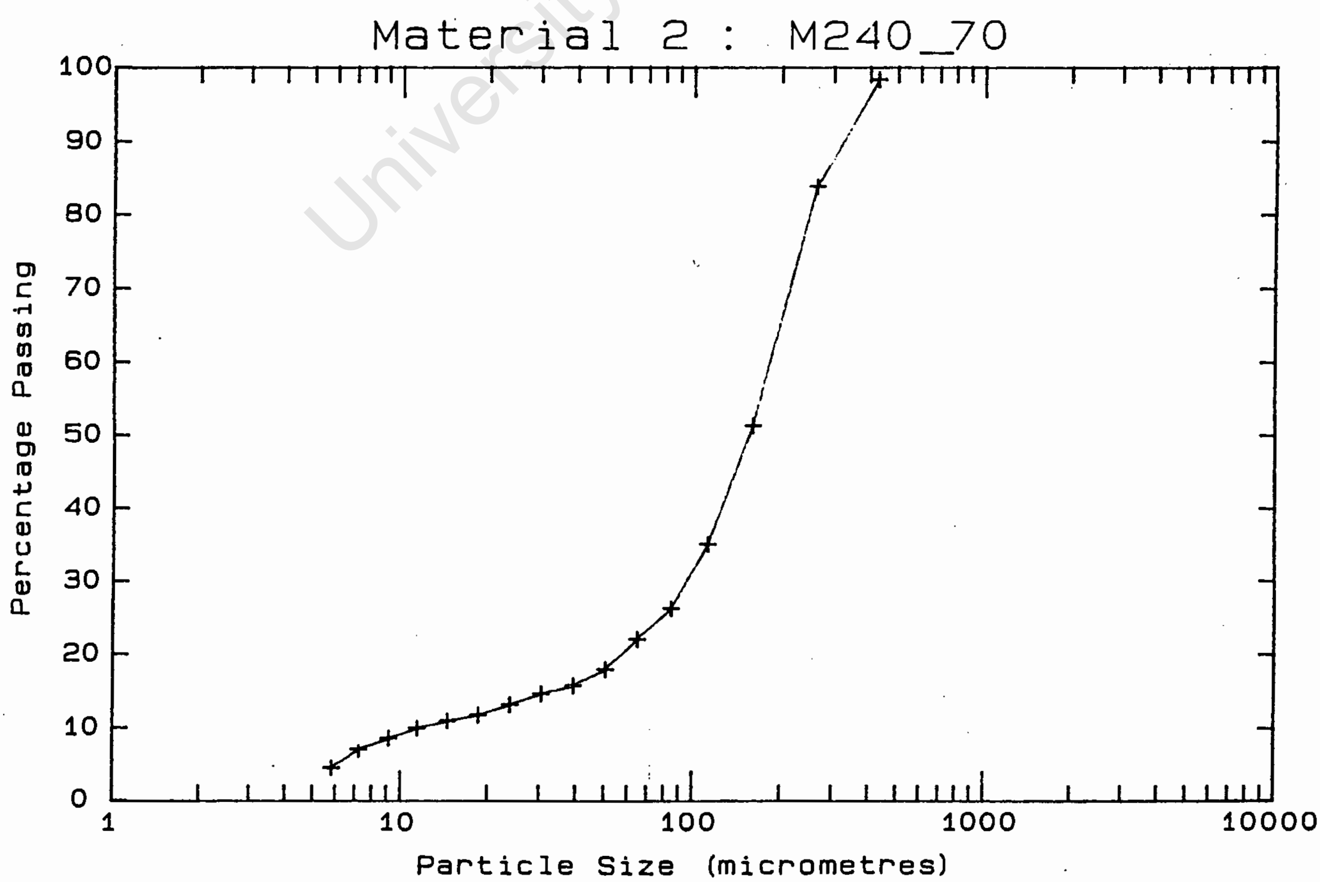
Size (µm)	% Passing	% Retained
425.0	98.2	1.8
261.6	83.8	14.4
160.4	51.3	32.5
112.8	35.1	16.2
84.3	26.2	8.9
64.6	22.0	4.2
50.2	17.9	4.1
39.0	15.7	2.2
30.3	14.6	1.1
23.7	13.1	1.5
18.5	11.7	1.4
14.5	10.9	.8
11.4	9.9	1.0
9.1	8.5	1.4
7.2	7.0	1.5
5.8	4.5	2.5
Pan	- .0	4.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 2 : M240D70
Pressure Gradient (kPa/m)
- 3
- 6
- 9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 2 : M240_70
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M240U70

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	Material 2
Material Relative Density	2.74
Slurry Relative Density	1.70
Solids Volumetric Concentration (%)	40.23
Solids Mass Concentration (%)	64.84
Mean Slurry Temperature (°C)	24.4
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.644	22.526	24.7
3.646	22.249	24.7
3.652	22.411	24.8
3.651	22.599	24.9
3.053	21.073	24.9
3.052	20.342	24.9
3.054	21.163	24.9
3.052	21.112	24.8
2.485	19.929	24.7
2.495	19.749	24.7
2.502	19.936	24.6
2.496	19.863	24.6
2.007	18.757	24.4
2.002	18.764	24.4
2.010	18.806	24.3
2.006	18.748	24.3
1.567	17.620	24.1
1.547	17.626	24.1
1.565	17.581	24.1
1.571	17.611	24.0
.869	17.395	24.0
.853	17.330	23.9
1.022	17.473	23.9
1.048	17.397	23.9
1.055	17.425	23.8
1.057	17.426	23.8

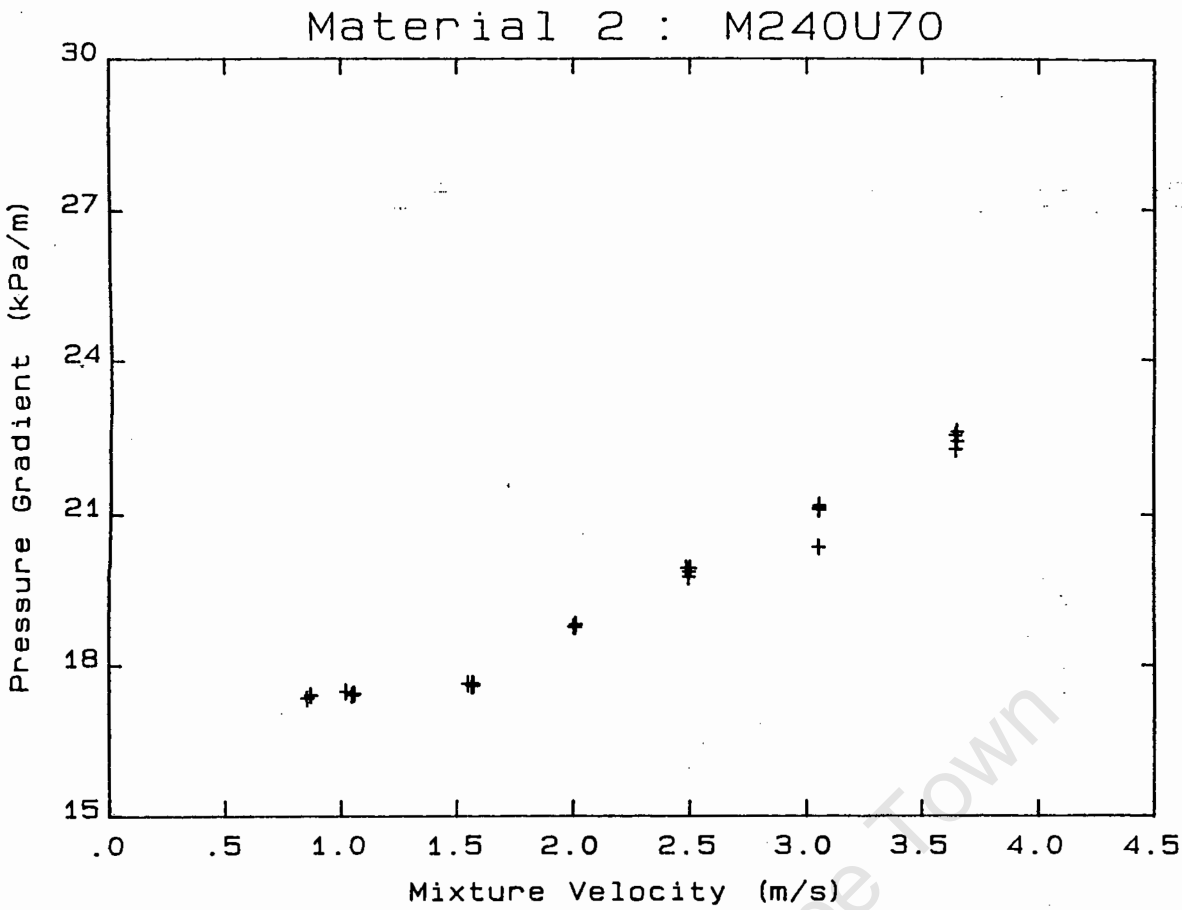
Particle Size Distribution
Sieve and Malvern Size Analysis *

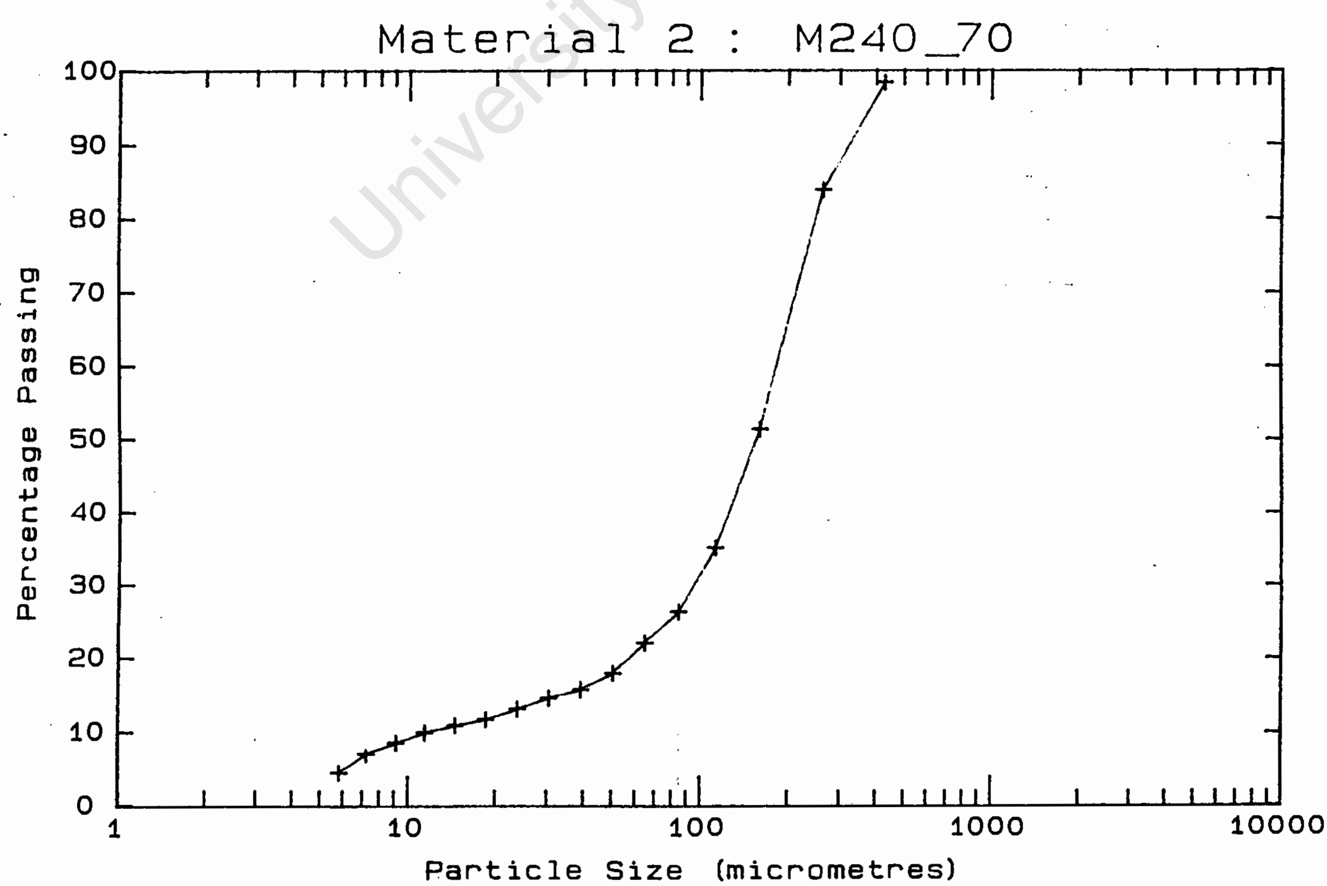
Size (µm)	% Passing	% Retained
425.0	98.2	1.8
261.6	83.8	14.4
160.4	51.3	32.5
112.8	35.1	16.2
84.3	26.2	8.9
64.6	22.0	4.2
50.2	17.9	4.1
39.0	15.7	2.2
30.3	14.6	1.1
23.7	13.1	1.5
18.5	11.7	1.4
14.5	10.9	.8
11.4	9.9	1.0
9.1	8.5	1.4
7.2	7.0	1.5
5.8	4.5	2.5
Pan	- .0	4.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 2 : M240U70
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 2 : M240_70
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M240H78

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	MATERIAL 2
Material Relative Density	2.74
Slurry Relative Density	1.78
Solids Volumetric Concentration (%)	44.83
Solids Mass Concentration (%)	69.00
Mean Slurry Temperature (°C)	23.1
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.054	8.264	23.1
4.064	9.268	23.3
4.063	8.974	23.4
4.067	8.877	23.5
3.540	7.145	23.7
3.553	7.092	23.7
3.544	7.172	23.7
3.549	7.533	23.7
3.021	4.912	23.6
3.032	5.570	23.5
3.028	5.455	23.5
3.029	5.438	23.5
3.022	5.526	23.4
2.520	3.296	23.2
2.496	3.194	23.2
2.491	3.177	23.2
2.513	3.305	23.1
1.972	2.440	23.0
1.960	2.451	23.0
1.994	2.538	22.9
2.043	2.653	22.9
1.577	2.503	22.7
1.565	2.712	22.7
1.584	2.585	22.6
1.607	2.293	22.6
.879	1.839	22.5
.869	2.065	22.5
.874	1.989	22.4
.863	1.925	22.4
.859	2.168	22.4

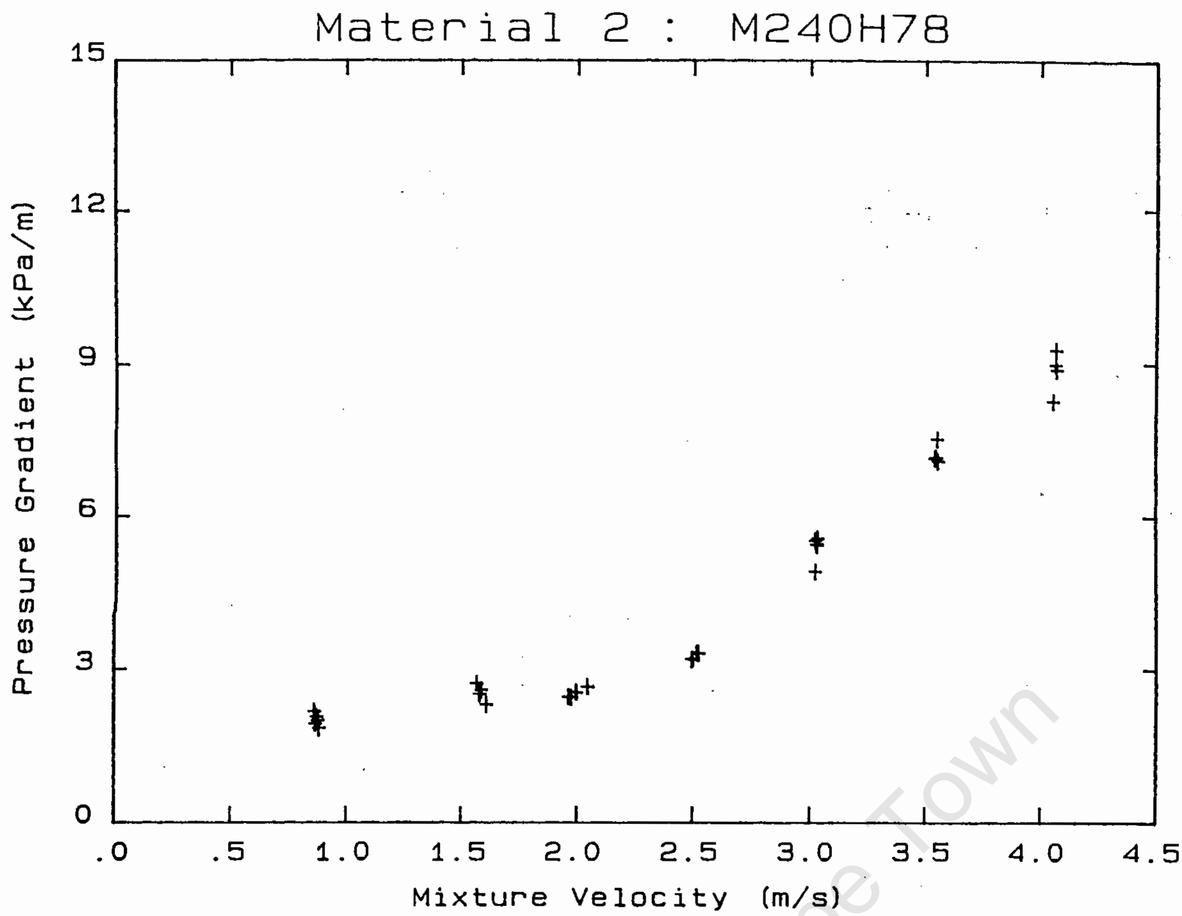
Particle Size Distribution
Sieve and Malvern Size Analysis *

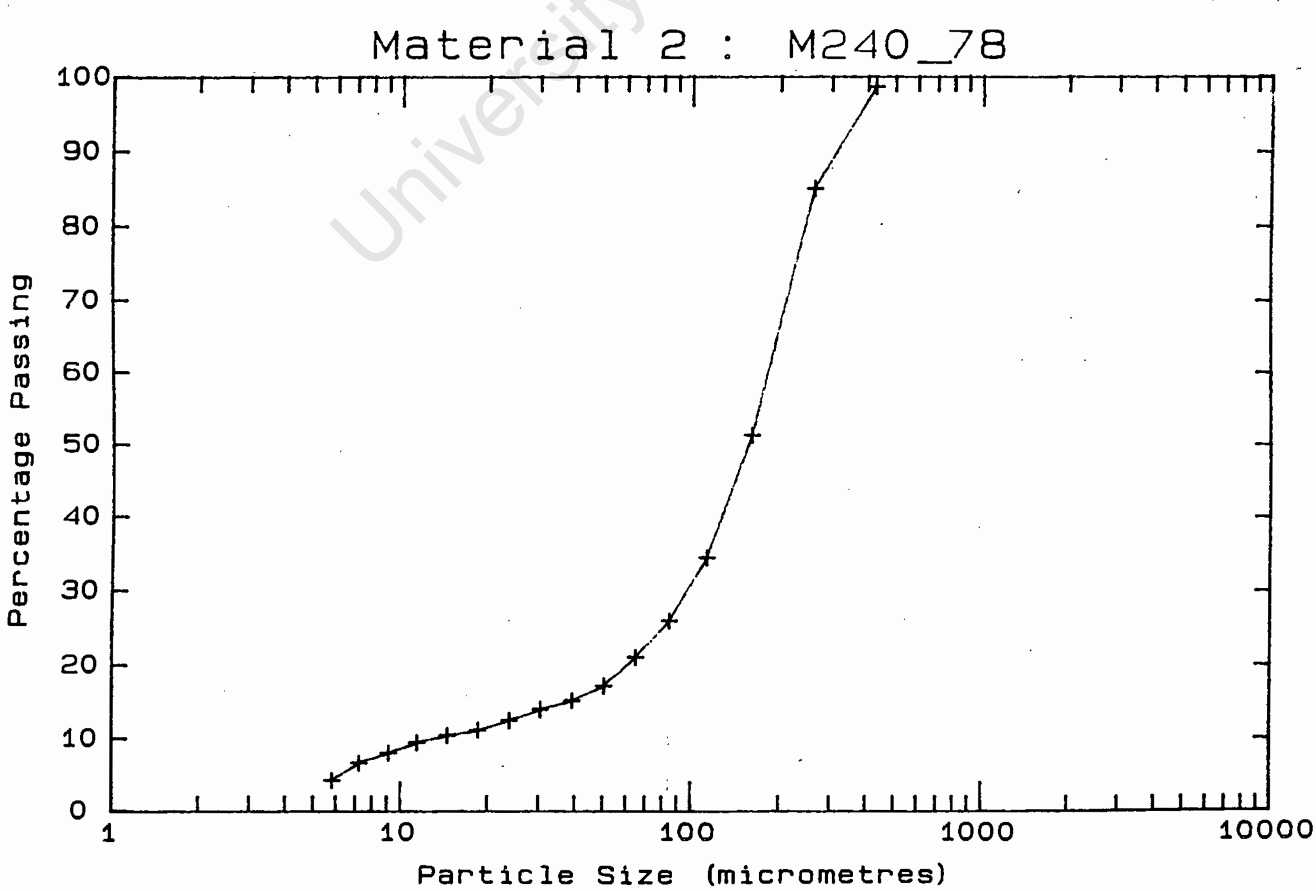
Size (µm)	% Passing	% Retained
425.0	98.5	1.5
261.6	85.0	13.5
160.4	51.2	33.8
112.8	34.4	16.8
84.3	25.9	8.5
64.6	21.0	4.9
50.2	17.1	3.9
39.0	15.1	2.0
30.3	13.9	1.2
23.7	12.4	1.5
18.5	11.1	1.3
14.5	10.4	.7
11.4	9.4	1.0
9.1	8.0	1.4
7.2	6.6	1.4
5.8	4.2	2.4
Pan	- .1	4.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.69	Sliding bed
1.24	Sliding bed
1.57	Asymetric
1.98	Asymetric
2.40	Appears homogeneous
2.81	Appears homogeneous
3.21	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 2 : M240H78
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 2 : M240_78
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M240D78

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	MATERIAL 2
Material Relative Density	2.74
Slurry Relative Density	1.78
Solids Volumetric Concentration (%)	44.83
Solids Mass Concentration (%)	69.00
Mean Slurry Temperature (°C)	23.1
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.054	- 8.164	23.1
4.064	- 7.650	23.3
4.063	- 7.773	23.4
4.067	- 7.620	23.5
3.540	- 9.254	23.7
3.553	- 9.013	23.7
3.544	- 9.196	23.7
3.549	- 9.130	23.7
3.021	-11.835	23.6
3.032	-12.135	23.5
3.028	-12.485	23.5
3.029	-12.255	23.5
3.022	-11.569	23.4
2.520	-14.392	23.2
2.496	-14.374	23.2
2.491	-14.150	23.2
2.513	-14.526	23.1
1.972	-14.372	23.0
1.960	-14.230	23.0
1.994	-14.616	22.9
2.043	-14.614	22.9
1.577	-14.826	22.7
1.565	-15.150	22.7
1.584	-15.027	22.6
1.607	-15.103	22.6
.879	-15.680	22.5
.869	-15.898	22.5
.874	-15.774	22.4
.863	-15.744	22.4
.859	-15.382	22.4

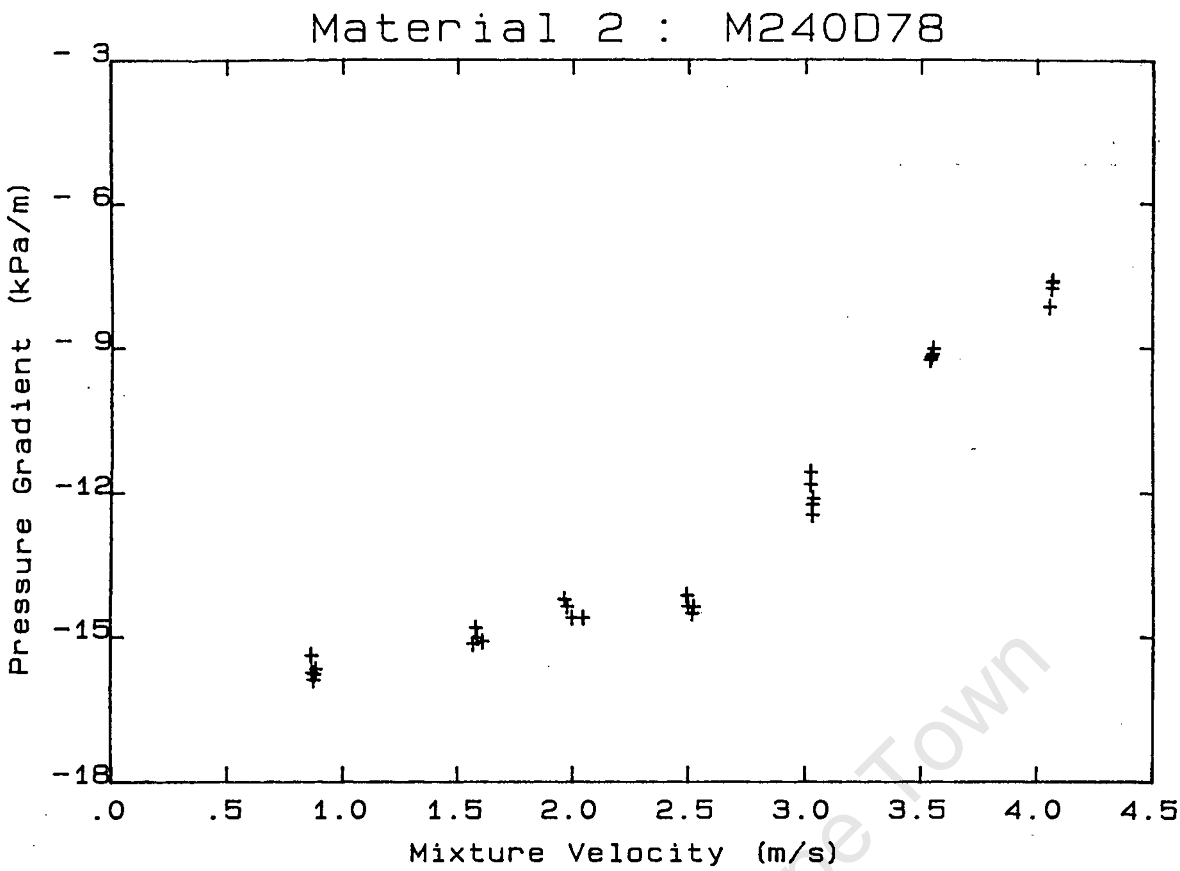
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	98.5	1.5
261.6	85.0	13.5
160.4	51.2	33.8
112.8	34.4	16.8
84.3	25.9	8.5
64.6	21.0	4.9
50.2	17.1	3.9
39.0	15.1	2.0
30.3	13.9	1.2
23.7	12.4	1.5
18.5	11.1	1.3
14.5	10.4	.7
11.4	9.4	1.0
9.1	8.0	1.4
7.2	6.6	1.4
5.8	4.2	2.4
Pan	- .1	4.3

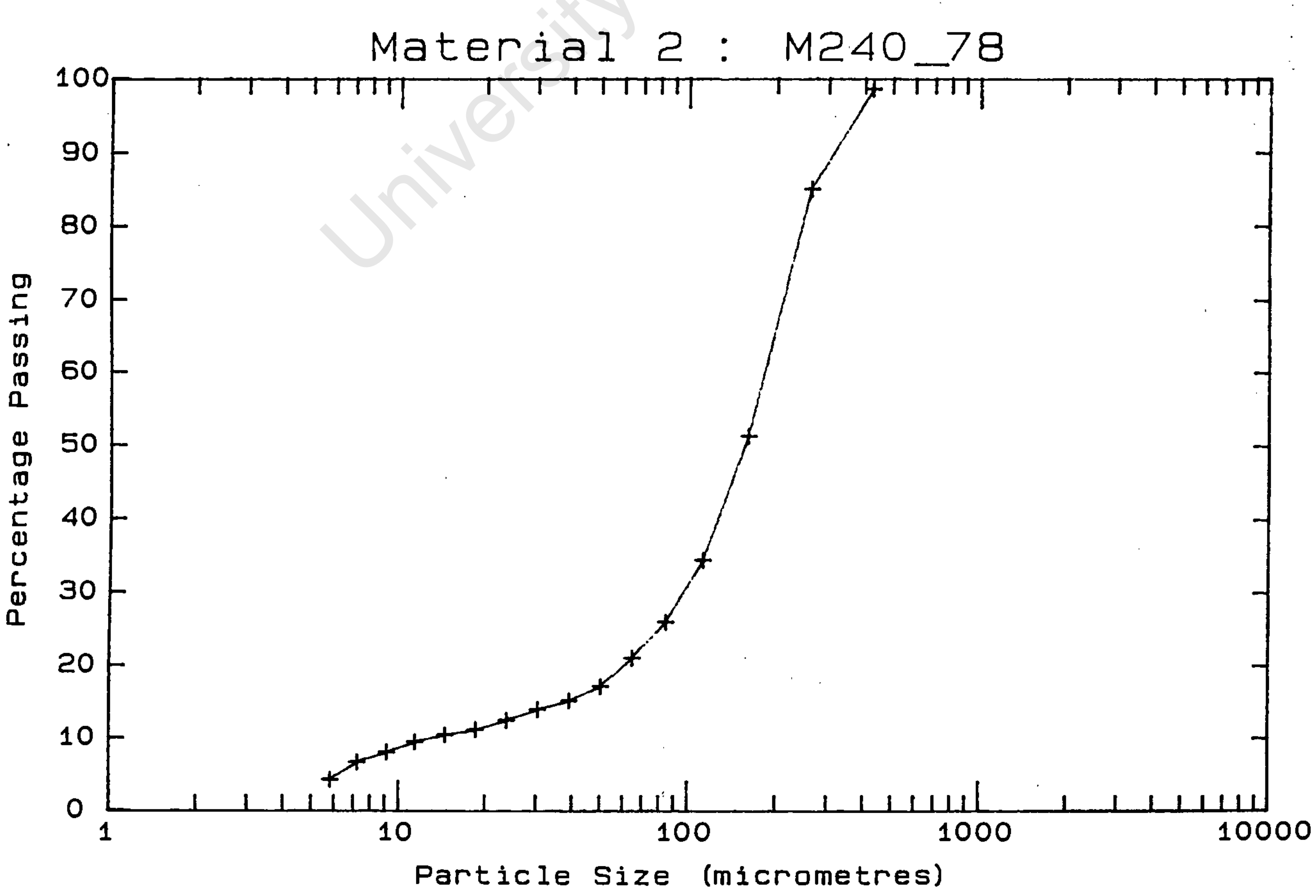
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser



Material 2 : M240D78
Pressure Gradient (kPa/m)
- 3
- 6
- 9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 2 : M240_78
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M240U78

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	MATERIAL 2
Material Relative Density	2.74
Slurry Relative Density	1.78
Solids Volumetric Concentration (%)	44.83
Solids Mass Concentration (%)	69.00
Mean Slurry Temperature (°C)	23.1
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.054	25.439	23.1
4.064	25.097	23.3
4.063	25.437	23.4
4.067	24.888	23.5
3.540	23.731	23.7
3.553	23.723	23.7
3.544	23.749	23.7
3.549	23.571	23.7
3.021	21.884	23.6
3.032	21.860	23.5
3.028	21.844	23.5
3.029	21.893	23.5
3.022	21.710	23.4
2.520	19.479	23.2
2.496	19.565	23.2
2.491	19.476	23.2
2.513	19.344	23.1
1.972	19.041	23.0
1.960	19.037	23.0
1.994	19.044	22.9
2.043	19.062	22.9
1.577	18.829	22.7
1.565	18.755	22.7
1.584	18.744	22.6
1.607	18.750	22.6
.879	18.426	22.5
.869	18.391	22.5
.874	18.415	22.4
.863	18.427	22.4
.859	18.308	22.4

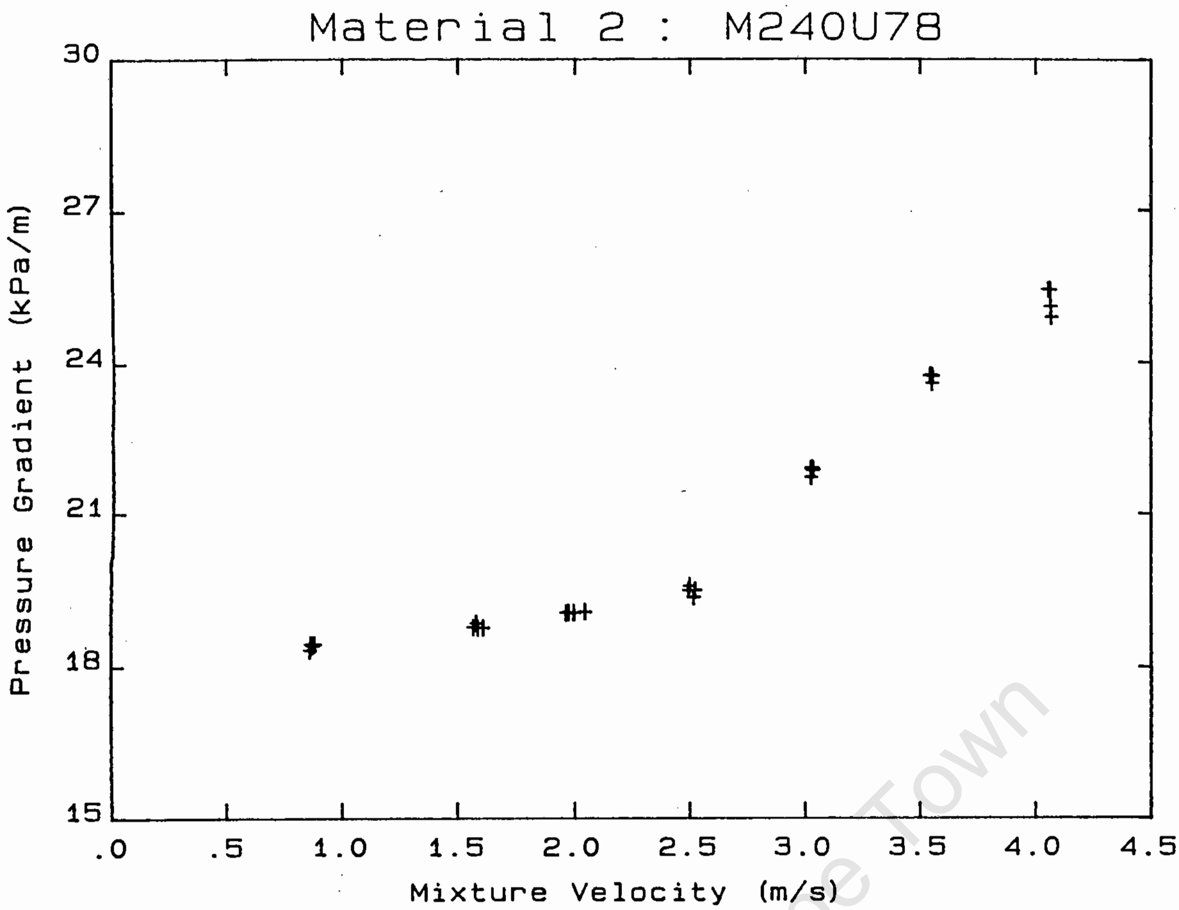
Particle Size Distribution
Sieve and Malvern Size Analysis *

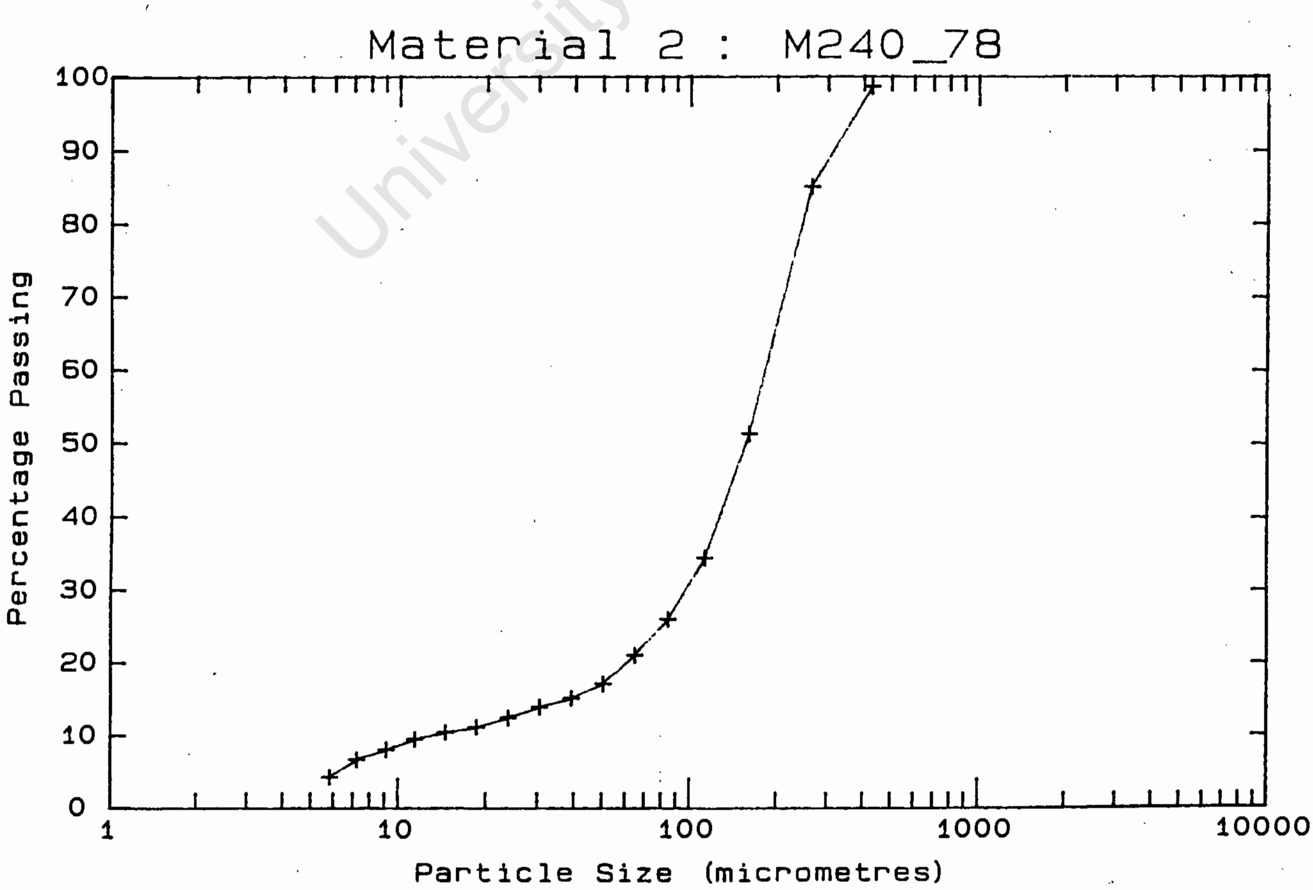
Size (µm)	% Passing	% Retained
425.0	98.5	1.5
261.6	85.0	13.5
160.4	51.2	33.8
112.8	34.4	16.8
84.3	25.9	8.5
64.6	21.0	4.9
50.2	17.1	3.9
39.0	15.1	2.0
30.3	13.9	1.2
23.7	12.4	1.5
18.5	11.1	1.3
14.5	10.4	.7
11.4	9.4	1.0
9.1	8.0	1.4
7.2	6.6	1.4
5.8	4.2	2.4
Pan	- .1	4.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 2 : M240U78
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 2 : M240_78
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M240H83

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	MATERIAL 2
Material Relative Density	2.74
Slurry Relative Density	1.83
Solids Volumetric Concentration (%)	47.70
Solids Mass Concentration (%)	71.42
Mean Slurry Temperature (°C)	23.6
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.008	8.406	23.2
4.087	7.902	23.3
4.081	8.022	23.4
4.078	8.344	23.4
4.076	8.076	23.5
3.556	6.990	23.6
3.529	7.141	23.6
3.496	6.599	23.7
3.504	6.825	23.7
3.014	6.173	23.8
3.016	5.809	23.8
3.002	6.199	23.8
2.999	6.107	23.8
2.483	5.198	23.8
2.452	5.308	23.8
2.438	5.167	23.8
2.470	5.089	23.8
2.035	4.034	23.8
1.992	4.032	23.7
1.973	3.999	23.7
1.954	3.893	23.7
1.447	3.436	23.6
1.460	3.491	23.6
1.456	3.360	23.6
1.442	3.497	23.5
.967	2.736	23.5
.993	2.741	23.4
1.012	2.841	23.4
1.004	2.915	23.4
.438	1.943	23.3
.389	1.953	23.3
.403	2.045	23.3
.422	2.030	23.2

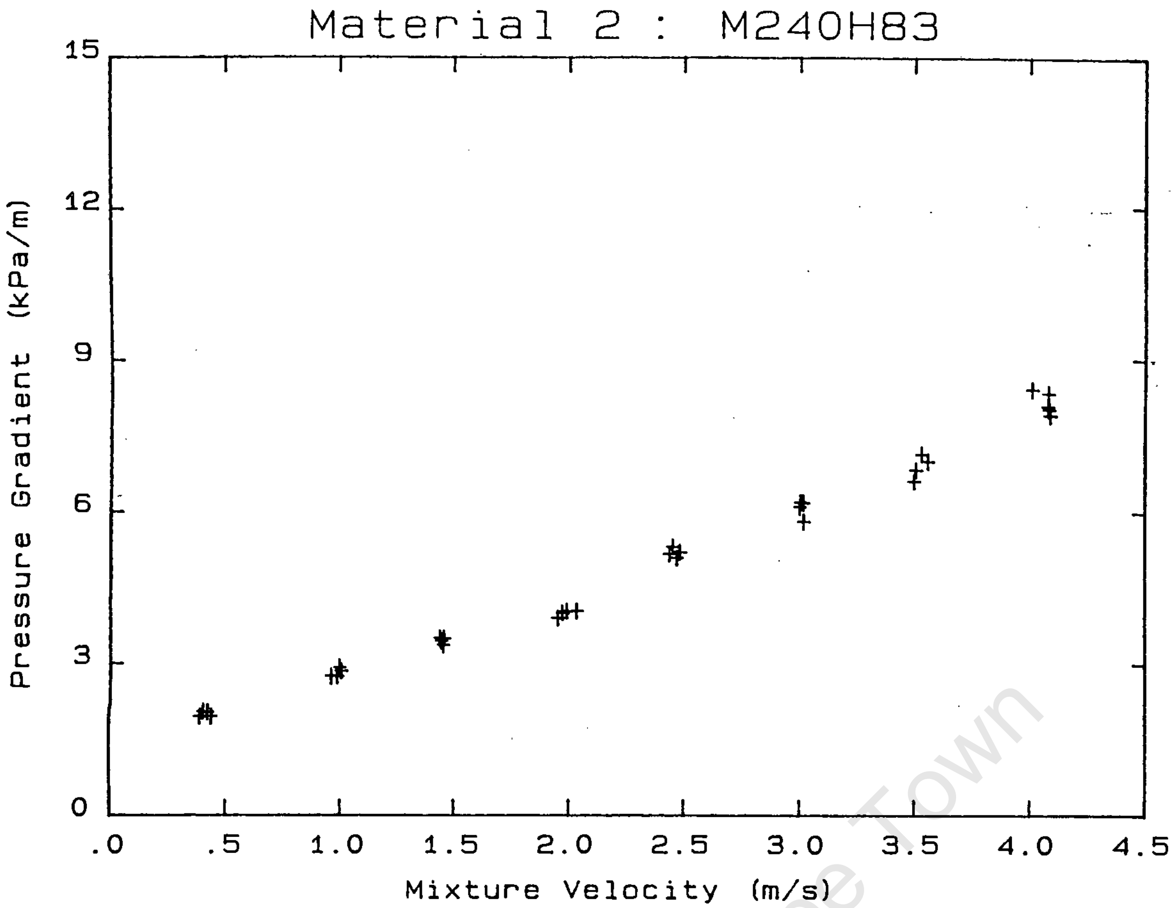
Particle Size Distribution
Sieve and Malvern Size Analysis *

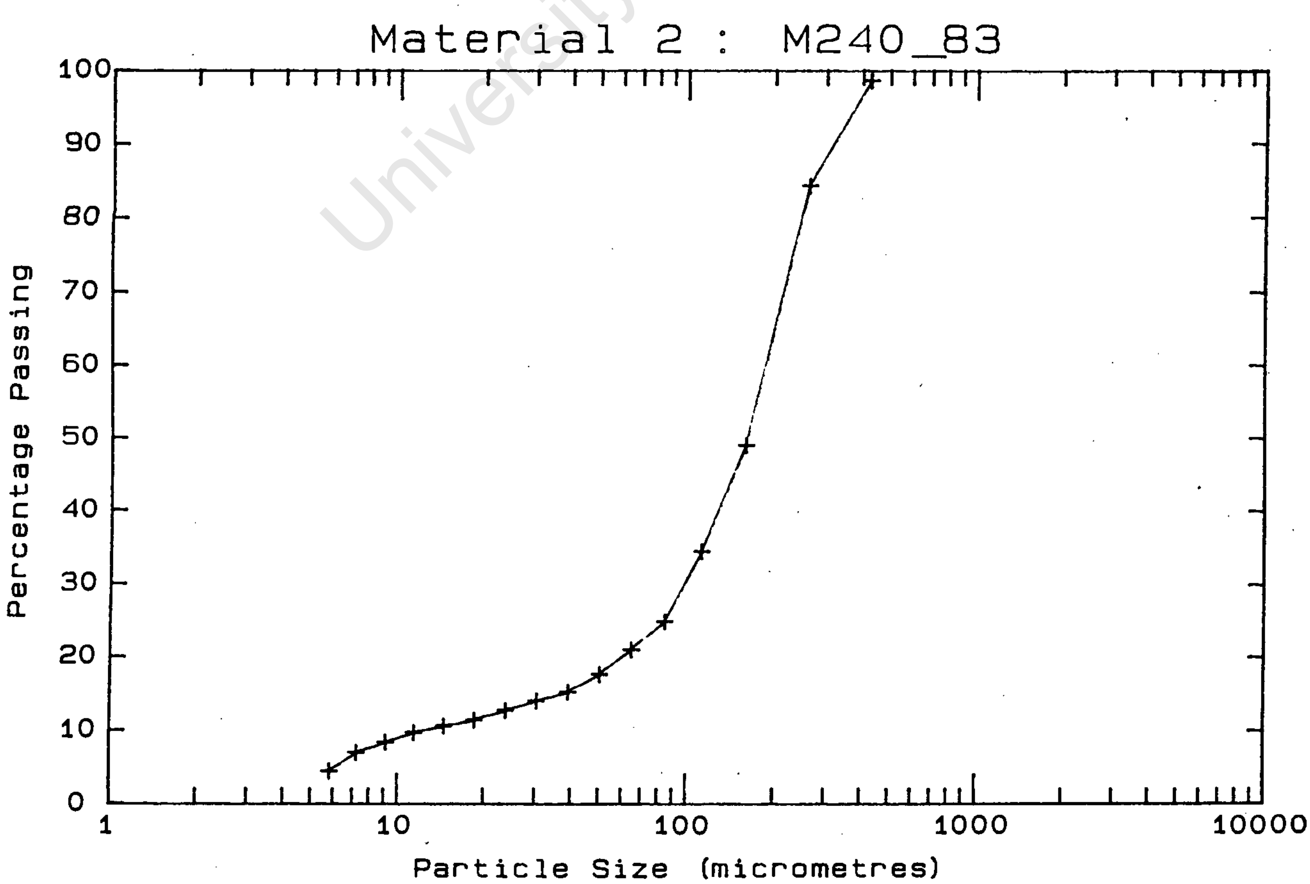
Size (µm)	% Passing	% Retained
425.0	98.5	1.5
261.6	84.2	14.3
160.4	48.9	35.3
112.8	34.4	14.5
84.3	24.8	9.6
64.6	20.9	3.9
50.2	17.5	3.4
39.0	15.1	2.4
30.3	13.9	1.2
23.7	12.6	1.3
18.5	11.3	1.3
14.5	10.5	.8
11.4	9.6	.9
9.1	8.3	1.3
7.2	6.9	1.4
5.8	4.4	2.5
Pan	- .1	4.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.35	Asymetric
.79	Asymetric
1.15	Asymetric
1.57	Asymetric
1.94	Asymetric
2.37	Appears homogeneous
2.77	Appears homogeneous
3.22	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 2 : M240H83
Pressure Gradient (kPa/m)
15
12
9
6
3
0
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 2 : M240_83
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M240D83

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	MATERIAL 2
Material Relative Density	2.74
Slurry Relative Density	1.83
Solids Volumetric Concentration (%)	47.70
Solids Mass Concentration (%)	71.42
Mean Slurry Temperature (°C)	23.6
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.008	-10.308	23.2
4.087	-11.070	23.3
4.081	-10.854	23.4
4.078	-10.943	23.4
4.076	-10.706	23.5
3.556	-11.377	23.6
3.529	-11.499	23.6
3.496	-11.456	23.7
3.504	-11.621	23.7
3.014	-12.472	23.8
3.016	-12.299	23.8
3.002	-12.245	23.8
2.999	-12.283	23.8
2.483	-13.193	23.8
2.452	-13.093	23.8
2.438	-13.141	23.8
2.470	-13.146	23.8
2.035	-13.699	23.8
1.992	-13.814	23.7
1.973	-13.799	23.7
1.954	-13.828	23.7
1.447	-13.827	23.6
1.460	-14.188	23.6
1.456	-14.001	23.6
1.442	-13.848	23.5
.967	-15.327	23.5
.993	-14.678	23.4
1.012	-14.389	23.4
1.004	-15.046	23.4
.438	-16.004	23.3
.389	-15.980	23.3
.403	-15.798	23.3
.422	-15.866	23.2

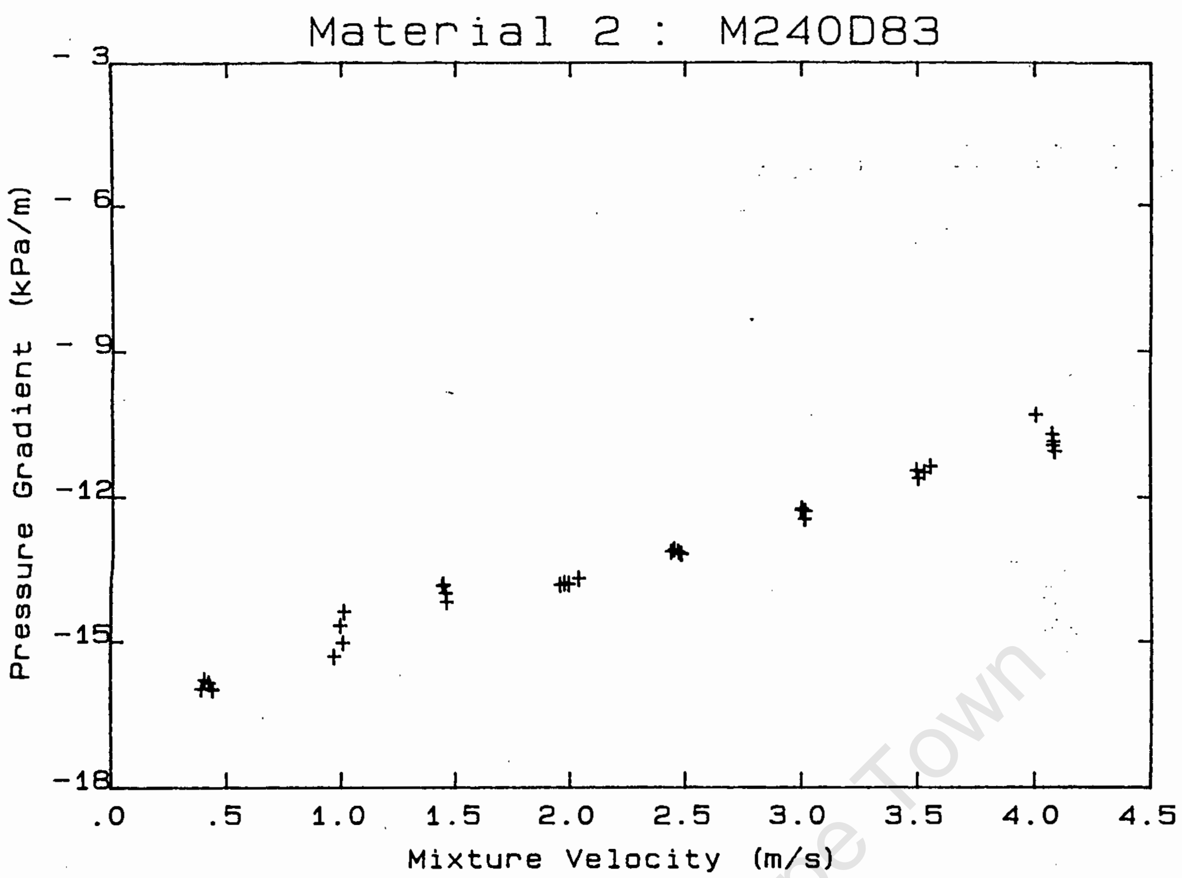
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	98.5	1.5
261.6	84.2	14.3
160.4	48.9	35.3
112.8	34.4	14.5
84.3	24.8	9.6
64.6	20.9	3.9
50.2	17.5	3.4
39.0	15.1	2.4
30.3	13.9	1.2
23.7	12.6	1.3
18.5	11.3	1.3
14.5	10.5	.8
11.4	9.6	.9
9.1	8.3	1.3
7.2	6.9	1.4
5.8	4.4	2.5
Pan	- .1	4.5

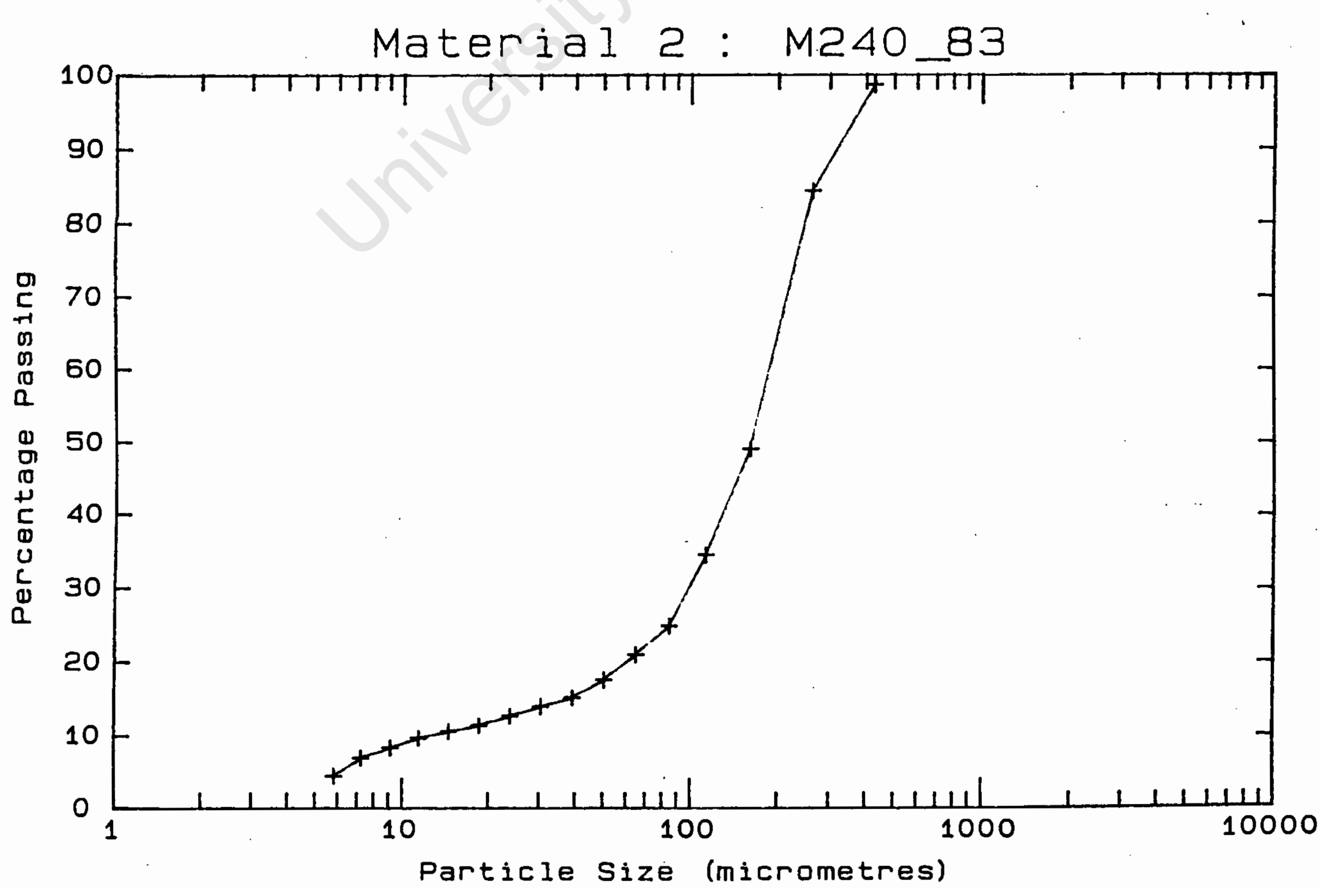
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser



Material 2 : M240D83
Pressure Gradient (kPa/m)
3
6
9
12
15
18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 2 : M240_83
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M240U83

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	MATERIAL 2
Material Relative Density	2.74
Slurry Relative Density	1.83
Solids Volumetric Concentration (%)	47.70
Solids Mass Concentration (%)	71.42
Mean Slurry Temperature (°C)	23.6
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.008	24.120	23.2
4.087	23.942	23.3
4.081	23.346	23.4
4.078	23.709	23.4
4.076	23.811	23.5
3.556	23.663	23.6
3.529	22.959	23.6
3.496	23.477	23.7
3.504	23.035	23.7
3.014	22.659	23.8
3.016	22.460	23.8
3.002	22.514	23.8
2.999	22.528	23.8
2.483	21.823	23.8
2.452	21.937	23.8
2.438	21.861	23.8
2.470	21.736	23.8
2.035	21.470	23.8
1.992	21.284	23.7
1.973	21.280	23.7
1.954	21.278	23.7
1.447	20.711	23.6
1.460	20.740	23.6
1.456	20.627	23.6
1.442	20.626	23.5
.967	20.277	23.5
.993	20.213	23.4
1.012	20.291	23.4
1.004	20.259	23.4
.438	19.818	23.3
.389	19.904	23.3
.403	19.931	23.3
.422	19.926	23.2

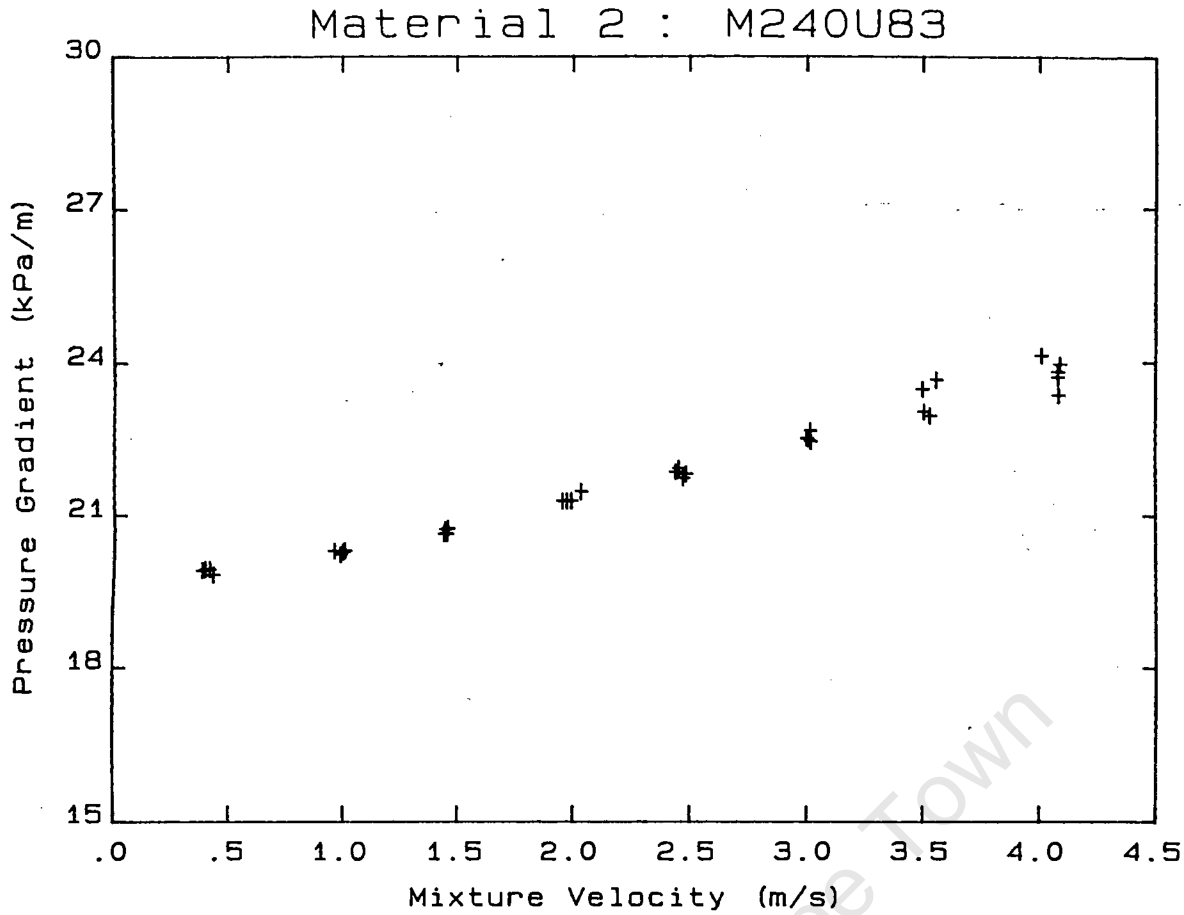
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	98.5	1.5
261.6	84.2	14.3
160.4	48.9	35.3
112.8	34.4	14.5
84.3	24.8	9.6
64.6	20.9	3.9
50.2	17.5	3.4
39.0	15.1	2.4
30.3	13.9	1.2
23.7	12.6	1.3
18.5	11.3	1.3
14.5	10.5	.8
11.4	9.6	.9
9.1	8.3	1.3
7.2	6.9	1.4
5.8	4.4	2.5
Pan	- .1	4.5

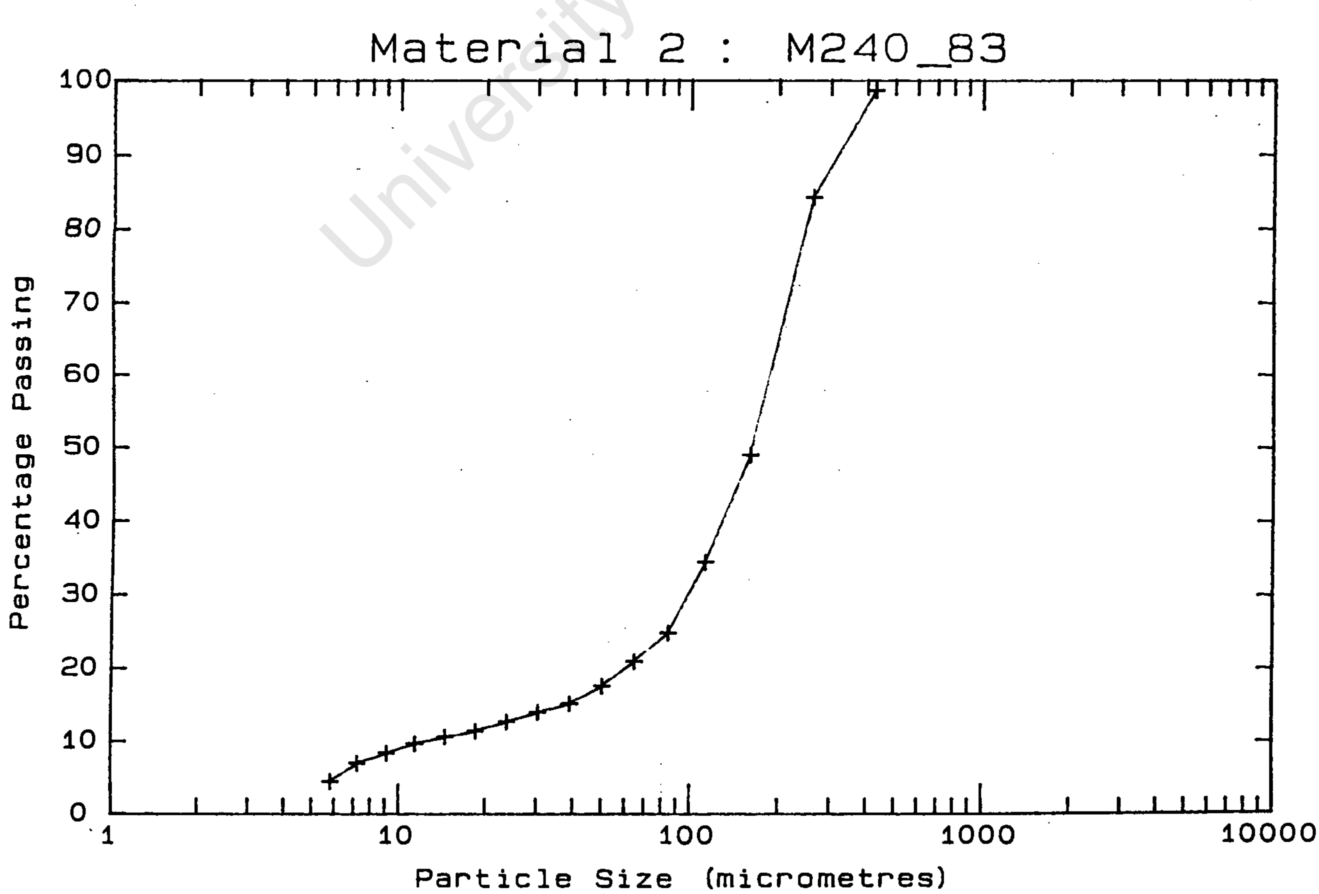
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser



Material 2 : M240U83
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 2 : M240_83
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M240H88

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	MATERIAL 2
Material Relative Density	2.74
Slurry Relative Density	1.88
Solids Volumetric Concentration (%)	50.57
Solids Mass Concentration (%)	73.71
Mean Slurry Temperature (°C)	28.3
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.803	13.371	26.7
3.771	13.502	27.1
3.755	13.599	27.7
3.743	13.535	27.9
3.707	12.885	28.1
3.075	9.872	28.4
3.079	9.978	28.5
3.116	10.134	28.6
3.140	10.419	28.6
2.495	7.475	28.7
2.494	7.766	28.8
2.499	7.753	28.8
2.577	7.552	28.8
1.971	7.067	28.8
1.952	6.904	28.8
1.963	6.987	28.8
1.979	6.854	28.8
1.486	6.295	28.7
1.439	6.221	28.6
1.415	6.539	28.5
1.438	6.579	28.5
.999	5.092	28.4
.984	5.106	28.4
.966	5.094	28.3
.956	5.075	28.3
.436	3.662	28.2
.394	3.703	28.1
.364	3.667	28.1
.341	3.622	28.0

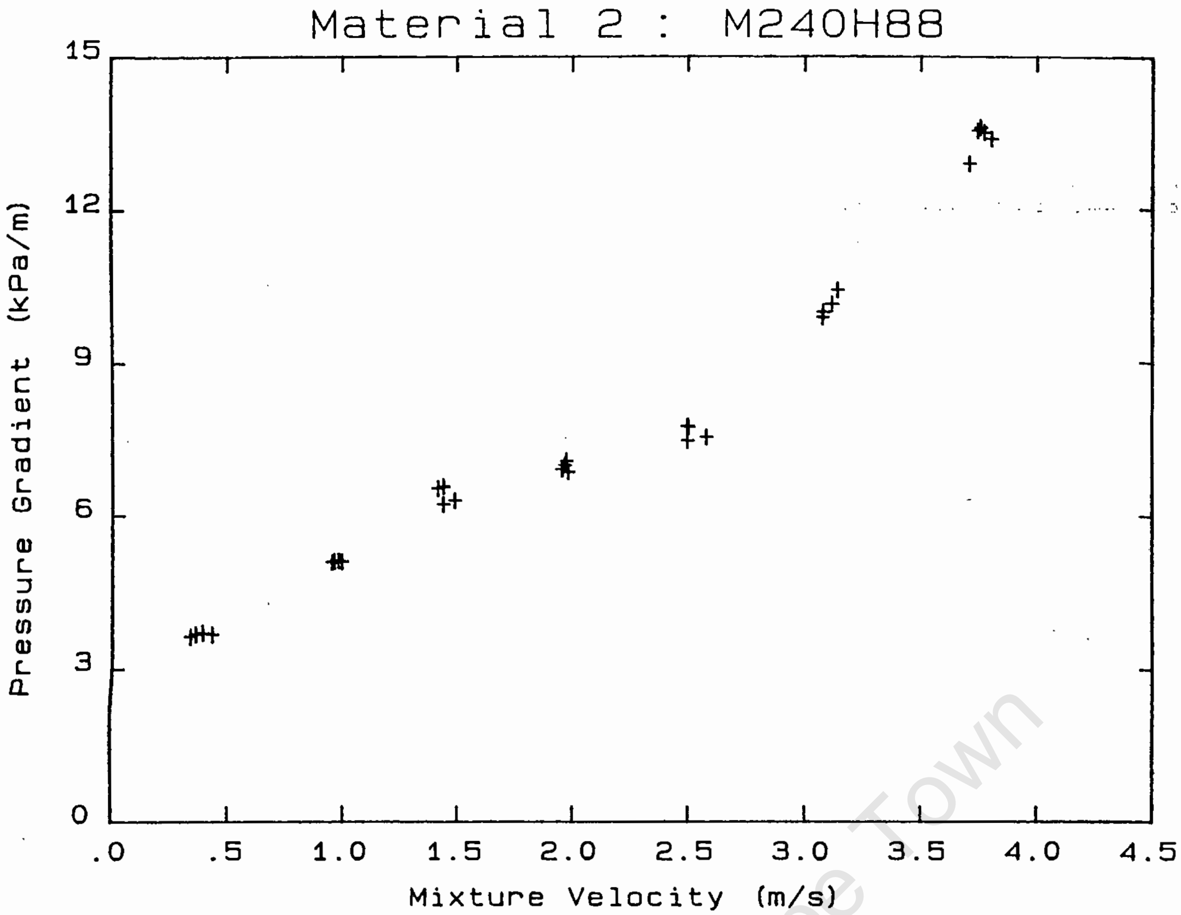
Particle Size Distribution
Sieve and Malvern Size Analysis *

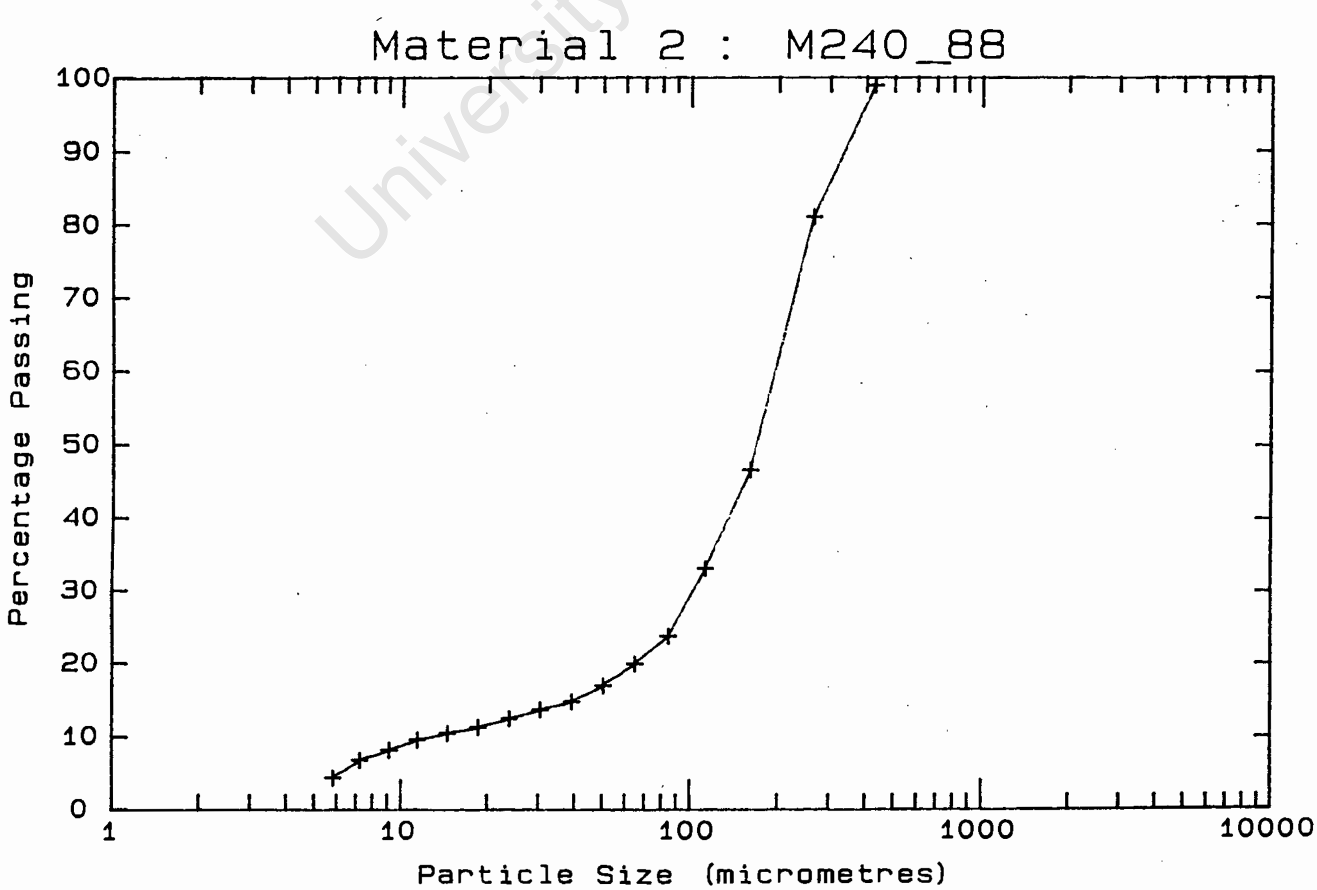
Size (µm)	% Passing	% Retained
425.0	98.8	1.2
261.6	80.9	17.9
160.4	46.5	34.4
112.8	33.0	13.5
84.3	23.7	9.3
64.6	19.9	3.8
50.2	16.9	3.0
39.0	14.7	2.2
30.3	13.6	1.1
23.7	12.4	1.2
18.5	11.2	1.2
14.5	10.4	.8
11.4	9.5	.9
9.1	8.1	1.4
7.2	6.7	1.4
5.8	4.3	2.4
Pan	- .1	4.4

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.32	Appears homogeneous
.78	Appears homogeneous
1.15	Appears homogeneous
1.55	Appears homogeneous
1.98	Appears homogeneous
2.45	Appears homogeneous
2.97	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 2 : M240H88
Pressure Gradient (kPa/m)
Mixture Velocity (m/s)
15
12
9
6
3
0
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Material 2 : M240_88
Percentage Passing
Particle Size (micrometres)
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000

DATA FILE : M240D88

Test Facility	UCT 40 mm NB
Test Date	29/05/91
Material Description	MATERIAL 2
Material Relative Density	2.74
Slurry Relative Density	1.88
Solids Volumetric Concentration (%)	50.57
Solids Mass Concentration (%)	73.71
Mean Slurry Temperature (°C)	28.3
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.803	- 6.681	26.7
3.771	- 6.598	27.1
3.755	- 7.089	27.7
3.743	- 7.075	27.9
3.707	- 6.783	28.1
3.075	- 8.420	28.4
3.079	- 8.929	28.5
3.116	- 8.543	28.6
3.140	- 8.730	28.6
2.495	- 9.586	28.7
2.494	- 9.306	28.8
2.499	- 9.739	28.8
2.577	- 9.382	28.8
1.971	-10.753	28.8
1.952	-11.257	28.8
1.963	-11.285	28.8
1.979	-11.020	28.8
1.486	-11.673	28.7
1.439	-12.210	28.6
1.415	-12.210	28.5
1.438	-12.237	28.5
.999	-13.227	28.4
.984	-13.212	28.4
.966	-13.189	28.3
.956	-13.244	28.3
.436	-14.418	28.2
.394	-14.451	28.1
.364	-14.400	28.1
.341	-13.970	28.0

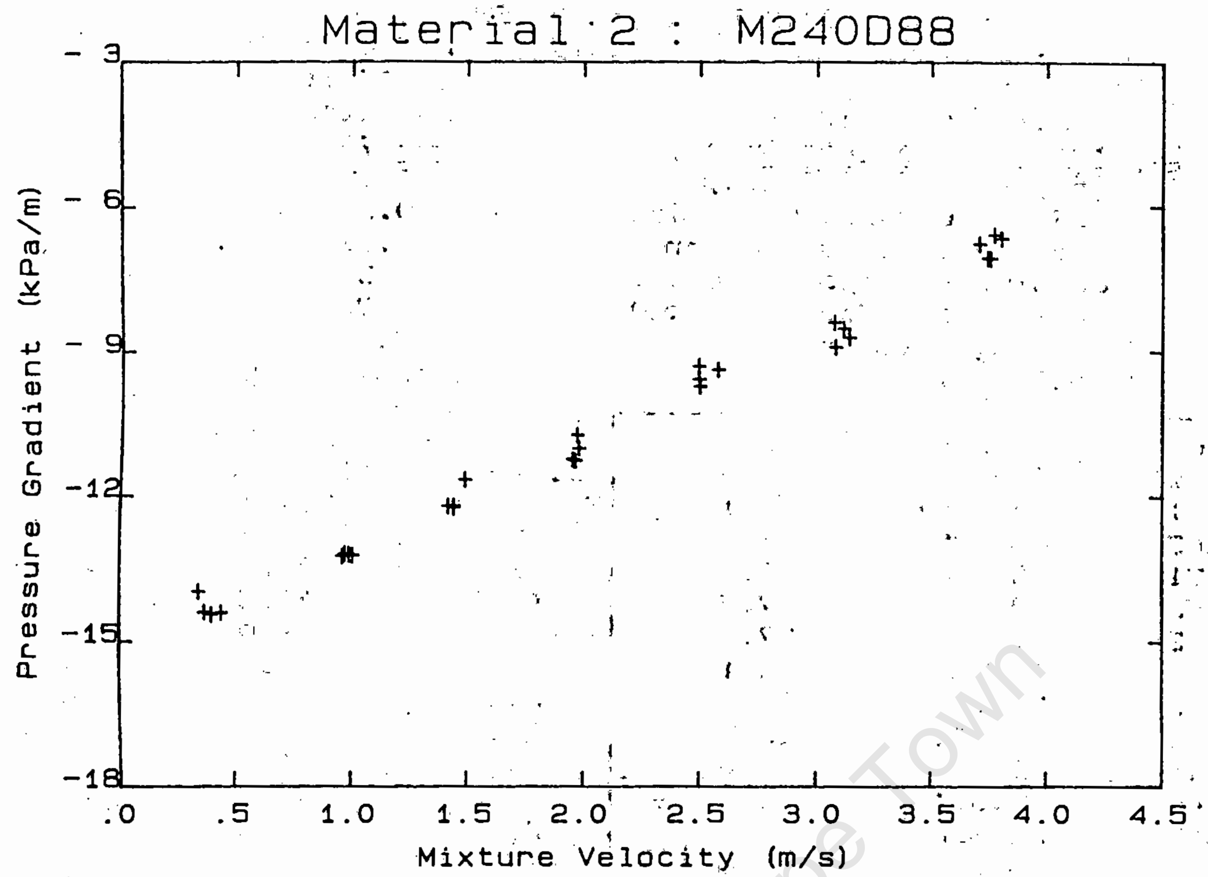
Particle Size Distribution
Sieve and Malvern Size Analysis *

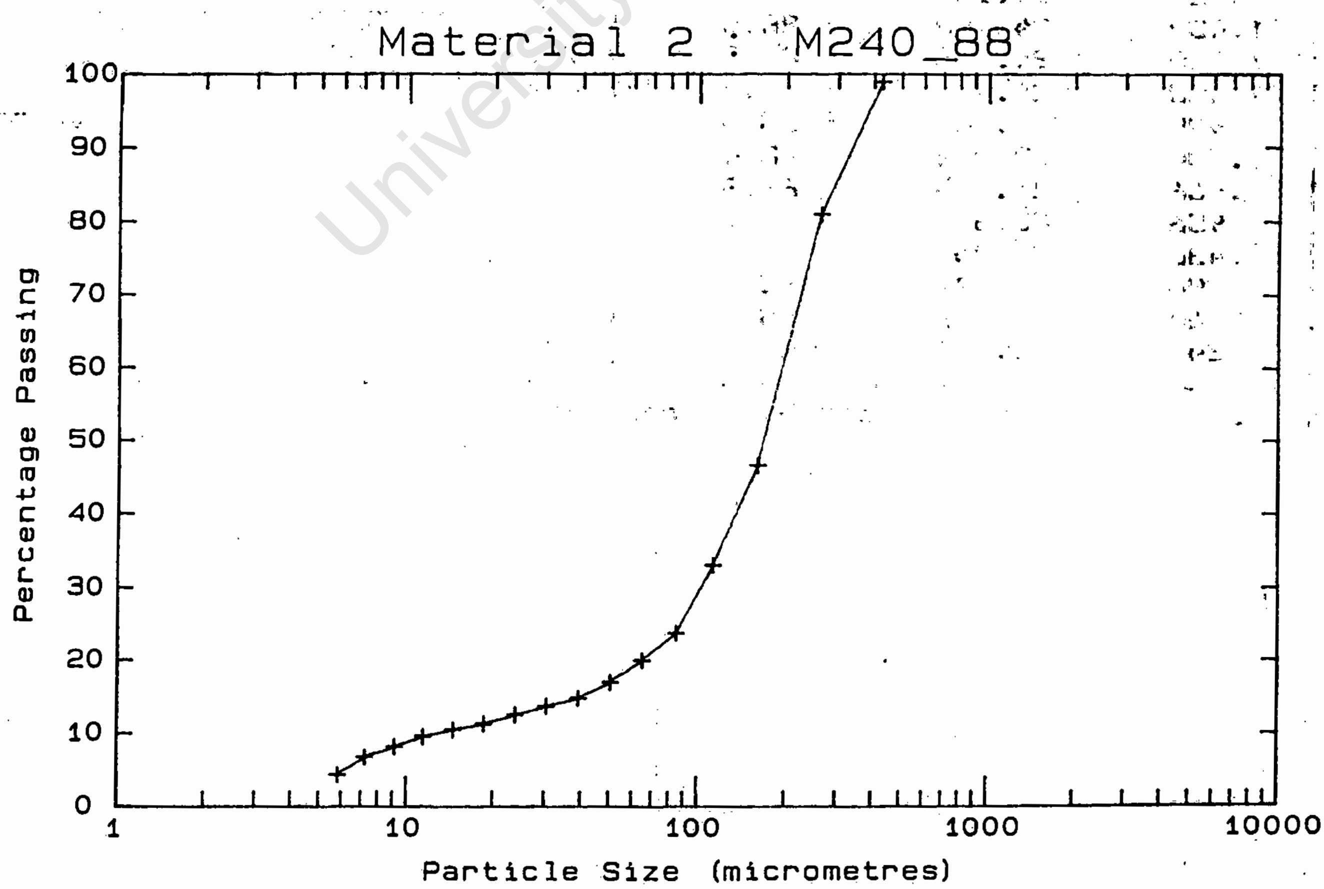
Size (µm)	% Passing	% Retained
425.0	98.8	1.2
261.6	80.9	17.9
160.4	46.5	34.4
112.8	33.0	13.5
84.3	23.7	9.3
64.6	19.9	3.8
50.2	16.9	3.0
39.0	14.7	2.2
30.3	13.6	1.1
23.7	12.4	1.2
18.5	11.2	1.2
14.5	10.4	.8
11.4	9.5	.9
9.1	8.1	1.4
7.2	6.7	1.4
5.8	4.3	2.4
Pan	- .1	4.4

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 2 : M240D88
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 2 : M240_88
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M340H62

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.62
Solids Volumetric Concentration (%)	35.63
Solids Mass Concentration (%)	60.27
Mean Slurry Temperature (°C)	20.6
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.634	6.339	21.0
3.635	6.233	21.0
3.640	6.413	21.1
3.645	6.335	21.1
3.274	5.397	21.2
3.285	5.409	21.2
3.274	5.461	21.1
3.272	5.349	21.1
2.903	4.373	21.1
2.905	4.461	21.0
2.901	4.414	21.0
2.904	4.355	21.0
2.527	3.596	20.9
2.517	3.656	20.9
2.522	3.400	20.8
2.522	3.625	20.8
2.129	2.682	20.7
2.144	2.841	20.7
2.134	2.781	20.6
2.145	2.834	20.6
1.830	2.299	20.5
1.830	2.361	20.5
1.827	2.960	20.5
1.832	2.228	20.4
1.829	1.988	20.4
1.401	1.849	20.3
1.437	1.597	20.3
1.400	1.309	20.3
1.389	1.420	20.2
1.389	1.720	20.2
1.103	2.265	20.1
1.072	1.015	20.1
1.155	1.995	20.1
1.142	1.058	20.1
1.108	1.690	20.1
1.081	.914	20.0

Particle Size Distribution
Sieve and Malvern Size Analysis *

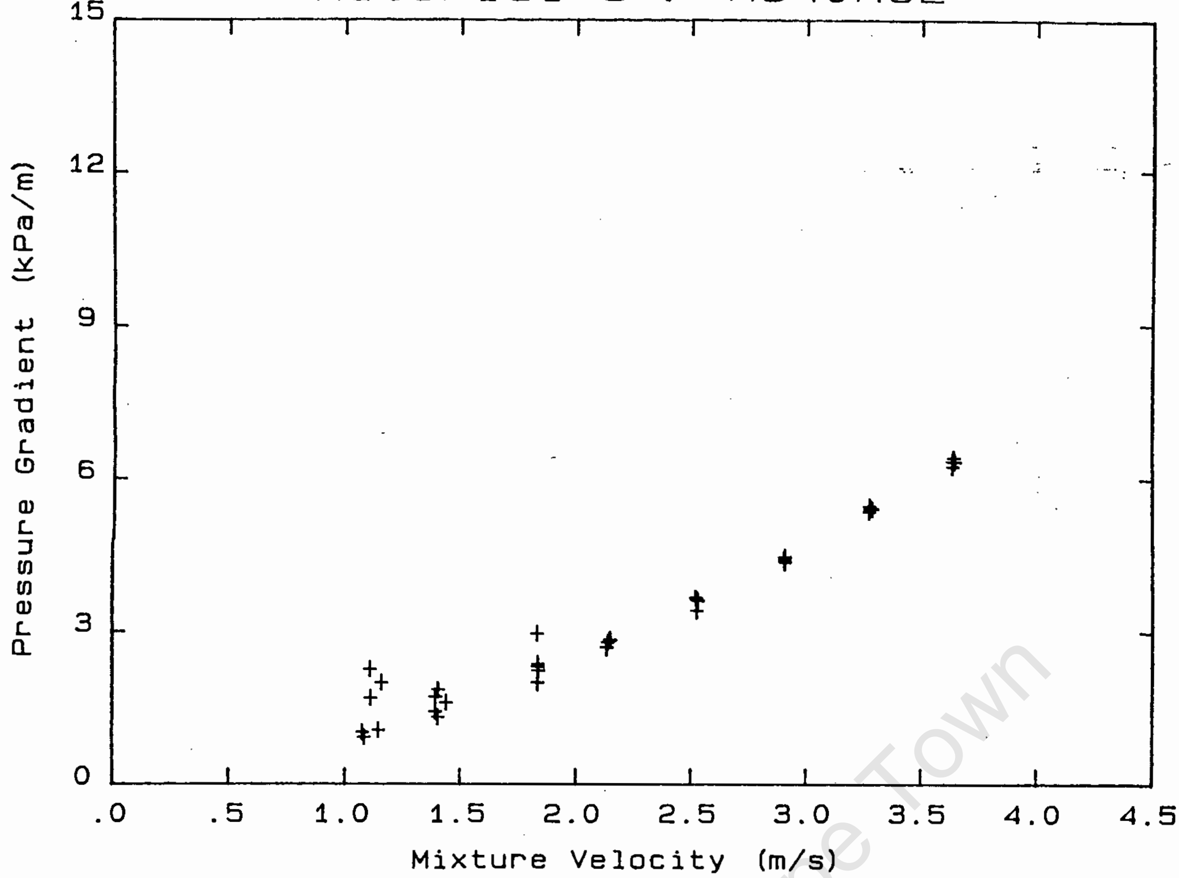
Size (µm)	% Passing	% Retained
425.0	98.6	1.4
261.6	87.9	10.7
160.4	61.2	26.7
112.8	45.4	15.8
84.3	35.8	9.6
64.6	29.9	5.9
50.2	25.5	4.4
39.0	22.6	2.9
30.3	20.5	2.1
23.7	18.4	2.1
18.5	16.6	1.8
14.5	15.3	1.3
11.4	13.7	1.6
9.1	11.7	2.0
7.2	9.5	2.2
5.8	6.0	3.5
Pan	- .2	6.2

OBSERVED FLOW BEHAVIOUR

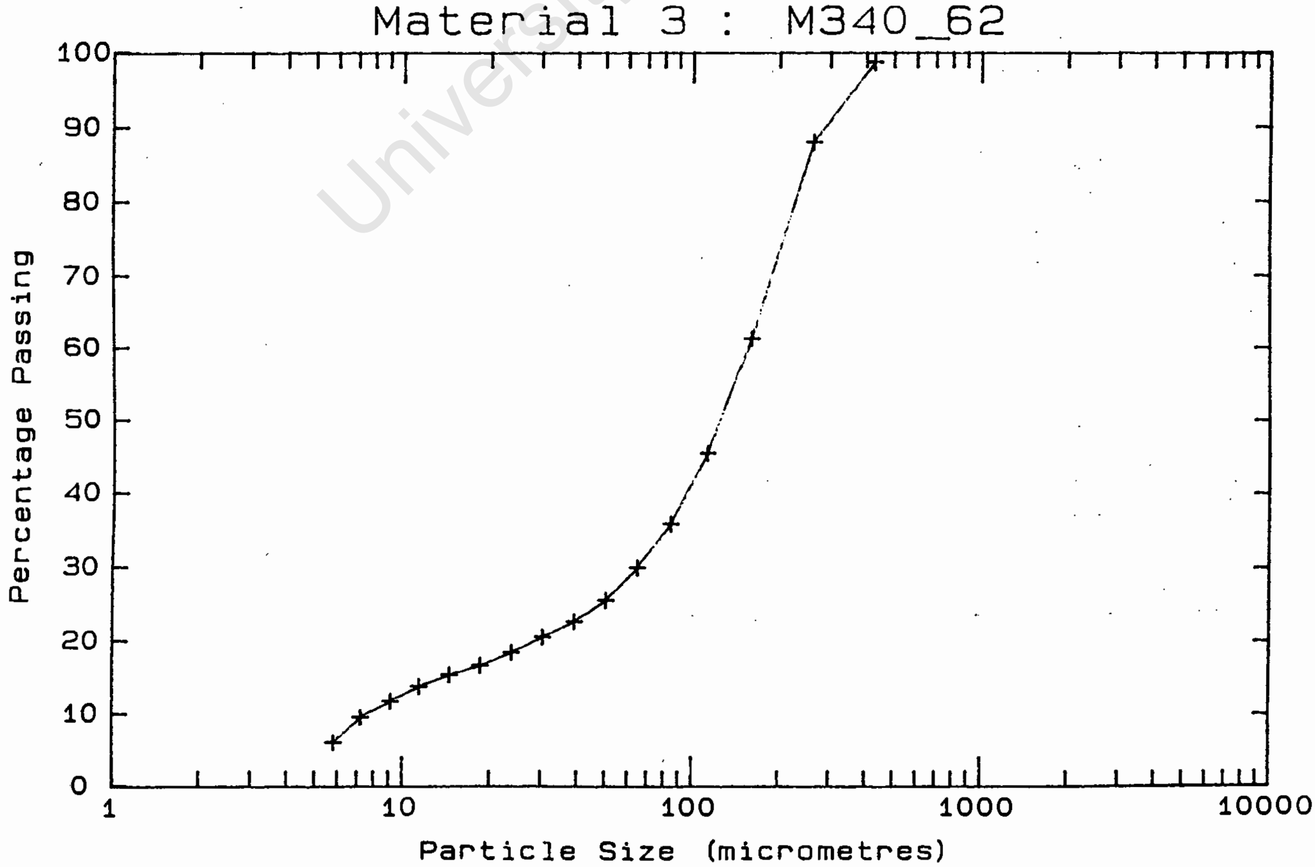
Velocity (m/s)	Observation (D = 46.0 mm)
.87	Stationary bed
1.11	Sliding bed
1.45	Asymetric
1.68	Asymetric
1.78	Appears homogeneous
2.29	Appears homogeneous
2.59	Appears homogeneous
2.88	Appears homogeneous

* -425 µm Malvern Particle Size Analyser

Material 3 : M340H62



Material 3 : M340_62



DATA FILE : M340D62

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.62
Solids Volumetric Concentration (%)	35.63
Solids Mass Concentration (%)	60.27
Mean Slurry Temperature (°C)	20.6
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.634	- 9.305	21.0
3.635	- 9.204	21.0
3.640	- 9.385	21.1
3.645	- 9.323	21.1
3.274	-10.525	21.2
3.285	-10.389	21.2
3.274	-10.440	21.1
3.272	-10.538	21.1
2.903	-11.189	21.1
2.905	-11.284	21.0
2.901	-11.267	21.0
2.904	-11.295	21.0
2.527	-12.093	20.9
2.517	-12.138	20.9
2.522	-12.213	20.8
2.522	-12.572	20.8
2.129	-13.064	20.7
2.144	-13.073	20.7
2.134	-13.053	20.6
2.145	-13.043	20.6
1.830	-13.658	20.5
1.830	-13.794	20.5
1.827	-13.475	20.5
1.832	-13.684	20.4
1.829	-13.647	20.4
1.401	-14.359	20.3
1.437	-14.463	20.3
1.400	-14.456	20.3
1.389	-14.685	20.2
1.389	-14.586	20.2
1.103	-14.754	20.1
1.072	-15.078	20.1
1.155	-14.825	20.1
1.142	-14.987	20.1
1.108	-14.958	20.1
1.081	-14.880	20.0

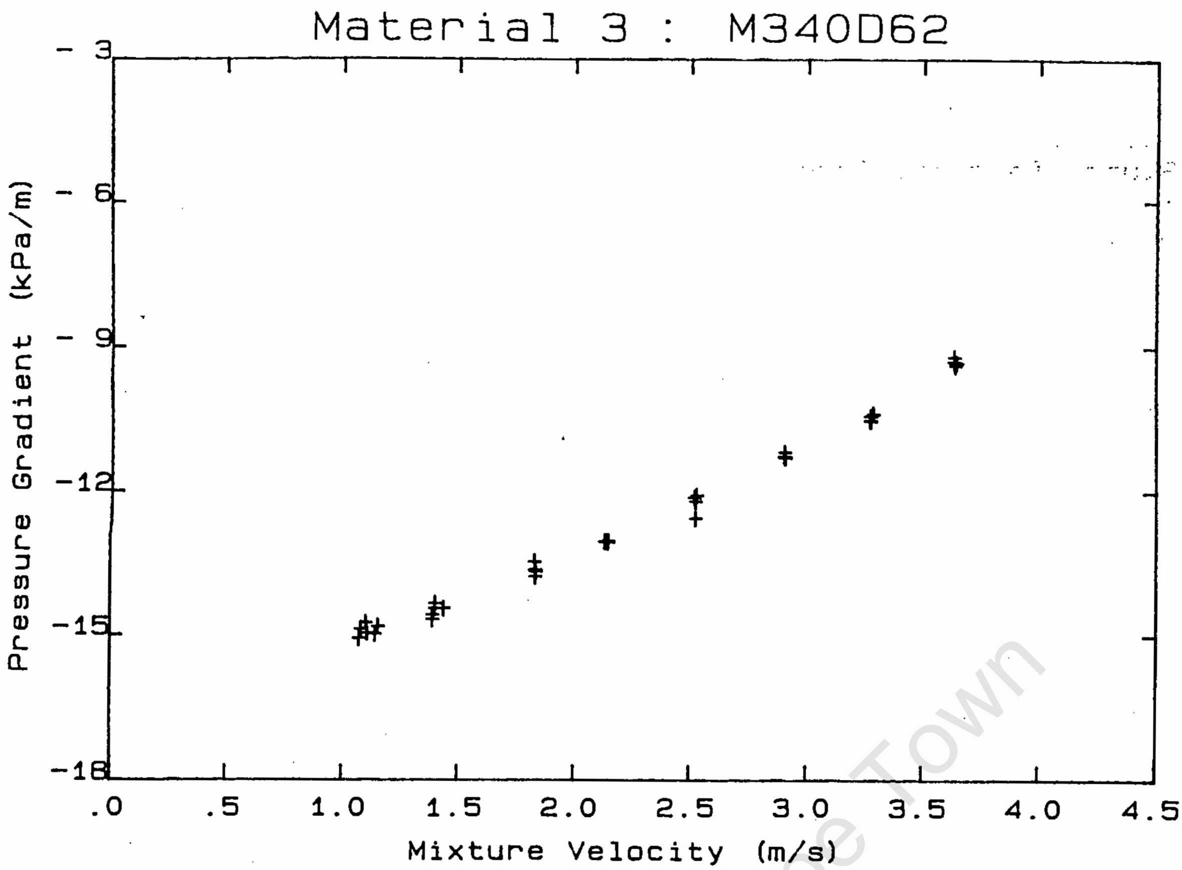
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	98.6	1.4
261.6	87.9	10.7
160.4	61.2	26.7
112.8	45.4	15.8
84.3	35.8	9.6
64.6	29.9	5.9
50.2	25.5	4.4
39.0	22.6	2.9
30.3	20.5	2.1
23.7	18.4	2.1
18.5	16.6	1.8
14.5	15.3	1.3
11.4	13.7	1.6
9.1	11.7	2.0
7.2	9.5	2.2
5.8	6.0	3.5
Pan	- .2	6.2

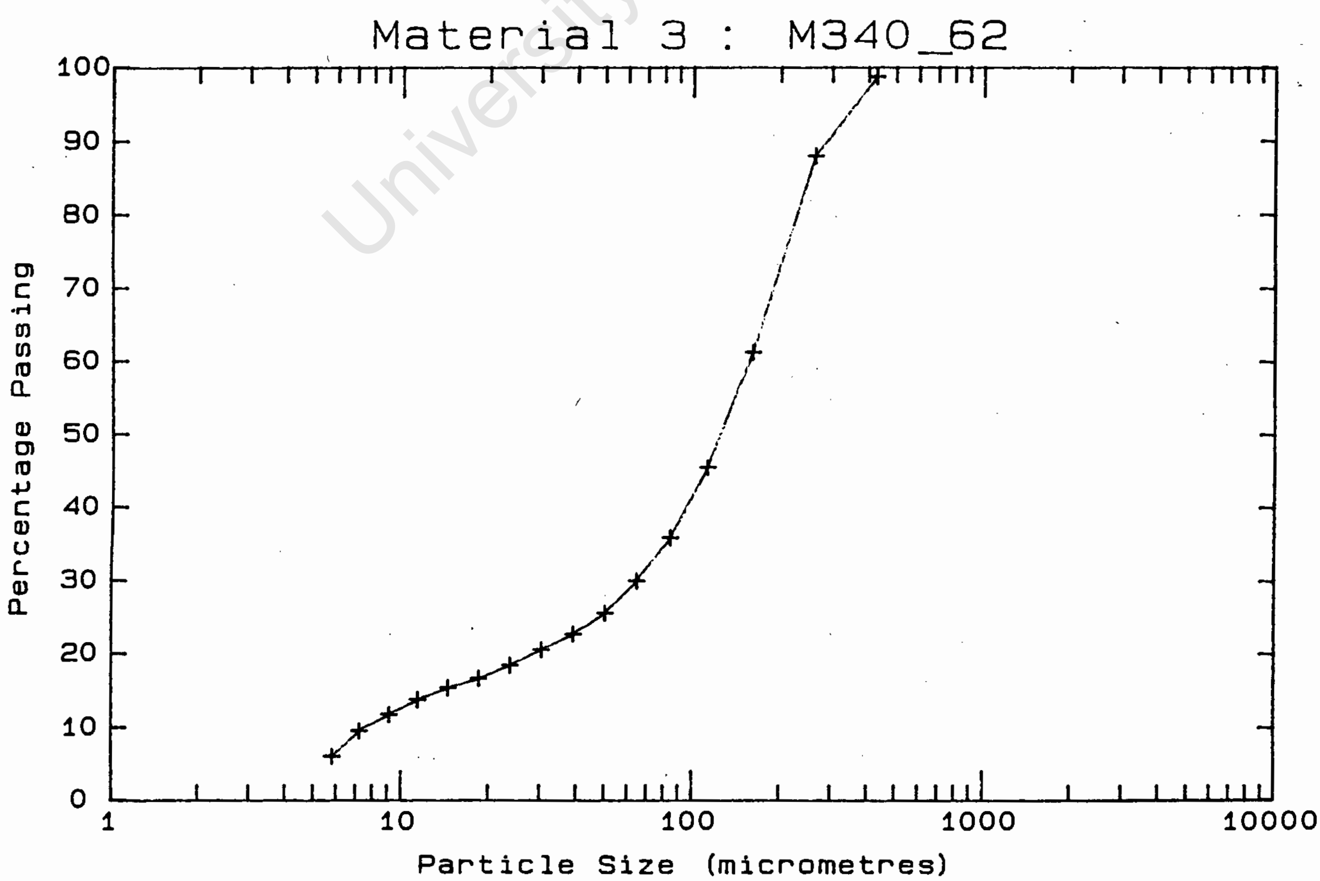
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser



Material 3 : M340D62
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 3 : M340_62
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M340U62

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.62
Solids Volumetric Concentration (%)	35.63
Solids Mass Concentration (%)	60.27
Mean Slurry Temperature (°C)	20.6
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.634	21.272	21.0
3.635	21.343	21.0
3.640	21.272	21.1
3.645	21.332	21.1
3.274	20.406	21.2
3.285	20.571	21.2
3.274	20.584	21.1
3.272	20.150	21.1
2.903	19.937	21.1
2.905	19.596	21.0
2.901	19.576	21.0
2.904	19.723	21.0
2.527	18.915	20.9
2.517	18.799	20.9
2.522	18.863	20.8
2.522	18.575	20.8
2.129	17.999	20.7
2.144	18.064	20.7
2.134	18.063	20.6
2.145	18.140	20.6
1.830	17.569	20.5
1.830	17.585	20.5
1.827	17.535	20.5
1.832	17.536	20.4
1.829	17.539	20.4
1.401	16.858	20.3
1.437	16.913	20.3
1.400	16.886	20.3
1.389	16.911	20.2
1.389	16.896	20.2
1.103	16.467	20.1
1.072	16.423	20.1
1.155	16.356	20.1
1.142	16.397	20.1
1.108	16.296	20.1
1.081	16.293	20.0

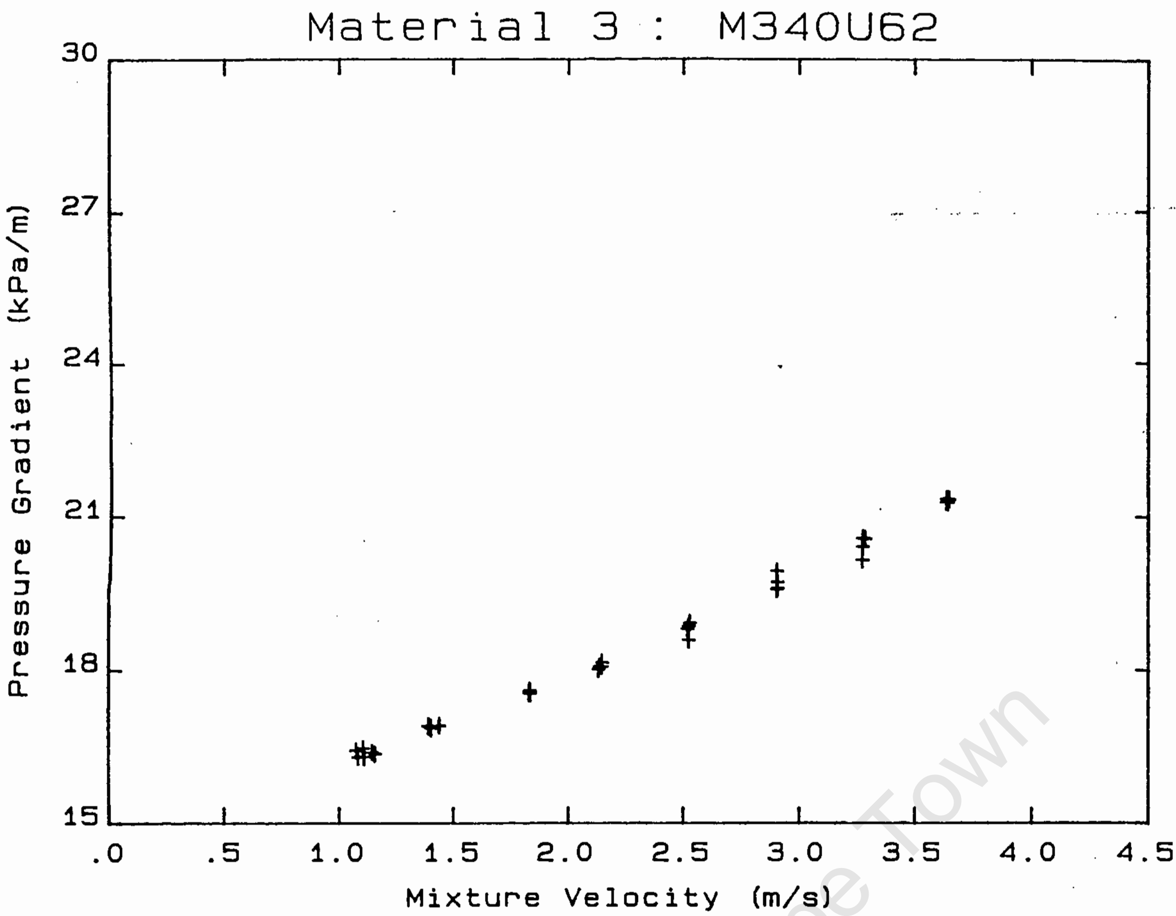
Particle Size Distribution
Sieve and Malvern Size Analysis *

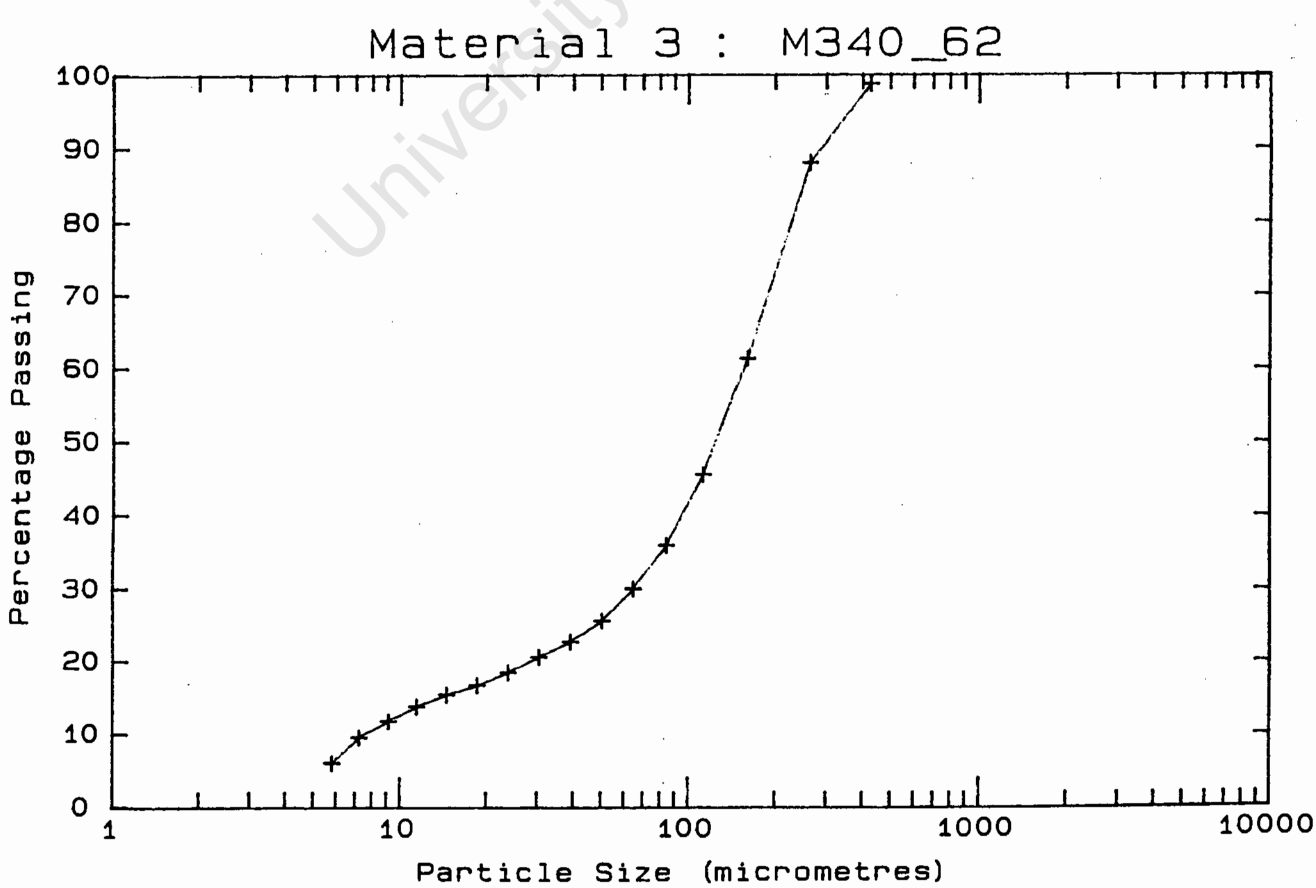
Size (µm)	% Passing	% Retained
425.0	98.6	1.4
261.6	87.9	10.7
160.4	61.2	26.7
112.8	45.4	15.8
84.3	35.8	9.6
64.6	29.9	5.9
50.2	25.5	4.4
39.0	22.6	2.9
30.3	20.5	2.1
23.7	18.4	2.1
18.5	16.6	1.8
14.5	15.3	1.3
11.4	13.7	1.6
9.1	11.7	2.0
7.2	9.5	2.2
5.8	6.0	3.5
Pan	- .2	6.2

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 3 : M340U62
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 3 : M340_62
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M340H72

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.72
Solids Volumetric Concentration (%)	41.38
Solids Mass Concentration (%)	65.92
Mean Slurry Temperature (°C)	20.3
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.620	8.096	19.7
3.631	8.080	19.8
3.626	7.971	19.9
3.634	7.874	20.0
3.628	7.934	20.1
3.282	6.839	20.3
3.261	6.601	20.4
3.251	6.908	20.5
3.272	6.818	20.5
2.898	5.634	20.5
2.877	5.375	20.5
2.875	5.387	20.5
2.875	5.615	20.5
2.518	4.510	20.5
2.510	4.425	20.5
2.554	4.482	20.5
2.559	4.300	20.5
2.114	2.814	20.4
2.138	2.645	20.4
2.094	2.360	20.4
2.154	2.987	20.3
2.145	2.867	20.3
1.678	2.247	20.2
1.687	1.781	20.2
1.685	2.526	20.2
1.678	1.371	20.2
1.681	2.291	20.2
1.222	2.347	20.2
1.224	2.749	20.2
1.230	2.864	20.2
1.230	1.252	20.1
.524	1.001	20.1
.500	1.101	20.1
.479	1.384	20.1
.523	1.346	20.1
.544	1.431	20.1

Particle Size Distribution
Sieve and Malvern Size Analysis *

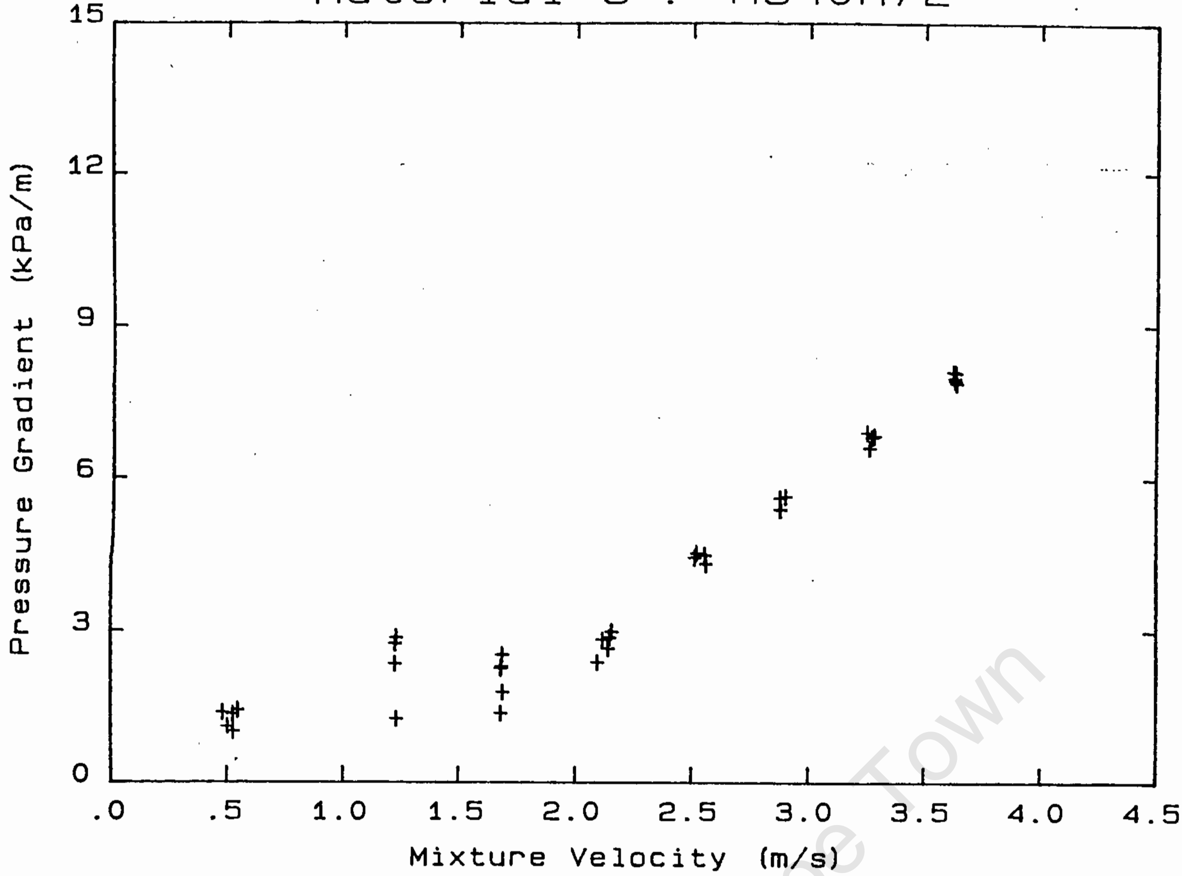
Size (µm)	% Passing	% Retained
425.0	98.3	1.7
261.6	89.0	9.3
160.4	61.4	27.6
112.8	48.8	12.6
84.3	37.5	11.3
64.6	31.7	5.8
50.2	27.6	4.1
39.0	24.3	3.3
30.3	21.9	2.4
23.7	19.8	2.1
18.5	17.9	1.9
14.5	16.5	1.4
11.4	14.7	1.8
9.1	12.5	2.2
7.2	10.3	2.2
5.8	6.7	3.6
Pan	– .1	6.8

OBSERVED FLOW BEHAVIOUR

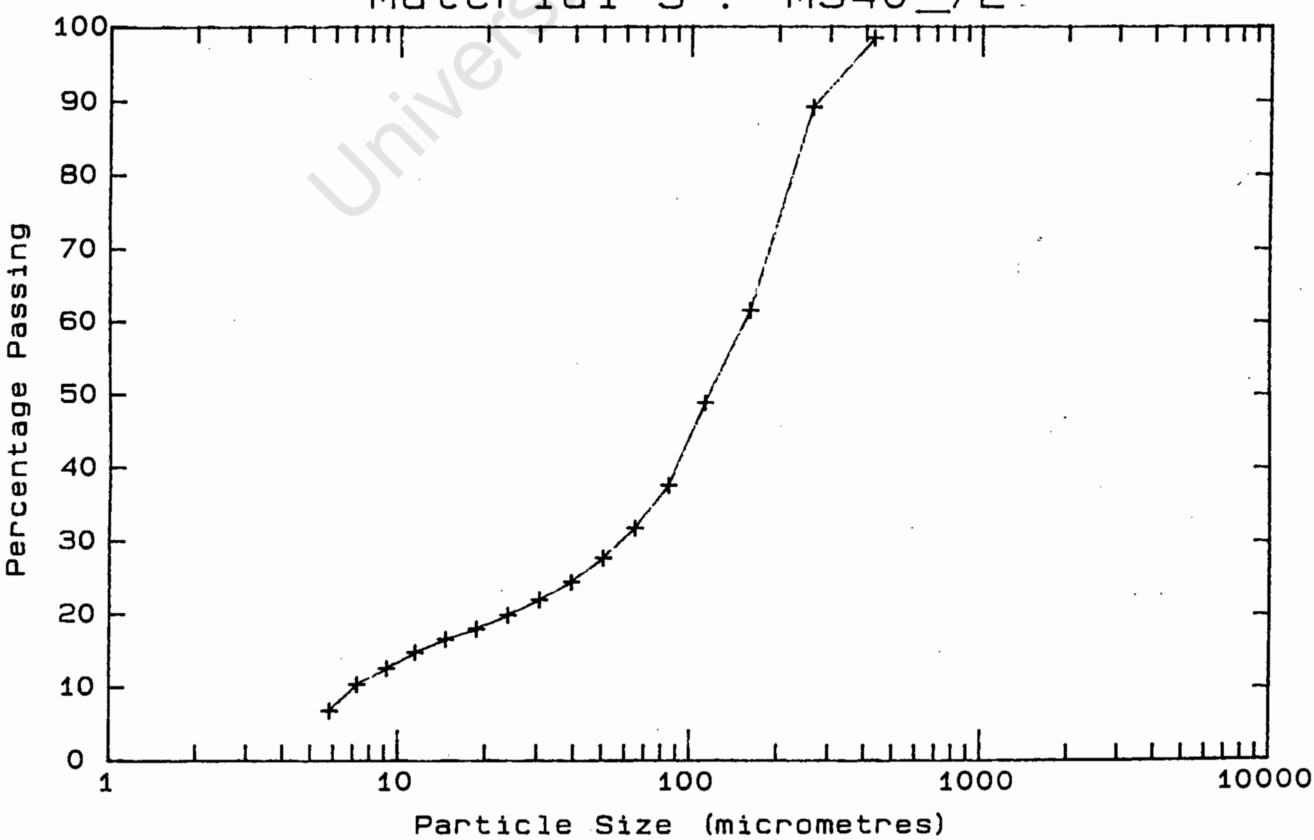
Velocity (m/s)	Observation (D = 46.0 mm)
.40	Sliding bed
.97	Sliding bed
1.33	Sliding bed
1.68	Asymetric
2.00	Appears homogeneous
2.28	Appears homogeneous
2.59	Appears homogeneous
2.87	Appears homogeneous

* –425 µm Malvern Particle Size Analyser

Material 3 : M340H72



Material 3 : M340_72



DATA FILE : M340D72

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.72
Solids Volumetric Concentration (%)	41.38
Solids Mass Concentration (%)	65.92
Mean Slurry Temperature (°C)	20.3
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.620	- 8.773	19.7
3.631	- 8.632	19.8
3.626	- 8.888	19.9
3.634	- 8.757	20.0
3.628	- 8.532	20.1
3.282	- 9.749	20.3
3.261	-10.071	20.4
3.251	-10.345	20.5
3.272	-10.175	20.5
2.898	-11.174	20.5
2.877	-11.182	20.5
2.875	-11.268	20.5
2.875	-11.394	20.5
2.518	-12.600	20.5
2.510	-12.419	20.5
2.554	-12.392	20.5
2.559	-12.109	20.5
2.114	-13.535	20.4
2.138	-14.243	20.4
2.094	-13.992	20.4
2.154	-14.276	20.3
2.145	-13.837	20.3
1.678	-15.197	20.2
1.687	-15.483	20.2
1.685	-15.144	20.2
1.678	-15.480	20.2
1.681	-15.206	20.2
1.222	-15.643	20.2
1.224	-15.283	20.2
1.230	-15.013	20.2
1.230	-15.563	20.1
.524	-16.189	20.1
.500	-15.671	20.1
.479	-15.968	20.1
.523	-16.072	20.1
.544	-16.262	20.1

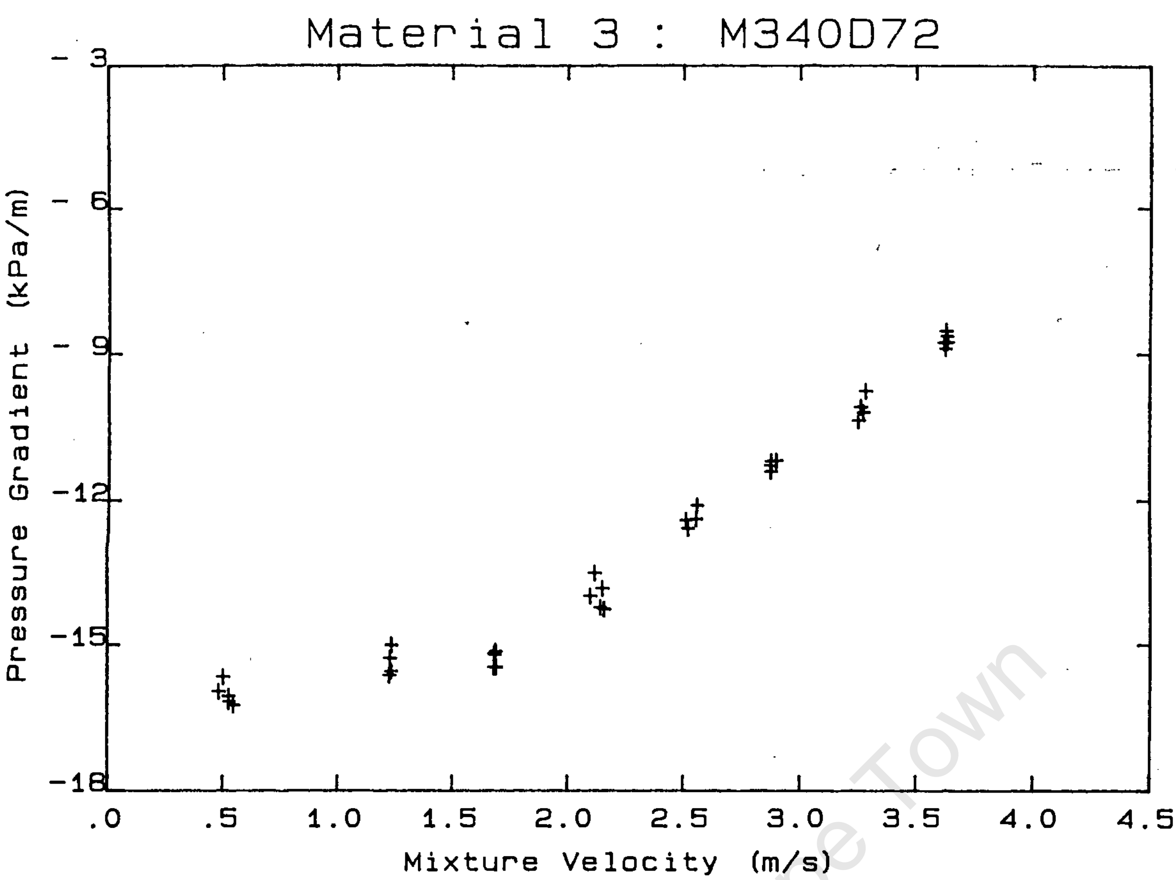
Particle Size Distribution
Sieve and Malvern Size Analysis *

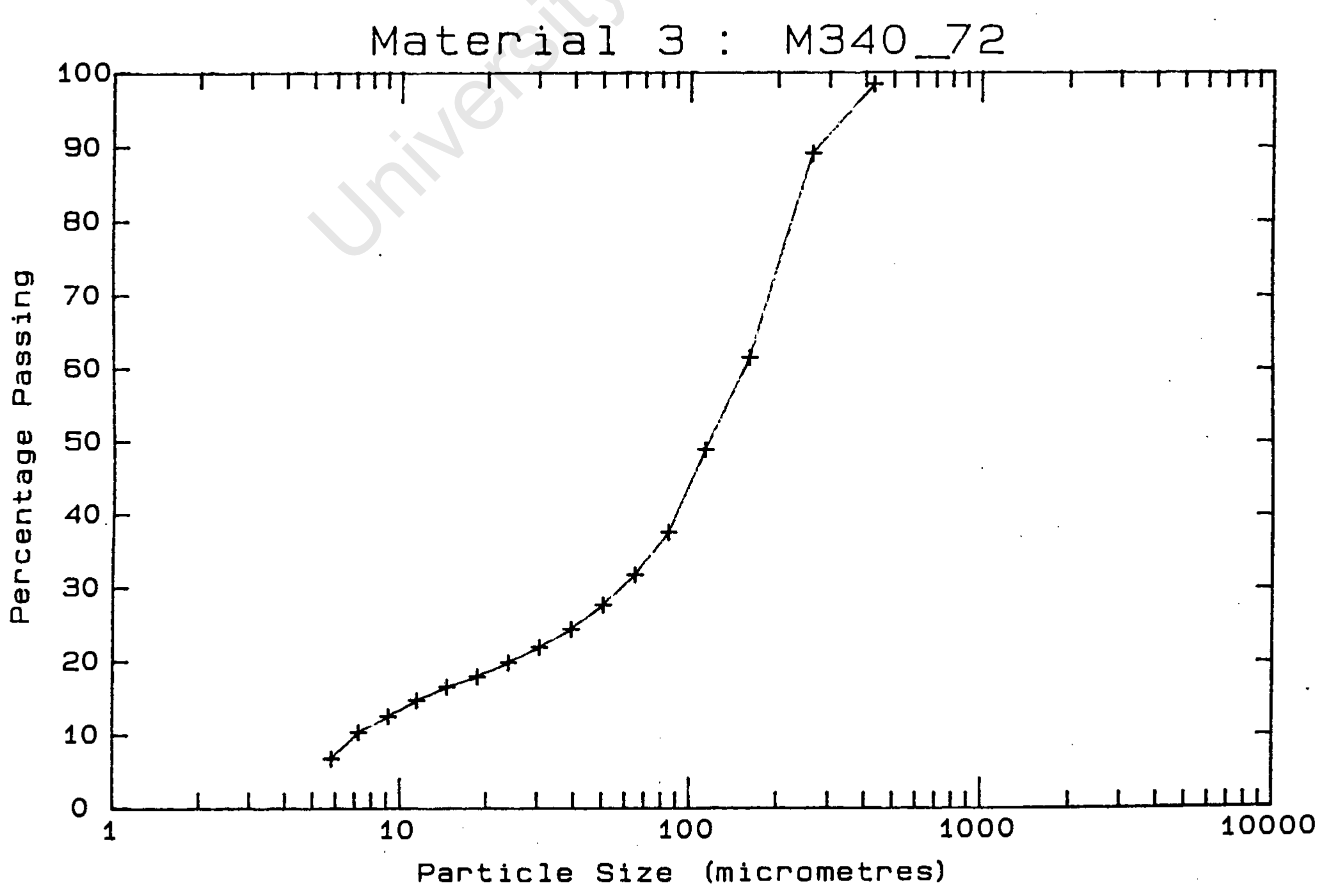
Size (µm)	% Passing	% Retained
425.0	98.3	1.7
261.6	89.0	9.3
160.4	61.4	27.6
112.8	48.8	12.6
84.3	37.5	11.3
64.6	31.7	5.8
50.2	27.6	4.1
39.0	24.3	3.3
30.3	21.9	2.4
23.7	19.8	2.1
18.5	17.9	1.9
14.5	16.5	1.4
11.4	14.7	1.8
9.1	12.5	2.2
7.2	10.3	2.2
5.8	6.7	3.6
Pan	- .1	6.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 3 : M340D72
Pressure Gradient (kPa/m)
Mixture Velocity (m/s)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Material 3 : M340_72
Percentage Passing
Particle Size (micrometres)
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000

DATA FILE : M340U72

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.72
Solids Volumetric Concentration (%)	41.38
Solids Mass Concentration (%)	65.92
Mean Slurry Temperature (°C)	20.3
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.620	23.975	19.7
3.631	23.430	19.8
3.626	23.256	19.9
3.634	23.732	20.0
3.628	23.568	20.1
3.282	22.572	20.3
3.261	22.737	20.4
3.251	22.301	20.5
3.272	22.437	20.5
2.898	21.462	20.5
2.877	21.453	20.5
2.875	21.525	20.5
2.875	21.560	20.5
2.518	20.302	20.5
2.510	20.360	20.5
2.554	20.360	20.5
2.559	20.564	20.5
2.114	19.161	20.4
2.138	19.339	20.4
2.094	19.277	20.4
2.154	19.134	20.3
2.145	19.279	20.3
1.678	18.110	20.2
1.687	18.112	20.2
1.685	18.078	20.2
1.678	18.141	20.2
1.681	18.080	20.2
1.222	17.827	20.2
1.224	17.892	20.2
1.230	17.861	20.2
1.230	17.906	20.1
.524	17.639	20.1
.500	17.514	20.1
.479	17.549	20.1
.523	17.667	20.1
.544	17.717	20.1

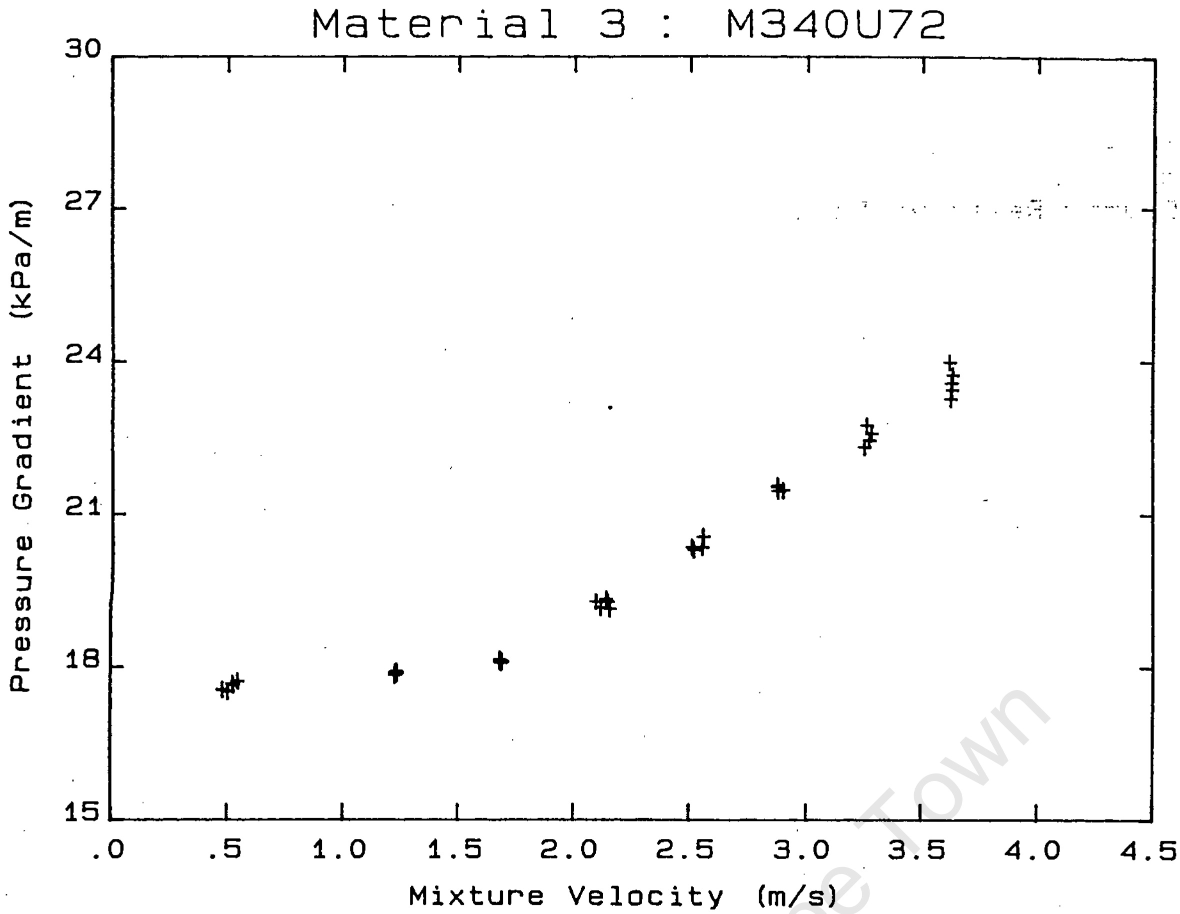
Particle Size Distribution
Sieve and Malvern Size Analysis *

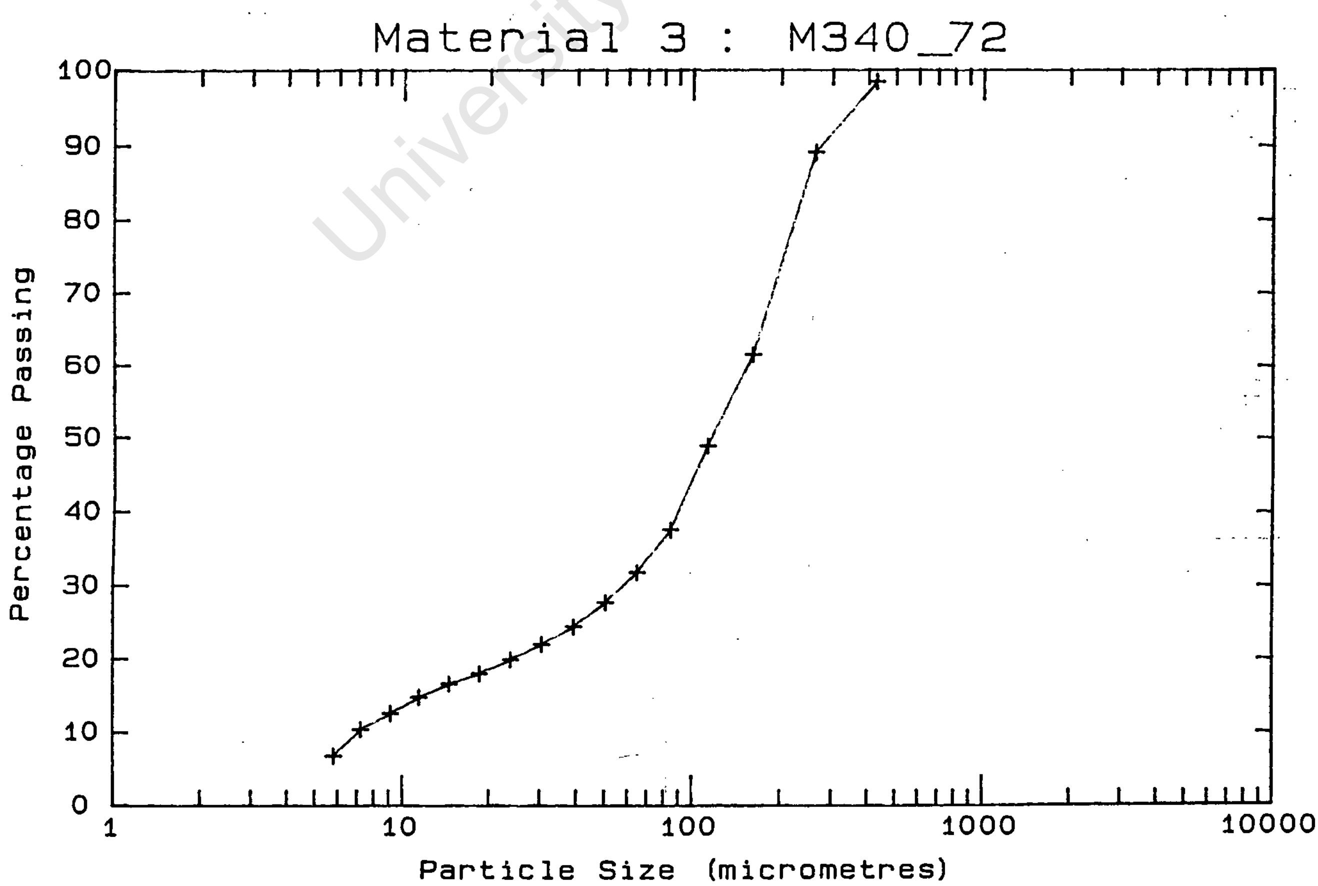
Size (µm)	% Passing	% Retained
425.0	98.3	1.7
261.6	89.0	9.3
160.4	61.4	27.6
112.8	48.8	12.6
84.3	37.5	11.3
64.6	31.7	5.8
50.2	27.6	4.1
39.0	24.3	3.3
30.3	21.9	2.4
23.7	19.8	2.1
18.5	17.9	1.9
14.5	16.5	1.4
11.4	14.7	1.8
9.1	12.5	2.2
7.2	10.3	2.2
5.8	6.7	3.6
Pan	- .1	6.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 3 : M340U72
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 3 : M340_72
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M340H79

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.79
Solids Volumetric Concentration (%)	45.40
Solids Mass Concentration (%)	69.50
Mean Slurry Temperature (°C)	22.8
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.682	7.010	22.1
3.681	6.583	22.2
3.666	6.413	22.3
3.670	7.140	22.3
3.694	6.760	22.4
3.258	6.170	22.6
3.256	5.964	22.7
3.263	6.097	22.8
3.260	6.245	22.8
2.870	5.513	23.0
2.870	5.376	23.0
2.869	5.292	23.0
2.859	5.302	23.0
2.872	5.079	23.1
2.533	4.990	23.0
2.509	4.799	23.0
2.522	4.710	23.0
2.510	4.743	23.0
2.105	4.210	23.0
2.054	4.152	23.0
2.048	4.115	23.0
2.043	4.077	23.0
1.737	3.695	22.9
1.790	3.758	22.9
1.776	3.779	22.9
1.787	3.781	22.9
1.273	3.103	22.8
1.285	3.124	22.8
1.279	3.101	22.8
1.283	3.073	22.7
.546	2.186	22.7
.517	2.129	22.7
.498	2.083	22.7
.464	2.131	22.7

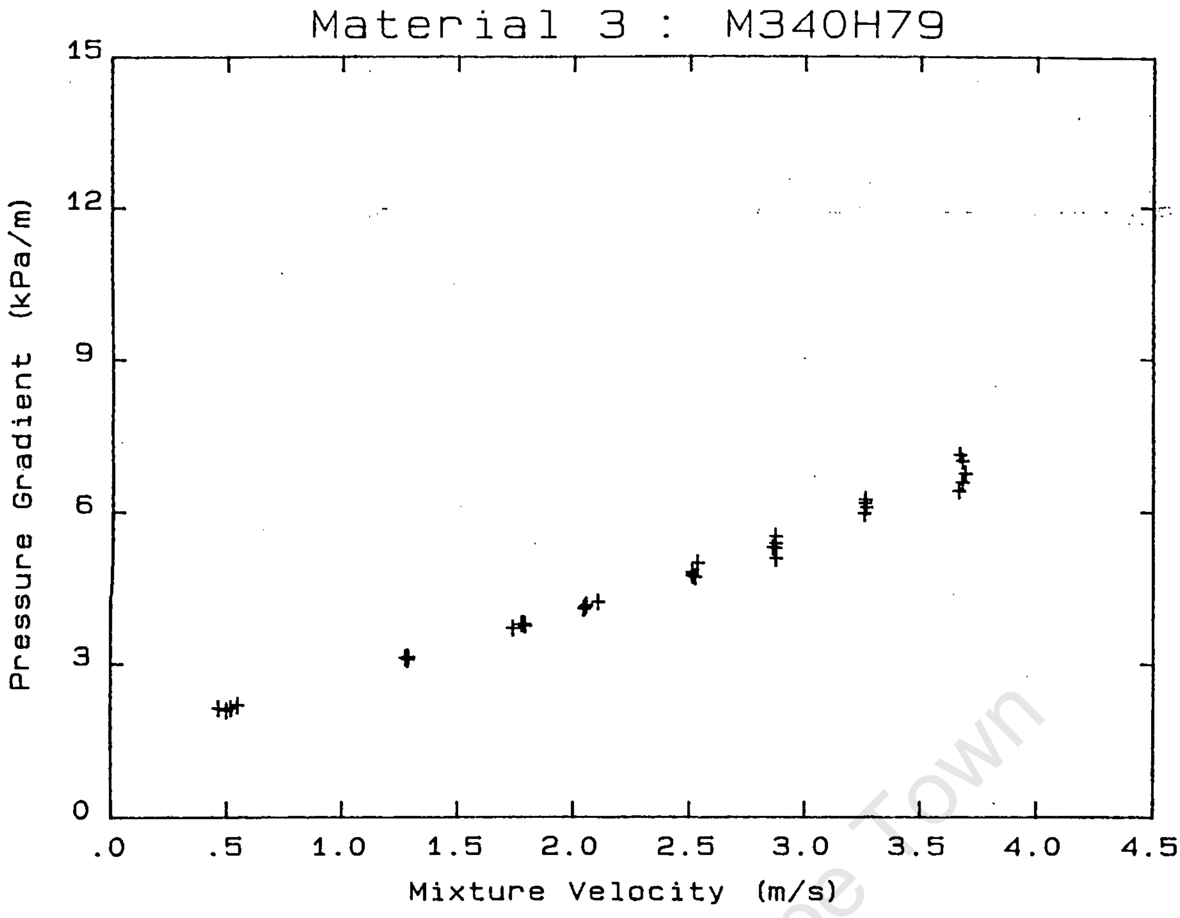
Particle Size Distribution
Sieve and Malvern Size Analysis *

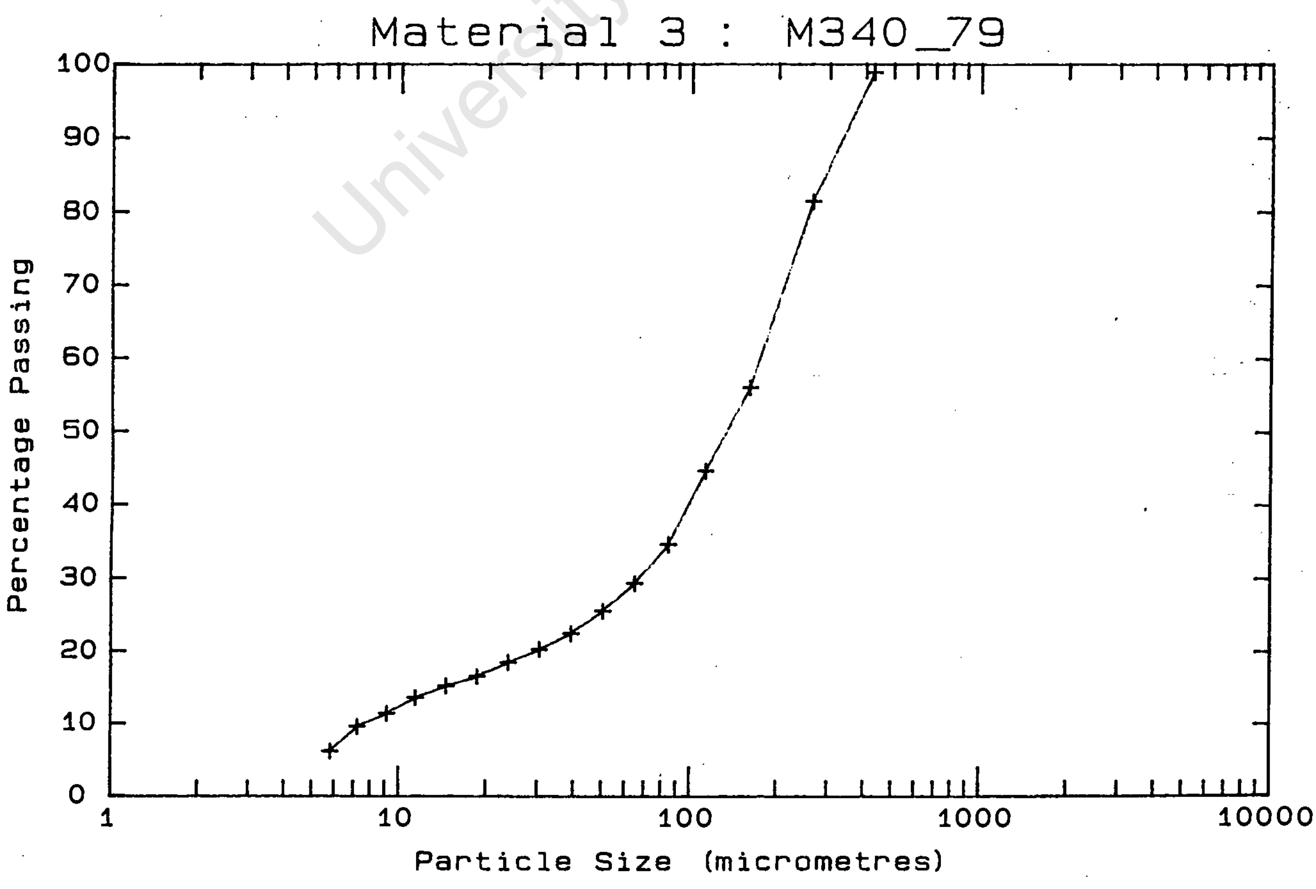
Size (µm)	% Passing	% Retained
425.0	98.7	1.3
261.6	81.3	17.4
160.4	55.9	25.4
112.8	44.5	11.4
84.3	34.5	10.0
64.6	29.2	5.3
50.2	25.4	3.8
39.0	22.3	3.1
30.3	20.1	2.2
23.7	18.3	1.8
18.5	16.4	1.9
14.5	15.1	1.3
11.4	13.5	1.6
9.1	11.3	2.2
7.2	9.5	1.8
5.8	6.1	3.4
Pan	- .3	6.4

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.40	Asymetric
1.01	Asymetric
1.41	Asymetric
1.63	Asymetric
1.99	Appears homogeneous
2.27	Appears homogeneous
2.58	Appears homogeneous
2.90	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 3 : M340H79
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 3 : M340_79
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M340D79

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.79
Solids Volumetric Concentration (%)	45.40
Solids Mass Concentration (%)	69.50
Mean Slurry Temperature (°C)	22.8
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.682	-11.586	22.1
3.681	-11.685	22.2
3.666	-11.581	22.3
3.670	-11.595	22.3
3.694	-11.542	22.4
3.258	-12.250	22.6
3.256	-12.277	22.7
3.263	-12.242	22.8
3.260	-11.969	22.8
2.870	-12.830	23.0
2.870	-12.832	23.0
2.869	-12.532	23.0
2.859	-12.708	23.0
2.872	-12.549	23.1
2.533	-13.109	23.0
2.509	-13.129	23.0
2.522	-13.318	23.0
2.510	-13.140	23.0
2.105	-13.708	23.0
2.054	-13.760	23.0
2.048	-13.833	23.0
2.043	-13.866	23.0
1.737	-14.154	22.9
1.790	-14.018	22.9
1.776	-14.038	22.9
1.787	-14.059	22.9
1.273	-14.438	22.8
1.285	-14.287	22.8
1.279	-14.351	22.8
1.283	-14.091	22.7
.546	-15.161	22.7
.517	-15.117	22.7
.498	-15.175	22.7
.464	-15.268	22.7

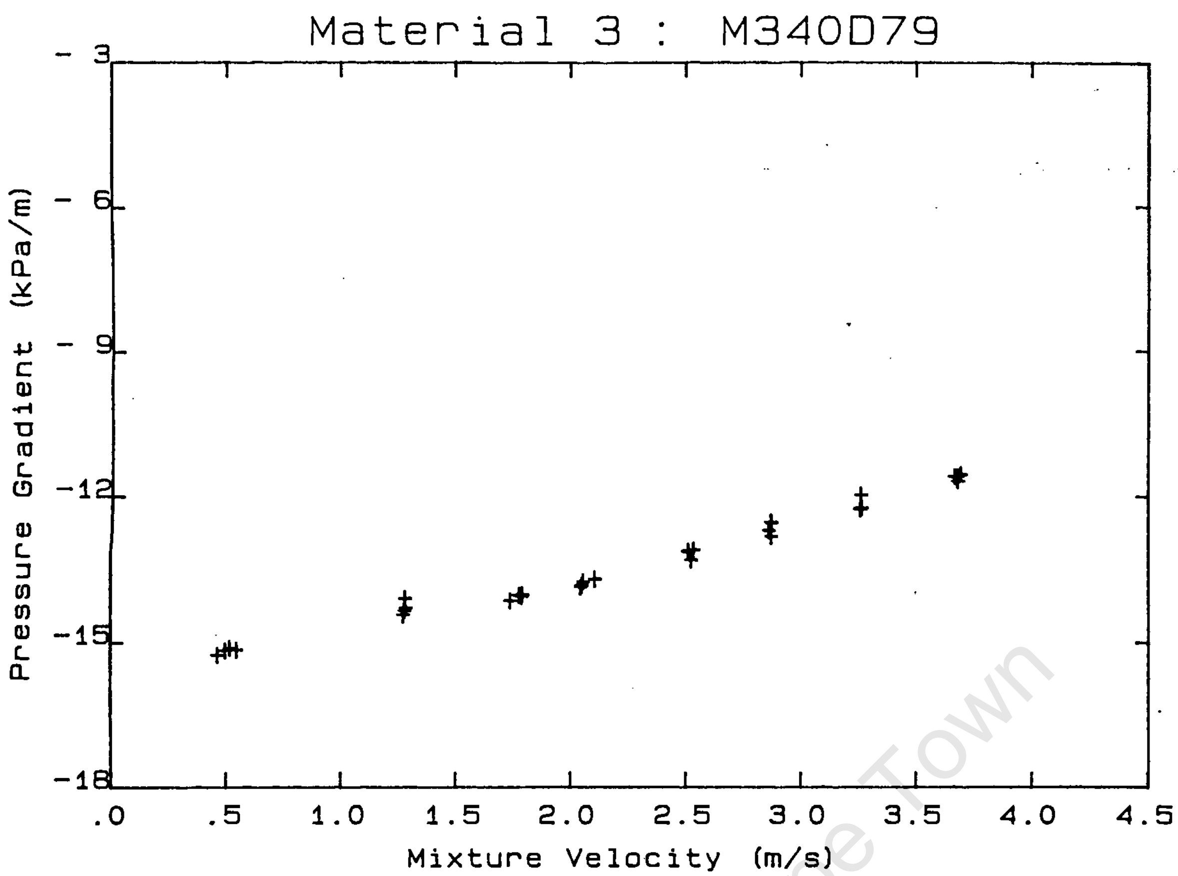
Particle Size Distribution
Sieve and Malvern Size Analysis *

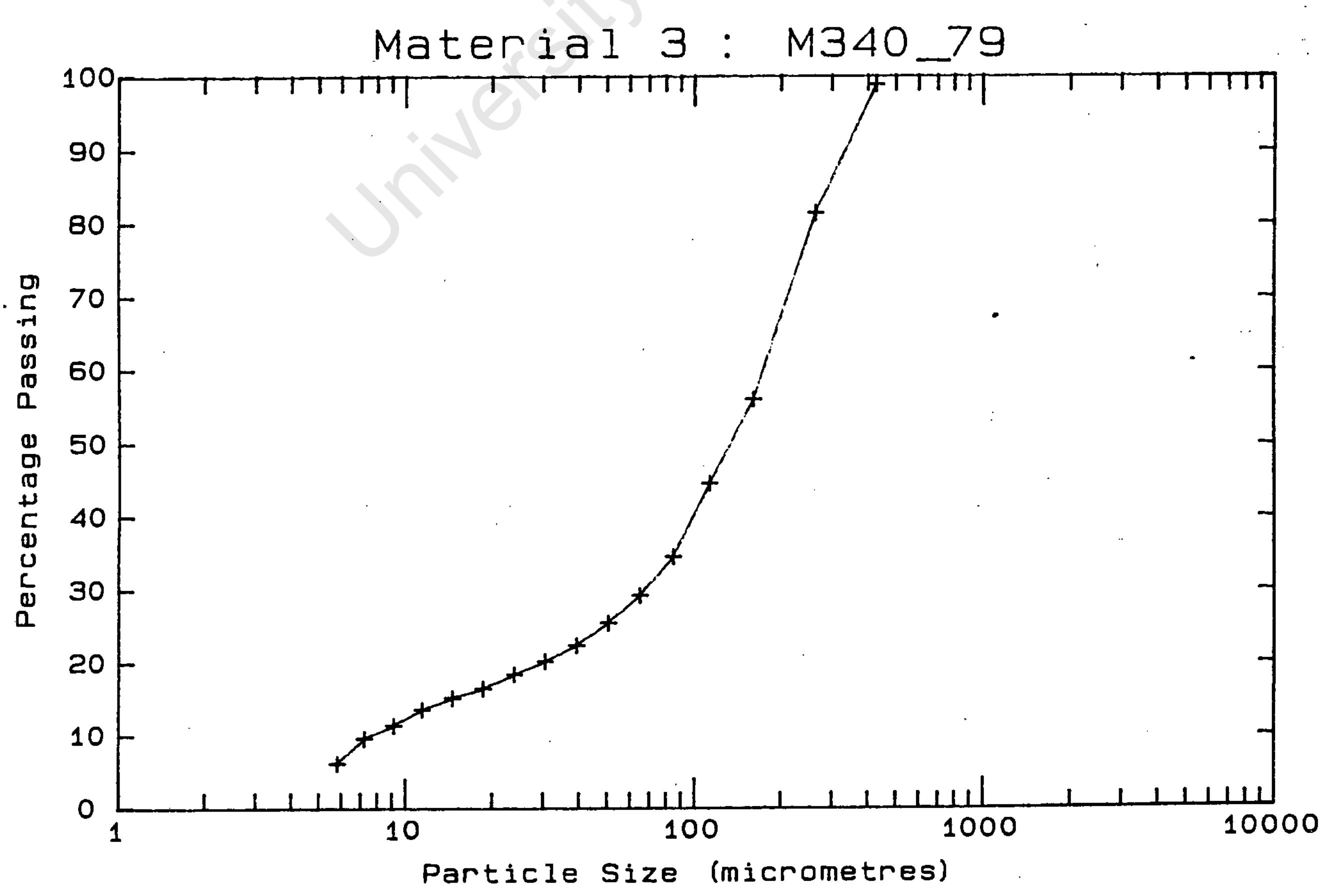
Size (μm)	% Passing	% Retained
425.0	98.7	1.3
261.6	81.3	17.4
160.4	55.9	25.4
112.8	44.5	11.4
84.3	34.5	10.0
64.6	29.2	5.3
50.2	25.4	3.8
39.0	22.3	3.1
30.3	20.1	2.2
23.7	18.3	1.8
18.5	16.4	1.9
14.5	15.1	1.3
11.4	13.5	1.6
9.1	11.3	2.2
7.2	9.5	1.8
5.8	6.1	3.4
Pan	- .3	6.4

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 μm Malvern Particle Size Analyser


Material 3 : M340D79
Pressure Gradient (kPa/m)
- 3
- 6
- 9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 3 : M340_79
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M340U79

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.79
Solids Volumetric Concentration (%)	45.40
Solids Mass Concentration (%)	69.50
Mean Slurry Temperature (°C)	22.8
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.682	22.912	22.1
3.681	23.236	22.2
3.666	23.603	22.3
3.670	23.317	22.3
3.694	23.274	22.4
3.258	22.594	22.6
3.256	22.268	22.7
3.263	22.319	22.8
3.260	22.341	22.8
2.870	22.049	23.0
2.870	22.049	23.0
2.869	22.372	23.0
2.859	22.198	23.0
2.872	22.633	23.1
2.533	21.863	23.0
2.509	21.856	23.0
2.522	21.973	23.0
2.510	21.814	23.0
2.105	21.201	23.0
2.054	21.258	23.0
2.048	21.255	23.0
2.043	21.220	23.0
1.737	20.906	22.9
1.790	21.051	22.9
1.776	20.964	22.9
1.787	20.910	22.9
1.273	20.405	22.8
1.285	20.528	22.8
1.279	20.501	22.8
1.283	20.442	22.7
.546	19.770	22.7
.517	19.803	22.7
.498	19.692	22.7
.464	19.602	22.7

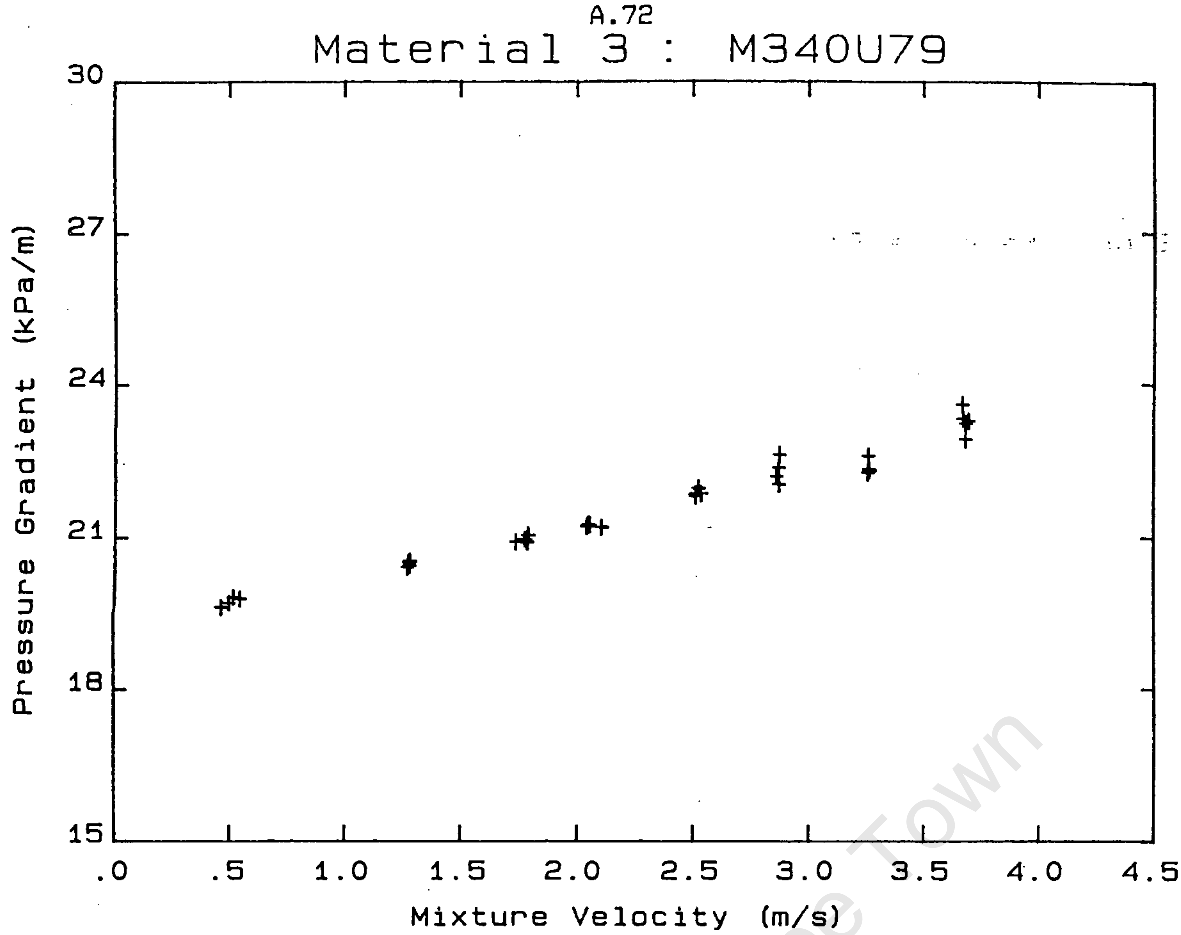
Particle Size Distribution
Sieve and Malvern Size Analysis *

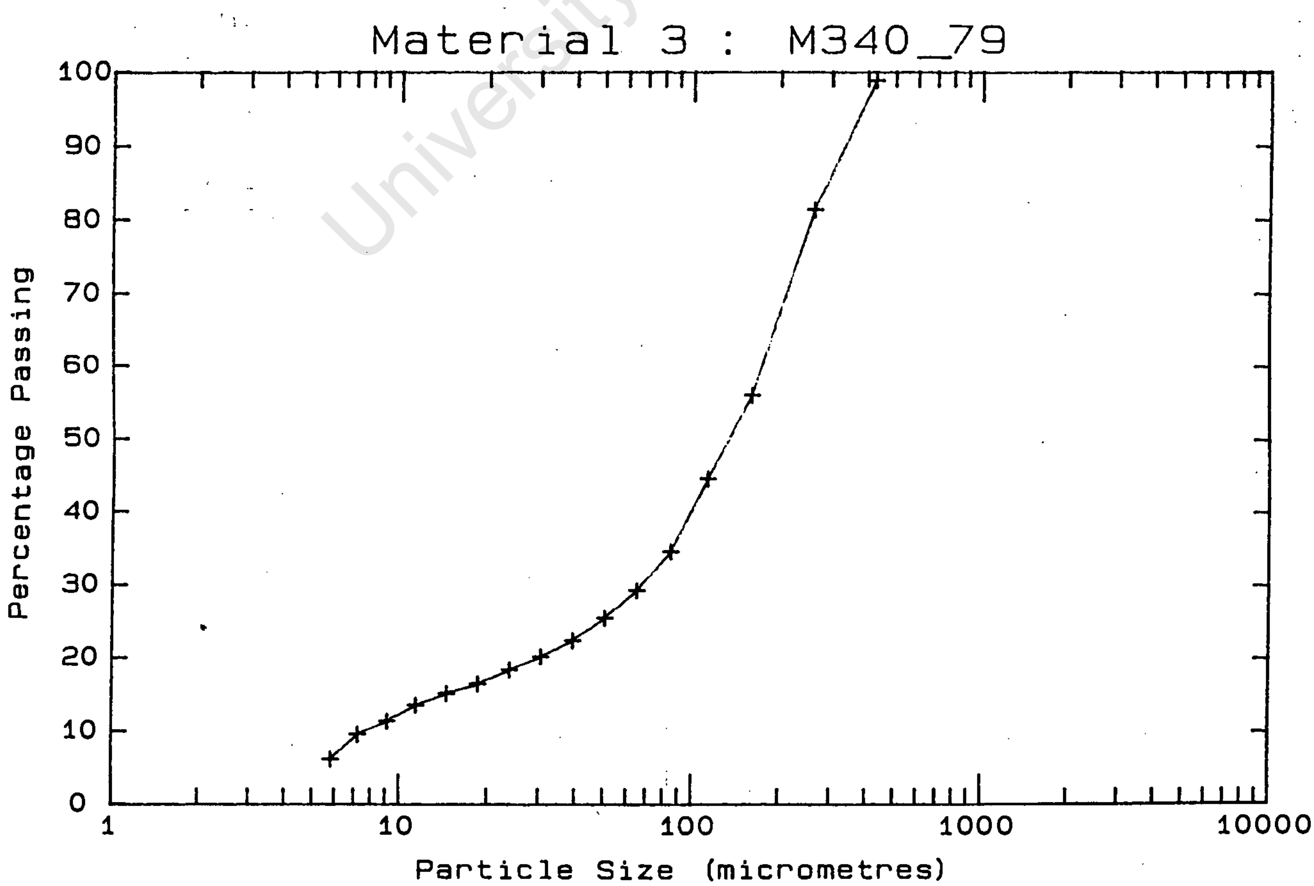
Size (µm)	% Passing	% Retained
425.0	98.7	1.3
261.6	81.3	17.4
160.4	55.9	25.4
112.8	44.5	11.4
84.3	34.5	10.0
64.6	29.2	5.3
50.2	25.4	3.8
39.0	22.3	3.1
30.3	20.1	2.2
23.7	18.3	1.8
18.5	16.4	1.9
14.5	15.1	1.3
11.4	13.5	1.6
9.1	11.3	2.2
7.2	9.5	1.8
5.8	6.1	3.4
Pan	– .3	6.4

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* –425 µm Malvern Particle Size Analyser


Material 3 : M340U79
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 3 : M340_79
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M340H86

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.86
Solids Volumetric Concentration (%)	49.43
Solids Mass Concentration (%)	72.81
Mean Slurry Temperature (°C)	26.0
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.086	13.194	24.3
4.082	13.032	24.6
4.065	12.686	25.0
4.068	12.692	25.2
3.458	12.100	25.4
3.441	11.899	25.5
3.441	11.878	25.7
3.430	11.497	25.8
3.031	10.608	26.1
3.044	10.735	26.1
3.060	10.823	26.2
3.060	10.306	26.2
2.471	8.934	26.3
2.436	9.153	26.4
2.397	9.011	26.4
2.357	8.947	26.4
2.026	8.116	26.4
2.011	7.963	26.4
2.029	8.084	26.4
2.046	8.291	26.4
1.483	6.650	26.4
1.451	7.138	26.4
1.415	6.879	26.4
1.367	6.891	26.4
.956	5.716	26.3
.945	5.681	26.3
.933	5.660	26.2
.918	5.596	26.2
.480	4.612	26.1
.459	4.600	26.1
.447	4.619	26.1
.434	4.582	26.1

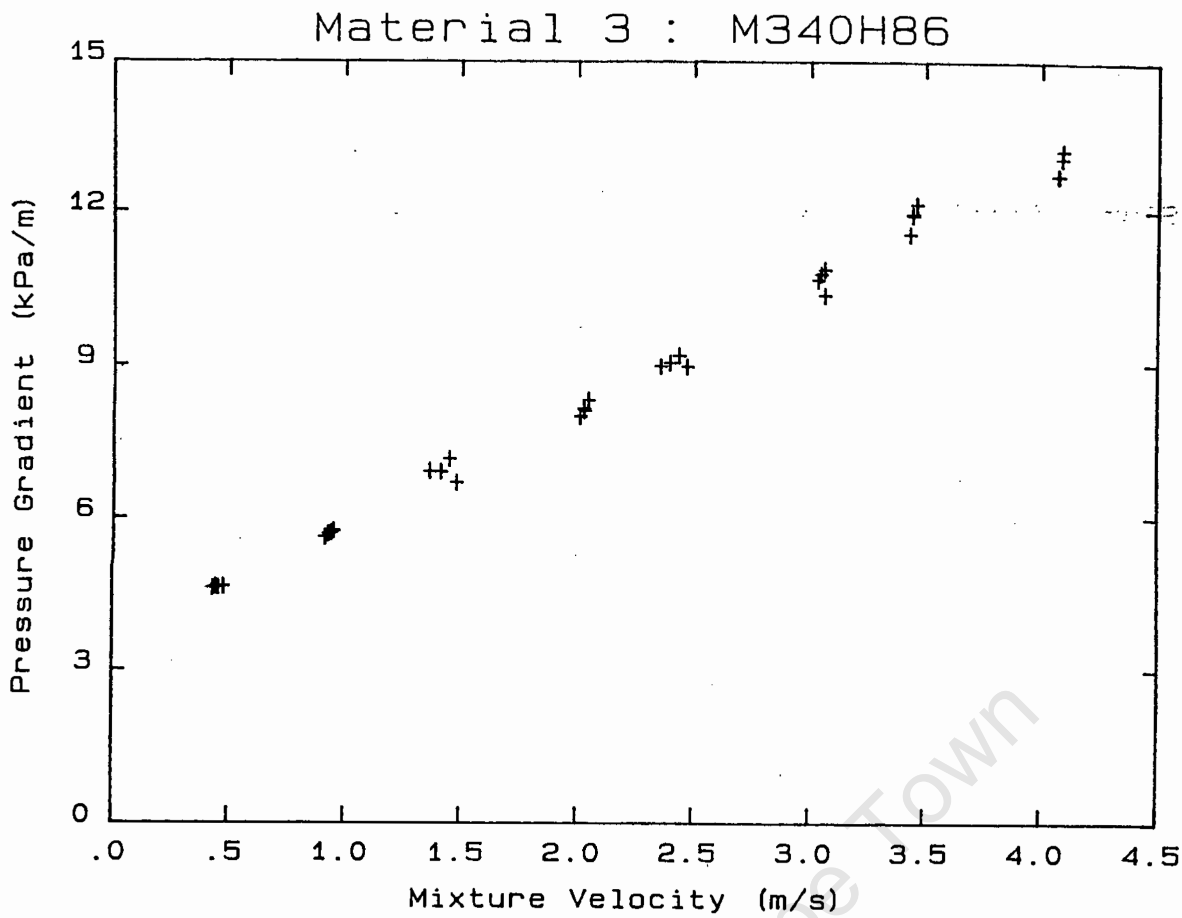
Particle Size Distribution
Sieve and Malvern Size Analysis *

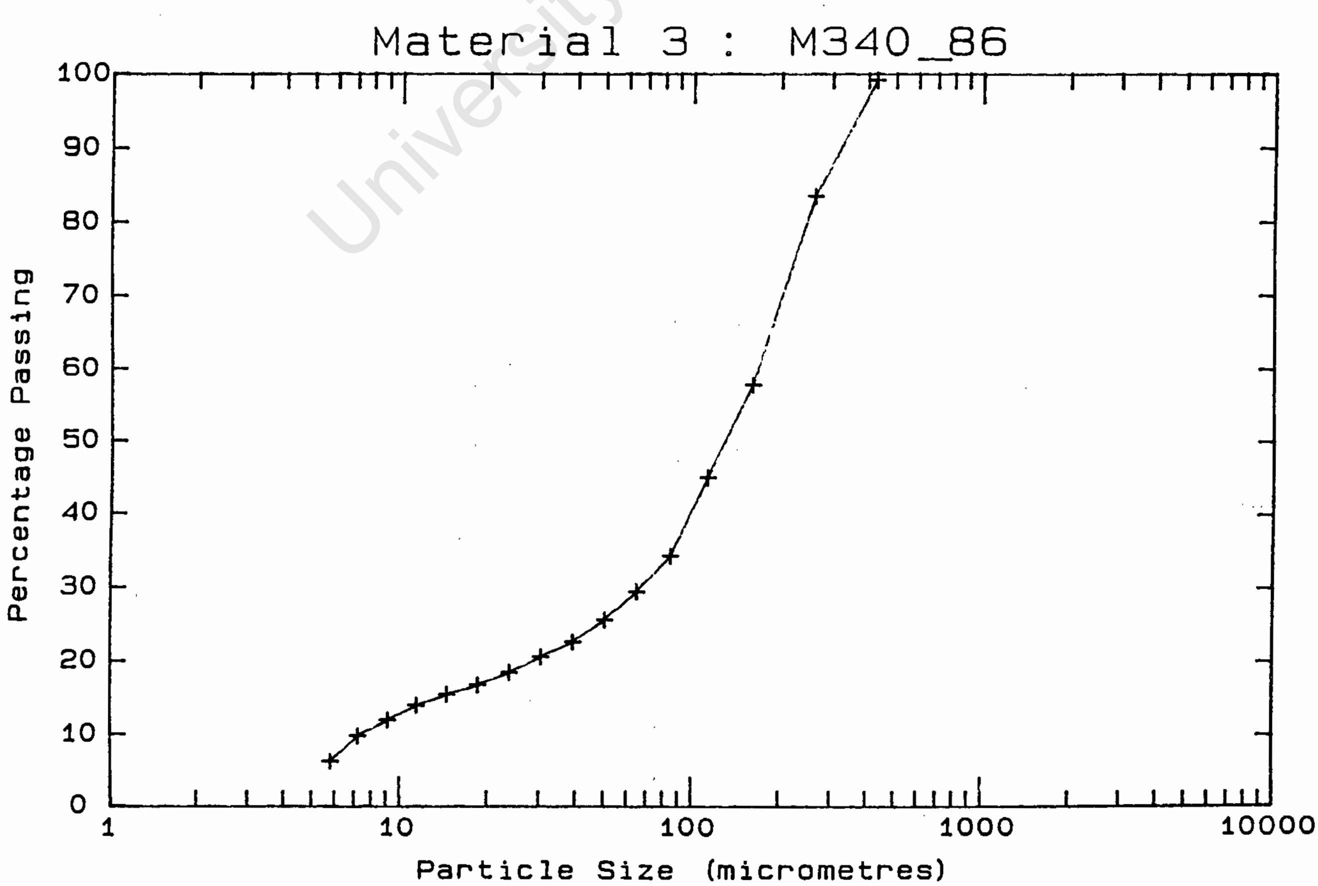
Size (µm)	% Passing	% Retained
425.0	99.0	1.0
261.6	83.4	15.6
160.4	57.7	25.7
112.8	44.9	12.8
84.3	34.2	10.7
64.6	29.3	4.9
50.2	25.5	3.8
39.0	22.5	3.0
30.3	20.5	2.0
23.7	18.4	2.1
18.5	16.7	1.7
14.5	15.4	1.3
11.4	13.9	1.5
9.1	11.9	2.0
7.2	9.7	2.2
5.8	6.2	3.5
Pan	.0	6.2

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.36	Appears homogeneous
.74	Appears homogeneous
1.12	Appears homogeneous
1.61	Appears homogeneous
1.90	Appears homogeneous
2.41	Appears homogeneous
2.72	Appears homogeneous
3.22	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 3 : M340H86
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 3 : M340_86
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M340D86

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.86
Solids Volumetric Concentration (%)	49.43
Solids Mass Concentration (%)	72.81
Mean Slurry Temperature (°C)	26.0
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.086	- 5.845	24.3
4.082	- 5.960	24.6
4.065	- 5.782	25.0
4.068	- 5.932	25.2
3.458	- 7.589	25.4
3.441	- 7.453	25.5
3.441	- 7.649	25.7
3.430	- 7.711	25.8
3.031	- 8.008	26.1
3.044	- 8.205	26.1
3.060	- 8.335	26.2
3.060	- 8.361	26.2
2.471	- 9.764	26.3
2.436	- 8.951	26.4
2.397	- 9.293	26.4
2.357	- 9.249	26.4
2.026	-10.053	26.4
2.011	-10.823	26.4
2.029	-10.315	26.4
2.046	-10.374	26.4
1.483	-11.857	26.4
1.451	-11.431	26.4
1.415	-11.458	26.4
1.367	-11.704	26.4
.956	-12.426	26.3
.945	-12.472	26.3
.933	-12.469	26.2
.918	-12.530	26.2
.480	-13.614	26.1
.459	-13.616	26.1
.447	-13.661	26.1
.434	-13.664	26.1

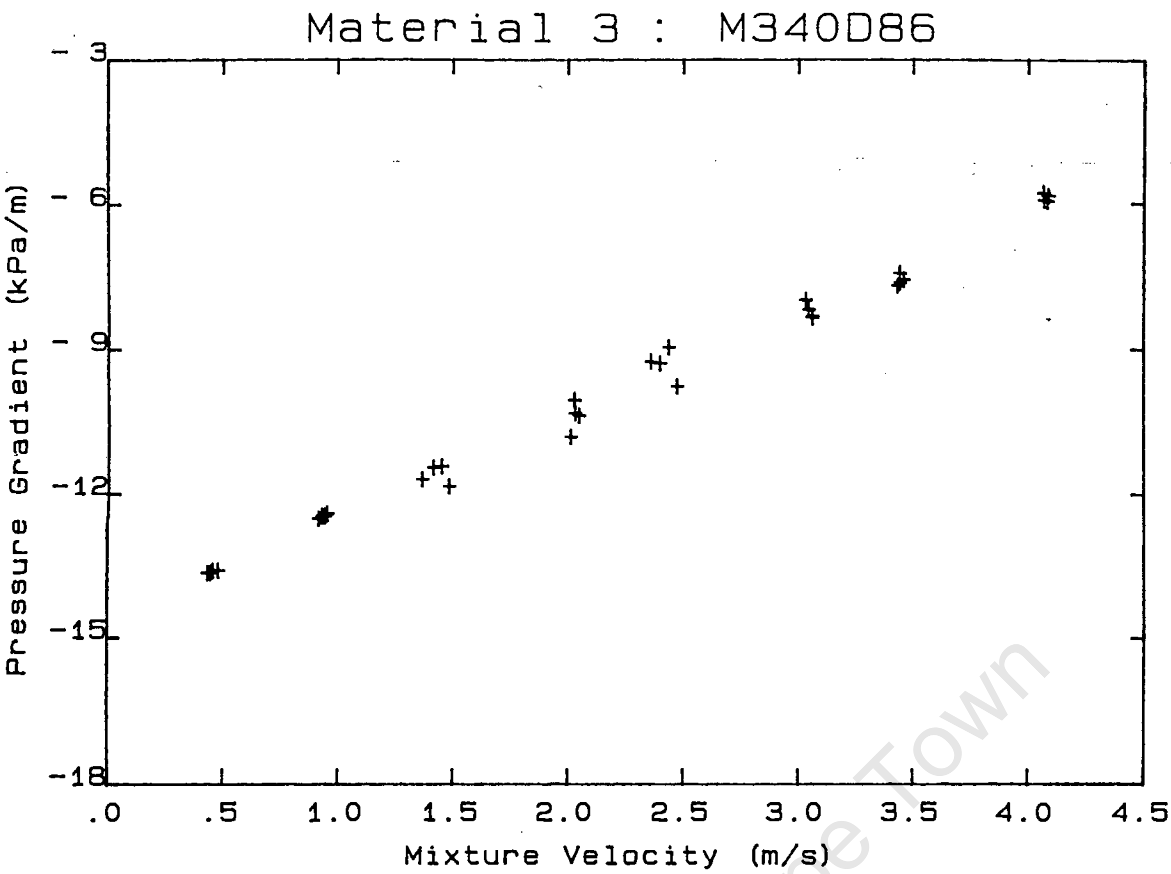
Particle Size Distribution
Sieve and Malvern Size Analysis *

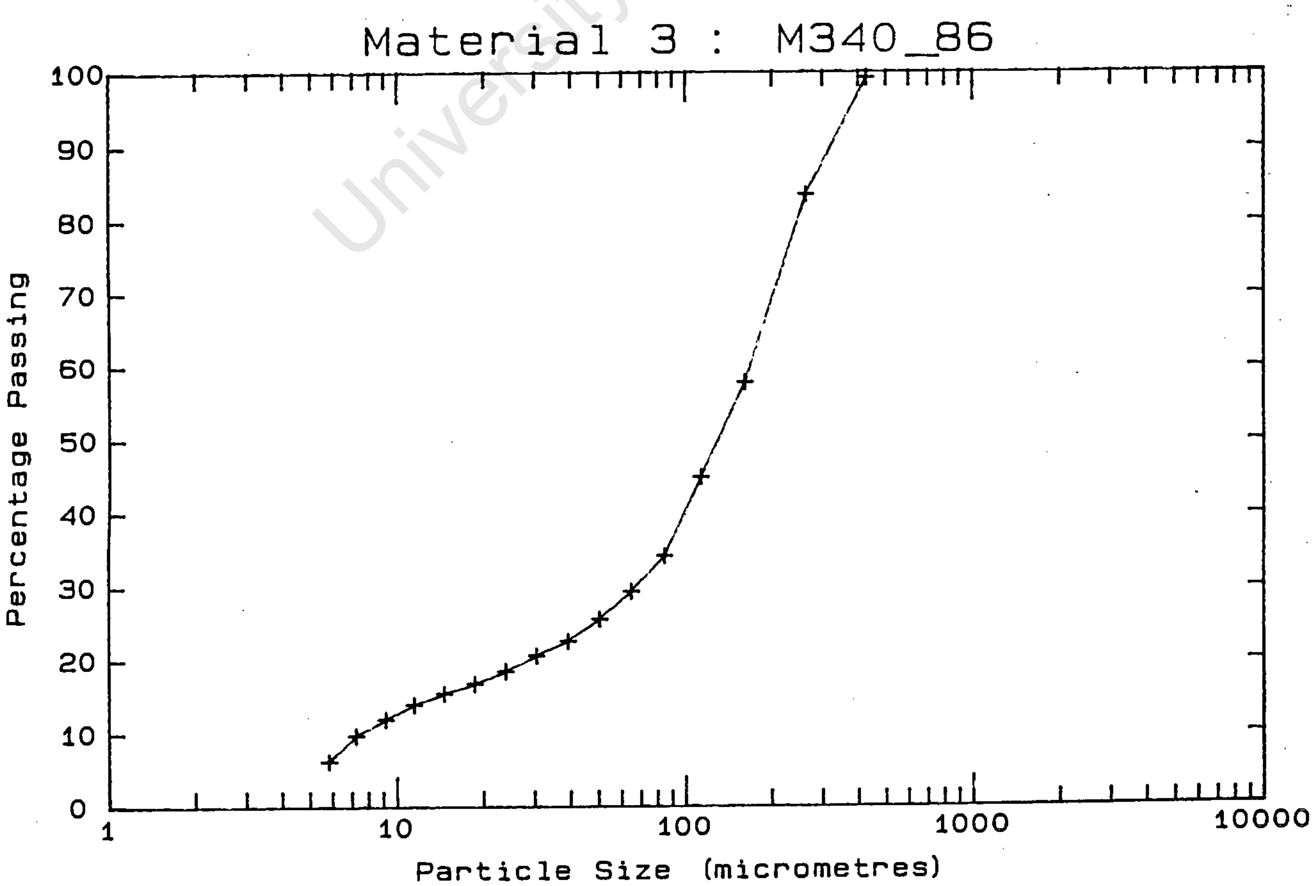
Size (µm)	% Passing	% Retained
425.0	99.0	1.0
261.6	83.4	15.6
160.4	57.7	25.7
112.8	44.9	12.8
84.3	34.2	10.7
64.6	29.3	4.9
50.2	25.5	3.8
39.0	22.5	3.0
30.3	20.5	2.0
23.7	18.4	2.1
18.5	16.7	1.7
14.5	15.4	1.3
11.4	13.9	1.5
9.1	11.9	2.0
7.2	9.7	2.2
5.8	6.2	3.5
Pan	.0	6.2

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 3 : M340D86
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 3 : M340_86
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M340U86

Test Facility	UCT 40 mm NB
Test Date	28/05/91
Material Description	MATERIAL 3
Material Relative Density	2.74
Slurry Relative Density	1.86
Solids Volumetric Concentration (%)	49.43
Solids Mass Concentration (%)	72.81
Mean Slurry Temperature (°C)	26.0
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.086	29.193	24.3
4.082	29.642	24.6
4.065	29.357	25.0
4.068	29.462	25.2
3.458	28.139	25.4
3.441	28.296	25.5
3.441	28.730	25.7
3.430	28.242	25.8
3.031	27.756	26.1
3.044	27.916	26.1
3.060	27.510	26.2
3.060	27.743	26.2
2.471	26.027	26.3
2.436	27.413	26.4
2.397	27.307	26.4
2.357	26.710	26.4
2.026	26.052	26.4
2.011	25.888	26.4
2.029	25.941	26.4
2.046	25.683	26.4
1.483	24.418	26.4
1.451	24.668	26.4
1.415	24.670	26.4
1.367	24.735	26.4
.956	23.715	26.3
.945	23.919	26.3
.933	23.744	26.2
.918	23.803	26.2
.480	22.997	26.1
.459	22.851	26.1
.447	22.977	26.1
.434	22.835	26.1

Particle Size Distribution
Sieve and Malvern Size Analysis *

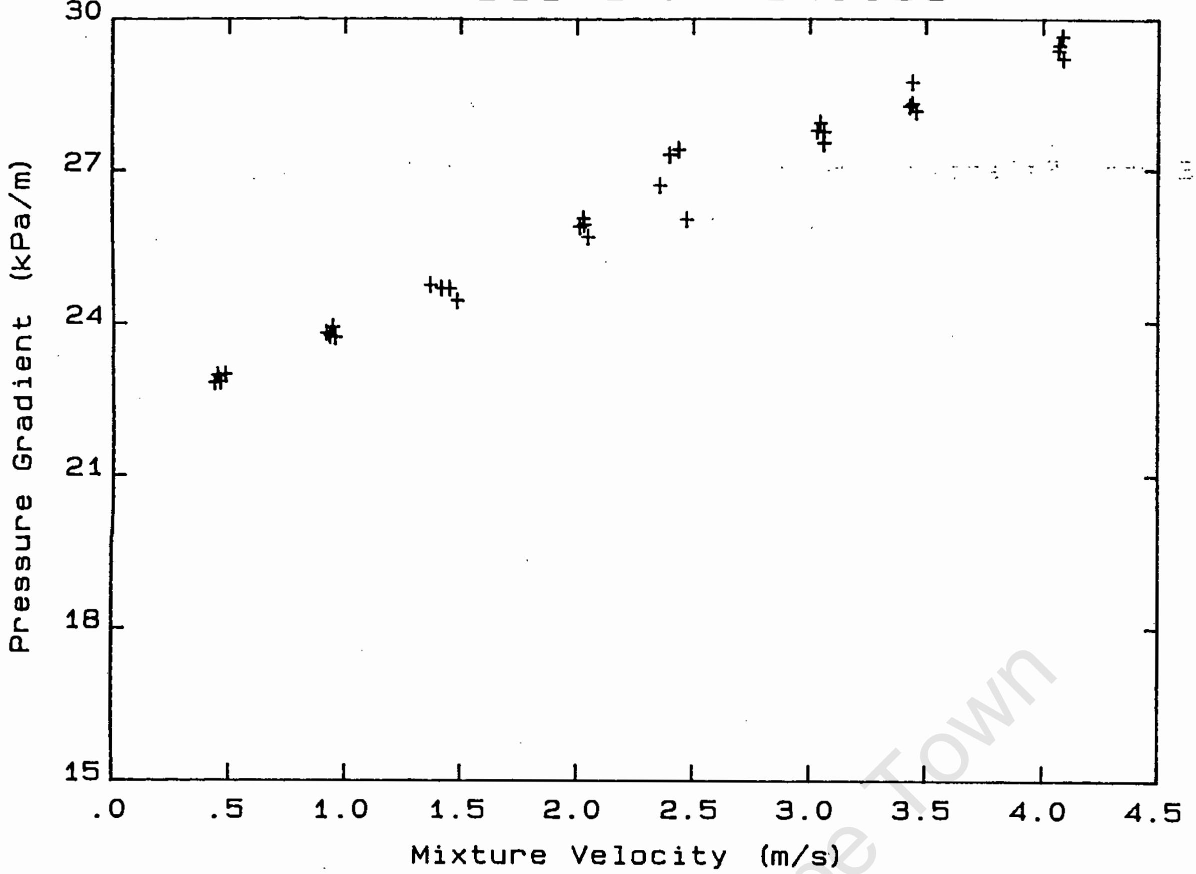
Size (µm)	% Passing	% Retained
425.0	99.0	1.0
261.6	83.4	15.6
160.4	57.7	25.7
112.8	44.9	12.8
84.3	34.2	10.7
64.6	29.3	4.9
50.2	25.5	3.8
39.0	22.5	3.0
30.3	20.5	2.0
23.7	18.4	2.1
18.5	16.7	1.7
14.5	15.4	1.3
11.4	13.9	1.5
9.1	11.9	2.0
7.2	9.7	2.2
5.8	6.2	3.5
Pan	.0	6.2

OBSERVED FLOW BEHAVIOUR

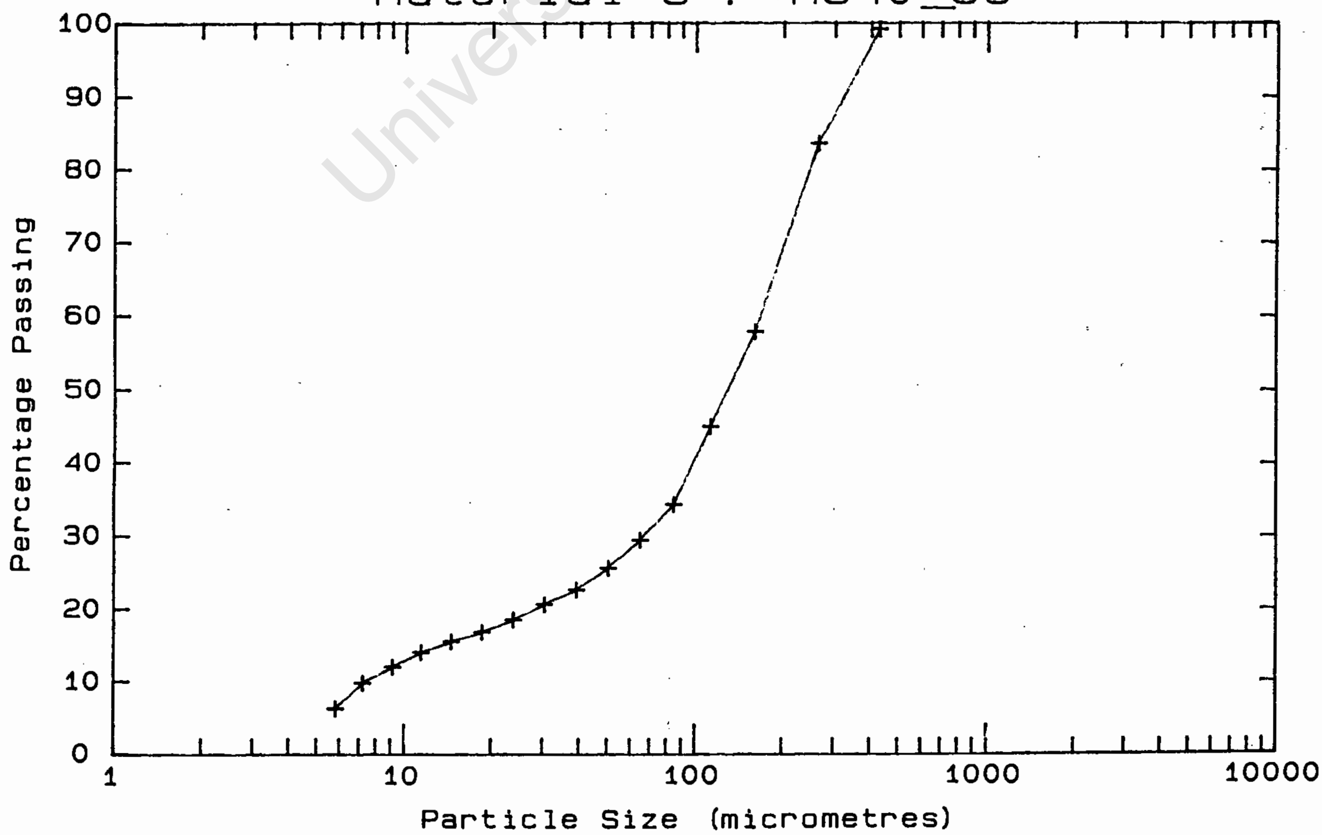
Velocity (m/s)	Observation (D = 46.0 mm)

* −425 µm Malvern Particle Size Analyser

Material 3 : M340U86



Material 3 : M340_86



DATA FILE : M440H67

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.66
Solids Volumetric Concentration (%)	37.93
Solids Mass Concentration (%)	62.61
Mean Slurry Temperature (°C)	20.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.065	9.173	20.2
4.076	9.450	20.3
4.076	8.871	20.3
4.073	8.880	20.3
3.553	7.366	20.4
3.548	7.311	20.4
3.552	7.217	20.4
3.547	7.139	20.4
3.041	5.709	20.4
3.058	5.777	20.4
3.039	5.591	20.4
3.060	5.795	20.4
2.551	4.145	20.3
2.548	4.212	20.3
2.553	4.185	20.3
2.553	4.286	20.3
2.017	2.875	20.2
2.012	2.936	20.2
2.017	2.634	20.2
2.026	3.077	20.2
1.533	2.778	20.1
1.551	1.785	20.1
1.546	1.405	20.0
1.558	2.510	20.1
1.563	1.859	20.1
1.561	2.087	20.0
.994	3.118	20.0
1.013	3.107	20.0
1.047	3.015	20.0
1.032	2.093	20.0
1.063	2.473	19.9

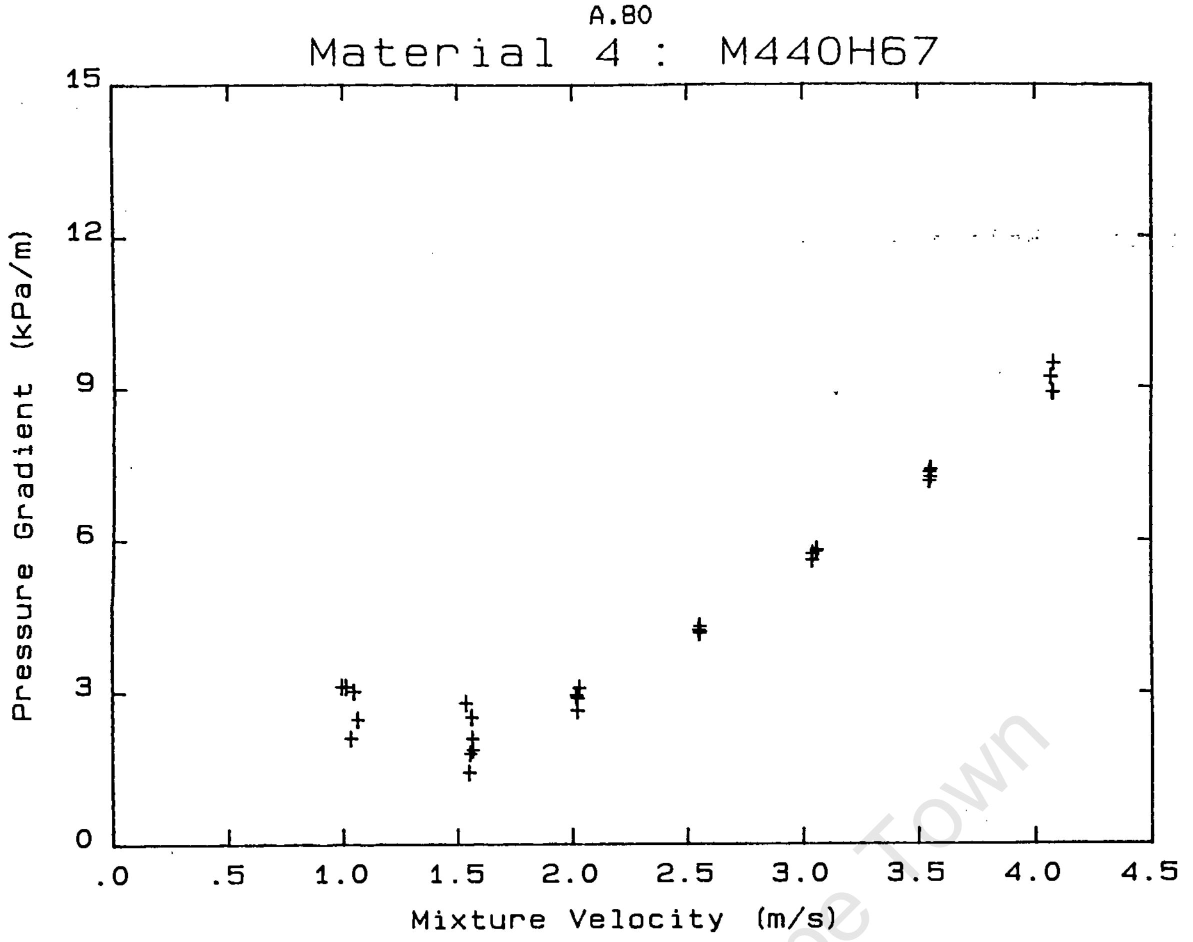
Particle Size Distribution
Sieve and Malvern Size Analysis *

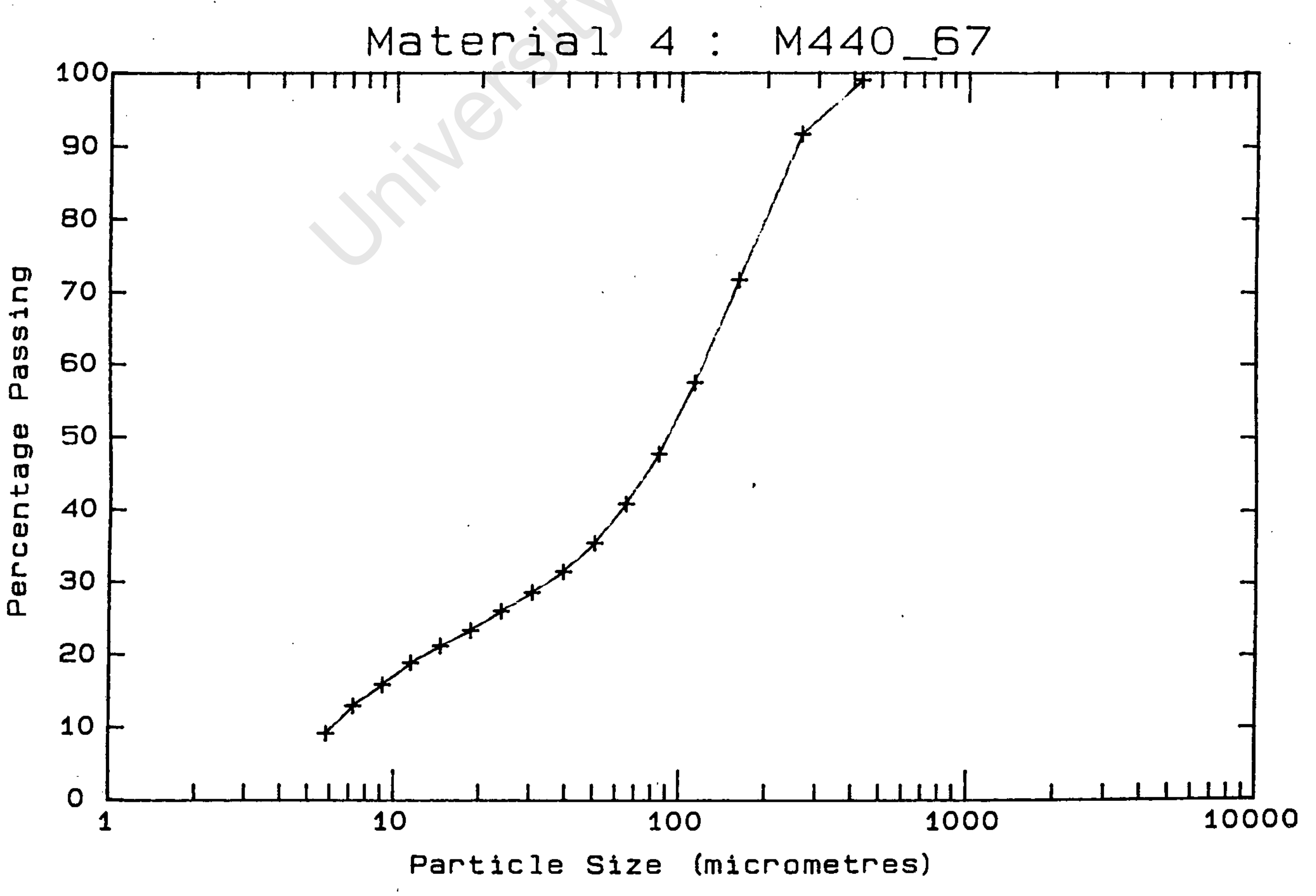
Size (μm)	% Passing	% Retained
425.0	98.9	1.1
261.6	91.5	7.4
160.4	71.6	19.9
112.8	57.3	14.3
84.3	47.6	9.7
64.6	40.8	6.8
50.2	35.4	5.4
39.0	31.4	4.0
30.3	28.5	2.9
23.7	25.9	2.6
18.5	23.2	2.7
14.5	21.1	2.1
11.4	18.8	2.3
9.1	15.8	3.0
7.2	12.9	2.9
5.8	9.1	3.8
Pan	- .2	9.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.81	Sliding bed
1.23	Asymetric
1.60	Asymetric
2.02	Appears homogeneous
2.41	Appears homogeneous
2.87	Appears homogeneous
3.22	Appears homogeneous

* -425 μm Malvern Particle Size Analyser


Material 4 : M440H67
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_67
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440D67

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.66
Solids Volumetric Concentration (%)	37.93
Solids Mass Concentration (%)	62.61
Mean Slurry Temperature (°C)	20.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.065	- 6.930	20.2
4.076	- 7.342	20.3
4.076	- 7.116	20.3
4.073	- 7.027	20.3
3.553	- 8.861	20.4
3.548	- 8.770	20.4
3.552	- 8.740	20.4
3.547	- 8.810	20.4
3.041	-10.576	20.4
3.058	-10.523	20.4
3.039	-10.460	20.4
3.060	-10.494	20.4
2.551	-12.009	20.3
2.548	-12.116	20.3
2.553	-12.040	20.3
2.553	-12.106	20.3
2.017	-13.337	20.2
2.012	-13.644	20.2
2.017	-13.722	20.2
2.026	-13.334	20.2
1.533	-13.933	20.1
1.551	-14.407	20.1
1.546	-14.861	20.0
1.558	-14.558	20.1
1.563	-14.516	20.1
1.561	-14.869	20.0
.994	-15.397	20.0
1.013	-14.921	20.0
1.047	-15.333	20.0
1.032	-14.970	20.0
1.063	-15.254	19.9

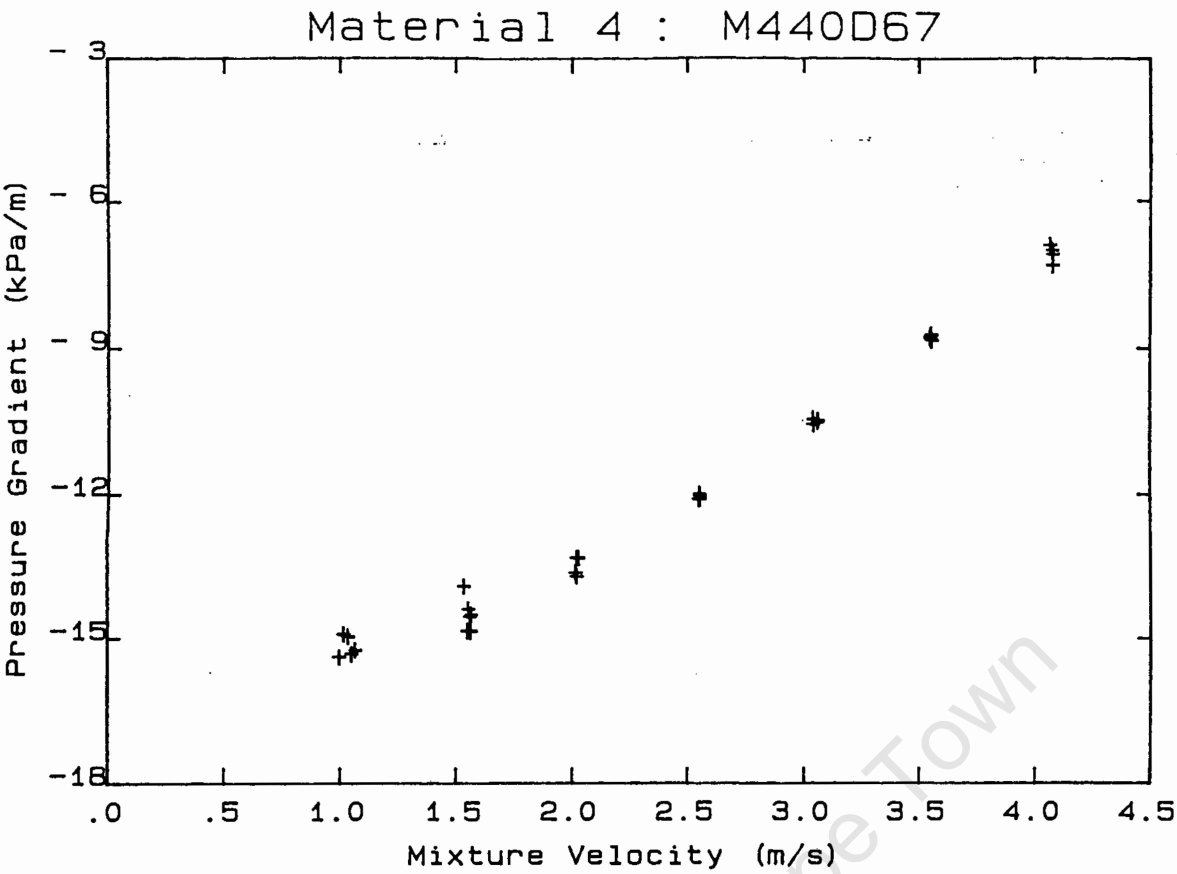
Particle Size Distribution
Sieve and Malvern Size Analysis *

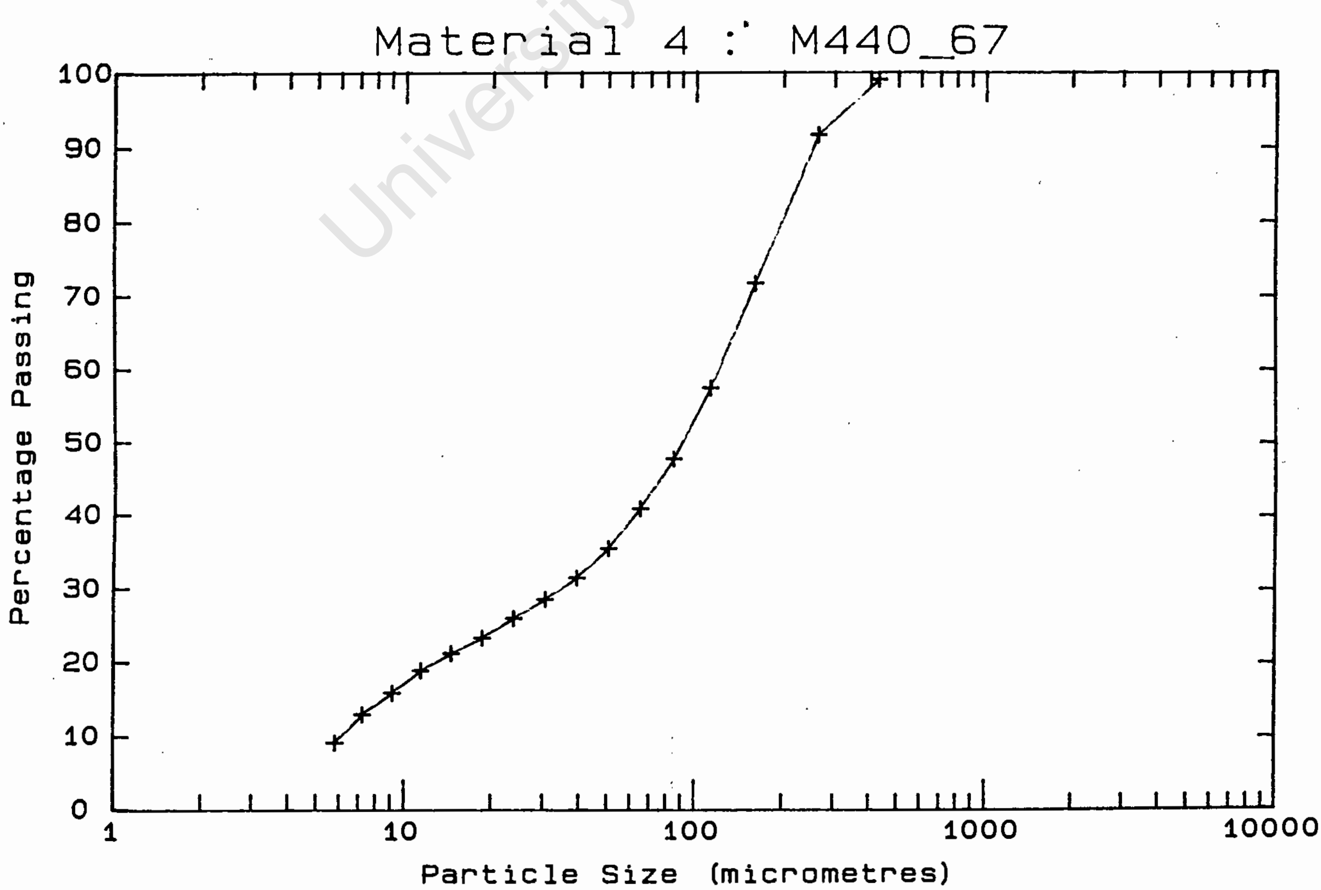
Size (µm)	% Passing	% Retained
425.0	98.9	1.1
261.6	91.5	7.4
160.4	71.6	19.9
112.8	57.3	14.3
84.3	47.6	9.7
64.6	40.8	6.8
50.2	35.4	5.4
39.0	31.4	4.0
30.3	28.5	2.9
23.7	25.9	2.6
18.5	23.2	2.7
14.5	21.1	2.1
11.4	18.8	2.3
9.1	15.8	3.0
7.2	12.9	2.9
5.8	9.1	3.8
Pan	- .2	9.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 4 : M440D67
Pressure Gradient (kPa/m)
- 3
- 6
- 9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_67
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440U67

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.66
Solids Volumetric Concentration (%)	37.93
Solids Mass Concentration (%)	62.61
Mean Slurry Temperature (°C)	20.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.065	24.337	20.2
4.076	23.849	20.3
4.076	24.291	20.3
4.073	24.116	20.3
3.553	22.643	20.4
3.548	22.605	20.4
3.552	22.683	20.4
3.547	22.664	20.4
3.041	21.191	20.4
3.058	21.158	20.4
3.039	21.180	20.4
3.060	21.328	20.4
2.551	19.889	20.3
2.548	20.036	20.3
2.553	19.824	20.3
2.553	19.834	20.3
2.017	18.610	20.2
2.012	18.550	20.2
2.017	18.586	20.2
2.026	18.567	20.2
1.533	17.503	20.1
1.551	17.477	20.1
1.546	17.470	20.0
1.558	17.480	20.1
1.563	17.364	20.1
1.561	17.406	20.0
.994	17.221	20.0
1.013	17.271	20.0
1.047	17.208	20.0
1.032	17.170	20.0
1.063	17.198	19.9

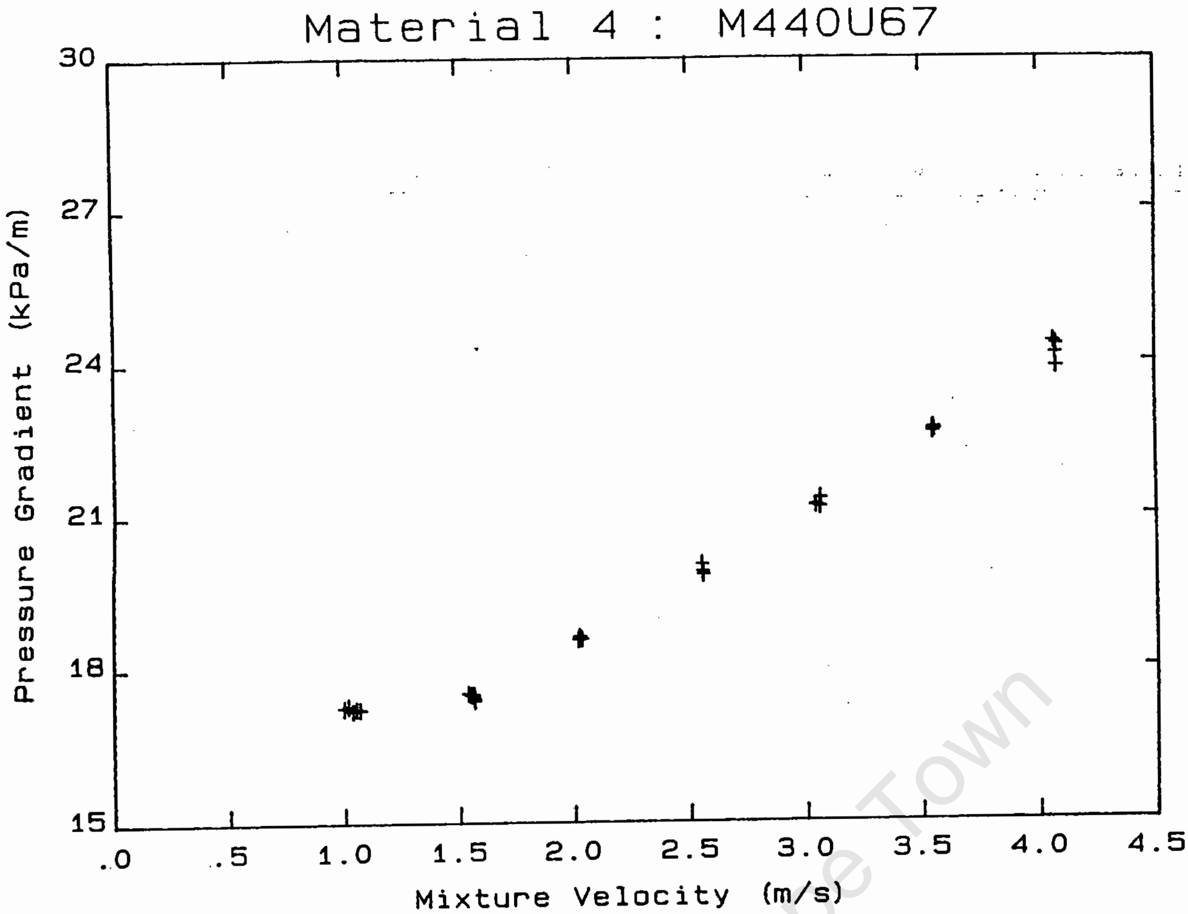
Particle Size Distribution
Sieve and Malvern Size Analysis *

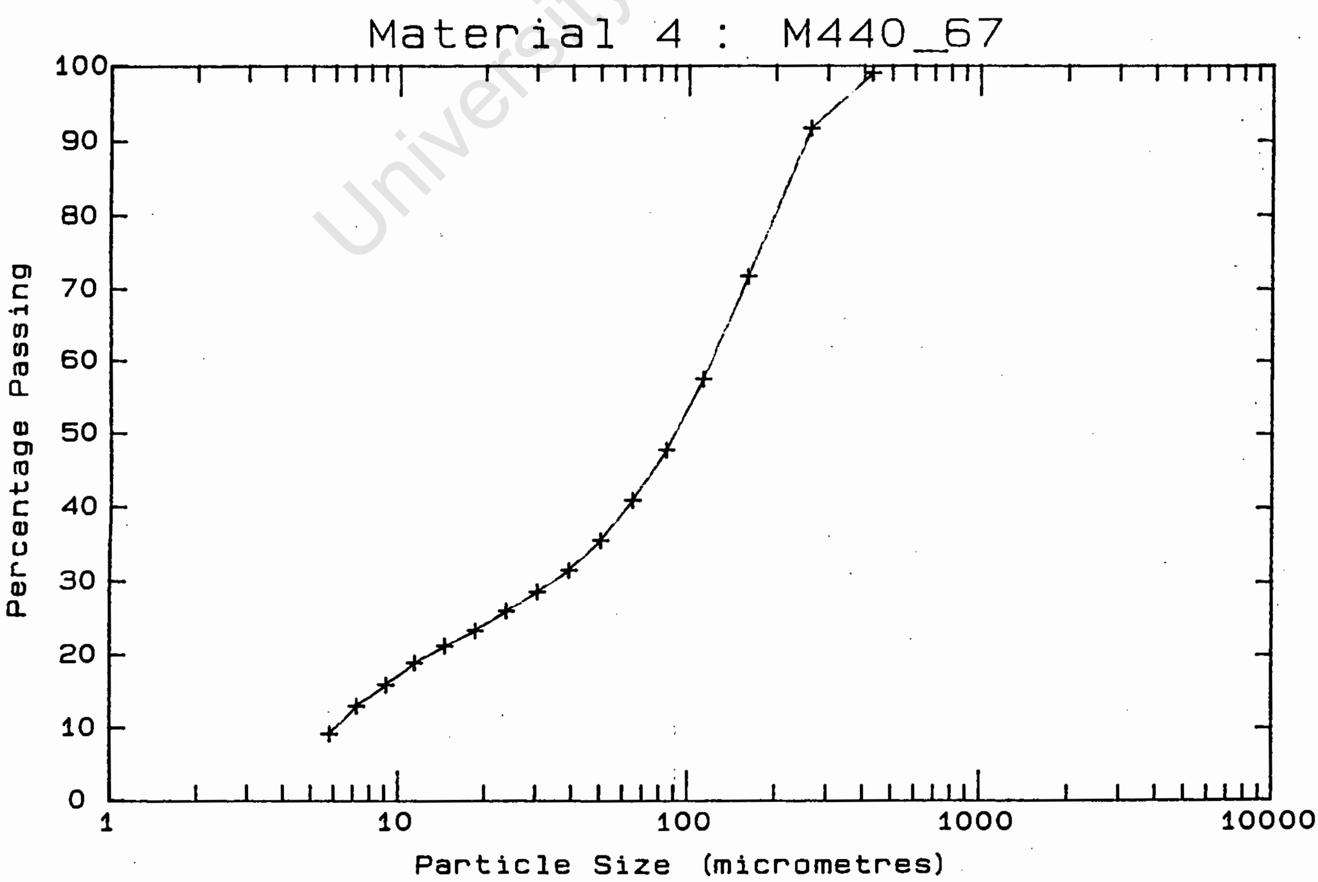
Size (μm)	% Passing	% Retained
425.0	98.9	1.1
261.6	91.5	7.4
160.4	71.6	19.9
112.8	57.3	14.3
84.3	47.6	9.7
64.6	40.8	6.8
50.2	35.4	5.4
39.0	31.4	4.0
30.3	28.5	2.9
23.7	25.9	2.6
18.5	23.2	2.7
14.5	21.1	2.1
11.4	18.8	2.3
9.1	15.8	3.0
7.2	12.9	2.9
5.8	9.1	3.8
Pan	- .2	9.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 μm Malvern Particle Size Analyser


Material 4 : M440U67
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_67
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440H73

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.73
Solids Volumetric Concentration (%)	41.95
Solids Mass Concentration (%)	66.45
Mean Slurry Temperature (°C)	20.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.983	10.054	19.8
4.003	10.984	19.9
4.003	10.647	20.0
4.005	10.528	20.0
3.536	8.096	20.1
3.537	8.304	20.2
3.535	8.048	20.2
3.531	7.857	20.2
2.990	5.951	20.3
2.989	6.355	20.3
3.002	6.124	20.4
2.998	5.758	20.4
2.559	3.301	20.4
2.571	3.594	20.4
2.537	3.464	20.4
2.546	3.858	20.3
2.025	2.811	20.3
2.013	2.640	20.3
2.030	2.805	20.3
2.034	2.685	20.3
1.520	2.458	20.3
1.521	2.011	20.3
1.545	2.140	20.2
1.542	2.261	20.2
.998	1.887	20.2
1.023	1.781	20.2
1.039	1.721	20.2
1.041	1.756	20.2
1.029	1.789	20.2
.442	1.345	20.1
.378	1.410	20.1
.311	1.761	20.1
.257	1.256	20.1
.233	1.168	20.1
.187	1.218	20.1

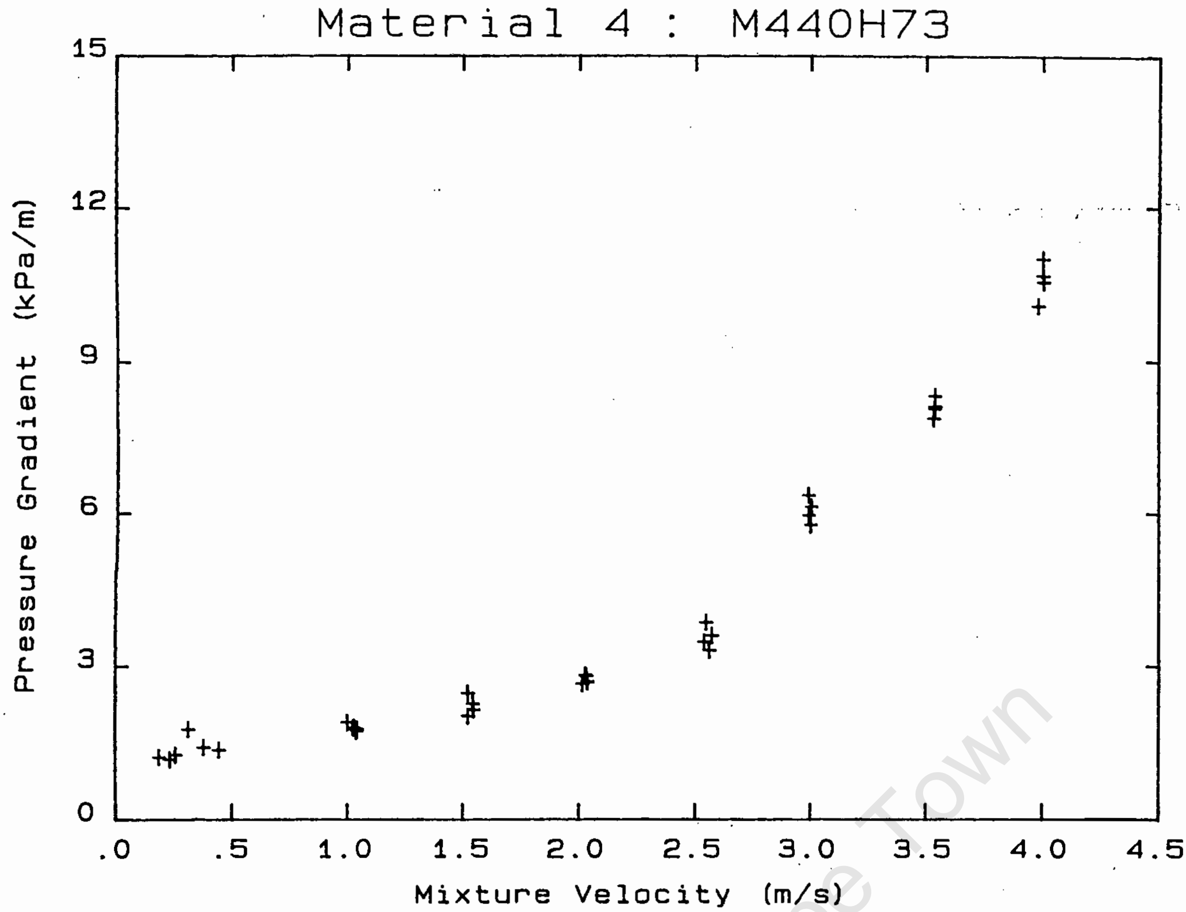
Particle Size Distribution
Sieve and Malvern Size Analysis *

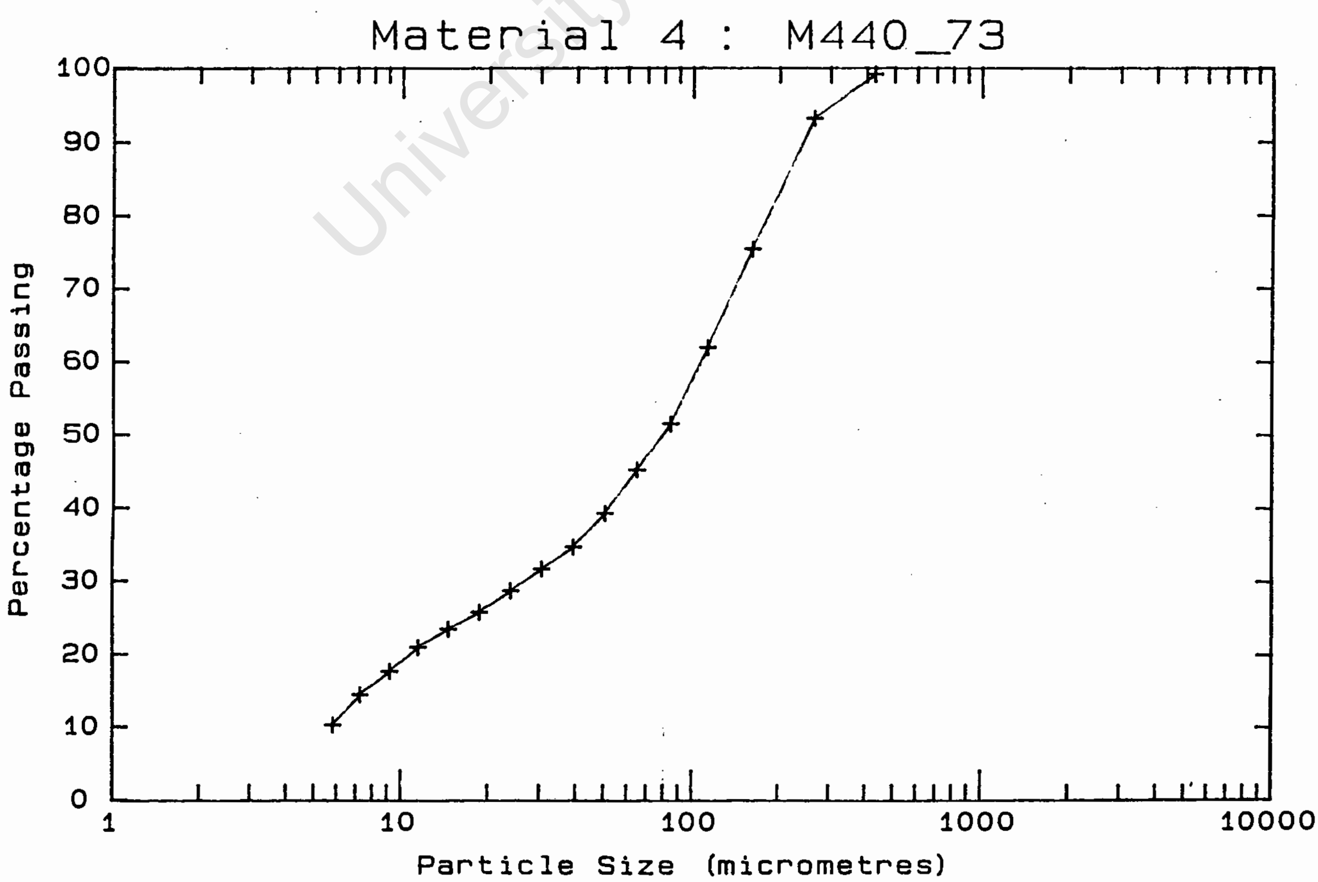
Size (µm)	% Passing	% Retained
425.0	99.0	1.0
261.6	93.1	5.9
160.4	75.3	17.8
112.8	61.8	13.5
84.3	51.4	10.4
64.6	45.1	6.3
50.2	39.2	5.9
39.0	34.6	4.6
30.3	31.6	3.0
23.7	28.6	3.0
18.5	25.7	2.9
14.5	23.4	2.3
11.4	20.9	2.5
9.1	17.6	3.3
7.2	14.4	3.2
5.8	10.2	4.2
Pan	- .1	10.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.24	Sliding particles
.81	Asymetric
1.21	Asymetric
1.61	Appears homogeneous
2.02	Appears homogeneous
2.36	Appears homogeneous
2.80	Appears homogeneous
3.16	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 4 : M440H73
Pressure Gradient (kPa/m)
15
12
9
6
3
0
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_73
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440D73

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.73
Solids Volumetric Concentration (%)	41.95
Solids Mass Concentration (%)	66.45
Mean Slurry Temperature (°C)	20.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.983	- 6.429	19.8
4.003	- 6.793	19.9
4.003	- 6.331	20.0
4.005	- 6.624	20.0
3.536	- 8.542	20.1
3.537	- 8.714	20.2
3.535	- 8.391	20.2
3.531	- 8.025	20.2
2.990	-10.591	20.3
2.989	-10.846	20.3
3.002	-10.666	20.4
2.998	-11.086	20.4
2.559	-13.603	20.4
2.571	-13.547	20.4
2.537	-13.608	20.4
2.546	-13.754	20.3
2.025	-14.183	20.3
2.013	-13.921	20.3
2.030	-14.185	20.3
2.034	-14.048	20.3
1.520	-14.570	20.3
1.521	-14.879	20.3
1.545	-14.447	20.2
1.542	-14.760	20.2
.998	-14.804	20.2
1.023	-14.500	20.2
1.039	-15.045	20.2
1.041	-14.854	20.2
1.029	-14.931	20.2
.442	-14.797	20.1
.378	-15.247	20.1
.311	-14.990	20.1
.257	-16.199	20.1
.233	-15.933	20.1
.187	-15.840	20.1

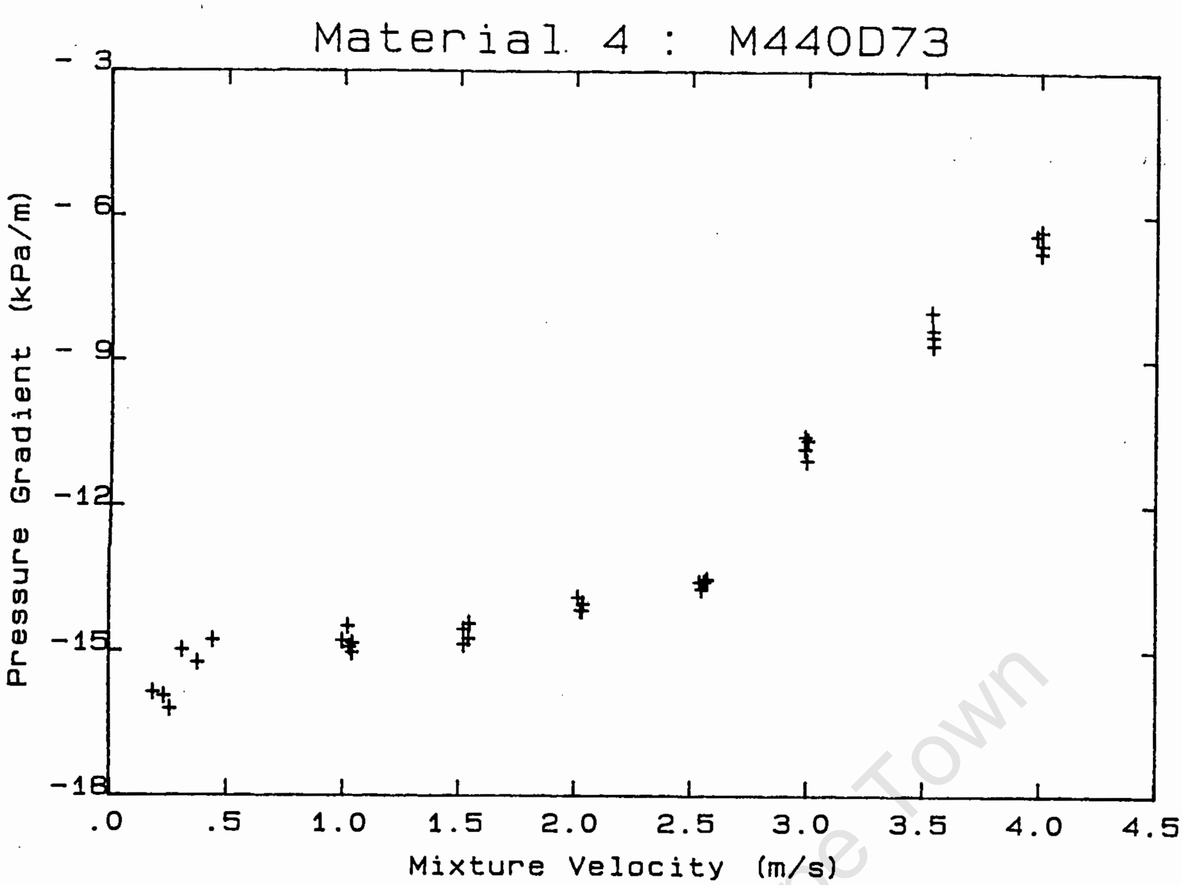
Particle Size Distribution
Sieve and Malvern Size Analysis *

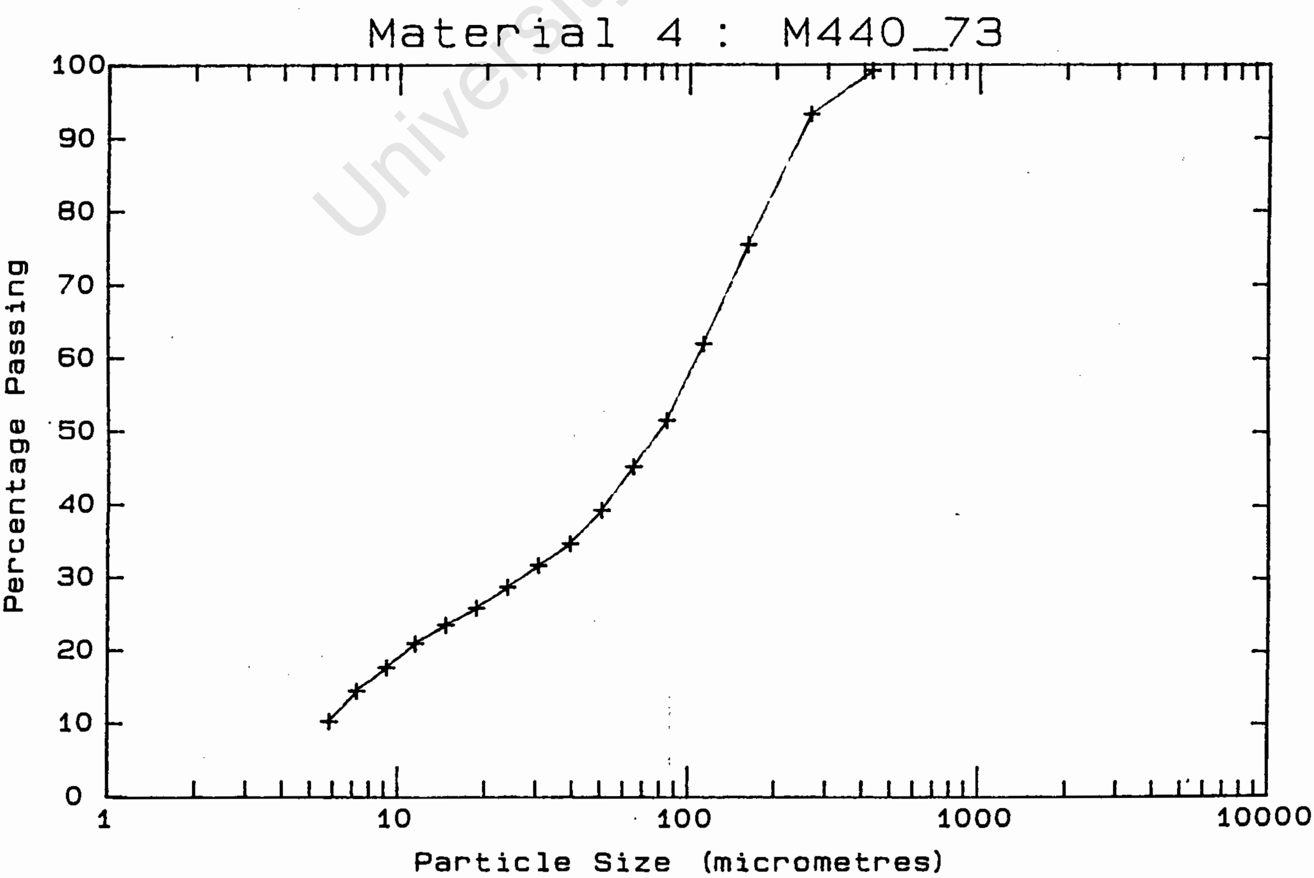
Size (μm)	% Passing	% Retained
425.0	99.0	1.0
261.6	93.1	5.9
160.4	75.3	17.8
112.8	61.8	13.5
84.3	51.4	10.4
64.6	45.1	6.3
50.2	39.2	5.9
39.0	34.6	4.6
30.3	31.6	3.0
23.7	28.6	3.0
18.5	25.7	2.9
14.5	23.4	2.3
11.4	20.9	2.5
9.1	17.6	3.3
7.2	14.4	3.2
5.8	10.2	4.2
Pan	- .1	10.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 μm Malvern Particle Size Analyser


Material 4 : M440D73
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_73
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440U73

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.73
Solids Volumetric Concentration (%)	41.95
Solids Mass Concentration (%)	66.45
Mean Slurry Temperature (°C)	20.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.983	26.188	19.8
4.003	26.051	19.9
4.003	26.007	20.0
4.005	25.736	20.0
3.536	24.228	20.1
3.537	23.622	20.2
3.535	23.763	20.2
3.531	23.957	20.2
2.990	22.044	20.3
2.989	21.834	20.3
3.002	22.228	20.4
2.998	22.551	20.4
2.559	20.721	20.4
2.571	20.231	20.4
2.537	20.345	20.4
2.546	20.323	20.3
2.025	19.303	20.3
2.013	19.248	20.3
2.030	19.201	20.3
2.034	19.204	20.3
1.520	18.885	20.3
1.521	18.865	20.3
1.545	18.872	20.2
1.542	18.895	20.2
.998	18.564	20.2
1.023	18.566	20.2
1.039	18.587	20.2
1.041	18.595	20.2
1.029	18.591	20.2
.442	18.210	20.1
.378	18.177	20.1
.311	18.245	20.1
.257	18.110	20.1
.233	18.083	20.1
.187	18.078	20.1

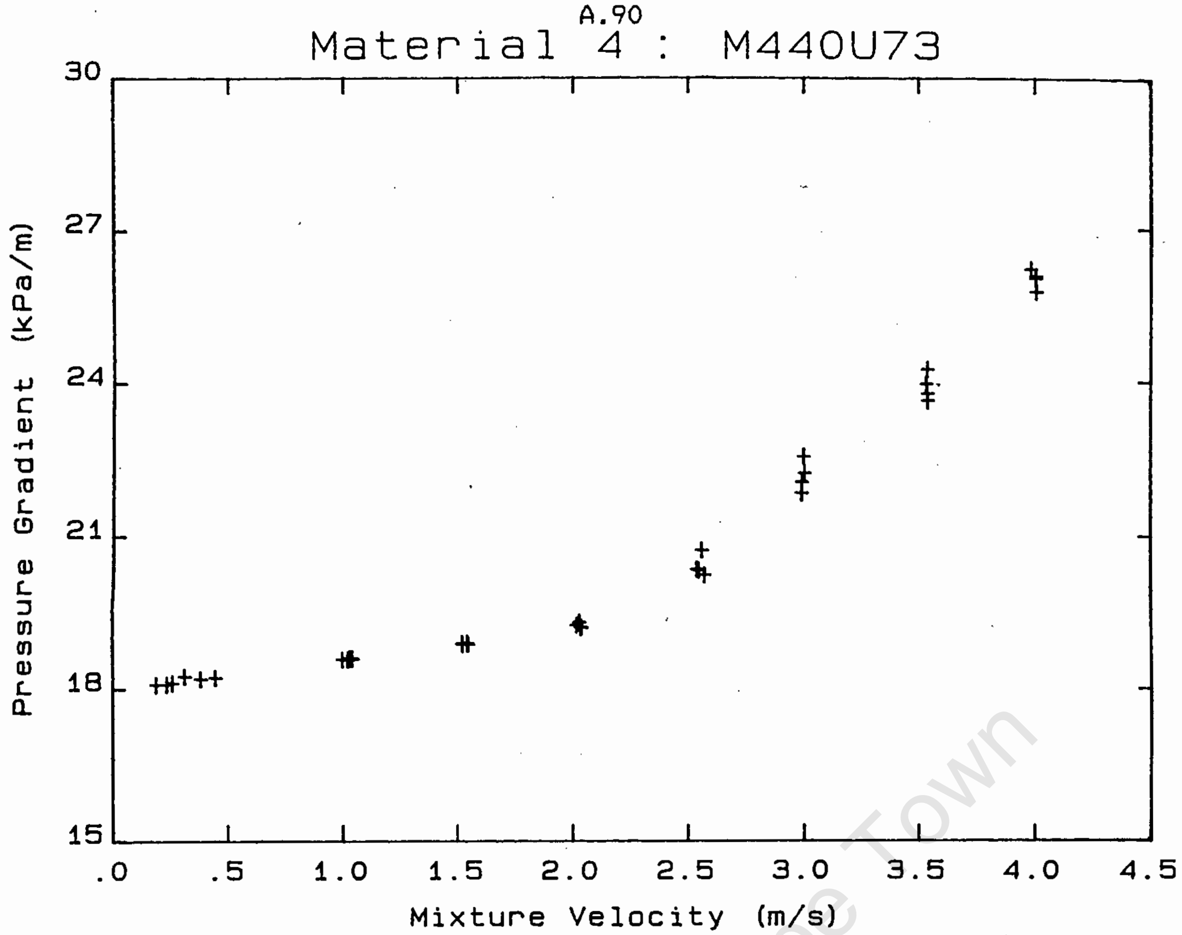
Particle Size Distribution
Sieve and Malvern Size Analysis *

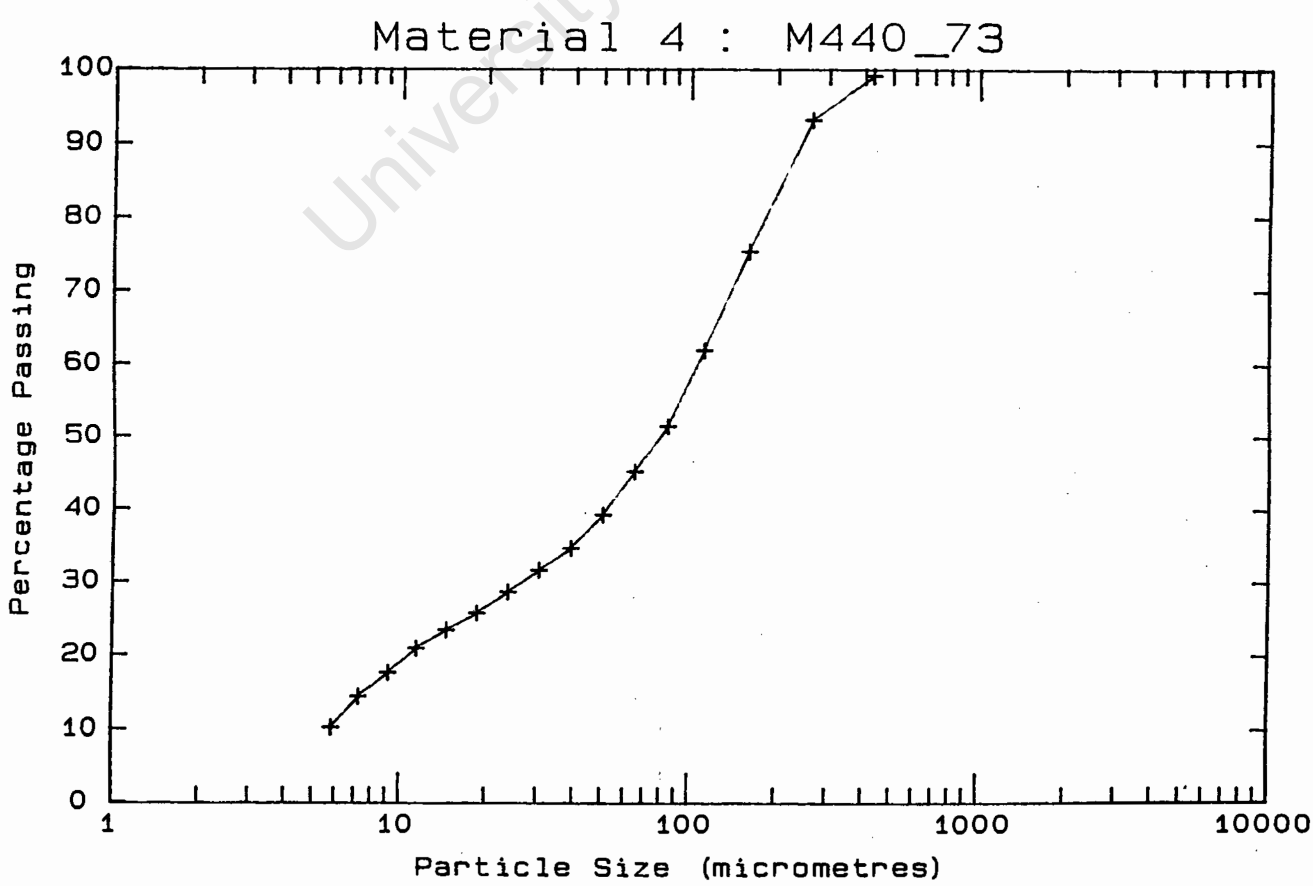
Size (µm)	% Passing	% Retained
425.0	99.0	1.0
261.6	93.1	5.9
160.4	75.3	17.8
112.8	61.8	13.5
84.3	51.4	10.4
64.6	45.1	6.3
50.2	39.2	5.9
39.0	34.6	4.6
30.3	31.6	3.0
23.7	28.6	3.0
18.5	25.7	2.9
14.5	23.4	2.3
11.4	20.9	2.5
9.1	17.6	3.3
7.2	14.4	3.2
5.8	10.2	4.2
Pan	- .1	10.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = .0 mm)

* -425 µm Malvern Particle Size Analyser


Material 4 : M440U73
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_73
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440H78

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.78
Solids Volumetric Concentration (%)	44.83
Solids Mass Concentration (%)	69.00
Mean Slurry Temperature (°C)	22.3
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.977	10.375	20.7
3.973	9.064	20.9
3.977	9.241	21.0
4.005	10.185	21.1
3.969	9.053	21.2
3.500	6.312	21.7
3.503	6.766	21.8
3.536	6.335	21.8
3.537	6.498	22.0
2.989	5.362	22.2
2.991	5.629	22.2
2.996	5.596	22.3
2.999	5.492	22.3
2.534	5.021	22.5
2.542	4.872	22.5
2.533	4.907	22.5
2.554	4.936	22.6
2.003	4.283	22.6
2.039	4.344	22.7
2.091	4.361	22.7
2.106	4.411	22.7
1.427	3.600	22.8
1.427	3.618	22.8
1.370	3.506	22.8
1.349	3.540	22.8
.958	3.079	22.8
.935	3.056	22.9
.914	3.038	22.9
.913	3.048	22.9
.501	2.504	22.9
.422	2.457	22.9
.321	2.319	22.9
.273	2.286	22.9
.250	2.266	22.9
.226	2.216	22.9

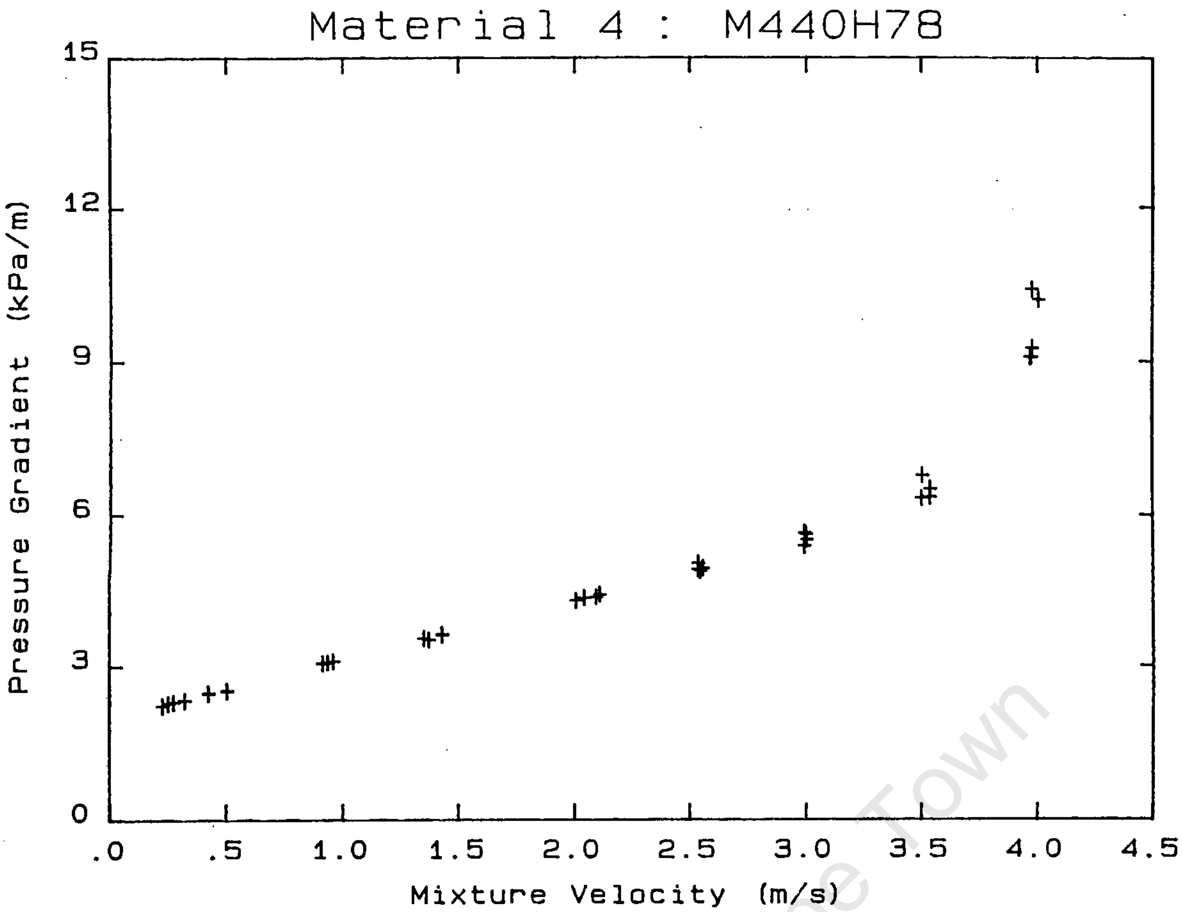
Particle Size Distribution
Sieve and Malvern Size Analysis *

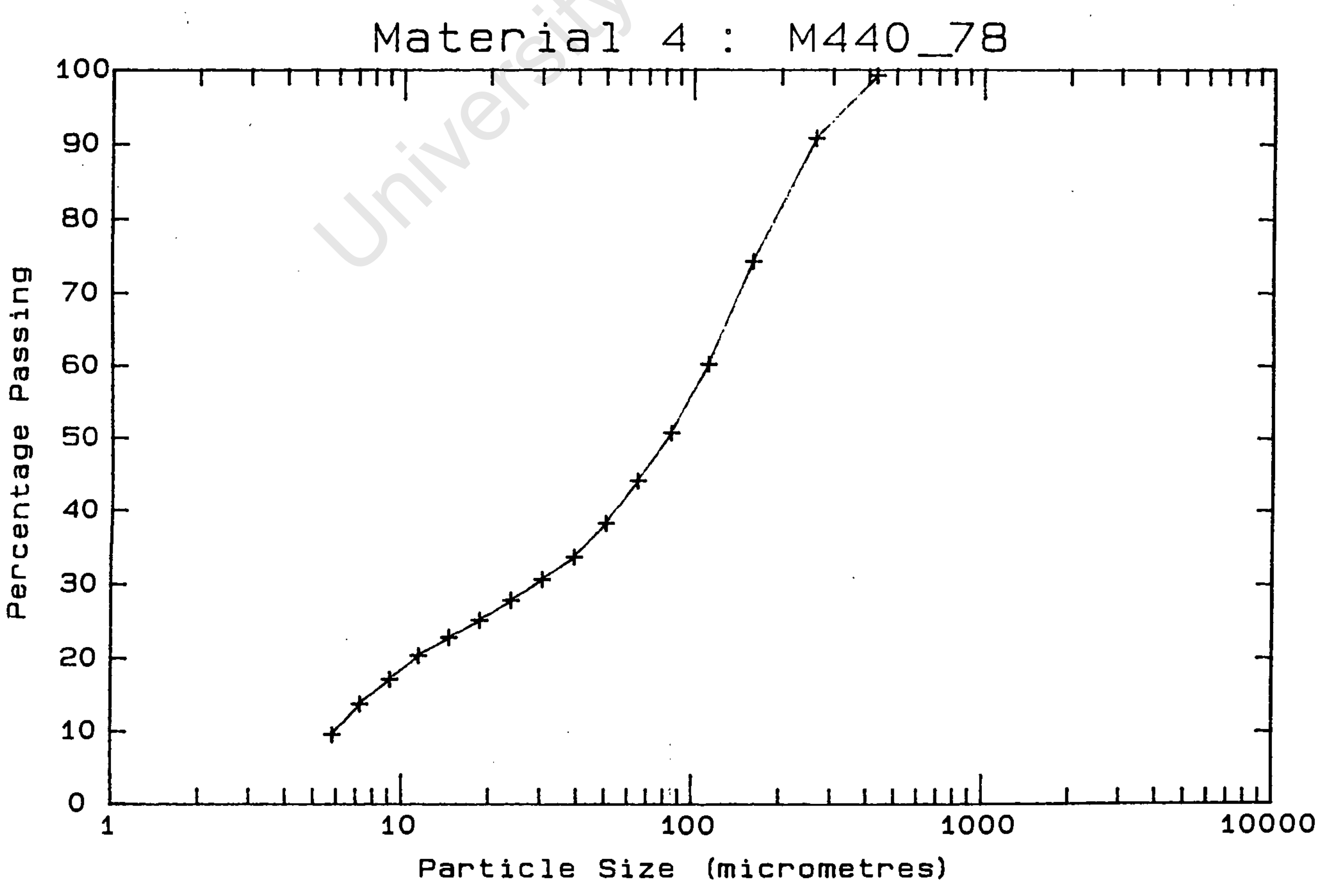
Size (μm)	% Passing	% Retained
425.0	99.1	.9
261.6	90.7	8.4
160.4	74.2	16.5
112.8	60.1	14.1
84.3	50.6	9.5
64.6	44.0	6.6
50.2	38.2	5.8
39.0	33.6	4.6
30.3	30.6	3.0
23.7	27.8	2.8
18.5	25.1	2.7
14.5	22.8	2.3
11.4	20.3	2.5
9.1	17.1	3.2
7.2	13.7	3.4
5.8	9.5	4.2
Pan	- .3	9.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.24	Asymetric
.74	Asymetric
1.11	Appears homogeneous
1.62	Appears homogeneous
2.01	Appears homogeneous
2.36	Appears homogeneous
2.78	Appears homogeneous
3.15	Appears homogeneous

* -425 μm Malvern Particle Size Analyser


Material 4 : M440H78
Pressure Gradient (kPa/m)
15
12
9
6
3
0
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_78
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440D78

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.78
Solids Volumetric Concentration (%)	44.83
Solids Mass Concentration (%)	69.00
Mean Slurry Temperature (°C)	22.3
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.977	- 6.623	20.7
3.973	- 5.822	20.9
3.977	- 6.730	21.0
4.005	- 8.199	21.1
3.969	- 6.908	21.2
3.500	-11.157	21.7
3.503	-11.507	21.8
3.536	-11.339	21.8
3.537	-11.329	22.0
2.989	-12.283	22.2
2.991	-11.997	22.2
2.996	-12.117	22.3
2.999	-12.063	22.3
2.534	-12.650	22.5
2.542	-12.672	22.5
2.533	-12.687	22.5
2.554	-12.531	22.6
2.003	-13.131	22.6
2.039	-13.064	22.7
2.091	-13.081	22.7
2.106	-13.022	22.7
1.427	-13.731	22.8
1.427	-13.805	22.8
1.370	-13.806	22.8
1.349	-13.927	22.8
.958	-14.021	22.8
.935	-14.675	22.9
.914	-14.574	22.9
.913	-14.049	22.9
.501	-14.662	22.9
.422	-14.694	22.9
.321	-14.780	22.9
.273	-14.778	22.9
.250	-15.085	22.9
.226	-15.493	22.9

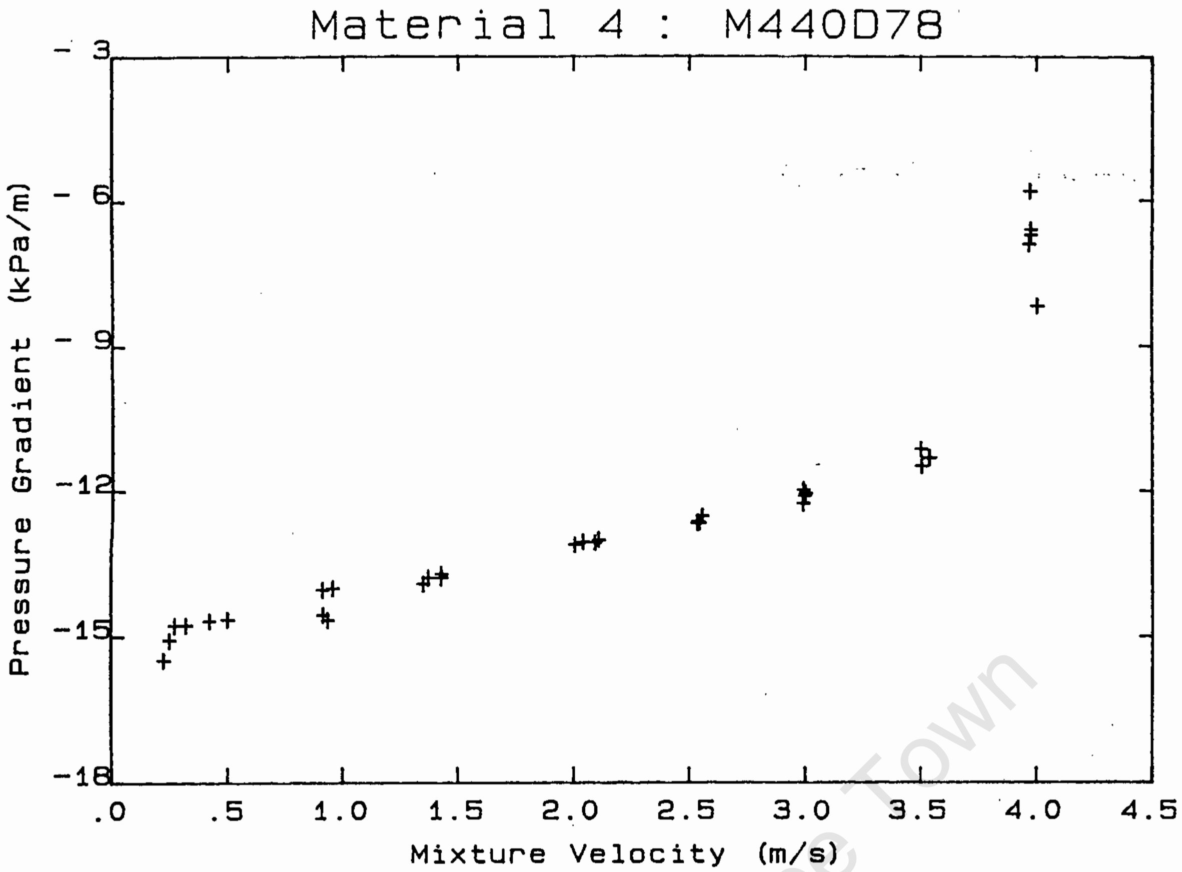
Particle Size Distribution
Sieve and Malvern Size Analysis *

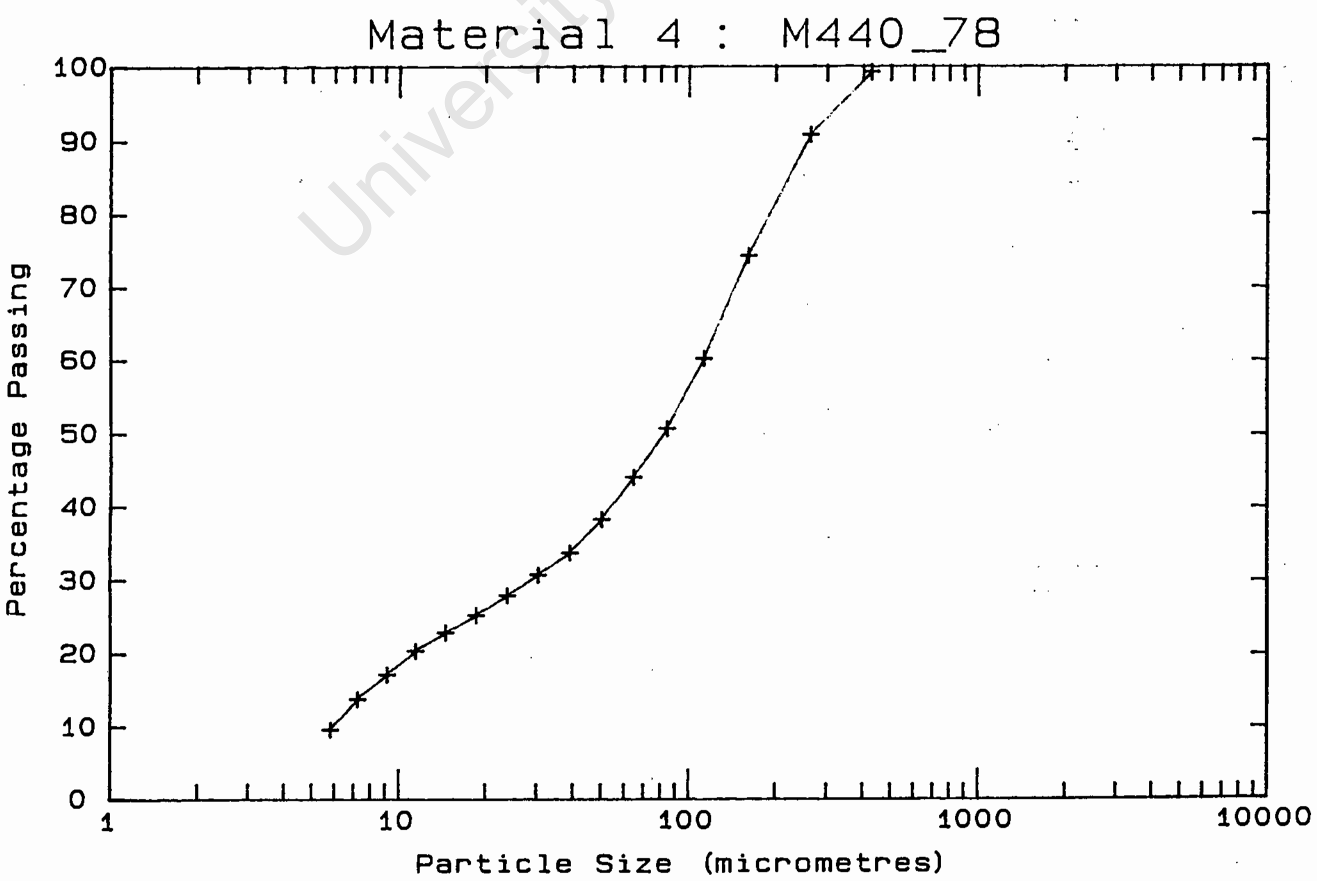
Size (μm)	% Passing	% Retained
425.0	99.1	.9
261.6	90.7	8.4
160.4	74.2	16.5
112.8	60.1	14.1
84.3	50.6	9.5
64.6	44.0	6.6
50.2	38.2	5.8
39.0	33.6	4.6
30.3	30.6	3.0
23.7	27.8	2.8
18.5	25.1	2.7
14.5	22.8	2.3
11.4	20.3	2.5
9.1	17.1	3.2
7.2	13.7	3.4
5.8	9.5	4.2
Pan	- .3	9.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 μm Malvern Particle Size Analyser


Material 4 : M440D78
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_78
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440U78

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.78
Solids Volumetric Concentration (%)	44.83
Solids Mass Concentration (%)	69.00
Mean Slurry Temperature (°C)	22.3
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.977	26.434	20.7
3.973	26.515	20.9
3.977	25.618	21.0
4.005	26.312	21.1
3.969	26.528	21.2
3.500	22.697	21.7
3.503	22.242	21.8
3.536	23.205	21.8
3.537	23.102	22.0
2.989	22.123	22.2
2.991	22.377	22.2
2.996	21.967	22.3
2.999	22.368	22.3
2.534	21.956	22.5
2.542	21.689	22.5
2.533	21.717	22.5
2.554	21.765	22.6
2.003	21.243	22.6
2.039	21.395	22.7
2.091	21.242	22.7
2.106	21.358	22.7
1.427	20.670	22.8
1.427	20.724	22.8
1.370	20.613	22.8
1.349	20.662	22.8
.958	20.261	22.8
.935	20.218	22.9
.914	20.235	22.9
.913	20.169	22.9
.501	19.755	22.9
.422	19.788	22.9
.321	19.578	22.9
.273	19.560	22.9
.250	19.632	22.9
.226	19.587	22.9

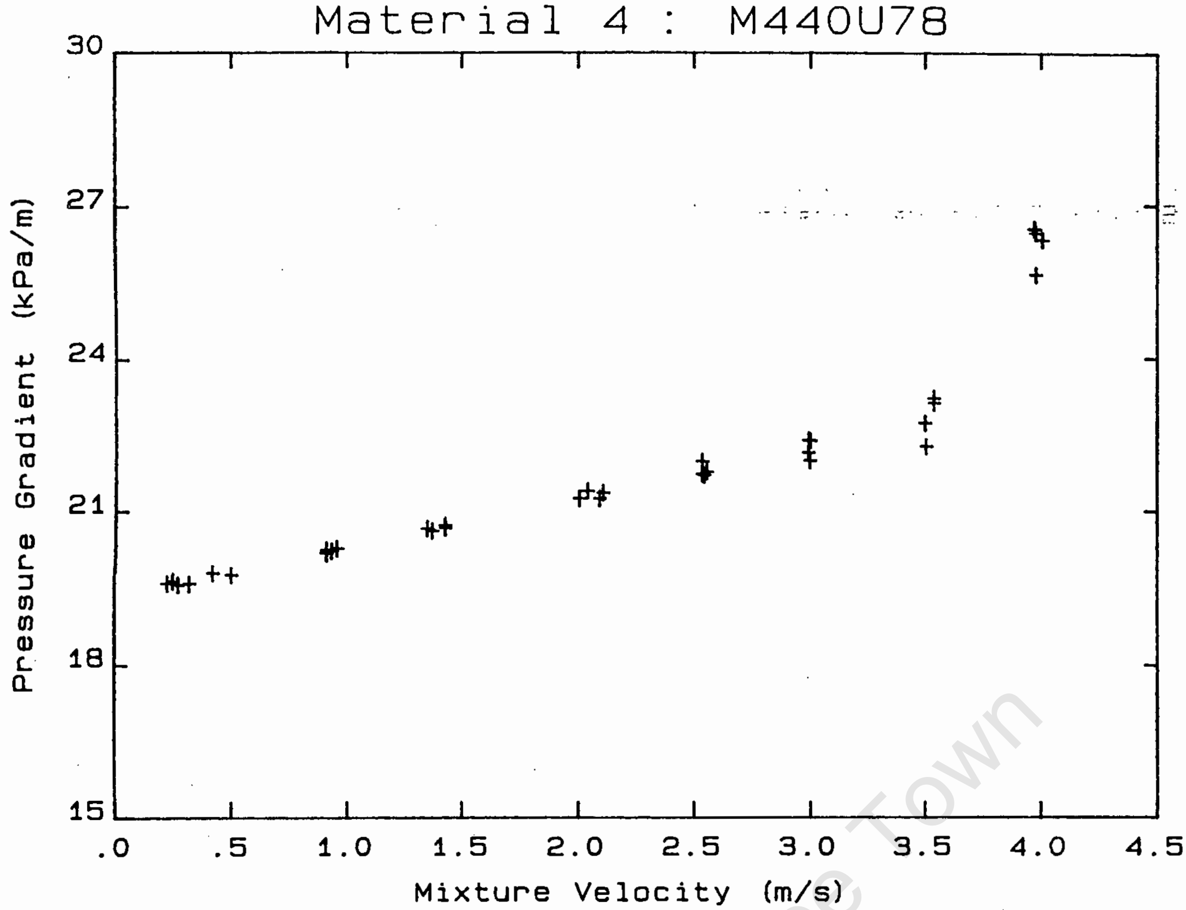
Particle Size Distribution
Sieve and Malvern Size Analysis *

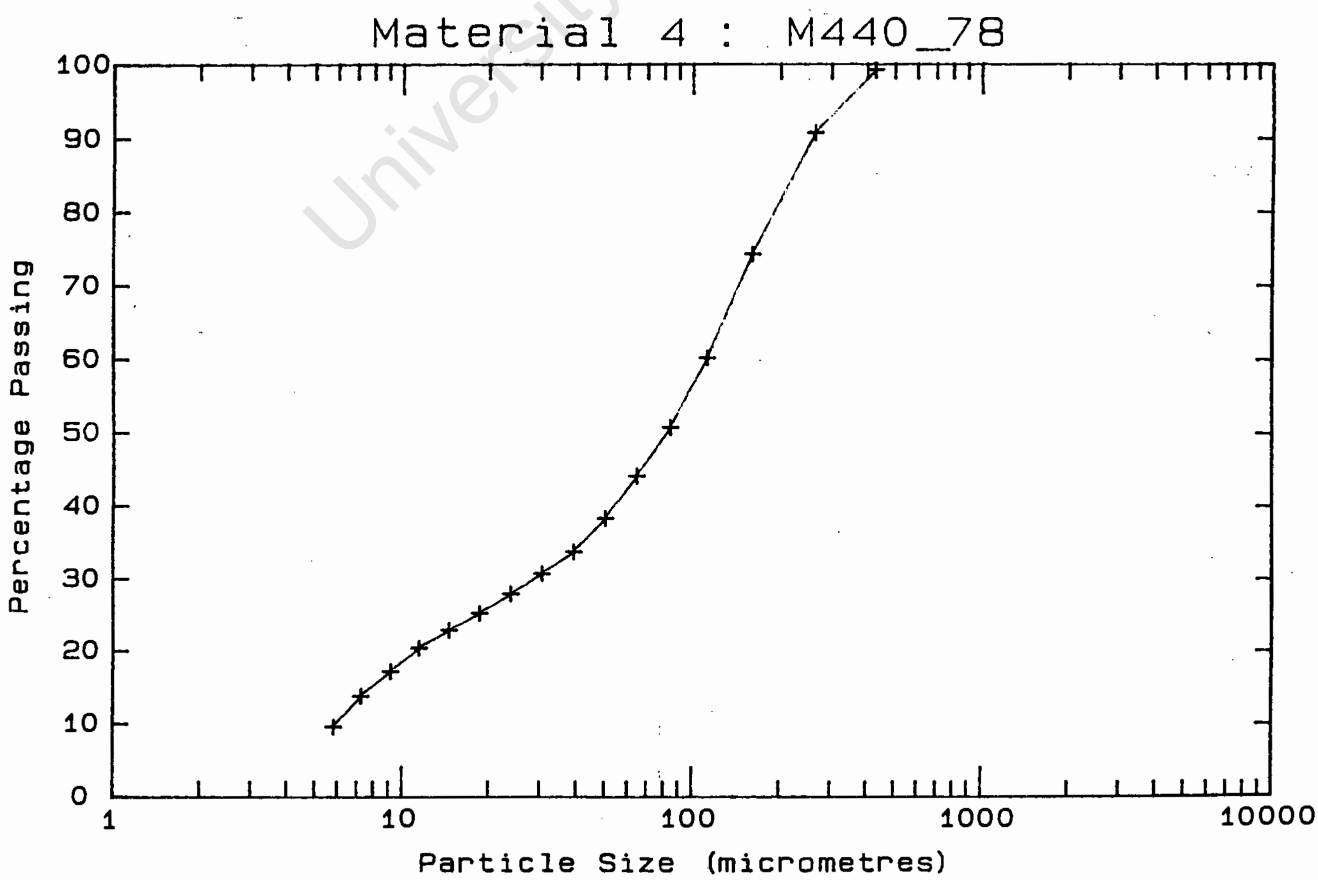
Size (µm)	% Passing	% Retained
425.0	99.1	.9
261.6	90.7	8.4
160.4	74.2	16.5
112.8	60.1	14.1
84.3	50.6	9.5
64.6	44.0	6.6
50.2	38.2	5.8
39.0	33.6	4.6
30.3	30.6	3.0
23.7	27.8	2.8
18.5	25.1	2.7
14.5	22.8	2.3
11.4	20.3	2.5
9.1	17.1	3.2
7.2	13.7	3.4
5.8	9.5	4.2
Pan	- .3	9.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 4 : M440U78
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_78
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440H84

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.84
Solids Volumetric Concentration (%)	48.28
Solids Mass Concentration (%)	71.89
Mean Slurry Temperature (°C)	25.8
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.148	11.610	24.5
4.133	11.919	24.7
4.149	11.643	24.8
4.139	10.803	25.0
3.545	9.844	25.2
3.529	10.158	25.3
3.541	9.937	25.4
3.545	9.822	25.5
3.021	8.631	25.7
3.013	8.900	25.8
3.027	9.154	25.8
3.045	8.841	25.9
2.529	8.110	26.0
2.539	7.706	26.0
2.539	8.334	26.0
2.543	7.826	26.1
1.960	6.844	26.1
1.920	6.610	26.1
1.910	6.221	26.1
1.921	6.205	26.1
1.467	6.040	26.1
1.469	6.170	26.1
1.370	6.064	26.1
1.393	6.280	26.1
1.034	5.728	26.0
1.028	5.737	26.0
1.007	5.695	26.0
.989	5.676	26.0
.511	4.850	25.9
.497	4.849	25.9
.488	4.865	25.9
.475	4.832	25.9
.472	4.829	25.8
.477	4.841	25.8

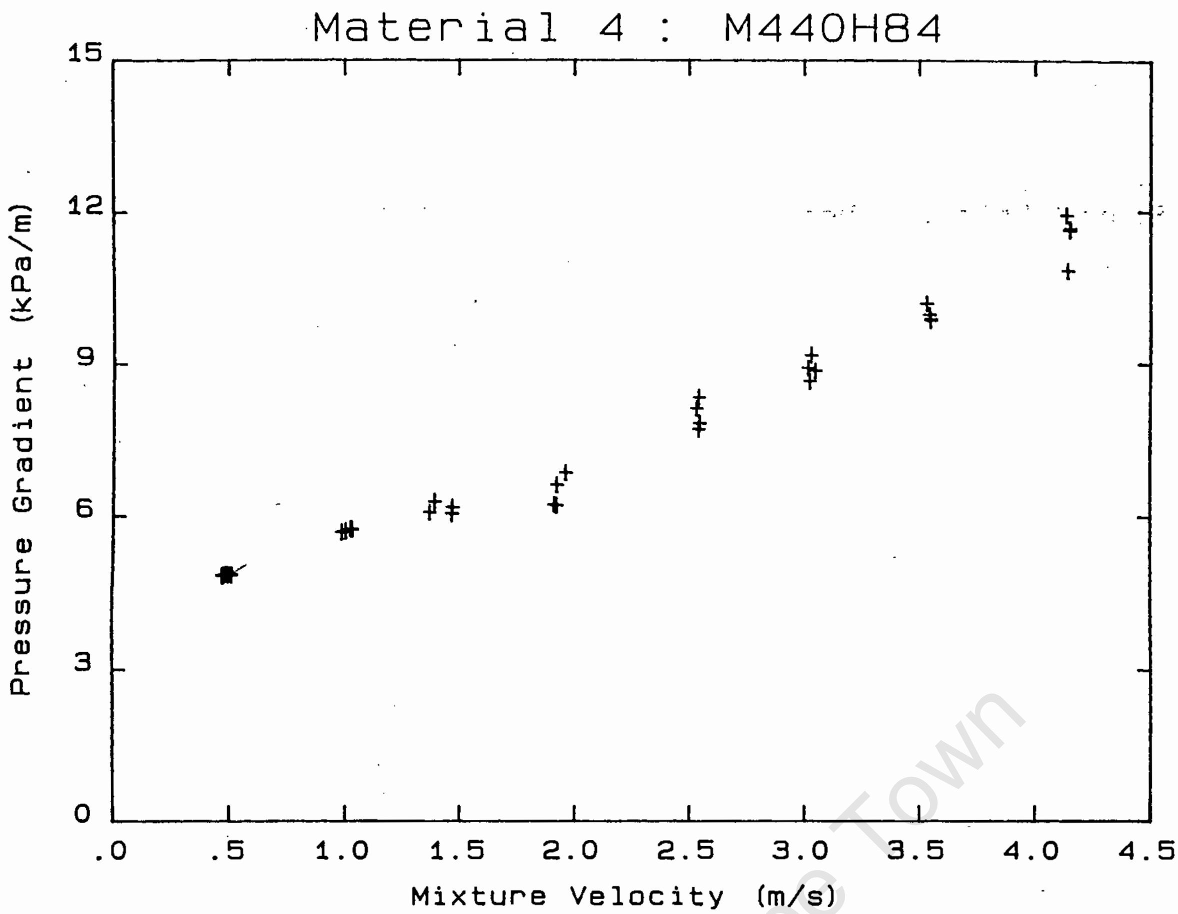
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (μm)	% Passing	% Retained
425.0	99.1	.9
261.6	93.0	6.1
160.4	77.9	15.1
112.8	64.5	13.4
84.3	55.1	9.4
64.6	48.3	6.8
50.2	42.6	5.7
39.0	38.1	4.5
30.3	34.7	3.4
23.7	31.6	3.1
18.5	28.6	3.0
14.5	25.8	2.8
11.4	22.7	3.1
9.1	18.8	3.9
7.2	15.6	3.2
5.8	12.7	2.9
Pan	- .1	12.8

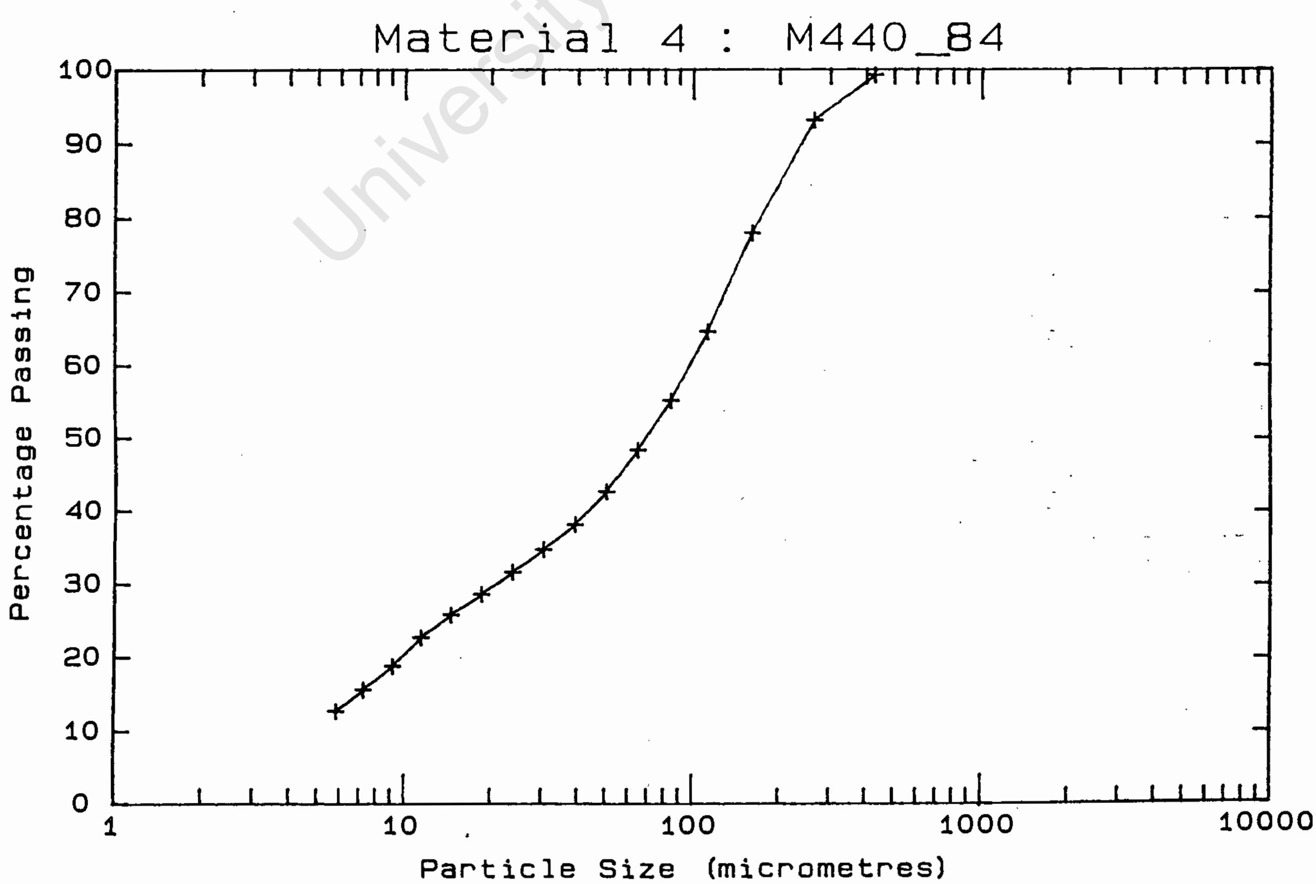
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.38	Asymetric
.81	Asymetric
1.12	appears homogeneous
1.52	Appears homogeneous
2.01	Appears homogeneous
2.39	Appears homogeneous
2.80	Appears homogeneous
3.27	Appears homogeneous

* -425 μm Malvern Particle Size Analyser



Material 4 : M440H84
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 4 : M440_84
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440D84

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.84
Solids Volumetric Concentration (%)	48.28
Solids Mass Concentration (%)	71.89
Mean Slurry Temperature (°C)	25.8
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.148	- 6.877	24.5
4.133	- 6.797	24.7
4.149	- 6.818	24.8
4.139	- 6.874	25.0
3.545	- 8.108	25.2
3.529	- 8.176	25.3
3.541	- 8.195	25.4
3.545	- 7.975	25.5
3.021	- 8.973	25.7
3.013	- 9.147	25.8
3.027	- 9.148	25.8
3.045	- 8.930	25.9
2.529	- 9.901	26.0
2.539	- 9.979	26.0
2.539	-10.170	26.0
2.543	- 9.975	26.1
1.960	-10.939	26.1
1.920	-10.979	26.1
1.910	-11.016	26.1
1.921	-10.498	26.1
1.467	-11.474	26.1
1.469	-11.535	26.1
1.370	-11.670	26.1
1.393	-11.701	26.1
1.034	-12.139	26.0
1.028	-12.117	26.0
1.007	-12.107	26.0
.989	-12.148	26.0
.511	-13.008	25.9
.497	-13.002	25.9
.488	-13.006	25.9
.475	-13.037	25.9
.472	-13.037	25.8
.477	-13.037	25.8

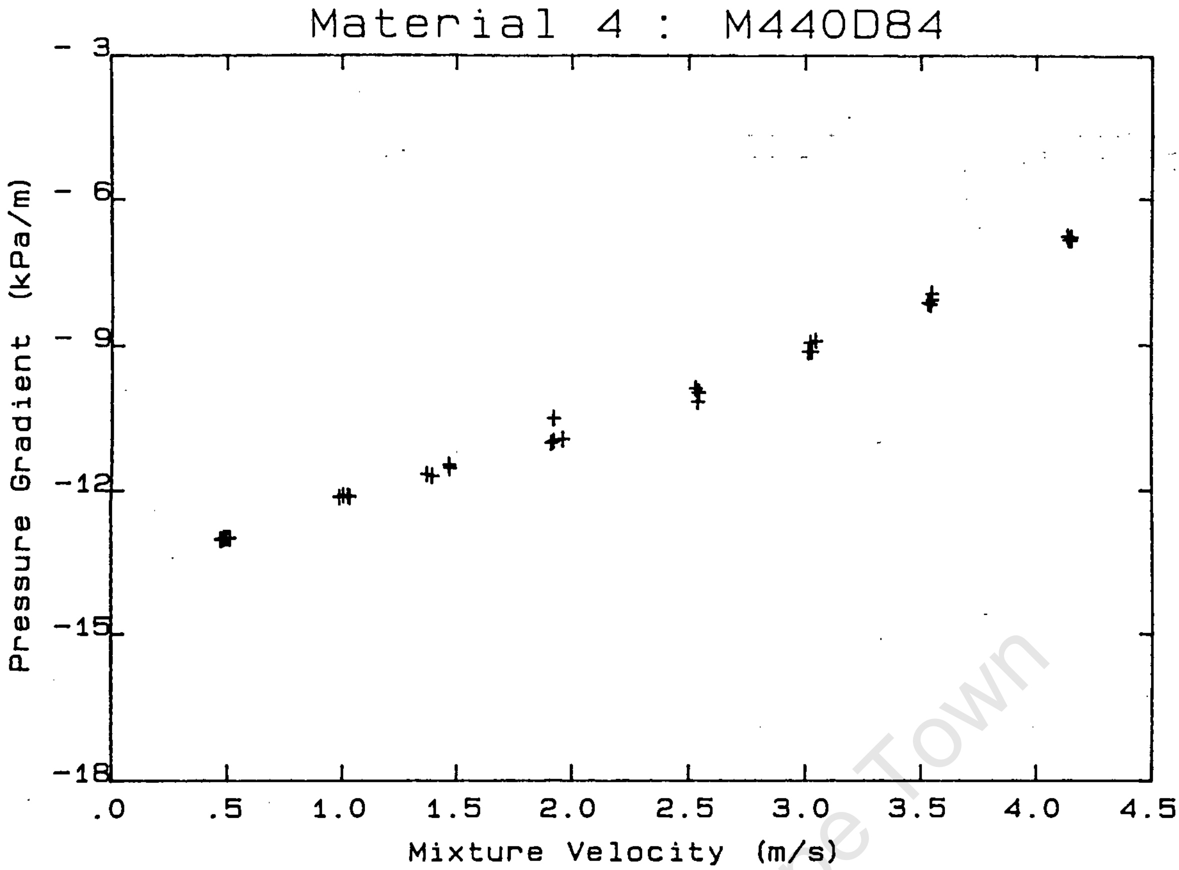
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (μm)	% Passing	% Retained
425.0	99.1	.9
261.6	93.0	6.1
160.4	77.9	15.1
112.8	64.5	13.4
84.3	55.1	9.4
64.6	48.3	6.8
50.2	42.6	5.7
39.0	38.1	4.5
30.3	34.7	3.4
23.7	31.6	3.1
18.5	28.6	3.0
14.5	25.8	2.8
11.4	22.7	3.1
9.1	18.8	3.9
7.2	15.6	3.2
5.8	12.7	2.9
Pan	- .1	12.8

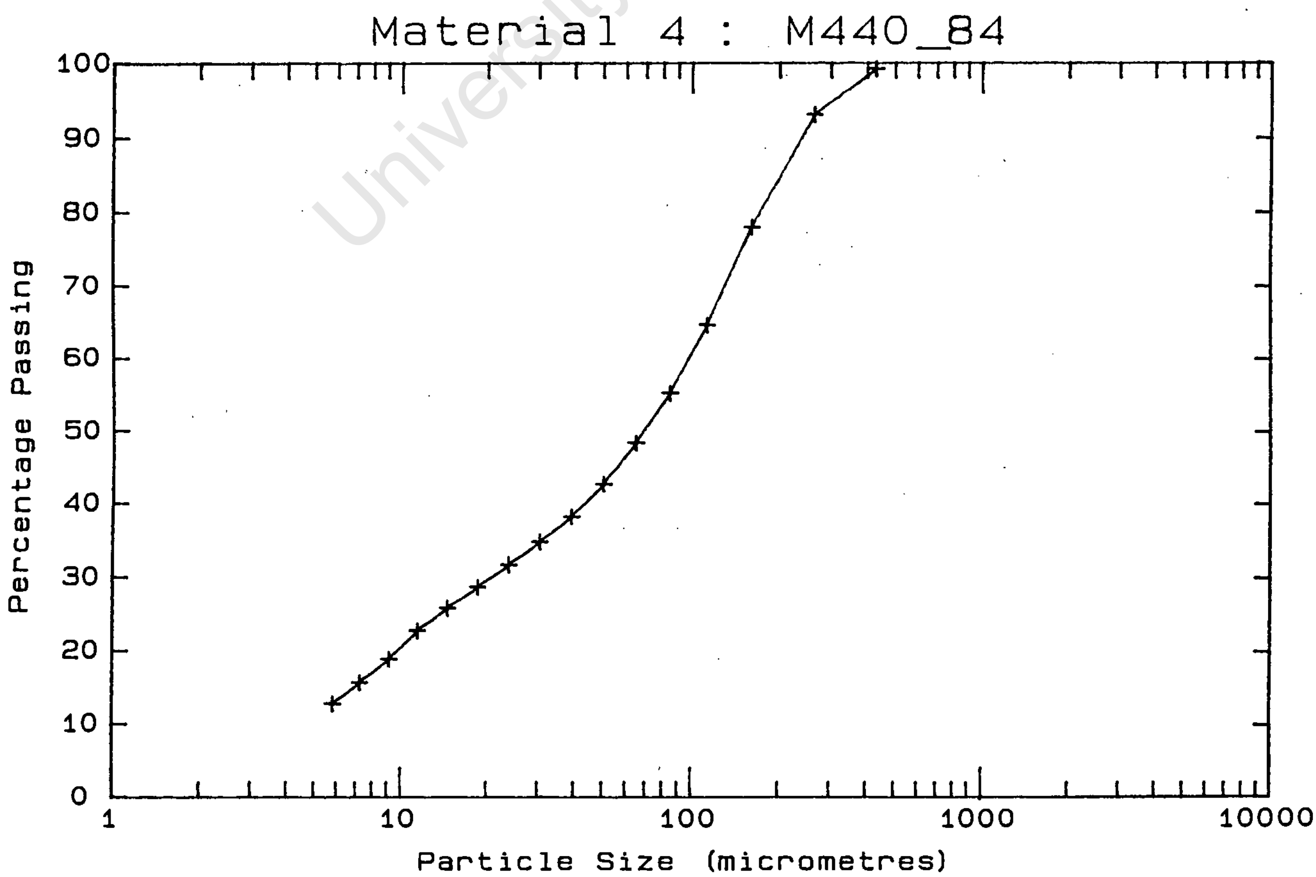
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 μm Malvern Particle Size Analyser



Material 4 : M440D84
Pressure Gradient (kPa/m)
- 3
- 6
- 9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 4 : M440_84
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M440U84

Test Facility	UCT 40 mm NB
Test Date	30/05/91
Material Description	MATERIAL 4
Material Relative Density	2.74
Slurry Relative Density	1.84
Solids Volumetric Concentration (%)	48.28
Solids Mass Concentration (%)	71.89
Mean Slurry Temperature (°C)	25.8
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.148	28.269	24.5
4.133	28.106	24.7
4.149	27.859	24.8
4.139	28.215	25.0
3.545	27.253	25.2
3.529	26.988	25.3
3.541	26.761	25.4
3.545	27.070	25.5
3.021	25.995	25.7
3.013	26.359	25.8
3.027	27.013	25.8
3.045	26.744	25.9
2.529	24.889	26.0
2.539	26.112	26.0
2.539	24.975	26.0
2.543	26.364	26.1
1.960	24.992	26.1
1.920	24.906	26.1
1.910	25.901	26.1
1.921	26.031	26.1
1.467	23.711	26.1
1.469	23.915	26.1
1.370	23.798	26.1
1.393	23.758	26.1
1.034	23.443	26.0
1.028	23.443	26.0
1.007	23.539	26.0
.989	23.261	26.0
.511	22.607	25.9
.497	22.576	25.9
.488	22.598	25.9
.475	22.632	25.9
.472	22.669	25.8
.477	22.612	25.8

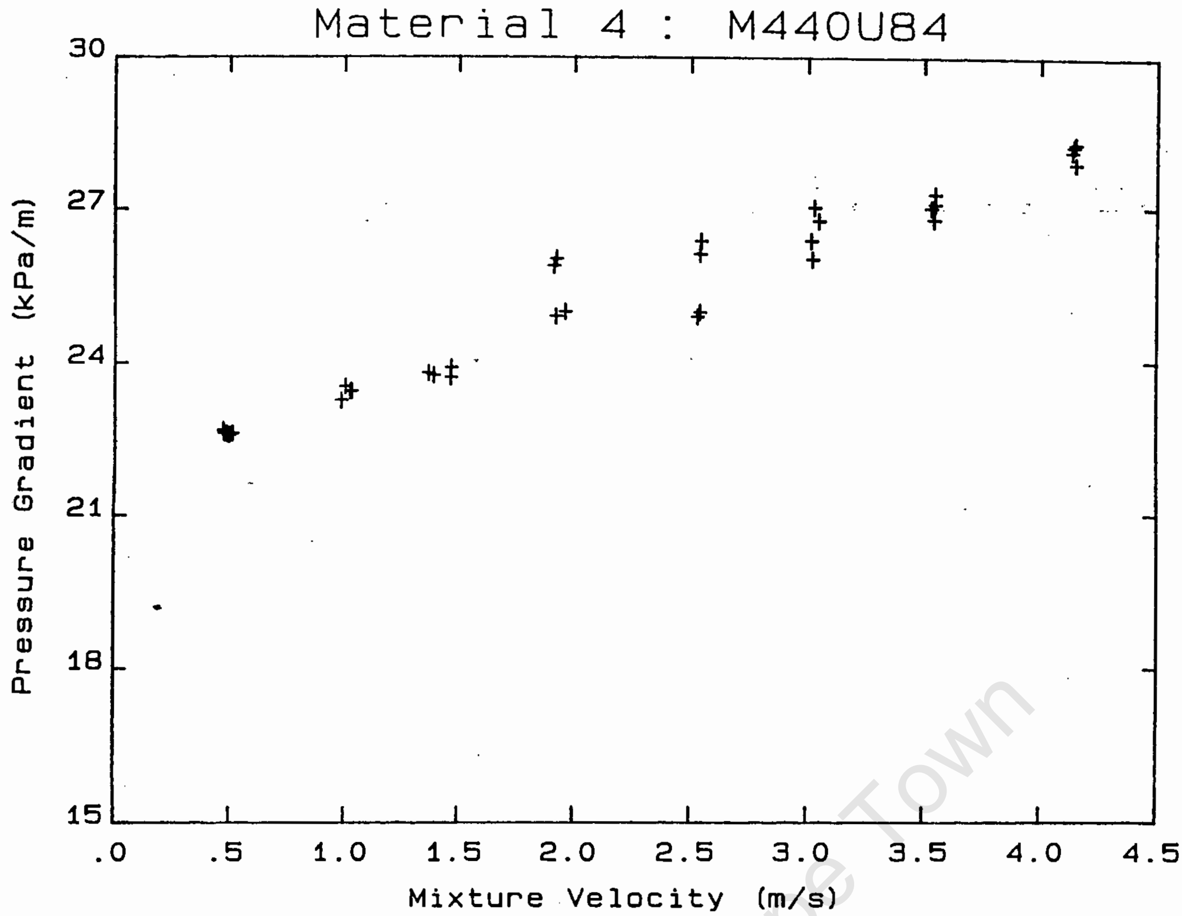
Particle Size Distribution
Sieve and Malvern Size Analysis *

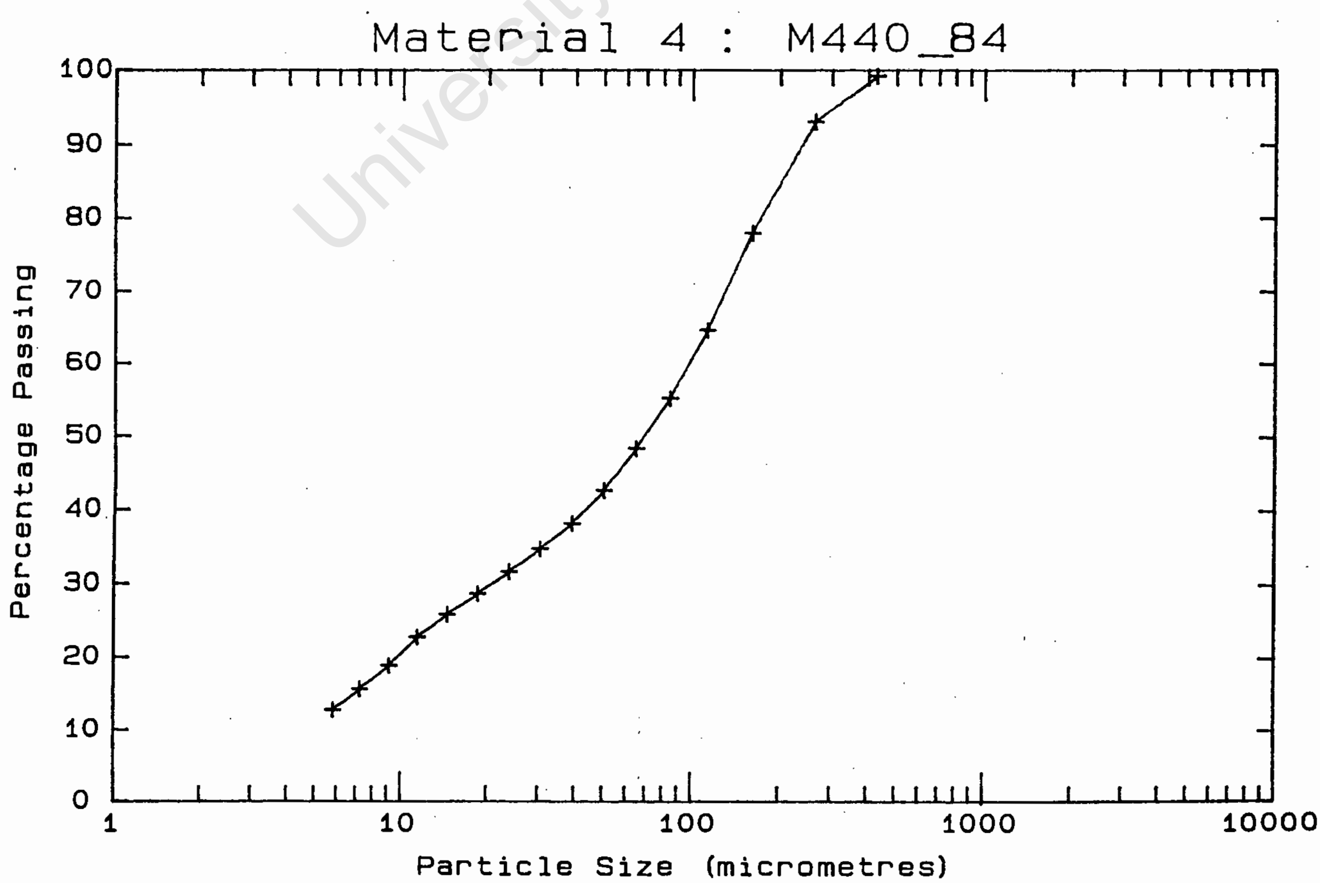
Size (µm)	% Passing	% Retained
425.0	99.1	.9
261.6	93.0	6.1
160.4	77.9	15.1
112.8	64.5	13.4
84.3	55.1	9.4
64.6	48.3	6.8
50.2	42.6	5.7
39.0	38.1	4.5
30.3	34.7	3.4
23.7	31.6	3.1
18.5	28.6	3.0
14.5	25.8	2.8
11.4	22.7	3.1
9.1	18.8	3.9
7.2	15.6	3.2
5.8	12.7	2.9
Pan	- .1	12.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 4 : M440U84
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 4 : M440_84
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540H58

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.58
Solids Volumetric Concentration (%)	33.33
Solids Mass Concentration (%)	57.81
Mean Slurry Temperature (°C)	20.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.584	6.801	19.9
3.590	6.984	20.0
3.584	1.005	20.0
3.590	6.849	20.0
3.135	5.318	20.2
3.125	5.234	20.2
3.122	5.346	20.3
3.122	5.432	20.3
2.775	4.306	20.3
2.780	4.517	20.4
2.780	4.537	20.4
2.775	4.436	20.4
2.406	3.297	20.4
2.409	3.502	20.3
2.405	3.327	20.3
2.409	3.459	20.3
2.031	2.518	20.3
2.035	2.588	20.3
2.027	2.569	20.3
2.034	2.491	20.2
1.635	2.312	20.2
1.622	1.981	20.2
1.616	1.901	20.2
1.624	1.179	20.1
1.623	1.207	20.1
1.608	1.711	20.1
1.615	1.668	20.0
1.622	.948	20.0
1.291	1.842	20.0
1.282	1.465	20.0
1.279	2.070	20.0
1.286	.875	19.9
1.295	1.324	19.9
1.269	1.001	19.9
1.267	1.833	19.9

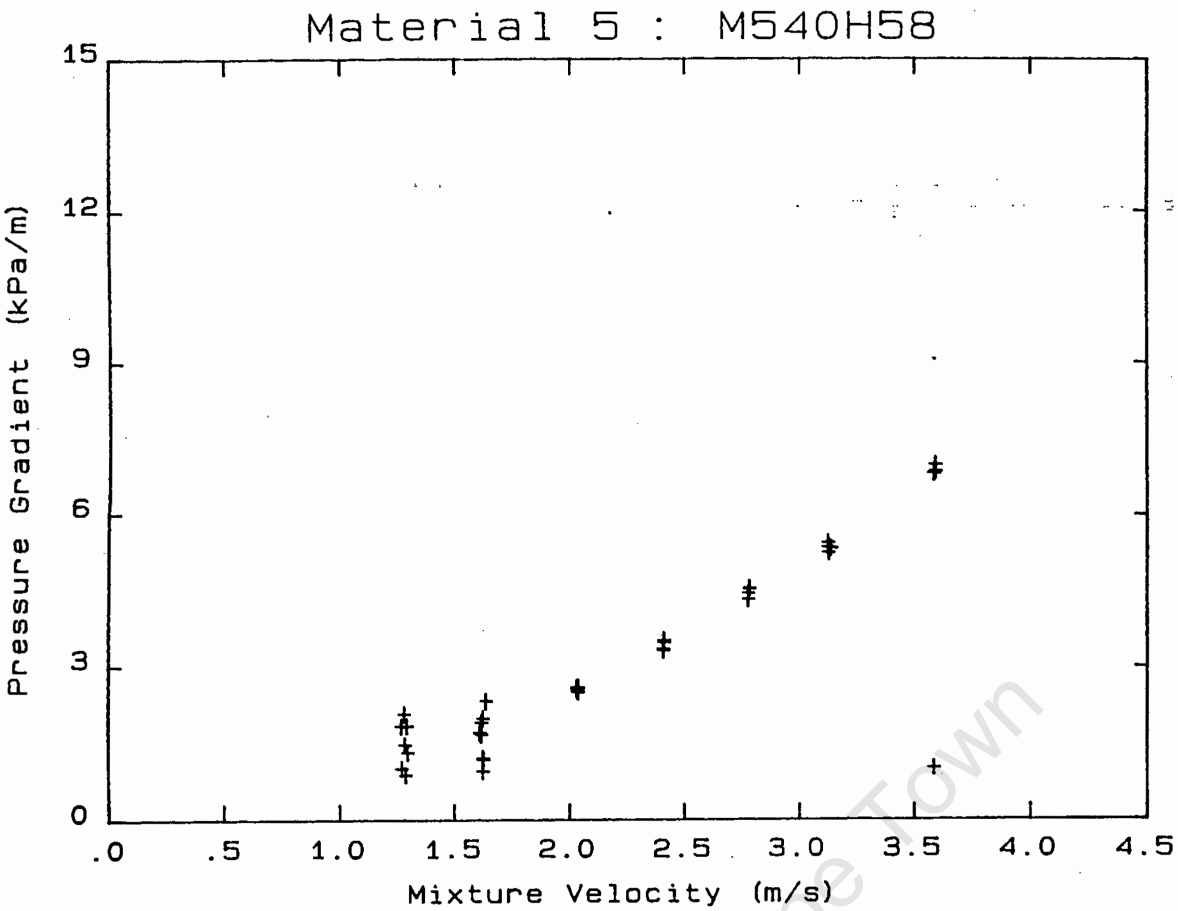
Particle Size Distribution
Sieve and Malvern Size Analysis *

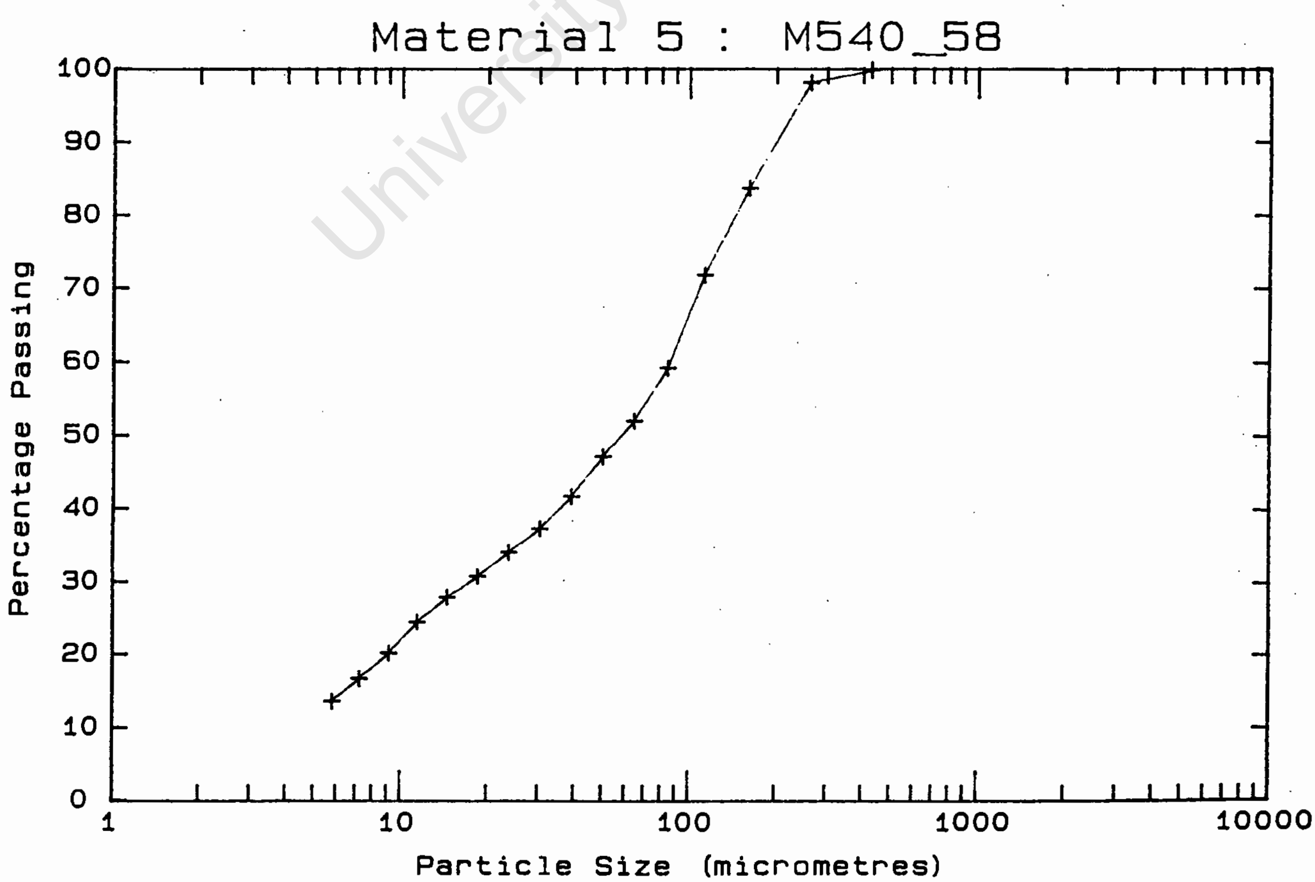
Size (µm)	% Passing	% Retained
425.0	99.7	.3
261.6	98.0	1.7
160.4	83.6	14.4
112.8	71.7	11.9
84.3	59.1	12.6
64.6	51.9	7.2
50.2	47.0	4.9
39.0	41.6	5.4
30.3	37.2	4.4
23.7	34.0	3.2
18.5	30.7	3.3
14.5	27.8	2.9
11.4	24.4	3.4
9.1	20.1	4.3
7.2	16.6	3.5
5.8	13.5	3.1
Pan	- .4	13.9

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
1.01	Sliding bed
1.28	Asymetric
1.61	Appears homogeneous
1.91	Appears homogeneous
2.20	Appears homogeneous
2.47	Appears homogeneous
2.84	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 5 : M540H58
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_58
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540D58

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.58
Solids Volumetric Concentration (%)	33.33
Solids Mass Concentration (%)	57.81
Mean Slurry Temperature (°C)	20.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.584	− 8.720	19.9
3.590	− 8.696	20.0
3.584	− 8.687	20.0
3.590	− 8.732	20.0
3.135	−10.090	20.2
3.125	−10.091	20.2
3.122	−10.075	20.3
3.122	−10.028	20.3
2.775	−11.142	20.3
2.780	−10.889	20.4
2.780	−11.112	20.4
2.775	−11.033	20.4
2.406	−11.905	20.4
2.409	−11.914	20.3
2.405	−11.939	20.3
2.409	−12.129	20.3
2.031	−12.858	20.3
2.035	−12.890	20.3
2.027	−12.887	20.3
2.034	−12.864	20.2
1.635	−13.770	20.2
1.622	−14.051	20.2
1.616	−13.875	20.2
1.624	−14.100	20.1
1.623	−13.693	20.1
1.608	−14.419	20.1
1.615	−13.782	20.0
1.622	−13.555	20.0
1.291	−14.184	20.0
1.282	−14.088	20.0
1.279	−15.070	20.0
1.286	−14.513	19.9
1.295	−14.095	19.9
1.269	−14.216	19.9
1.267	−14.612	19.9

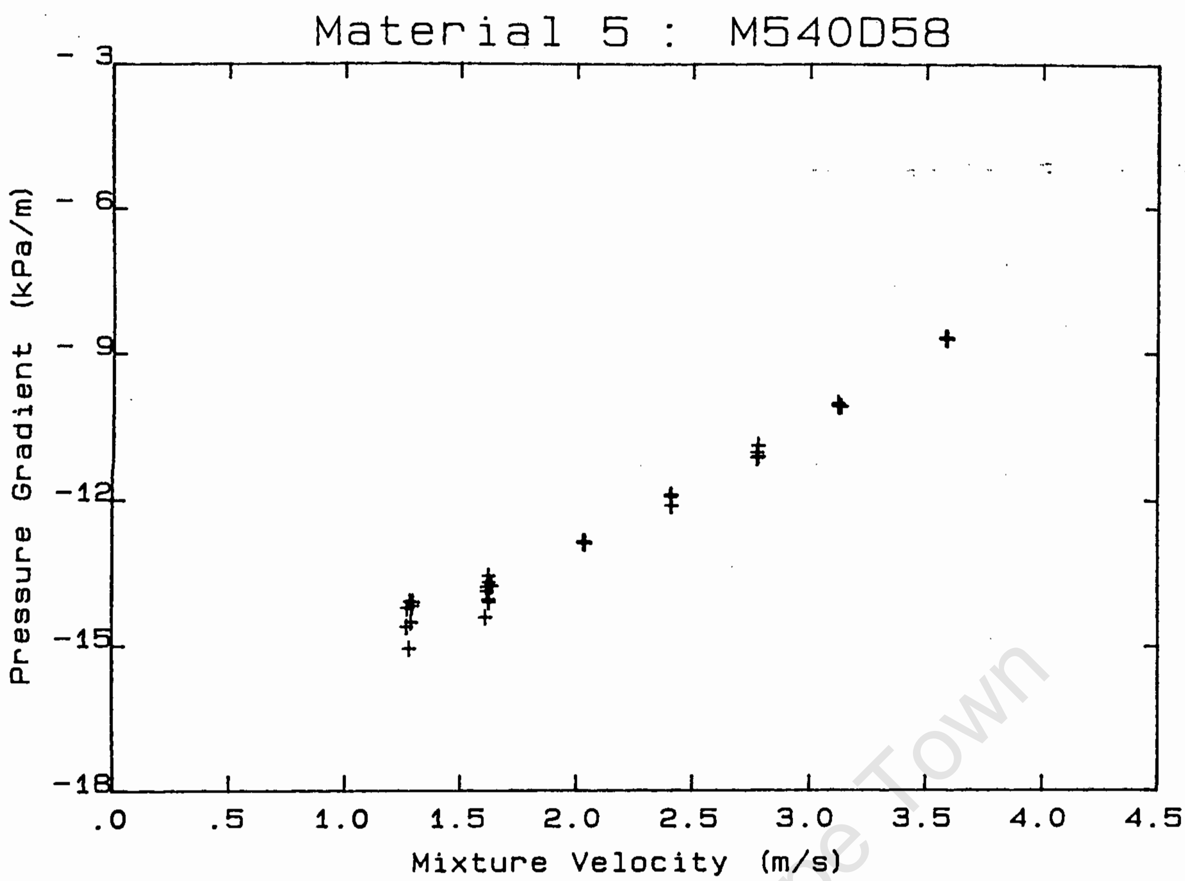
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	99.7	.3
261.6	98.0	1.7
160.4	83.6	14.4
112.8	71.7	11.9
84.3	59.1	12.6
64.6	51.9	7.2
50.2	47.0	4.9
39.0	41.6	5.4
30.3	37.2	4.4
23.7	34.0	3.2
18.5	30.7	3.3
14.5	27.8	2.9
11.4	24.4	3.4
9.1	20.1	4.3
7.2	16.6	3.5
5.8	13.5	3.1
Pan	− .4	13.9

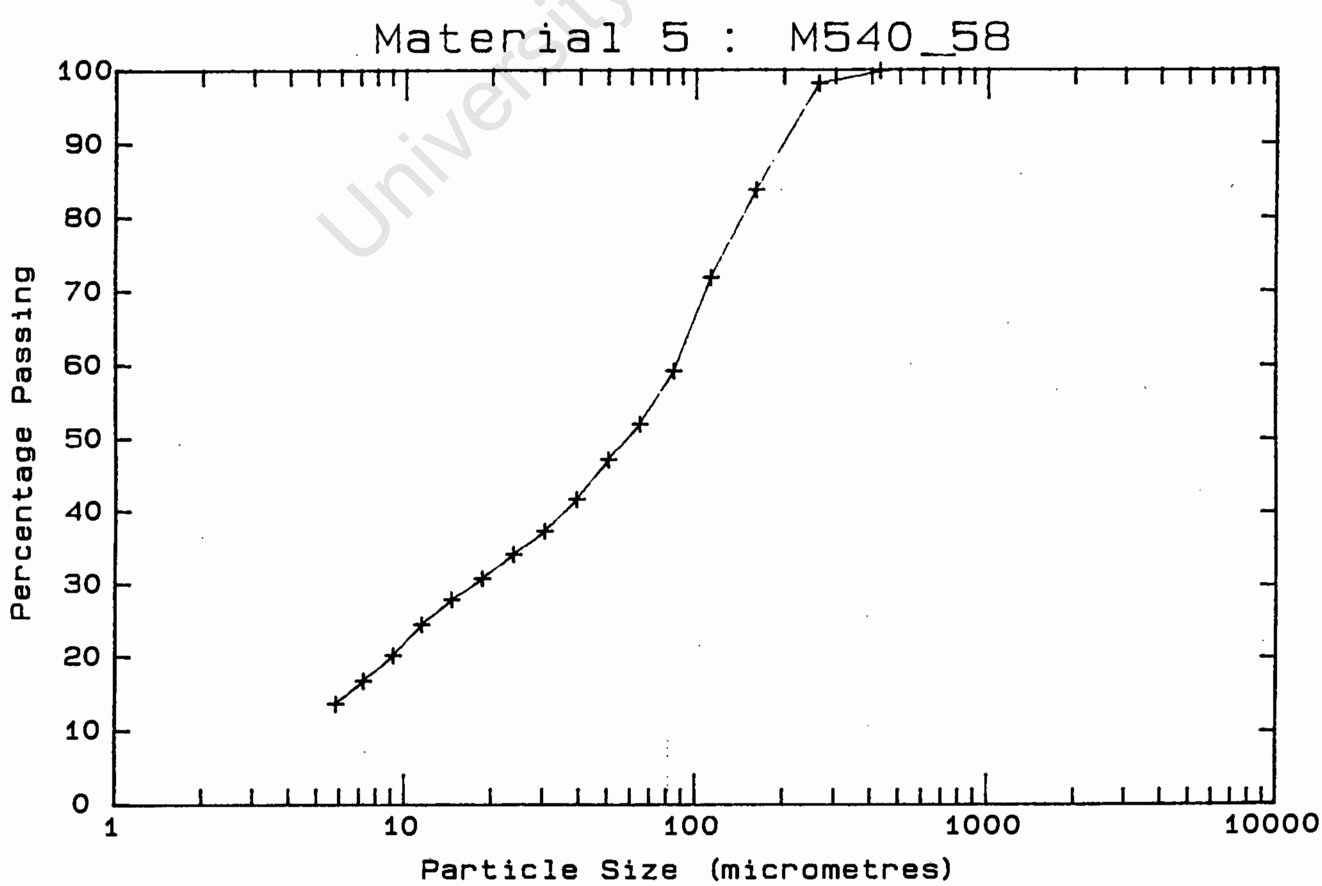
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* −425 µm Malvern Particle Size Analyser



Material 5 : M540D58
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 5 : M540_58
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540U58

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.58
Solids Volumetric Concentration (%)	33.33
Solids Mass Concentration (%)	57.81
Mean Slurry Temperature (°C)	20.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.584	21.487	19.9
3.590	21.301	20.0
3.584	21.309	20.0
3.590	21.076	20.0
3.135	20.204	20.2
3.125	20.263	20.2
3.122	20.191	20.3
3.122	20.246	20.3
2.775	19.611	20.3
2.780	19.045	20.4
2.780	18.957	20.4
2.775	19.279	20.4
2.406	18.639	20.4
2.409	18.149	20.3
2.405	18.871	20.3
2.409	18.283	20.3
2.031	16.333	20.3
2.035	16.353	20.3
2.027	16.396	20.3
2.034	16.423	20.2
1.635	15.462	20.2
1.622	15.486	20.2
1.616	15.448	20.2
1.624	15.598	20.1
1.623	15.536	20.1
1.608	15.468	20.1
1.615	15.430	20.0
1.622	15.378	20.0
1.291	14.506	20.0
1.282	14.515	20.0
1.279	14.658	20.0
1.286	14.575	19.9
1.295	14.323	19.9
1.269	14.135	19.9
1.267	14.228	19.9

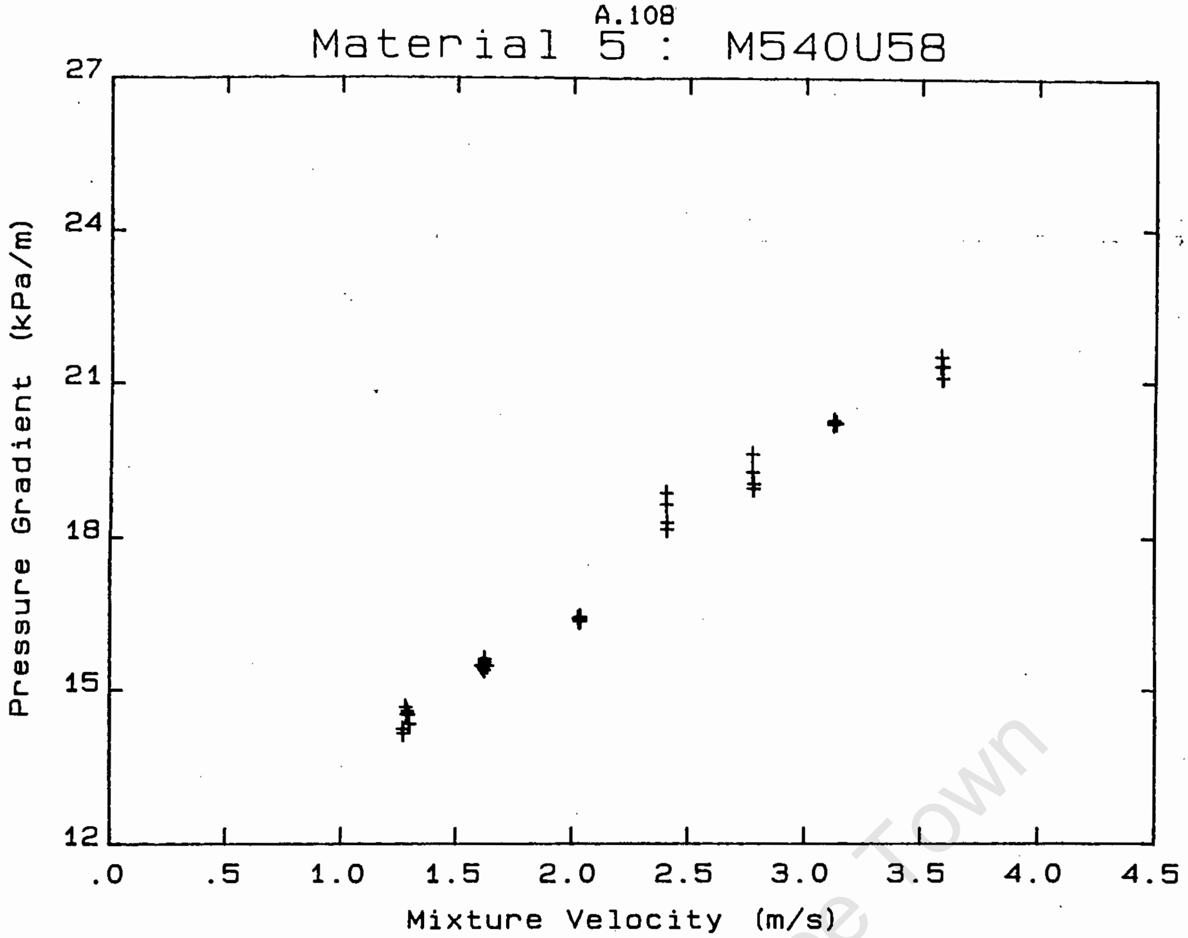
Particle Size Distribution
Sieve and Malvern Size Analysis *

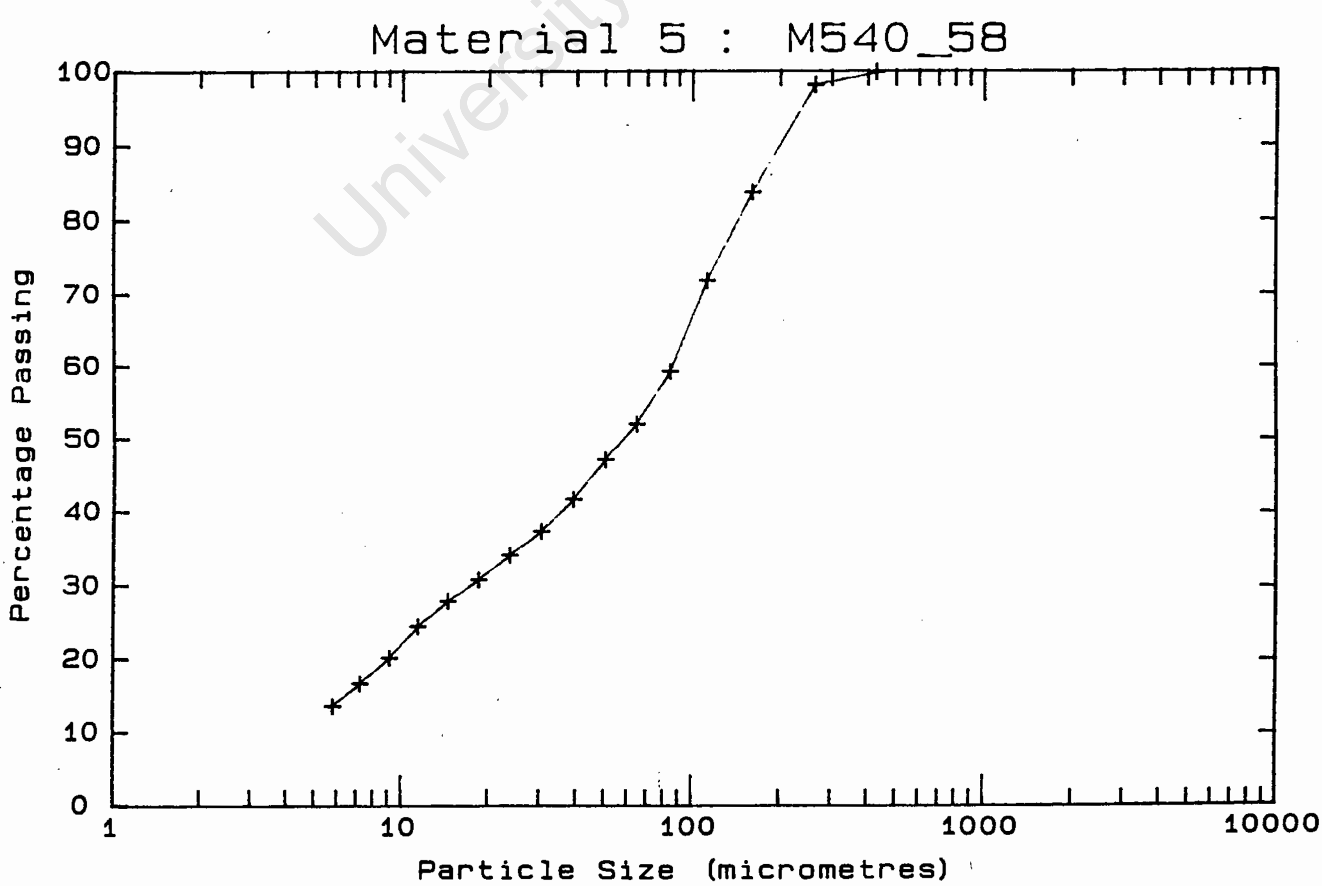
Size (µm)	% Passing	% Retained
425.0	99.7	.3
261.6	98.0	1.7
160.4	83.6	14.4
112.8	71.7	11.9
84.3	59.1	12.6
64.6	51.9	7.2
50.2	47.0	4.9
39.0	41.6	5.4
30.3	37.2	4.4
23.7	34.0	3.2
18.5	30.7	3.3
14.5	27.8	2.9
11.4	24.4	3.4
9.1	20.1	4.3
7.2	16.6	3.5
5.8	13.5	3.1
Pan	- .4	13.9

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 5 : M540U58
Pressure Gradient (kPa/m)
27
24
21
18
15
12
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_58
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540H66

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.66
Solids Volumetric Concentration (%)	37.93
Solids Mass Concentration (%)	62.61
Mean Slurry Temperature (°C)	19.6
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.612	8.229	19.3
3.610	7.850	19.4
3.615	8.063	19.4
3.624	8.115	19.5
3.268	6.711	19.6
3.267	6.312	19.7
3.271	6.485	19.7
3.265	6.476	19.7
2.932	5.509	19.7
2.932	5.482	19.7
2.937	5.441	19.7
2.928	5.755	19.7
2.925	5.633	19.7
2.535	4.137	19.7
2.534	4.208	19.7
2.543	3.987	19.7
2.536	4.147	19.7
2.162	2.672	19.6
2.139	2.418	19.6
2.130	2.426	19.6
2.160	2.527	19.6
1.744	2.037	19.6
1.747	1.507	19.5
1.755	1.963	19.5
1.752	2.272	19.5
1.743	1.506	19.5
1.384	1.933	19.5
1.365	1.960	19.5
1.361	1.818	19.5
1.363	1.895	19.5
1.365	1.921	19.6

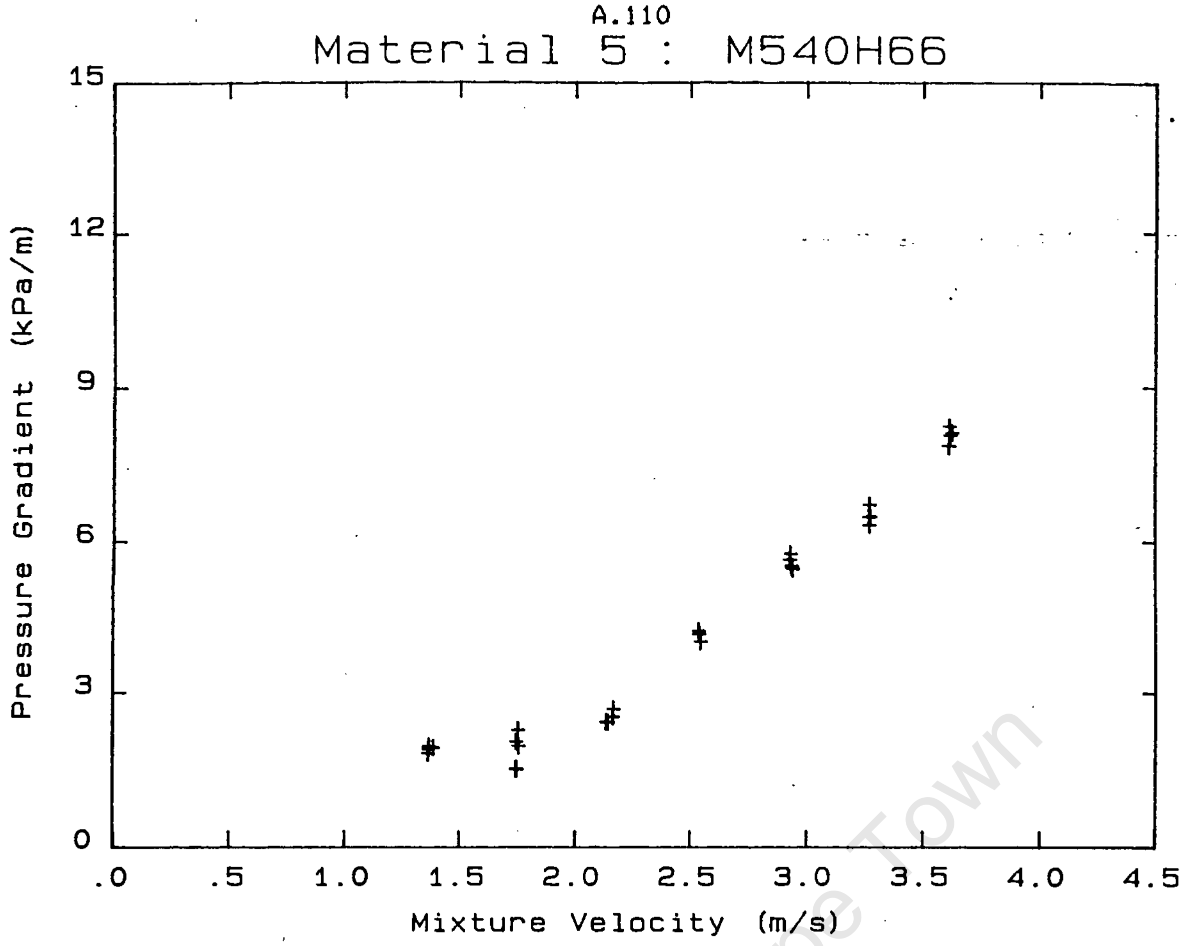
Particle Size Distribution
Sieve and Malvern Size Analysis *

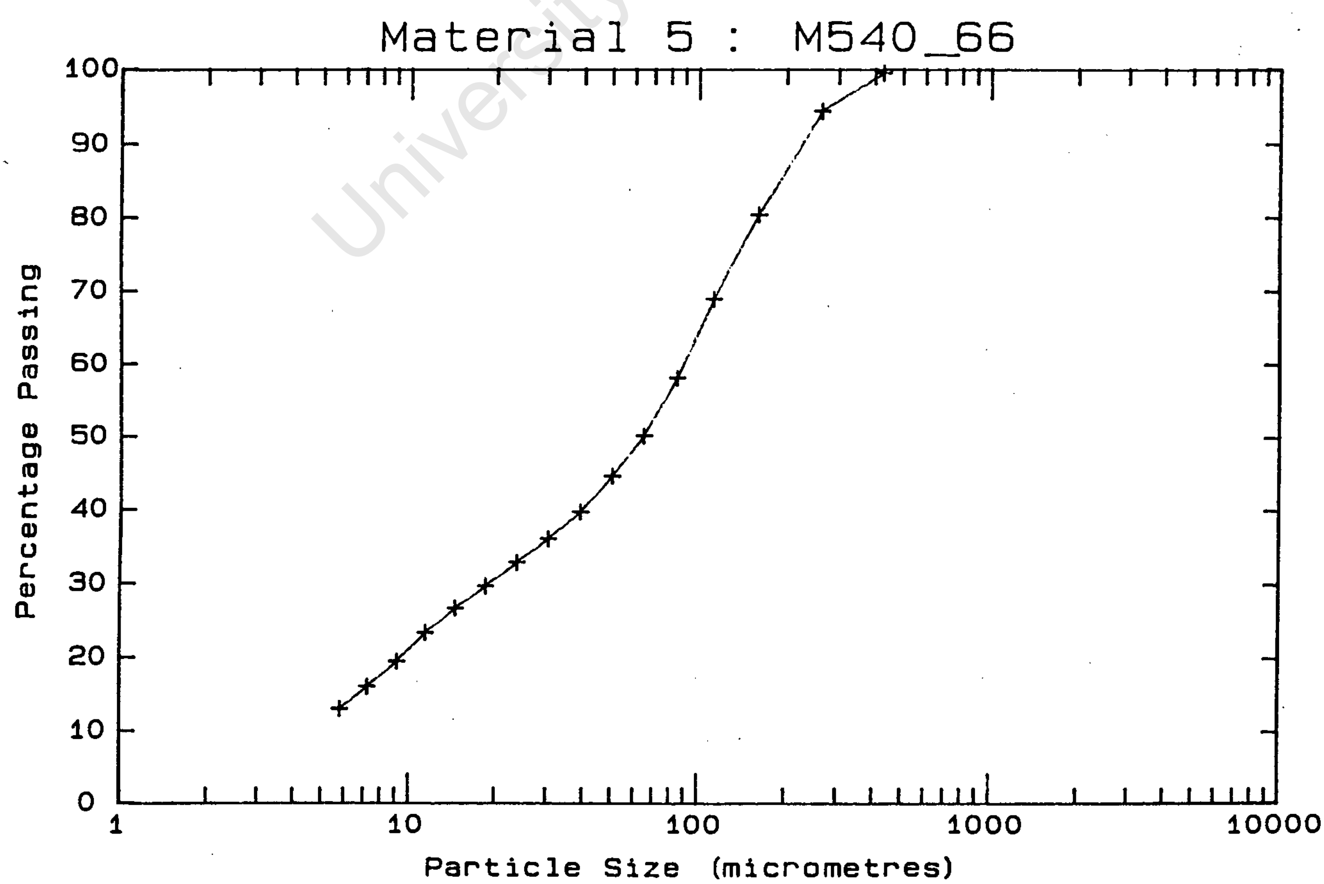
Size (μm)	% Passing	% Retained
425.0	99.4	.6
261.6	94.3	5.1
160.4	80.3	14.0
112.8	68.8	11.5
84.3	58.0	10.8
64.6	50.1	7.9
50.2	44.6	5.5
39.0	39.7	4.9
30.3	36.0	3.7
23.7	32.8	3.2
18.5	29.6	3.2
14.5	26.6	3.0
11.4	23.3	3.3
9.1	19.4	3.9
7.2	16.0	3.4
5.8	13.0	3.0
Pan	- .2	13.2

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
1.08	Asymetric
1.38	Asymetric
1.70	Appears homogeneous
2.01	Appears homogeneous
2.32	Appears homogeneous
2.59	Appears homogeneous
2.86	Appears homogeneous

* -425 μm Malvern Particle Size Analyser


Material 5 : M540H66
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_66
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540D66

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.66
Solids Volumetric Concentration (%)	37.93
Solids Mass Concentration (%)	62.61
Mean Slurry Temperature (°C)	19.6
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.612	- 8.022	19.3
3.610	- 8.375	19.4
3.615	- 7.990	19.4
3.624	- 8.011	19.5
3.268	- 9.432	19.6
3.267	- 9.279	19.7
3.271	- 9.032	19.7
3.265	- 9.212	19.7
2.932	-10.627	19.7
2.932	-10.627	19.7
2.937	-10.546	19.7
2.928	-10.632	19.7
2.925	-10.661	19.7
2.535	-11.800	19.7
2.534	-11.653	19.7
2.543	-12.041	19.7
2.536	-11.992	19.7
2.162	-13.642	19.6
2.139	-13.475	19.6
2.130	-13.467	19.6
2.160	-13.616	19.6
1.744	-14.312	19.6
1.747	-14.148	19.5
1.755	-14.485	19.5
1.752	-14.348	19.5
1.743	-14.404	19.5
1.384	-14.470	19.5
1.365	-14.667	19.5
1.361	-14.464	19.5
1.363	-14.603	19.5
1.365	-14.629	19.6

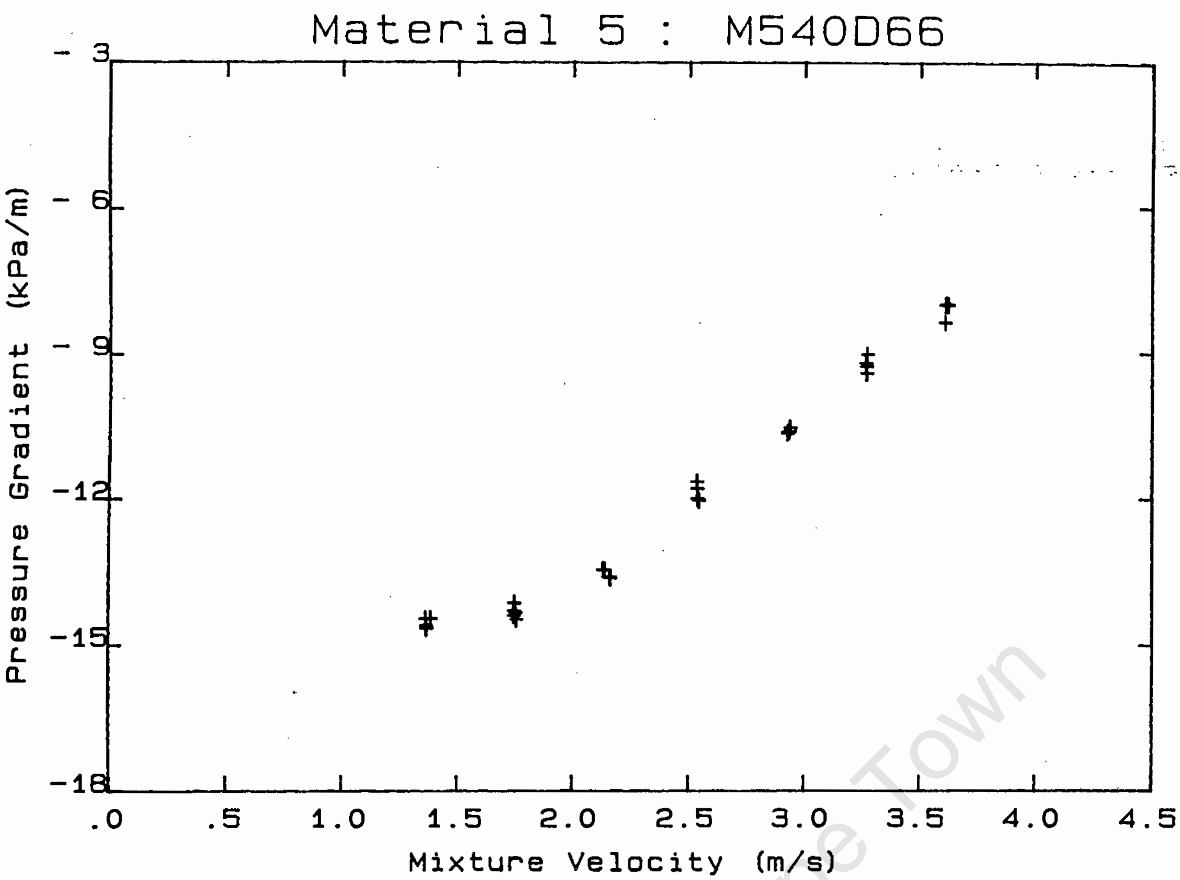
Particle Size Distribution
Sieve and Malvern Size Analysis *

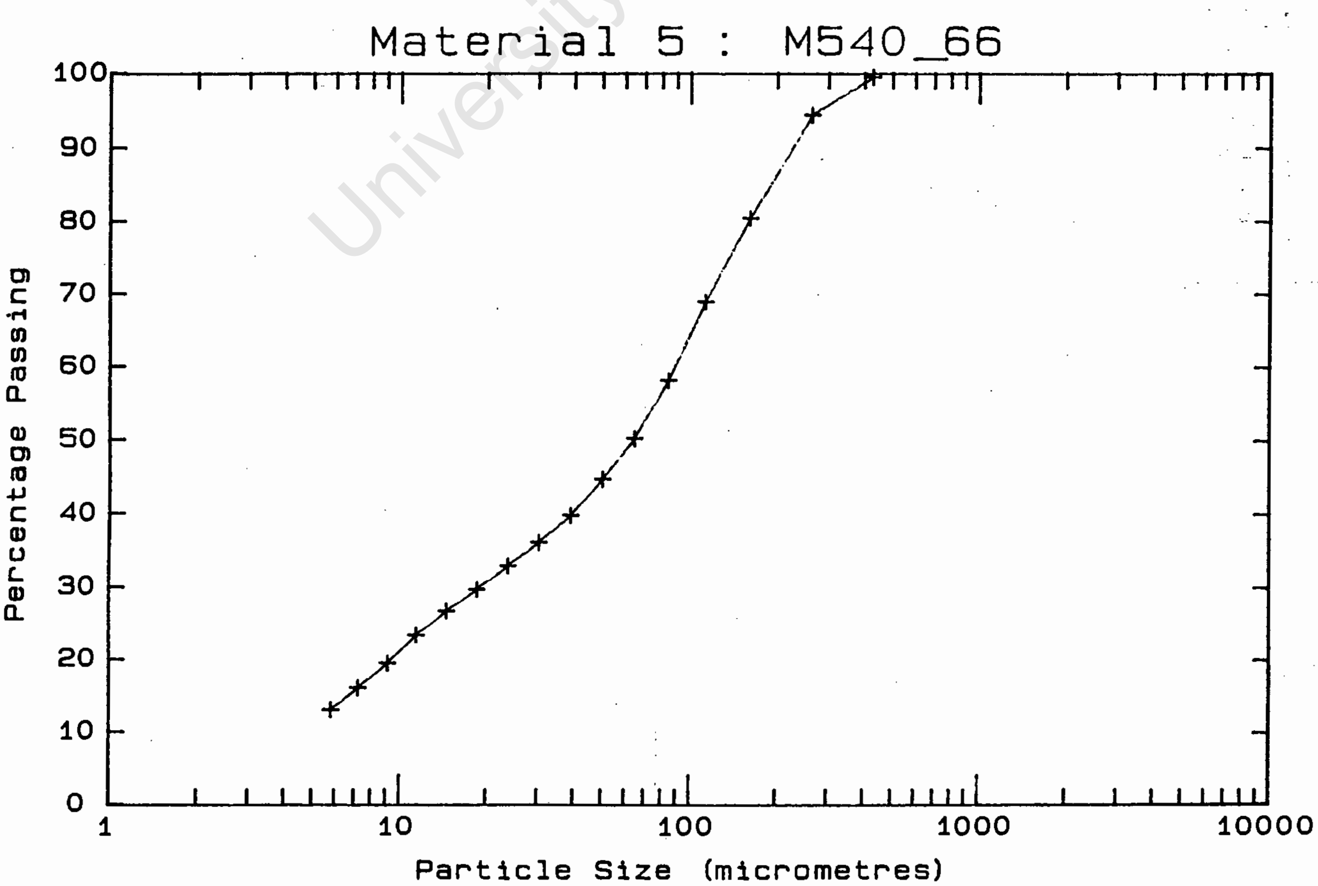
Size (μm)	% Passing	% Retained
425.0	99.4	.6
261.6	94.3	5.1
160.4	80.3	14.0
112.8	68.8	11.5
84.3	58.0	10.8
64.6	50.1	7.9
50.2	44.6	5.5
39.0	39.7	4.9
30.3	36.0	3.7
23.7	32.8	3.2
18.5	29.6	3.2
14.5	26.6	3.0
11.4	23.3	3.3
9.1	19.4	3.9
7.2	16.0	3.4
5.8	13.0	3.0
Pan	- .2	13.2

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 μm Malvern Particle Size Analyser


Material 5 : M540D66
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_66
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540U66

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.66
Solids Volumetric Concentration (%)	37.93
Solids Mass Concentration (%)	62.61
Mean Slurry Temperature (°C)	19.6
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.612	22.654	19.3
3.610	22.359	19.4
3.615	21.898	19.4
3.624	22.659	19.5
3.268	20.922	19.6
3.267	21.223	19.7
3.271	21.449	19.7
3.265	21.290	19.7
2.932	19.741	19.7
2.932	19.596	19.7
2.937	19.413	19.7
2.928	18.915	19.7
2.925	18.826	19.7
2.535	17.703	19.7
2.534	17.106	19.7
2.543	17.735	19.7
2.536	17.656	19.7
1.747	15.385	19.5
1.755	15.354	19.5
1.752	15.441	19.5
1.743	15.419	19.5
1.384	15.221	19.5
1.365	15.269	19.5
1.361	15.276	19.5
1.363	15.276	19.5
1.365	15.302	19.6

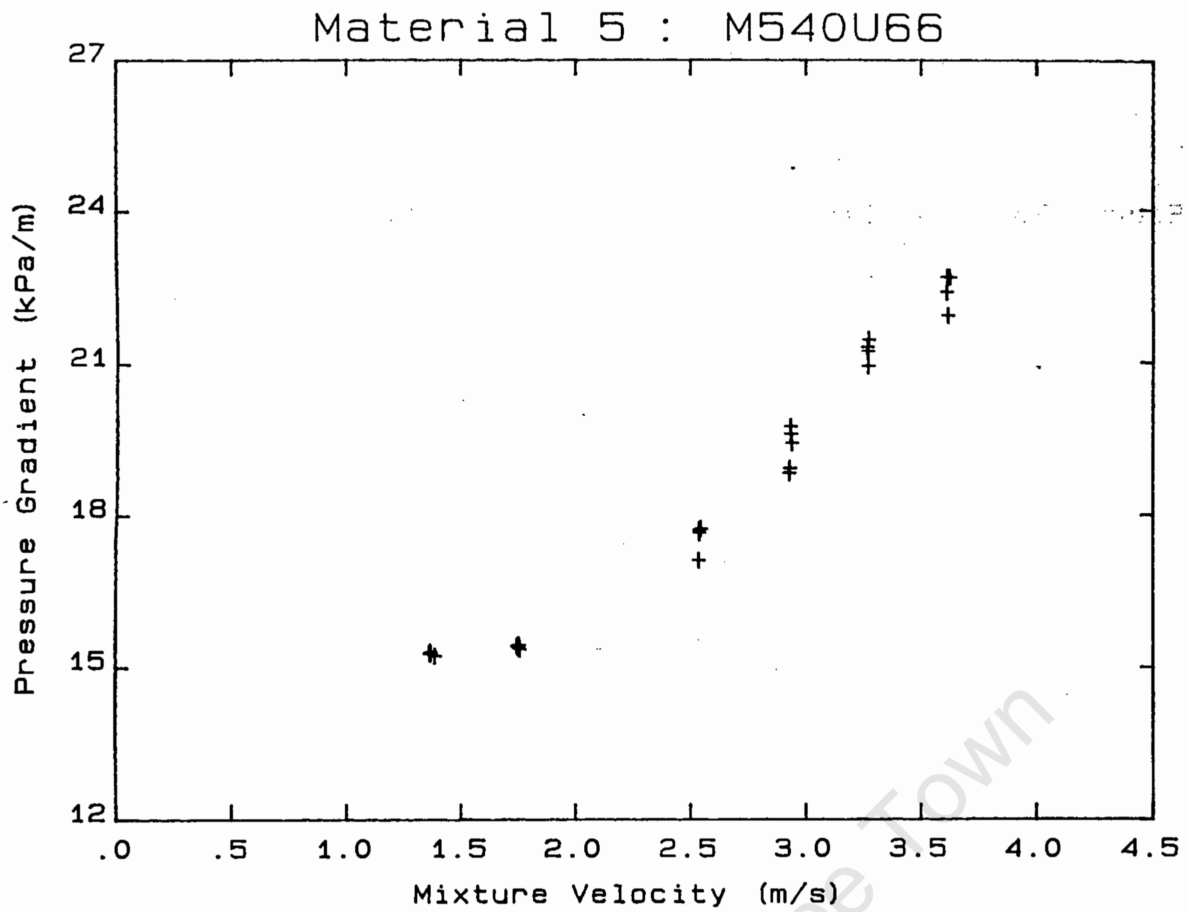
Particle Size Distribution
Sieve and Malvern Size Analysis *

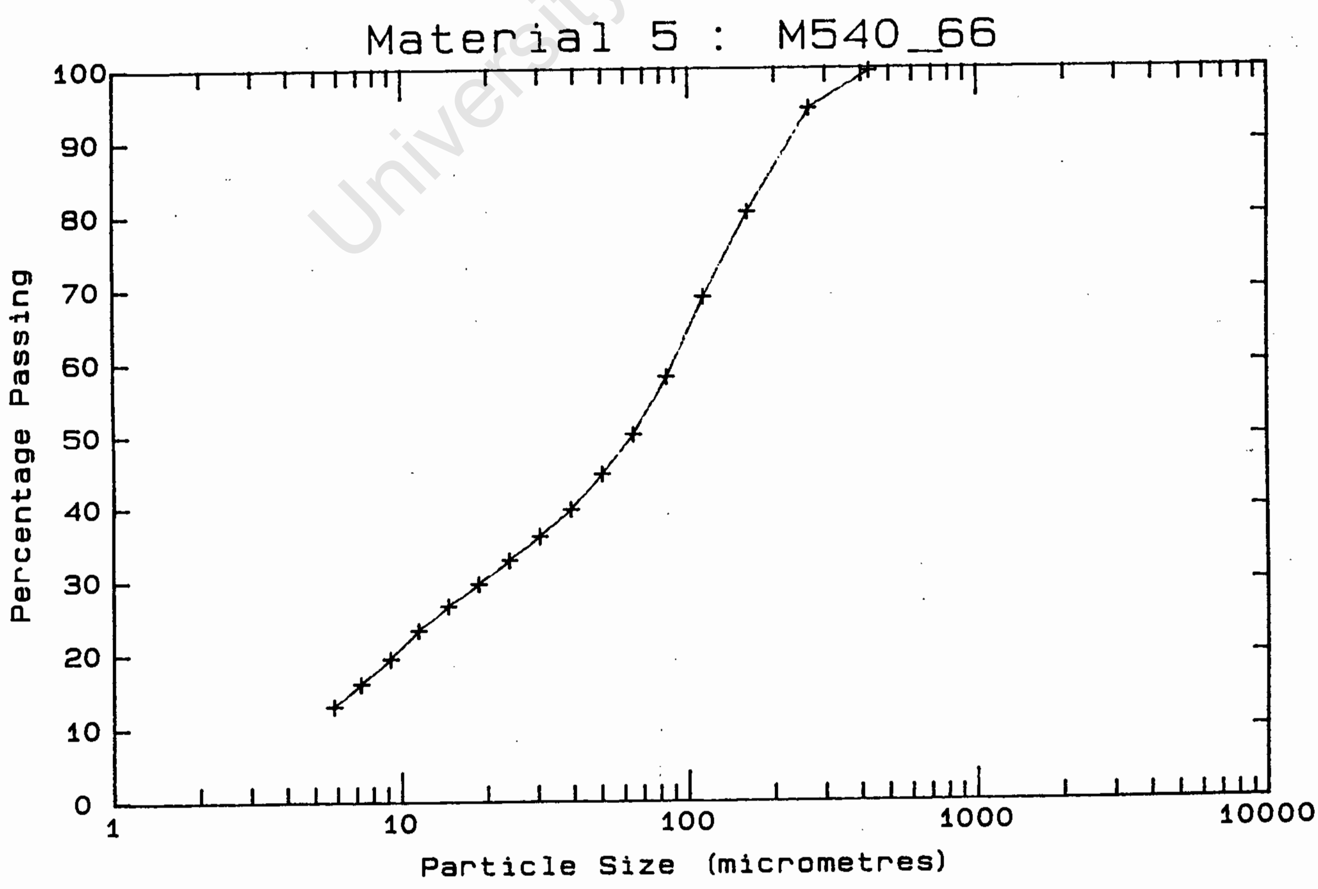
Size (µm)	% Passing	% Retained
425.0	99.4	.6
261.6	94.3	5.1
160.4	80.3	14.0
112.8	68.8	11.5
84.3	58.0	10.8
64.6	50.1	7.9
50.2	44.6	5.5
39.0	39.7	4.9
30.3	36.0	3.7
23.7	32.8	3.2
18.5	29.6	3.2
14.5	26.6	3.0
11.4	23.3	3.3
9.1	19.4	3.9
7.2	16.0	3.4
5.8	13.0	3.0
Pan	- .2	13.2

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 5 : M540U66
Pressure Gradient (kPa/m)
27
24
21
18
15
12
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_66
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540H74

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.74
Solids Volumetric Concentration (%)	42.53
Solids Mass Concentration (%)	66.97
Mean Slurry Temperature (°C)	21.1
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.668	8.738	20.2
3.668	8.431	20.3
3.668	8.484	20.4
3.671	7.794	20.5
3.311	5.669	20.7
3.324	6.194	20.7
3.340	6.111	20.8
3.343	5.852	20.8
2.848	4.968	20.9
2.850	4.793	21.0
2.863	5.050	21.0
2.858	4.916	21.0
2.866	4.879	21.0
2.537	4.649	21.1
2.522	4.580	21.1
2.517	4.580	21.2
2.099	4.121	21.2
2.102	4.206	21.2
2.104	4.048	21.2
2.108	4.070	21.3
1.799	3.803	21.3
1.803	3.768	21.3
1.804	3.780	21.3
1.441	3.409	21.3
1.420	3.398	21.3
1.419	3.392	21.3
1.424	3.387	21.3
1.099	3.122	21.4
1.095	3.046	21.4
1.079	3.083	21.4
1.085	3.055	21.4
.741	2.711	21.4
.715	2.700	21.4
.721	2.732	21.4
.687	2.659	21.4

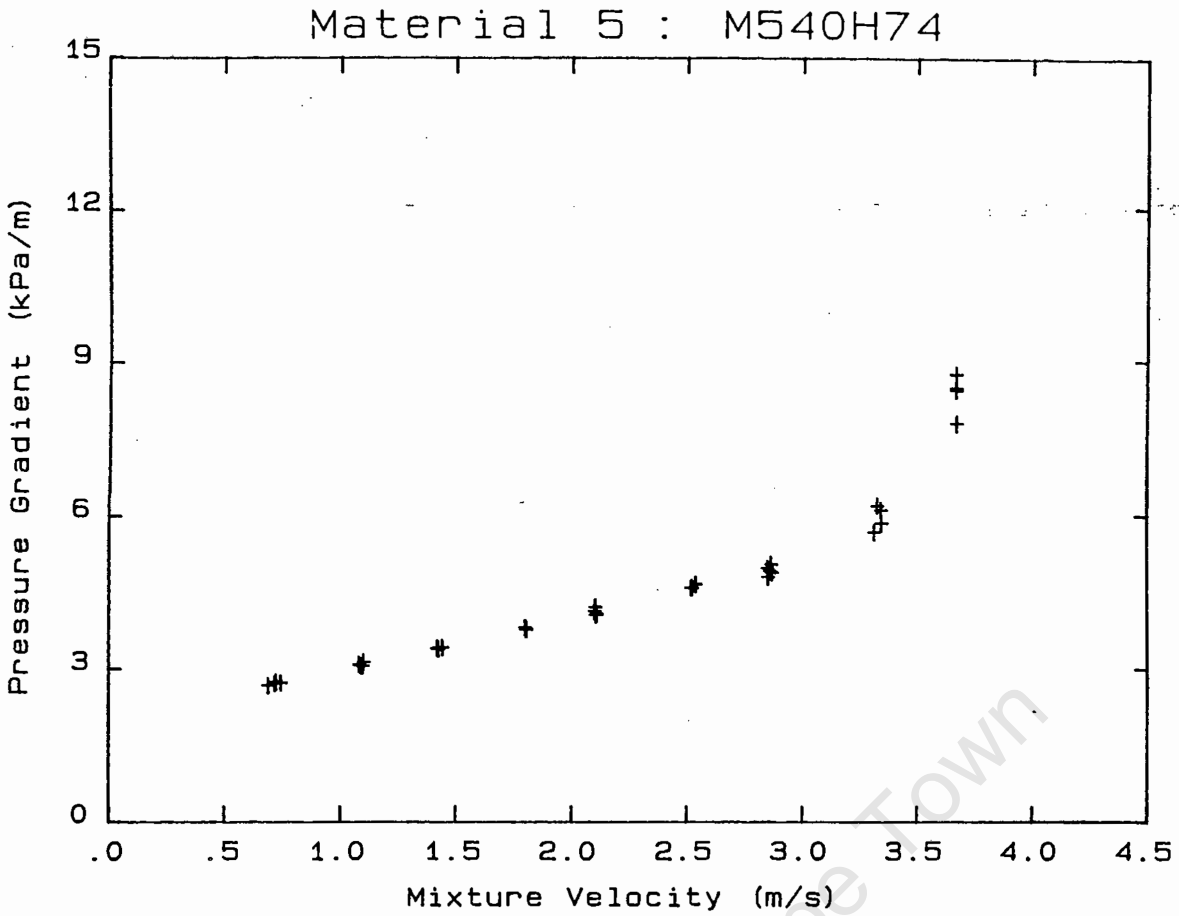
Particle Size Distribution
Sieve and Malvern Size Analysis *

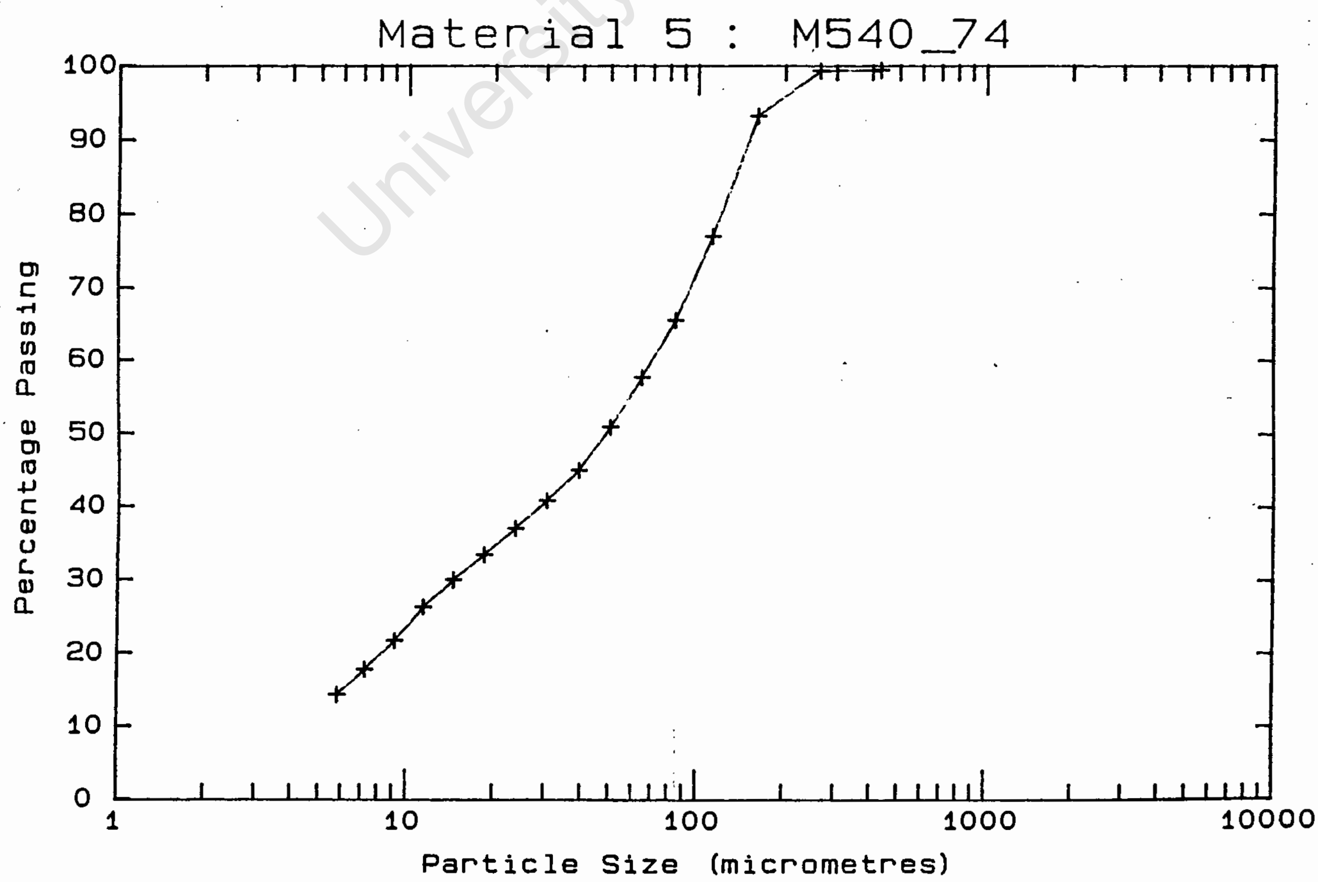
Size (µm)	% Passing	% Retained
425.0	99.3	.7
261.6	99.2	.1
160.4	93.0	6.2
112.8	76.9	16.1
84.3	65.4	11.5
64.6	57.5	7.9
50.2	50.8	6.7
39.0	44.9	5.9
30.3	40.7	4.2
23.7	36.9	3.8
18.5	33.3	3.6
14.5	29.9	3.4
11.4	26.2	3.7
9.1	21.6	4.6
7.2	17.7	3.9
5.8	14.3	3.4
Pan	- .5	14.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.57	Appears homogeneous
.86	Appears homogeneous
1.13	Appears homogeneous
1.42	Appears homogeneous
1.66	Appears homogeneous
2.00	Appears homogeneous
2.26	Appears homogeneous
2.63	Appears homogeneous
2.90	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 5 : M540H74
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_74
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540D74

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.74
Solids Volumetric Concentration (%)	42.53
Solids Mass Concentration (%)	66.97
Mean Slurry Temperature (°C)	21.1
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.668	- 7.389	20.2
3.668	- 7.933	20.3
3.668	- 7.773	20.4
3.671	- 7.389	20.5
3.311	- 9.717	20.7
3.324	- 9.837	20.7
3.340	- 9.567	20.8
3.343	- 9.795	20.8
2.848	-11.993	20.9
2.850	-11.889	21.0
2.863	-12.041	21.0
2.858	-12.005	21.0
2.866	-12.280	21.0
2.537	-12.604	21.1
2.522	-12.479	21.1
2.517	-12.368	21.2
2.099	-12.953	21.2
2.102	-12.925	21.2
2.104	-12.959	21.2
2.108	-12.917	21.3
1.799	-13.173	21.3
1.803	-13.117	21.3
1.804	-13.187	21.3
1.441	-13.484	21.3
1.420	-13.500	21.3
1.419	-13.531	21.3
1.424	-13.430	21.3
1.099	-13.902	21.4
1.095	-13.734	21.4
1.079	-13.727	21.4
1.085	-13.578	21.4
.741	-14.650	21.4
.715	-14.064	21.4
.721	-13.938	21.4
.687	-13.335	21.4

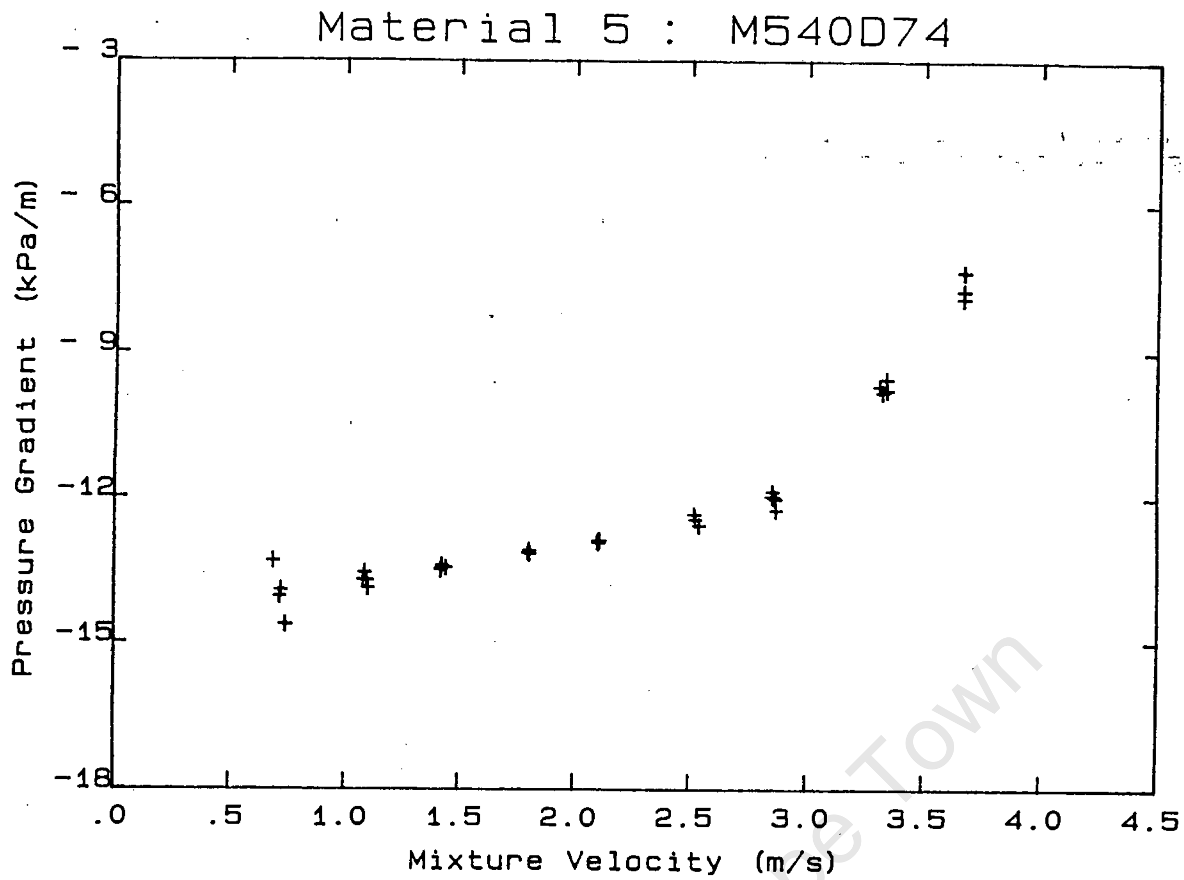
Particle Size Distribution
Sieve and Malvern Size Analysis *

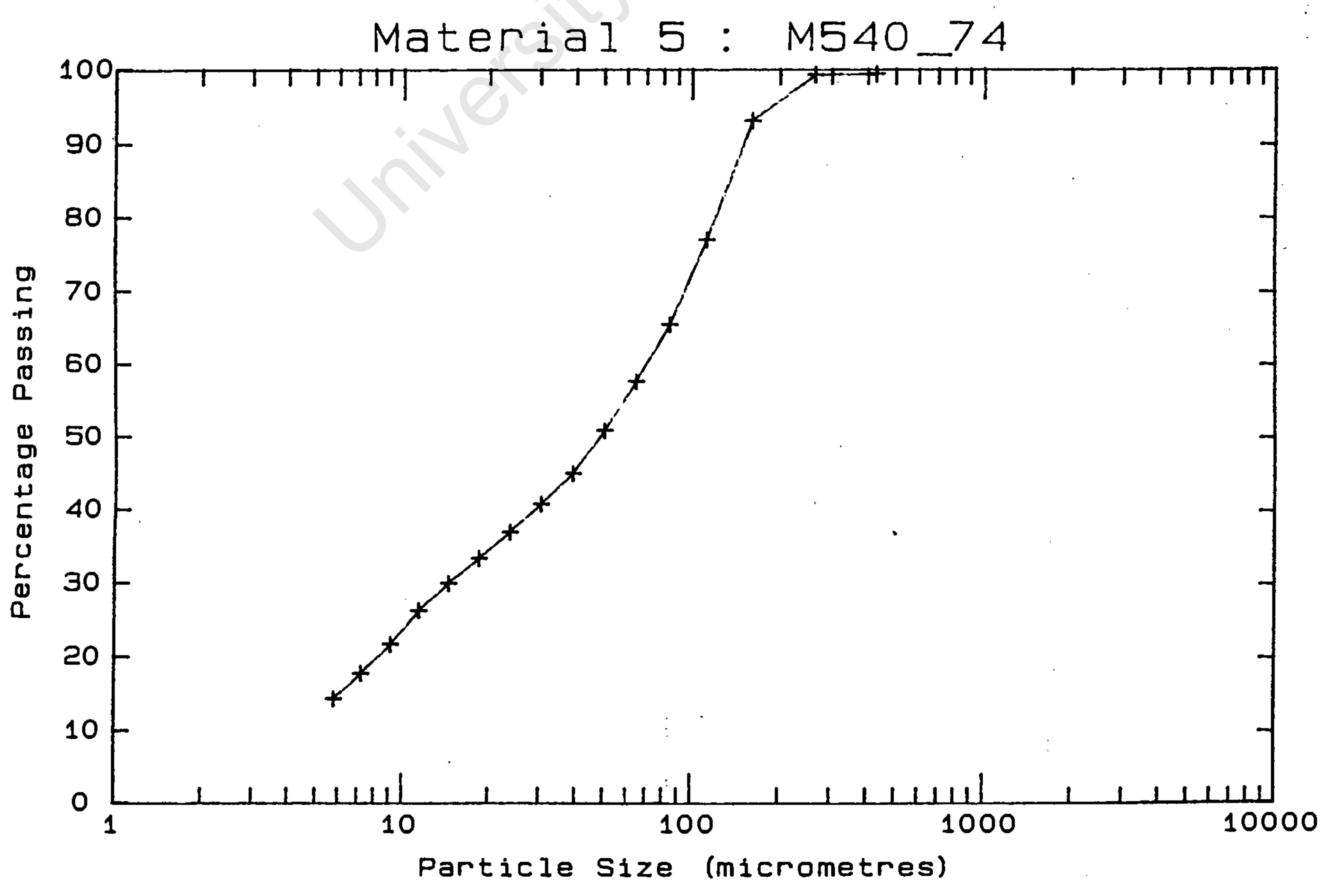
Size (µm)	% Passing	% Retained
425.0	99.3	.7
261.6	99.2	.1
160.4	93.0	6.2
112.8	76.9	16.1
84.3	65.4	11.5
64.6	57.5	7.9
50.2	50.8	6.7
39.0	44.9	5.9
30.3	40.7	4.2
23.7	36.9	3.8
18.5	33.3	3.6
14.5	29.9	3.4
11.4	26.2	3.7
9.1	21.6	4.6
7.2	17.7	3.9
5.8	14.3	3.4
Pan	- .5	14.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 5 : M540D74
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_74
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540U74

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.74
Solids Volumetric Concentration (%)	42.53
Solids Mass Concentration (%)	66.97
Mean Slurry Temperature (°C)	21.1
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.668	25.446	20.2
3.668	26.761	20.3
3.668	26.490	20.4
3.671	25.751	20.5
3.311	21.331	20.7
3.324	21.518	20.7
3.340	21.158	20.8
3.343	20.811	20.8
2.848	19.338	20.9
2.850	19.551	21.0
2.863	19.395	21.0
2.858	19.587	21.0
2.866	19.801	21.0
2.537	18.863	21.1
2.522	18.793	21.1
2.517	18.785	21.2
2.099	17.543	21.2
2.102	17.390	21.2
2.104	17.485	21.2
2.108	17.416	21.3
1.799	16.978	21.3
1.803	16.989	21.3
1.804	16.876	21.3
1.441	16.867	21.3
1.420	16.465	21.3
1.419	16.775	21.3
1.424	17.075	21.3
1.099	16.606	21.4
1.095	16.708	21.4
1.079	16.684	21.4
1.085	16.829	21.4
.741	16.548	21.4
.715	16.468	21.4
.721	16.504	21.4
.687	16.494	21.4

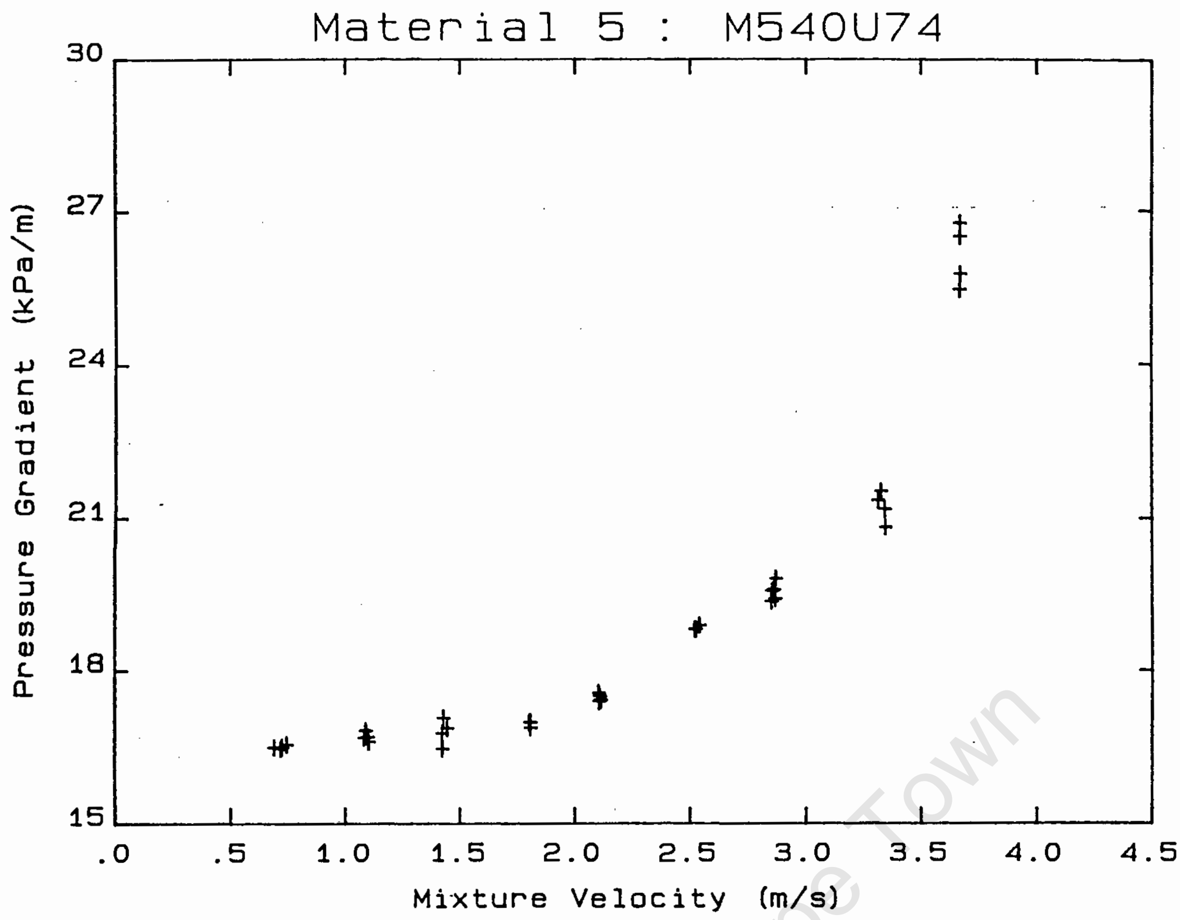
Particle Size Distribution
Sieve and Malvern Size Analysis *

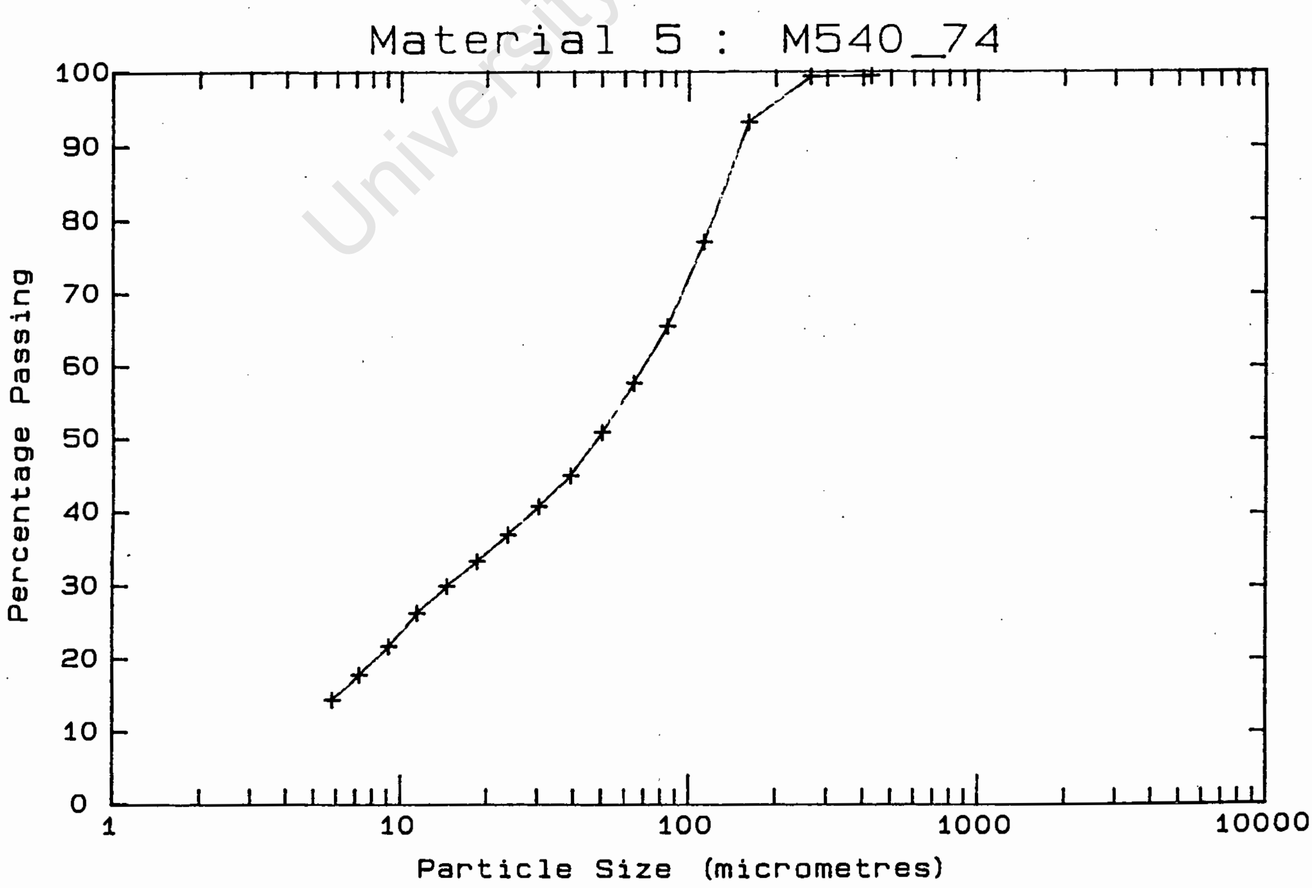
Size (μm)	% Passing	% Retained
425.0	99.3	.7
261.6	99.2	.1
160.4	93.0	6.2
112.8	76.9	16.1
84.3	65.4	11.5
64.6	57.5	7.9
50.2	50.8	6.7
39.0	44.9	5.9
30.3	40.7	4.2
23.7	36.9	3.8
18.5	33.3	3.6
14.5	29.9	3.4
11.4	26.2	3.7
9.1	21.6	4.6
7.2	17.7	3.9
5.8	14.3	3.4
Pan	- .5	14.8

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 μm Malvern Particle Size Analyser


Material 5 : M540U74
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_74
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540H76

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.76
Solids Volumetric Concentration (%)	43.68
Solids Mass Concentration (%)	68.00
Mean Slurry Temperature (°C)	25.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.681	6.791	24.6
3.709	7.776	24.7
3.672	6.580	24.7
3.701	7.445	24.8
3.724	7.506	24.8
3.733	7.498	24.9
3.221	5.902	24.9
3.202	6.091	25.0
3.190	6.057	25.0
3.197	6.009	25.0
3.192	6.036	25.1
2.907	5.345	25.2
2.905	5.484	25.2
2.898	5.689	25.2
2.905	5.687	25.2
2.414	4.881	25.3
2.399	4.883	25.3
2.397	4.936	25.3
2.393	4.851	25.3
1.984	4.452	25.4
1.969	4.394	25.4
1.963	4.498	25.4
1.954	4.476	25.4
1.606	4.167	25.4
1.586	4.103	25.4
1.575	4.077	25.4
1.569	4.114	25.5
1.317	3.840	25.5
1.319	3.848	25.5
1.324	3.849	25.5
1.316	3.836	25.5
.360	2.805	25.5
.337	2.839	25.5
.291	2.704	25.5
.479	2.952	25.5
.455	3.040	25.5

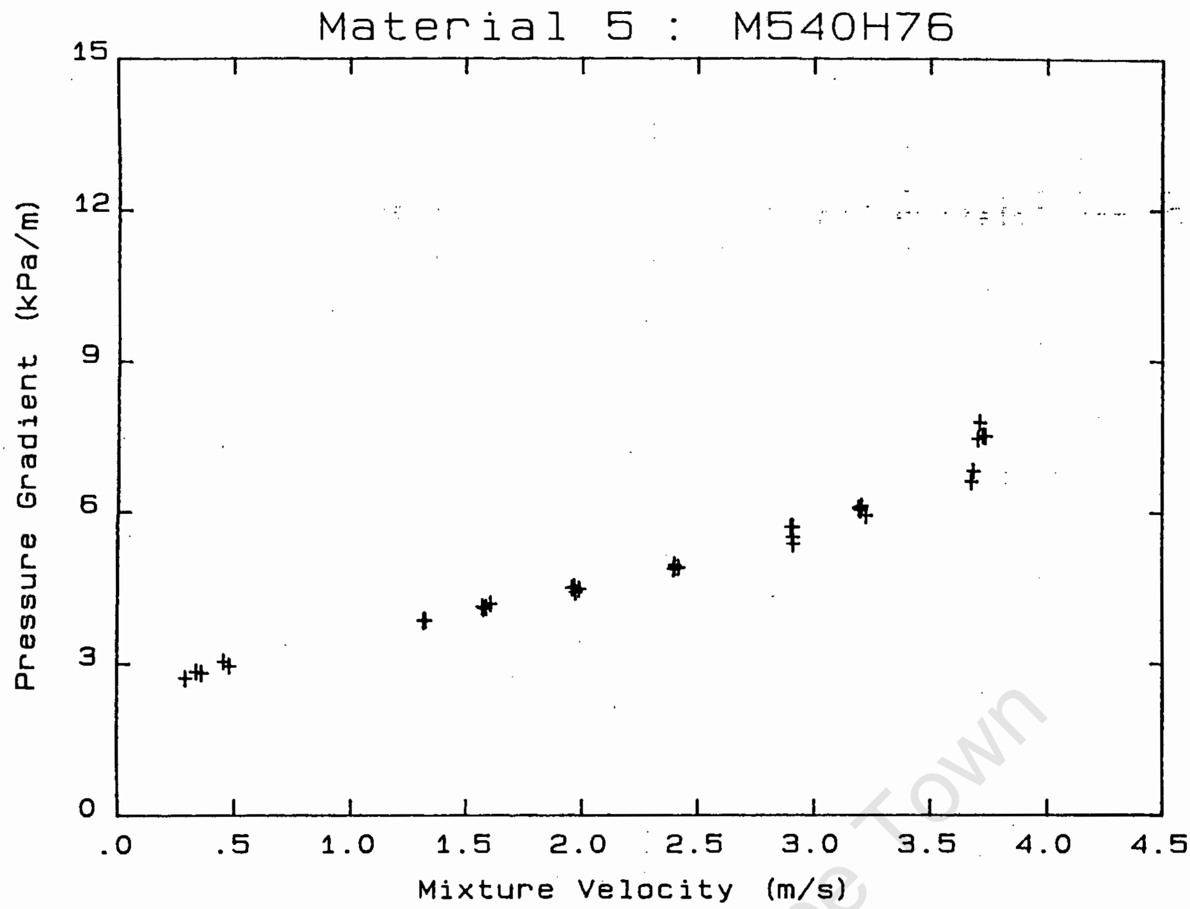
Particle Size Distribution
Sieve and Malvern Size Analysis *

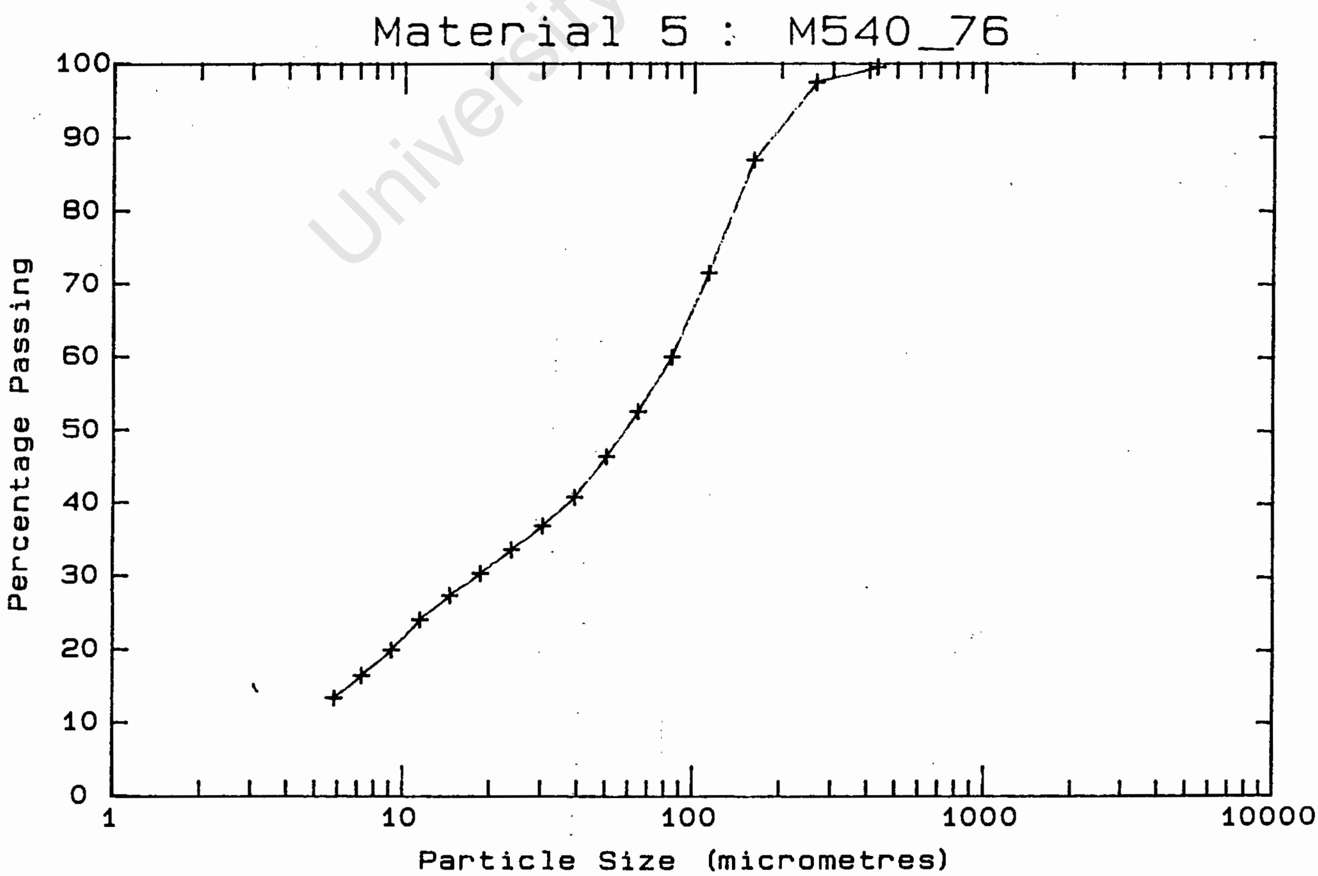
Size (μm)	% Passing	% Retained
425.0	99.4	.6
261.6	97.3	2.1
160.4	86.8	10.5
112.8	71.4	15.4
84.3	59.9	11.5
64.6	52.5	7.4
50.2	46.3	6.2
39.0	40.7	5.6
30.3	36.8	3.9
23.7	33.5	3.3
18.5	30.3	3.2
14.5	27.3	3.0
11.4	24.0	3.3
9.1	19.9	4.1
7.2	16.4	3.5
5.8	13.3	3.1
Pan	- .3	13.6

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.24	Appears homogeneous
1.04	Appears homogeneous
1.24	Appears homogeneous
1.56	Appears homogeneous
1.90	Appears homogeneous
2.29	Appears homogeneous
2.53	Appears homogeneous
2.93	Appears homogeneous

* -425 μm Malvern Particle Size Analyser


Material 5 : M540H76
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_76
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540D76

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.76
Solids Volumetric Concentration (%)	43.68
Solids Mass Concentration (%)	68.00
Mean Slurry Temperature (°C)	25.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.681	- 9.155	24.6
3.709	- 9.449	24.7
3.672	- 9.609	24.7
3.701	- 9.584	24.8
3.724	- 9.251	24.8
3.733	- 9.619	24.9
3.221	-11.189	24.9
3.202	-11.996	25.0
3.190	-11.326	25.0
3.197	-11.269	25.0
3.192	-11.345	25.1
2.907	-11.761	25.2
2.905	-12.041	25.2
2.898	-11.724	25.2
2.905	-11.563	25.2
2.414	-12.433	25.3
2.399	-12.263	25.3
2.397	-12.290	25.3
2.393	-12.247	25.3
1.984	-12.507	25.4
1.969	-12.753	25.4
1.963	-12.621	25.4
1.954	-12.566	25.4
1.606	-12.937	25.4
1.586	-12.962	25.4
1.575	-12.939	25.4
1.569	-12.936	25.5
1.317	-13.204	25.5
1.319	-13.187	25.5
1.324	-13.202	25.5
1.316	-13.238	25.5
.360	-14.229	25.5
.337	-14.233	25.5
.291	-14.347	25.5
.479	-14.126	25.5
.455	-14.085	25.5

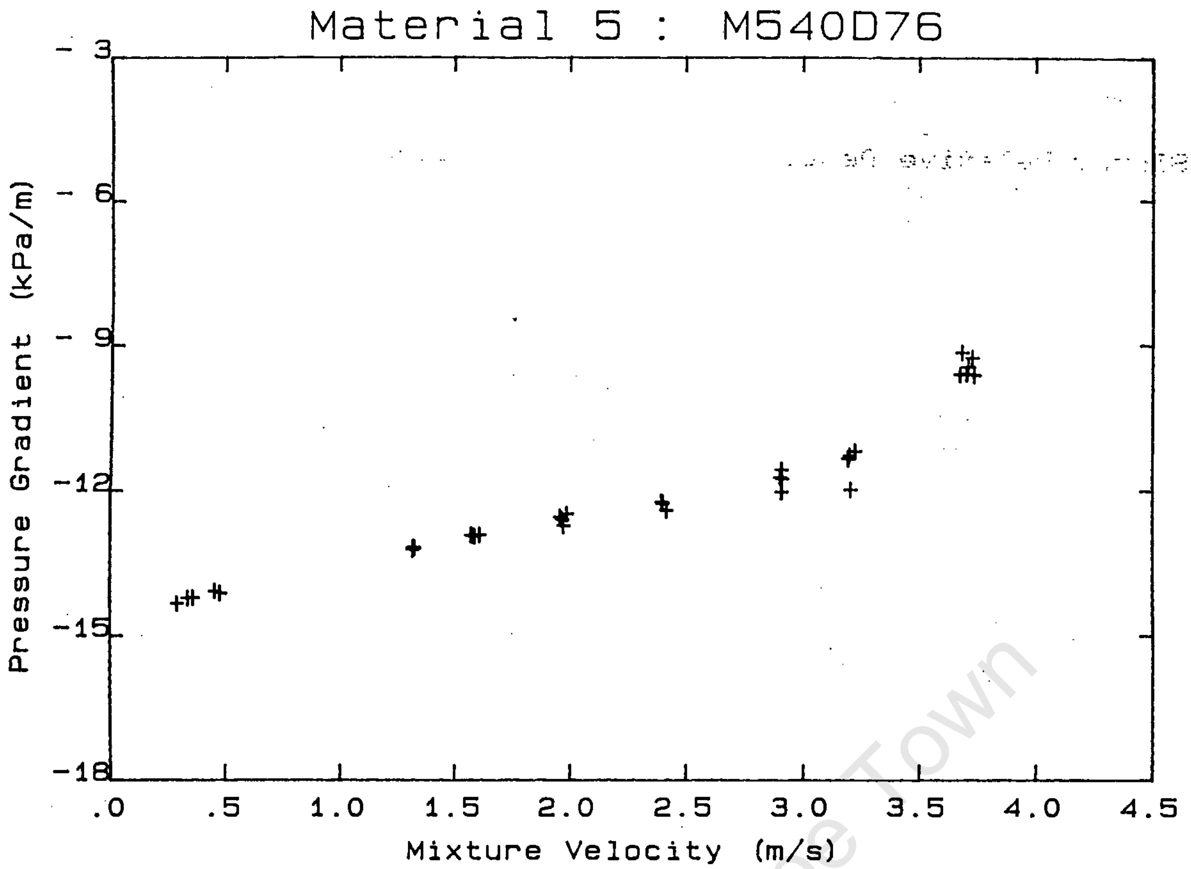
Particle Size Distribution
Sieve and Malvern Size Analysis *

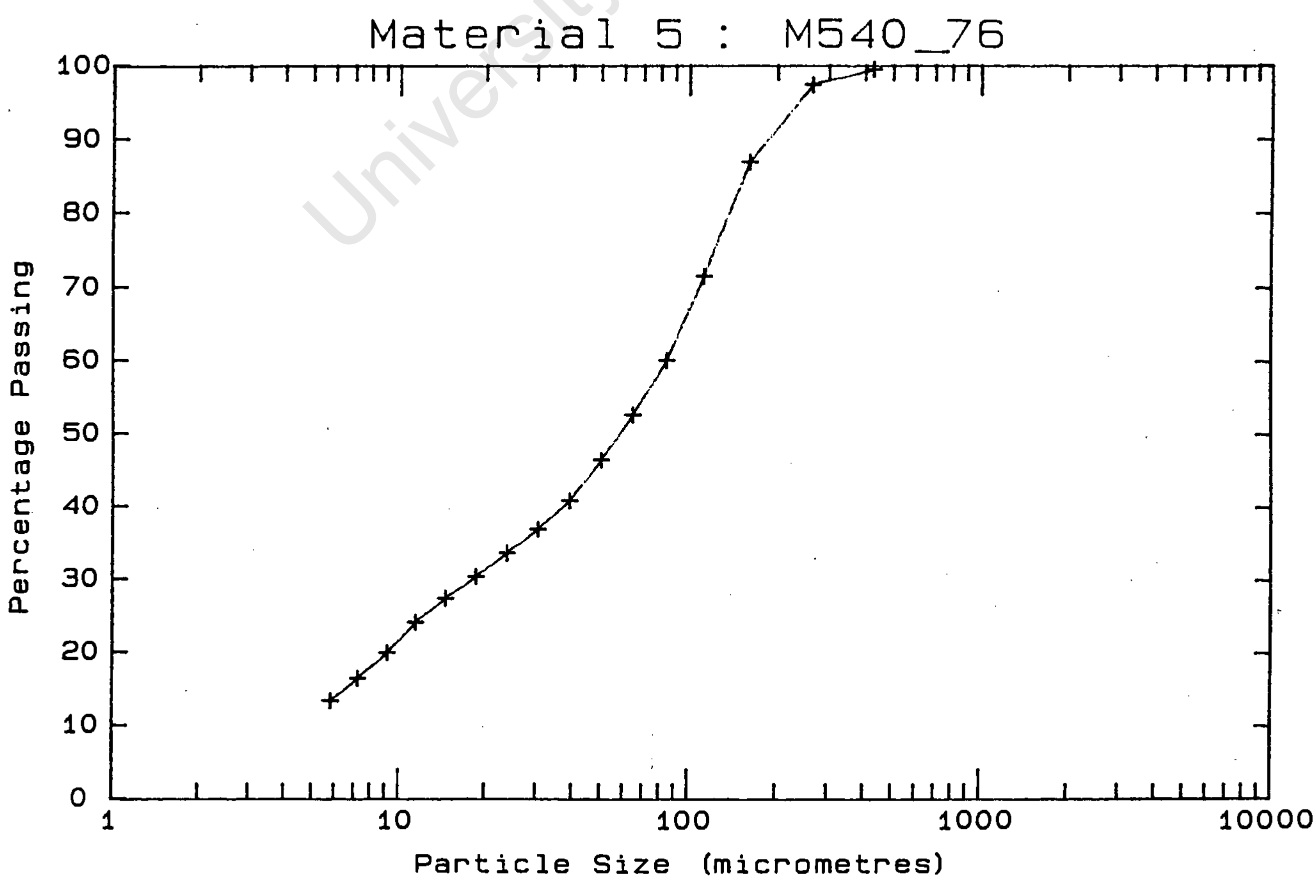
Size (µm)	% Passing	% Retained
425.0	99.4	.6
261.6	97.3	2.1
160.4	86.8	10.5
112.8	71.4	15.4
84.3	59.9	11.5
64.6	52.5	7.4
50.2	46.3	6.2
39.0	40.7	5.6
30.3	36.8	3.9
23.7	33.5	3.3
18.5	30.3	3.2
14.5	27.3	3.0
11.4	24.0	3.3
9.1	19.9	4.1
7.2	16.4	3.5
5.8	13.3	3.1
Pan	- .3	13.6

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 5 : M540D76
Pressure Gradient (kPa/m)
-3
-6
-9
-12
-15
-18
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_76
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540U76

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.76
Solids Volumetric Concentration (%)	43.68
Solids Mass Concentration (%)	68.00
Mean Slurry Temperature (°C)	25.2
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.681	22.603	24.6
3.709	23.082	24.7
3.672	23.401	24.7
3.701	23.002	24.8
3.724	23.129	24.8
3.733	23.079	24.9
3.221	21.554	24.9
3.202	21.627	25.0
3.190	21.153	25.0
3.197	21.607	25.0
3.192	21.484	25.1
2.907	21.430	25.2
2.905	20.977	25.2
2.898	21.426	25.2
2.905	21.431	25.2
2.414	20.190	25.3
2.399	20.608	25.3
2.397	20.104	25.3
2.393	20.668	25.3
1.984	19.396	25.4
1.969	19.111	25.4
1.963	19.259	25.4
1.954	19.081	25.4
1.606	18.721	25.4
1.586	18.494	25.4
1.575	18.441	25.4
1.569	18.349	25.5
1.317	18.252	25.5
1.319	18.143	25.5
1.324	18.262	25.5
1.316	18.186	25.5
.360	17.367	25.5
.337	17.024	25.5
.291	17.313	25.5
.479	17.481	25.5
.455	17.348	25.5

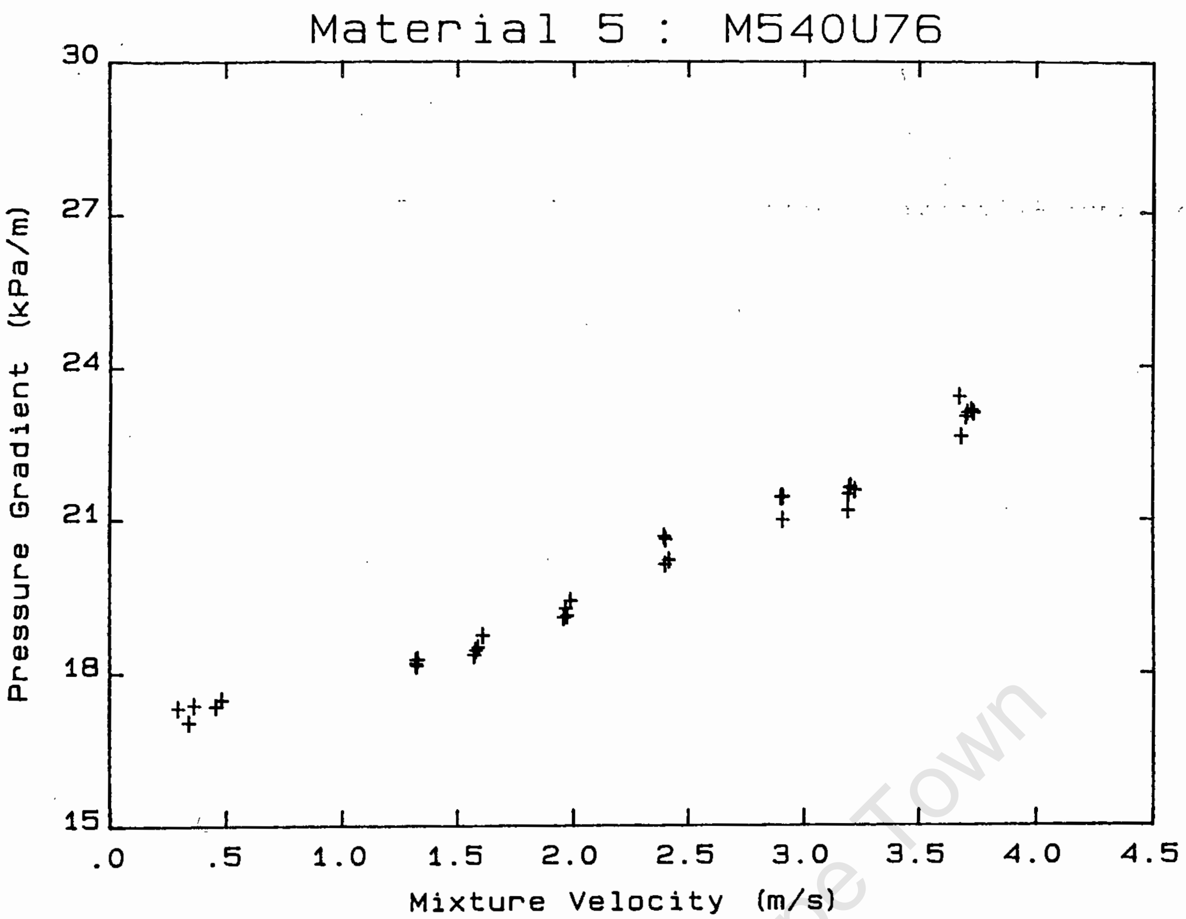
Particle Size Distribution
Sieve and Malvern Size Analysis *

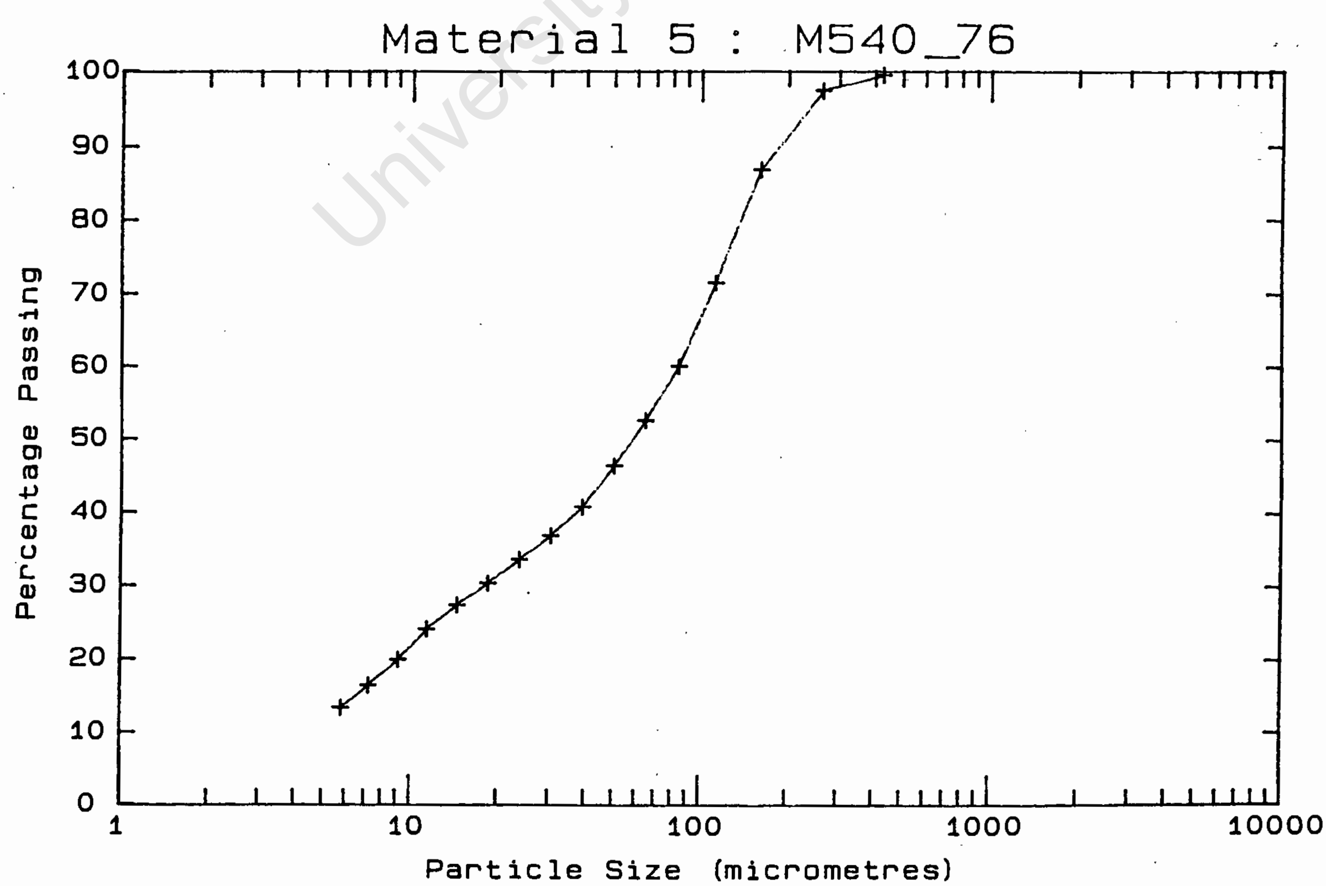
Size (µm)	% Passing	% Retained
425.0	99.4	.6
261.6	97.3	2.1
160.4	86.8	10.5
112.8	71.4	15.4
84.3	59.9	11.5
64.6	52.5	7.4
50.2	46.3	6.2
39.0	40.7	5.6
30.3	36.8	3.9
23.7	33.5	3.3
18.5	30.3	3.2
14.5	27.3	3.0
11.4	24.0	3.3
9.1	19.9	4.1
7.2	16.4	3.5
5.8	13.3	3.1
Pan	- .3	13.6

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 5 : M540U76
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_76
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540H80

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.80
Solids Volumetric Concentration (%)	45.98
Solids Mass Concentration (%)	69.99
Mean Slurry Temperature (°C)	27.0
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	62.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.931	12.957	25.6
3.947	12.618	25.8
3.955	12.412	25.9
3.963	12.653	26.1
3.548	11.928	26.4
3.560	12.036	26.5
3.563	11.917	26.6
3.570	11.877	26.7
3.084	10.987	26.9
3.089	11.222	27.0
3.088	10.995	27.1
3.082	10.983	27.2
2.564	10.310	27.3
2.537	10.087	27.4
2.543	9.975	27.5
2.539	10.040	27.5
1.992	8.936	27.5
1.961	8.982	27.5
1.964	8.932	27.5
1.931	8.944	27.5
1.492	8.168	27.4
1.446	8.104	27.4
1.416	7.825	27.4
1.392	8.162	27.3
1.104	7.572	27.2
1.073	7.558	27.2
1.058	7.422	27.2
1.035	7.386	27.2
.543	6.635	27.1
.519	6.622	27.1
.503	6.529	27.0
.496	6.616	27.0

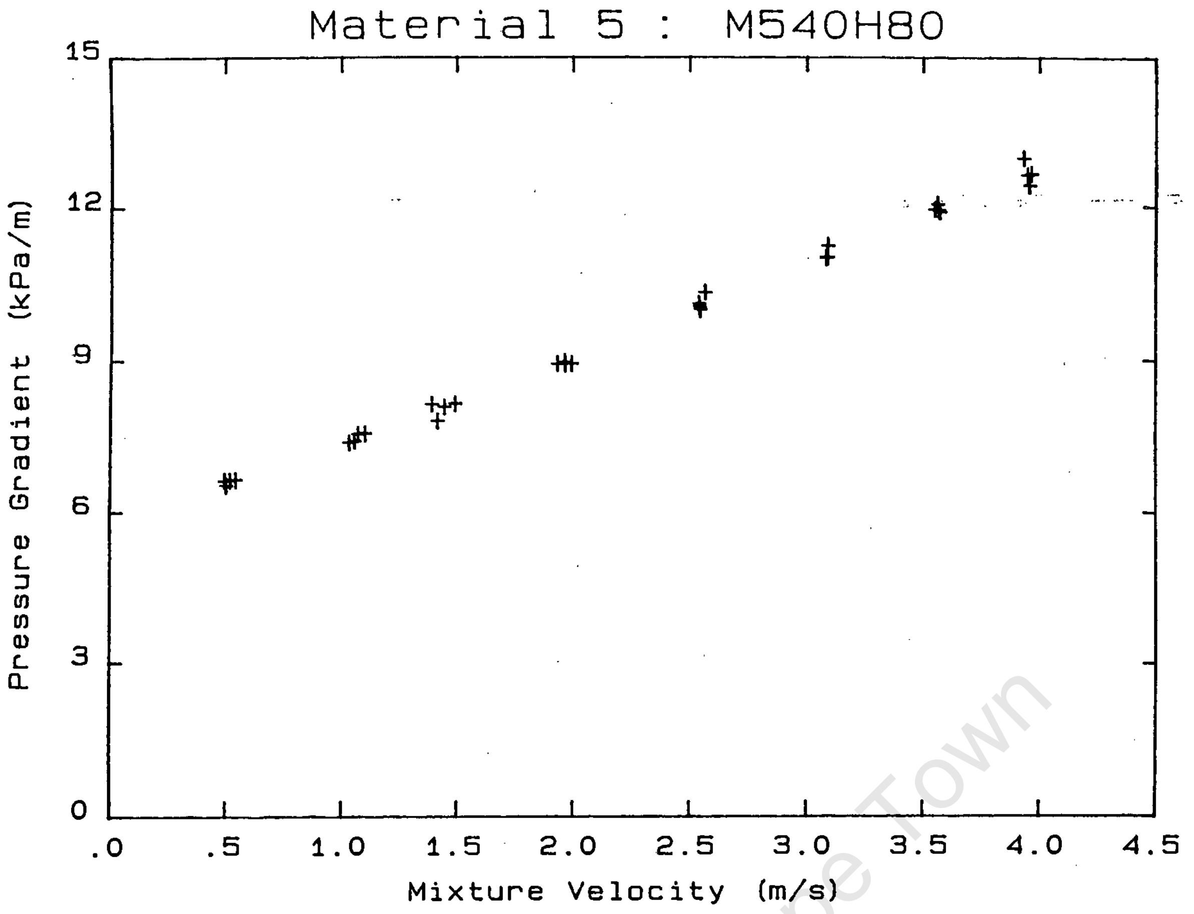
Particle Size Distribution
Sieve and Malvern Size Analysis *

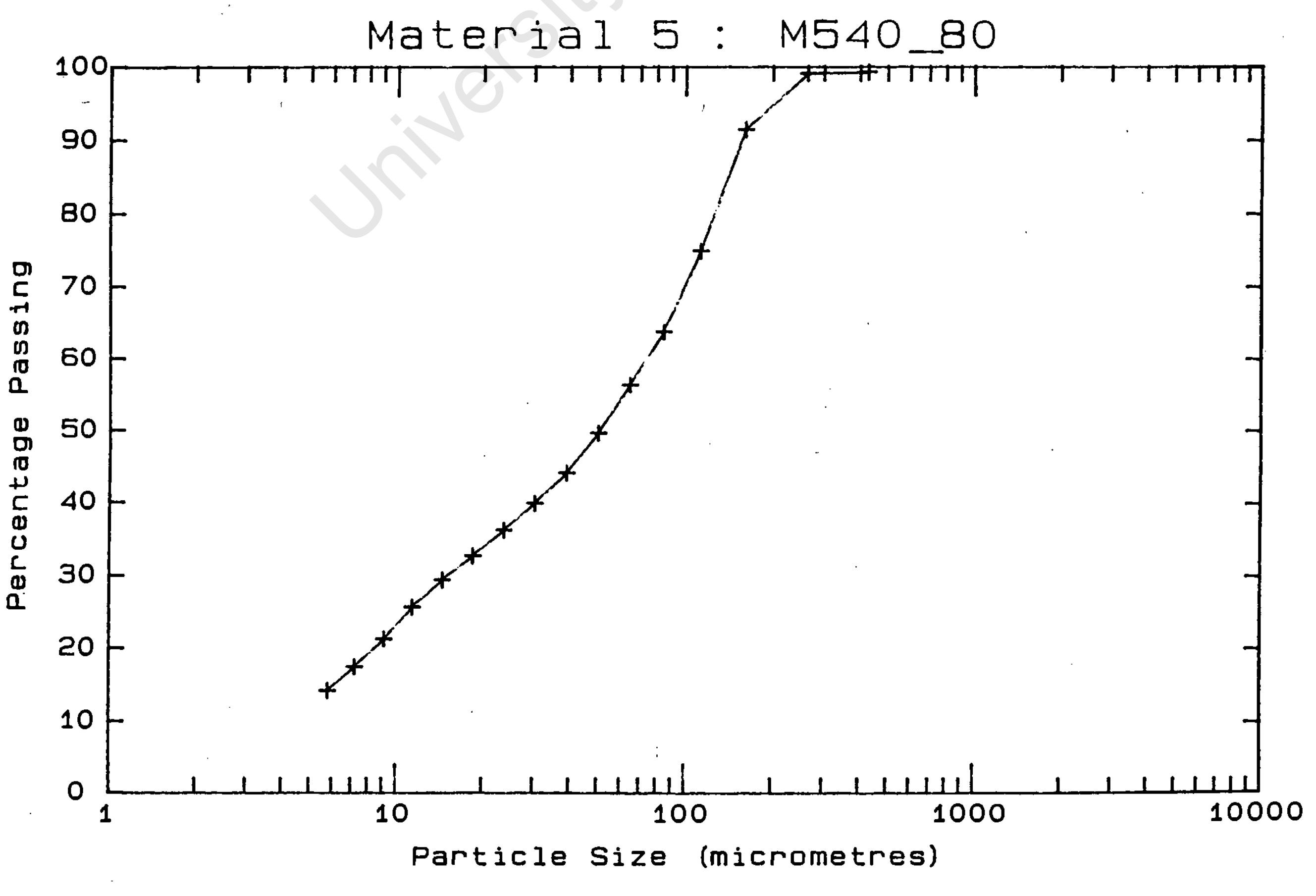
Size (µm)	% Passing	% Retained
425.0	99.1	.9
261.6	98.9	.2
160.4	91.3	7.6
112.8	74.8	16.5
84.3	63.6	11.2
64.6	56.2	7.4
50.2	49.5	6.7
39.0	44.0	5.5
30.3	39.8	4.2
23.7	36.1	3.7
18.5	32.6	3.5
14.5	29.3	3.3
11.4	25.6	3.7
9.1	21.2	4.4
7.2	17.4	3.8
5.8	14.1	3.3
Pan	- .3	14.4

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)
.41	Appears homogeneous
.85	Appears homogeneous
1.15	Appears homogeneous
1.55	Appears homogeneous
2.02	Appears homogeneous
2.44	Appears homogeneous
2.81	Appears homogeneous
3.12	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 5 : M540H80
Pressure Gradient (kPa/m)
0
3
6
9
12
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_80
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540D80

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.80
Solids Volumetric Concentration (%)	45.98
Solids Mass Concentration (%)	69.99
Mean Slurry Temperature (°C)	27.0
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (μm)	60.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.931	- 4.900	25.6
3.947	- 5.222	25.8
3.955	- 4.907	25.9
3.963	- 4.754	26.1
3.548	- 5.952	26.4
3.560	- 5.635	26.5
3.563	- 5.999	26.6
3.570	- 5.941	26.7
3.084	- 6.570	26.9
3.089	- 6.683	27.0
3.088	- 6.810	27.1
3.082	- 6.714	27.2
2.564	- 7.506	27.3
2.537	- 7.648	27.4
2.543	- 7.700	27.5
2.539	- 7.651	27.5
1.992	- 8.522	27.5
1.961	- 8.623	27.5
1.964	- 8.602	27.5
1.931	- 8.429	27.5
1.492	- 9.263	27.4
1.446	- 9.324	27.4
1.416	- 9.465	27.4
1.392	- 9.459	27.3
1.104	-10.238	27.2
1.073	-10.388	27.2
1.058	-10.362	27.2
1.035	-10.100	27.2
.543	-10.924	27.1
.519	-10.877	27.1
.503	-10.983	27.0
.496	-10.916	27.0

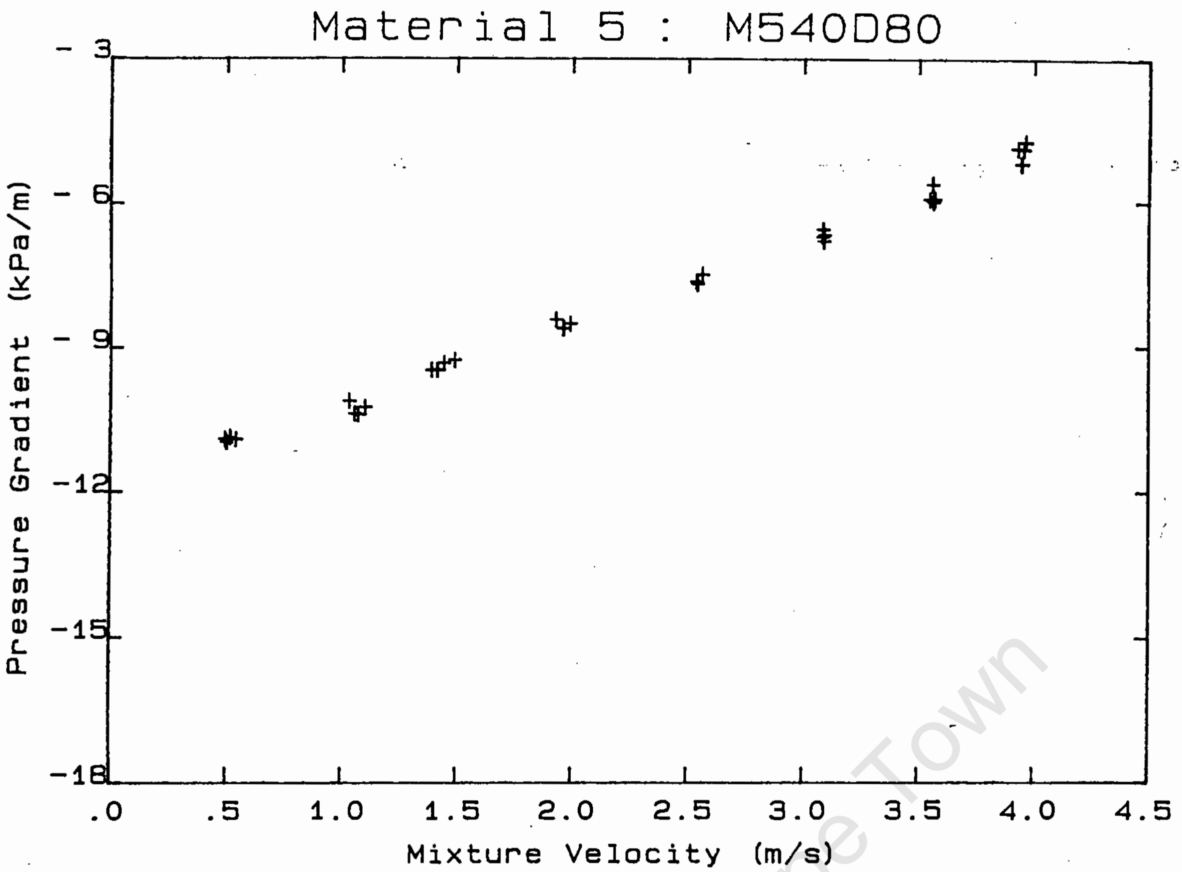
Particle Size Distribution
Sieve and Malvern Size Analysis *

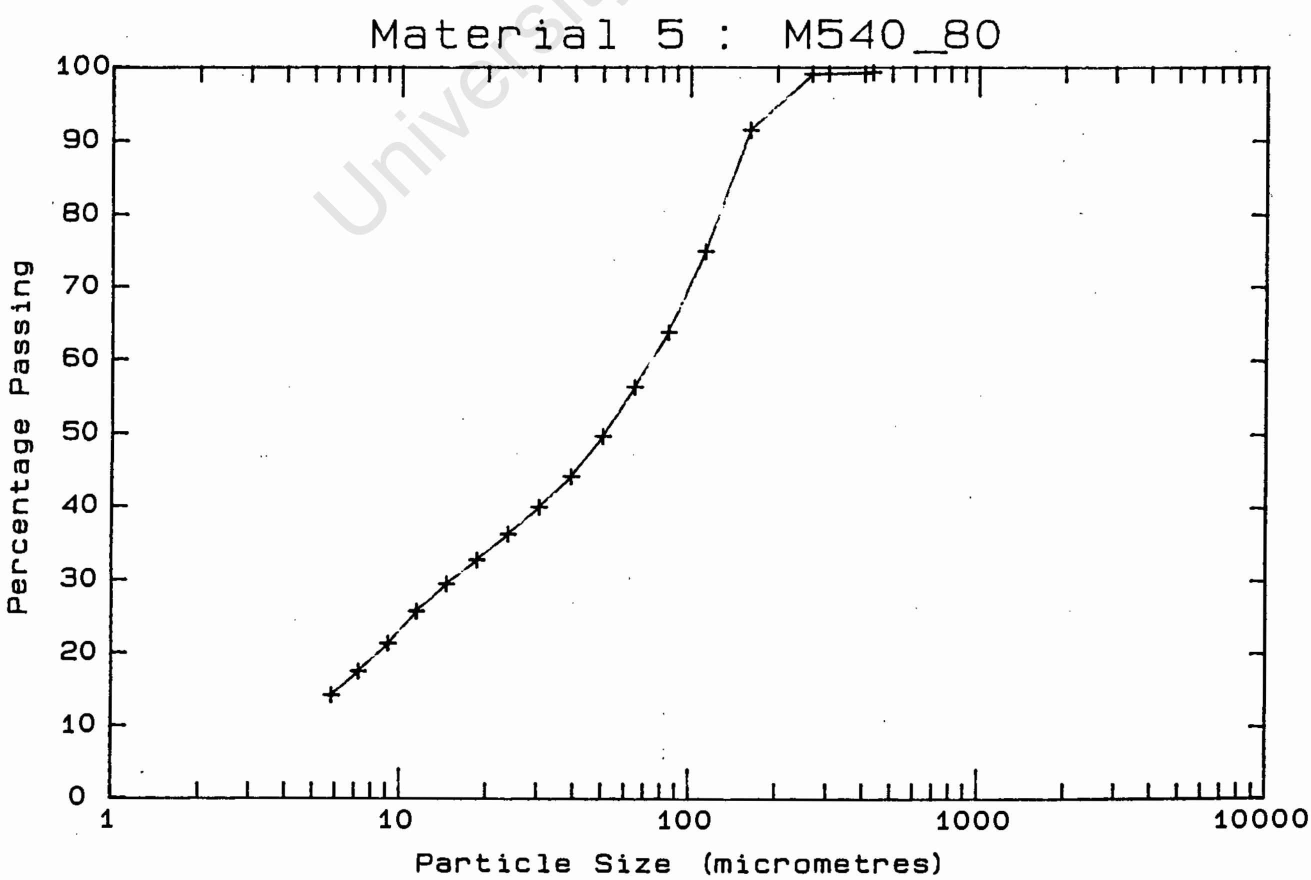
Size (μm)	% Passing	% Retained
425.0	99.1	.9
261.6	98.9	.2
160.4	91.3	7.6
112.8	74.8	16.5
84.3	63.6	11.2
64.6	56.2	7.4
50.2	49.5	6.7
39.0	44.0	5.5
30.3	39.8	4.2
23.7	36.1	3.7
18.5	32.6	3.5
14.5	29.3	3.3
11.4	25.6	3.7
9.1	21.2	4.4
7.2	17.4	3.8
5.8	14.1	3.3
Pan	- .3	14.4

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 μm Malvern Particle Size Analyser


Material 5 : M540D80
- 3
- 6
- 9
-12
-15
-18
Pressure Gradient (kPa/m)
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_80
100
90
80
70
60
50
40
30
20
10
0
Percentage Passing
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M540U80

Test Facility	UCT 40 mm NB
Test Date	27/05/91
Material Description	MATERIAL 5
Material Relative Density	2.74
Slurry Relative Density	1.80
Solids Volumetric Concentration (%)	45.98
Solids Mass Concentration (%)	69.99
Mean Slurry Temperature (°C)	27.0
Pipe Internal Diameter (mm)	40.90
Pipe Roughness (µm)	19.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.931	29.467	25.6
3.947	29.506	25.8
3.955	29.520	25.9
3.963	29.906	26.1
3.548	28.527	26.4
3.560	28.431	26.5
3.563	28.482	26.6
3.570	28.607	26.7
3.084	28.353	26.9
3.089	28.010	27.0
3.088	27.729	27.1
3.082	27.879	27.2
2.564	27.001	27.3
2.537	26.806	27.4
2.543	27.431	27.5
2.539	26.823	27.5
1.992	25.789	27.5
1.961	26.033	27.5
1.964	25.838	27.5
1.931	25.943	27.5
1.492	24.976	27.4
1.446	25.119	27.4
1.416	24.680	27.4
1.392	24.731	27.3
1.104	23.604	27.2
1.073	24.065	27.2
1.058	24.404	27.2
1.035	24.032	27.2
.543	22.945	27.1
.519	23.264	27.1
.503	23.119	27.0
.496	23.119	27.0

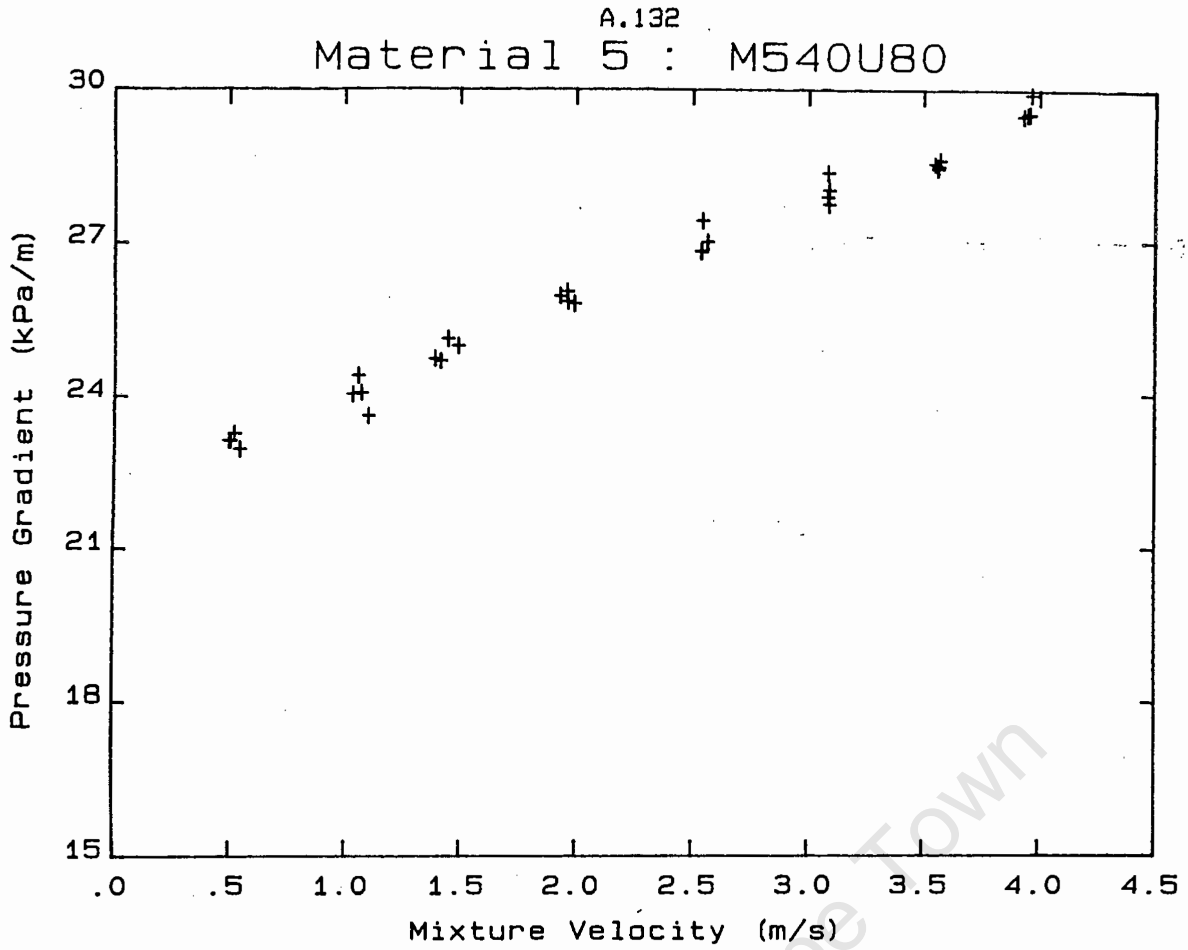
Particle Size Distribution
Sieve and Malvern Size Analysis *

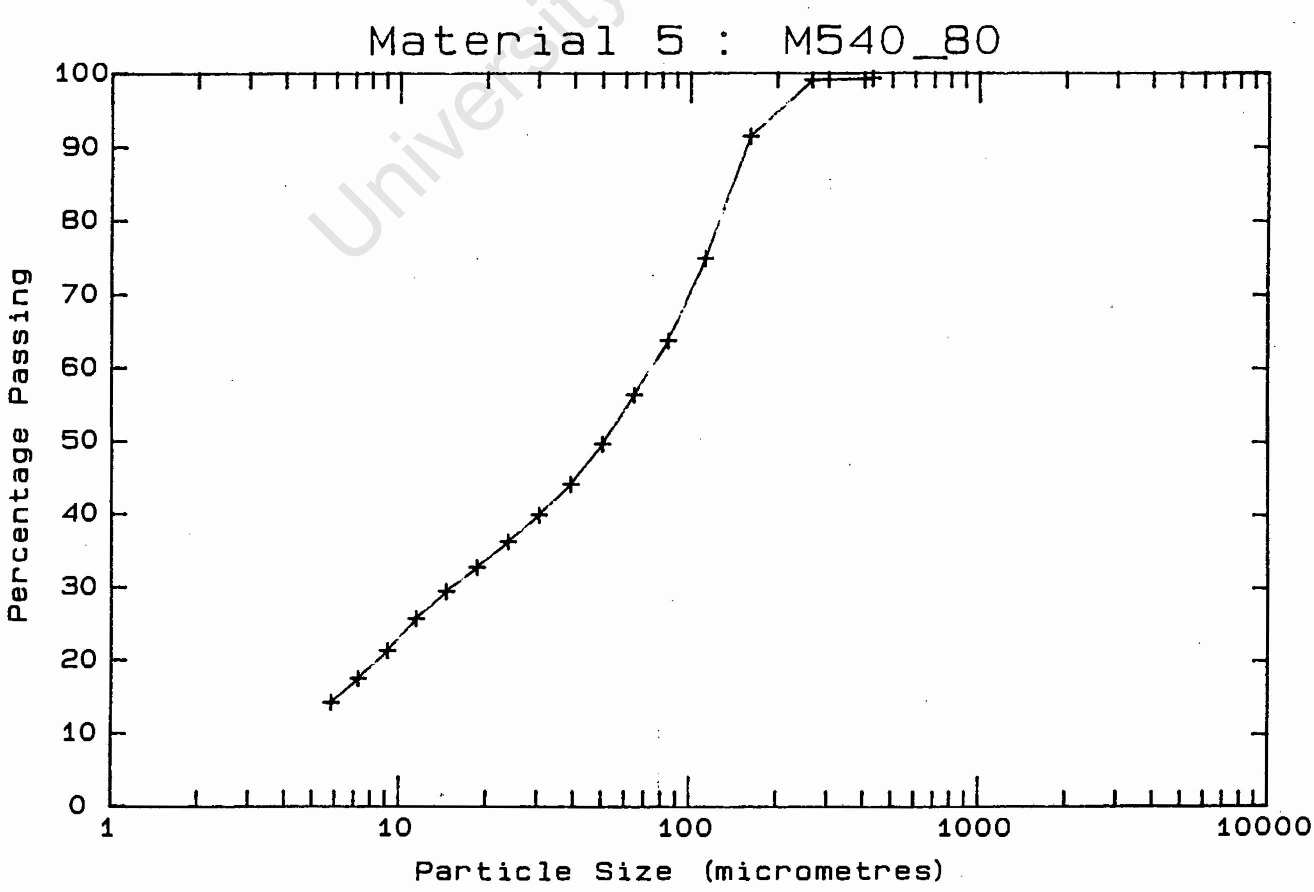
Size (µm)	% Passing	% Retained
425.0	99.1	.9
261.6	98.9	.2
160.4	91.3	7.6
112.8	74.8	16.5
84.3	63.6	11.2
64.6	56.2	7.4
50.2	49.5	6.7
39.0	44.0	5.5
30.3	39.8	4.2
23.7	36.1	3.7
18.5	32.6	3.5
14.5	29.3	3.3
11.4	25.6	3.7
9.1	21.2	4.4
7.2	17.4	3.8
5.8	14.1	3.3
Pan	- .3	14.4

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 46.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 5 : M540U80
Pressure Gradient (kPa/m)
30
27
24
21
18
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5 : M540_80
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180H75

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.75
Solids Volumetric Concentration (%)	43.35
Solids Mass Concentration (%)	67.63
Mean Slurry Temperature (°C)	22.6
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.371	3.350	21.7
3.381	2.774	21.8
3.383	3.329	22.1
3.384	3.361	22.3
3.092	2.744	22.5
3.097	2.674	22.6
3.091	2.842	22.6
3.098	2.911	22.7
2.799	2.308	22.8
2.805	2.262	22.8
2.803	2.280	22.8
2.804	2.399	22.8
2.171	1.644	22.9
2.179	1.485	22.9
2.165	2.008	22.9
2.174	1.904	22.8
1.561	1.023	22.7
1.566	1.187	22.7
1.562	1.469	22.7
1.568	2.128	22.6
1.563	1.575	22.6
.945	2.185	22.5
.958	2.843	22.5
.962	3.382	22.4
.956	4.088	22.4
.965	2.795	22.3

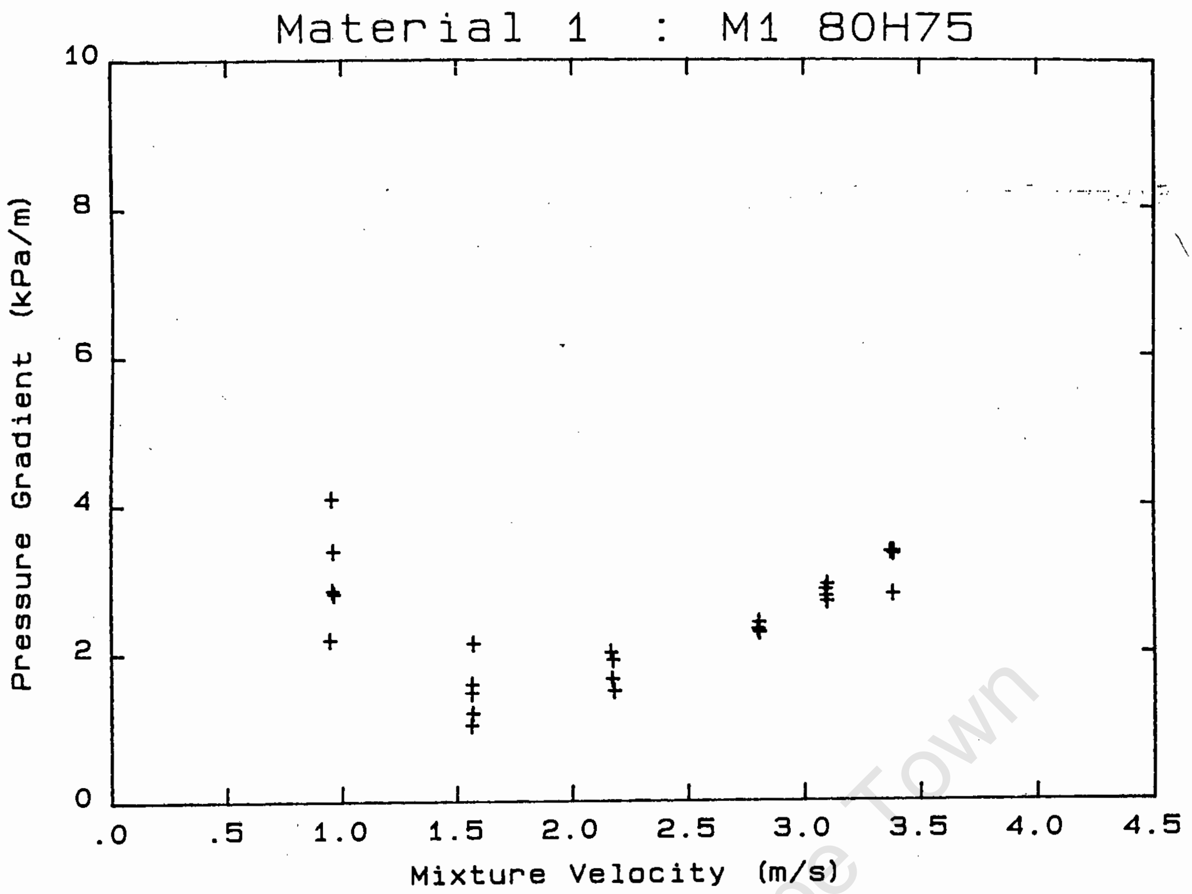
Particle Size Distribution
Sieve and Malvern Size Analysis *

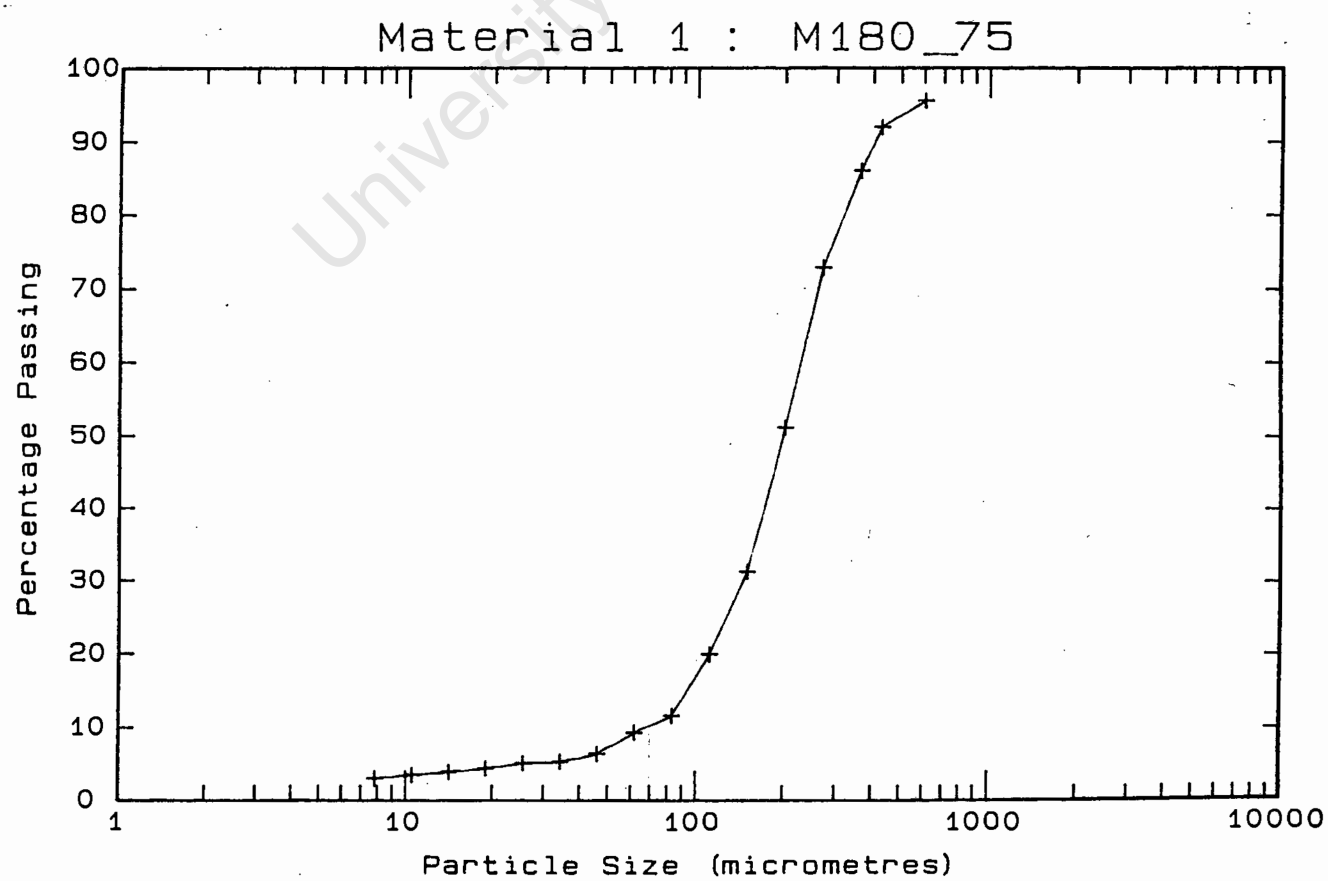
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
1.02	40% Stationary bed
1.68	Sliding particles
2.34	Asymetric
3.02	Asymetric
3.34	Appears homogeneous
3.64	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80H75
Pressure Gradient (kPa/m)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_75
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180U75

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.75
Solids Volumetric Concentration (%)	43.06
Solids Mass Concentration (%)	67.37
Mean Slurry Temperature (°C)	22.6
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.371	19.886	21.7
3.381	19.986	21.8
3.383	19.816	22.1
3.384	19.547	22.3
3.092	19.405	22.5
3.097	19.443	22.6
3.091	19.298	22.6
3.098	19.390	22.7
2.799	19.050	22.8
2.805	18.952	22.8
2.803	19.045	22.8
2.804	18.940	22.8
2.171	18.482	22.9
2.179	18.349	22.9
2.165	18.362	22.9
2.174	18.414	22.8
1.561	17.693	22.7
1.566	17.768	22.7
1.562	17.733	22.7
1.568	17.782	22.6
1.563	17.763	22.6
.945	17.473	22.5
.958	17.349	22.5
.962	17.369	22.4
.956	17.367	22.4
.965	17.350	22.3

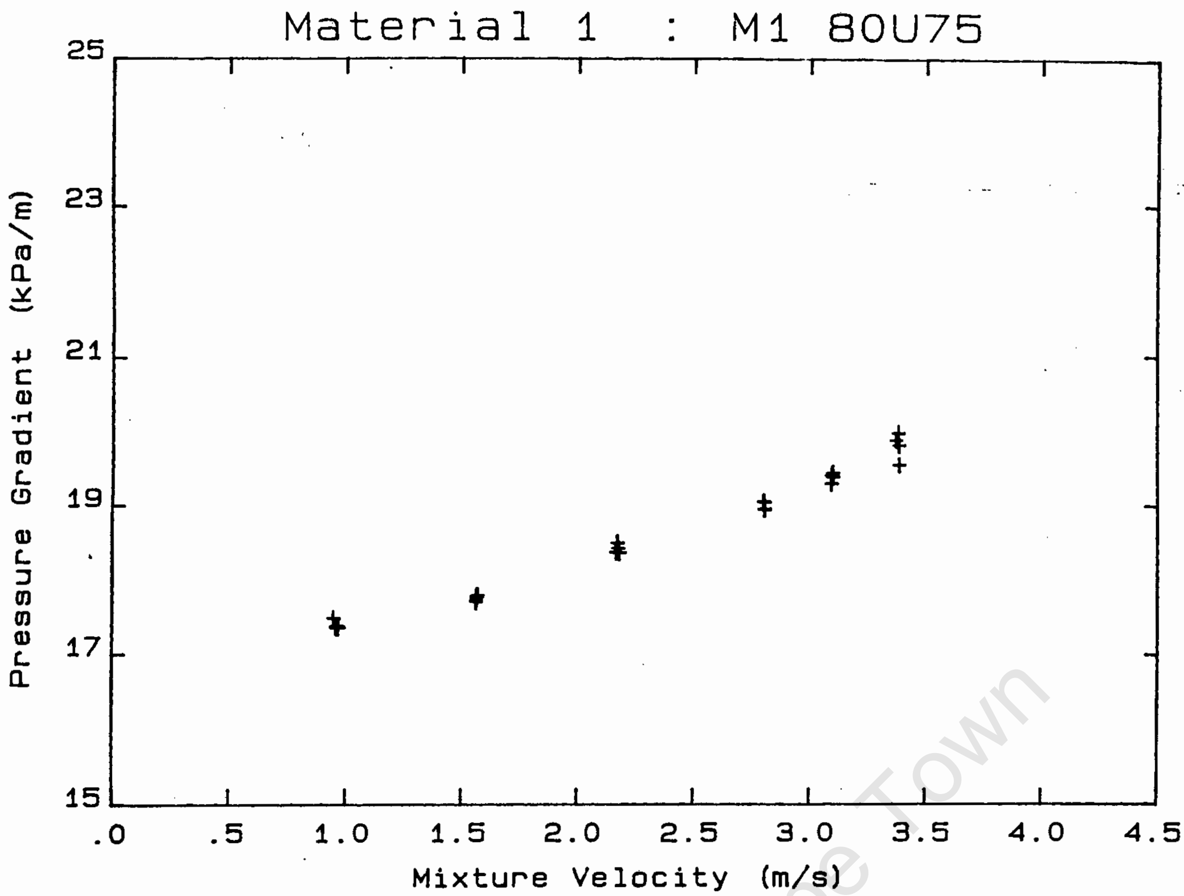
Particle Size Distribution
Sieve and Malvern Size Analysis *

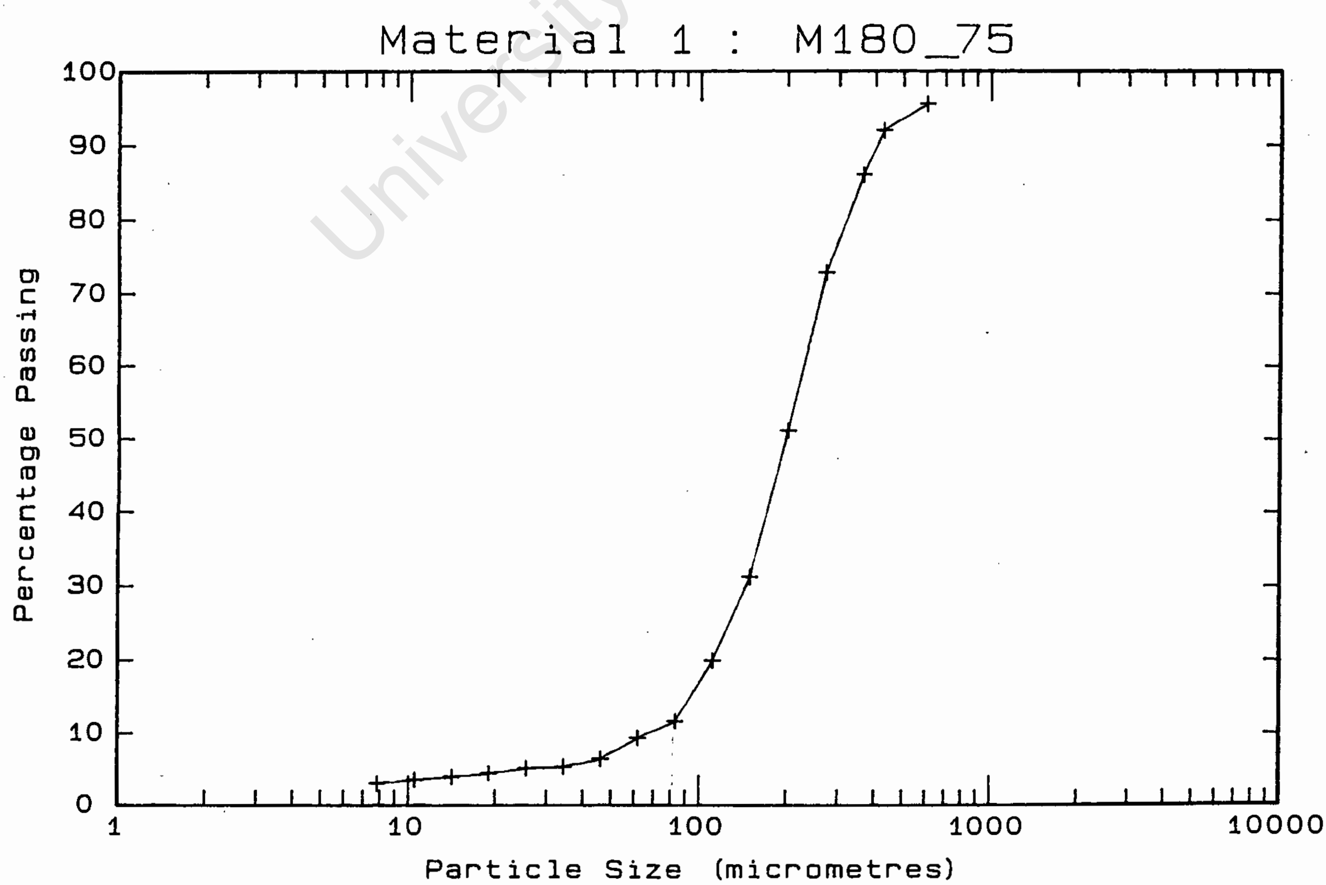
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80U75
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_75
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180H77

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1'
Material Relative Density	2.73
Slurry Relative Density	1.77
Solids Volumetric Concentration (%)	44.68
Solids Mass Concentration (%)	68.80
Mean Slurry Temperature (°C)	24.4
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (μm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.704	4.046	22.4
3.714	4.368	22.6
3.749	3.692	24.4
3.747	3.960	24.6
3.751	3.046	24.7
3.763	3.954	24.8
3.105	2.662	25.1
3.098	2.639	25.1
3.111	2.840	25.1
3.105	2.413	25.1
2.475	2.229	25.2
2.490	2.257	25.1
2.492	2.101	25.1
2.489	1.706	25.1
1.840	2.098	24.9
1.852	1.783	24.9
1.845	1.582	24.8
1.844	2.524	24.7
1.233	2.721	24.6
1.248	2.811	24.5
1.247	1.987	24.4
1.246	2.296	24.4
.970	2.595	24.2
.974	3.008	24.0
.978	2.820	23.8
.978	2.980	23.8
.624	4.000	23.7
.502	2.917	23.7
.436	3.029	23.6
.398	2.828	23.5
.330	2.600	23.5

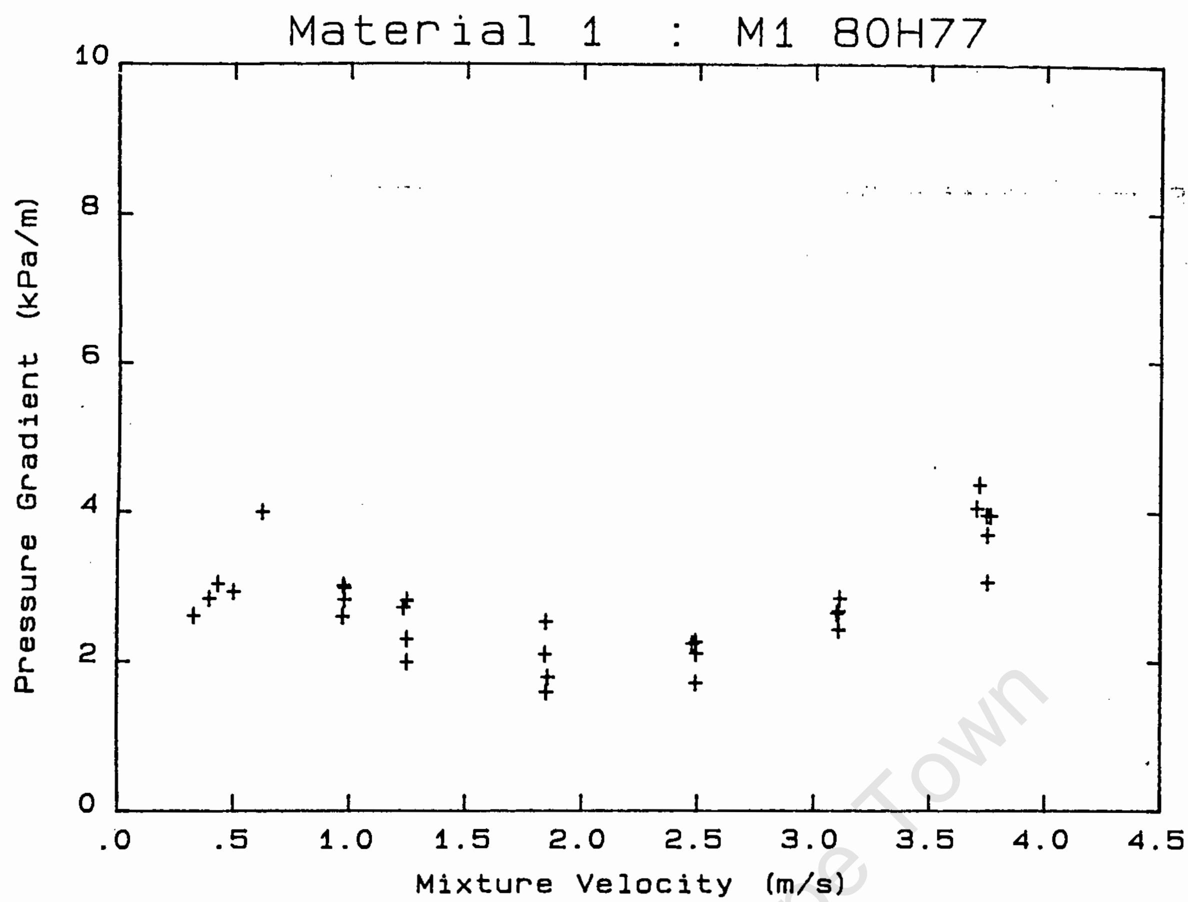
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (μm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

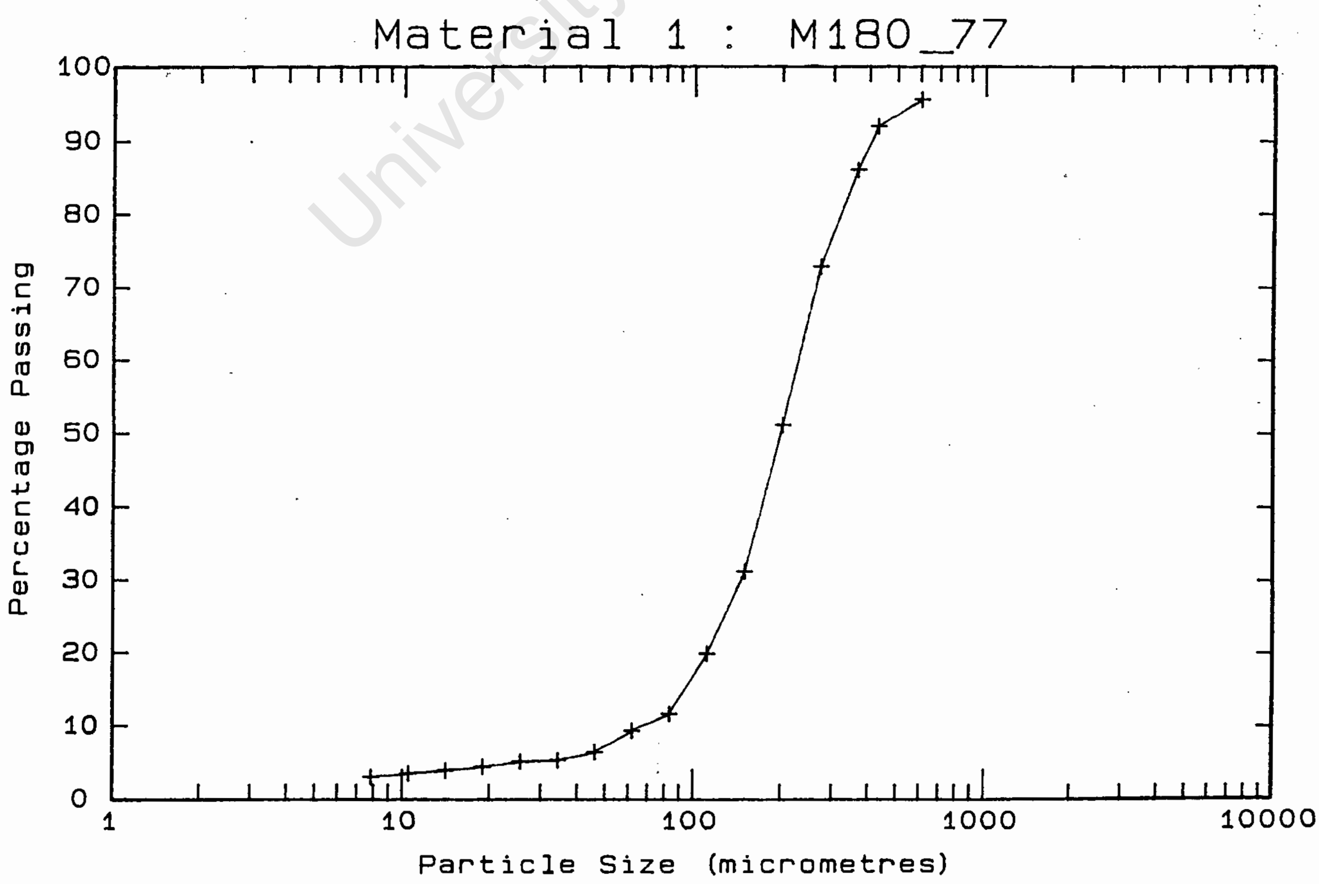
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.43	70% Stationary bed
1.05	50% Stationary bed
1.34	30% Stationary bed
1.99	Sliding particles
2.68	Asymetric
3.34	Appears homogeneous
4.01	Appears homogeneous

* -425 μm Malvern Particle Size Analyser



Material 1 : M1 80H77
Pressure Gradient (kPa/m)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 1 : M180_77
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180D77

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.77
Solids Volumetric Concentration (%)	44.68
Solids Mass Concentration (%)	68.80
Mean Slurry Temperature (°C)	24.5
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (μm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.749	-12.318	24.4
3.747	-12.759	24.6
3.751	-12.612	24.7
3.763	-12.727	24.8
3.105	-14.489	25.1
3.098	-14.194	25.1
3.111	-14.599	25.1
3.105	-14.251	25.1
2.475	-15.482	25.2
2.490	-15.494	25.1
2.492	-15.486	25.1
2.489	-15.477	25.1
1.840	-15.946	24.9
1.852	-15.984	24.9
1.845	-15.968	24.8
1.844	-15.975	24.7
1.233	-16.470	24.6
1.248	-16.301	24.5
1.247	-16.172	24.4
1.246	-16.249	24.4
.970	-16.352	24.2
.974	-16.405	24.0
.978	-16.320	23.8
.978	-16.354	23.8
.624	-16.896	23.7
.502	-17.020	23.7
.436	-16.965	23.6
.398	-17.091	23.5
.330	-16.930	23.5

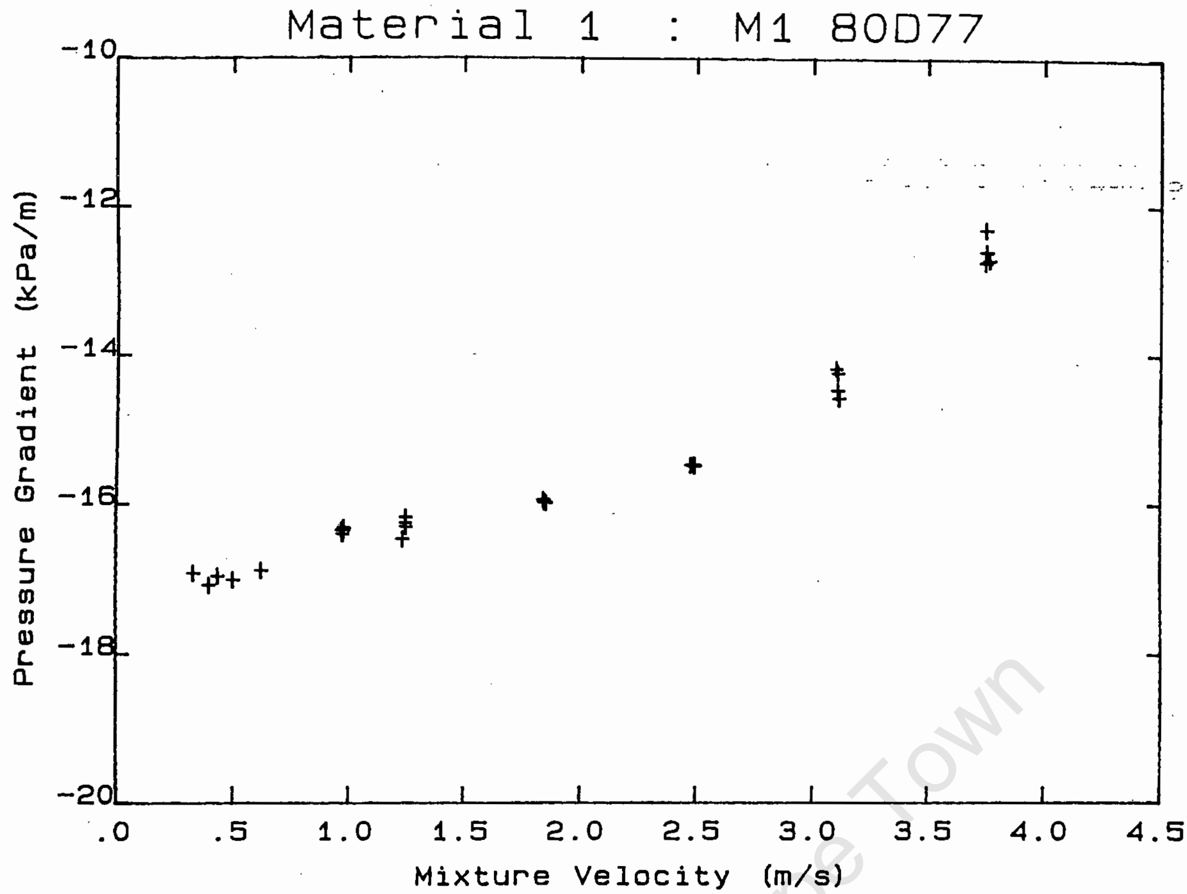
Particle Size Distribution
Sieve and Malvern Size Analysis *

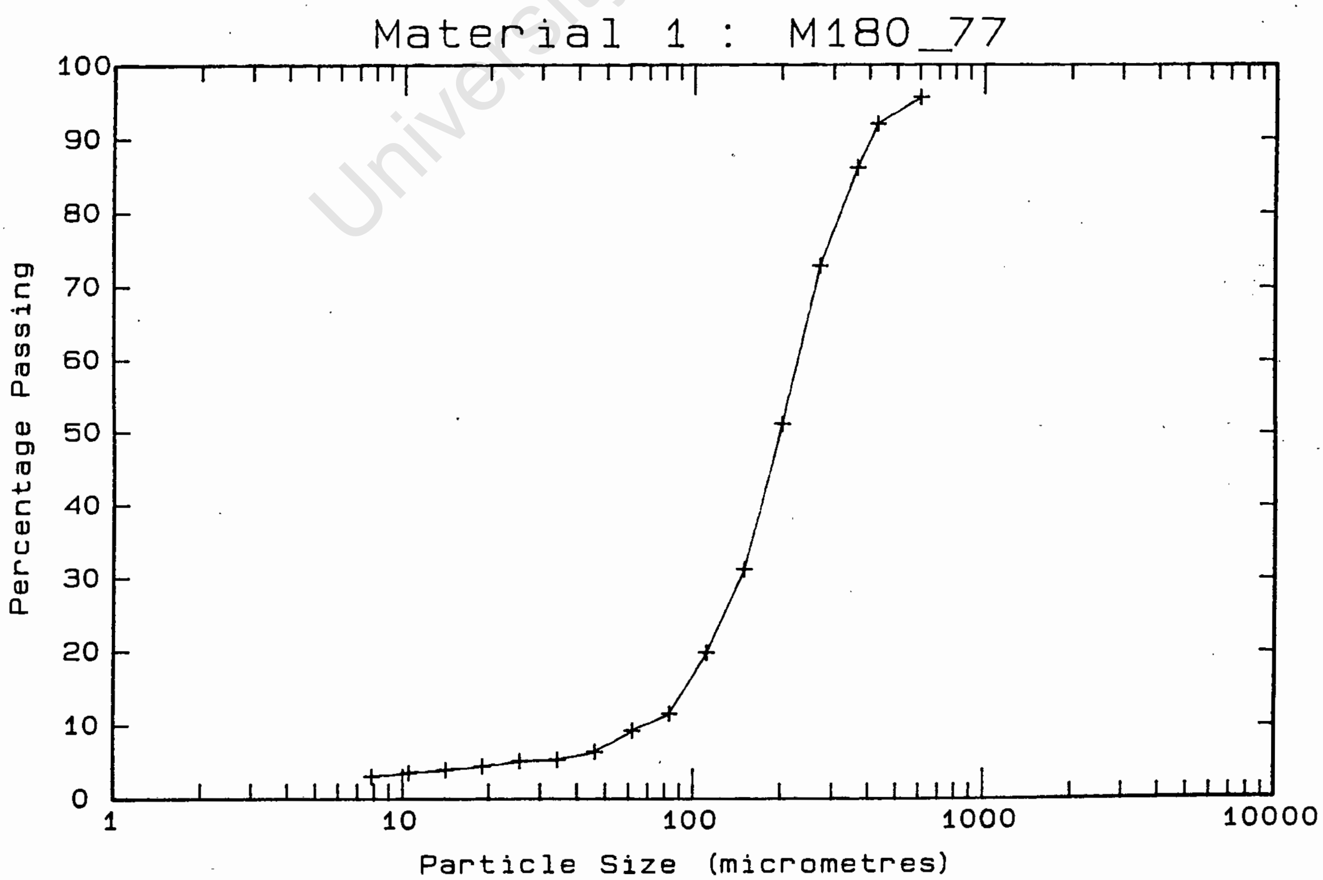
Size (μm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -425 μm Malvern Particle Size Analyser


Material 1 : M1 80D77
Pressure Gradient (kPa/m)
-10
-12
-14
-16
-18
-20
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_77
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180U77

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.77
Solids Volumetric Concentration (%)	44.68
Solids Mass Concentration (%)	68.80
Mean Slurry Temperature (°C)	24.4
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.704	20.890	22.4
3.714	20.481	22.6
3.749	21.136	24.4
3.747	20.593	24.6
3.751	21.434	24.7
3.763	20.710	24.8
3.105	19.985	25.1
3.098	19.917	25.1
3.111	20.065	25.1
3.105	20.043	25.1
2.475	18.925	25.2
2.490	19.171	25.1
2.492	19.039	25.1
2.489	18.940	25.1
1.840	18.406	24.9
1.852	18.181	24.9
1.845	18.253	24.8
1.844	18.259	24.7
1.233	17.931	24.6
1.248	17.972	24.5
1.247	17.922	24.4
1.246	17.925	24.4
.970	17.849	24.2
.974	17.874	24.0
.978	17.834	23.8
.978	17.804	23.8
.624	17.802	23.7
.502	17.820	23.7
.436	17.719	23.6
.398	17.816	23.5
.330	17.895	23.5

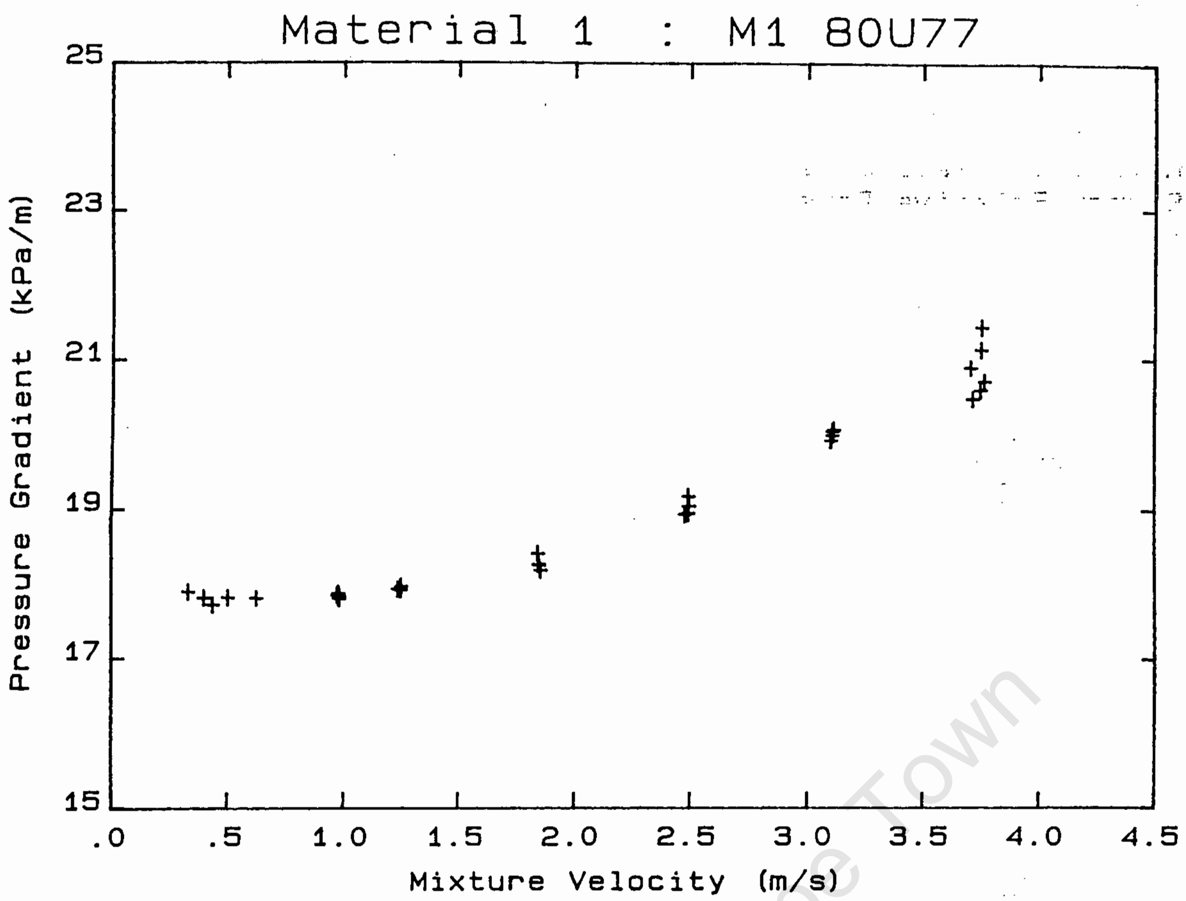
Particle Size Distribution
Sieve and Malvern Size Analysis *

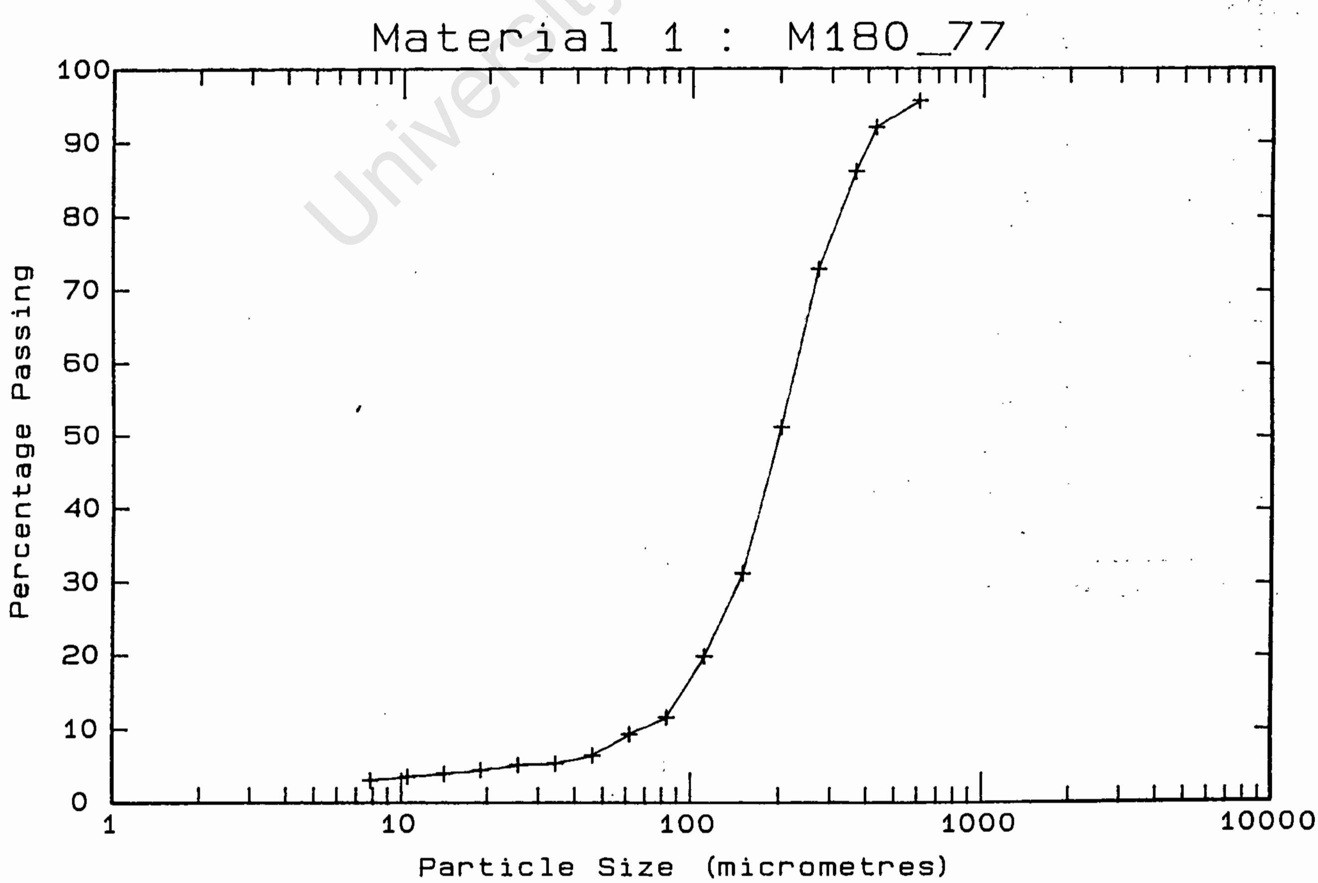
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80U77
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_77
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180H82

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.82
Solids Volumetric Concentration (%)	47.17
Solids Mass Concentration (%)	70.91
Mean Slurry Temperature (°C)	25.1
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (μm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.750	4.622	24.4
3.755	4.468	24.7
3.769	3.960	24.9
3.773	4.564	25.1
3.779	3.795	25.3
3.071	3.721	25.7
3.075	3.205	25.8
3.075	3.401	25.8
3.077	3.310	25.8
2.470	3.081	25.9
2.470	2.585	25.9
2.473	2.702	25.8
2.473	2.608	25.8
1.891	2.142	25.7
1.884	1.948	25.7
1.893	1.907	25.6
1.896	2.263	25.6
1.277	3.327	25.4
1.286	2.361	25.4
1.280	2.697	25.3
1.283	2.947	25.2
1.287	2.660	25.2
.938	2.800	25.0
.954	2.354	25.0
.941	3.244	24.9
.952	2.470	24.8
.944	2.602	24.8
.950	2.970	24.7
.512	2.008	24.6
.411	2.602	24.5
.356	2.725	24.5
.339	2.908	24.4
.275	3.369	24.4
.222	3.266	24.3
.192	3.595	24.3

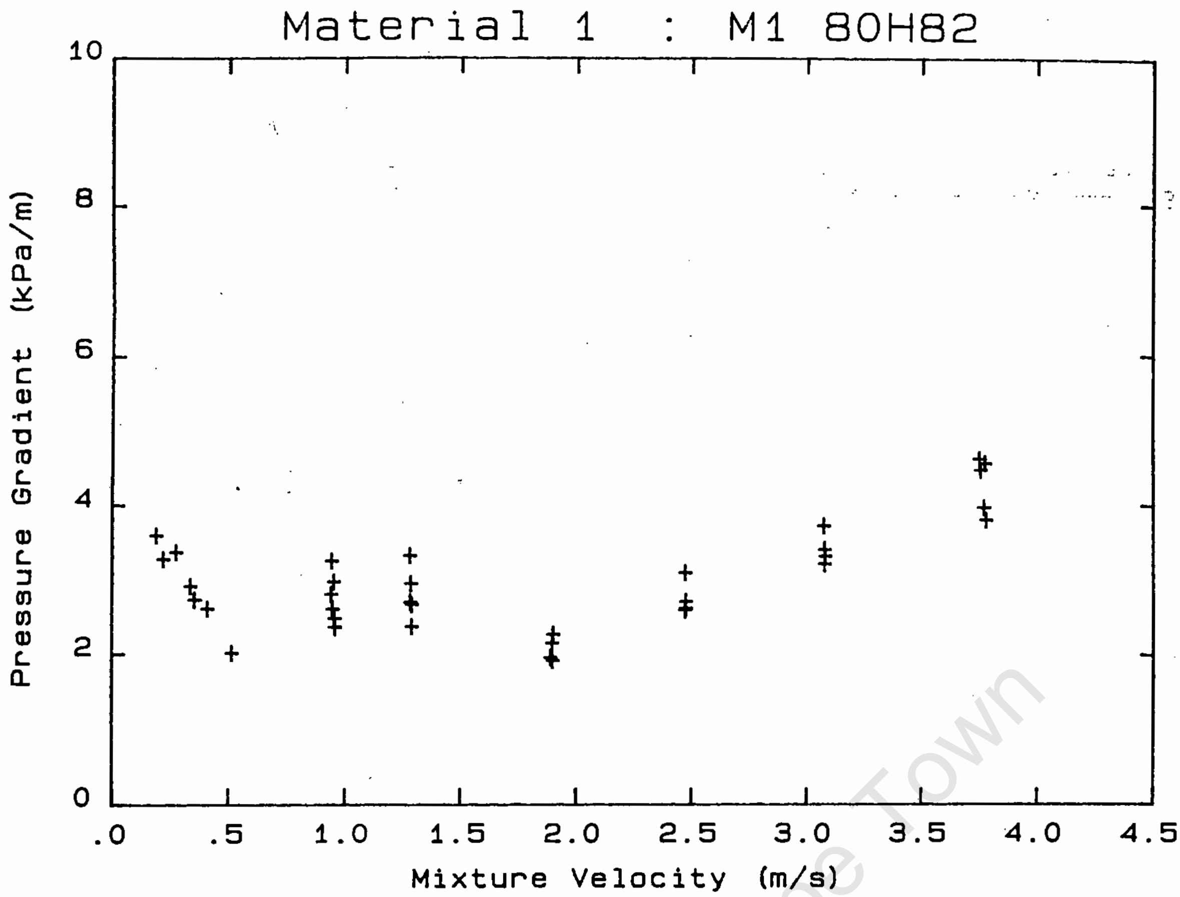
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (μm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

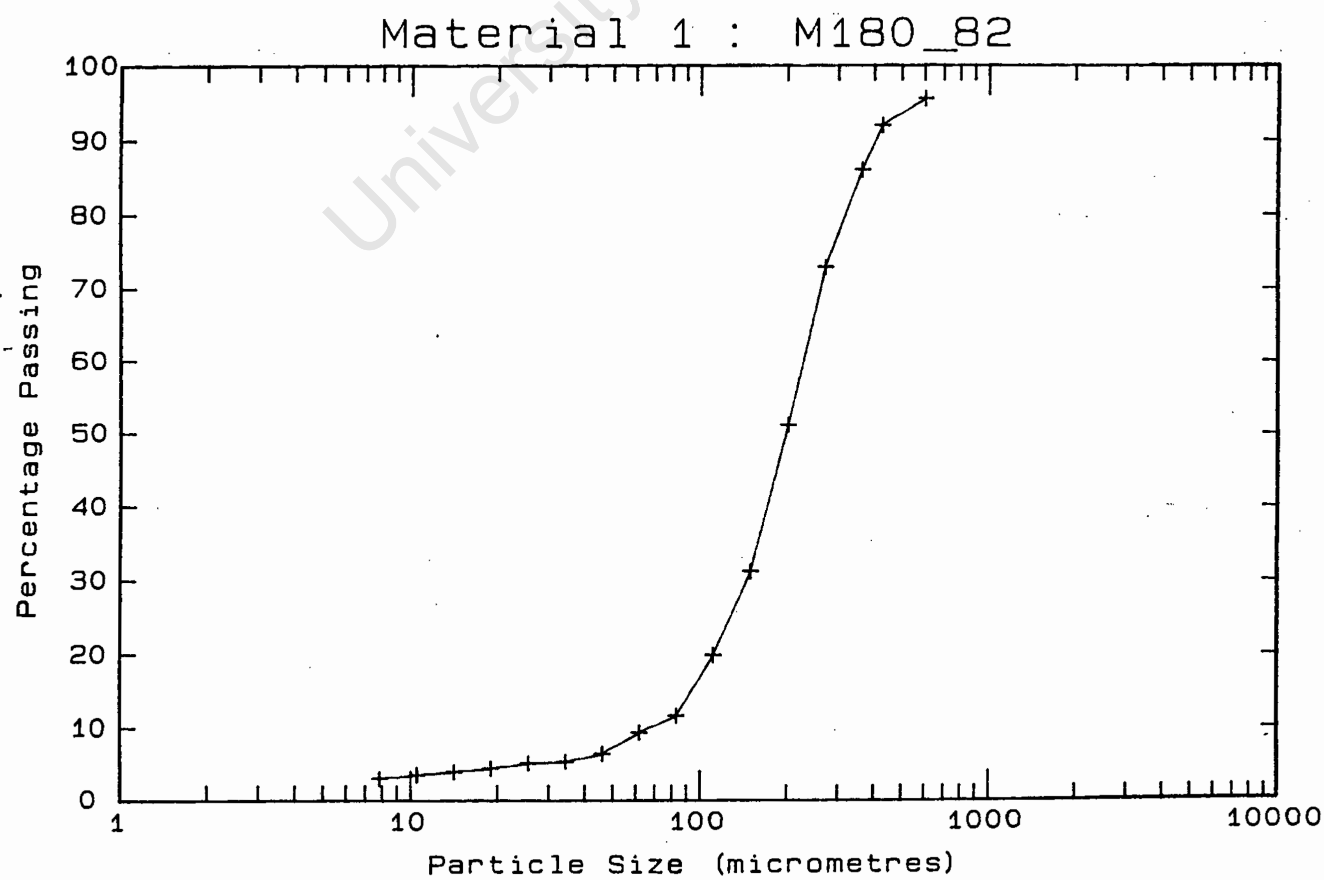
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.38	50% Stationary bed
1.02	Sliding particles
1.38	Sliding particles
2.04	Asymetric
2.66	Asymetric
3.32	Appears homogeneous
4.05	Appears homogeneous

* -425 μm Malvern Particle Size Analyser



Material 1 : M1 80H82
Pressure Gradient (kPa/m)
Mixture Velocity (m/s)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5



Material 1 : M180_82
Percentage Passing
Particle Size (micrometres)
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000

DATA FILE : M180D82

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.82
Solids Volumetric Concentration (%)	47.17
Solids Mass Concentration (%)	70.91
Mean Slurry Temperature (°C)	25.2
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.750	-14.169	24.4
3.755	-14.006	24.7
3.769	-14.037	24.9
3.773	-13.811	25.1
3.779	-13.825	25.3
3.071	-14.842	25.7
3.075	-14.672	25.8
3.075	-14.896	25.8
3.077	-14.664	25.8
2.470	-15.279	25.9
2.470	-15.257	25.9
2.473	-15.265	25.8
2.473	-15.263	25.8
1.891	-15.691	25.7
1.884	-15.764	25.7
1.893	-15.654	25.6
1.896	-15.808	25.6
1.277	-16.338	25.4
1.286	-16.039	25.4
1.280	-16.065	25.3
1.283	-16.137	25.2
1.287	-15.965	25.2
.938	-17.170	25.0
.954	-17.053	25.0
.941	-16.946	24.9
.952	-16.869	24.8
.944	-16.778	24.8
.950	-16.699	24.7
.512	-16.593	24.6
.411	-16.474	24.5
.275	-17.115	24.4
.222	-17.202	24.3
.192	-17.245	24.3

Particle Size Distribution
Sieve and Malvern Size Analysis *

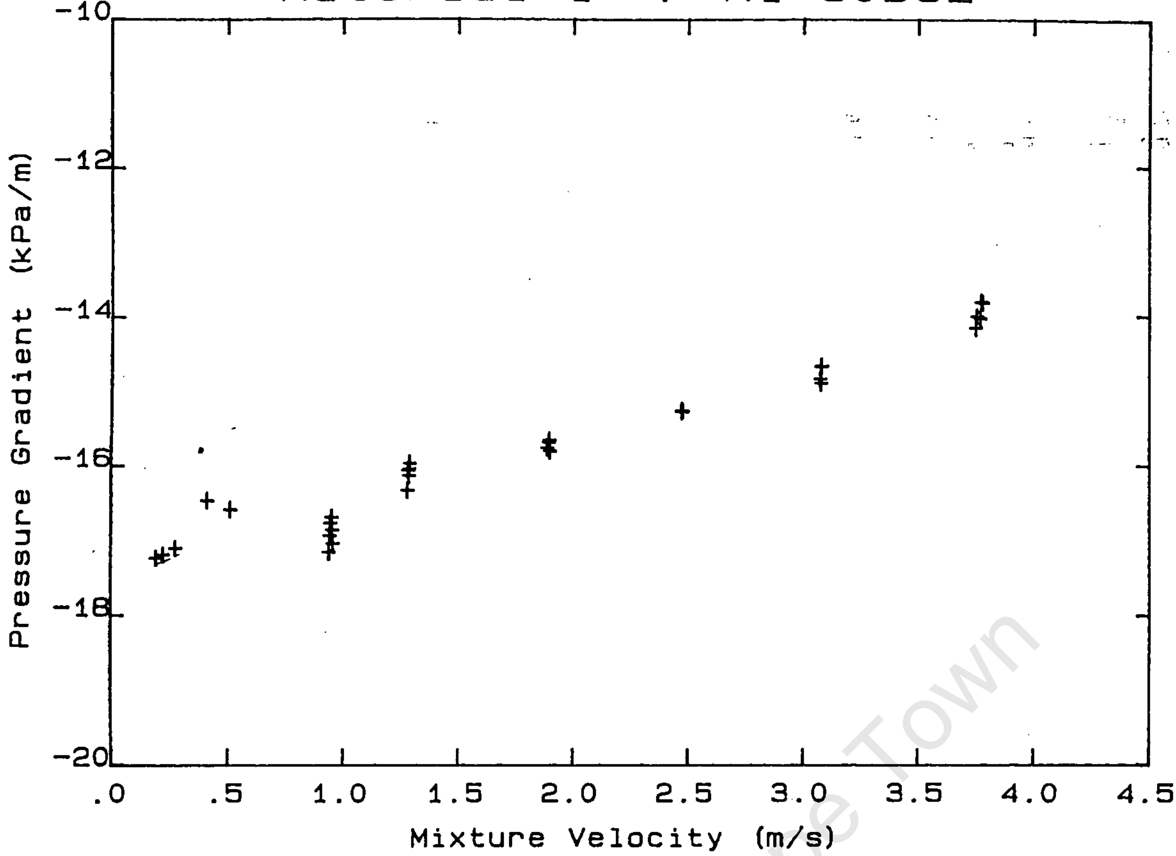
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

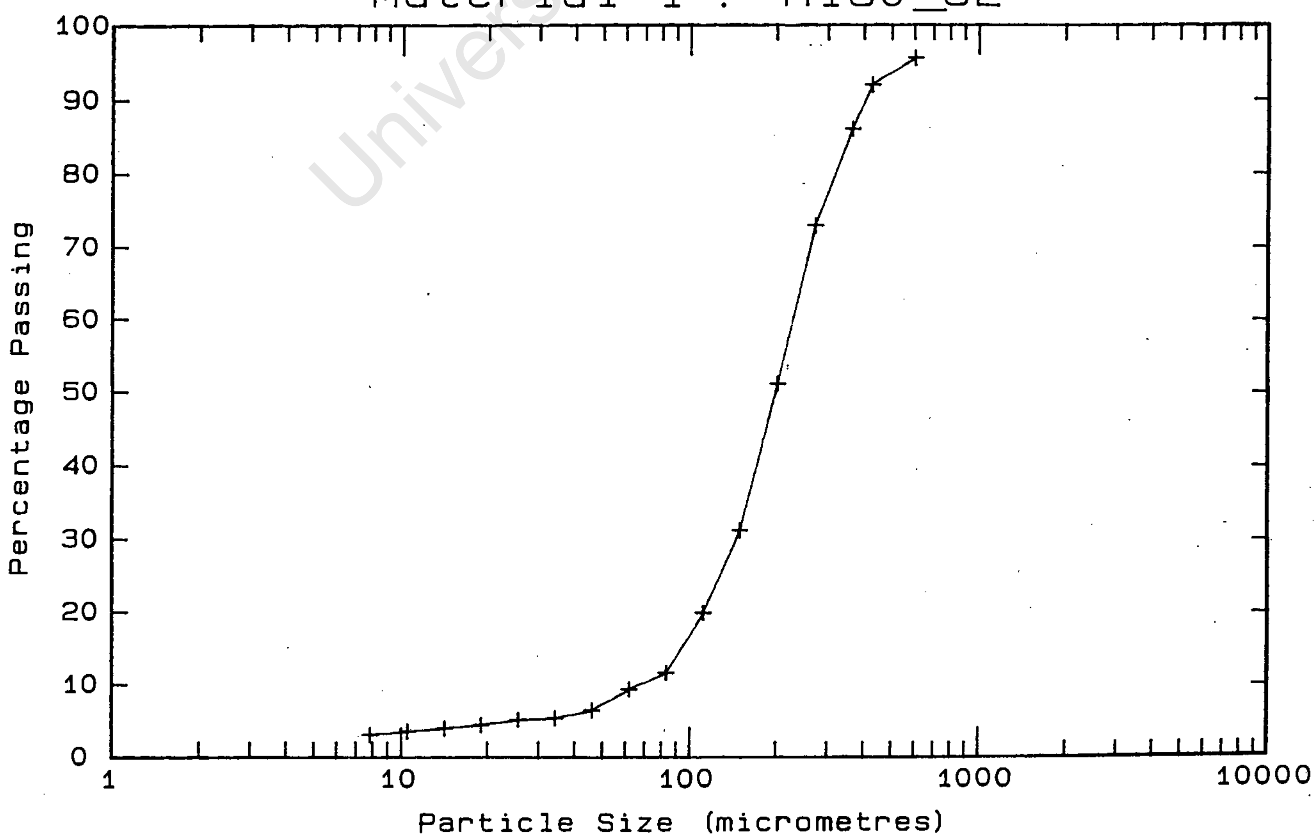
Velocity (m/s)	Observation (D = 71.0 mm)

* -425 µm Malvern Particle Size Analyser

Material 1 : M1 80D82



Material 1 : M180_82



DATA FILE : M180U82

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.82
Solids Volumetric Concentration (%)	47.17
Solids Mass Concentration (%)	70.91
Mean Slurry Temperature (°C)	25.1
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.750	20.923	24.4
3.755	20.612	24.7
3.769	21.331	24.9
3.773	21.040	25.1
3.779	21.949	25.3
3.071	19.830	25.7
3.075	19.978	25.8
3.075	19.960	25.8
3.077	20.110	25.8
2.470	19.500	25.9
2.470	19.436	25.9
2.473	19.374	25.8
2.473	19.471	25.8
1.891	19.038	25.7
1.884	19.037	25.7
1.893	19.101	25.6
1.896	19.140	25.6
1.277	18.768	25.4
1.286	18.664	25.4
1.280	18.733	25.3
1.283	18.744	25.2
1.287	18.747	25.2
.938	18.560	25.0
.954	18.577	25.0
.941	18.549	24.9
.952	18.543	24.8
.944	18.594	24.8
.950	18.595	24.7
.512	18.491	24.6
.411	18.558	24.5
.356	18.499	24.5
.339	18.539	24.4
.275	19.049	24.4
.222	19.632	24.3
.192	19.941	24.3

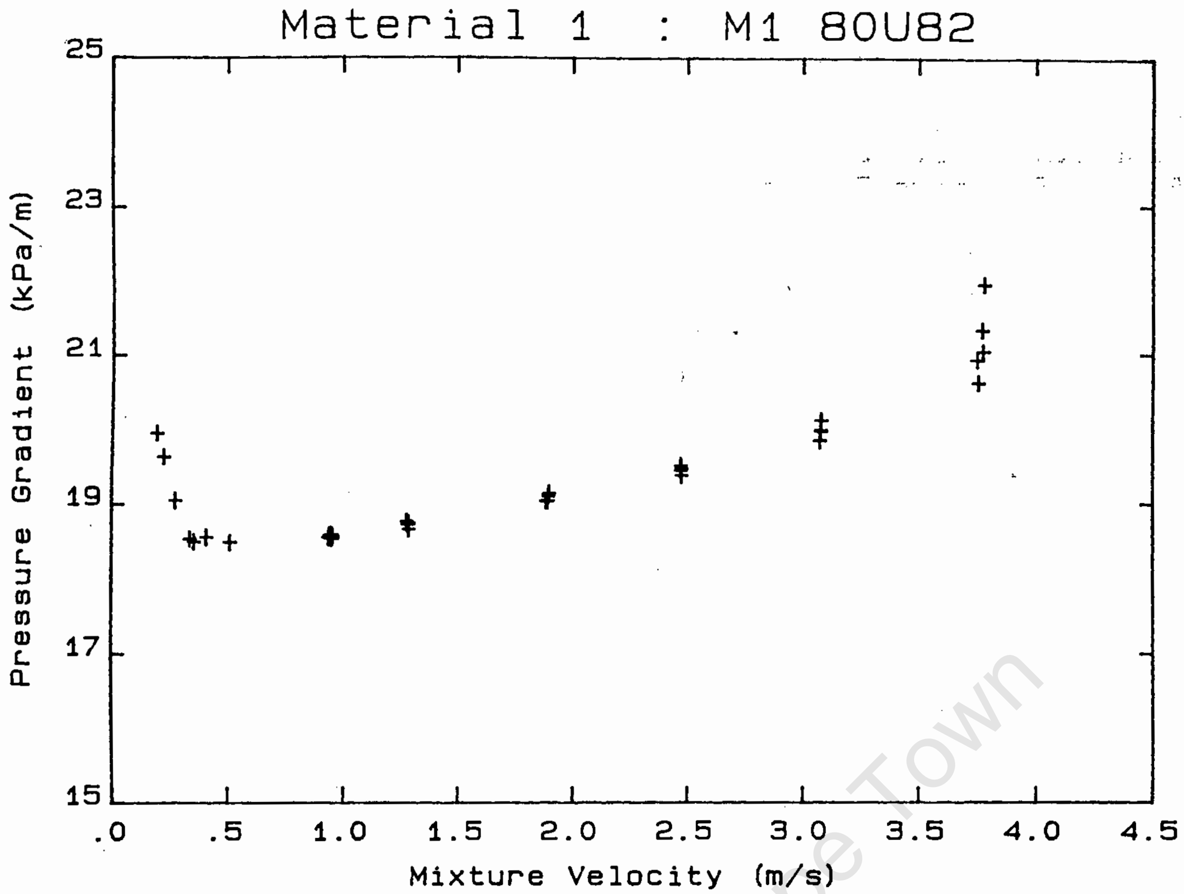
Particle Size Distribution
Sieve and Malvern Size Analysis *

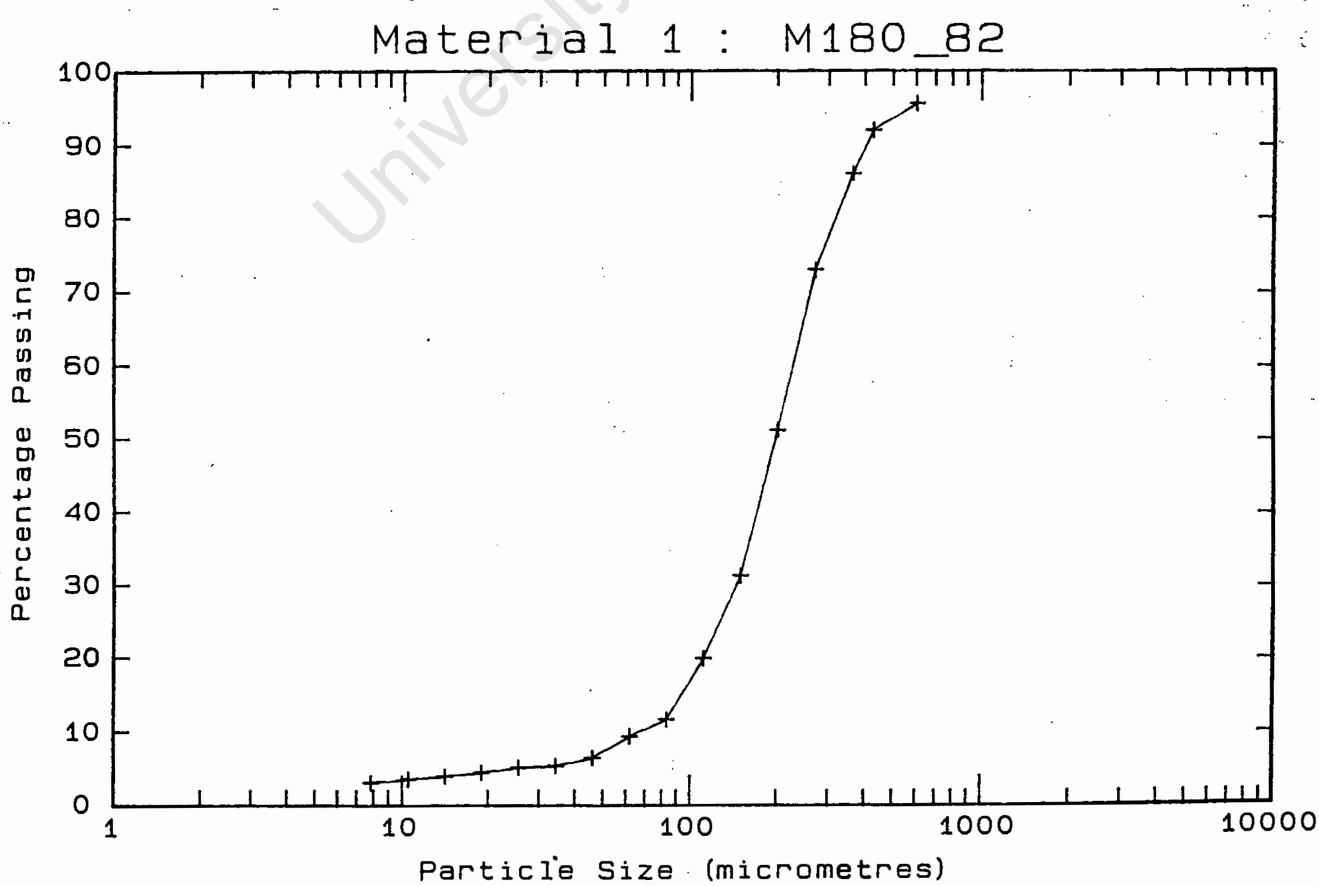
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80U82
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_82
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180H85

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.85
Solids Volumetric Concentration (%)	49.31
Solids Mass Concentration (%)	72.64
Mean Slurry Temperature (°C)	25.6
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.418	5.265	24.1
3.432	5.195	24.3
3.438	5.206	24.6
3.451	5.349	24.8
3.081	4.708	25.5
3.079	4.660	25.6
3.084	4.116	25.7
3.088	4.395	25.8
2.464	3.649	26.1
2.460	3.629	26.2
2.462	3.751	26.2
2.467	3.671	26.2
2.467	3.898	26.2
1.875	2.496	26.2
1.872	2.912	26.2
1.874	2.833	26.2
1.874	2.688	26.1
1.267	2.276	26.0
1.263	2.382	26.0
1.261	2.120	25.9
1.262	1.972	25.9
.642	2.312	25.7
.668	2.376	25.6
.661	2.072	25.6
.648	2.178	25.5
.648	2.812	25.5
.194	2.136	25.2
.137	2.016	25.1
.106	2.607	25.1
.085	2.645	25.1

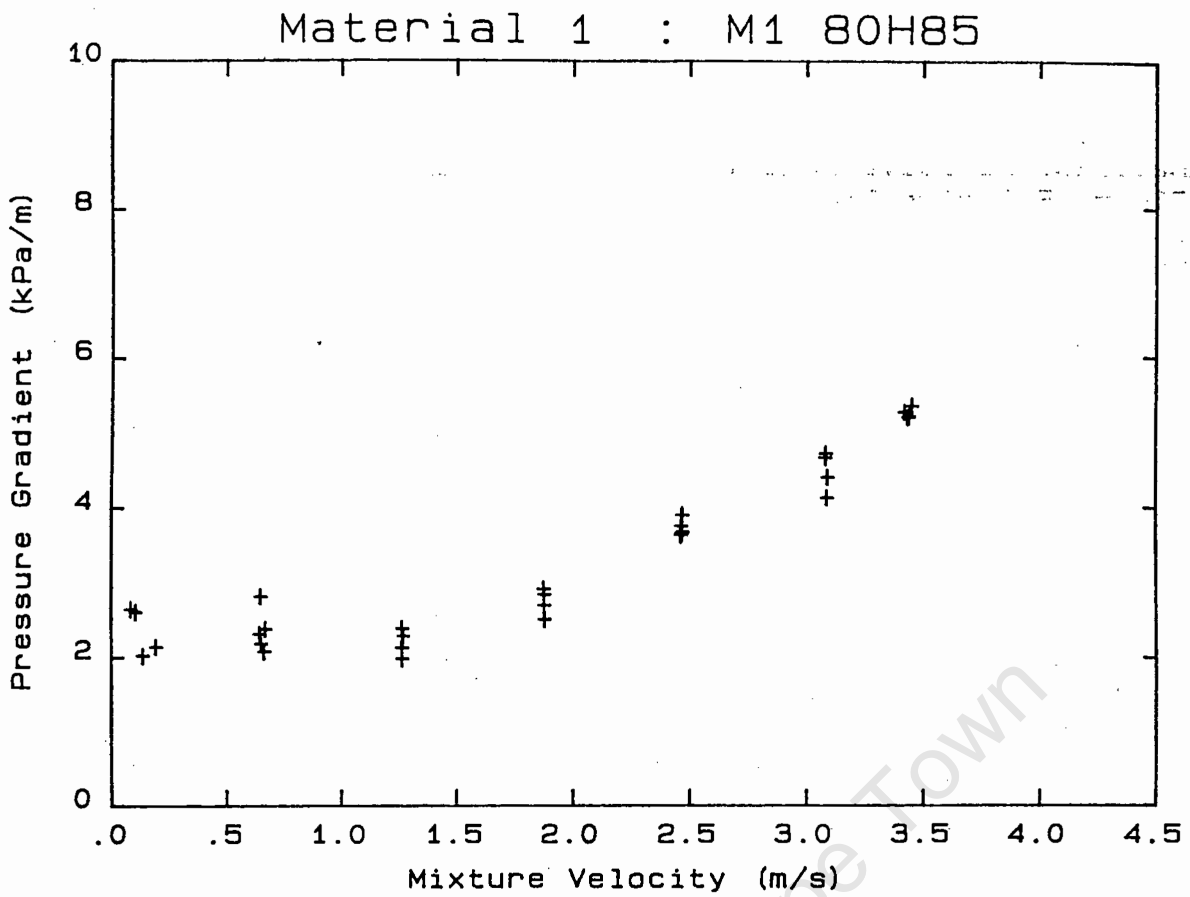
Particle Size Distribution
Sieve and Malvern Size Analysis *

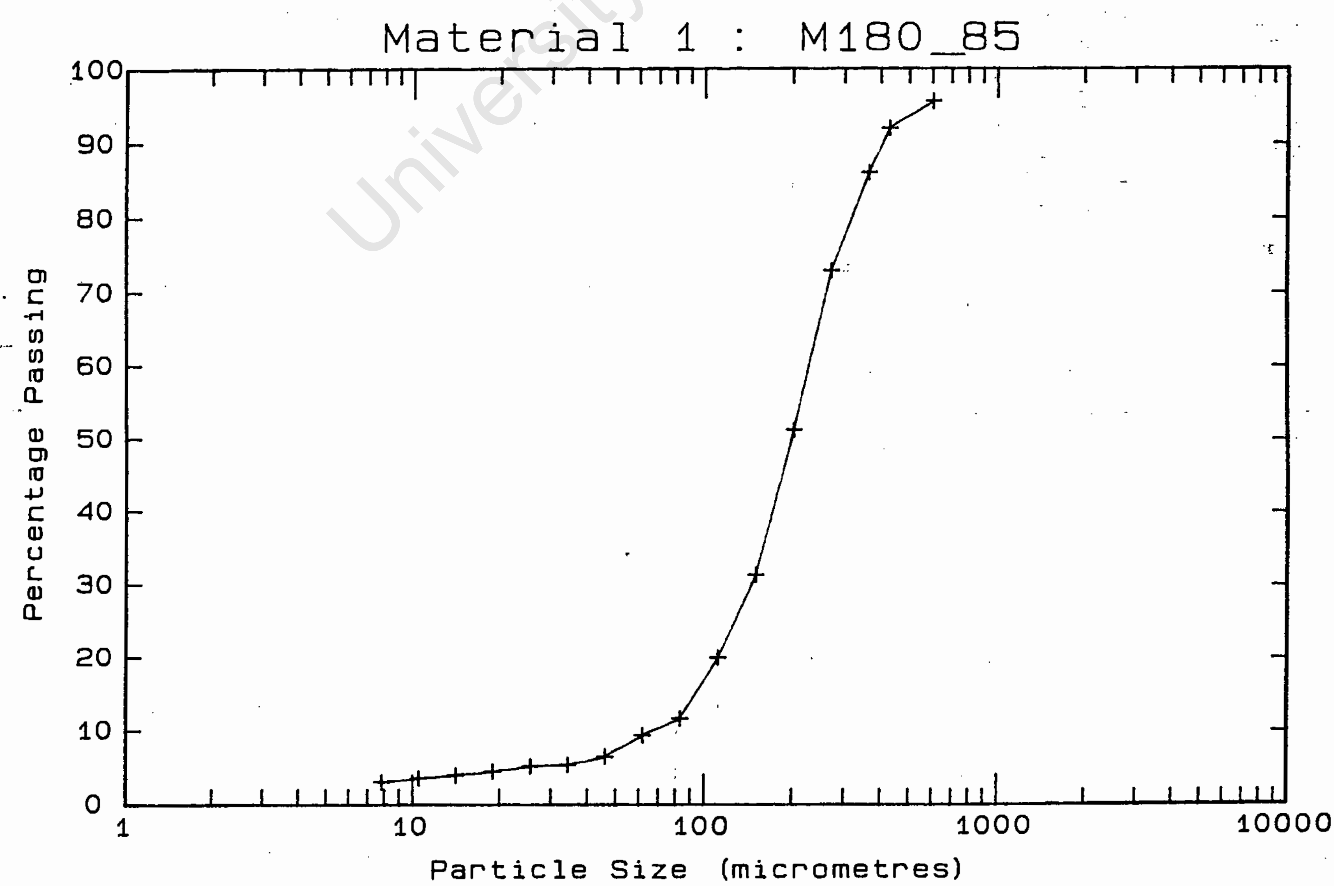
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.16	60% Stationary bed
.71	Asymetric
1.36	Asymetric
2.02	Appears homogeneous
2.65	Appears homogeneous
3.32	Appears homogeneous
3.70	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80H85
Pressure Gradient (kPa/m)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_85
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180D85

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.85
Solids Volumetric Concentration (%)	49.31
Solids Mass Concentration (%)	72.64
Mean Slurry Temperature (°C)	25.6
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.418	-13.088	24.1
3.432	-13.189	24.3
3.438	-13.131	24.6
3.451	-12.930	24.8
3.081	-13.432	25.5
3.079	-13.673	25.6
3.084	-13.519	25.7
3.088	-13.625	25.8
2.464	-14.412	26.1
2.460	-14.491	26.2
2.462	-14.457	26.2
2.467	-14.715	26.2
2.467	-14.719	26.2
1.875	-15.091	26.2
1.872	-15.042	26.2
1.874	-15.132	26.2
1.874	-15.102	26.1
1.267	-15.625	26.0
1.263	-15.582	26.0
1.261	-15.722	25.9
1.262	-15.621	25.9
.642	-15.221	25.7
.668	-16.396	25.6
.661	-16.067	25.6
.648	-15.921	25.5
.648	-15.813	25.5
.194	-17.374	25.2
.137	-18.960	25.1
.106	-18.702	25.1
.085	-17.526	25.1

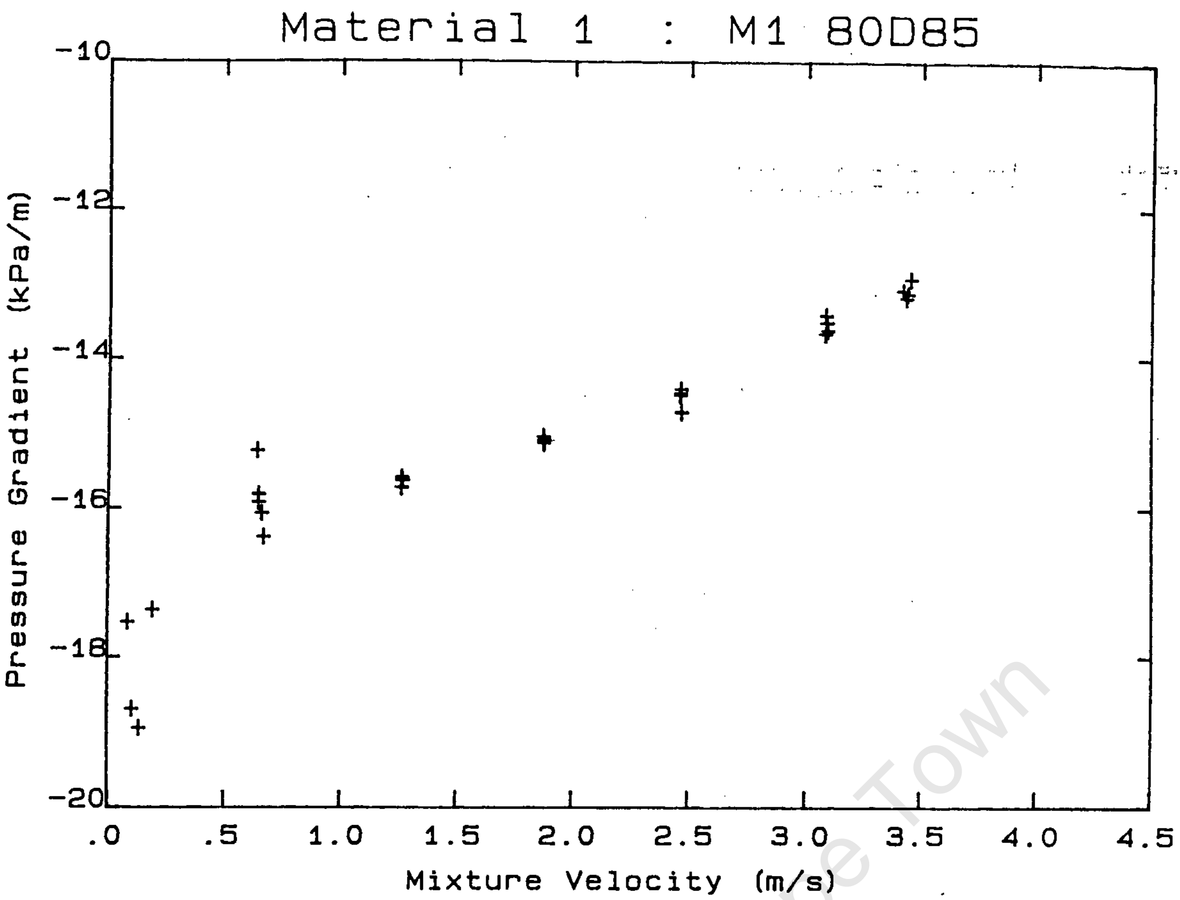
Particle Size Distribution
Sieve and Malvern Size Analysis *

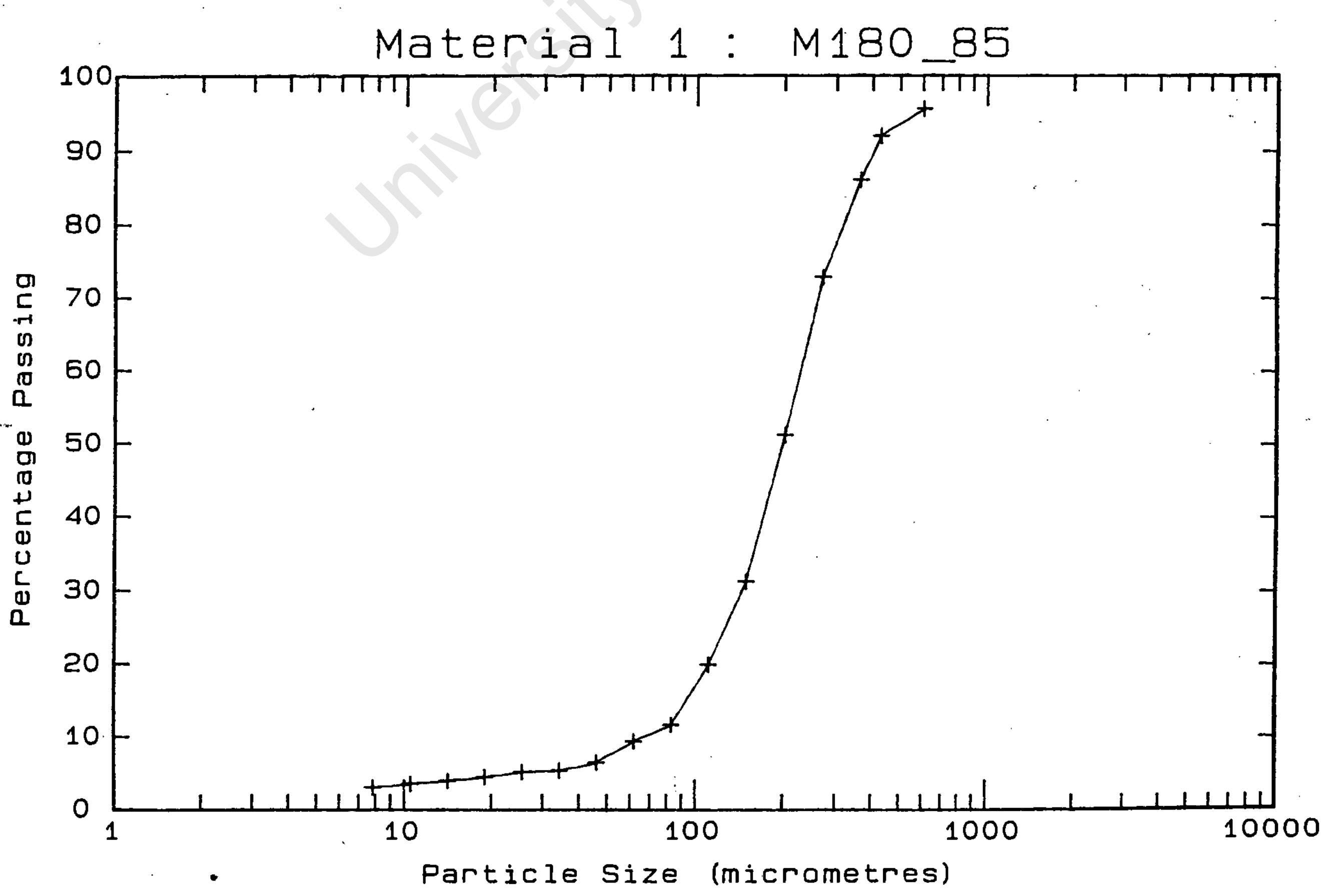
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80D85
Pressure Gradient (kPa/m)
-10
-12
-14
-16
-18
-20
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_85
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180U85

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.85
Solids Volumetric Concentration (%)	49.31
Solids Mass Concentration (%)	72.64
Mean Slurry Temperature (°C)	25.6
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.418	21.900	24.1
3.432	22.393	24.3
3.438	21.877	24.6
3.451	22.180	24.8
3.081	21.733	25.5
3.079	21.290	25.6
3.084	21.892	25.7
3.088	22.015	25.8
2.464	20.783	26.1
2.460	20.828	26.2
2.462	20.718	26.2
2.467	20.833	26.2
2.467	21.009	26.2
1.875	20.262	26.2
1.872	20.357	26.2
1.874	20.347	26.2
1.874	20.256	26.1
1.267	19.826	26.0
1.263	19.826	26.0
1.261	19.824	25.9
1.262	19.814	25.9
.642	19.547	25.7
.668	19.446	25.6
.661	19.443	25.6
.648	19.389	25.5
.648	19.451	25.5
.194	18.952	25.2
.137	18.910	25.1
.106	18.894	25.1
.085	18.848	25.1

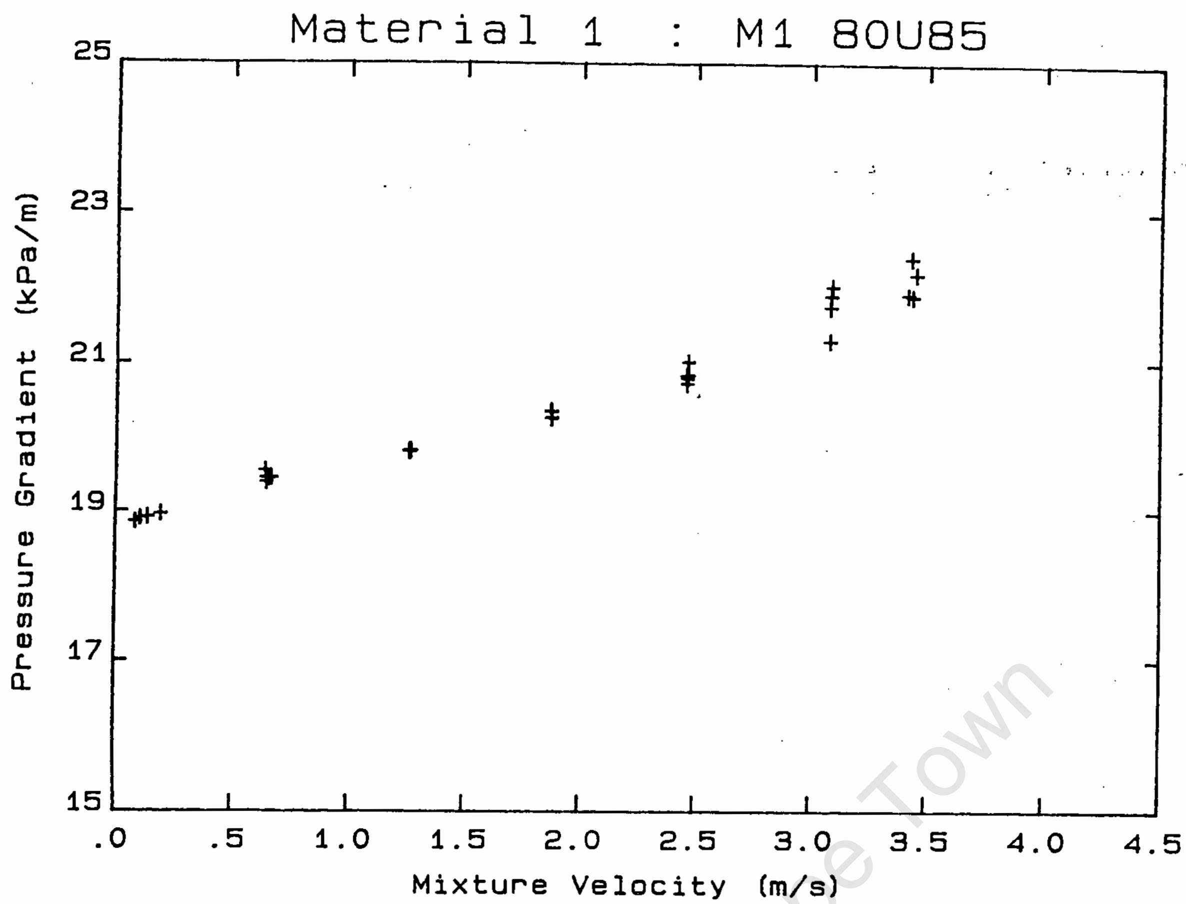
Particle Size Distribution
Sieve and Malvern Size Analysis *

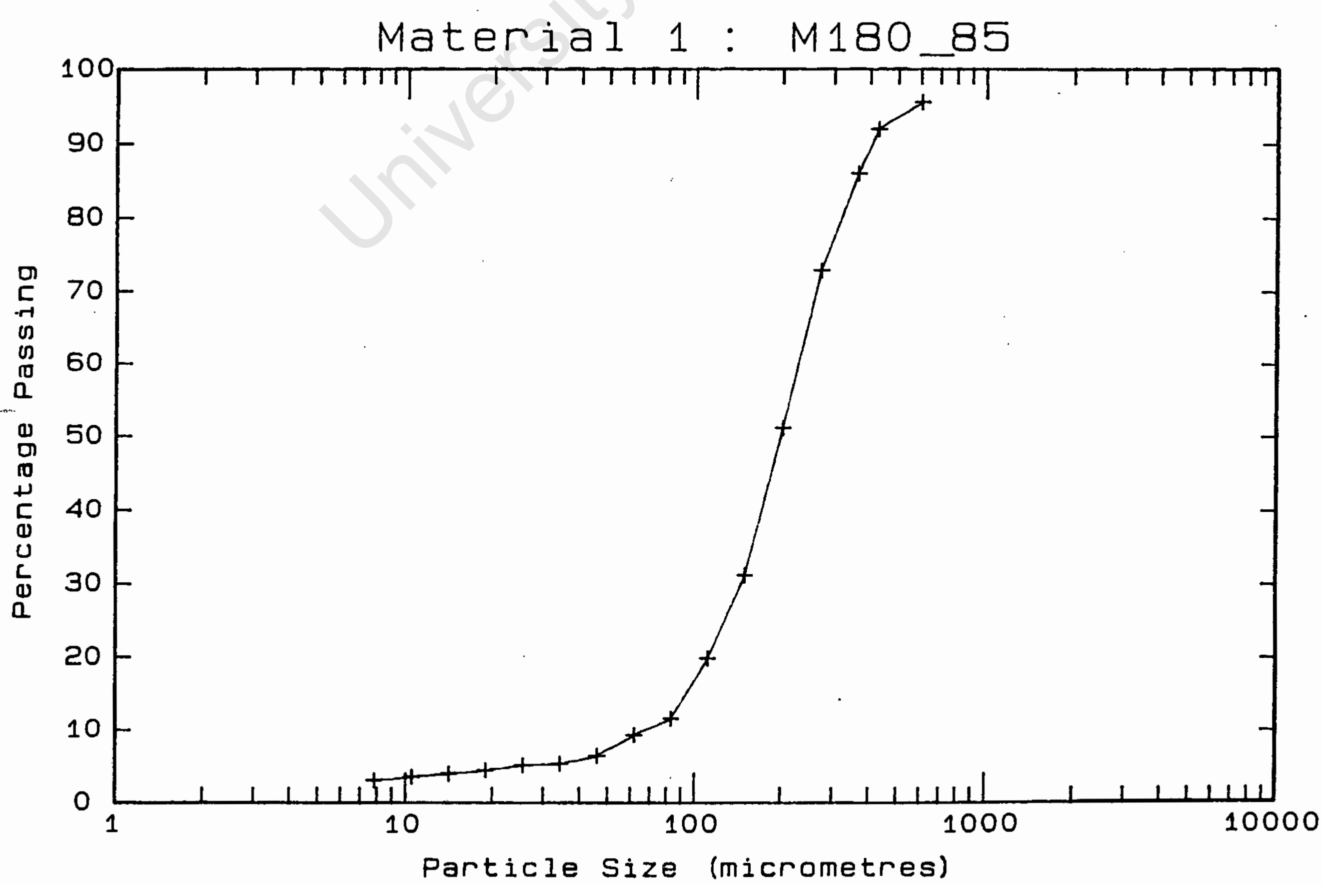
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80U85
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_85
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180H89

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.89
Solids Volumetric Concentration (%)	51.27
Solids Mass Concentration (%)	74.18
Mean Slurry Temperature (°C)	27.2
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (μm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
2.912	7.182	25.5
2.936	6.901	25.8
2.958	7.010	26.2
2.969	6.866	26.5
2.491	6.313	27.2
2.489	5.729	27.4
2.486	6.196	27.5
2.494	5.899	27.6
1.876	4.504	27.8
1.868	4.534	27.9
1.866	4.429	27.9
1.870	4.455	27.9
1.200	2.917	27.8
1.179	3.141	27.7
1.178	2.892	27.6
1.162	3.273	27.6
.643	2.428	27.4
.643	2.537	27.3
.637	2.469	27.3
.636	2.325	27.2
.639	2.525	27.2
.312	1.992	27.0
.281	2.126	26.9
.256	2.238	26.9
.241	2.223	26.9
.229	2.516	26.8
.224	1.995	26.8

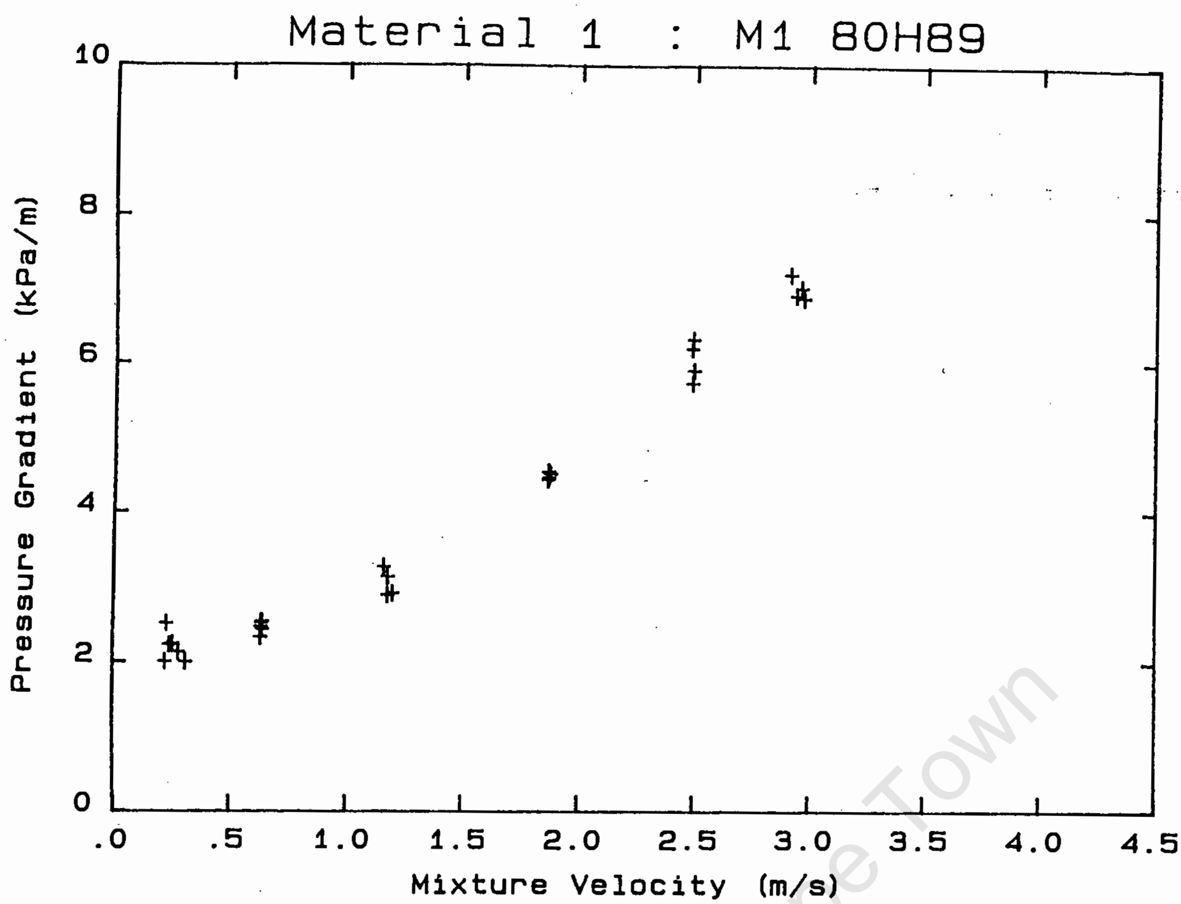
Particle Size Distribution
Sieve and Malvern Size Analysis *

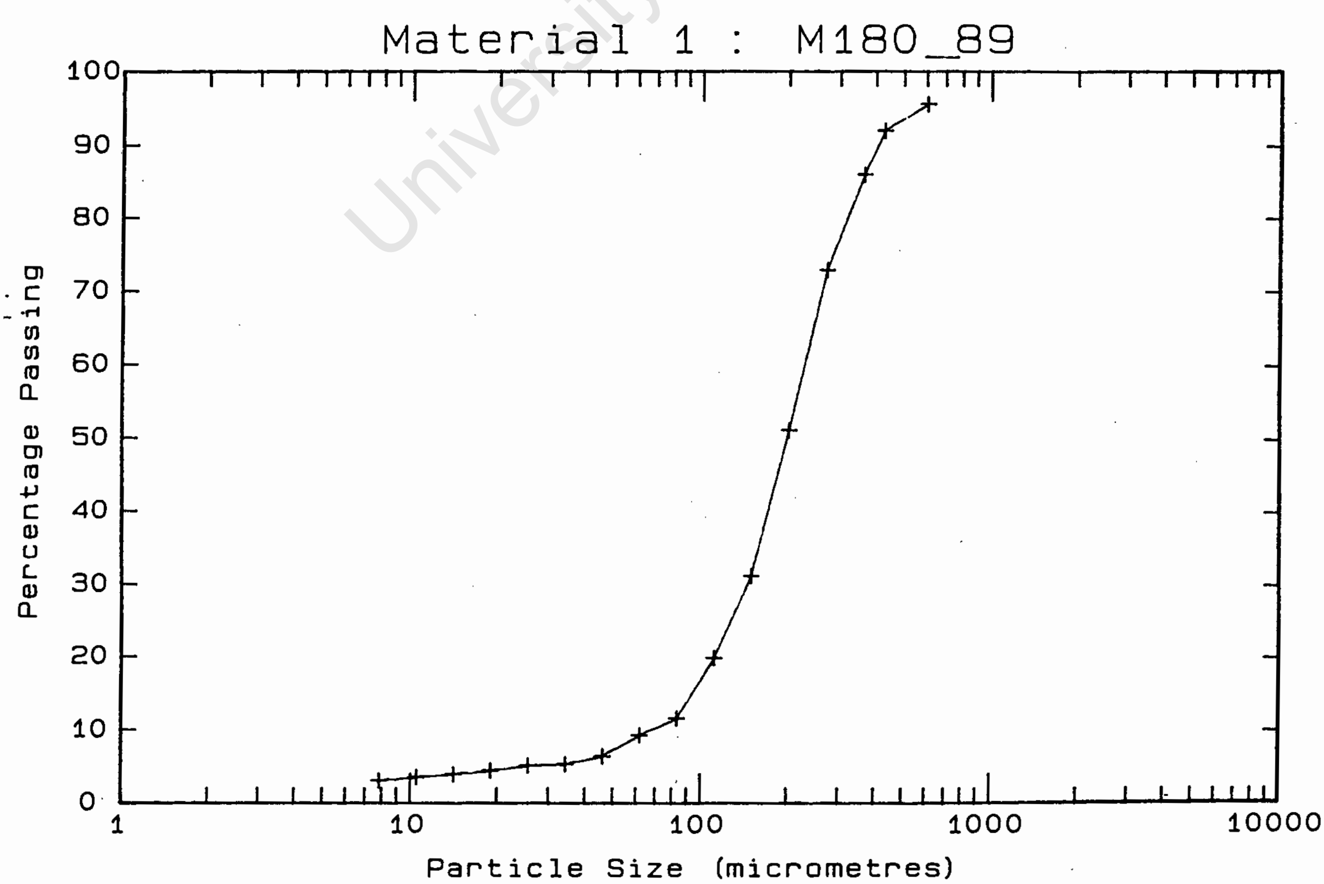
Size (μm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.26	Asymetric
.69	Asymetric
1.27	Appears homogeneous
2.02	Appears homogeneous
2.68	Appears homogeneous
3.17	Appears homogeneous

* -425 μm Malvern Particle Size Analyser


Material 1 : M1 80H89
Pressure Gradient (kPa/m)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_89
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180D89

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.89
Solids Volumetric Concentration (%)	51.27
Solids Mass Concentration (%)	74.18
Mean Slurry Temperature (°C)	27.2
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
2.912	-11.668	25.5
2.936	-11.712	25.8
2.958	-11.855	26.2
2.969	-11.864	26.5
2.491	-12.599	27.2
2.489	-12.764	27.4
2.486	-12.964	27.5
2.494	-12.594	27.6
1.876	-13.825	27.8
1.868	-13.855	27.9
1.866	-13.885	27.9
1.870	-13.974	27.9
1.200	-15.017	27.8
1.179	-15.013	27.7
1.178	-14.918	27.6
1.162	-15.004	27.6
.643	-15.913	27.4
.643	-15.857	27.3
.637	-15.985	27.3
.636	-15.902	27.2
.639	-15.933	27.2
.312	-15.790	27.0
.281	-15.742	26.9
.256	-15.602	26.9
.241	-15.600	26.9
.229	-15.594	26.8
.224	-15.585	26.8

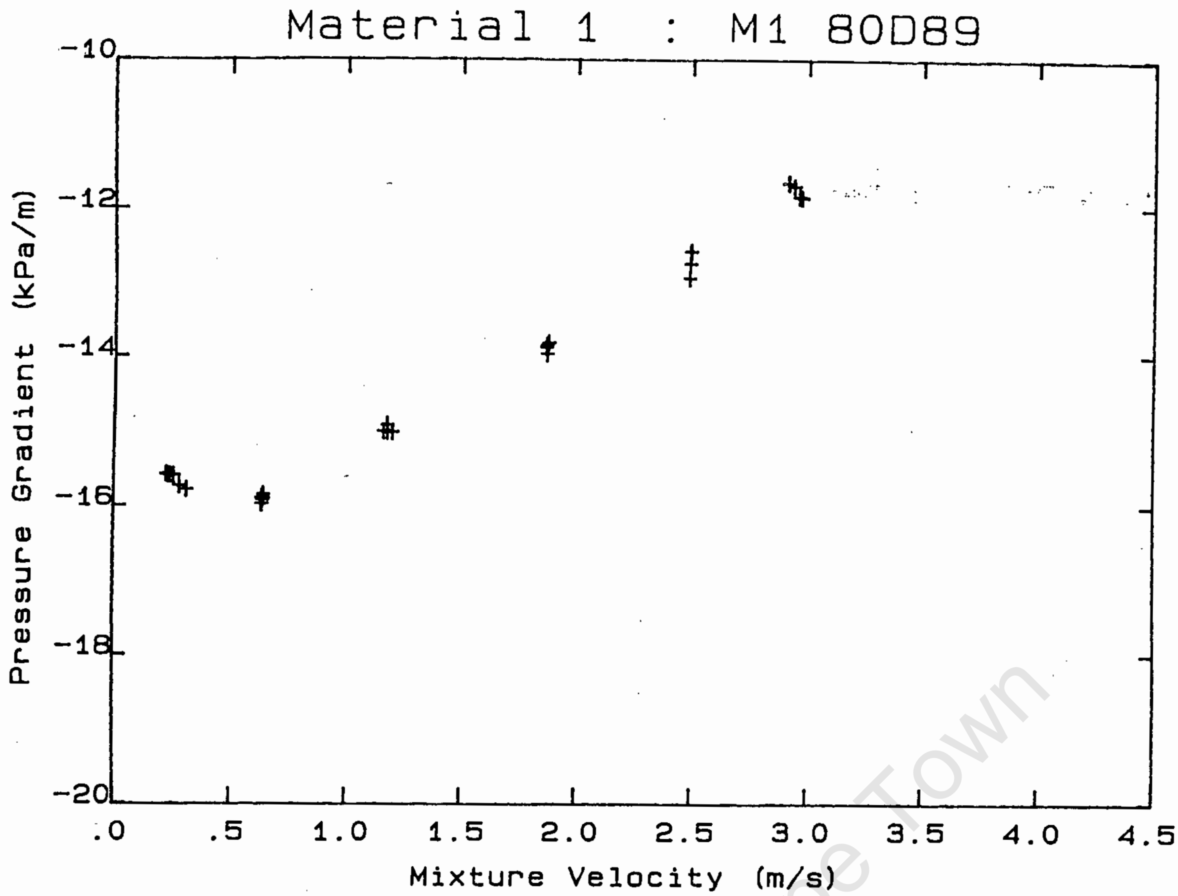
Particle Size Distribution
Sieve and Malvern Size Analysis *

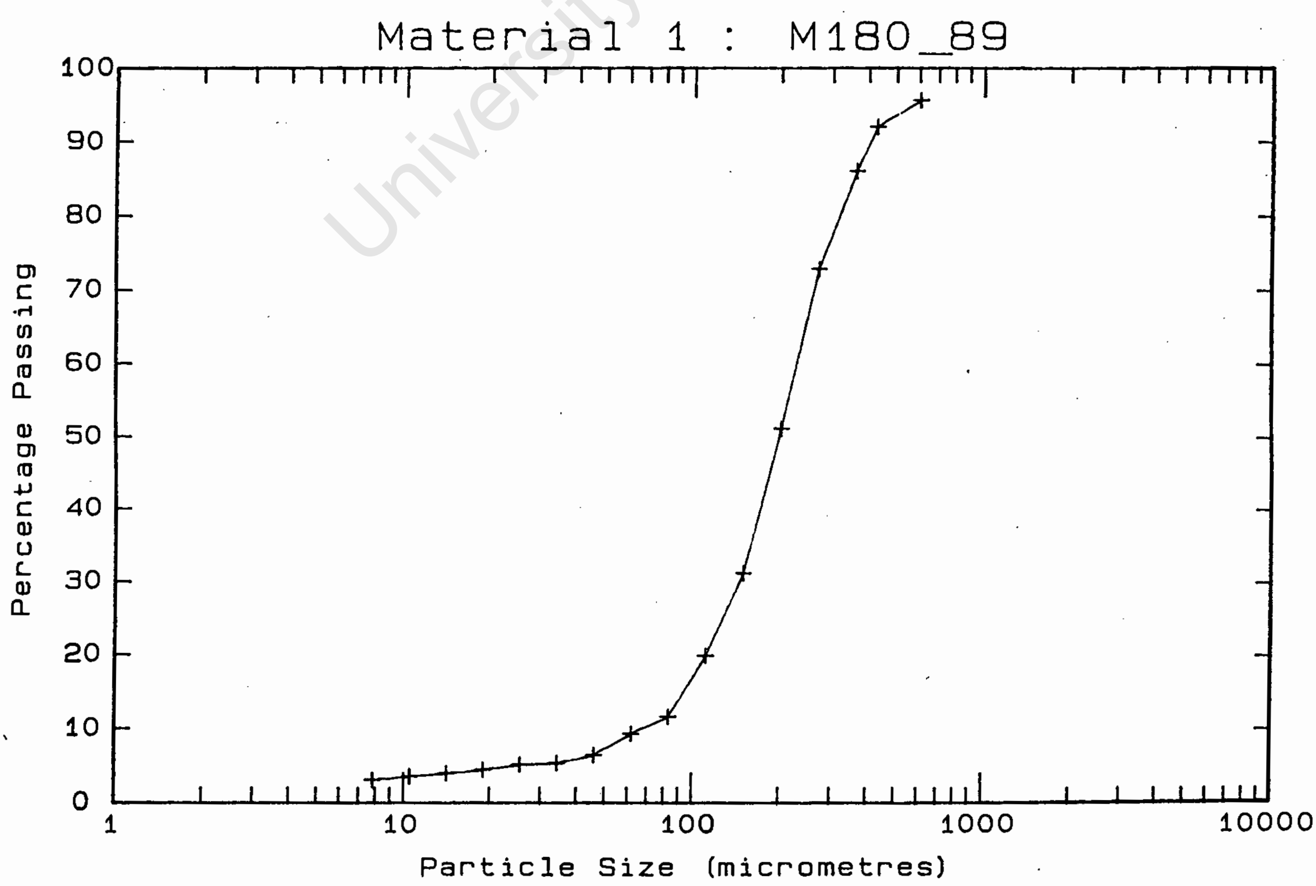
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80D89
-10
-12
-14
-16
-18
-20
Pressure Gradient (kPa/m)
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_89
100
90
80
70
60
50
40
30
20
10
0
Percentage Passing
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180U89

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.89
Solids Volumetric Concentration (%)	51.27
Solids Mass Concentration (%)	74.18
Mean Slurry Temperature (°C)	27.2
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
2.912	23.547	25.5
2.936	23.939	25.8
2.958	23.567	26.2
2.969	23.677	26.5
2.491	22.734	27.2
2.489	23.477	27.4
2.486	22.699	27.5
2.494	23.309	27.6
1.876	22.314	27.8
1.868	22.363	27.9
1.866	22.386	27.9
1.870	22.224	27.9
1.200	21.485	27.8
1.179	21.409	27.7
1.178	21.455	27.6
1.162	21.477	27.6
.643	20.661	27.4
.643	20.617	27.3
.637	20.602	27.3
.636	20.527	27.2
.639	20.559	27.2
.312	19.972	27.0
.281	20.056	26.9
.256	20.035	26.9
.241	20.100	26.9
.229	20.136	26.8
.224	20.063	26.8

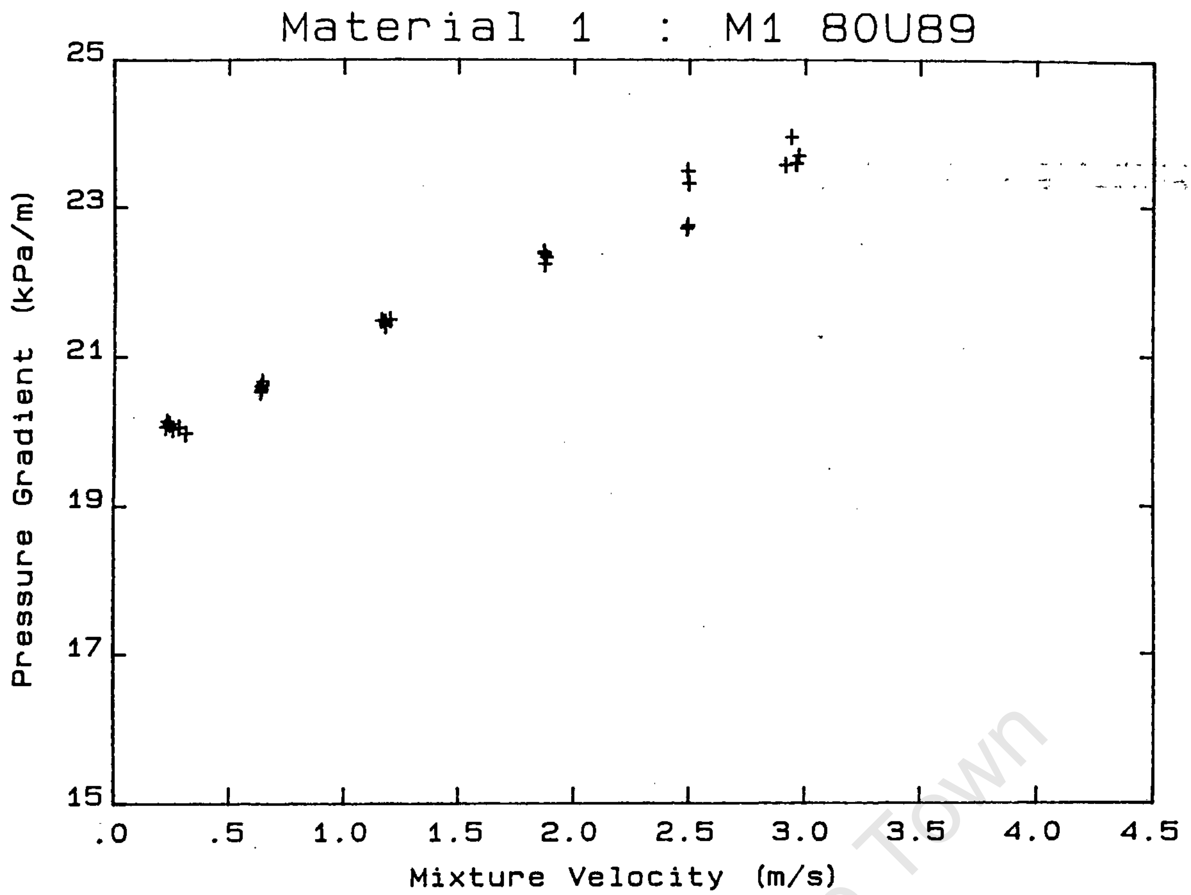
Particle Size Distribution
Sieve and Malvern Size Analysis *

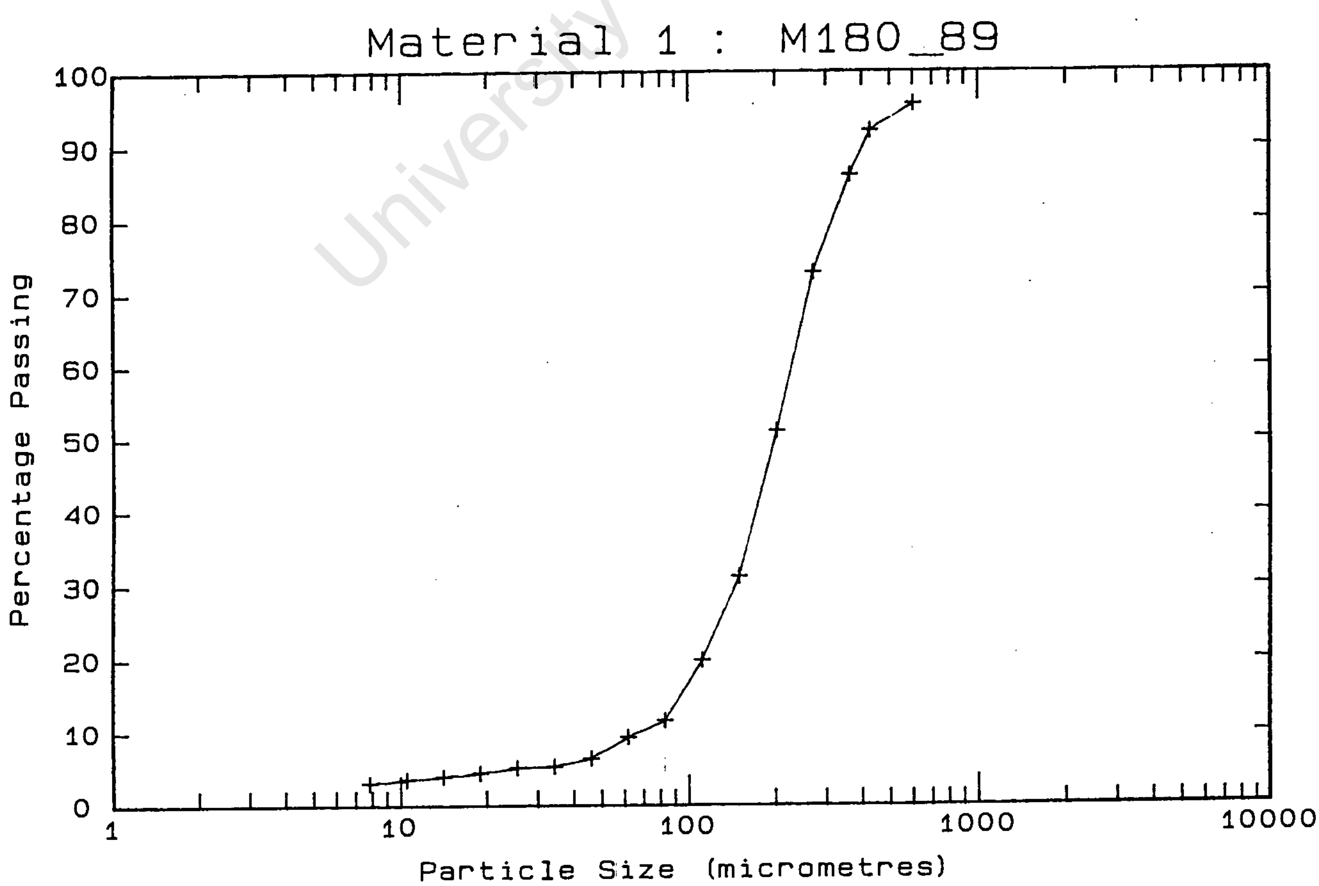
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80U89
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_89
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M180H92

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.92
Solids Volumetric Concentration (%)	52.95
Solids Mass Concentration (%)	75.44
Mean Slurry Temperature (°C)	29.2
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
2.806	8.015	28.0
2.814	8.054	28.4
2.830	8.246	28.7
2.839	7.984	29.0
2.456	6.615	29.5
2.465	6.716	29.6
2.456	7.315	29.7
2.440	6.931	29.7
1.839	5.018	29.9
1.845	4.956	29.9
1.843	5.197	29.9
1.840	4.977	29.8
1.235	3.693	29.7
1.231	3.813	29.7
1.239	3.782	29.6
1.217	3.957	29.5
.630	2.644	29.2
.625	2.887	29.2
.615	2.882	29.1
.611	2.807	29.0
.304	2.161	28.7
.291	2.243	28.6
.266	2.353	28.6
.257	2.106	28.5
.250	2.456	28.5

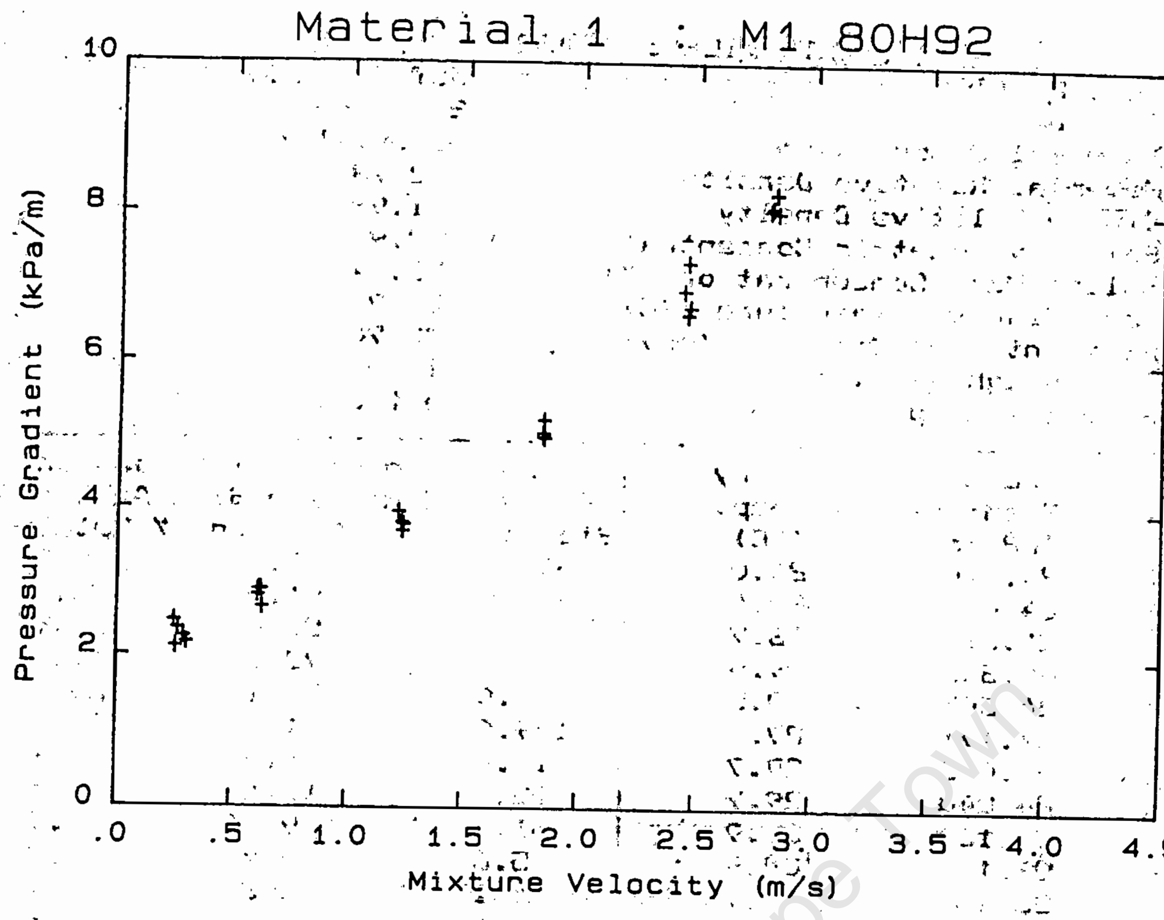
Particle Size Distribution
Sieve and Malvern Size Analysis *

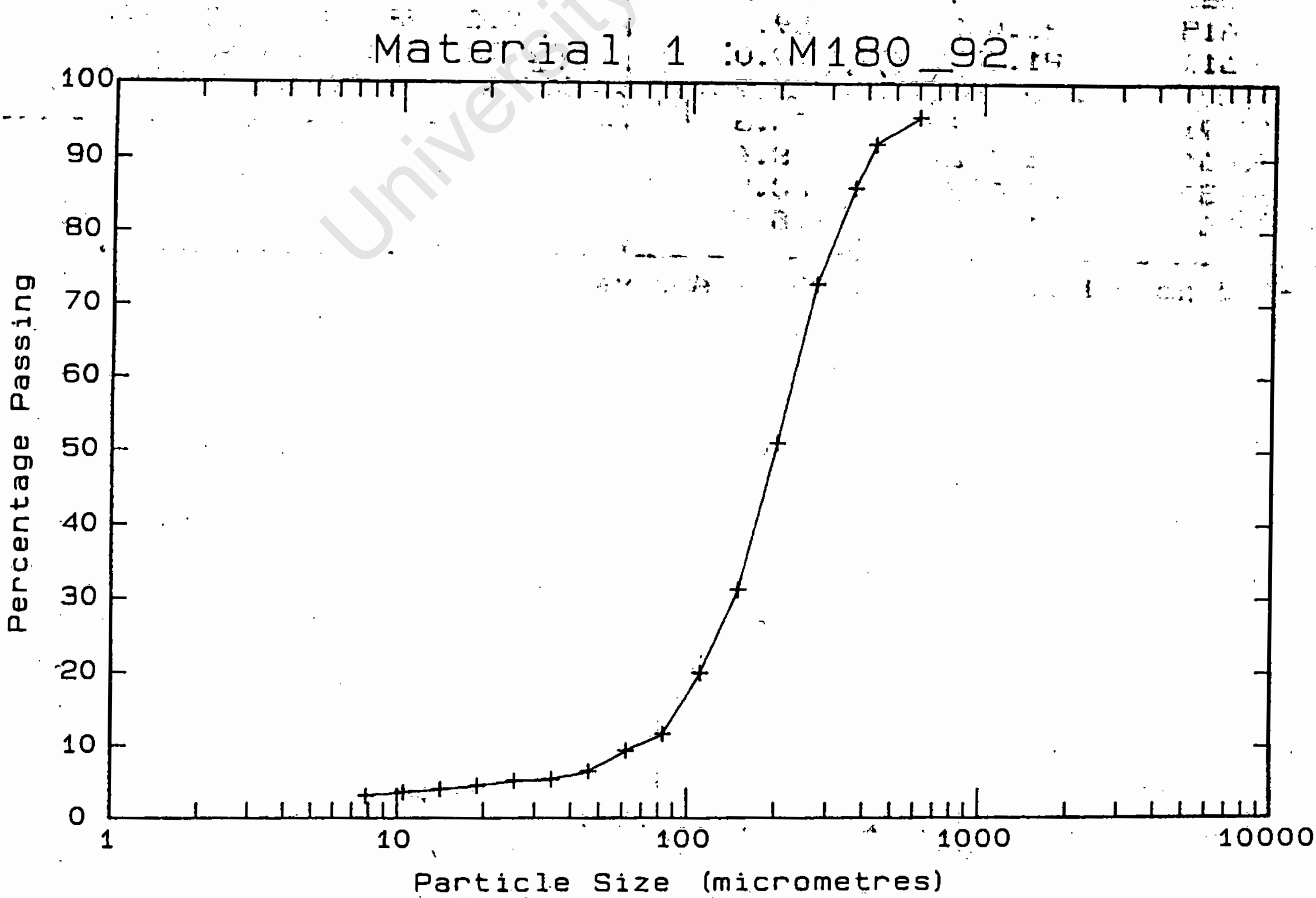
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.31	Appears homogeneous
.67	Appears homogeneous
1.33	Appears homogeneous
1.98	Appears homogeneous
2.64	Appears homogeneous
3.04	Appears homogeneous

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80H92
Pressure Gradient (kPa/m)
Mixture Velocity (m/s)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Material 1 : M180_92
Percentage Passing
Particle Size (micrometres)
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000

DATA FILE : M180D92

Test Facility	UCT 80 mm NB
Test Date	21/11/90
Material Description	Material 1
Material Relative Density	2.73
Slurry Relative Density	1.92
Solids Volumetric Concentration (%)	52.95
Solids Mass Concentration (%)	75.44
Mean Slurry Temperature (°C)	29.2
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
2.806	-11.282	28.0
2.814	-11.256	28.4
2.830	-11.357	28.7
2.839	-11.144	29.0
2.456	-12.347	29.5
2.465	-11.868	29.6
2.456	-12.099	29.7
2.440	-11.721	29.7
1.839	-13.292	29.9
1.845	-13.264	29.9
1.843	-13.394	29.9
1.840	-13.322	29.8
1.235	-14.345	29.7
1.231	-14.711	29.7
1.239	-14.456	29.6
1.217	-14.361	29.5
.630	-15.360	29.2
.625	-15.439	29.2
.615	-15.453	29.1
.611	-15.467	29.0
.304	-14.703	28.7
.291	-14.757	28.6
.266	-14.892	28.6
.257	-14.830	28.5
.250	-14.826	28.5

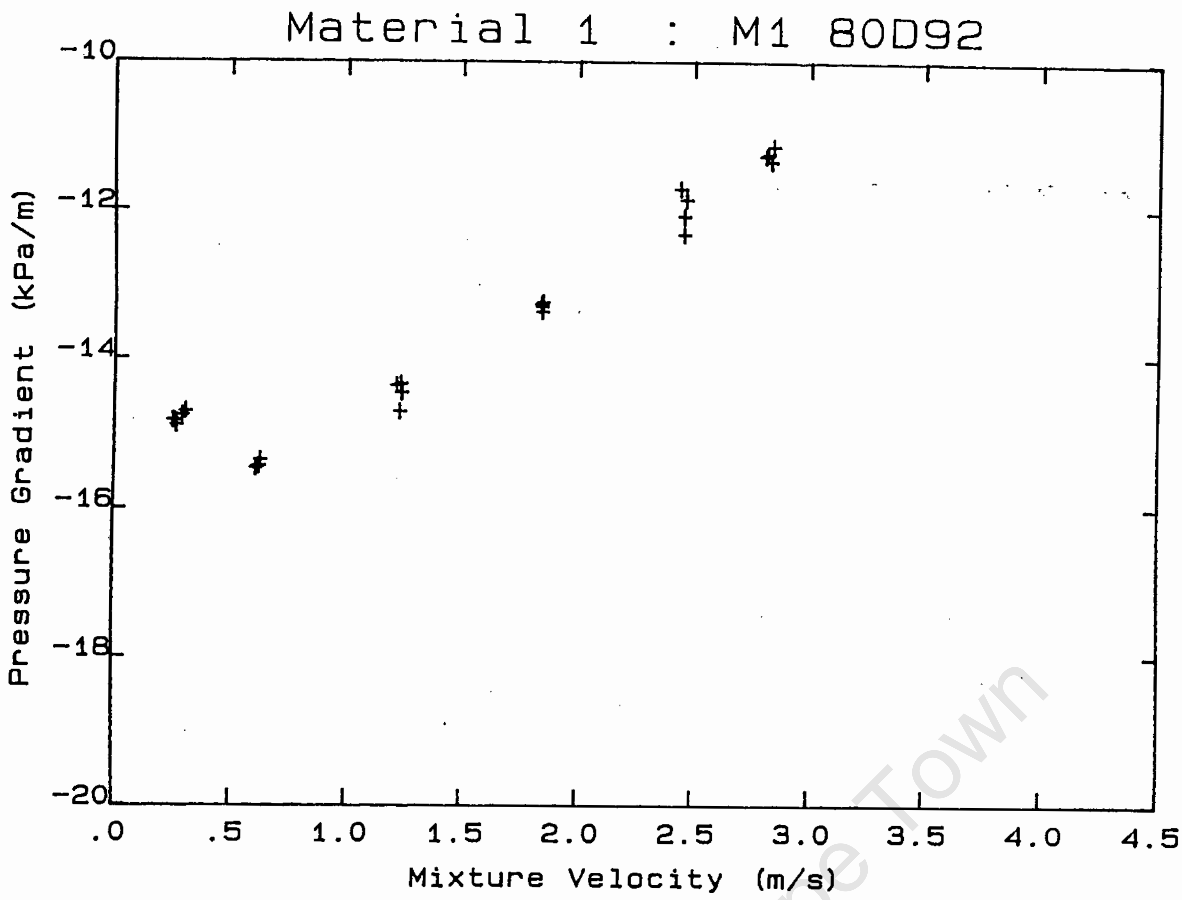
Particle Size Distribution
Sieve and Malvern Size Analysis *

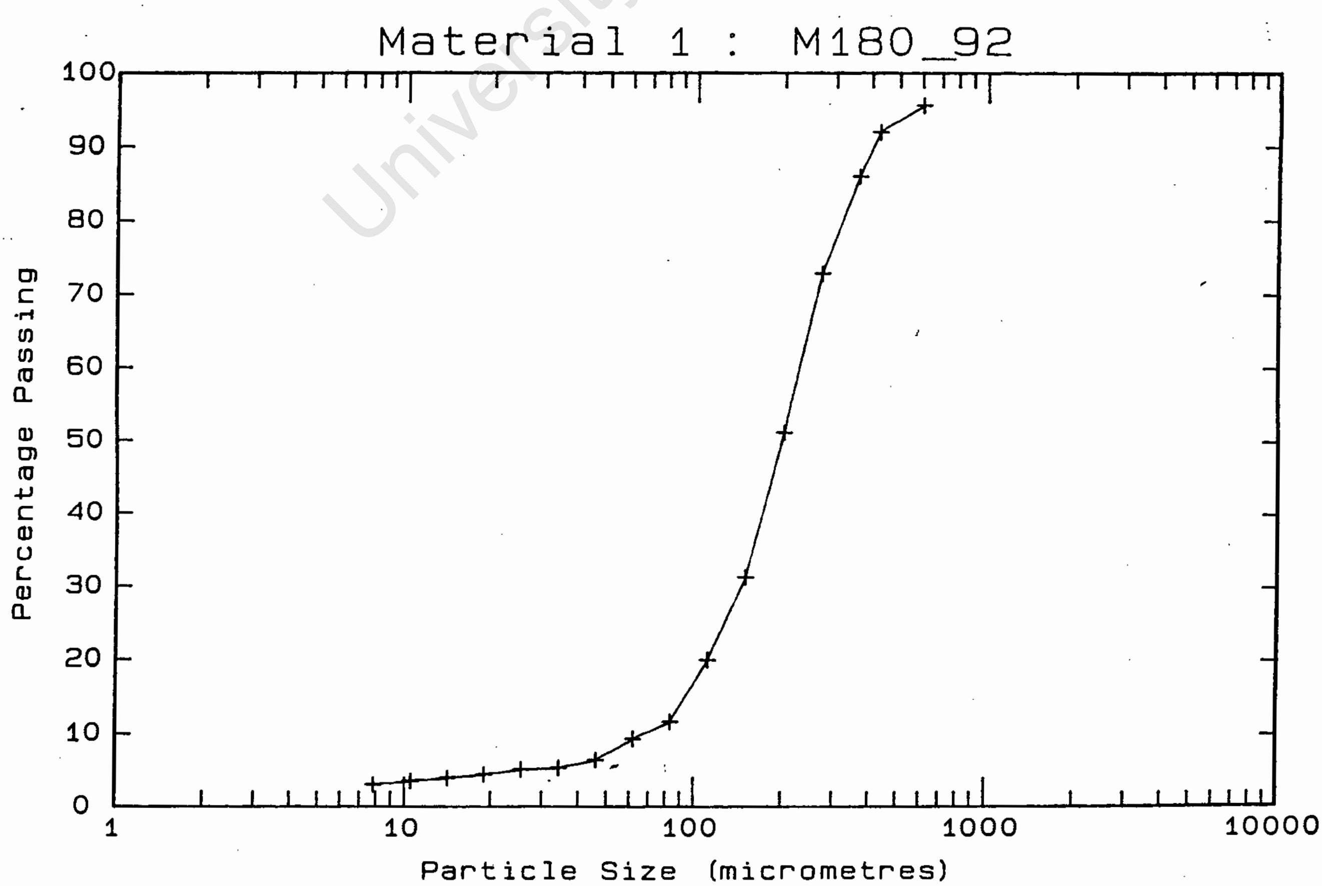
Size (µm)	% Passing	% Retained
600.0	95.5	4.5
425.0	91.9	3.6
362.0	86.0	5.9
270.0	72.8	13.2
201.0	51.1	21.7
149.0	31.2	19.9
111.0	19.9	11.3
82.7	11.6	8.3
61.6	9.3	2.3
45.8	6.4	2.9
34.1	5.3	1.1
25.4	5.1	.2
18.9	4.4	.7
14.1	3.9	.5
10.5	3.5	.4
7.8	3.0	.5
Pan	- .3	3.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -425 µm Malvern Particle Size Analyser


Material 1 : M1 80D92
Pressure Gradient (kPa/m)
-10
-12
-14
-16
-18
-20
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 1 : M180_92
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80H63

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.63
Solids Volumetric Concentration (%)	36.30
Solids Mass Concentration (%)	60.87
Mean Slurry Temperature (°C)	22.7
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.691	3.122	23.0
3.694	3.282	23.1
3.699	2.959	23.1
3.690	3.194	23.1
3.690	3.181	23.2
3.089	2.248	23.3
3.087	2.384	23.3
3.085	2.368	23.2
3.080	2.336	23.2
2.471	1.407	23.2
2.470	1.303	23.2
2.470	1.685	23.1
2.460	1.691	23.1
2.464	1.773	23.1
1.885	1.040	22.9
1.883	1.037	22.9
1.883	1.197	22.9
1.924	.542	22.8
1.248	1.922	22.7
1.250	2.742	22.7
1.252	.703	22.7
1.250	1.326	22.6
1.248	1.317	22.6
.638	.702	22.5
.637	.775	22.5
.658	.917	22.4
.662	.795	22.4
.663	.483	22.3
.661	.717	22.3
.229	.496	22.2
.180	.437	22.2
.158	.457	22.1
.128	.396	22.1
.122	.445	22.1
.104	.460	22.1
.071	.427	22.0

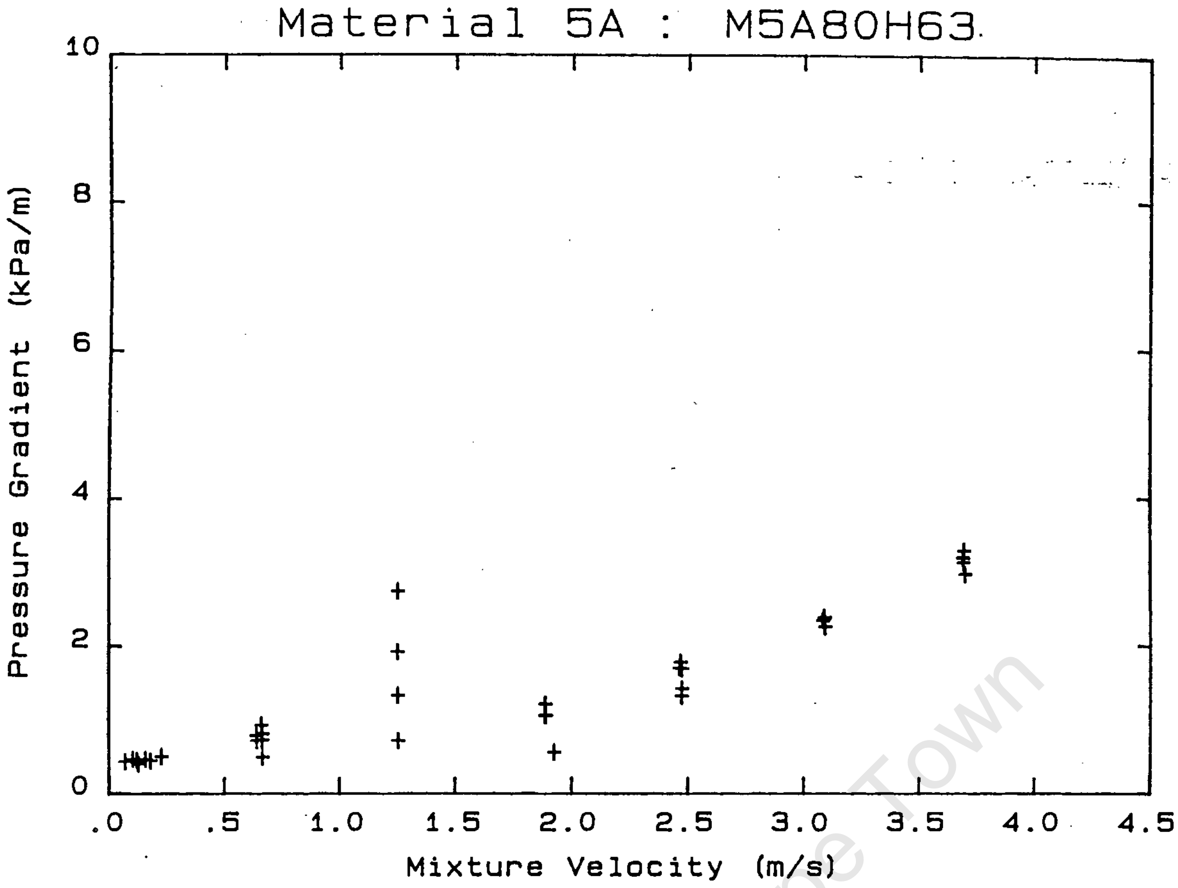
Particle Size Distribution
Sieve and Malvern Size Analysis *

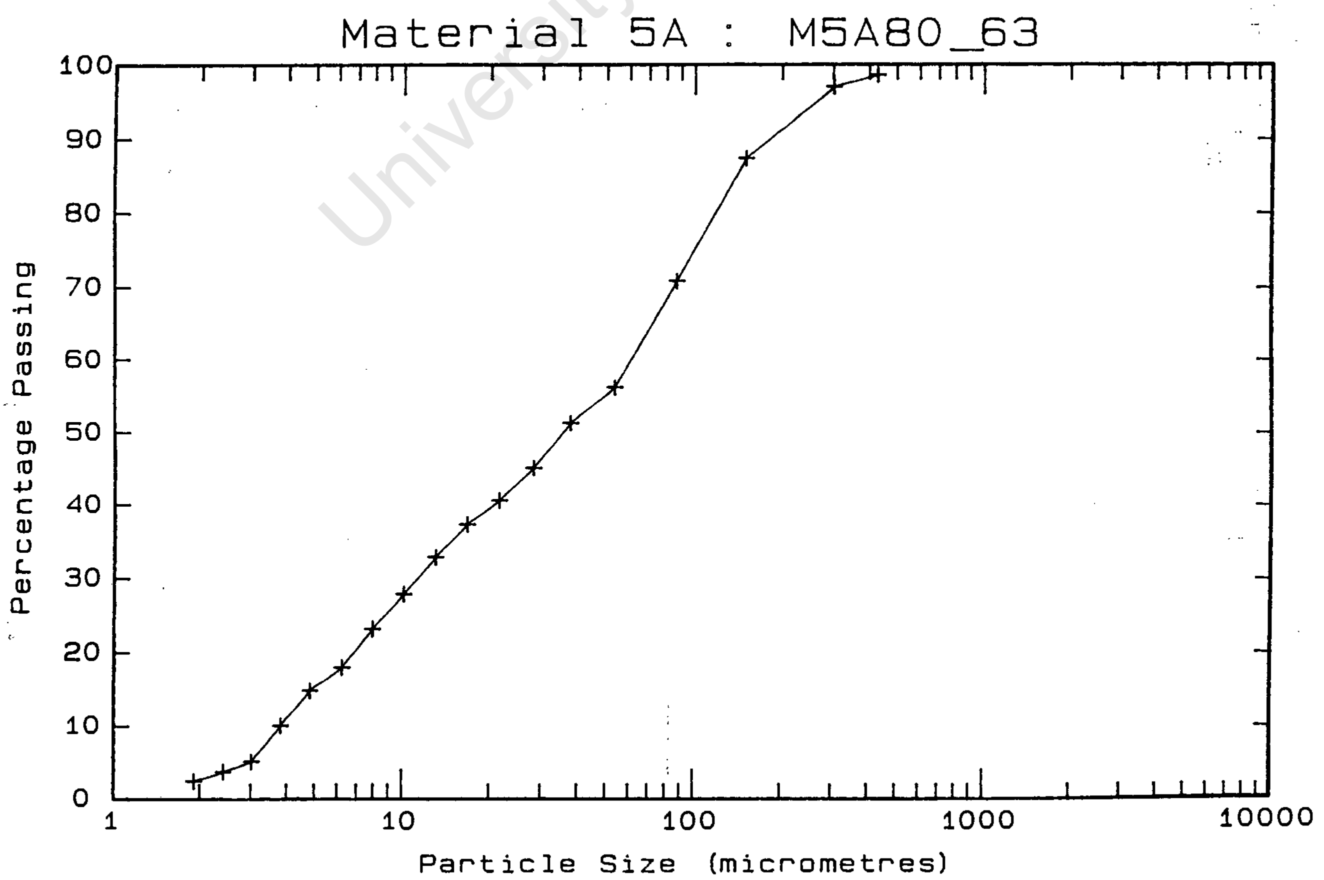
Size (µm)	% Passing	% Retained
425.0	98.5	1.5
300.0	96.9	1.6
150.0	87.3	9.6
87.2	70.8	16.5
53.5	56.1	14.7
37.6	51.2	4.9
28.1	45.0	6.2
21.5	40.5	4.5
16.7	37.2	3.3
13.0	32.8	4.4
10.1	27.8	5.0
7.9	23.1	4.7
6.2	17.9	5.2
4.8	14.8	3.1
3.8	10.0	4.8
3.0	5.1	4.9
2.4	3.7	1.4
1.9	2.4	1.3
Pan	- .1	2.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.15	30% Stationary bed
.70	Some sliding particles
1.35	Appears homogeneous
2.03	Appears homogeneous
2.66	Appears homogeneous
3.33	Appears homogeneous
3.98	Appears homogeneous

* -150 µm Malvern Particle Size Analyser


Material 5A : M5A80H63
Pressure Gradient (kPa/m)
Mixture Velocity (m/s)
10
8
6
4
2
0
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Material 5A : M5A80_63
Percentage Passing
Particle Size (micrometres)
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000

DATA FILE : M5A80D63

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.63
Solids Volumetric Concentration (%)	36.30
Solids Mass Concentration (%)	60.87
Mean Slurry Temperature (°C)	22.7
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (μm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.691	-11.905	23.0
3.694	-11.861	23.1
3.699	-11.805	23.1
3.690	-11.830	23.1
3.690	-11.838	23.2
3.089	-12.901	23.3
3.087	-12.942	23.3
3.085	-12.917	23.2
3.080	-12.901	23.2
2.471	-13.986	23.2
2.470	-14.047	23.2
2.470	-13.862	23.1
2.460	-13.997	23.1
2.464	-14.123	23.1
1.885	-14.867	22.9
1.883	-14.233	22.9
1.883	-14.644	22.9
1.924	-14.251	22.8
1.248	-15.457	22.7
1.250	-15.395	22.7
1.252	-15.195	22.7
1.250	-14.950	22.6
1.248	-15.266	22.6
.638	-15.585	22.5
.637	-15.640	22.5
.658	-15.711	22.4
.662	-15.538	22.4
.663	-15.397	22.3
.661	-15.357	22.3
.229	-15.676	22.2
.180	-15.610	22.2
.158	-15.633	22.1
.128	-15.630	22.1
.122	-15.661	22.1
.104	-15.696	22.1
.071	-15.635	22.0

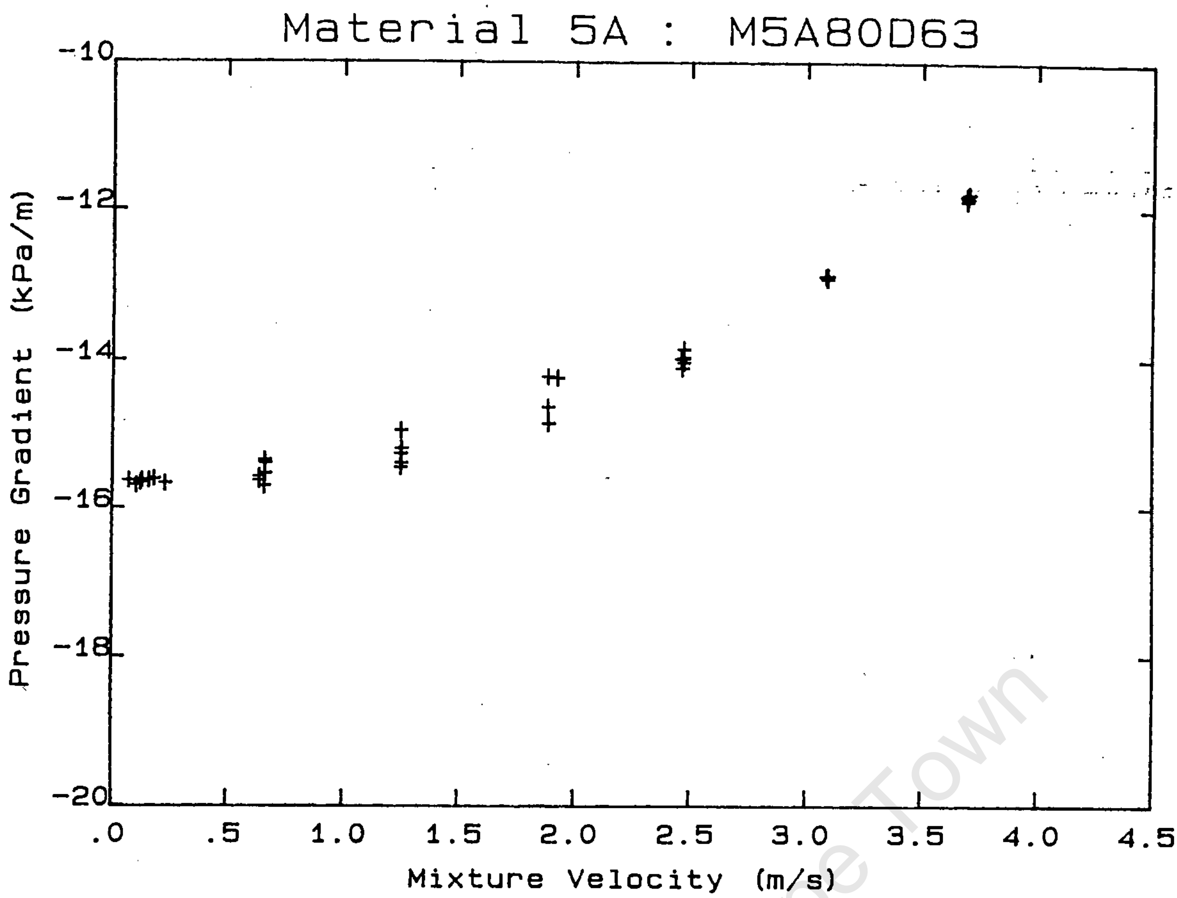
Particle Size Distribution
Sieve and Malvern Size Analysis *

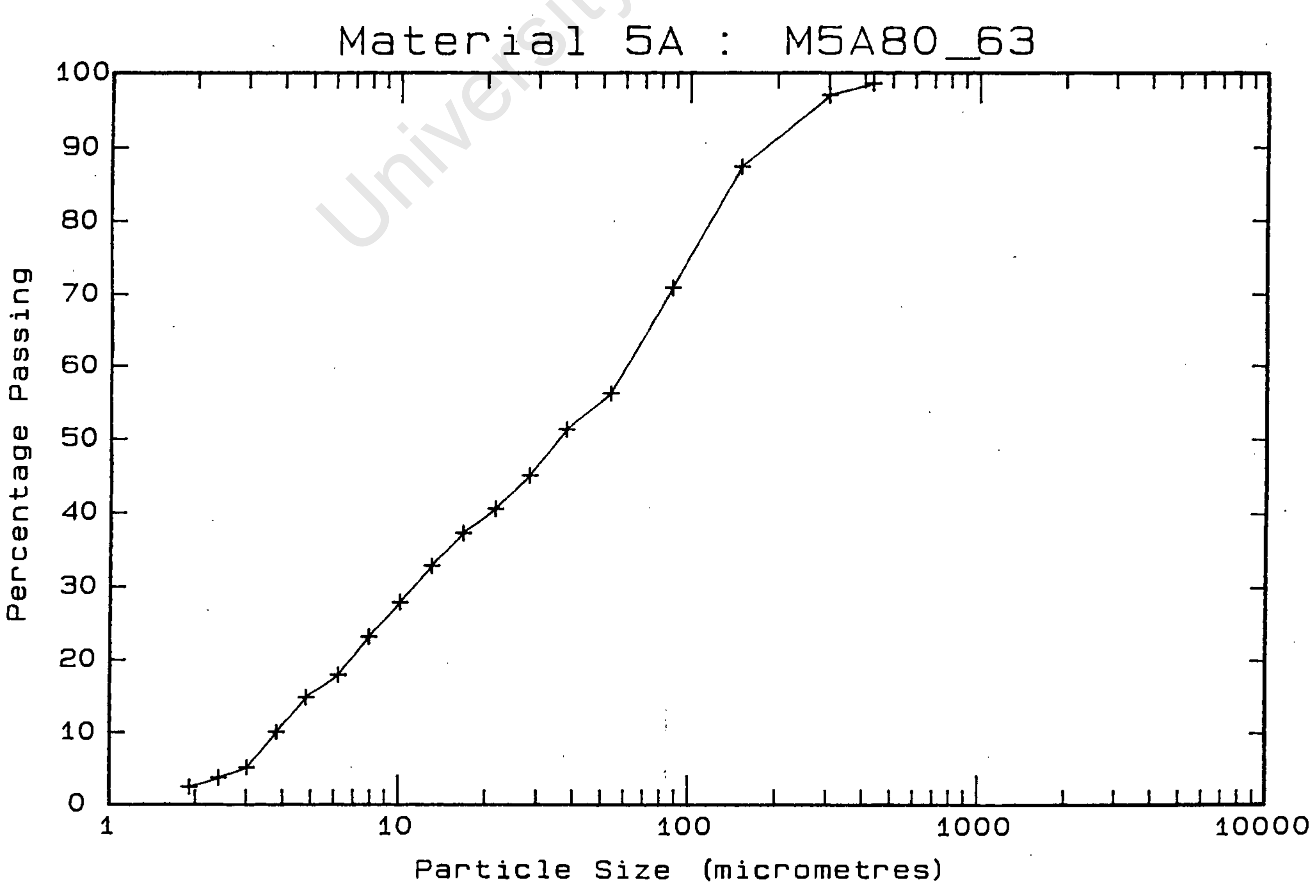
Size (μm)	% Passing	% Retained
425.0	98.5	1.5
300.0	96.9	1.6
150.0	87.3	9.6
87.2	70.8	16.5
53.5	56.1	14.7
37.6	51.2	4.9
28.1	45.0	6.2
21.5	40.5	4.5
16.7	37.2	3.3
13.0	32.8	4.4
10.1	27.8	5.0
7.9	23.1	4.7
6.2	17.9	5.2
4.8	14.8	3.1
3.8	10.0	4.8
3.0	5.1	4.9
2.4	3.7	1.4
1.9	2.4	1.3
Pan	- .1	2.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -150 μm Malvern Particle Size Analyser


Material 5A : M5A80D63
Pressure Gradient (kPa/m)
-10
-12
-14
-16
-18
-20
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_63
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80U63

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.63
Solids Volumetric Concentration (%)	36.30
Solids Mass Concentration (%)	60.87
Mean Slurry Temperature (°C)	22.7
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (μm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.691	19.037	23.0
3.694	19.056	23.1
3.699	19.270	23.1
3.690	19.337	23.1
3.690	19.140	23.2
3.089	18.265	23.3
3.087	18.282	23.3
3.085	18.242	23.2
3.080	18.333	23.2
2.471	17.544	23.2
2.470	17.565	23.2
2.470	17.396	23.1
2.460	17.511	23.1
2.464	17.549	23.1
1.885	16.881	22.9
1.883	16.902	22.9
1.883	16.823	22.9
1.924	16.950	22.8
1.248	16.464	22.7
1.250	16.421	22.7
1.252	16.463	22.7
1.250	16.461	22.6
1.248	16.470	22.6
.638	16.393	22.5
.637	16.373	22.5
.658	16.360	22.4
.662	16.354	22.4
.663	16.364	22.3
.661	16.346	22.3
.229	16.250	22.2
.180	16.302	22.2
.158	16.275	22.1
.128	16.296	22.1
.122	16.282	22.1
.104	16.281	22.1
.071	16.284	22.0

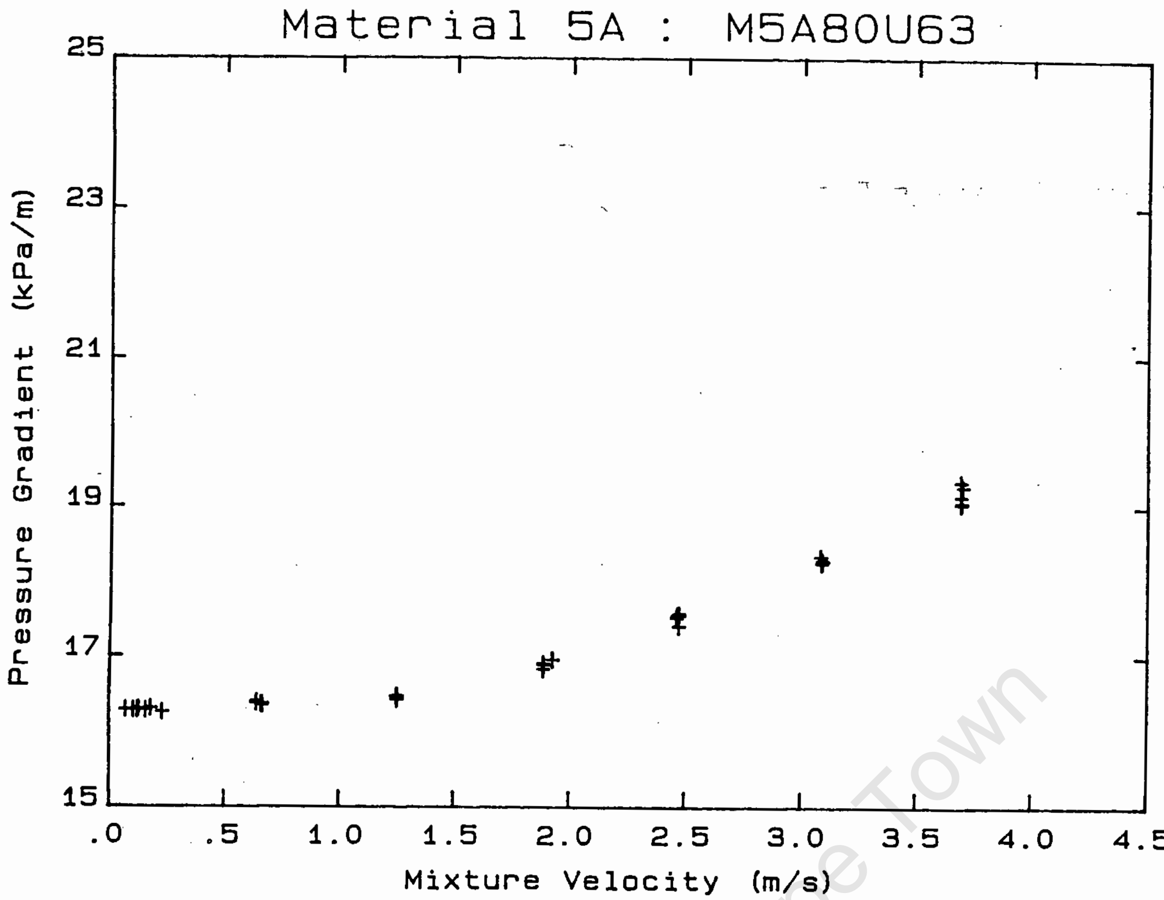
Particle Size Distribution
Sieve and Malvern Size Analysis *

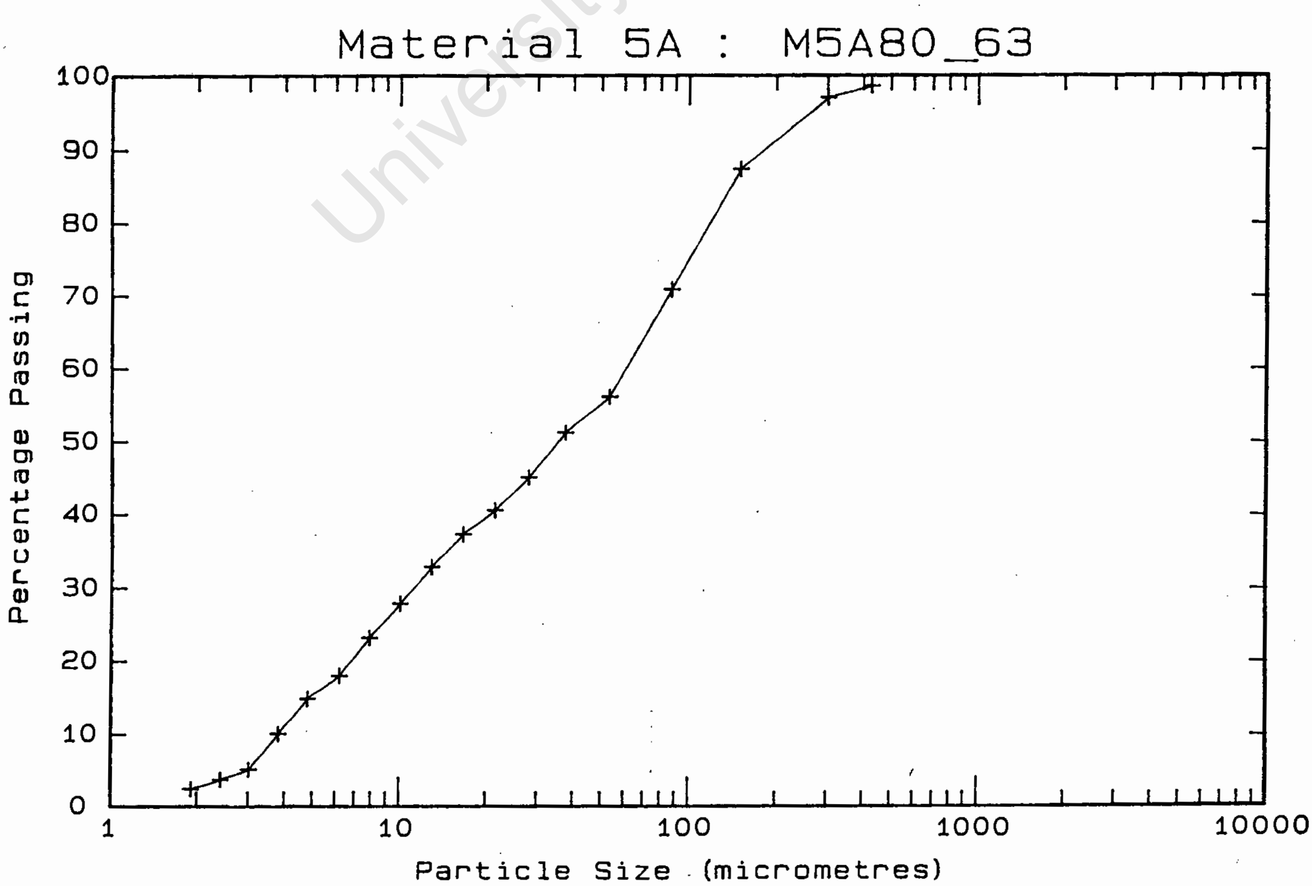
Size (μm)	% Passing	% Retained
425.0	98.5	1.5
300.0	96.9	1.6
150.0	87.3	9.6
87.2	70.8	16.5
53.5	56.1	14.7
37.6	51.2	4.9
28.1	45.0	6.2
21.5	40.5	4.5
16.7	37.2	3.3
13.0	32.8	4.4
10.1	27.8	5.0
7.9	23.1	4.7
6.2	17.9	5.2
4.8	14.8	3.1
3.8	10.0	4.8
3.0	5.1	4.9
2.4	3.7	1.4
1.9	2.4	1.3
Pan	– .1	2.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* −150 μm Malvern Particle Size Analyser


Material 5A : M5A80U63
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_63
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80H66

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.66
Solids Volumetric Concentration (%)	38.27
Solids Mass Concentration (%)	62.86
Mean Slurry Temperature (°C)	23.5
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.690	3.339	24.0
3.672	3.238	24.1
3.675	3.267	24.1
3.684	3.394	24.1
3.084	2.430	24.1
3.082	2.417	24.1
3.079	2.393	24.1
2.480	1.746	24.0
2.477	1.719	24.0
2.485	1.567	23.9
2.485	1.591	23.9
1.867	1.500	23.8
1.869	.245	23.7
1.867	.879	23.7
1.866	.766	23.6
1.868	1.333	23.6
1.247	1.489	23.4
1.247	.330	23.4
1.243	1.488	23.3
1.240	2.179	23.3
.626	1.502	23.2
.622	.690	23.1
.613	.447	23.1
.610	.661	23.0
.604	.817	23.0
.152	.520	22.9
.138	.487	22.9
.127	.527	22.8
.108	.528	22.8
.094	.549	22.8

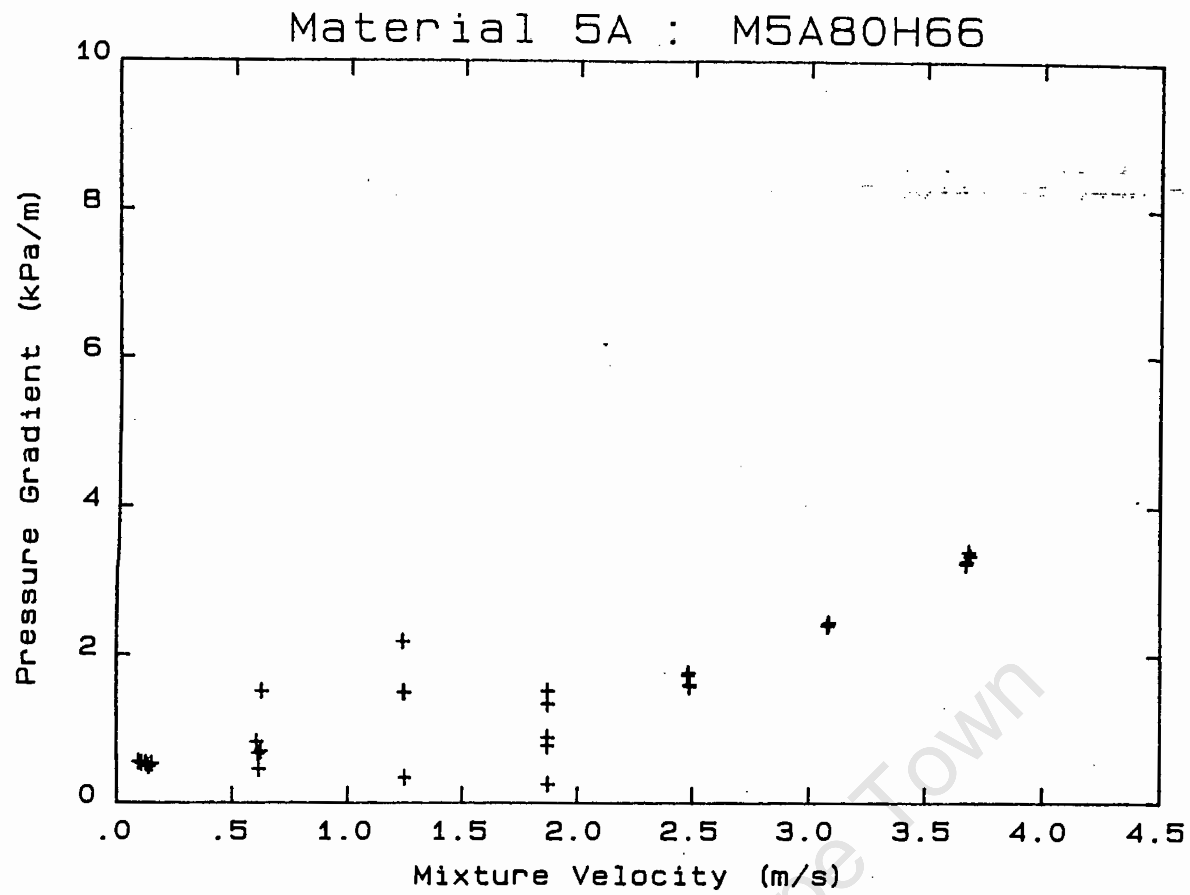
Particle Size Distribution
Sieve and Malvern Size Analysis *

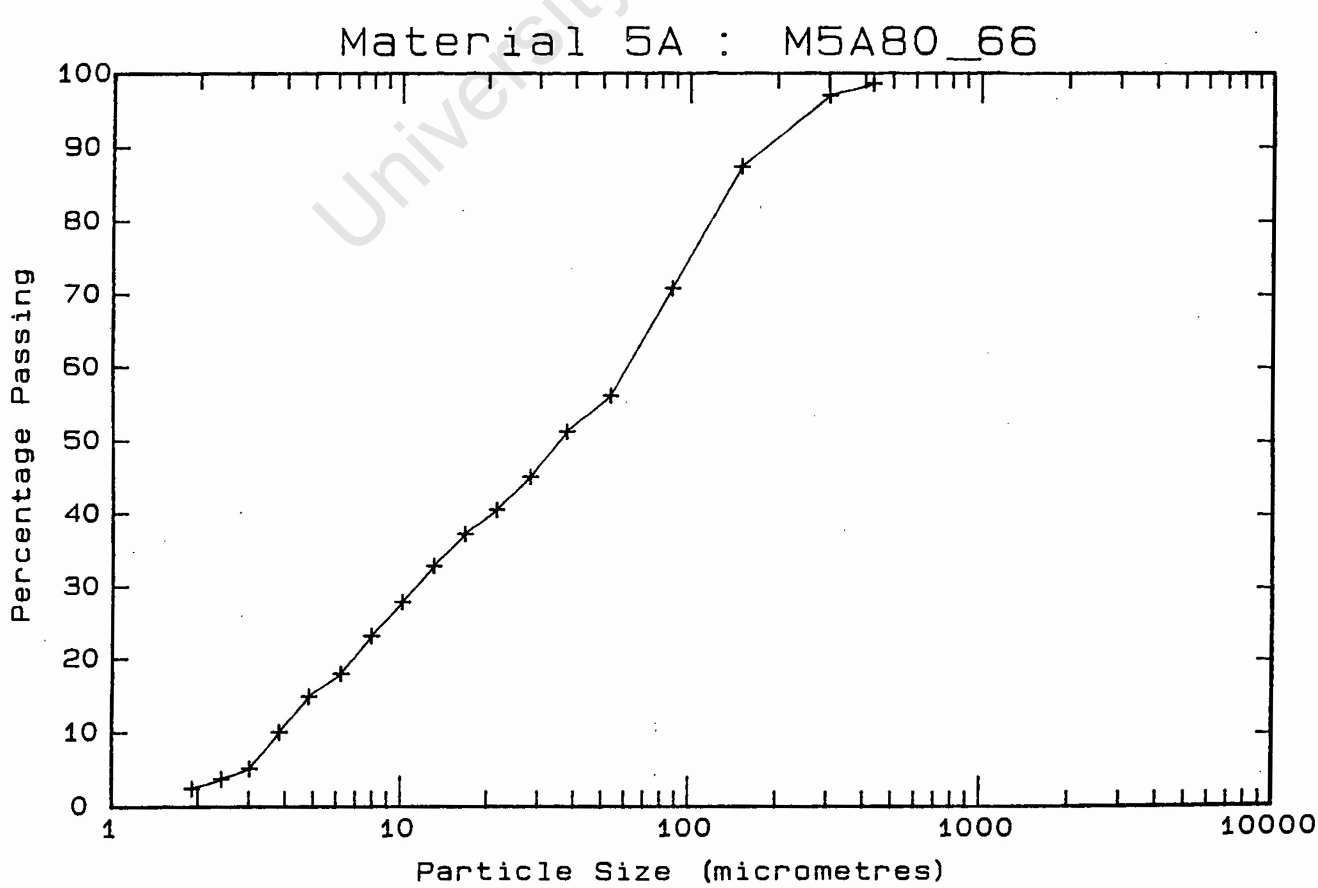
Size (µm)	% Passing	% Retained
425.0	98.5	1.5
300.0	96.9	1.6
150.0	87.3	9.6
87.2	70.8	16.5
53.5	56.1	14.7
37.6	51.2	4.9
28.1	45.0	6.2
21.5	40.5	4.5
16.7	37.2	3.3
13.0	32.8	4.4
10.1	27.8	5.0
7.9	23.1	4.7
6.2	17.9	5.2
4.8	14.8	3.1
3.8	10.0	4.8
3.0	5.1	4.9
2.4	3.7	1.4
1.9	2.4	1.3
Pan	- .1	2.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.14	Some sliding particles
.67	Some sliding particles
1.34	Appears homogeneous
2.02	Appears homogeneous
2.67	Appears homogeneous
3.32	Appears homogeneous
3.97	Appears homogeneous

* -150 µm Malvern Particle Size Analyser


Material 5A : M5A80H66
Pressure Gradient (kPa/m)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_66
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80D66

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.66
Solids Volumetric Concentration (%)	38.27
Solids Mass Concentration (%)	62.86
Mean Slurry Temperature (°C)	23.5
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.690	-11.945	24.0
3.672	-11.946	24.1
3.675	-11.974	24.1
3.684	-11.939	24.1
3.084	-13.087	24.1
3.082	-13.097	24.1
3.079	-13.064	24.1
2.480	-14.226	24.0
2.477	-14.208	24.0
2.485	-14.396	23.9
2.485	-14.354	23.9
1.867	-15.382	23.8
1.869	-14.857	23.7
1.867	-14.481	23.7
1.866	-15.239	23.6
1.868	-15.402	23.6
1.247	-15.290	23.4
1.247	-15.029	23.4
1.243	-15.387	23.3
1.240	-15.745	23.3
.626	-16.055	23.2
.622	-15.655	23.1
.613	-15.615	23.1
.610	-15.571	23.0
.604	-15.654	23.0
.152	-15.684	22.9
.138	-15.735	22.9
.127	-15.715	22.8
.108	-15.694	22.8
.094	-15.796	22.8

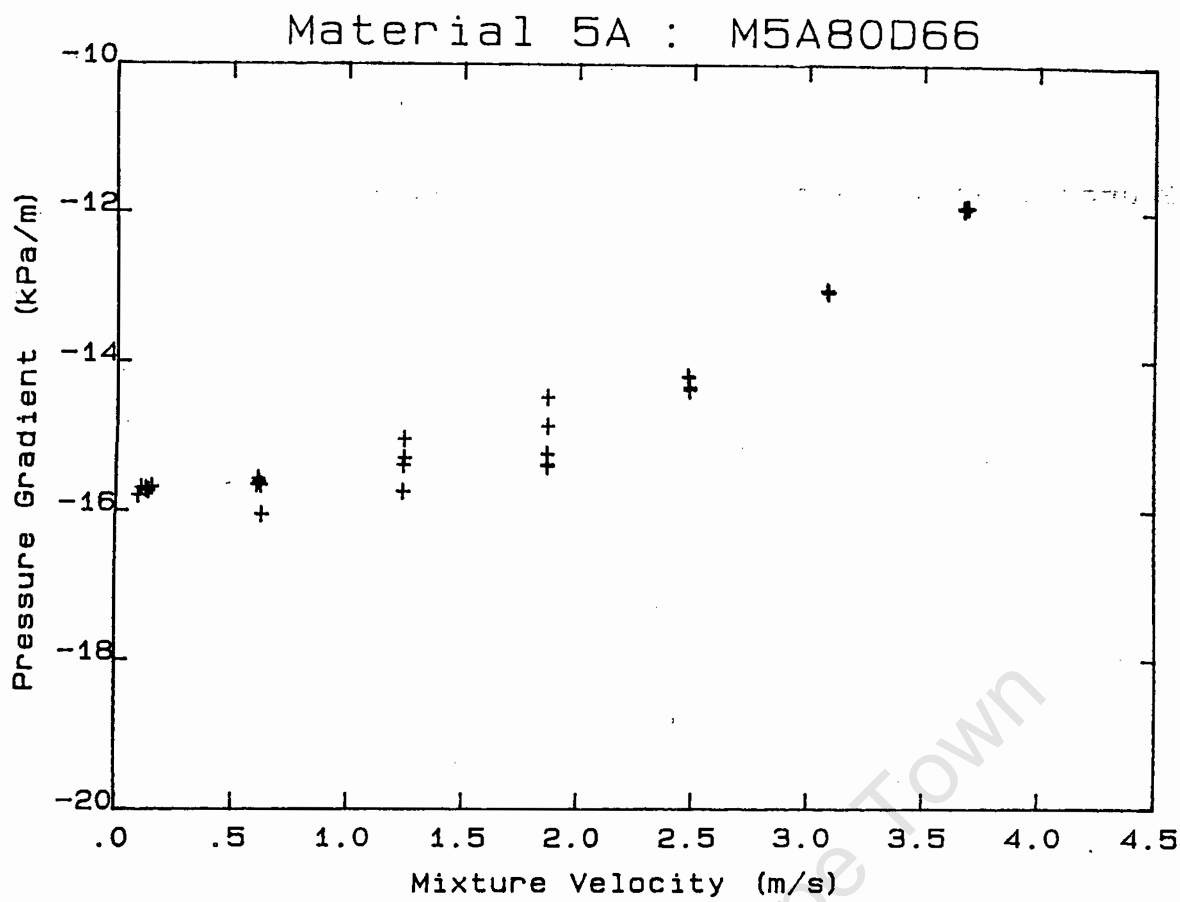
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	98.5	1.5
300.0	96.9	1.6
150.0	87.3	9.6
87.2	70.8	16.5
53.5	56.1	14.7
37.6	51.2	4.9
28.1	45.0	6.2
21.5	40.5	4.5
16.7	37.2	3.3
13.0	32.8	4.4
10.1	27.8	5.0
7.9	23.1	4.7
6.2	17.9	5.2
4.8	14.8	3.1
3.8	10.0	4.8
3.0	5.1	4.9
2.4	3.7	1.4
1.9	2.4	1.3
Pan	- .1	2.5

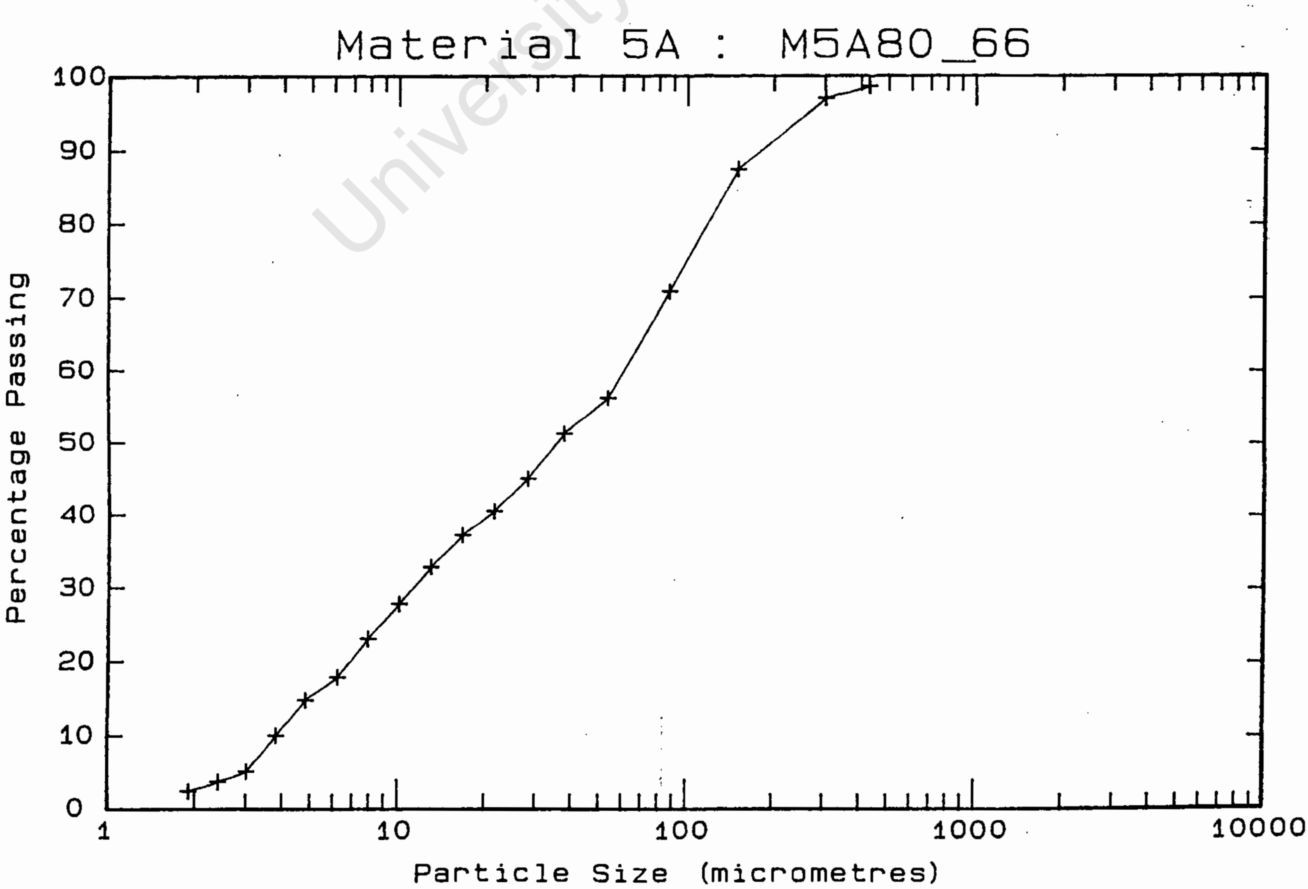
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -150 µm Malvern Particle Size Analyser



Material 5A : M5A80D66
Pressure Gradient (kPa/m)
-10
-12
-14
-16
-18
-20
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 5A : M5A80_66
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80U66

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.66
Solids Volumetric Concentration (%)	38.27
Solids Mass Concentration (%)	62.86
Mean Slurry Temperature (°C)	23.5
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.690	19.810	24.0
3.672	19.576	24.1
3.675	19.737	24.1
3.684	19.710	24.1
3.084	18.736	24.1
3.082	18.696	24.1
3.079	18.775	24.1
2.480	17.912	24.0
2.477	17.924	24.0
2.485	17.831	23.9
2.485	17.911	23.9
1.867	17.245	23.8
1.869	17.226	23.7
1.867	17.202	23.7
1.866	17.151	23.6
1.868	17.194	23.6
1.247	17.027	23.4
1.247	16.993	23.4
1.243	17.030	23.3
1.240	17.055	23.3
.626	16.914	23.2
.622	16.910	23.1
.613	16.920	23.1
.610	16.888	23.0
.604	16.898	23.0
.152	16.761	22.9
.138	16.783	22.9
.127	16.844	22.8
.108	16.827	22.8
.094	16.810	22.8

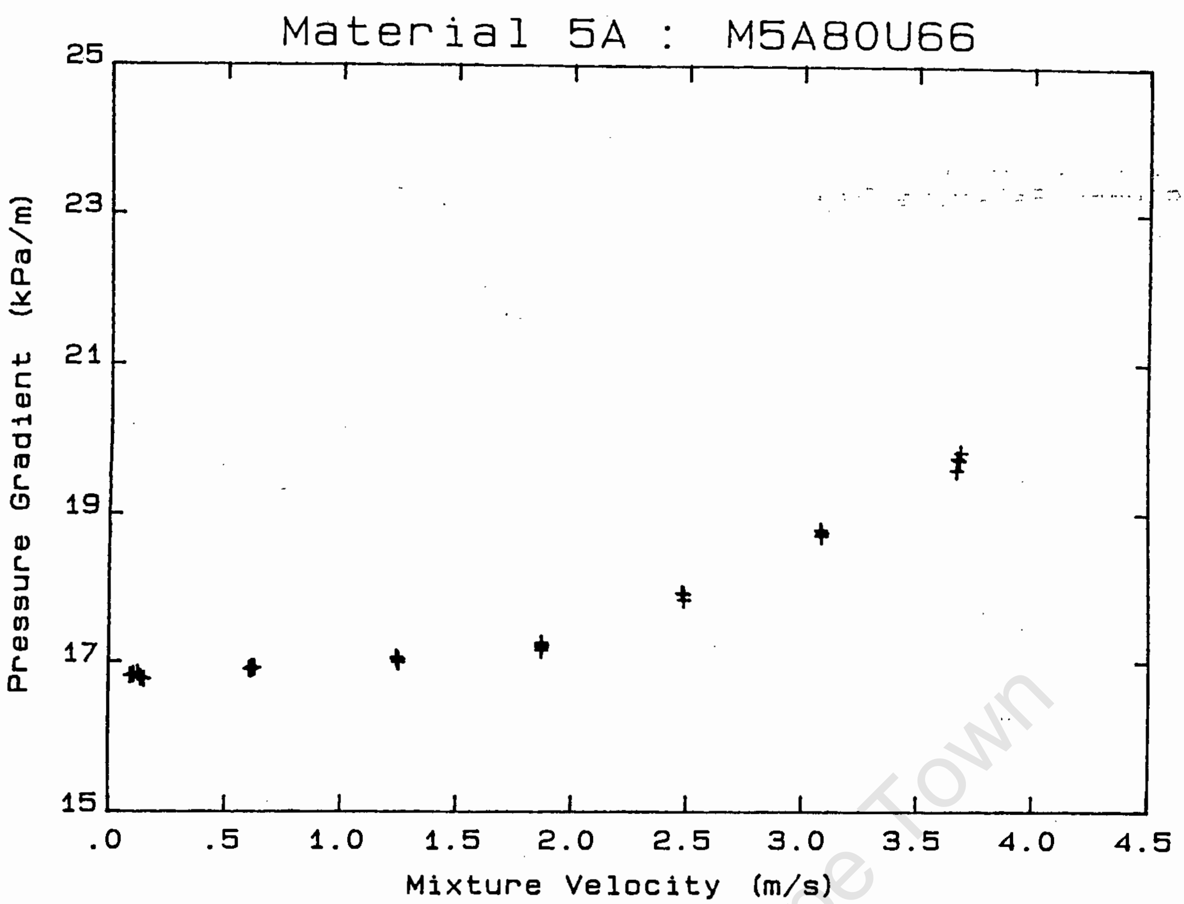
Particle Size Distribution
Sieve and Malvern Size Analysis *

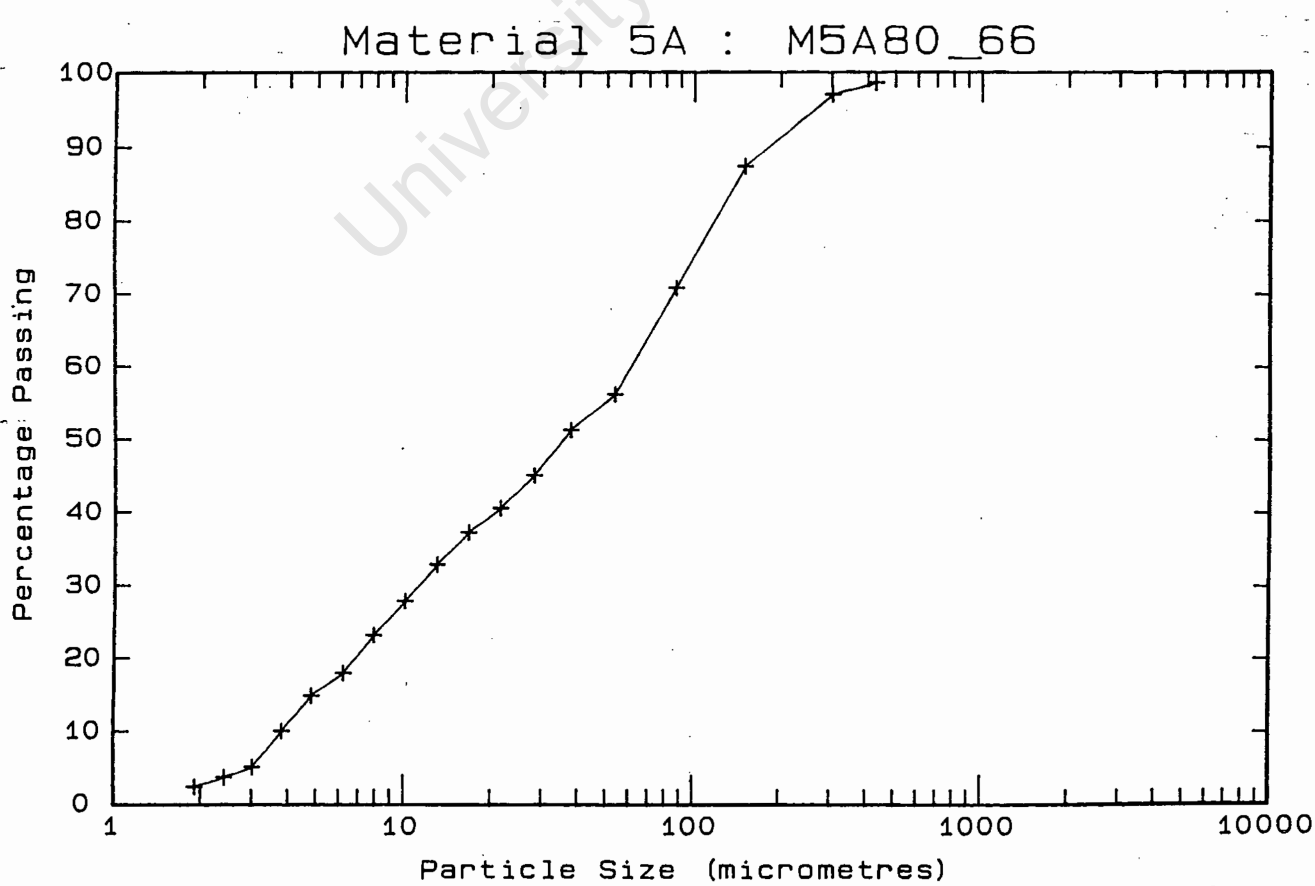
Size (µm)	% Passing	% Retained
425.0	98.5	1.5
300.0	96.9	1.6
150.0	87.3	9.6
87.2	70.8	16.5
53.5	56.1	14.7
37.6	51.2	4.9
28.1	45.0	6.2
21.5	40.5	4.5
16.7	37.2	3.3
13.0	32.8	4.4
10.1	27.8	5.0
7.9	23.1	4.7
6.2	17.9	5.2
4.8	14.8	3.1
3.8	10.0	4.8
3.0	5.1	4.9
2.4	3.7	1.4
1.9	2.4	1.3
Pan	- .1	2.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -150 µm Malvern Particle Size Analyser


Material 5A : M5A80U66
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_66
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80H72

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.72
Solids Volumetric Concentration (%)	41.50
Solids Mass Concentration (%)	65.95
Mean Slurry Temperature (°C)	24.7
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (μm)	132.0
Pipeline Slope	Vertical

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.086	4.960	24.7
4.099	3.977	24.9
4.084	4.369	25.0
3.699	3.628	25.1
3.699	3.485	25.2
3.696	3.565	25.2
3.693	3.631	25.2
3.067	2.421	25.2
3.057	2.211	25.2
3.070	2.375	25.2
2.447	1.997	25.2
2.450	1.853	25.1
2.445	2.278	25.1
2.448	1.792	25.0
1.859	2.173	24.9
1.864	1.461	24.9
1.862	2.469	24.8
1.256	2.626	24.6
1.256	.702	24.6
1.256	1.147	24.5
1.247	1.063	24.5
.640	1.057	24.3
.623	1.443	24.3
.600	1.287	24.2
.175	.936	24.1
.158	.895	24.0
.142	.999	24.0
.133	.845	24.0

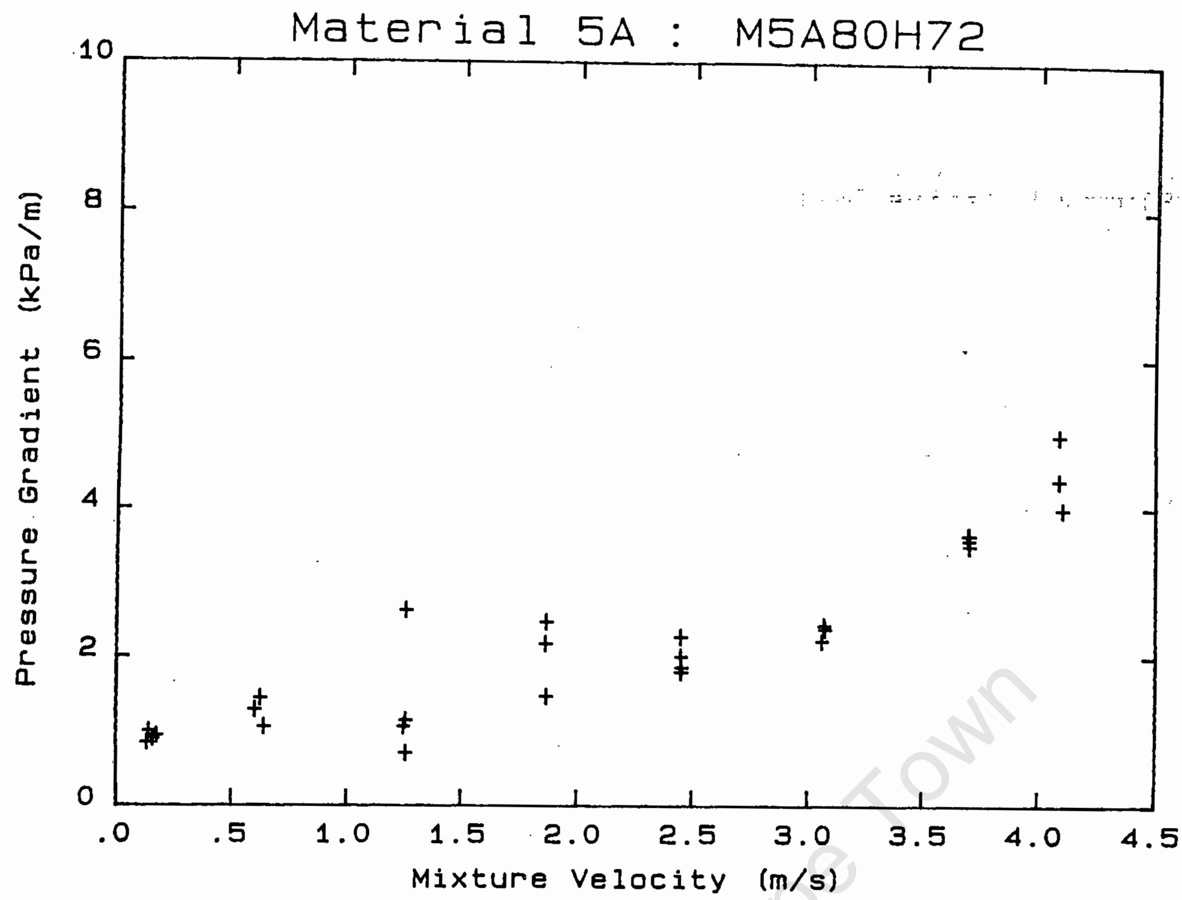
Particle Size Distribution
Sieve and Malvern Size Analysis *

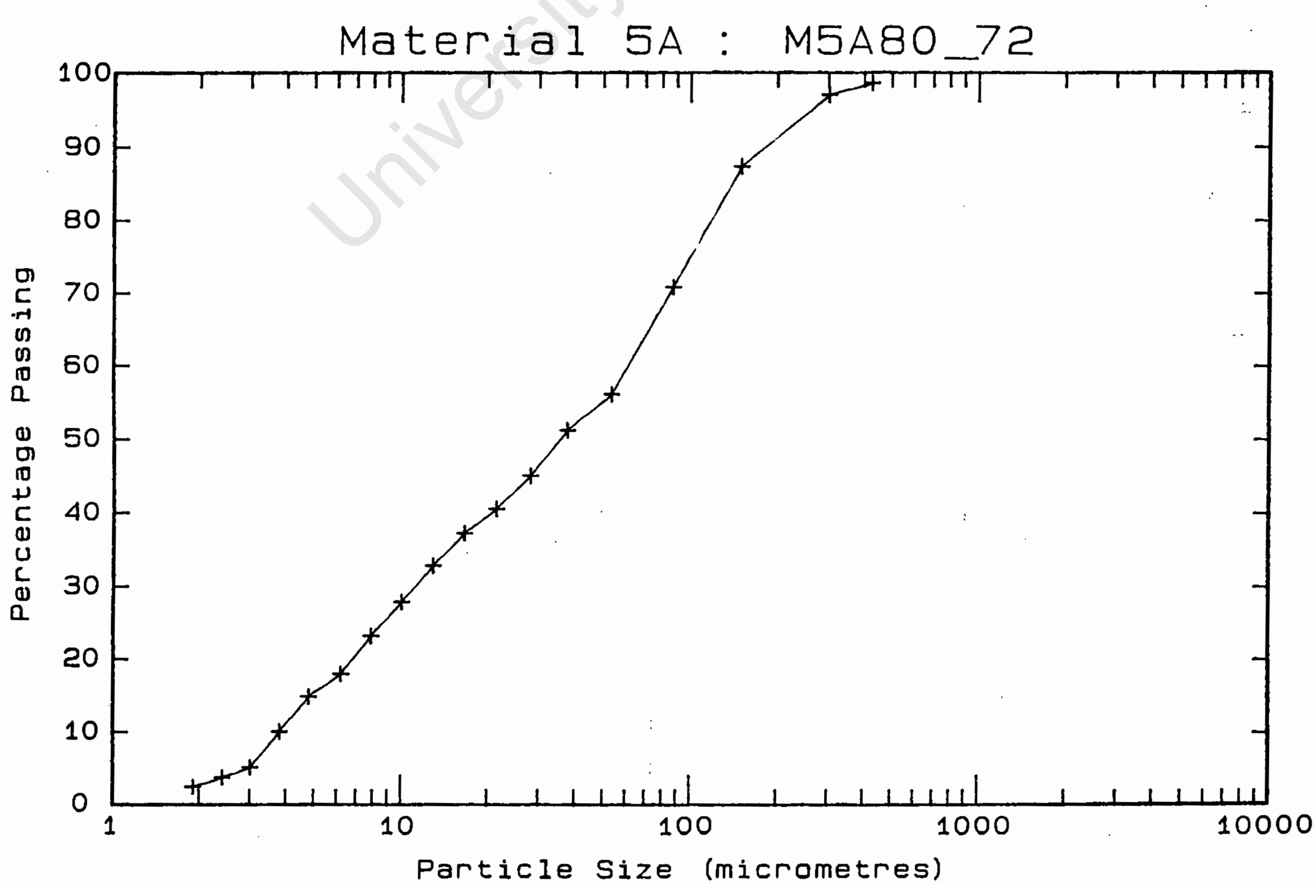
Size (μm)	% Passing	% Retained
425.0	98.5	1.5
300.0	96.9	1.6
150.0	87.3	9.6
87.2	70.8	16.5
53.5	56.1	14.7
37.6	51.2	4.9
28.1	45.0	6.2
21.5	40.5	4.5
16.7	37.2	3.3
13.0	32.8	4.4
10.1	27.8	5.0
7.9	23.1	4.7
6.2	17.9	5.2
4.8	14.8	3.1
3.8	10.0	4.8
3.0	5.1	4.9
2.4	3.7	1.4
1.9	2.4	1.3
Pan	- .1	2.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.15	Asymetric
.67	Asymetric
1.36	Appears homogeneous
2.01	Appears homogeneous
2.64	Appears homogeneous
3.30	Appears homogeneous
3.99	Appears homogeneous
4.41	Appears homogeneous

* -150 μm Malvern Particle Size Analyser


Material 5A : M5A80H72
Pressure Gradient (kPa/m)
Mixture Velocity (m/s)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Material 5A : M5A80_72
Percentage Passing
Particle Size (micrometres)
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000

DATA FILE : M5A80D72

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.72
Solids Volumetric Concentration (%)	41.50
Solids Mass Concentration (%)	65.95
Mean Slurry Temperature (°C)	24.7
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.086	-11.567	24.7
4.099	-12.088	24.9
4.084	-11.695	25.0
3.699	-11.889	25.1
3.699	-11.937	25.2
3.696	-11.863	25.2
3.693	-11.925	25.2
3.067	-13.451	25.2
3.057	-13.449	25.2
3.070	-13.502	25.2
2.447	-15.039	25.2
2.450	-14.444	25.1
2.445	-15.073	25.1
2.448	-14.777	25.0
1.859	-15.494	24.9
1.864	-15.090	24.9
1.862	-15.494	24.8
1.256	-15.419	24.6
1.256	-14.896	24.6
1.256	-15.416	24.5
1.247	-15.434	24.5
.640	-15.249	24.3
.623	-15.397	24.3
.600	-15.559	24.2
.175	-15.824	24.1
.158	-15.810	24.0
.142	-15.822	24.0
.133	-15.810	24.0

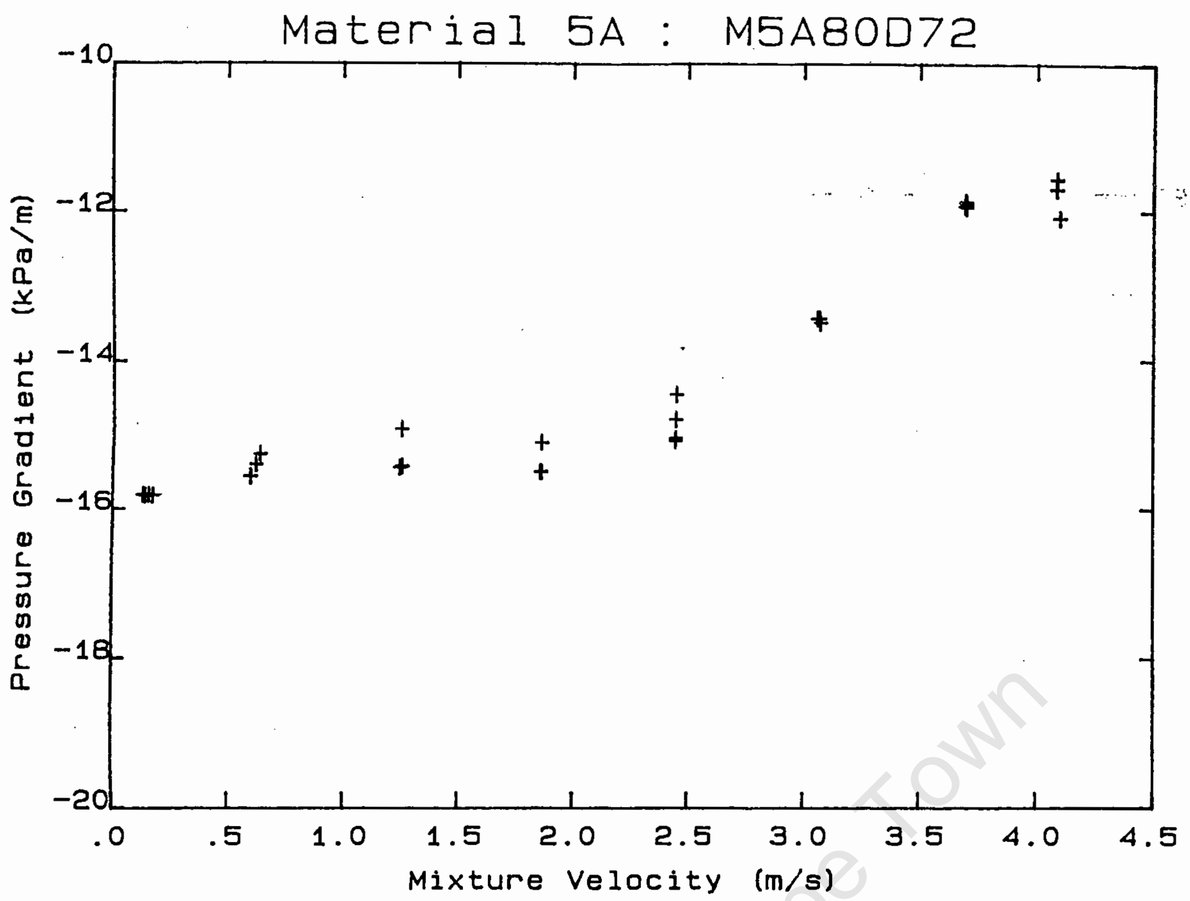
Particle Size Distribution
Sieve and Malvern Size Analysis *

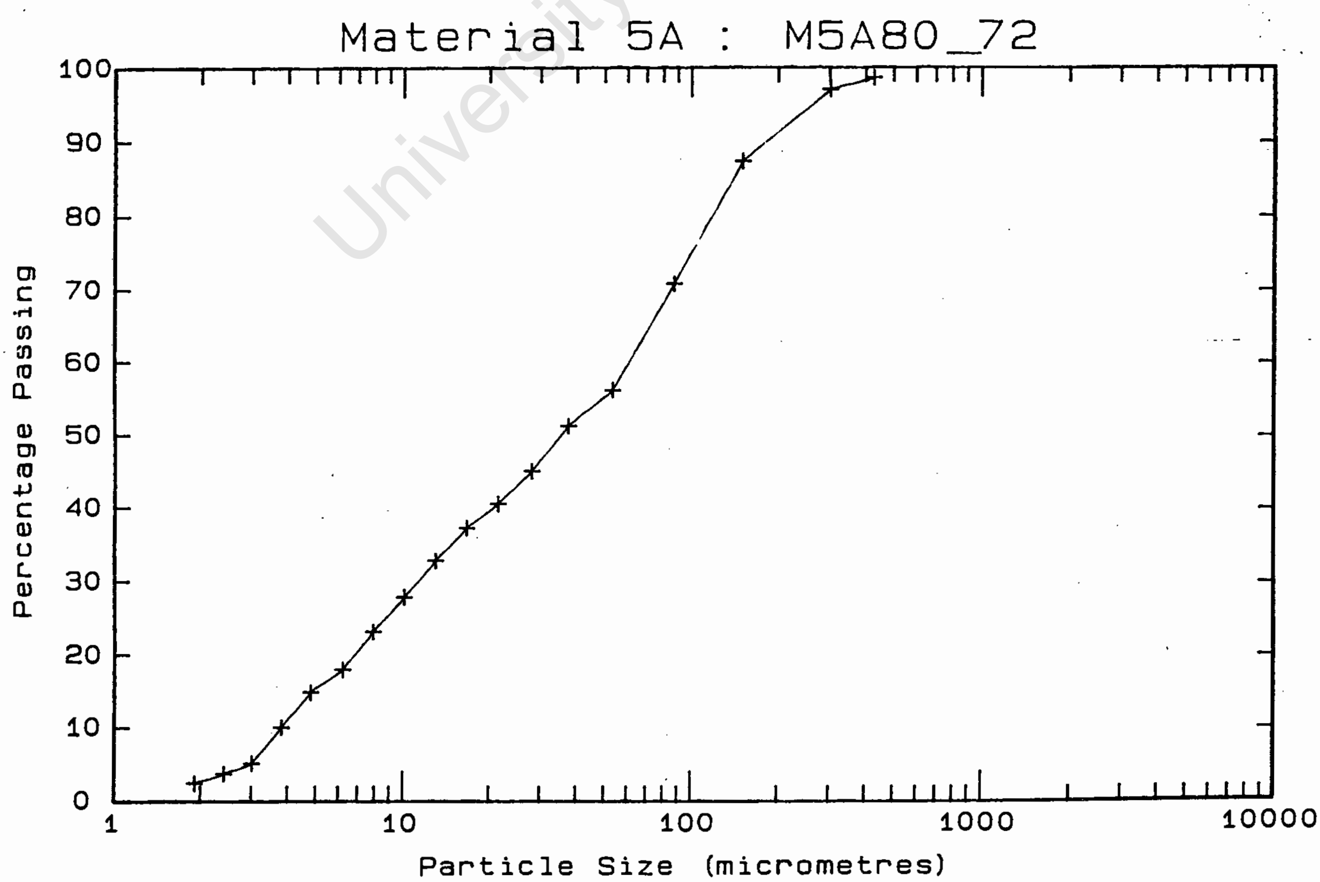
Size (µm)	% Passing	% Retained
425.0	98.5	1.5
300.0	96.9	1.6
150.0	87.3	9.6
87.2	70.8	16.5
53.5	56.1	14.7
37.6	51.2	4.9
28.1	45.0	6.2
21.5	40.5	4.5
16.7	37.2	3.3
13.0	32.8	4.4
10.1	27.8	5.0
7.9	23.1	4.7
6.2	17.9	5.2
4.8	14.8	3.1
3.8	10.0	4.8
3.0	5.1	4.9
2.4	3.7	1.4
1.9	2.4	1.3
Pan	- .1	2.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -150 µm Malvern Particle Size Analyser


Material 5A : M5A80D72
Pressure Gradient (kPa/m)
-10
-12
-14
-16
-18
-20
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_72
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80U72

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.72
Solids Volumetric Concentration (%)	41.50
Solids Mass Concentration (%)	65.95
Mean Slurry Temperature (°C)	24.7
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
4.086	9.810	24.7
4.099	21.173	24.9
4.084	21.359	25.0
3.699	20.427	25.1
3.699	20.351	25.2
3.696	20.475	25.2
3.693	20.442	25.2
3.067	19.260	25.2
3.057	19.133	25.2
3.070	19.197	25.2
2.447	18.366	25.2
2.450	18.436	25.1
2.445	18.418	25.1
2.448	18.363	25.0
1.859	18.147	24.9
1.864	18.156	24.9
1.862	18.173	24.8
1.256	18.041	24.6
1.256	18.024	24.6
1.256	18.025	24.5
1.247	18.073	24.5
.640	17.845	24.3
.623	17.882	24.3
.600	17.881	24.2
.175	17.715	24.1
.158	17.744	24.0
.142	17.756	24.0
.133	17.770	24.0

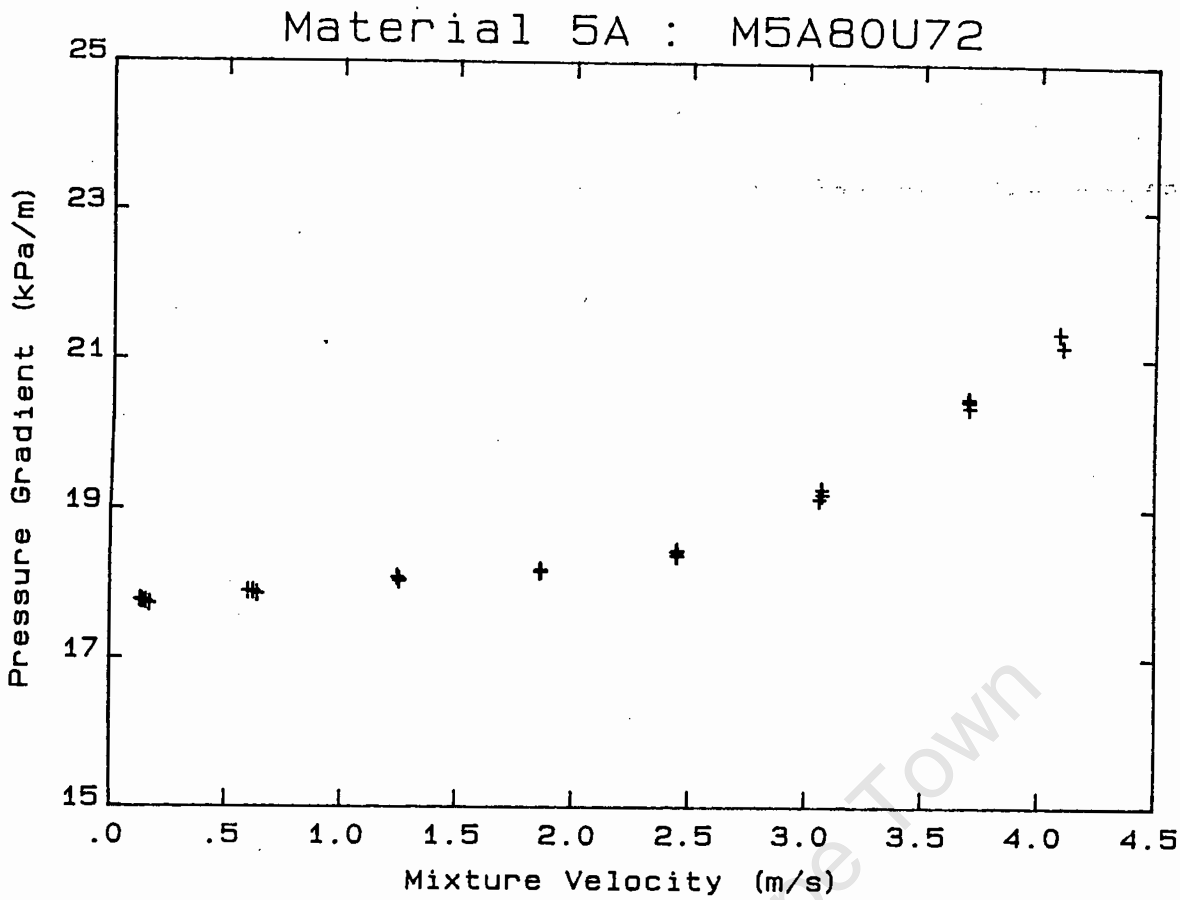
Particle Size Distribution
Sieve and Malvern Size Analysis *

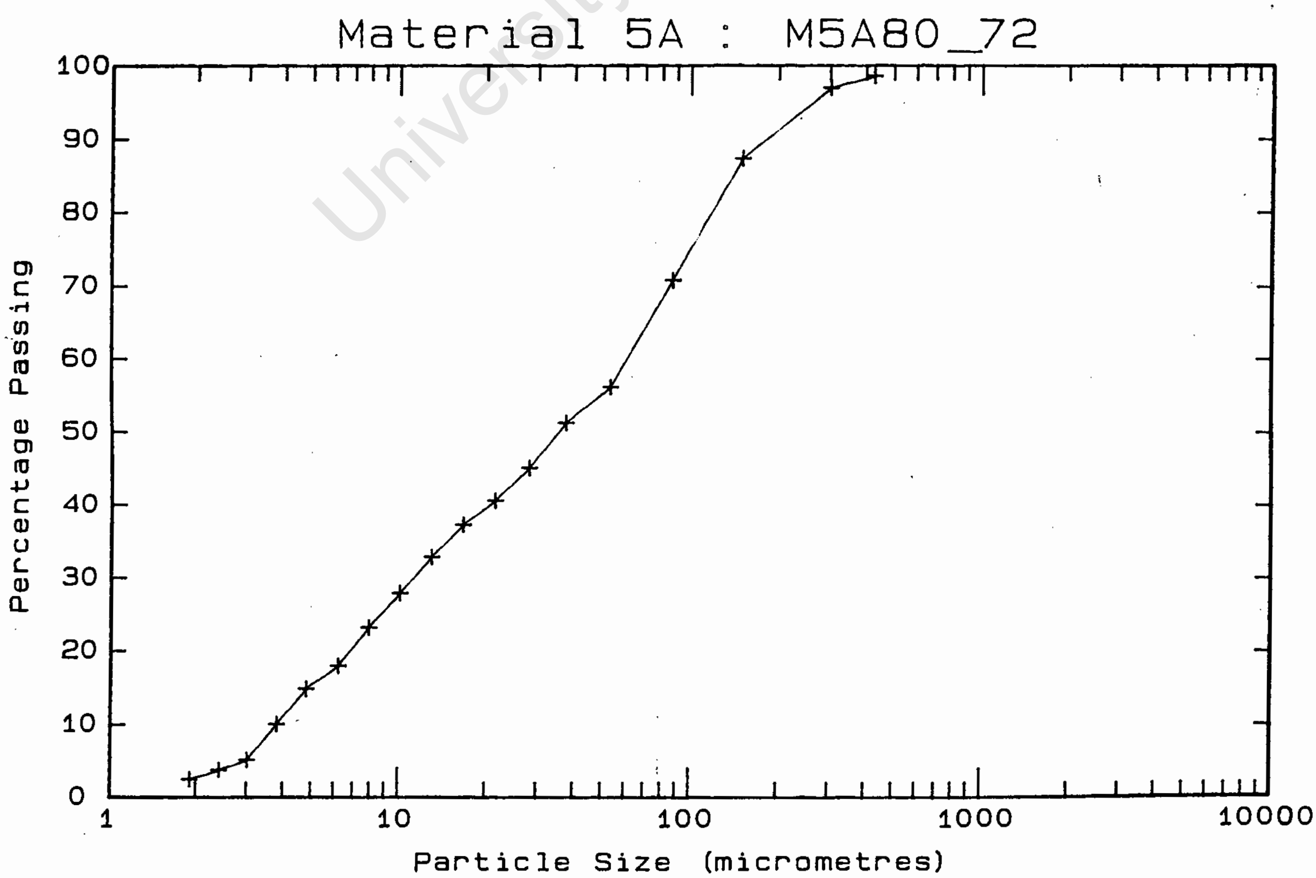
Size (µm)	% Passing	% Retained
425.0	98.5	1.5
300.0	96.9	1.6
150.0	87.3	9.6
87.2	70.8	16.5
53.5	56.1	14.7
37.6	51.2	4.9
28.1	45.0	6.2
21.5	40.5	4.5
16.7	37.2	3.3
13.0	32.8	4.4
10.1	27.8	5.0
7.9	23.1	4.7
6.2	17.9	5.2
4.8	14.8	3.1
3.8	10.0	4.8
3.0	5.1	4.9
2.4	3.7	1.4
1.9	2.4	1.3
Pan	- .1	2.5

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -150 µm Malvern Particle Size Analyser


Material 5A : M5A80U72
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_72
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80H75

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.75
Solids Volumetric Concentration (%)	43.58
Solids Mass Concentration (%)	67.84
Mean Slurry Temperature (°C)	25.0
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.653	3.673	24.9
3.621	3.179	25.0
3.688	3.645	25.1
3.604	3.326	25.2
3.068	2.714	25.4
3.066	2.889	25.4
3.068	2.884	28.4
3.066	2.847	25.4
2.475	2.519	25.3
2.483	2.435	25.3
2.488	2.124	25.2
2.482	2.544	25.2
1.837	2.189	25.1
1.838	1.965	25.0
1.850	1.498	25.0
1.240	1.518	24.8
1.274	1.551	24.8
1.261	2.115	24.7
1.253	2.170	24.7
.616	1.699	24.5
.601	1.529	24.5
.595	1.824	24.4
.057	1.406	24.3
.055	1.407	24.2
.046	1.396	24.2
.043	1.305	24.2
.040	1.285	24.2
.030	1.292	24.2

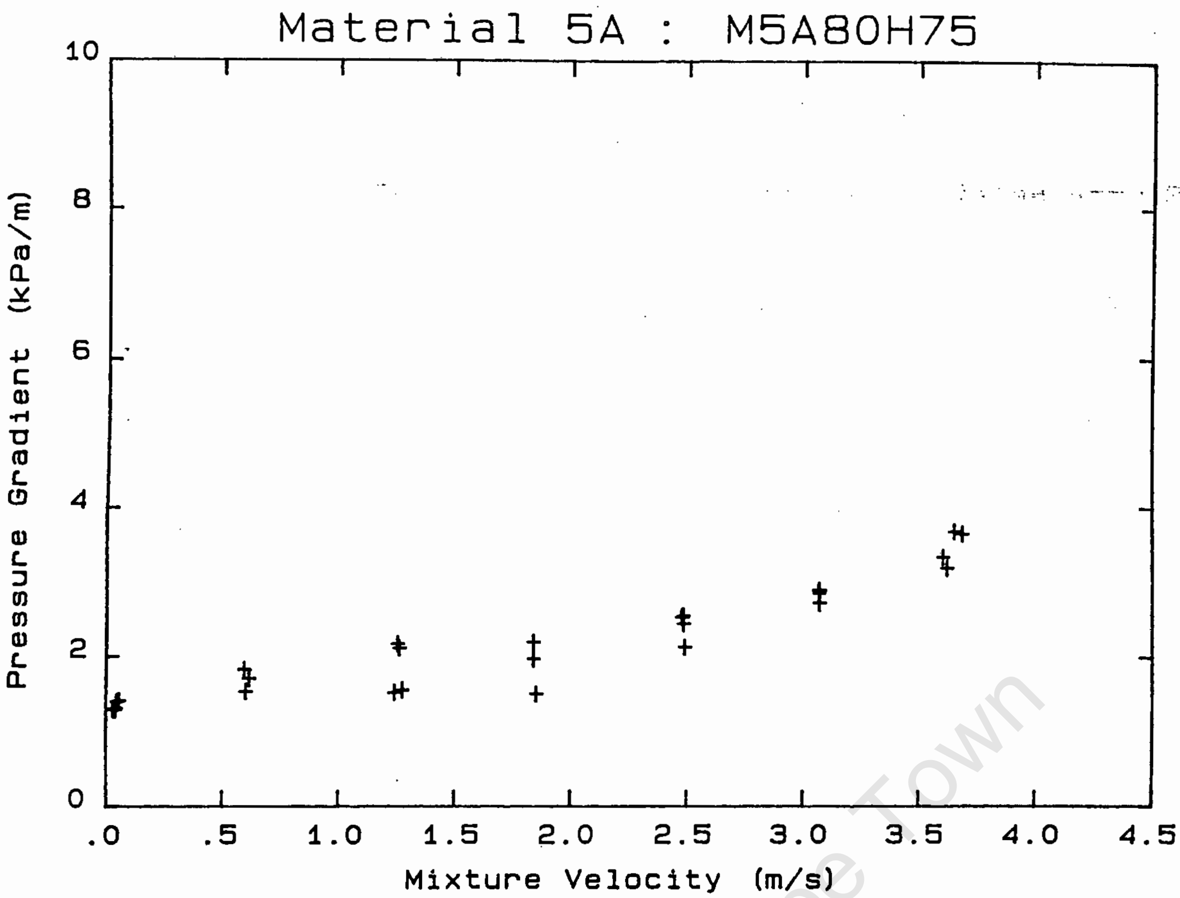
Particle Size Distribution
Sieve and Malvern Size Analysis *

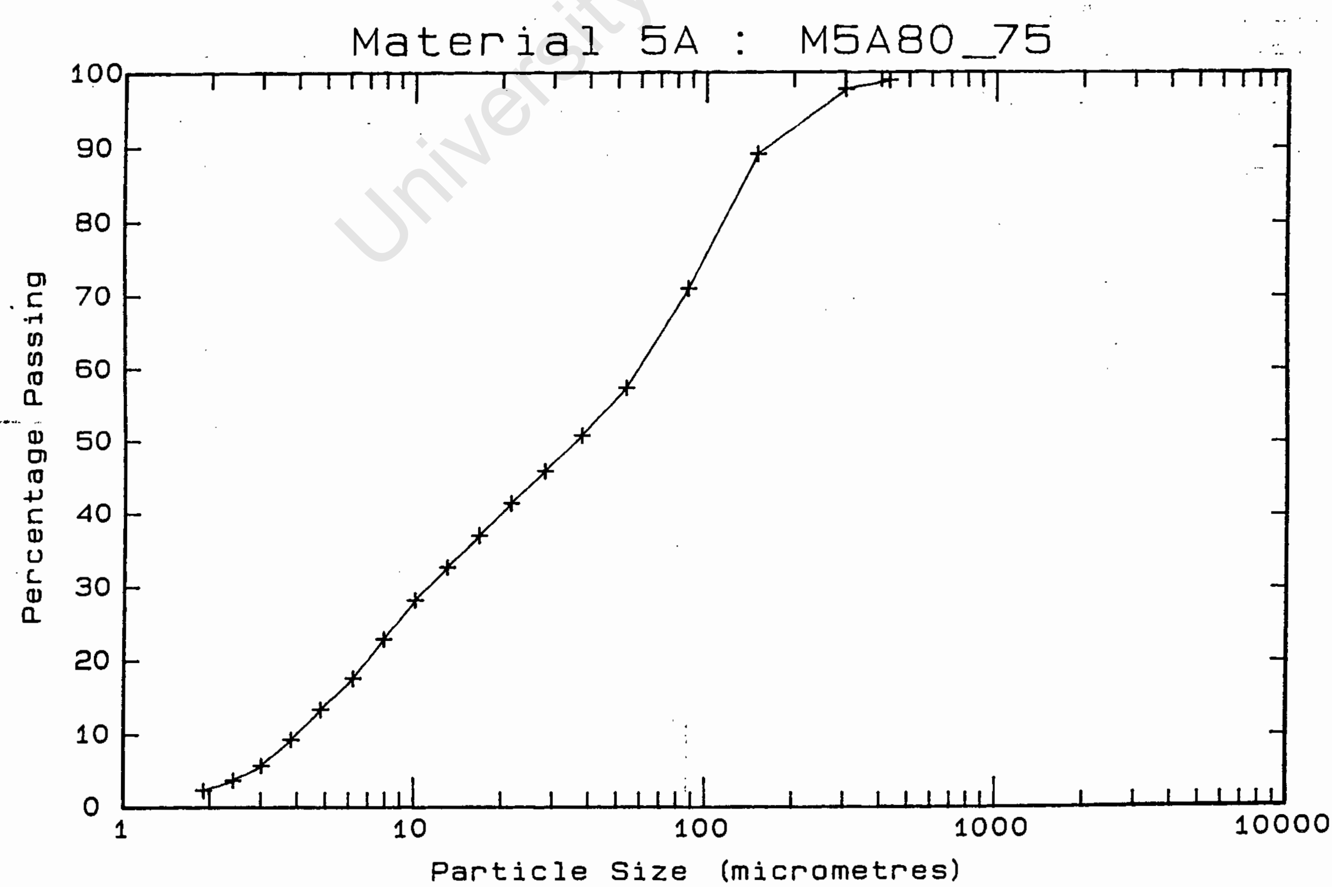
Size (µm)	% Passing	% Retained
425.0	98.8	1.2
300.0	97.6	1.2
150.0	89.0	8.6
87.2	70.9	18.1
53.5	57.3	13.6
37.6	50.7	6.6
28.1	45.8	4.9
21.5	41.4	4.4
16.7	37.0	4.4
13.0	32.7	4.3
10.1	28.2	4.5
7.9	22.9	5.3
6.2	17.6	5.3
4.8	13.4	4.2
3.8	9.3	4.1
3.0	5.7	3.6
2.4	3.7	2.0
1.9	2.3	1.4
Pan	.0	2.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.05	Asymetric
.65	Asymetric
1.35	Appears homogeneous
1.98	Appears homogeneous
2.67	Appears homogeneous
3.31	Appears homogeneous
3.91	Appears homogeneous

* -150 µm Malvern Particle Size Analyser


Material 5A : M5A80H75
Pressure Gradient (kPa/m)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_75
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80D75

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.75
Solids Volumetric Concentration (%)	43.58
Solids Mass Concentration (%)	67.84
Mean Slurry Temperature (°C)	25.0
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.653	-12.253	24.9
3.621	-12.206	25.0
3.688	-12.130	25.1
3.604	-12.413	25.2
3.068	-13.894	25.4
3.066	-13.888	25.4
3.068	-14.008	28.4
3.066	-13.994	25.4
2.475	-14.305	25.3
2.483	-14.327	25.3
2.488	-14.226	25.2
2.482	-14.396	25.2
1.837	-14.655	25.1
1.838	-14.620	25.0
1.850	-14.626	25.0
1.240	-14.926	24.8
1.274	-15.153	24.8
1.261	-15.009	24.7
1.253	-15.409	24.7
.616	-15.436	24.5
.601	-15.263	24.5
.595	-15.415	24.4
.057	-15.636	24.3
.055	-15.632	24.2
.046	-15.671	24.2
.043	-15.682	24.2
.040	-15.678	24.2
.030	-15.726	24.2

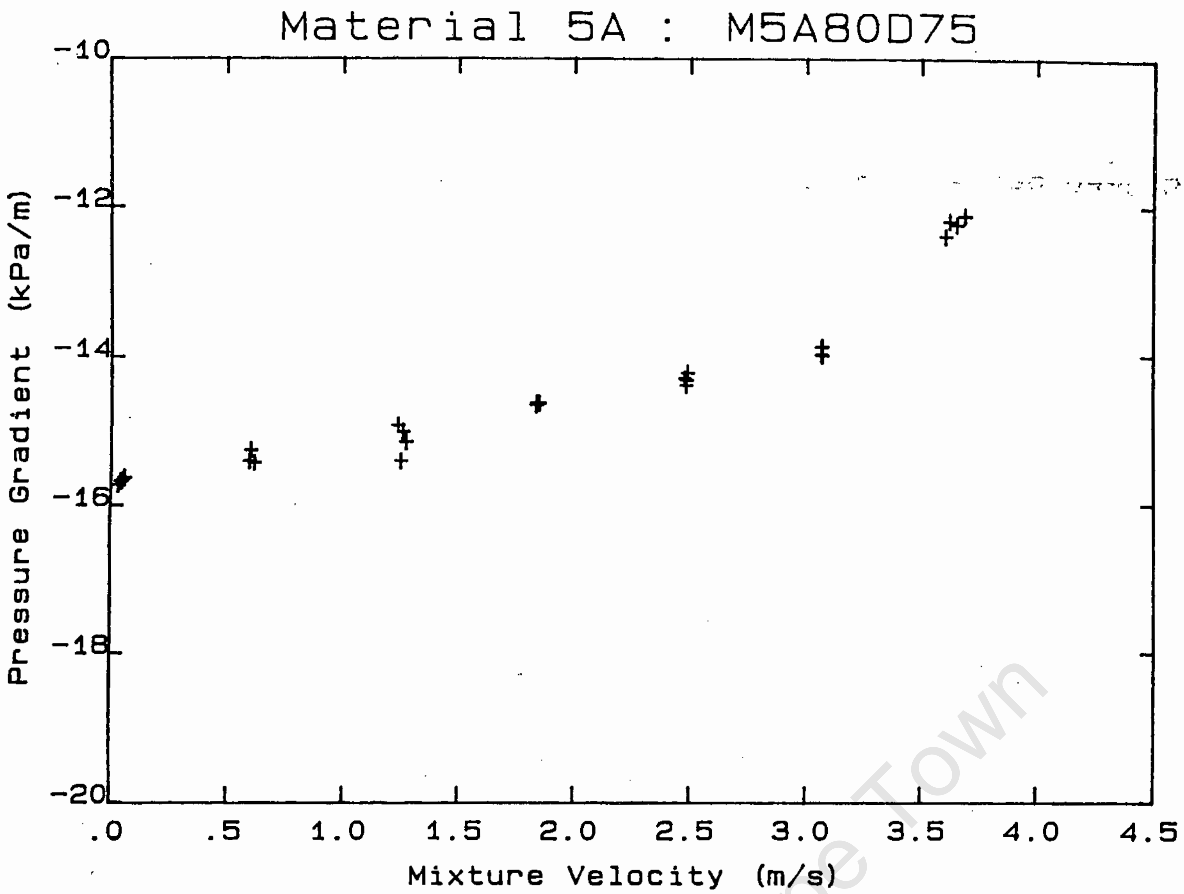
Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	98.8	1.2
300.0	97.6	1.2
150.0	89.0	8.6
87.2	70.9	18.1
53.5	57.3	13.6
37.6	50.7	6.6
28.1	45.8	4.9
21.5	41.4	4.4
16.7	37.0	4.4
13.0	32.7	4.3
10.1	28.2	4.5
7.9	22.9	5.3
6.2	17.6	5.3
4.8	13.4	4.2
3.8	9.3	4.1
3.0	5.7	3.6
2.4	3.7	2.0
1.9	2.3	1.4
Pan	.0	2.3

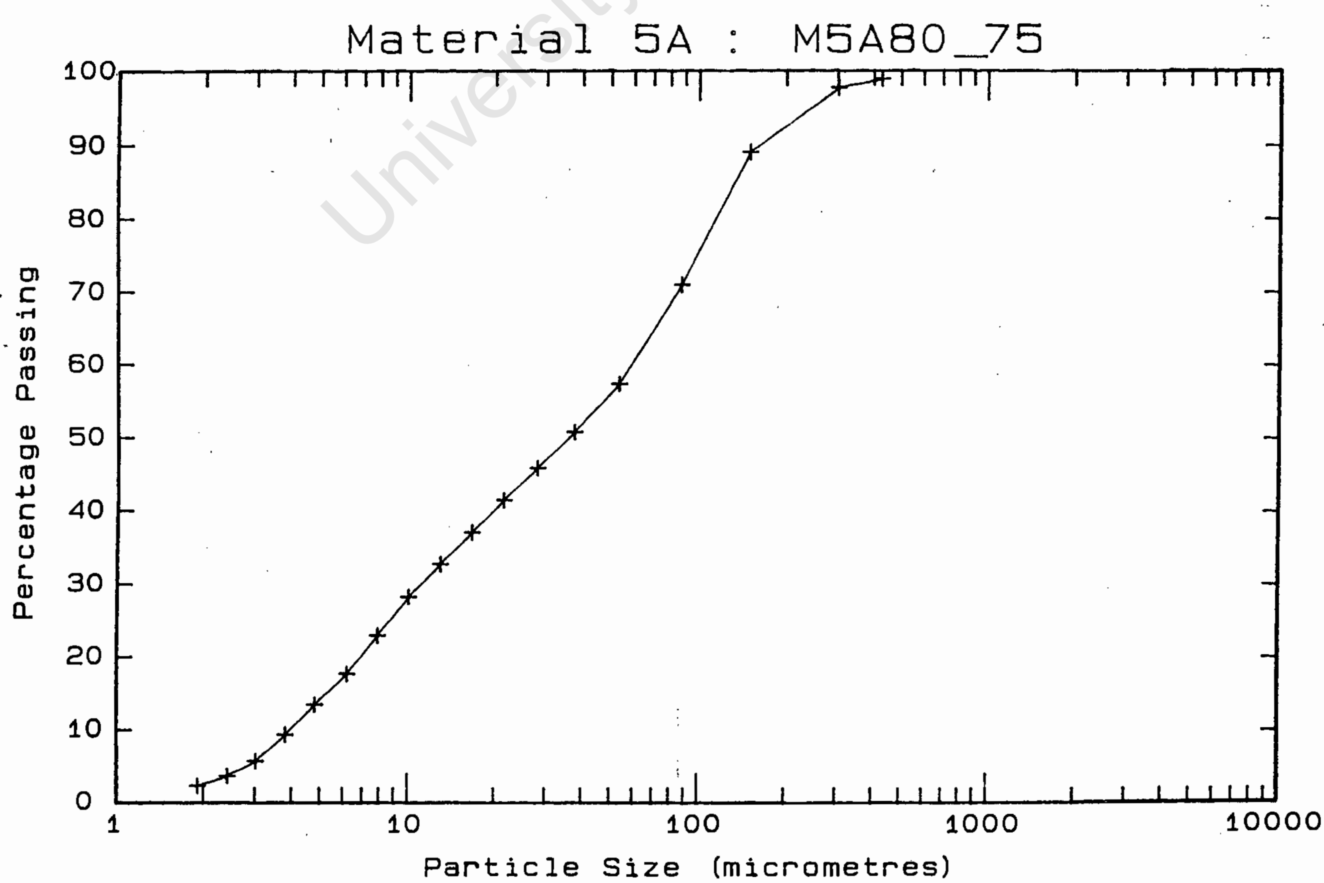
OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -150 µm Malvern Particle Size Analyser



Material 5A : M5A80D75
Pressure Gradient (kPa/m)
-10
-12
-14
-16
-18
-20
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)



Material 5A : M5A80_75
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80U75

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.75
Solids Volumetric Concentration (%)	43.58
Solids Mass Concentration (%)	67.84
Mean Slurry Temperature (°C)	25.0
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.653	20.423	24.9
3.621	20.695	25.0
3.688	21.202	25.1
3.604	20.283	25.2
3.068	19.658	25.4
3.066	19.467	25.4
3.068	19.554	28.4
3.066	19.502	25.4
2.475	19.310	25.3
2.483	19.293	25.3
2.488	19.212	25.2
2.482	19.332	25.2
1.837	19.069	25.1
1.838	19.063	25.0
1.850	19.088	25.0
1.240	18.949	24.8
1.274	18.953	24.8
1.261	18.928	24.7
1.253	18.905	24.7
.616	18.700	24.5
.601	18.698	24.5
.595	18.710	24.4
.057	18.424	24.3
.055	18.388	24.2
.046	18.373	24.2
.043	18.378	24.2
.040	18.427	24.2
.030	18.426	24.2

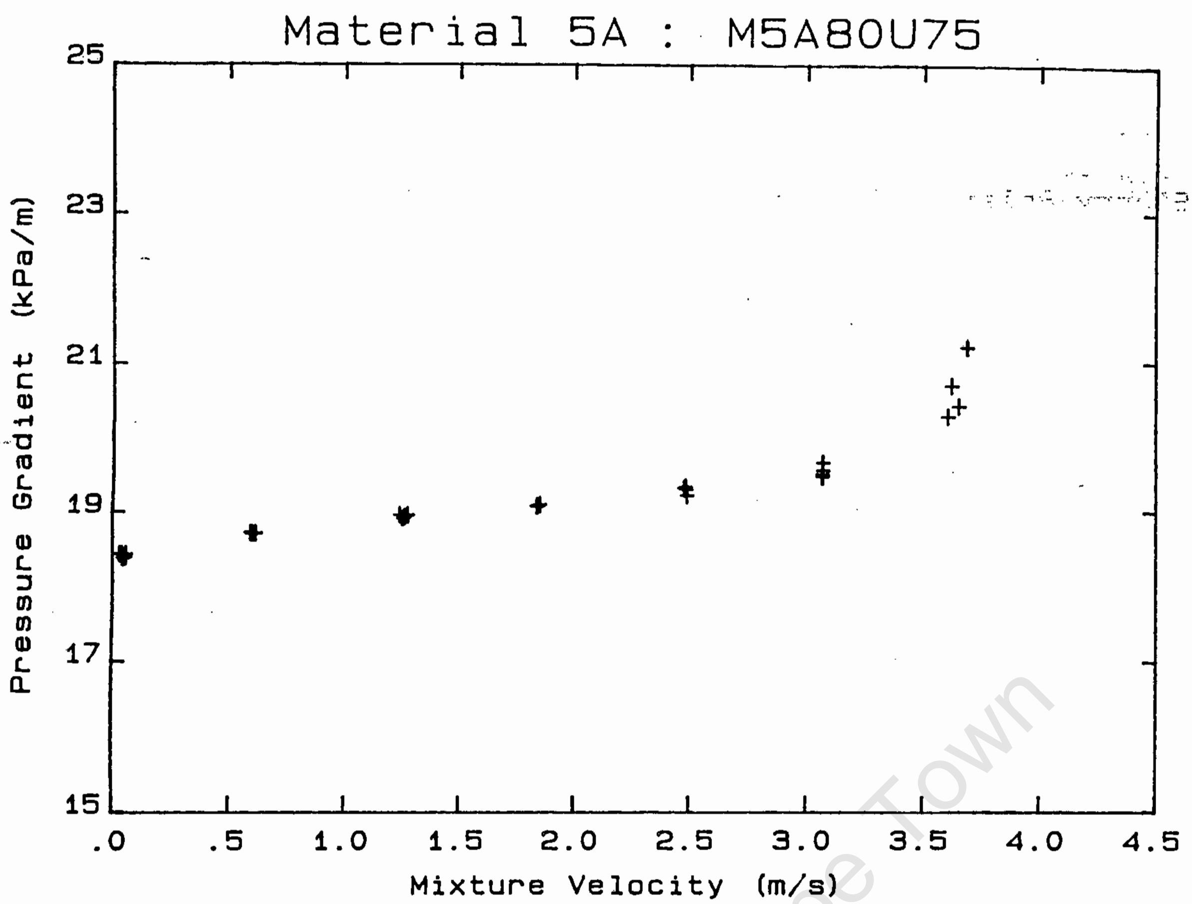
Particle Size Distribution
Sieve and Malvern Size Analysis *

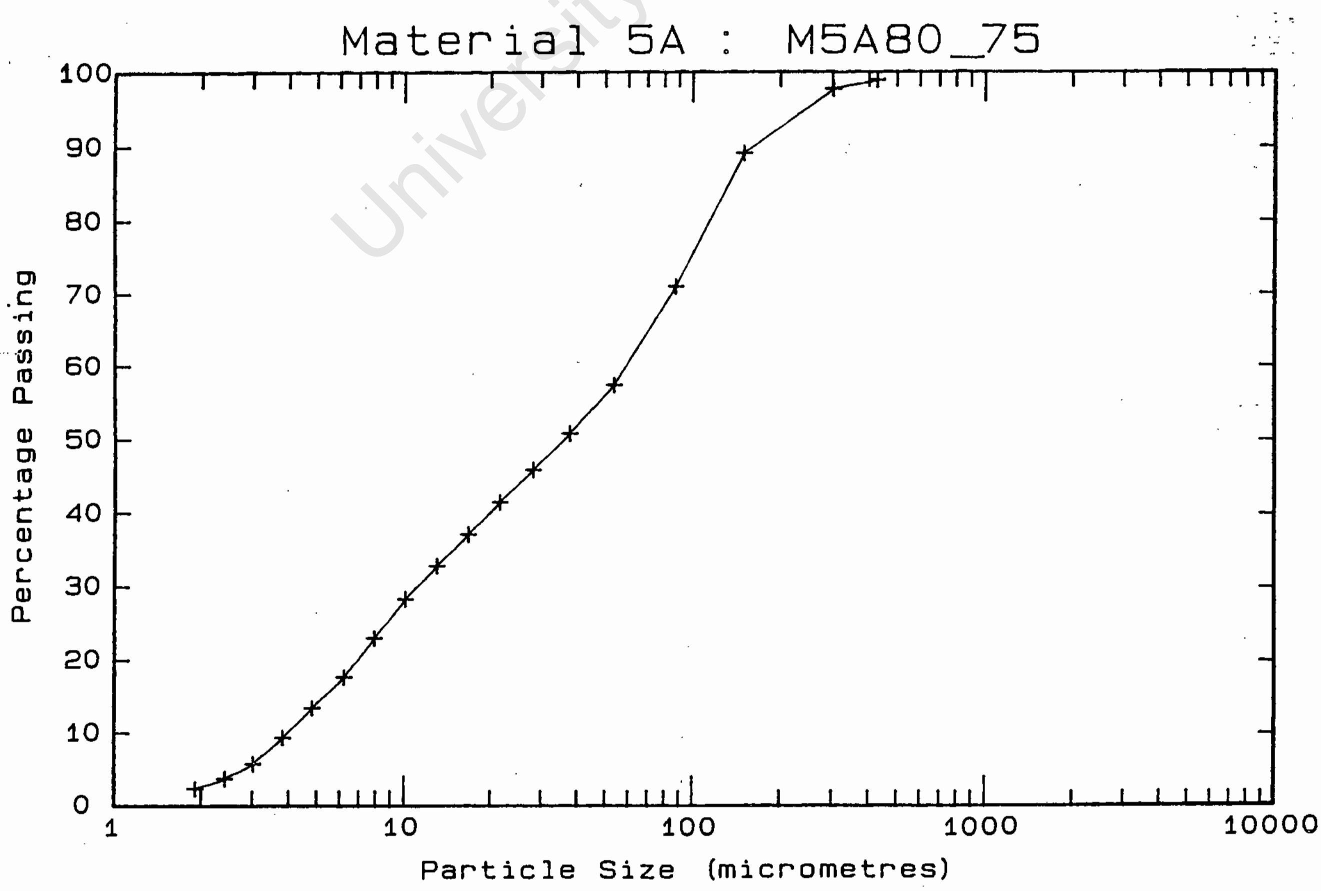
Size (µm)	% Passing	% Retained
425.0	98.8	1.2
300.0	97.6	1.2
150.0	89.0	8.6
87.2	70.9	18.1
53.5	57.3	13.6
37.6	50.7	6.6
28.1	45.8	4.9
21.5	41.4	4.4
16.7	37.0	4.4
13.0	32.7	4.3
10.1	28.2	4.5
7.9	22.9	5.3
6.2	17.6	5.3
4.8	13.4	4.2
3.8	9.3	4.1
3.0	5.7	3.6
2.4	3.7	2.0
1.9	2.3	1.4
Pan	.0	2.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* −150 µm Malvern Particle Size Analyser


Material 5A : M5A80U75
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_75
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80H77

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.77
Solids Volumetric Concentration (%)	44.51
Solids Mass Concentration (%)	68.65
Mean Slurry Temperature (°C)	25.6
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.583	3.767	25.6
3.573	3.861	25.8
3.637	3.639	25.9
3.637	3.568	26.0
3.063	3.415	26.3
3.076	3.383	26.3
3.065	3.413	26.3
2.468	2.991	26.3
2.480	3.084	26.2
2.473	3.043	26.2
1.862	2.654	25.9
1.864	2.702	25.9
1.864	2.682	25.8
1.866	2.785	25.8
1.240	2.434	25.6
1.220	2.460	25.5
1.217	2.316	25.5
1.187	2.529	25.4
.614	2.271	25.2
.597	2.194	25.2
.590	2.124	25.1
.570	2.175	25.0
.097	1.919	24.9
.092	2.288	24.9
.090	1.961	24.9
.083	2.111	24.9

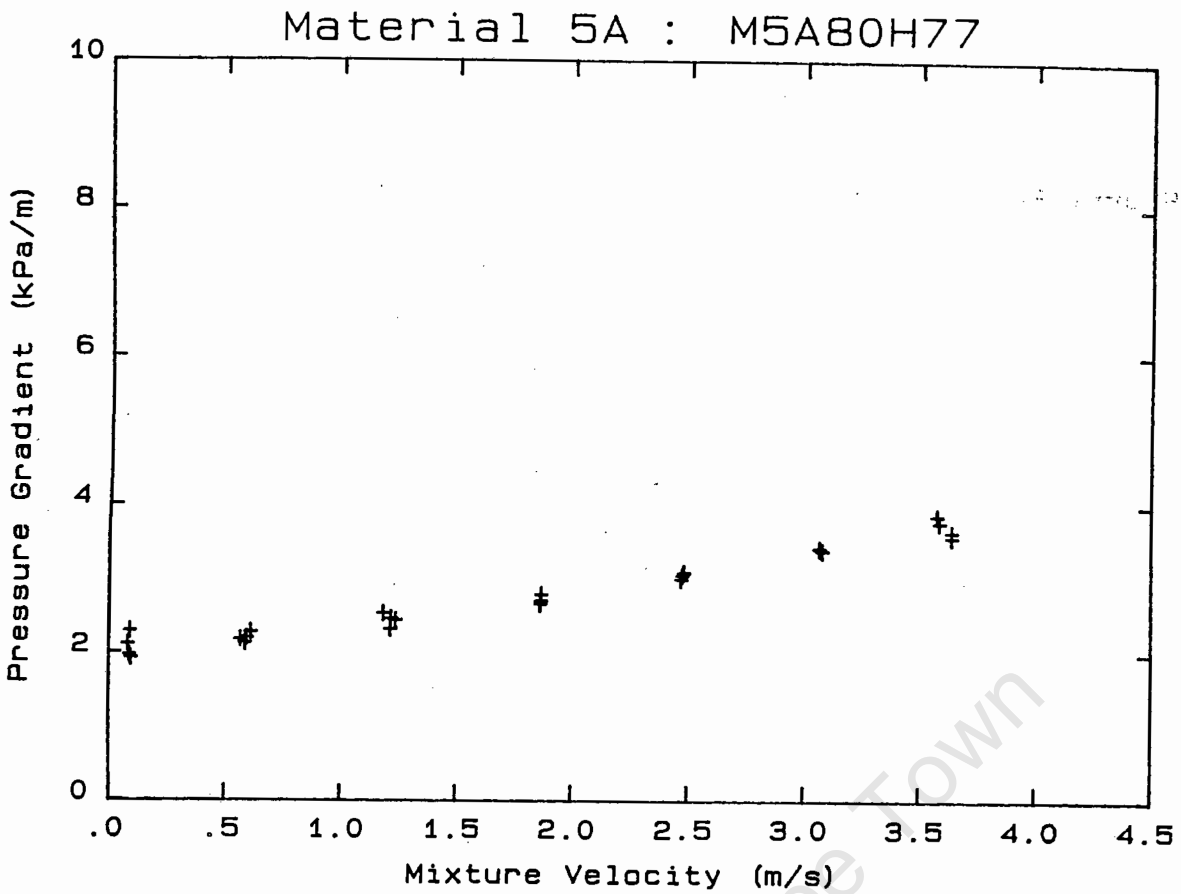
Particle Size Distribution
Sieve and Malvern Size Analysis *

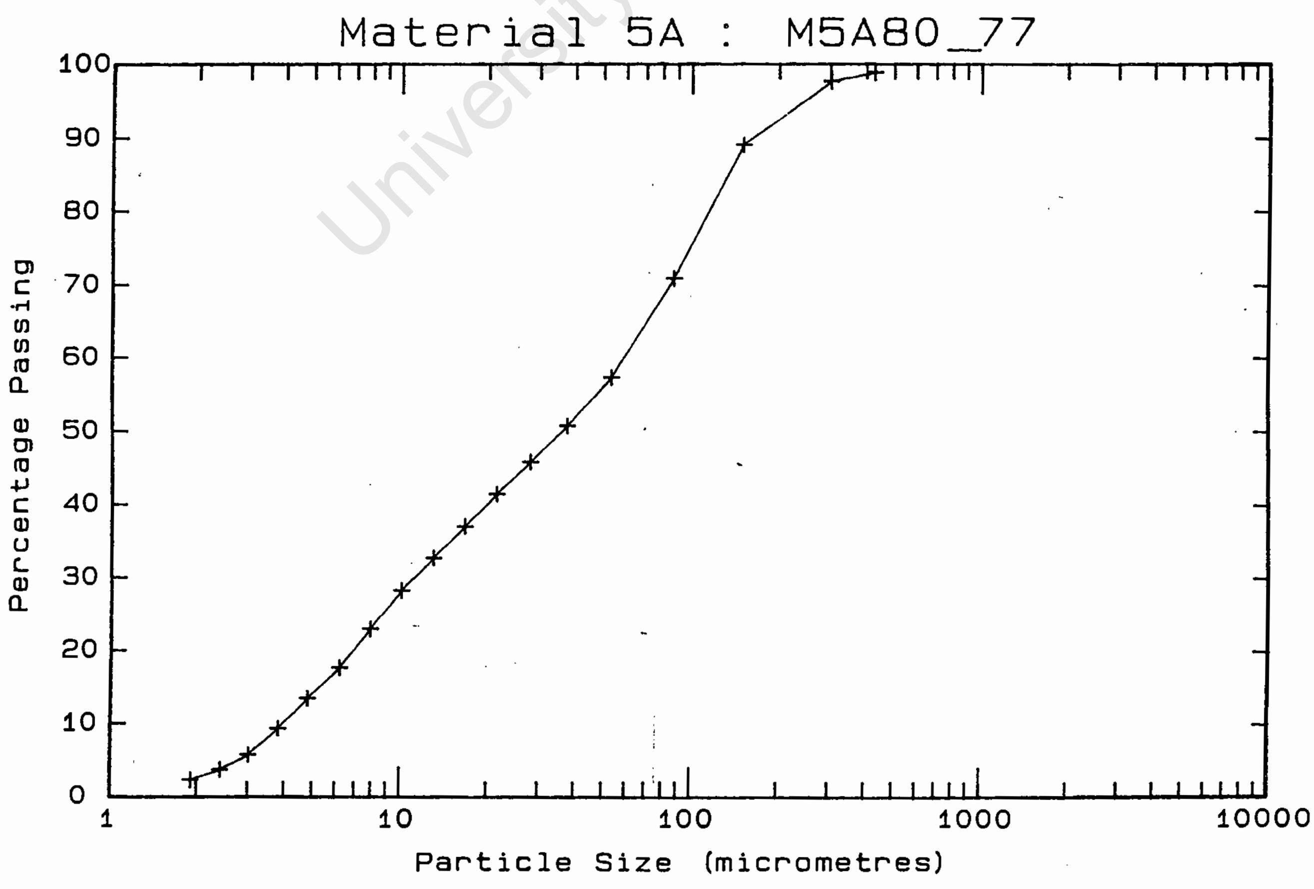
Size (µm)	% Passing	% Retained
425.0	98.8	1.2
300.0	97.6	1.2
150.0	89.0	8.6
87.2	70.9	18.1
53.5	57.3	13.6
37.6	50.7	6.6
28.1	45.8	4.9
21.5	41.4	4.4
16.7	37.0	4.4
13.0	32.7	4.3
10.1	28.2	4.5
7.9	22.9	5.3
6.2	17.6	5.3
4.8	13.4	4.2
3.8	9.3	4.1
3.0	5.7	3.6
2.4	3.7	2.0
1.9	2.3	1.4
Pan	.0	2.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.10	Asymetric
.65	Asymetric
1.32	Appears homogeneous
2.01	Appears homogeneous
2.66	Appears homogeneous
3.31	Appears homogeneous
3.88	Appears homogeneous

* −150 µm Malvern Particle Size Analyser


Material 5A : M5A80H77
Pressure Gradient (kPa/m)
Mixture Velocity (m/s)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Material 5A : M5A80_77
Percentage Passing
Particle Size (micrometres)
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000

DATA FILE : M5A80D77

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.77
Solids Volumetric Concentration (%)	44.51
Solids Mass Concentration (%)	68.65
Mean Slurry Temperature (°C)	25.6
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (μm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.583	-13.113	25.6
3.573	-13.079	25.8
3.637	-12.765	25.9
3.637	-12.808	26.0
3.063	-13.441	26.3
3.076	-13.360	26.3
3.065	-13.392	26.3
2.468	-13.778	26.3
2.480	-13.823	26.2
2.473	-13.848	26.2
1.862	-14.054	25.9
1.864	-14.216	25.9
1.864	-14.168	25.8
1.866	-14.153	25.8
1.240	-14.544	25.6
1.220	-14.509	25.5
1.217	-15.738	25.5
1.187	-15.050	25.4
.614	-14.609	25.2
.597	-14.750	25.2
.590	-14.652	25.1
.570	-14.645	25.0
.097	-15.261	24.9
.092	-15.229	24.9
.090	-15.272	24.9
.083	-15.396	24.9

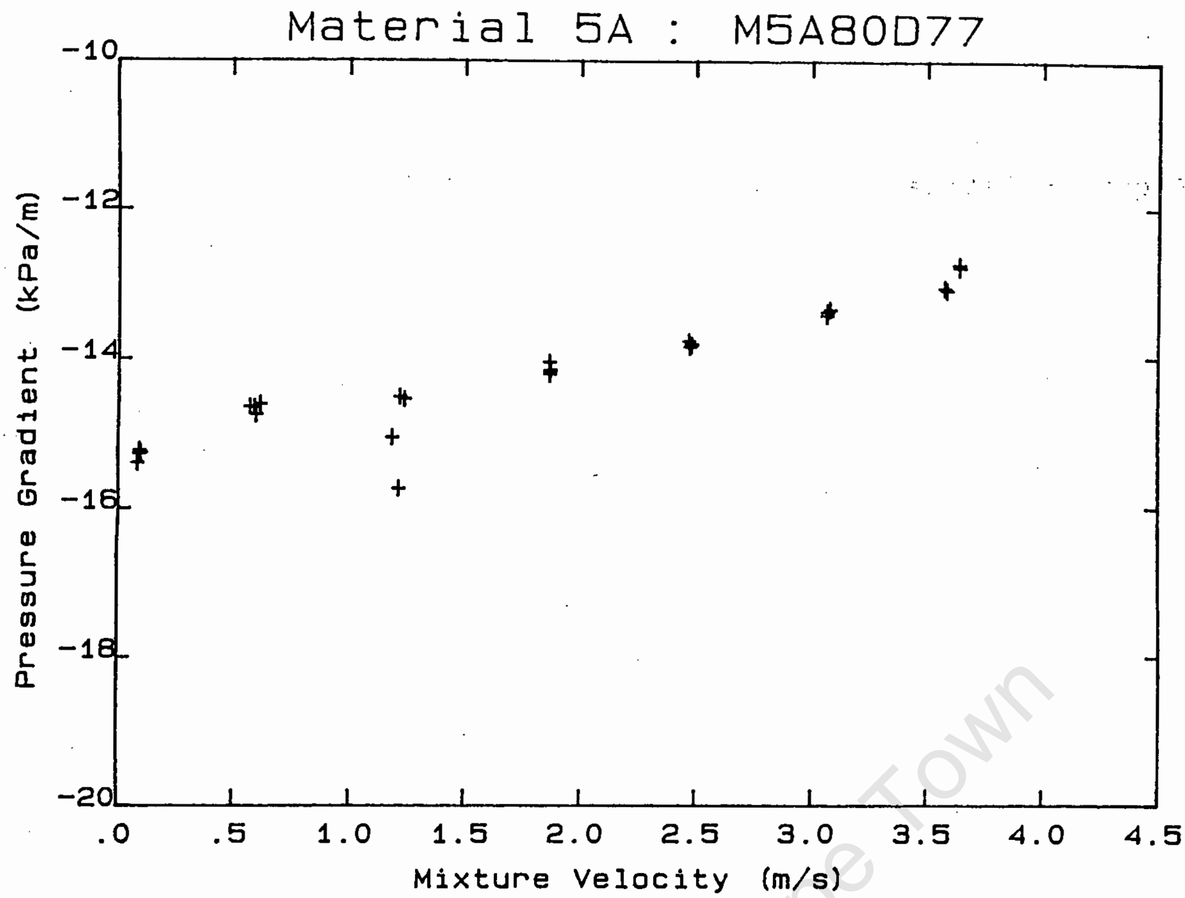
Particle Size Distribution
Sieve and Malvern Size Analysis *

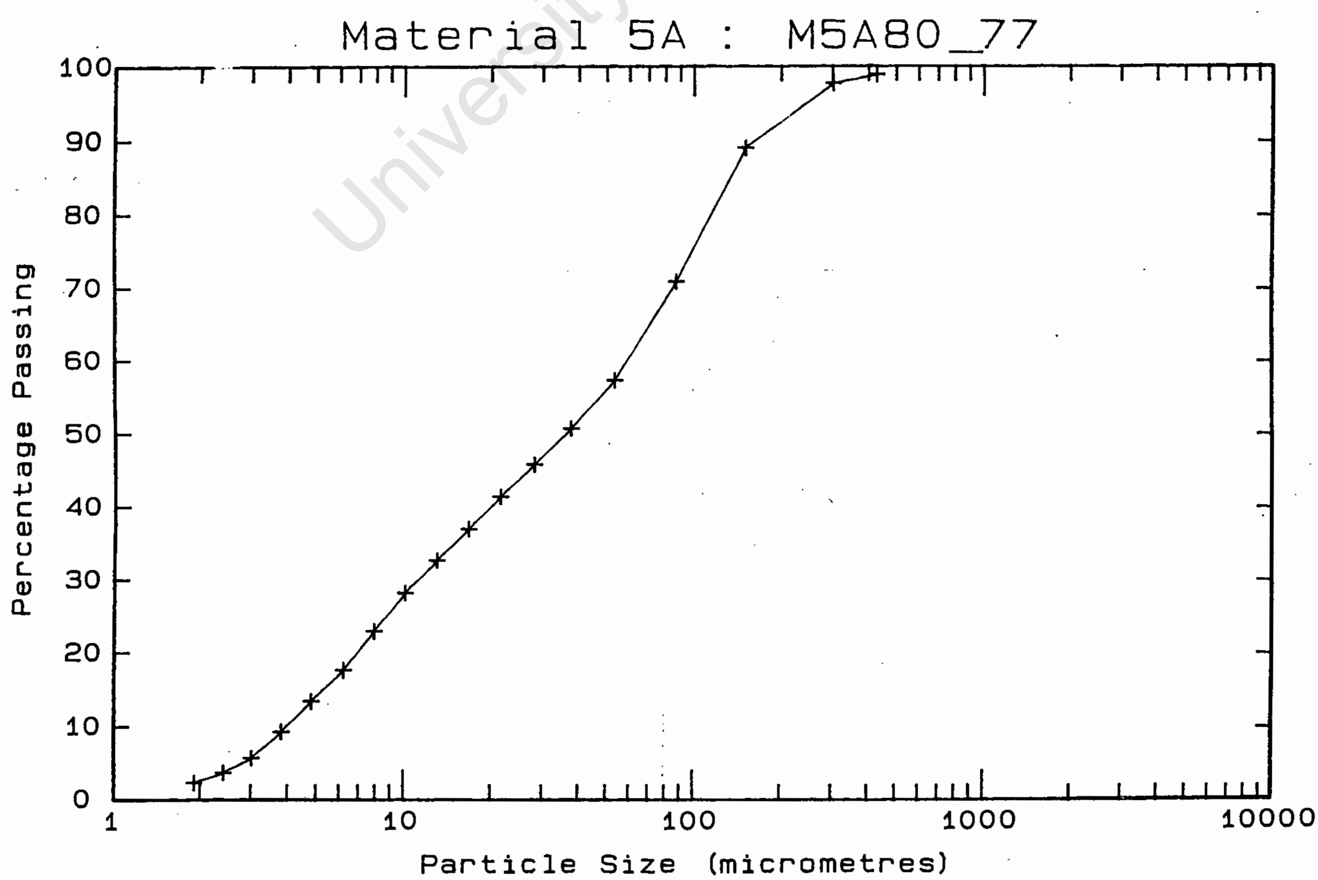
Size (μm)	% Passing	% Retained
425.0	98.8	1.2
300.0	97.6	1.2
150.0	89.0	8.6
87.2	70.9	18.1
53.5	57.3	13.6
37.6	50.7	6.6
28.1	45.8	4.9
21.5	41.4	4.4
16.7	37.0	4.4
13.0	32.7	4.3
10.1	28.2	4.5
7.9	22.9	5.3
6.2	17.6	5.3
4.8	13.4	4.2
3.8	9.3	4.1
3.0	5.7	3.6
2.4	3.7	2.0
1.9	2.3	1.4
Pan	.0	2.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -150 μm Malvern Particle Size Analyser


Material 5A : M5A80D77
Pressure Gradient (kPa/m)
-10
-12
-14
-16
-18
-20
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_77
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80U77

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.77
Solids Volumetric Concentration (%)	44.51
Solids Mass Concentration (%)	68.65
Mean Slurry Temperature (°C)	25.6
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.583	20.598	25.6
3.573	20.772	25.8
3.637	20.716	25.9
3.637	20.558	26.0
3.063	20.410	26.3
3.076	20.211	26.3
3.065	20.388	26.3
2.468	20.232	26.3
2.480	20.101	26.2
2.473	20.123	26.2
1.862	19.929	25.9
1.864	19.923	25.9
1.864	19.954	25.8
1.866	19.935	25.8
1.240	19.761	25.6
1.220	19.718	25.5
1.217	19.722	25.5
1.187	19.791	25.4
.614	19.484	25.2
.597	19.518	25.2
.590	19.551	25.1
.570	19.550	25.0
.097	19.816	24.9
.092	19.205	24.9
.090	19.190	24.9
.083	19.230	24.9

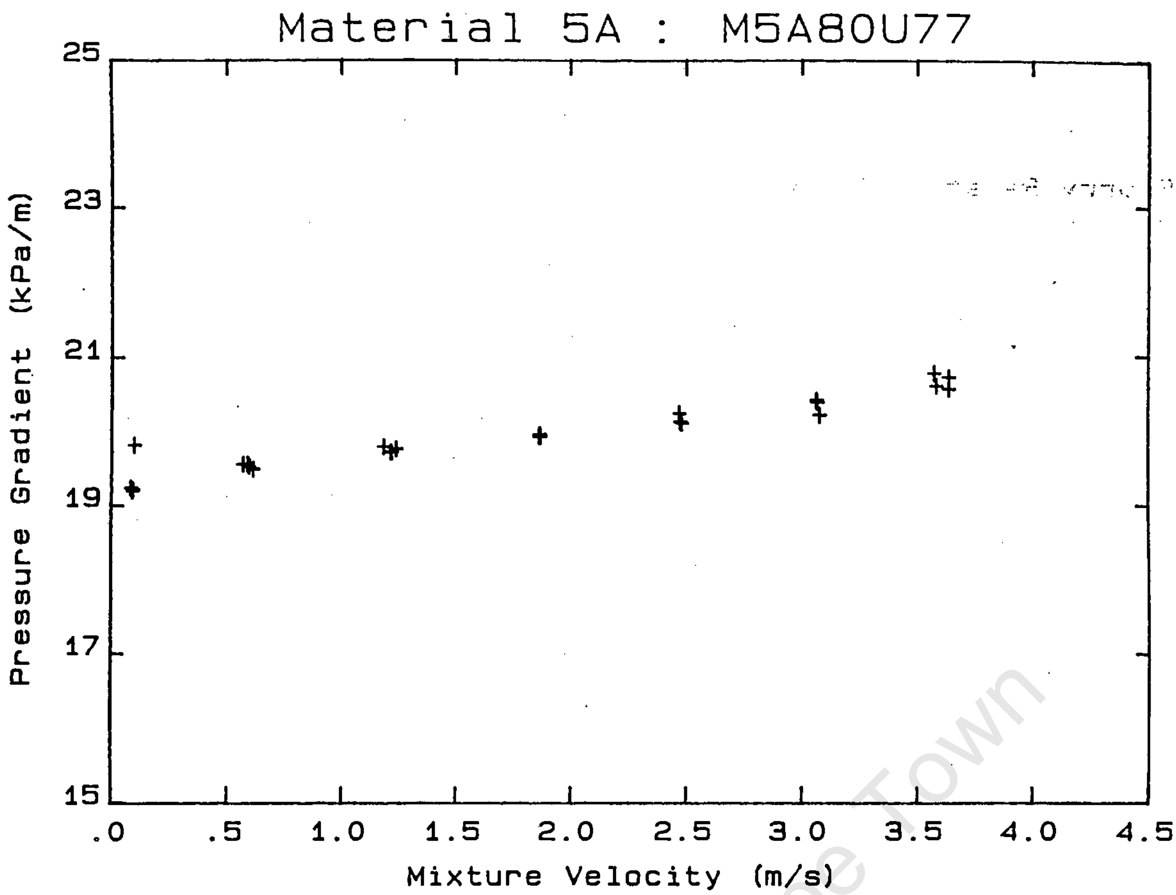
Particle Size Distribution
Sieve and Malvern Size Analysis *

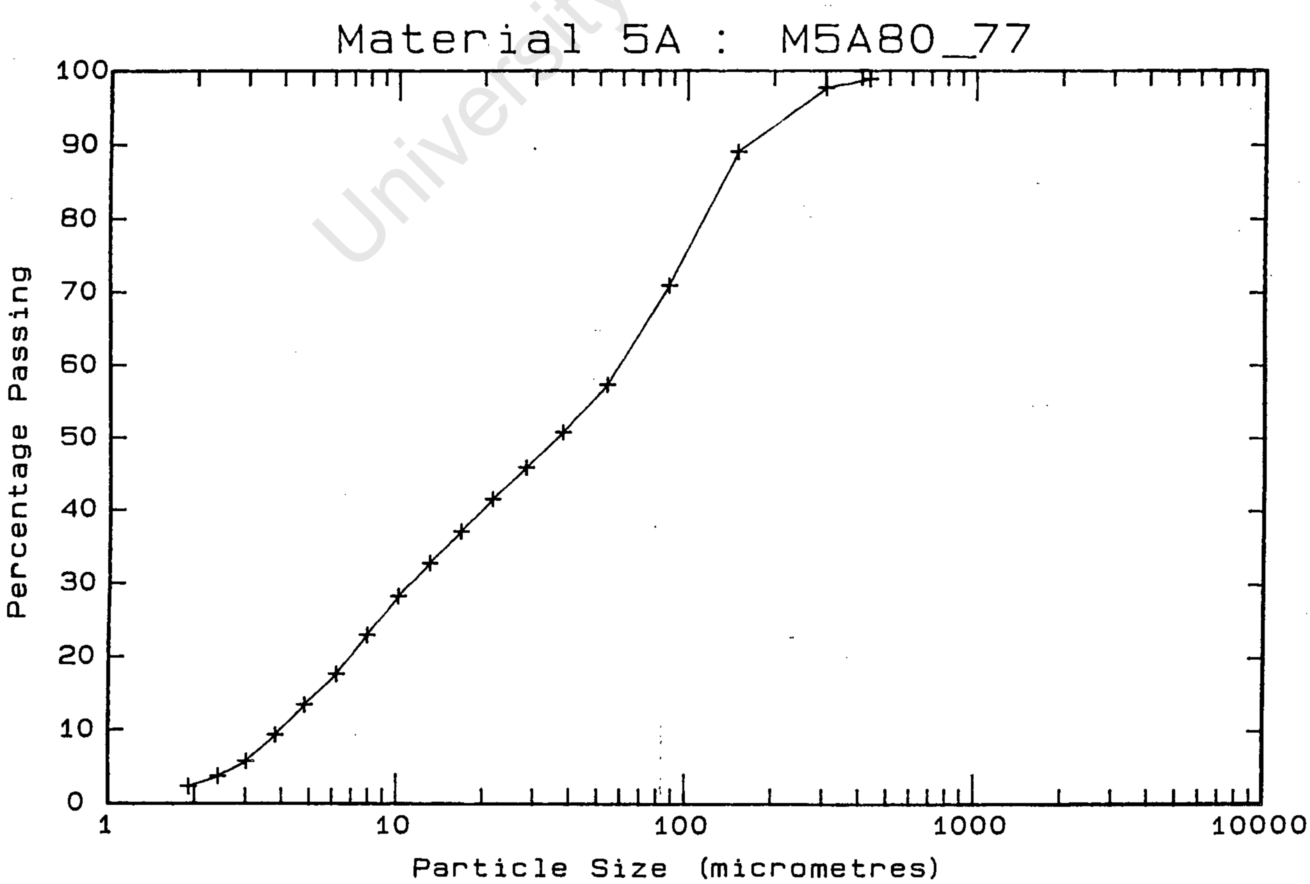
Size (µm)	% Passing	% Retained
425.0	98.8	1.2
300.0	97.6	1.2
150.0	89.0	8.6
87.2	70.9	18.1
53.5	57.3	13.6
37.6	50.7	6.6
28.1	45.8	4.9
21.5	41.4	4.4
16.7	37.0	4.4
13.0	32.7	4.3
10.1	28.2	4.5
7.9	22.9	5.3
6.2	17.6	5.3
4.8	13.4	4.2
3.8	9.3	4.1
3.0	5.7	3.6
2.4	3.7	2.0
1.9	2.3	1.4
Pan	.0	2.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -150 µm Malvern Particle Size Analyser


Material 5A : M5A80U77
Pressure Gradient (kPa/m)
25
23
21
19
17
15
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_77
Percentage Passing
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80H81

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.81
Solids Volumetric Concentration (%)	46.71
Solids Mass Concentration (%)	70.52
Mean Slurry Temperature (°C)	26.3
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	132.0
Pipeline Slope	Horizontal

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.561	5.190	26.1
3.601	5.184	26.2
3.627	5.178	26.4
3.487	5.172	26.5
3.526	5.167	26.6
3.132	5.156	26.8
3.124	5.153	26.8
3.159	5.148	26.9
2.468	5.138	26.8
2.469	5.135	26.8
2.464	5.132	26.8
2.463	5.128	26.7
2.464	5.125	26.7
1.840	5.121	26.6
1.864	5.116	26.5
1.857	5.113	26.5
1.257	5.106	26.3
1.184	5.104	26.2
1.089	5.102	26.2
1.073	5.100	26.1
.627	5.096	26.0
.636	5.094	25.9
.632	5.091	25.9
.130	5.086	25.8
.098	5.084	25.7
.083	5.083	25.7
.074	5.080	25.7
.053	5.078	25.7

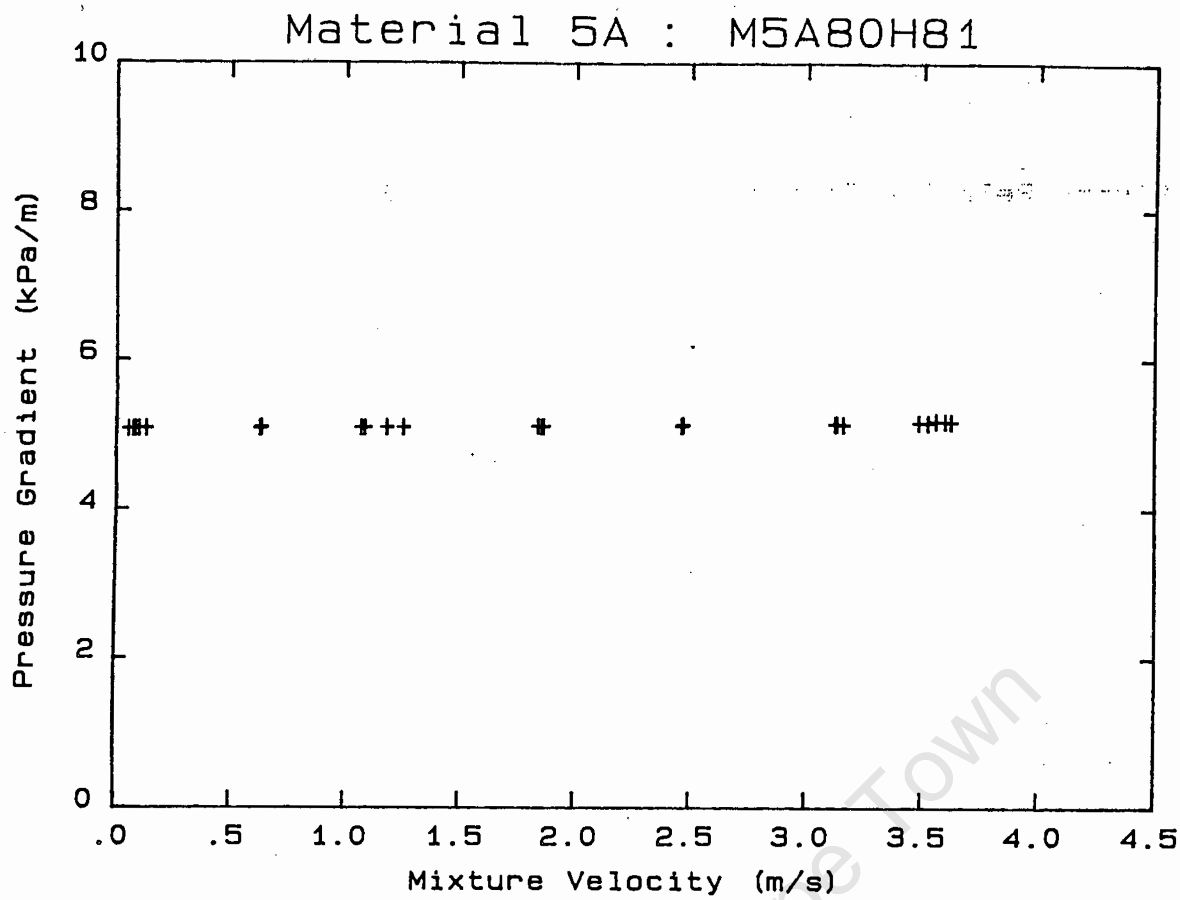
Particle Size Distribution
Sieve and Malvern Size Analysis *

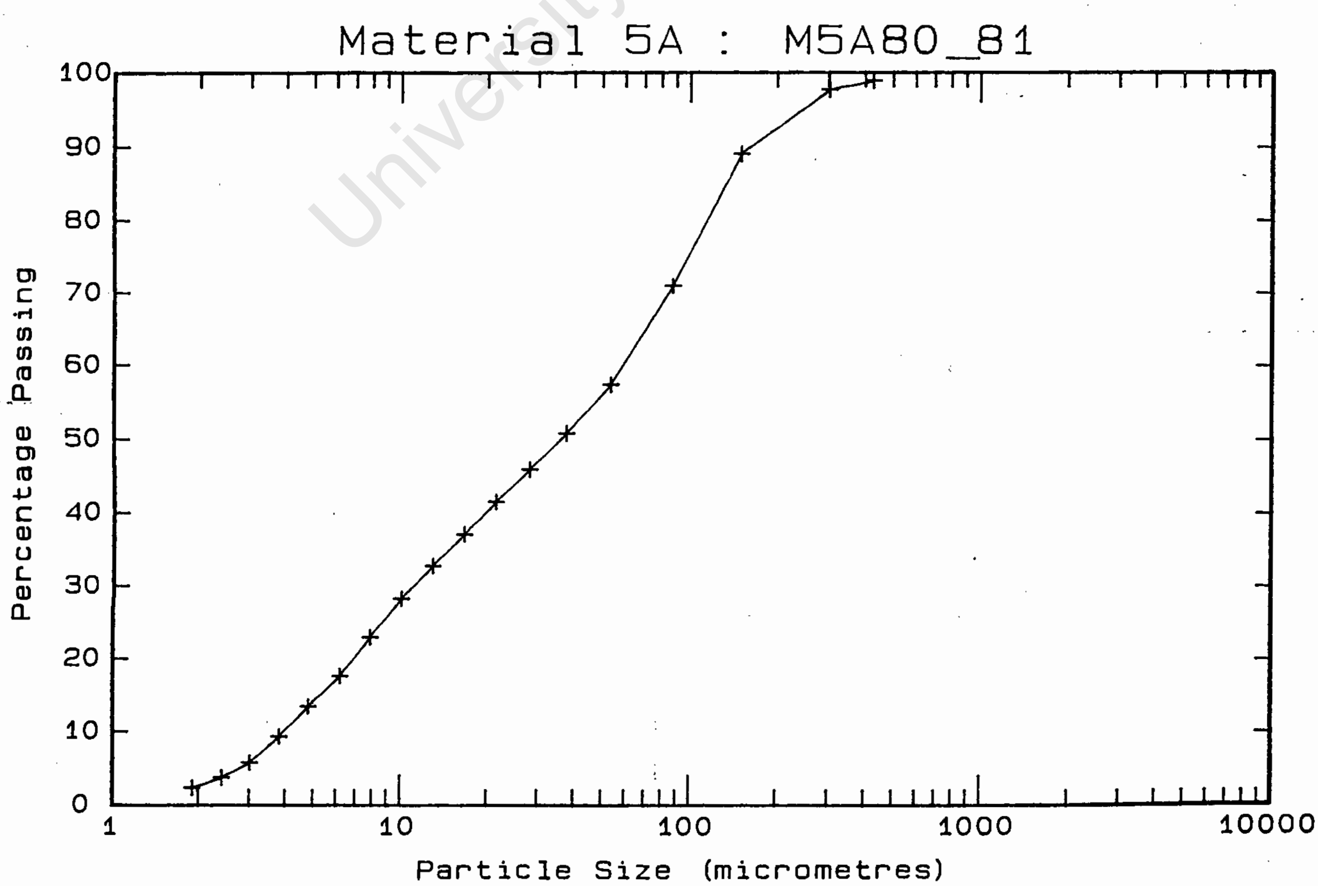
Size (µm)	% Passing	% Retained
425.0	98.8	1.2
300.0	97.6	1.2
150.0	89.0	8.6
87.2	70.9	18.1
53.5	57.3	13.6
37.6	50.7	6.6
28.1	45.8	4.9
21.5	41.4	4.4
16.7	37.0	4.4
13.0	32.7	4.3
10.1	28.2	4.5
7.9	22.9	5.3
6.2	17.6	5.3
4.8	13.4	4.2
3.8	9.3	4.1
3.0	5.7	3.6
2.4	3.7	2.0
1.9	2.3	1.4
Pan	.0	2.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)
.09	Appears homogeneous
.68	Appears homogeneous
1.19	Appears homogeneous
1.99	Appears homogeneous
2.66	Appears homogeneous
3.39	Appears homogeneous
3.88	Appears homogeneous

* −150 µm Malvern Particle Size Analyser


Material 5A : M5A80H81
Pressure Gradient (kPa/m)
0
2
4
6
8
10
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_81
Percentage Passing
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80D81

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.81
Solids Volumetric Concentration (%)	46.71
Solids Mass Concentration (%)	70.52
Mean Slurry Temperature (°C)	26.3
Pipe Internal Diameter (mm)	73.70
Pipe Roughness (µm)	96.0
Pipeline Slope	Vertical down

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.561	-12.022	26.1
3.601	-12.422	26.2
3.627	-12.211	26.4
3.487	-11.851	26.5
3.526	-12.395	26.6
3.132	-12.747	26.8
3.124	-12.755	26.8
3.159	-12.653	26.9
2.468	-13.148	26.8
2.469	-13.152	26.8
2.464	-13.215	26.8
2.463	-13.117	26.7
2.464	-13.186	26.7
1.840	-13.671	26.6
1.864	-13.548	26.5
1.857	-13.595	26.5
1.257	-14.074	26.3
1.184	-13.940	26.2
1.089	-13.986	26.2
1.073	-14.018	26.1
.627	-14.224	26.0
.636	-14.254	25.9
.632	-14.233	25.9
.130	-14.009	25.8
.098	-14.043	25.7
.083	-13.850	25.7
.074	-15.293	25.7
.053	-15.491	25.7

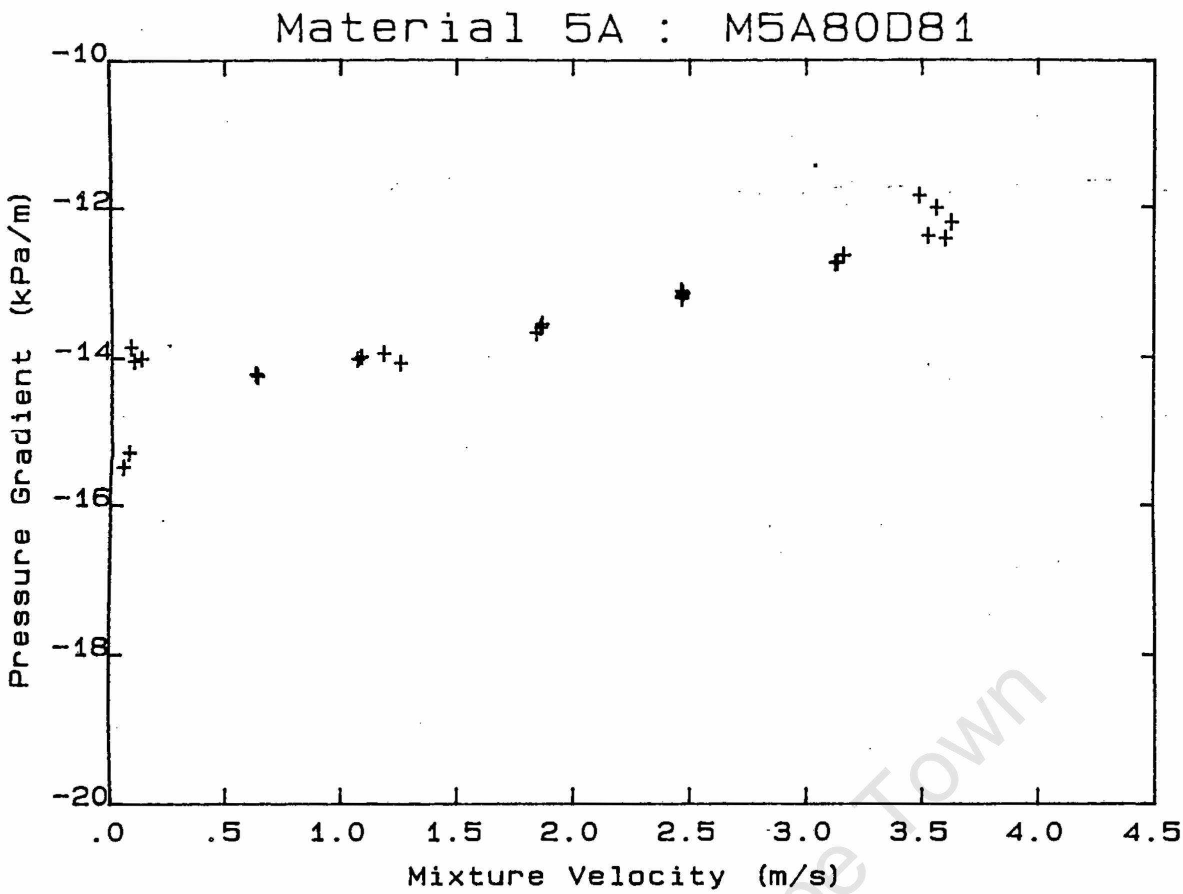
Particle Size Distribution
Sieve and Malvern Size Analysis *

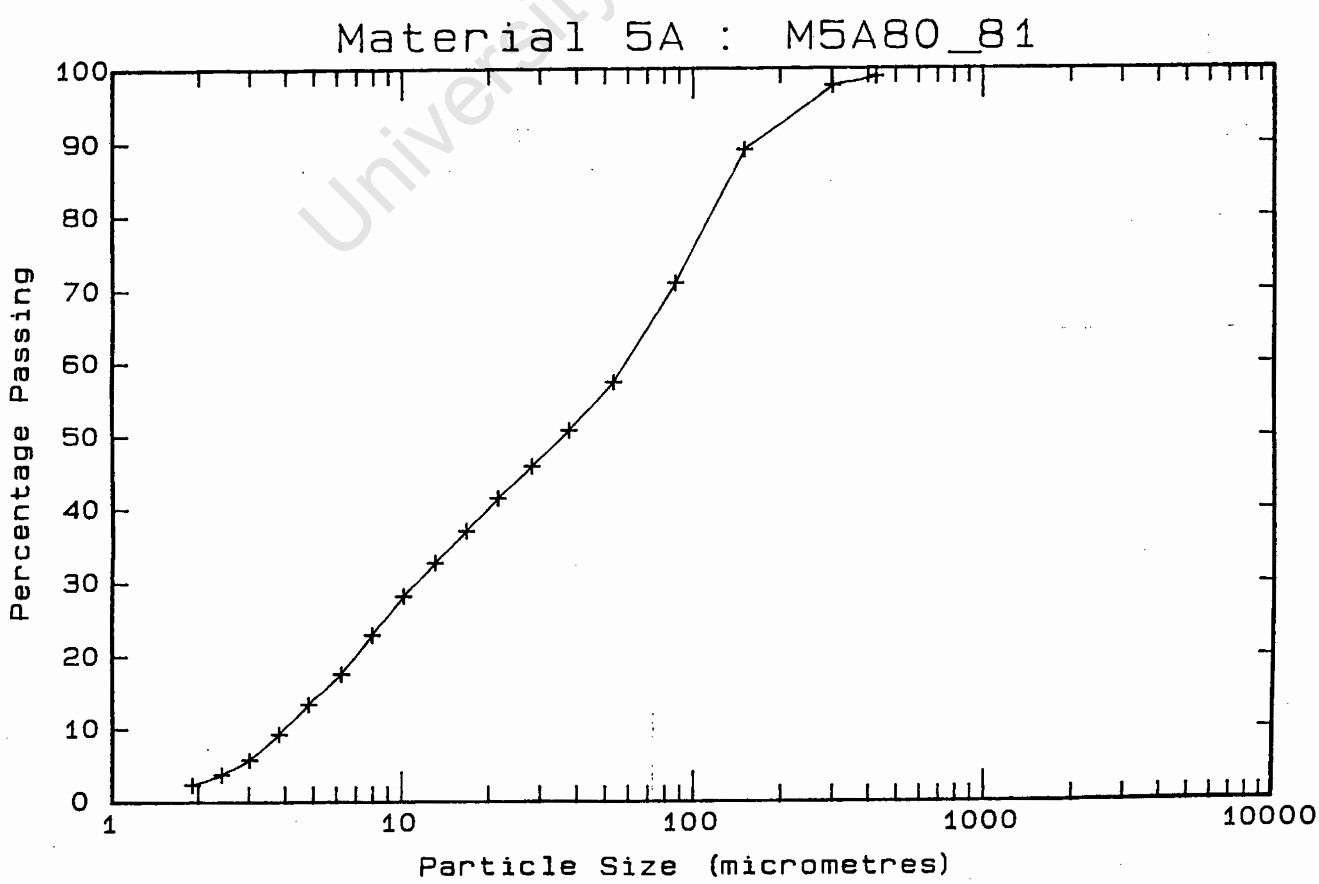
Size (µm)	% Passing	% Retained
425.0	98.8	1.2
300.0	97.6	1.2
150.0	89.0	8.6
87.2	70.9	18.1
53.5	57.3	13.6
37.6	50.7	6.6
28.1	45.8	4.9
21.5	41.4	4.4
16.7	37.0	4.4
13.0	32.7	4.3
10.1	28.2	4.5
7.9	22.9	5.3
6.2	17.6	5.3
4.8	13.4	4.2
3.8	9.3	4.1
3.0	5.7	3.6
2.4	3.7	2.0
1.9	2.3	1.4
Pan	.0	2.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* -150 µm Malvern Particle Size Analyser


Material 5A : M5A80D81
-10
-12
-14
-16
-18
-20
Pressure Gradient (kPa/m)
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Mixture Velocity (m/s)


Material 5A : M5A80_81
100
90
80
70
60
50
40
30
20
10
0
Percentage Passing
1
10
100
1000
10000
Particle Size (micrometres)

DATA FILE : M5A80U81

Test Facility	UCT 80 mm NB
Test Date	22/11/90
Material Description	Material 5A
Material Relative Density	2.73
Slurry Relative Density	1.81
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Pipe Roughness (µm)	18.0
Pipeline Slope	Vertical up

Mixture Velocity (m/s)	Pressure Gradient (kPa/m)	Slurry Temp. (°C)
3.561	21.519	26.1
3.601	21.550	26.2
3.627	21.678	26.4
3.487	22.451	26.5
3.526	21.503	26.6
3.132	21.520	26.8
3.124	21.566	26.8
3.159	21.556	26.9
2.468	21.119	26.8
2.469	21.141	26.8
2.464	21.156	26.8
2.463	21.228	26.7
2.464	21.157	26.7
1.840	20.965	26.6
1.864	20.935	26.5
1.857	20.987	26.5
1.257	20.738	26.3
1.184	20.740	26.2
1.089	20.767	26.2
1.073	20.658	26.1
.627	20.400	26.0
.636	20.429	25.9
.632	20.402	25.9
.130	19.970	25.8
.098	19.932	25.7
.083	19.873	25.7
.074	19.967	25.7
.053	20.083	25.7

Particle Size Distribution
Sieve and Malvern Size Analysis *

Size (µm)	% Passing	% Retained
425.0	98.8	1.2
300.0	97.6	1.2
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87.2	70.9	18.1
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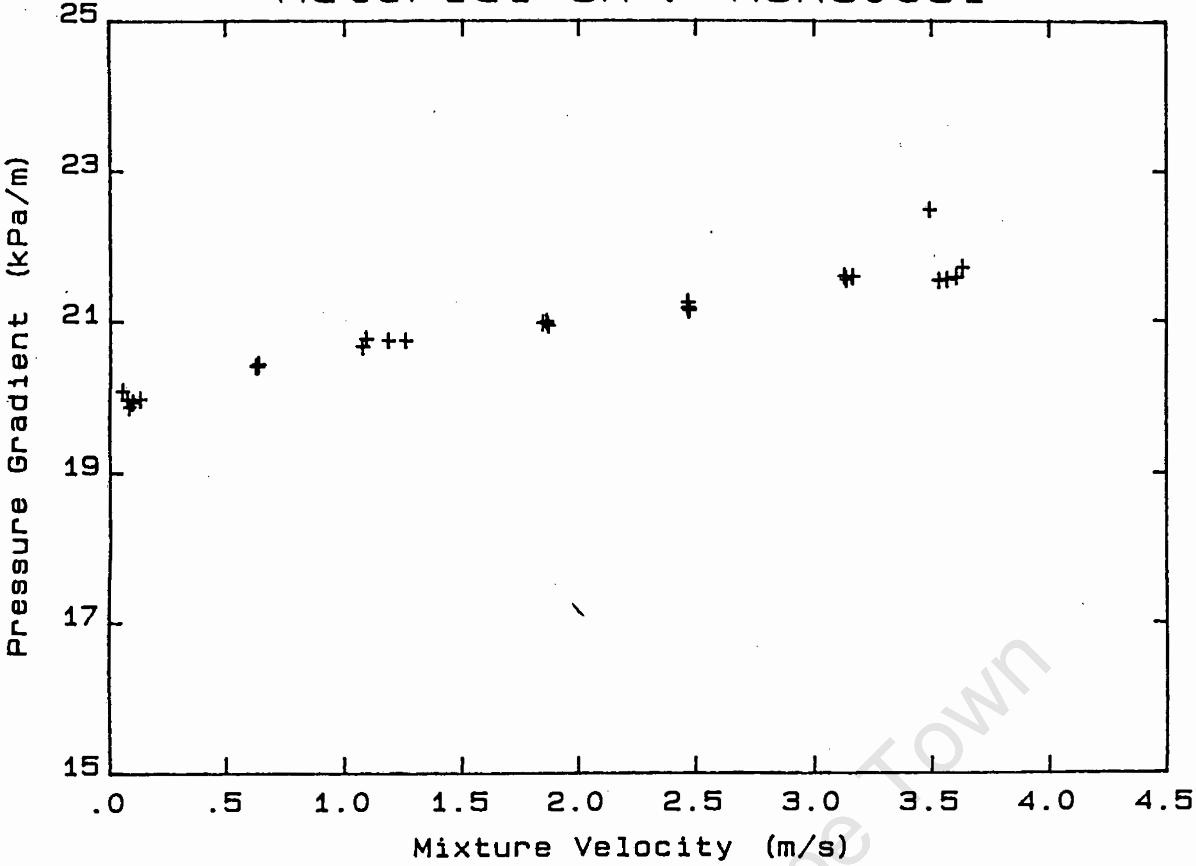
21.5	41.4	4.4
16.7	37.0	4.4
13.0	32.7	4.3
10.1	28.2	4.5
7.9	22.9	5.3
6.2	17.6	5.3
4.8	13.4	4.2
3.8	9.3	4.1
3.0	5.7	3.6
2.4	3.7	2.0
1.9	2.3	1.4
Pan	.0	2.3

OBSERVED FLOW BEHAVIOUR

Velocity (m/s)	Observation (D = 71.0 mm)

* −150 µm Malvern Particle Size Analyser

Material 5A : M5A80U81



Material 5A : M5A80_81