INVESTIGATING THE EFFECT OF COARSE PARTICLE ADDITION ON THE MEASURED RHEOLOGICAL PARAMETERS OF FINE CLAY SLURRIES

by

Eric Paulsen

Thesis submitted in fulfilment
of the requirements for the Degree

of

MASTER OF SCIENCE IN ENGINEERING
(EXTRACTIVE METALLURGY)

in the Department of Process Engineering
at the University of Stellenbosch

Supervised by
Prof. C. Aldrich

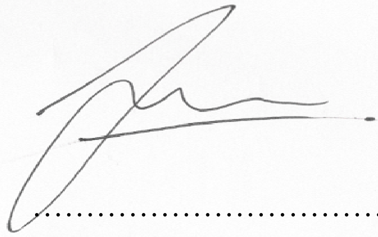
Co-Supervised by
Prof. R. Sumner (University of Saskatchewan)

STELLENBOSCH

December 2007

Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.



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ABSTRACT

Due to economic and environmental constraints mining operations are placed under increasing pressure to effectively manage and operate tailings disposal operations. Restrictions imposed on water usage and tailings operations footprint have led to higher density and wider particle size distribution slurries conveyed to tailings areas. One means of efficiently disposing the tailings is co-disposal. In this method a concentrated fine vehicle slurry is used to convey a coarser fraction. This produces a higher density of tailings, with a number of advantages both upstream and downstream of the tailings process. Limited research has been conducted on the effect of coarse particles on the non-Newtonian rheological properties of these slurries. This lack of information complicates the design and reliable operation of these systems.

This project aims at gaining a clearer understanding as to the mechanisms involved in the addition of coarse particles to a fine clay slurry vehicle; and to provide a means of estimating the measured slurry rheological properties. A number of experiments were designed to test the slurry (both Kaolin only, and Kaolin-coarse particle mixtures) rheological properties using a Couette viscometer (for the dynamic flow properties of yield stress and plastic viscosity) and a vane instrument (for the static yield stress measurements).

The slurries were prepared in varying Kaolin clay solids concentrations with reverse osmosis water. Glass beads and two types of industrial sand were used as the coarse fractions. All of the coarse particles had a similar size but varied significantly in shape. Slurry pH and temperature readings were monitored throughout the tests.

Tests were done initially on clay only slurries. The rheological properties of these slurries were repeatable, and no noticeable variations of properties with time were observed. The yield stress (both static and dynamic) and plastic viscosity data were well correlated with established relationships.

Coarse particles were added to the clay only slurries, and then removed. The remaining clay only slurry exhibited the same rheological properties as the initial clay

only slurry. The presence of coarse particles increased all the measured rheological properties (i.e. dynamic yield stress, Bingham viscosity, and static vane yield stress) in a fashion resembling the effect of adding clay to a clay only slurry. In addition, the change in measured rheological property by addition of coarse particle was independent of the clay fraction in the clay slurry. Furthermore, with both the clay only slurries and clay and coarse sand slurries, a constant linear relationship existed between the static and dynamic yield stress.

Several correlations from the literature were found to provide reasonable prediction of the rheological property variations observed. These empirical and semi-empirical models however did little to explain the mechanisms involved in coarse particle addition. A new correlation has been proposed, Residual Clay Concentration, which predicts the change in rheological property based on an additional clay concentration, which in turn is a linear function of the coarse particle concentration. The accuracy of this model further strengthens the belief that the coarse particle acts in a similar fashion to a floc.

By means of a case study example the importance of selecting an appropriate model for design was illustrated. The Residual Clay Concentration method provided the most conservative results. This combined with its theoretical basis strengthens the models recommendation for use in design.

OPSOMMING

As gevolg van ekonomiese en omgewings beperkinge word mynwese nywerhede onder toenemende druk geplaas om doeltreffende afvalstroom bestuur en operasie toe te pas. Beperkinge geplaas op water gebruik en afvalstroom area-groote ly tot hoër digthede en wyer partikel-grooteverspreidings van flodders vervoer na afval areas. Een manier om van die afval doeltreffend ontslae te raak en te berg is deur mede-berging. In die metode word ‘n gekonsentreerde fyn flodder gebruik as draer van ‘n growwer partikel-fraksie. Dit ly tot ‘n hoër digtheid flodder, met verskeie voordele in beide die op – en afstroom prosesse. Beperkte navorsing is gedoen op die effek van growwe partikels op die nie-Newoniese rheolgiese eienskappe van hierdie flodders. Hierdie tekort aan informasie maak die effektiewe, betroubare bedryf en operasie van die sisteme meer ingewikkeld.

Hierdie projek is daarheen gemik om ‘n beter begrip te ontwikkel met betrekking tot die meganismes betrokke in die byvoeging van growwe partikels aan ‘n fyn klei-agtige flodder draer; en om ‘n manier te voorsien wat die rheologiese eienskappe kan beraam. Verskeie eksperimente was ontwerp om die flodders (beide slegs Kaolien, en Kaolien-growwe partikel mengsels) se rheologiese eienskappe te toets deur die gebruik van ‘n Couette-viskometer. Die Couette viskometer was gebruik om die dinamiese eienskappe (van grens-spanning, en plastiese viskositet) te meet. ‘n Vaan apparaat is gebruik om die eienskap van statiese grens-spanning te meet.

Die flodders was voorberei in verskeie Kaolien konsentrasies met tru-osmosis water. Glas krale en twee tipes industriële sand is gebruik as die growwe fraksies. Al die growwe partikels het soortgelyke groottes gehad, maar het grootliks verskil in vorm. Die flodder pH en temperatuur lesings is deurentyd nagegaan.

Toetse was aanvanklik gedoen op die klei-alleenlike flodders. Die gemete reologiese eienskappe van die flodders was herhaalbaar, en geen opmerkbare veranderinge van die eienskappe met betrekking tot tyd is gemeet nie. Die grens-spanning (beide statiese en dinamiese) en plastiese viskositeit is goed gekorrelleer met gevestigde verhoudinge.

Growwe partikels is aan die klei-alleenlike flodders bygevoeg, en daarnae verwyder. Die oorblywende klei-alleenlike flodder het dieselfde gemete rheologiese eienskappe getoon as die oorspronklike klei-allenlike flodder. Die teenwoordigheid van growwe partikels het na ‘n toename van al die gamete rheologiese eienskappe gelei wat fisies baie soortgelyk is aan die byvoeging van klei tot ‘n klei-alleenlike flodder. Verder, met beide die klei-alleenlike en klei-growwe partikel flodders het ‘n konstante liniëre funksie tussen die statiese en dinamiese grens-spannings bestaan.

Verskeie verhoudings uit die literatuur het goeie korrelasie bewerkstellig met die waargenome rheologie veranderinge. Hierdie empiriese en semi-empiriese modelle doen egter min om die megansimes betrokke in die toevoeging van growwe partikels te verduidelik. ‘n Nuwe korrelasie is voorgestel, naamlik die Residu Klei Konsentrasie. Hierdie model voorspel die verandering in reologiese eienskappe gebaseer op ‘n addisionele klei konsentrasie, wat ‘n liniëre funkise is van die growwe partikel konsentrasie. Die goeie korrelasie gesien met die model versterk die idée dat die growwe partikel in ‘n soortgelyke manier as ‘n flok gedra in die teenwoordigheid van ander flokke.

Deur middel van ‘n tipiese industriële voorbeeld is die belangrikheid in die keuse van die regte korrelasie geillustreer. Die Residu Klei Konsentrasie metode het die mees konservatiewe resultate gelewer. Hierdie feit gekombineerd met die model se soliede teoreitiese beginsels versterk dit as voorgestelde korrelasie vir ontwerp.

CONTENTS

NOMENCLATURE

General Symbols

Symbol	Description	Units
A	Correlation parameter	-
B	Correlation parameter	-
C	Volume solids concentration	-
d	Particle diameter	m
D	Equipment diameter	m
F	Force	N
g	Gravitational acceleration constant	9.81 m/s²
H_A	Hamaker constant	J
H	Height of fluid	m
k_B	Boltzmann constant	1.3806×10^{-23} J/k
K	Fluid consistency index	$Pa.s^n$
L	Length	m
M	Correlation parameter	-
M	Mass	kg
N	Flow behaviour index	-
N	Hydrodynamic dimensionless number	-
P	Pressure	Pa
P_{abs}	Absorbed pump power	W
P_e	Peclet number	-
Q	Flow rate	m³/s
R	Radius	m
Re	Reynolds number	-
R	Incremental radius	m
S	Relative density (fluid to water density)	
T	Time	s
T_{AD}	Ancey dimensionless number	-
T_a	Taylor number	-
U	Average pipeline velocity	m/s
V	Volume	m³
W	Work	J
X	Cartesian plane	
Y	Cartesian plane	-
T	Temperature	K
n	Number of particles	-

Greek Symbols

Symbol	Description	Units
α	Correlation parameter	-
$\dot{\gamma}$	Shear rate	s^{-1}
μ	Viscosity	Pa.s
ε	Depletion layer thickness	M
η	Pump efficiency	-
Γ	Torque	N.m
λ	Particle separation ratio	-
θ	Degrees from tangential	°
ρ	Density	kg/m³
τ	Shear stress	Pa
τ_0	Wall shear stress	Pa
τ_y	Yield stress	Pa
ω	Angular velocity	s^{-1}

Subscripts

Symbol	Description	Units
0	Initial property	-
B	Bingham dynamic	-
b	Bulk property	-
C	Casson	-
c	Coarse fraction	-
e	End property	-
f	Fluid property	
floc	Floc property	-
k	Clay fraction	-
m	Mixture	-
max	Maximum packing concentration	-
p	Particle property	-
pipe	Pipeline property	-
s	Solid property	-
V	Vane	-
v	Volume property	-
w	Water	-

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ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and appreciation to Dr. R. J. Sumner, for introducing me to the field of research, and for aiding me in the document preparation, and data analysis. I wish to also thank Prof. C. Aldrich my supervisor. Without their guidance this thesis could not have been completed.

Thanks also go to the Saskatchewan Research Councils Pipe Flow Technology Centre for the use of their research facility. Without their patience and willingness to allow me to complete the research at their facility this project would never have taken place.

My deepest gratitude is also extended to Robert Cooke, Angus Paterson, and Graeme Johnson from Paterson & Cooke Engineers, without whose financial support and understanding this work would not have been possible.

I am further thankful to the Niels Verkerk and the Hydraulic Conveying Association of South Africa for their financial support.

Finally I would like to thank my family and friends for all their support during my research.

DEDICATION

This work is dedicated to my wife Amanda, without whose understanding, loving support, energy, and willingness to re-read this thesis countless times it would not have been possible.

1. INTRODUCTION

1.1 Background

The transport of solids, in particular mineral slurries in pipelines, has become an increasing area of focus in the mining industry since the coal pipelines designed in the late 1950's (Duckworth, Pullum, Lockyear, and Lenard, 1983). Of particular interest to this study are the waste or tailings streams generated by mining operations. Due to the nature of most mining processes, the volumetric flow rates of tailings streams are typically large in comparison to the related product streams. Processing challenges associated with these high throughput streams include the potential requirement for large tailings placement sites and the significant volumes of water disposed of with the solid tailings.

The tailings streams are typically produced as an aqueous slurry where the solids are generated as a residue from the metallurgical or mineral processing operation. The tailings may be dry-stacked or require further dilution with water before they are transported to a disposal site. Depending on the nature of the ore and the mining process, the total tailings solids may have wide particle size distributions. It is convenient to distinguish between particles that tend to be homogeneously distributed over cross-section of a pipe (fines) and those particles which have tendency toward settling (coarse). Out of convenience, the particle size associated with a 200 mesh screen has been chosen to make this distinction (Shook, Gillies, and Sanders, 2002). Conventionally the finer tailings are thickened and disposed on a tailings dam, and the coarser fractions are used as backfill or dry-stacked.

The current trend in tails operations towards tailings slurries with higher solids loadings is in response to extreme water shortages (due to the possibility of mining in isolated areas) such as, stricter water usage regulations, increased environmental awareness, and economic and infrastructural limitations. This has placed considerable focus on the design of pipeline systems to convey and dispose of the tailings with the minimum amount of water usage (Paterson 2004). Many efforts have been made to minimise the usage of water in the disposal of mineral slurry tailings, in order to meet water restriction demands, and to minimise the disposal area utilised over the life of the mine. Changes in the upstream processes, and variation in the mined ore have contributed to variations in the properties (particularly particle size) of the tailings. These factors have led to increased tailings slurry densities, and a wider particle size distribution of the conveyed slurries. An increase in the level of non-Newtonian behaviour would be anticipated with higher solids fraction of fine particles, which has been well documented (Nguyen and Boger, 1983). This study focuses on the increase in non-Newtonian behaviour resulting from increasing the overall concentration of coarser particles. Very limited research has been conducted on the effect of coarse particles on the non-Newtonian rheology of these slurries. A thorough understanding of the fluid mechanics associated with the flow of these slurries is required in order to effectively design and operate tailings pipelines.

Co-disposal is the disposal of both the coarse and fines fractions simultaneously. The advantages of co-disposal include (Vector Engineering 2004):

- Increased tailings dam stability and smaller tailings dam footprint, due to higher density tailings.
- In existing tailings dumps and waste rock, the co-disposed slurry is used to fill voids.
- The use of the high density fines as the “carrier fluid” allows more flexibility and stability in pipeline operation. This is since the effect of settling and other heterogonous flow phenomenon are reduced.
- Addition of the coarse fraction increases the apparent viscosity of the slurry and reduces the amount of flocculent required to achieve thickened slurry.
- In many cases, it is more convenient to combine the coarse and fines fractions at the plant compared to remote combination.

The effect of coarse material on slurry rheological parameters typically used in industry has been investigated by researchers and empirical expressions have been presented (Thomas 1999). However little is understood regarding the physical mechanisms involved (Ancey and Jorrot, 2001). It is therefore imperative that these mechanisms are thoroughly understood so as to optimally design pumping systems, and to avoid unanticipated fluid behaviour during operation and fluid testing (Sumner Munkler, Carriere, and Shook, 2000).

In most cases, the most appropriate means of characterising slurries is to conduct laboratory tests, including viscometer measurements, before designing the equipment. However, this approach may be impractical and/or too costly. Furthermore, viscometer measurements cannot be conducted if the coarse particles settle during the test. In this case it is necessary to scalp (remove) the coarse fraction (Shook et al., 2002). As a result, a means of estimating the effect of the addition of coarse particles on the rheological parameters of a fine particle slurry would be very useful for the design and operation of a tailings pipeline. The primary purpose of this project is to conduct a series of rheology measurements where controlled concentrations of coarse particles are introduced into fine particle slurries. This is done with a view to develop a method to reliably predicting the effect on the measured slurry rheological properties.

Shook et al. (2002) defines slurries according to the velocity at which solid particles settle in the mixture. Coarse particles settle rapidly in water and form heterogeneous slurries; fine particles settle slowly in water and form homogenous slurries, and mixtures of fast and slow settling particles are called heterogeneous slurries. The slurries investigated in this project are heterogeneous, and it is therefore important to ensure that under the test work flow conditions (laminar or static flow) no settling took place. Using industry standard criteria (Thomas 1977) it was ensured that the coarse fraction would not settle during the test work.

Coussot and Piau (1995) further classify particles according to the interactions they induce with each other and water. Coarse particles (sand, stones, boulders, etc) give rise to hydrodynamic interactions, frictions, or collisions. He believed that clay particles essentially interact with each other through ionized double layers surrounding them in water. Coussot (1997) detailed these ranges based on the International Society of Soil Science classifications. In this system clays have a grain size less than 2 μm, fine sands 20-200 μm, and coarse sand 200 μm to 2 mm. Further to these effects, this study aims to investigate the interactions between the coarse and fine particles.

For this study, glass beads and two types of industrial sand were used as the coarse fractions. All of the coarse particles considered had a similar size but varied significantly in shape. Kaolinite clay was chosen for the fine particle fraction as it has been used in a number of non-Newtonian homogeneous slurry studies including Litzenerger (2003), as a result its properties have been well documented. All slurries were prepared using de-ionized water to ensure consistency. Slurry pH and temperature readings were monitored throughout the tests.

Both Couette and vane viscometer measurements were performed to characterise the slurry flow properties.

1.2 Objectives

The objectives of this project are to:

- Gain a clearer understanding as to the mechanisms involved in the addition of coarse particles to a fine clay slurry vehicle.
- Provide a means of estimating the slurry rheological properties based on the rheological properties of the clay slurry, and physical properties of the coarse material.
- Ensure that the results of the study formulated such that they are applicable to industry.

1.3 Validity

The slurry test work and subsequent modelling performed in this study has a direct impact on the hydraulic design and operation of industrial tailings slurry pipelines and the overall disposal systems. Inadequate or inaccurate mineral slurry testing and modelling could lead to the design of highly inefficient, unreliable and even inoperable systems. It is therefore imperative that accurate methods of estimating the effect of coarse particles on the flow behaviour of tailings slurries are available.

2. LITERATURE REVIEW

2.1 Flow Properties

Rheology is defined as the study of deformation of matter (Hackley and Ferraris, 2001). Two types of fluid behaviour exist for incompressible fluids (fluids for which the volume of the fluid does not depend on its pressure) namely Newtonian and Non-Newtonian fluids.

Slurries consist of two distinct phases, namely the solids, and liquid phases. Slurries studied in this investigation are considered to be homogeneous mixtures. This condition assumes that the two phases are homogeneously distributed over the cross-section of the test apparatus for the duration of the test work while the slurry is flowing. The rheological properties of the slurry are also considered to be time independent such that any variation in the resistance to flow of the slurry with respect to time is considered to be negligible.

2.1.1 Newtonian fluids (adapted from Bird, Stewart, and Lightfoot, 1960)

Consider a thin layer of fluid between two parallel plates as shown in Figure 2.1. Initially the fluid is at rest and at t=0 the lower plate is moved in the *x*-direction. The momentum of the fluid gains with time until the steady state velocity profile is established.

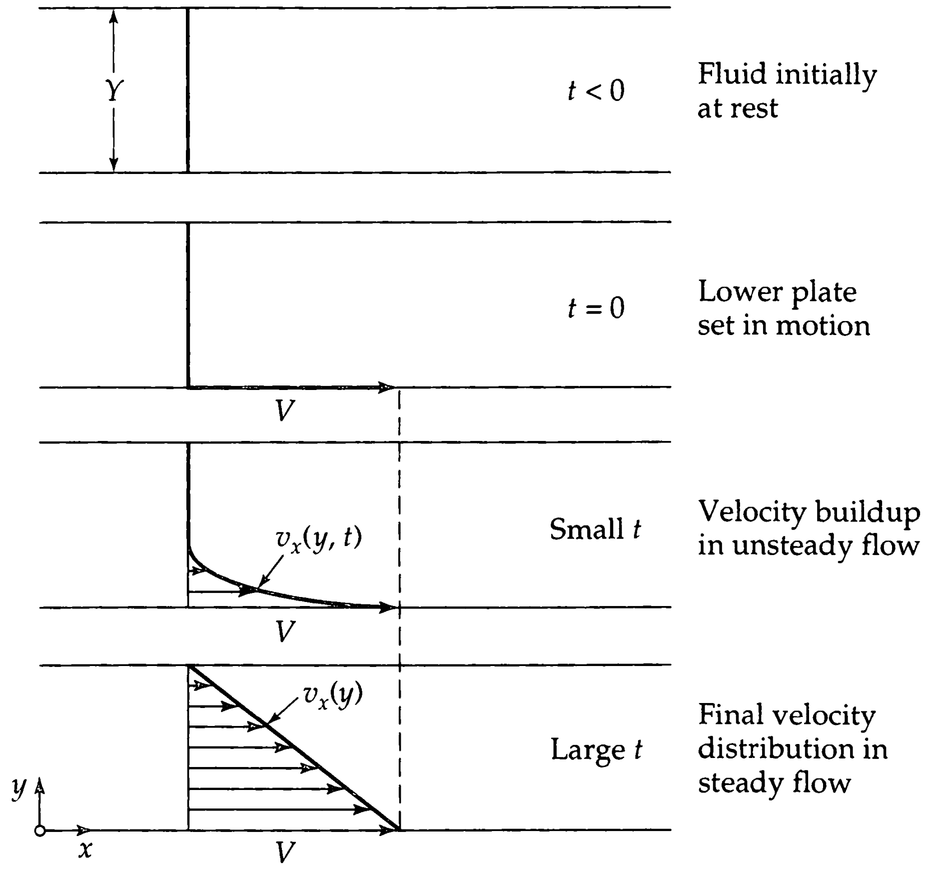

Figure 2.1: Shearing Flow Illustration (from Bird et al., 1960)

Once the steady state motion is attained a constant force,   is required to maintain the motion. If the flow is laminar this force may be expressed as shown in Equation (2.1).

(2.1)

By definition, the constant, μ (ratio of shear stress to rate of shear) is independent of the shear stress and shear rate. This constant is defined as the Newtonian viscosity. The shear stress exerted in the *x*-direction on a fluid surface of constant *y* by the fluid in the region of lower *y* is shown as:

(2.2)

This equation, which states that the shearing force per unit area is proportional to the negative of the velocity gradient, is often called Newton's law of viscosity, and fluids behaving in this way are called Newtonian fluids. Note the use of the term, $\dot{\gamma}$, which is referred to as the shear rate.

The rheogram (plot of shear stress versus shear rate) for a Newtonian fluid is therefore a straight line of slope μ, and passes through the origin. A typical Newtonian rheogram is shown in Figure 2.2.

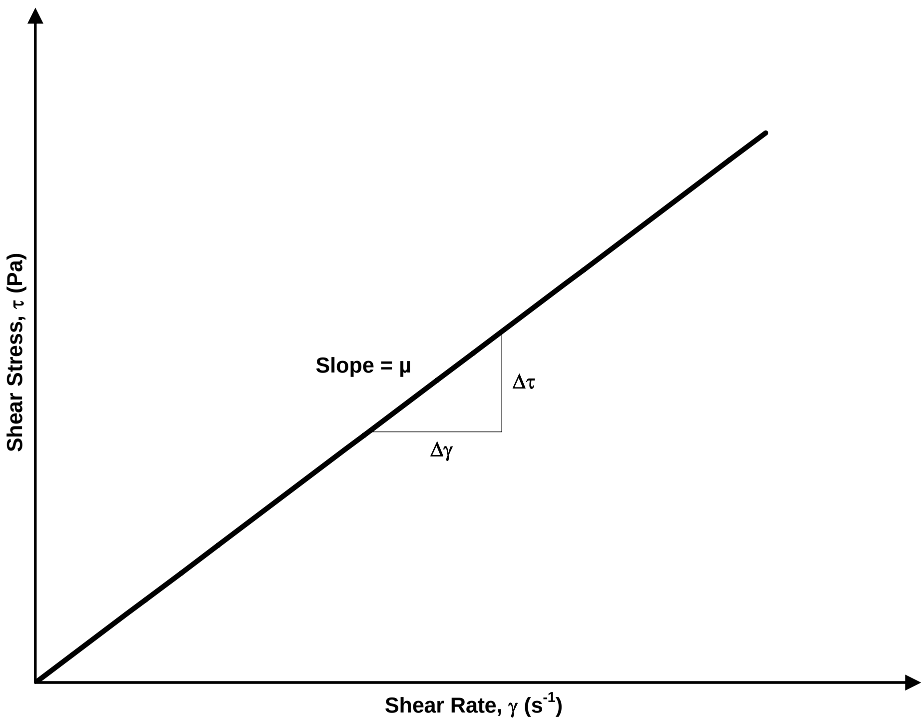

Figure 2.2: Newtonian Fluid Rheogram

2.1.2 *Non-Newtonian fluids*

A non-Newtonian fluid does not have a constant apparent viscosity (ratio of shear stress to rate of shear). The apparent viscosity (ratio of shear stress to rate of shear) of a non-Newtonian fluid varies with the level of shear rate, and shear rate history. Two important distinctions are made in categorising the rheology of fluids:

- Time independent versus time dependent fluid. The rheological properties of a time independent fluid do not vary with time. With time dependant fluids, the fluid rheology is dependent on the earlier shear history experienced by the fluid.
- Newtonian versus non-Newtonian fluids. With a Newtonian fluid, the shear stress associated with the fluid is related to the shear rate by a single constant, the Newtonian viscosity. To model the rheology of a non-Newtonian fluid, at least two constants are required. The fluid behaviour may follow a power law model. Some fluids exhibit a yield stress where a net shear stress must be applied before any shear occurs. These fluids are known as visco-plastic fluids.

Fluids may exhibit varying degrees of both time dependent and non-Newtonian properties. In most cases, there is a dominant non-Newtonian property and the use of more complicated models is not justified (R. Sumner, private communication, 2007). For the slurries considered in this research, the time dependent behaviour was determined to be insignificant and the fluids were considered time independent. The time independent behaviour was verified by repeating a number of Kaolin slurry flow tests, and observing the variance in the observed flow curves.

Various models exist for predicting time independent non-Newtonian behaviour. Some of the more general models are presented in Figure 2.3. Power law fluids can exhibit either pseudo-plastic (shear thinning) or dilatant (shear thickening) behaviour. The power law fluid shown in the diagram represents a pseudo-plastic fluid. Dilatant behaviour is less common. Several visco-plastic models are also provided in Figure 2.3. The two parameter Casson and, in particular, Bingham fluid have been used successfully to represent most visco-plastic fluids. Fluids exhibiting yield-pseudoplastic behaviour are rare and an involved set of measurements are required to confirm this behaviour. Table 2.1 displays the relationship between shear stress and shear rate based on the rheological parameters for the models illustrated in Figure 2.3.

The flow behaviour of Kaolin slurries have been well documented with a number of slurry models (Litzenberger 2003). Since the Bingham model (Equation (2.5) in Table 2.1) has been demonstrated in both this study and the other studies associated with Kaolin clay slurries, it was used to represent the rheology of the clay slurries considered in this study. The rheological parameters in the Bingham model parameters are determined directly from the flow curves, and are therefore dynamic. These parameters are the dynamic Bingham yield stress, and dynamic Bingham viscosity.

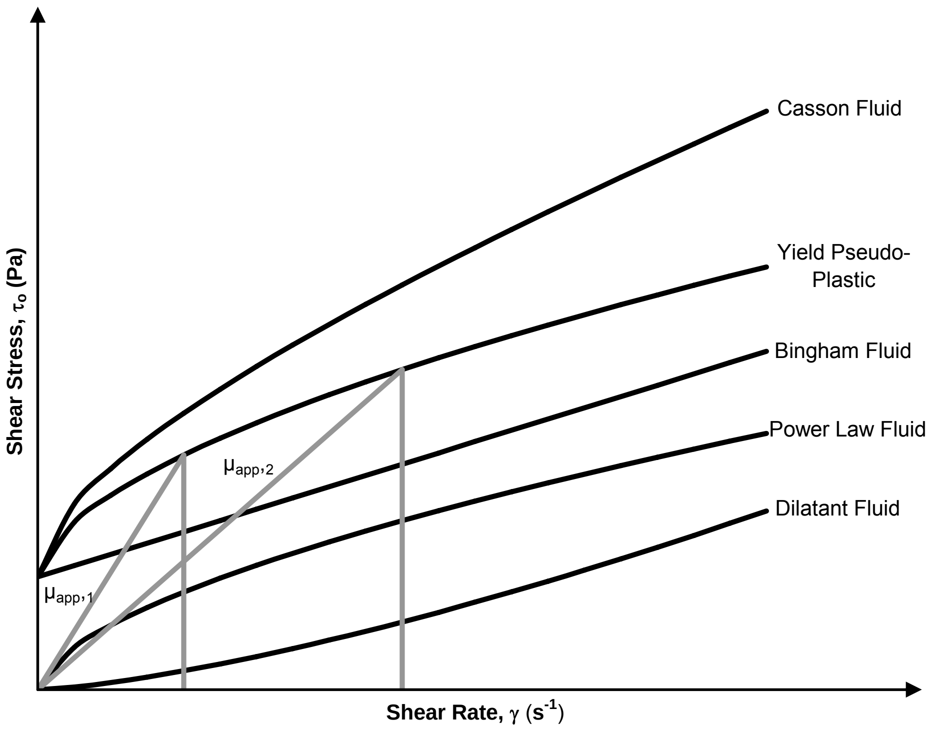

Figure 2.3: Non-Newtonian Models

Table 2.1: Non-Newtonian Models and Parameters

Model	Definition	
Casson	$\tau_o^{\frac{1}{2}} = -(K_c\dot{\gamma})^{\frac{1}{2}} + \tau_c^{\frac{1}{2}}$	(2.3)
Yield Pseudo-Plastic	$\tau_o = K\dot{\gamma}^n + \tau_y; 0 < n < 1$	(2.4)
Bingham	$\tau_o = K_B\dot{\gamma} + \tau_{y,B}$	(2.5)
Power Law	$\tau_o = K\dot{\gamma}^n; 0 < n < 1$	(2.6)
Dilatant	$\tau_o = K\dot{\gamma}^n; n > 1$	(2.7)

2.1.3 *Time-effects*

Some slurries exhibit time effect phenomena, due to chemistry variations, flocculent structure changes, and settling. Michaels and Bolger (1962) and Litzenberger (2003) witnessed changes in the rheology over time of the Kaolin. However due to the relatively short duration of the tests involved in this project (approximately 15 minutes a test) and reproducibility of the results it is assumed that negligible variation of the Kaolin rheology takes place.

In order to ensure that there is no settling the Thomas (1977) criterion was used for stable slurries under static conditions such that the mixture yield stress, $\tau_{y,m}$, was higher than the calculated minimum required yield stress as shown below:

$$\tau_{y,m} \geq 0.092 \cdot g \cdot d_p(\rho_s - \rho_v). \qquad (2.8)$$

2.2 Viscometry

The rheology of the slurries investigated were determined using standard viscometric methods. These were the Couette (or concentric cylinder) and vane viscometers.

2.2.1 *Rotational/Couette flow*

With Couette flow, the fluid is sheared between two concentric cylinders of length L. Depending on the configuration, the inner or outer cylinder can be stationary (Bird et al., 1960). With the Couette viscometer considered in this investigation, the outer cylinder (radius R_2) is stationary, while the inner cylinder (radius R_1) rotates at angular velocity ω. The device measures the torque, Γ, required to rotate the inner cylinder at the set angular velocity. Figure 2.4 illustrates the Couette viscometer geometry.

The Couette viscometer has the advantage of requiring only a small amount of sample compared to the tube viscometer. However the shear rates and shear distributions between the tube and Couette viscometers differ and it should be ensured that similar shear rate ranges are used when comparing the devices (Paterson & Cooke 2007).

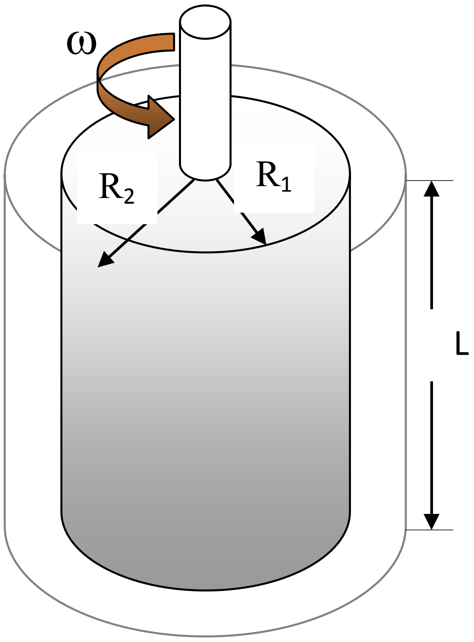

Figure 2.4: Geometry of Couette Viscometer

From the definitions for the various rheological models presented in Table 2.1 the constitutive equations for Couette flow can be written as shown for the Newtonian and Bingham fluid cases in Equations (2.9) and (2.10) respectively (Shook and Roco, 1991).

$$\tau_{r\theta} = -\mu r \left(\frac{d\left(\frac{V_\theta}{r}\right)}{dr} \right) \tag{2.9}$$

$$\tau_{r\theta} = -K_B r \left(\frac{d\left(\frac{V_\theta}{r}\right)}{dr} \right) + \tau_{y,B}. \tag{2.10}$$

In the derivation of Equations 2.8 and 2.9, it was assumed that the only velocity component is in the tangential (θ) direction.

The relationship between the torque and shear stress at some distance r from rotating cylinder is represented as follows:

$$\Gamma = 2\pi L r^2 \tau_{r\theta}. \tag{2.11}$$

Equations 2.12 and 2.13 are obtained by substituting Equation (2.11) into Equations (2.9) and (2.10), respectively, and integrating over the annulus (R_1 to R_2). The following boundary condition at ($r = R_1$) is applied:

$$v_\theta(r = R_1) = R_1\omega. \tag{2.12}$$

Newtonian:

$$\omega = \frac{\Gamma}{4\pi L\mu\left[\frac{1}{{R_1}^2} - \frac{1}{{R_2}^2}\right]} \tag{2.13}$$

Bingham:

$$\omega = \frac{\Gamma}{4\pi L K_B\left[\frac{1}{{R_1}^2} - \frac{1}{{R_2}^2}\right]} - \frac{\tau_{y,B}}{K_B}\ln\frac{R_2}{R_1}. \tag{2.14}$$

Using the known values for the viscometer dimensions the rheological parameters can be fit to the data, by optimising the predicted rotational velocity with the measured rotational velocity. The Newtonian viscosity (μ) is calculated from the gradient of the linear relationship between the rotational velocity and torque. The dynamic Bingham parameters (K_B and $\tau_{y,B}$) are calculated from the gradient and intercept of the linear relationship between rotational velocity and torque.

Under steady state conditions the torque is constant throughout the annulus (with varying r). This implies that the term $r^2\tau_{r\theta}$ is constant, and that the shear stress varies with the annulus radius. It is therefore imperative that the fluid is completely sheared in the annulus. The shear stress for yield stress fluids must thus exceed the fluid yield stress throughout the annulus. This is achieved by assuming that there is some critical radius at which the applied shear stress equals the yield stress, and then ensuring that the angular velocity is sufficiently high enough to ensure that this critical radius is larger than R_2.

The shear stress in the gap between the inner and outer cylinder decays according to the square of radial distance. The shear stress being applied to the fluid by the inner cylinder (τ_o) associated with a shear stress equivalent to the yield stress at the outer cylinder can be determined using the following equation:

$$\tau_o = \tau_y \left(\frac{R_1}{R_2}\right)^2. \tag{2.15}$$

The minimum required angular velocity can then be calculated by substituting τ_o in either Equation (2.14) or (2.13).

It is also important that the flow measurements only take place in flow regions where the tangential velocity associated with Couette flow is the only contributor to shear stress. At excessive angular velocities secondary flows may result, which also contribute to shear stress. In this scenario the rotating cylinder induces inertial forces which result in a secondary motion of the fluid called Taylor vortices, as shown in Figure 2.5. When this occurs the relationship between the torque and linear velocity become non-linear and curves upward, consequently all data at these shear rates must be discarded.

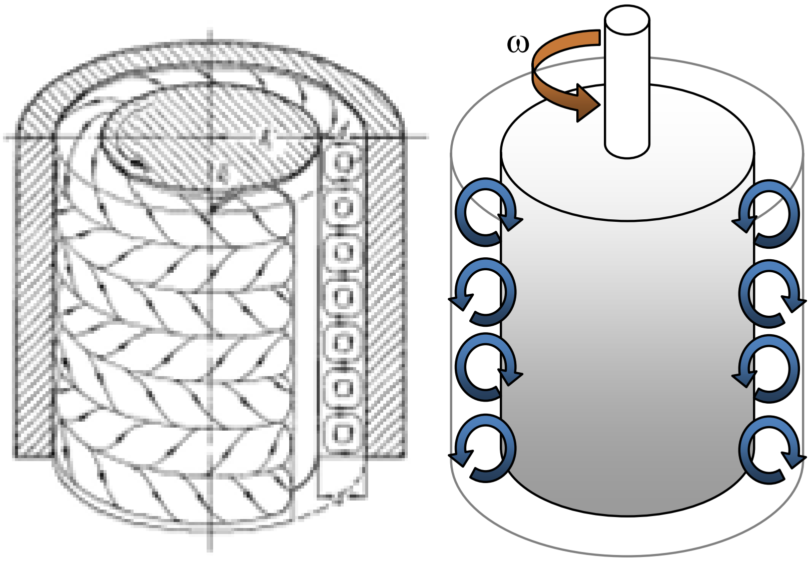

Figure 2.5: Taylor Vortex Development (from Schlichting 2000)

Shook and Roco (1991) suggest that vortices occur in a rotating spindle when the maximum Taylor number is exceeded; where the maximum Taylor number is defined as:

$$T_{a,max} = 45\left(\frac{\frac{(R_2+R_1)}{2}}{R_2-R_1}\right)^{\frac{1}{2}}. \tag{2.16}$$

The Taylor number is defined as follows:

$$T_a = \frac{\frac{(R_2+R_1)}{2}\omega(R_2-R_1)\rho_m}{\mu_m}. \tag{2.17}$$

The maximum angular velocity is determined by substituting Equation (2.17) into Equation (2.16) and solving the resulting expressing. It is interesting to note that the density of the fluid (ρ_m) is required for this calculation along with the geometry of the viscometer and the fluid viscosity.

2.2.2 *Vane*

Concentrated suspensions of colloidal particles with strong inter-particle interactions often exhibit unique plastic flow behaviour and the existence of yield stress (Nguyen and Boger, 1983). In these systems particles are attracted to each other due to strong Van der Waals forces resulting in the formation of flocs, which are small assemblages of particles and floc networks (Michaels and Bolger, 1962). Thomas (1963) suggested that, on a macroscopic level, the yield stress is simply a force required to initiate flow, whereas on a microscopic level it is related to the floc characteristics. On this basis the yield stress is related to the strength of the floc network structure per unit of area required to break down this structure to permit flow to occur.

According to Nguyen, under the application of small stress these fluids deform elastically (similar to a solid), and when the applied stress exceeds the yield value it behaves as a viscous fluid with continuous deformation. The yield stress is then defined as the minimum shear stress corresponding to this first point of flow (or the measured shear stress at zero velocity gradient). A second concept of yield stress exists where flow measurements are conducted and the results are extrapolated to determine the yield stress corresponding to a shear rate equal to zero. It is sometimes convenient to differentiate between these two yield stress values by referring to the yield stress obtained when the flow first occurs as the static yield stress, and the extrapolated value as the extrapolated or dynamic yield stress. Based on a number of viscometer experiments performed with mineral slurries exhibiting a yield stress, the two values often found not to be equivalent (R. Sumner, private communication, 2007).

Direct and indirect measurements of the yield stress exist. Indirect methods are based on the interpretation of shear stress-shear rate data, and obtaining the shear stress at zero shear rate. Often the yield stress is obtained in this way by fitting the Bingham model constitutive equation to the data, and extrapolating the fitted value to zero shear rate (as shown in Figure 2.6). Although good agreement has been obtained in comparing the extrapolated yield stress obtained using two different methods with the same slurry (ex. Litzenberger 2003), it is important to consider the possibility of wall slip, particularly at higher yield stress values.

Since the rheological behaviour of mineral slurries often exhibit a linear relationship, the Bingham model has been found to be appropriate in a number of cases (Nguyen and Boger, 1983). Discrepancies with this method have been reported, as presented by Nguyen, and in some cases yield stress values in the region of 4-5 times higher than that obtained by non-linear extrapolation have been found. This difference could be as a result of a high degree of time dependence of the fluid, and the inability of the flow equations presented here to deal with this behaviour. Based on the experience of the Saskatchewan Research Council and previous workers, the Bingham equation is more than suitable for the purposes of this project (Nguyen and Boger 1983, Sumner 2007, Litzenberger 2003, and Michaels and Bolger 1962).

It should be kept in mind that the yield stress determined by non-linear methods is not necessarily a physical property of the fluid, so far as it is a fitted parameter, dependant on the rheological model chosen. Caution should also be used when applying non-linear equations at high shear rates as the function will become physically unrealistic. Determination of the yield stress by means of a direct method is therefore the most desirable.

Figure 2.6: Indirect Determination of Yield Stress from Bingham Fitted Model

One means of determining the yield stress directly is by applying a constant very low shear rate to the fluid, and measuring the static shear stress at the point of shearing (where the fluid flows). The problems associated with the rotating cylinder geometry in yield stress measurements, such as the possibility of wall slip, has led investigators to use geometries such as the vane. The vane also has the added advantage of minimal disturbance caused by its introduction into the fluid, and has consequently been used by a number of workers in soil mechanics.

The vane method provides a means to directly measure this yield stress under essentially static conditions. The static yield stress obtained using the vane is directly associated with the strength of a continuous network structure within the flocculated suspension. The vane consists of a number of thin blades arranged around a cylindrical shaft as shown in Figure 2.7.

A vane test is performed by gently immersing the vane spindle completely in the sample fluid. According to Nguyen the depth of the suspension should be at least twice the length and diameter of the vane in order to minimize any effects from the rigid boundaries. The vane is rotated at a constant speed (recommended at approximately 0.1 rpm) and the torque is measured with time.

A typical Torque vs. Time curve for a yield stress fluid is shown in Figure 2.8. The initial linear increase in torque with time relates to the motor loading the spring of the vane instrument, since little or no movement occurs at the vane. The yield stress occurs as a result of several forces, attractive forces (over short distances) and repulsive forces (over longer distances), and these are in turn determined by several factors including zeta potential and the double layer. During the vane tests a gradual change in the force balance within the fluid occurs, until yielding of the fluid takes place. This yielding happens in an irreversible manner since once the motion is sustained at low shear rates, the hydrodynamic forces are not sufficient to bring the flow structure to a stationary state. For this reason, the observed peak in the Torque vs. Time diagram is assumed to represent the static yield stress.

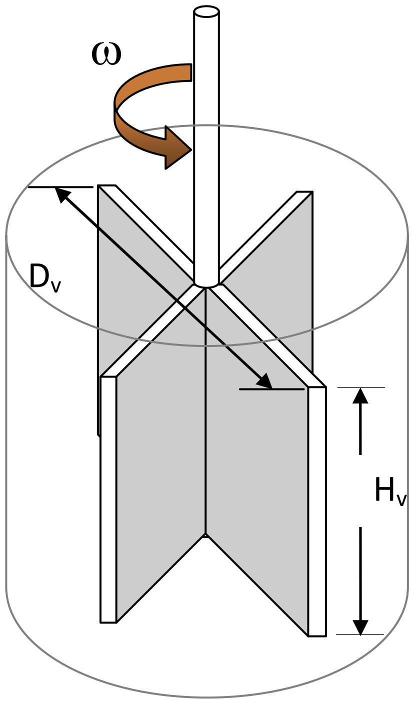

Figure 2.7: Schematic Representation of the Vane

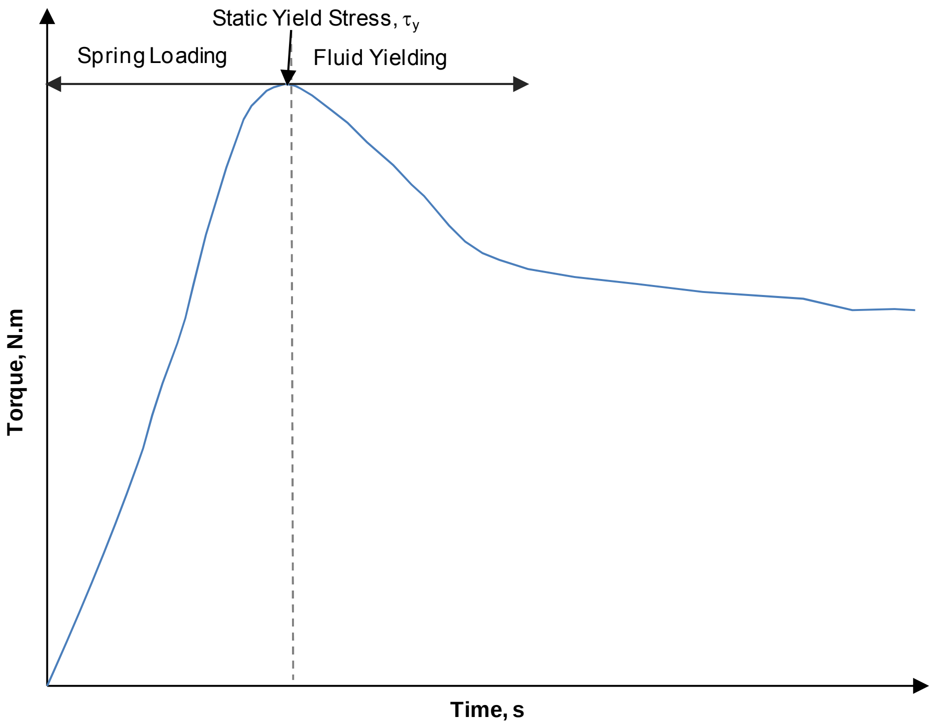

Figure 2.8: Direct Determination of Static Yield Stress from Vane Method

To calculate the static yield stress from the maximum measured torque the following assumptions are made:

1. The vane is replaced by a cylinder of dimensions equal to the extent of the vane blades.
2. The total torque is composed of one component due to shearing on the cylinder wall, and another to shearing at the end surfaces.
3. The vane is of sufficiently small diameter to ensure that the end surface shear stress is distributed uniformly.
4. The material yields instantaneously at the cylindrical surface.

The torque balance can now be given by (Nguyen and Boger, 1983):

$$\Gamma = 2\pi {R_v}^2 H_v \tau_w + 2\left[2\pi \int_0^{R_v} \tau_e(r)\, r\, dr\right]. \qquad (2.18)$$

From assumption 3 the end wall shear stress (τ_e) is equal to the cylindrical wall shear stress (τ_w). Since it is further assumed that the material yield instantaneously the wall stress is equal to the yield stress (τ_y) at the point of yielding. Equation (2.18) now becomes:

$$\Gamma = \frac{\pi}{2} {D_v}^2 \left(\frac{H_v}{D_v} + \frac{1}{3}\right) \tau_y. \qquad (2.19)$$

Equation (2.19) can be used to calculate the static yield stress with a good degree of accuracy. Nguyen investigated various vane dimensions and determined that for H/D_v ratios in the region of 1.5 the assumption of uniform shear stress distribution at the vane ends holds true, and provides yield stress values well within the expected experimental error.

2.2.3 *Alternative viscometric devices*

Additional commonly used means of viscometric measurement, particularly with regards to high concentration solids, are the pipeline or tube viscometer, and cone and plate viscometer (Bird et al., 1960). Although these viscometric devices were not used in this project it is important to note that they could offer valuable information with regards to the slurry properties due to the different flow geometries.

Tube viscometer

Consider a homogenous fluid flowing at an average pipeline velocity, U vertical pipe section as shown below:

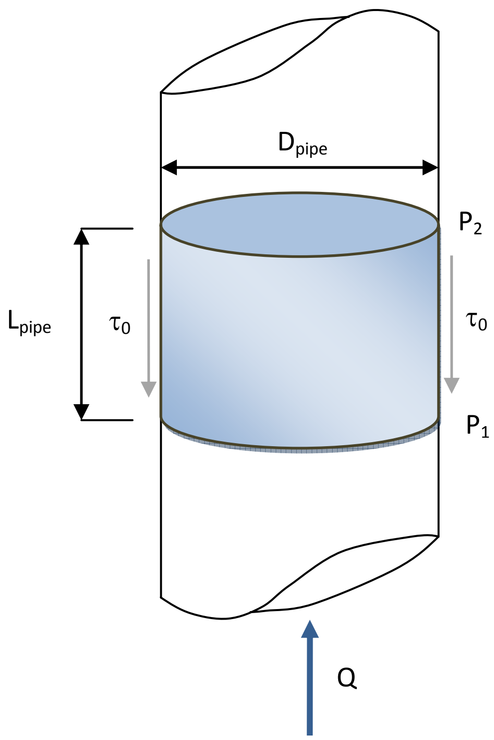

Figure 2.9: Vertical Pipeline Flow

A force balance over the test section provides the following relationship between the pipeline pressure gradient and wall shear stress:

$$\frac{4\tau_0}{D} = -\frac{\mathrm{dP}}{\mathrm{dL}} - \rho g \frac{\mathrm{dh}}{\mathrm{dL}}. \tag{2.20}$$

The left side of the above equation presents the frictional resistance to flow. The frictional energy loss for a Newtonian fluid can be represented in terms of the Fanning friction factor, f:

$$f = \frac{2\tau_0}{\rho U^2}. \tag{2.21}$$

The friction factor for a Newtonian fluid can be estimated from the Colebrook-White relationship (Colebrook, 1938-9):

$$\frac{-1}{\sqrt{f}} = 4 \cdot \ln\left(\frac{k_{rough}}{3.7 \cdot D_{pipe}} + \frac{1.26}{\sqrt{f} \cdot Re}\right), \tag{2.22}$$

where the Reynolds number, Re is calculated as follows:

$$\frac{\rho \cdot U \cdot D_{pipe}}{\mu} \tag{2.23}$$

In order to obtain the fluid rheological properties from pipeline test data the shear stress is integrated as a function of the radial position within the pipeline. By assuming no slip exists at the pipeline wall, the laminar pipeflow equations for Newtonian and Bingham fluids is obtained.

Newtonian:

$$\frac{8U}{D_{pipe}} = \frac{\tau_0}{\mu}. \tag{2.24}$$

Bingham:

$$\frac{8\mathrm{U}}{\mathrm{D_{pipe}}} = \frac{\tau_0}{\mathrm{K_B}}\left[1 - \frac{4}{3}\frac{\tau_0}{\tau_{y,B}} + \frac{1}{3}\left(\frac{\tau_0}{\tau_{y,B}}\right)^4\right]. \tag{2.25}$$

The wall shear stress is determined directly from the measured pressure loss over the pipeline section of length, L. The values of calculated pseudo-shear rate, $^{8\mathrm{U}}/_{\mathrm{D_{pipe}}}$, and wall shear stress are plotted and the best fit parameters determined from Equation (2.25). It is important that the parameters are determined from laminar pipeflow data only. Turbulent data is determined from the intersection between modelled laminar flow and predicted turbulent flow. The predicted turbulent curve is determined from the Wilson and Thomas (1985) method. This model is widely used in industry for fine particle slurries exhibiting a yield stress. Turbulent flow of a Newtonian fluid in a pipeline is separated into the thin sub-layer near the wall of the pipeline, where viscous effects dominate, and into the turbulent core, where momentum transfer occurs by inertial turbulent mixing. The Wilson & Thomas model proposes that for a non-Newtonian fluid the thickness of the viscous sub-layer near the pipeline wall increases.

For Bingham fluids the Wilson & Thomas model for the bulk velocity, U is written in terms of the frictional velocity, $V_* = \sqrt{\frac{\tau_0}{\rho}}$, as shown below:

$$\mathrm{U} = \mathrm{V_N} + 2.5\left[V_*\ln\frac{\left(1 - \frac{\tau_y}{\tau_0}\right)}{\left(1 + \frac{\tau_y}{\tau_0}\right)} + \frac{\tau_y}{\tau_0}\left(14.1 + 1.25\frac{\tau_y}{\tau_0}\right)\right] \tag{2.26}$$

where $\mathrm{V_N}$ is the bulk velocity calculated using the Newtonian frictional energy loss. The apparent viscosity and mixture density are used to calculate the Reynolds number:

$$\mathrm{Re} = \frac{\mathrm{D_{pipe}V_N}\rho\left(1 - \frac{\tau_y}{\tau_0}\right)}{\mathrm{K_B}}. \tag{2.27}$$

The disadvantage of this means of measurement is the high volume of sample required for each test, as well as the complications involved in pipeline operation, instrumentation calibration, and sample degradation due to pumping and pipeline flow.

Cone and plate viscometer (from Bird et al., 1960)

A cone-and-plate viscometer consists of a stationary flat plate and an inverted cone, whose apex just touches the plate, as shown in Figure 2.10. The liquid is placed in the gap between the cone and plate. The cone is rotated at a known angular velocity, ω and the torque, Γ required to rotate the cone is measured. For commercial instruments the cone angle, α is approximately 1 degree.

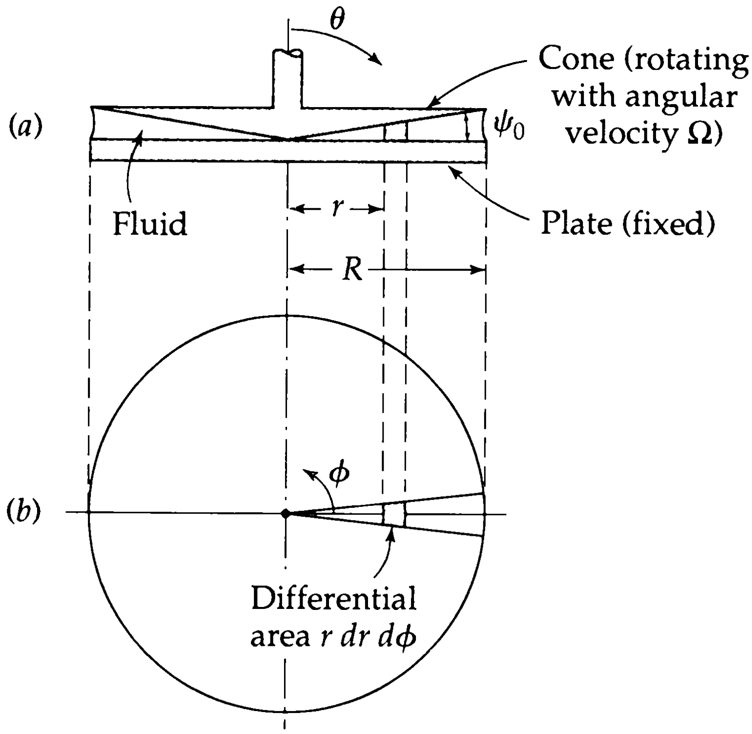

Figure 2.10: Cone and Plate Flow (From Bird et al., 1960)

The shear stress for this instrument can be calculated from the measured torque, Γ as follows:

$$\tau_0 = \frac{3\Gamma}{2\pi R^3}, \tag{2.28}$$

and the shear rate from the cone angular velocity, Ω:

$$\dot{\gamma} = \frac{\Omega}{\psi}. \tag{2.29}$$

By measuring the torque on the cone over a range of rotational velocities the flow curves can be determined, from which the rheological parameters (depending on flow model) are calculated.

The primary advantage of this instrument is that the shear stress is uniform throughout the shearing gap. This significantly simplifies the analysis process. The primary disadvantage of this means of viscometry is the maximum allowable particle size that can be tested in the instrument. This is due to the narrow gap width.

2.3 Clay Rheology

With pipeflow systems, slurries composed of fine particles with diameters less than 75 μm are considered homogeneous slurries where particles are assumed to be equally distributed over the pipe-cross-section (Shook et al., 2002). This investigation considered fine particle slurries with the predominate particle species being Kaolinite clay. The rheology of clay slurries is known to be significantly affected by surface chemistry effects. With the finest particles in the slurries used in this investigation (approximately $d_p \leq 1$ μm) colloidal behaviour would be anticipated (Masliyah and Bhattacharjee, 2006). These particles and their interactions strongly affect the fluid rheology. Due to the high surface area to mass ratio associated with the fine clay particles, attractive Van der Waals forces and electrostatic repulsion forces would be expected to play a dominant role in the particle interactions (Litzenberger 2003 and Coussot 1997).

When Van der Waals forces dominate, particles can form aggregates. The maximum size of the aggregates is in the order of 50 - 400 μm, also known as the process of flocculation (Michaels and Bolger, 1962).When the repulsive forces dominate the particles will not form aggregates and they will remain in a dispersed state. Slurry systems typically fall into a state which is between these limits of flocculation and dispersion depending on the solution chemistry.

According to Michaels and Bolger (1962), under acidic conditions the aluminium exposed at the edges of the Kaolin particles binds to hydrogen ions and assumes a positive charge. This causes electrostatic attraction between edges and faces which leads to the formation of "card house" flocs. Figure 2.11 illustrates the modes of particle associations that exist for plate-like particles such as Kaolin. Under alkali conditions, the edges become neutral or negatively charged, resulting in deflocculation.

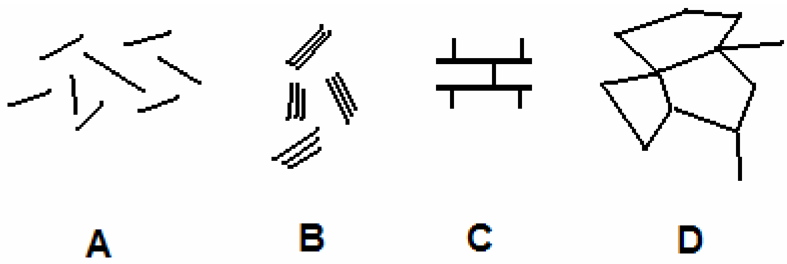

Figure 2.11: Plate-Like Particle Associations(Van Olphen 1977). A) Dispersed. B) Face to Face. C) Edge to Face (Card House). D) Edge to Edge

When strong attractive forces are present in highly concentrated Kaolin suspensions, non-Newtonian behaviour would be anticipated. Under these conditions, the apparent viscosity of the fluid decreases with increasing shear rate. Michaels and Bolger (1962) explain this behaviour by the shear forces pulling floc clusters apart as quickly as they are formed (by collision) during high shear, resulting in aggregate break-up. At low shear rates all the flocs are still contained in aggregates even though the aggregates may reduce in size. This process is illustrated in Figure 2.12.

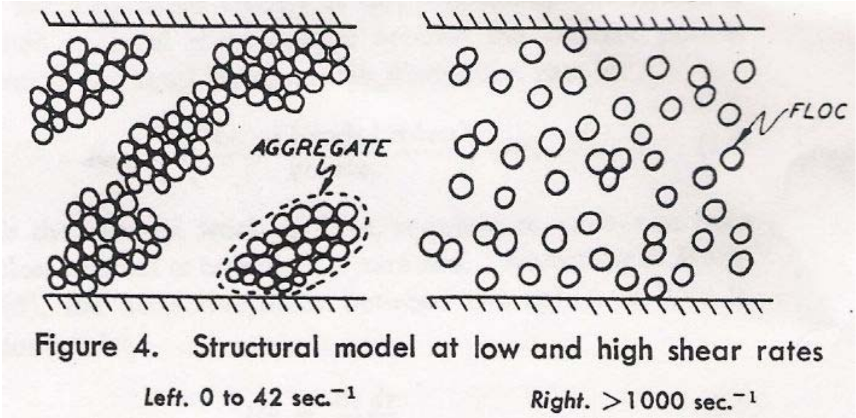

Figure 2.12: Floc and Aggregate Structures during Shear (From Michaels (1962)

For the suspensions described above, the two parameter Bingham model is often employed to represent the rheological behaviour since it incorporates both the existence of a yield stress, as well as a "viscosity" term. Thomas (1963) found that that the yield stress was proportional to the cube of the solids concentration and inversely proportional to the square of the particle diameter with the slurries that he investigated. The Bingham plastic viscosity term has been related to the Einstein equation which was derived by calculating the viscous energy loss due to the presence of dispersed non-attracting particles (Thomas 1965).

2.3.1 *Suspension yield stress*

As previously mentioned the yield stress of flocculated suspension has been found to be a direct function of the particle size and solids volume concentration, C_v. Thomas (1963) obtained the relationship based on a number of Kaolin slurry tests, which could be represented as follows:

$$\tau_y = A\frac{{C_v}^3}{{d_p}^2}. \tag{2.30}$$

A number of empirical correlations have been proposed to describe the yield stress dependence on suspension volume concentration (Coussot and Piau, 1995). The general form of these correlations is as shown below in Equation (2.31).

$$\tau_y = Ae^{BC_v}. \tag{2.31}$$

Where A and B are empirical coefficients to be fitted to the yield stress data.

Michaels and Bolger (1962) proposed a more intricate model where the yield stress was proportional to the square of the floc concentration. Their approach also included the introduction of an additional network strength contribution represented by $\left(C_{floc} - C_{0,floc}\right)^3$. The constant $C_{0,floc}$ is the minimum solids concentration required to form a continuous aggregate network.

More recently Zhou, Solomon, Scales, and Boger (1999) elaborated on a potential model for the yield stress based on mean field theory for particles governed by Van der Waal's forces. In this model the yield stress is computed as the sum of all pair wise inter-particle forces. Zhou et al. then applied this to a range of particle sizes. The geometric resistance, which produces the yield stress, is related to the number of particle contacts. Assuming the coordination number is given by Rumpf's expression as ${}^{3.1}/_{1-C_k}$ Zhou postulated that the yield stress could be scaled as a power function of ${}^{C_k}/_{1-C_k}$. The conclusion was that the maximum yield stress could then be written as (analogous to Equation (2.30)):

$$\tau_y = K\left(\frac{C_k}{1-C_k}\right)^c \frac{1}{{d_p}^2}. \tag{2.32}$$

Where c is a parameter to be fitted from experimental data, and the constant, K is defined as follows:

$$K = 3.1H_A \frac{b}{24\pi h_0 hh'} \tag{2.33}$$

where H_A is the Hamaker constant, h_0 is an inter-particle separation parameter, and b is a constant to be fitted experimentally.

Zhou explained the increase in yield stress with solids concentration due to the breakdown of weak links between flocs at low solids concentrations, and the rupture of inter-particle bonds and resistance to network deformation at high concentrations. This implies an existence of a critical solids concentration above which the exponential parameter, c, increases. This critical concentration was shown to range from 26%$_v$ to 44%$_v$ with aluminium suspensions, and to be dependent on the particle size.

2.3.2 *Bingham plastic viscosity*

The plastic viscosity term has been historically based on the Einstein relation for dispersed non-attracting particles (Michaels and Bolger, 1962):

$$\frac{\mu}{\mu_w} = 1 + 2.5C_v. \tag{2.34}$$

The above equation has often been the starting point for semi-empirical relationships for the viscosity term. Thomas (1963) further states that the viscosity term for any given suspension is constant when expressed as $ln(\mu/\mu_w)/_{C_v}$.

A number of expansions for the above relationships have been proposed. For example, the following empirical relationship was proposed by Thomas (1965) for low and moderate concentration non-interacting spheres:

$$\frac{\mu}{\mu_w} = 1 + 2.5C_v + 10{C_v}^2 + 0.00273e^{16.6\,C_v}. \tag{2.35}$$

However, the following empirical equation, suggested by Thomas (1999), is currently the most common method of representing the effect of solids concentration on the Bingham viscosity term:

$$K_B = Ae^{B\,C_v}, \tag{2.36}$$

where A, and B are empirical coefficients.

Since this equation, which is considerably simpler in form compared to Equation (2.35), has been shown to adequately represent the concentration effect, it will be employed in this study.

2.4 The Influence of the Addition of Coarse Particles

The rheological behaviour of a fluid to which particles has been added is dependent on a number of factors including the composition, density and viscosity of the carrier fluid, particle size and solids concentration. For the purposes of this investigation the following situations exist:

- The carrier fluid is composed of kaolin clay and an incompressible fluid (water). The properties of this mixture are governed by factors described in Section 2.3.
- Coarse, chemically inert particles are added to the clay-water mixture. The rheological properties of this slurry are determined by the characteristics of the clay-water mixture, interactions between coarse particles, and the interactions between coarse particles and clay-water mixture.

The two types of particles, carrier fluid and coarse, can be distinguished by the nature of the particle interactions. Mechanisms which impact the behaviour of coarse particle include hydrodynamic interactions, frictional effects, and particle-particle collisions. The important particle-particle mechanisms associated with the finer clay particles are associated with the ionized double layers generated when they are introduced into an aqueous solution. Due to significant differences in these mechanisms, the effect of the coarse particles will first be analyzed from the perspective addition to a Newtonian fluid. The effect of coarse particle addition to a non-Newtonian clay-water mixture will then be considered.

2.4.1 *Coarse particles in a Newtonian fluid*

The addition of solid particles to a Newtonian fluid causes an increase in the Newtonian viscosity providing the particles are suspended in the fluid and they are large enough that particle-particle attraction forces are not important. Einstein (Michaels and Bolger, 1962 and Thomas 1965) analysed the hydrodynamic effect of dilute concentration of spheres in a Newtonian carrier fluid, and developed Equation (2.34). A number of equations, such as Equation (2.35), have been developed using Equation (2.34) as their basis. Measurements conducted with well- rounded sand grains showed slightly higher viscosity values compared to those predicted by Equation (2.35). A new expression, Equation (2.37), was proposed to address this effect which was particularly evident at higher solids concentrations:

$$\frac{\mu}{\mu_w} = 1 + 2.5C_v + 10{C_v}^2 + 0.0019e^{20\,C_v}. \tag{2.37}$$

Studies conducted by Thomas (1999) suggested that the ratio ${C_v}/{C_{v,max}}$ is important for representing the effect of particle shape and size distributions, where $C_{v,max}$ is the volume concentration of the solids at maximum packing. Landel, Moser, and Bauman (1965) found that the viscosity increase due to the addition of a range of spherical and non-spherical particles of both narrow and wide particle size distributions could be represented as:

$$\frac{\mu}{\mu_w} = \left(1 - \frac{C_v}{C_{v,max}}\right)^{-2.5}. \tag{2.38}$$

Another correlation for both moderate and highly concentrated suspensions is the empirical equation developed by Chong, Christiansen, and Baer (1971) who fitted data to suspensions containing a wide variety of spherical particles:

$$\frac{\mu}{\mu_w} = \left(1 + \frac{3}{4\left(\frac{C_{v,max}}{C_v} - 1\right)}\right)^2. \tag{2.39}$$

One of the primary mechanisms causing the increase in Newtonian viscosity in these mixtures is hydrodynamic interaction, another being particle-particle interactions. Hydrodynamic interactions can be further classified into the excluded volume effect, and additional hydrodynamic effects, such as coarse particle wake-effects, and lubrication layers. It is further important to note that when hydrodynamic effects dominate the suspensions retains its Newtonian behaviour. These effects are summarised in Figure 2.13.

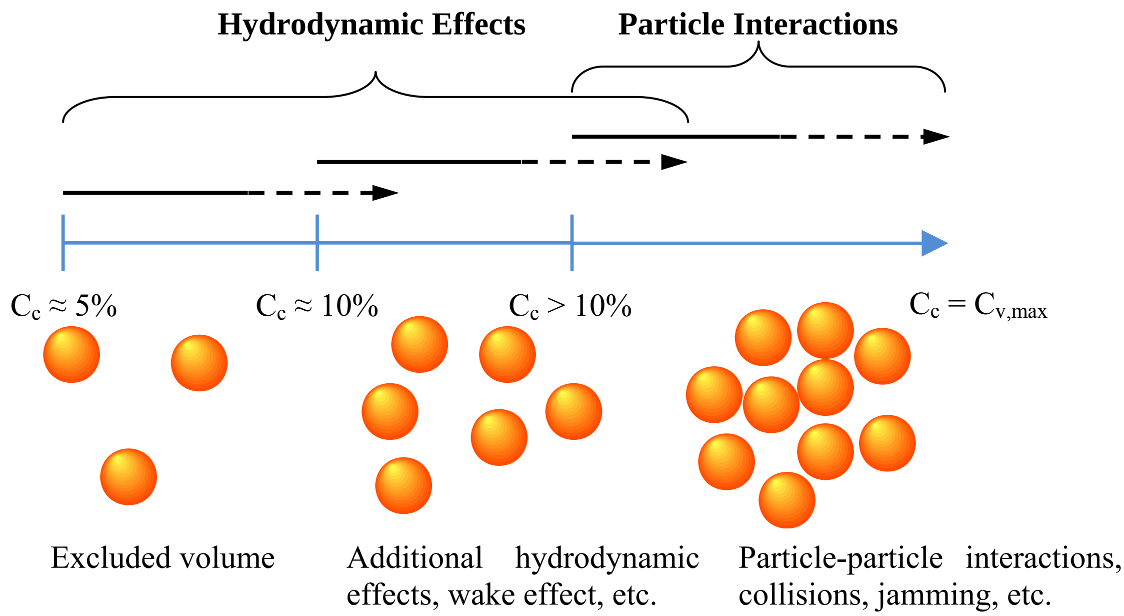

Figure 2.13: Summary of Coarse Particle Addition Effects in a Newtonian Fluid

Hydrodynamic effects-excluded volume

Assume the case of two spheres suspended in a homogenous fluid. The particles take up a certain volume previously occupied by the fluid, thus reducing the effective thickness of the sheared fluid, and increasing the overall viscosity of the fluid. This is the effect described by the Einstein equation, and is only applicable to concentrations of particles between 5% and 10% by volume. All variations from the original Einstein equation (Equation (2.34)) were an attempt to take into account the additional effects witnessed at higher concentrations.

Additional hydrodynamic effects

A further mechanism is the so-called wake-effect. When this occurs the wake caused by fluid motion and the particle presence influences neighbouring particle motion, increasing the forces required to maintain flow, and consequently increasing the fluid rheology.

As the concentration of the particles is increased they are increasingly brought closer to each other, and the force due to fluid flow between them increases, generally pushing the particles away from each other. This so-called lubricated contact is a form of hydrodynamic interaction, and occurs when the ratio of the diameter of the spheres to their separation distance is much larger than 1 (assuming that the interstitial flow is still laminar). This ratio is defined as follows for uniform spheres(Bagnold 1954):

$$\lambda = \left[\left(\frac{C_{v,max}}{C_v}\right)^{1/3} - 1\right]^{-1}. \qquad (2.40)$$

Particle interactions

Even higher concentrations may lead to direct contacts, collisions, and jamming (Ancey 2001). In order to distinguish between flow regimes and the major mechanisms at play dimensionless numbers are often used. In order to distinguish between direct contacts and lubricated flow Ancey further describes a dimensionless number T_{AD}, which defines the ratio of the squeezing force to the bouyant force expereinced by a particle. In highly concentrated suspensions where direct contact occurs frequently, gravity is transmitted through layers such that at a depth h:

$$T_{\mathrm{AD}} = \frac{9d_p}{8}\frac{\mathrm{K_B}\dot{\gamma}}{C_{v,max}\, ghH(\rho_s - \rho_f)}. \tag{2.41}$$

When T_{AD} << 0.1 there are generally no real contacts and the mixture properties are consequently governed by the interstitial fluid. When this is the case the Newtonian fluid imparts its Newtonian properties on the mixture. As the volume fraction tends to the maximum packing concentration the mixture viscosity tends towards infinity.

2.4.2 *Coarse particles in a non-Newtonian fluid*

The increase in apparent viscosity associated with the addition of coarse particles to a non-Newtonian fluid has been noted by a number of researchers including Ancey (2001), Coussot (1995), Sumner et al. (2000), and Thomas (1999). In addition, a number of empirical and semi-empirical models have been proposed to represent the mixture behaviour. Ancey (2001) suggests that the empirical models do not provide the mechanisms and interactions causing the effect. Little work has therefore been done to explain the mechanisms involved in coarse particle addition.

Further to the effects of coarse particle addition to Newtonian fluids discussed in the previous section, there are several possible effects that could occur when coarse particles are added to clay-water mixtures:

- For intermediate to low coarse particle concentrations considered in this investigation, the interstitial carrier fluid has the predominant influence on rheology, thus imparting its non-Newtonian (in the case of concentrated clay-water mixtures) properties on the mixture.
- There is an increase in dry solids surface. It is possible that a significant fraction of the water volume is immobilized on the added solids surface resulting in a net reduction in “free” water. As a result, the effective water fraction in the carrier fluid is reduced and therefore the apparent viscosity of the carrier fluid will increase.
- It is possible that a net attractive force could exist between the coarse particles and the clay particles. As a result, it is possible that the coarse particles become part of the floc-aggregate clay particle network. If this occurs, one

would anticipate an increase in yield stress with the heightened degree of networking between particles.

An important goal of this investigation is to determine the relative importance of these different mechanisms.

In their study of clay-water slurries containing coarse particles, Sengun and Probstein (1989) stated that the coarse fraction acts independantly of the clay-water mixture, and only contributes to the increase in rheology through an excluded volume mechanism, and particle interactions. Their experimental data obtained with coarse coal showed good agreement with this assumption providing the coal concentration did not exceed a moderate concentration of 30$\%_v$. Deviations from the excluded volume assumption were observed at higher concentrations. Sengun and Probstein corrected for the non-ideal effects by adding a shear rate correction and suggested that higher shear rates were the result of fluid being "squeezed" between particles

More recent work by Coussot (1995) also showed that the degree that the yield stress increases varied with coarse fraction concentration. Coussot suggest that the major coarse particle properties that affect the yield stress are coarse particle size, shape, and density. In another study Ancey (2001) showed that his yield stress results could be explained by dividing the coarse volume concentration into two regions. He proposed that at medium to low bulk concentrations (< 40 $\%_v$), the effect of coarse particles on the yield stress is governed by surface repulsion forces between kaolin clay and coarse particles resulting in significant changes in floc structures. For higher coarse particle concentrations (> 40 $\%_v$), the yield stress increase was observed to be very significant. Ancey suggested that a network forms between the coarse particles and the clay particles. The substantial increase in yield stress could also be explained by particle-particle interactions where there are increased direct contacts between coarse particles at the higher concentrations.

Wildemuth and Williams (1985) suggested the existance of yield stress in non-interacting coal particle suspensions was due to the dependance of maximum packing concentration on shear stress. It was shown that the yield stress should arise over a given range of solids concentrations following the relationship:

$$\tau_c = \sqrt[m]{\alpha \left(\frac{C_v/C_0 - 1}{1 - C_v/C_\infty} \right)}, \tag{2.42}$$

where α, m, C_0, and C_∞ are parameters. C_∞ corresponds to the high shear limit of the solids concentration, and C_0 the minimum or percolation threshold concentration.

Bearing the above factors in mind the primary mechanisms involved in coarse particle, and clay-water interactions are described below.

Brownian\colloidal particle interactions

If the particles in a given slurry are fine enough, collisions between liquid molecules, which exhibit random motion, and particles will influence the particle velocity. This is known as Brownian motion. These fluctuating forces give rise to rapid, disordered, rotational and translational motions of the particles resulting in dispersive effects (Van Olphen 1977).

The effect of Brownian motions will be negligible if the time needed by them to affect particle motion is large compared to that needed by flow. This ratio can be expressed in terms of a dimensionless parameter Peclet number, P_e (Coussot 1997):

$$P_\mathrm{e} = \frac{R^2\dot{\gamma}}{Diffusion\ Coefficient} = \frac{3\pi R^3 \tau_y}{k_B T}, \tag{2.43}$$

where k_B is the Boltzmann constant. This implies that if the Peclet number is much larger than 1, the effect of Brownian motion is negligible.

Effect of coarse particles on structure of fluid flow

As described in Section 2.4.1 when the coarse particles are separated by a thickness much larger than the clay diameter the coarse particles interact hydrodynamically, and the rheology increase varies with the parameter λ. When the concentration of coarse particles is sufficiently high contacts between them become more important, and the yield stress increases with ${C_c}^3$. In order to distinguish between these two phenomena Ancey (2001) defined a dimensionless parameter describing the ratio of the buoyant force to the yield strength:

$$N=\frac{2}{3}\frac{\rho_b(\rho_s-\rho_f)gd_p}{\tau_{yc}}. \tag{2.44}$$

When $N \gg 1$ contacts between the coarse particles are direct, and when $N \ll 1$ the coarse particles are lubricated by the interstitial fluid.

Fine and coarse particle interactions

Coarse particles could become integrated into the floc structure, thus changing the floc structure, and consequently affecting the yield stress. According to Sumner et al. (2000), an increase in yield stress greater than the cubic relationship ${}^{1}/_{(1-C_c)^3}$ could suggest a change such that the floc size approaches that of the coarse particles. This assumes that the increase in yield stress results from a decrease in the distance between flocs and the subsequent increase in the probability of floc-floc interactions. This explanation assumes that attractive/repulsive forces associated with the coarse particles are not important. When the size of the particle is much larger than the floc, the presence of the particle does not significantly affect floc-floc interaction. When the size of the particle approaches that of the floc, the coarse particle would cause a crowding effect. Under these circumstances, the effect of the coarse particle on floc-floc interactions would be further complicated by the shielding effect of the coarse particles which would affect the level of the yield stress.

The effect of coarse particle addition on the value of the dynamic plastic viscosity, K_B, was also considered. Sumner et al. (2000) suggested that if the increase in plastic viscosity is more rapid than that predicted by the relationships in Equations (2.37) and (2.39), this would imply that the floc and coarse particle sizes are very different. This was the case observed in this study. However, the yield stress increased more than the relationship ${}^{1}/_{(1-C_c)^3}$ predicted which would suggest that there was some degree of interaction between the coarse particles and the flocs.

Another possible interaction mechanism is associated with depletion which is observed with colloidal dispersions in polymeric liquids (Asakura and Oosawa, 1954). Consider two parallel plates immersed in a solution of rigid spherical macromolecules. If these plates are separated by a distance less than the particle diameter, no particles can enter between them, resulting in a solution devoid of particles between the plates. This increases the local concentration of macromolecules outside of the plates. For the slurries considered in this study, it is possible that clay particles behave in a manner similar to the macromolecules in the space between large particles or between a large particle and the wall of the viscometer (Ancey 2000). This induces a slight increase in the effective solid concentration in clay. This effect is illustrated in Figure 2.14.

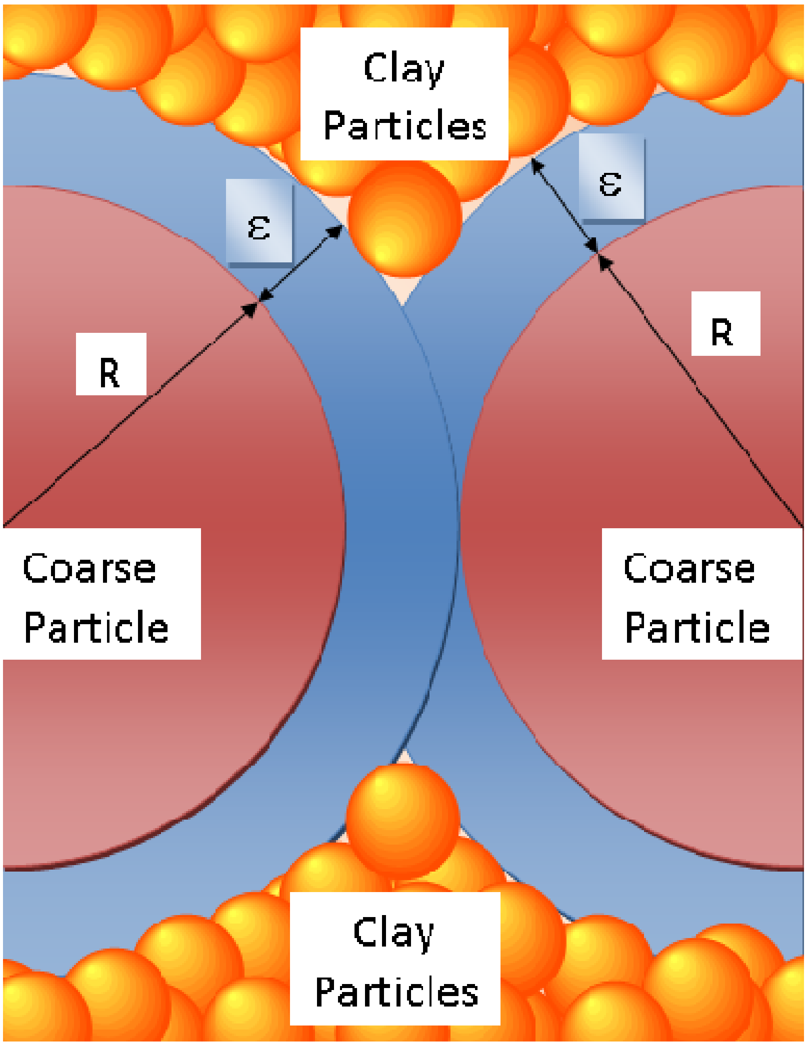

Figure 2.14: Depletion Effect Illustration

To evaluate this effect, it is assumed that the depletion thickness, , occurs between the coarse particles where clay particles are expelled. The Kaolin concentration is now:

which can be represented by:

$$= \frac{V_b(1 - C_c)C_k}{V_b(1 - C_c) - \frac{4}{3}n_c\pi[(R + \varepsilon)^3 - R^3]}$$

which reduces to:

$$= \frac{C_k}{1 - \frac{[(R + \varepsilon)^3 - R^3]}{R^3}\frac{C_k}{1 - C_k}} \tag{2.45}$$

and represents the relationship for the modified clay concentration. Based on geometric constraints, Ancey (2000) showed that the depletion layer should be in the order of:

$$\varepsilon = \frac{5d_p C_k}{32}. \tag{2.46}$$

Now, by applying Equation (2.32), the modified bulk yield stress due to depletion, as a result of the presence of the coarse particles, is represented as:

$$\tau_y = K\left(\frac{\widetilde{C_k}}{1 - \widetilde{C_k}}\right)^c \frac{1 - C_c}{{d_p}^2}. \tag{2.47}$$

Ancey determined that the values inferred for ε were as much as 70 times higher than that predicted by geometric constraints. This implies that if depletion is the correct explanation it does not originate from geometric constraints but more likely from surface repulsion forces or significant changes in floc structures.

It is important to note that this model suggests that the depletion zone occurs over the entire particle rather than in specific regions where the coarse particle comes in close contact with another particle. For this reason not too much gravity should be placed on this model. The uptake of water to wet the surface of the dry coarse particles could offer a potential explanation for a zone of water near the surface of the sand. This depleted zone at the surface of the particles will be several molecules thick and is associated with the water molecule, particle surface interaction. Typically this layer is in the order of 3-10 molecules of water, or approximately 0.8 - 3.0 nm, thick (Grim and Cuthbert, 1945).

Semi empirical relationships

A number of researchers have presented empirical and semi-empirical equations to relate the increase in rheology to coarse particle properties. These relationships are based on the effect of coarse particles on the structure of fluid flow, involving physical properties of the coarse fraction (maximum packing concentration, and/or particle size). One such relationship was proposed by Thomas (1999) which is analogous to Equation (2.38):

$$\frac{\tau_{yb}}{\tau_{yk}} = \left(1 - \frac{C_v}{A\,C_{v,max}}\right)^{-2.5}, \tag{2.48}$$

where A is a correlation parameter found to be of the order 1.5. A similar relationship was developed by Thomas for the Bingham viscosity:

$$\frac{K_b}{K_k} = \left(1 - \frac{C_v}{A\,C_{v,max}}\right)^{-2.5}. \tag{2.49}$$

Good correlation with the above relationships were obtained with sand concentrations less 35%$_v$. Thomas further extended the correlation by substituting the above relationships in the empirical Equations (2.31) and (2.36).

Schaan, Sumner, Gillies, and Shook (2000) showed that the increase in the rheological parameters for Bingham suspensions is generally a function of the distance ratio, λ:

$$\frac{\tau_{yb}}{\tau_{yk}} \text{ and } \frac{K_b}{K_k} = \mathrm{f}(\lambda) = \left(1 + A\lambda^B\right). \tag{2.50}$$

Ancey (2001) developed another equation by extending the empirical model proposed by Wildemuth and Williams (Equation (2.42)) to the case where the interstitial fluid was a viscoplastic fluid. He proposed that the bulk yield stress is composed of a coarse particle and clay-water contribution. The bulk yield stress is then expressed as:

$$\tau_c = \tau_{yk} \left[1 + \alpha \left(\frac{{C_c}/{C_k} - 1}{1 - {C_c}/{1 - C_k}} \right)^{1/m} \right]. \tag{2.51}$$

Ancey found good correlation using the above relationship for the entire range of concentrations tested ($0.3 < C_b < 0.7$). Furthermore it was determined that the parameters α, and m were constant regardless of the Kaolin clay concentration, implying that the Kaolin concentration had little to no effect on the increase in apparent viscosity due to coarse fraction addition.

Zhou et al. (1999) proposed that for bimodal mixtures, there exists some average particle radius, $\bar{r}$, which would produce the same yield stress as the mixture. A yield stress ratio can be defined based on this average radius:

$$\frac{\tau_{y,bimodal}}{\tau_{y,mono}} = \frac{\tau_{yb}}{\tau_{yk}} = \left(\frac{\frac{r_k}{\bar{r}} + \frac{r_c}{\bar{r}} - 1}{\frac{r_k r_c}{\bar{r}^2}} \right)^2. \tag{2.52}$$

These are the primary correlations that will be investigated and compared to test data, with a view to better understanding the mechanisms involved in coarse particle addition to clay-water suspensions.

3. MATERIALS, APPARATUS AND PROCEDURES

3.1 Materials

The materials used in this project were the following:

- Reverse osmosis water
- Pioneer Kaolin
- Lane Mountain silica sand
- Ottawa silica sand
- Quackenbush glass beads.

For the purpose of consistency, the coarse fractions were selected such that the solids densities and particle size distributions were similar. In this way, the effect of particle shape on the measured rheological properties could be determined. In cases where the obtained coarse fractions had dissimilar particle sizes, subsequent screening of the particles was performed to provide the desired distributions.

3.1.1 Reverse osmosis water

Reverse osmosis water was used for all experiments in this research project which was obtained from the University of Saskatchewan Department of Chemical Engineering. This was done in order to maintain consistency throughout the test work as municipal water properties contain significant levels of ions which are known to affect clay slurry rheology.

3.1.2 Pioneer Kaolin

The Pioneer clay was obtained from Dry Branch Kaolin Clay Company, in Dry Branch GA, USA. For the sake of consistency, the clay used for all experiments was obtained from a single 25 kg bag of the Pioneer clay. General supplier provided properties are presented in Table 3.1. Specific details regarding the surface and clay properties can be found in Litzenberger (2003).

Table 3.1: Supplier Provided Kaolin Properties

Property	**Value**
Particle size < 2 μm	55-65 %
Mean particle size	1.0-1.2 μm
44 μm Retained fraction	0.75 % maximum
20%v Slurry pH	4.0-6.5

3.1.3 Lane Mountain sand

Lane Mountain Silica sand, which was obtained from the Lane Mountain Company in Valley, WA, USA, was used as one of the coarse sand fractions. Lane Mountain sand is industrially ground. As a result, the particles have highly angular shapes.

All of the Lane sand used in this experimental program was obtained from a single 25 kg bag of LM #150 sand. The properties of the LM#150 sand were provided by the supplier and are presented in Table 3.2. Due to the relatively high fines fraction (20-40% <75 μm) of this sand, the main sample was screened at 75 μm using a shaker, and 75 μm sieve. Only the + 75 μm sand was retained for subsequent tests. This ensured that only a very small fraction of fines was added with the coarse fraction to the Kaolin slurry.

Table 3.2: Supplier Provided Lane Mountain Sand Properties

Property	**Value**
Specific gravity	2.2-2.5
Size 425 μm 300 μm 212 μm 150 μm 103 μm 75 μm Pan	Fraction retained 0 % 0-2 % 0-5 % 0-10 % 15-25 % 30-50 % 20-40 %
Packing concentration	56.4-71.4%v

3.1.4 Ottawa sand

Ottawa Silica sand, obtained from US Silica in Ottawa, IL, USA, represented another sand used in the experimental program. Ottawa foundry sand is a well-rounded, river sand. Although this sand has the same density and similar particle size distribution to that of the Lane Mountain sand, its spheroid shape is quite different from the angular shape of the Lane sand.

One 5 kg sample of F-110 sand was used to provide sand sub-samples for this research project. The characteristics of the F-110 sand were provided by the Supplier and are shown in Table 3.3. The particle size distribution data indicates that there is a significant fraction of -75 μm (9.9% < 75 μm) and + 212 μm particles fraction compared to the Lane Mountain sand. These sand fractions were removed from the sample used in test by screening the 5 kg sample using the appropriate sieves.

Table 3.3: Supplier Provided Ottawa Sand Properties

Property	**Value**
Specific gravity	2.65
Size	Fraction retained
425 μm	0 %
300 μm	0.2 %
212 μm	4.5 %
150 μm	20.0 %
103 μm	38.4 %
75 μm	27.0 %
Pan	9.9 %

3.1.5 Quackenbush glass beads

Quackenbush glass beads, obtained from the Quackenbush Company, Inc in Crystal Lake, IL, USA, were also employed as a coarse particle fraction in this study. The glass beads are uniformly spherical, with a very narrow particle size range.

A single 25 kg bag of Quackenbush glass beads was used in this research project. The properties of the glass beads were provided by the supplier and are presented in Table 3.4. The fines (-75 μm) and +212 μm fractions were removed from the received sample to provide consistency with the sands.

Table 3.4: Supplier Provided Quackenbush Glass Properties

Property	**Value**
Specific gravity	2.50
Size	Fraction retained
425 μm	0.0%
300 μm	0.0%
212 μm	0.0%
150 μm	0.0 %
103 μm	54.6%
75 μm	39.4%
Pan	6.0%

3.2 Material Properties

3.2.1 Slurry density and concentrations

Slurry densities were determined by weighing a mass of sample in a 200 ml flask, and using water to fill the remainder of the flask in order to determine the exact slurry volume. A vacuum was applied to remove any entrained air bubbles. The density was calculated from the readings as follows:

$$\rho_m = \frac{M_m}{0.2 - \frac{M_w}{\rho_w}}. \tag{3.1}$$

The total solids weight concentration was determined by drying a known mass of sample in an oven for a minimum of 8 hours. The weight concentration is then determined by:

$$C_w = \frac{M_s}{M_m}. \tag{3.2}$$

The solids volume concentration is then determined from the mixture density and weight concentration as follows:

$$C_v = \frac{\rho_m}{\rho_s} C_w. \tag{3.3}$$

The coarse fraction volume concentration is defined as the total volume of coarse particles divided by the total mixture volume.

The total solids volume concentration is expressed as:

$$C_{vb} = C_{vc} + C_{vk}(1 - C_{vc}), \quad (3.4)$$

where the total volume concentration is determined from the measured density and weight concentrations as follows:

$$C_{vb} = \frac{\rho_w + \rho_b(C_{wb} - 1)}{\rho_w}. \quad (3.5)$$

The sand volume concentration is therefore calculated from the known total volume and clay concentrations.

3.2.2 Particle density

The experimental setup used to measure the particle density is shown in Figure 3.1. The particle solids density was determined by mixing the solids with water and placing it in a 200 ml flask. A vacuum was applied to the flask to remove any entrained air. After a minimum of 20 minutes the vacuum was removed and the flask was filled to the 200 ml mark using water. The slurry was removed and dried in an oven. The particle solids density is then calculated as follows:

$$\rho_s = \frac{M_s}{0.2 - \frac{M_w}{\rho_w}}. \quad (3.6)$$

Figure 3.1: Solids Density Experimental Setup

3.2.3 *Maximum settled bed concentration*

The maximum settled bed concentration is calculated by allowing a known mass of coarse particles to completely settle in a 1 litre volumetric flask. Once the particles have completely settled, the volume of the settled bed is determined and compared to the volume of solids added. The experimental setup is illustrated in Figure 3.2. The maximum settled bed concentration is calculated as follows:

$$C_{v,max} = \frac{M_s}{\rho_s V_{bed}}. \tag{3.7}$$

This material property represents the maximum random packing of particles in a bed. For spherical particles, the maximum concentration is approximately 0.63 (Ancey 2001) and Shook et. al, 1991). As has been stated in earlier research (Schaan et al., 2000) this parameter gives a good indication of the particle shape relative to a sphere (sphericity). Highly angular particles have $C_{v,max}$ much less than 0.63 and samples of particles approach 0.63 as the shape become more spherical.

Figure 3.2: Maximum Settled Bed Concentration Experimental Setup

3.2.4 Particle size distribution

The method used to determine particle size distribution depends on the size range of the particle to be measured. In general, coarser materials are classified using sieving methods. With finer particles, techniques such as wet sieving, laser sizing and sedimentation must be used.

The size distribution of the coarse particles was determined using standard sieve sizes. Particle size ranges above 75 μm were dry sieved. Dry sieving entails placing the coarse material on a predetermined stack of sieves and shaking the sieves for 15 minute intervals using an industrial shaker. The fractions retained on each sieve were then weighed and recorded. Smaller size ranges (between 75 and 45 μm) were wet sieved. Only a small fraction of solids were found in this range since all of the coarse particles were previous screened to provide a + 75 μm size distribution. During the wet sieving procedure, water is rinsed through the sieves to ensure all the fine material is passed through the sieve stack. The solids are then collected and dried in an oven.

The particle size distribution of the Kaolin clay particles was determined using an Andreasen pipette. The Andreasen pipette has been proven to successfully determine fine Kaolin clay particle size distributions (Loomis 1938, and Litzenberger 2003), and was therefore deemed suitable for this project. The Andreasen pipette method is useful for sub-sieve particle sizes. It classifies particle size based on the sedimentation rate of the particles in a viscous fluid. This method is only applicable for particles between 45 µm and 0.6 µm. This technique is not applicable for particles smaller than 0.6 µm because the settling rate is influenced by Brownian motion as discussed in Section 2.4.2.

The equivalent spherical diameter of a particle settling under gravity in the Stokes region under gravity can be determined using the following equation:

$$d_p = \sqrt{\frac{18h\mu}{2(\rho_s - \rho_w)gt}}. \tag{3.8}$$

The following assumptions apply when using the Andreasen pipette (Loomis, 1938):

- The particles immediately reach terminal settling velocity.
- The particle concentration is sufficiently low to ensure that hindered settling effects are insignificant.
- The settling vessel diameter is significantly larger than the particle size. This ensures that particle-wall effects are negligible.
- Since it is assumed a single particle is settling in the Stokes region, it is important that there are no flocculated particles. This is ensured by adding the dispersant tetrasodium pyrophosphate (TSPP) to the slurry.
- The liquid in the cylinder is quiescent.

The Andreasen pipette is illustrated in Figure 3.3. The stem of the pipette is inserted into a graduated 550 ml glass cylinder. The pipette extends 20 cm below the surface of the fluid and is elevated ≈ 4 cm off the bottom of the cylinder. A 3-way stopcock arrangement is positioned at the top of the pipette to facilitate sample collection.

Figure 3.3: Andreasen Sedimentation Pipette

The following procedure is a summary of the procedure described by Loomis (1938) for determining grain sizes of white ware clays.

1. Weigh out a sufficient mass of solid material (clay) so that upon dilution, a 1 % by volume solids slurry will exist. One must make sure that a representative sample of clay is obtained from the source so that an accurate particle size

distribution can be obtained. This is achieved by removing the clay from the bag, and placing it in a large, clean drum. The clay is then manually mixed with a handheld spade.

2. For a separate sample, determine the moisture content to determine the true particle mass percent.

3. Prepare the suspension so that a high degree of dispersion is obtained. In all cases tetrasodium pyrophosphate ($Na_4P_2O_7$) was added at 0.002 g-mol/L and RO water was used as the medium (Loomis, 1938).

4. Transfer the dispersed sample to the Andreasen Pipette and add RO water up to the 20 cm mark.

5. Before the test is initiated, sufficient time should be permitted to allow the slurry to come to thermal equilibrium with the room. This is achieved by standing the container with the slurry in the room for a minimum of 30 minutes. Insert a stopper in the pipette and shake the apparatus vigorously.

6. Once thermal equilibrium is obtained with the room, the apparatus should once again be shaken for approximately 2 minutes to ensure that the particles are homogeneously distributed within the cylinder. The exact time when the shaking is stopped is noted.

7. Take the first sample from the apparatus with the pipette bulb immediately by drawing 10 ml of slurry into the pipette. A reasonable sampling time is approximately 20 seconds. If the sample is drawn too fast one might create a disturbance within the apparatus and thus the quiescent fluid assumption will not be valid. All results obtained after this sample will therefore be biased by the first sample.

8. Drain the sample into a pre-weighed crucible (weighing vessel) and immediately weigh the sample. Then place the sample in an oven and dry it until all moisture is eliminated from the slurry. Once again weigh the sample.

One can now calculate the mass percent of solids in the slurry.

9. Withdraw samples from the Andreasen pipette at the appropriate intervals and weigh and dry samples.

10. The particle size distribution of the particles can be obtained by interpreting the time variation of the solids concentration obtained from sampling.

3.2.5 pH Measurement

The pH of all of the slurries generated for tests was determined using Fisher Scientific pH indicator paper with a range of 5.0 - 10.0 and accuracy of 5%. A pH probe was available, however problems had been experienced with measuring pH of particulate suspensions with the probe (Sumner, 2007) and it was consequently not used. Since the measured pH was constant during the test work, and due to the reproducibility of the flow curve data (see Section 4.4.1) this error is deemed acceptable. The pH was monitored at all times to ensure that the pH of the slurry was constant.

3.2.6 Temperature measurement

The temperature of all fluids tested in the viscometer was maintained at a constant temperature of 25 °C. The temperature of the slurry was maintained by circulating water through a heat exchange jacket on the outside of the viscometer cup. The temperature of the water was maintained at 25 °C through the use of a PolyScience 9005 constant temperature bath. The accuracy of this unit is ± 0.1 °C.

3.2.7 Micrographs

Micrographs were taken of the coarse particles using a Nikon ME 600 Eclipse microscope set at 10 × magnification and a Nikon Coolpix 990 digital camera. The micrographs were used to illustrate the difference in shape of the different coarse particles tested.

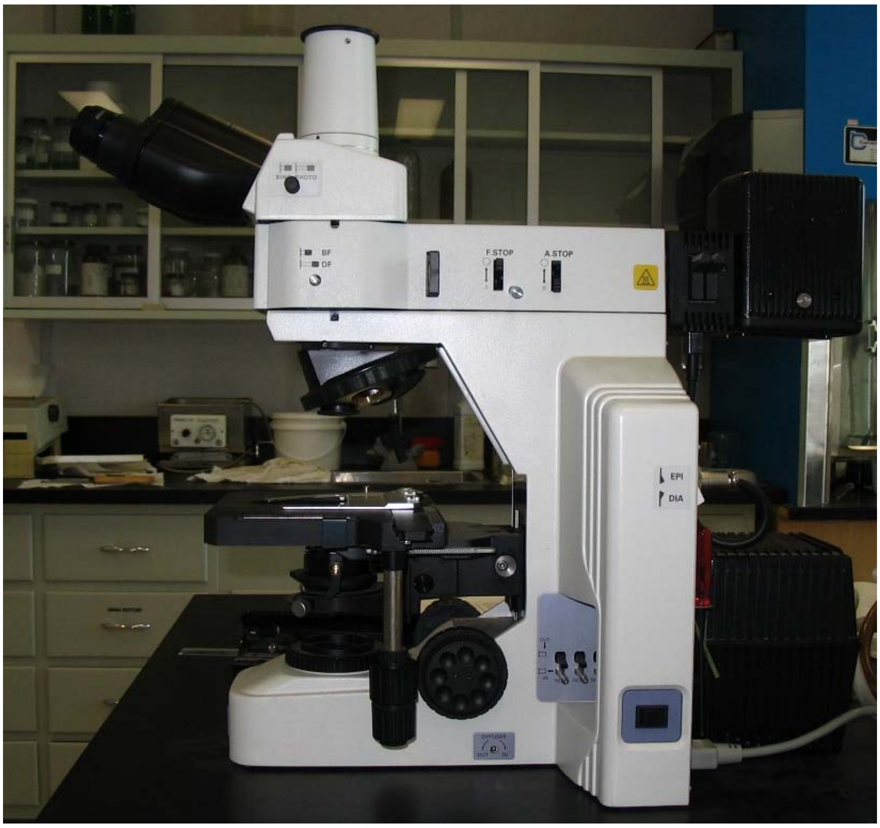

Figure 3.4: Nikon Microscope

3.3 Rotational (Couette Flow) Viscometer

3.3.1 Instrumentation and calibration

A Haake Rotovisco 3 (RV 3) Concentric Cylinder Viscometer (Haake, Inc., Saddlebrook, NJ, USA) was initially used to perform the viscometer experiments. During the course of these tests, the motor drive for the RV 3 unit failed. A Haake Rotovisco RV 12 unit was used to complete the viscometer tests. The operation of the older RV 12 unit is identical to that of the RV 3. The viscometer system consists of a drive, measuring head, sensor system, control console and chart recorder. A cup of radius 21.00 mm and a spindle of radius 20.04 mm were used with tests performed with both the RV 3 and RV 12 models. The RV 3 Unit configuration is shown in Figure 3.5.

Figure 3.5: RV 3 Viscometer Unit

Two spring torque heads were used with the RV3 unit. These are the MK50 and MK 500 configurations. Both these heads were calibrated using standard viscometer oils.

The MK 50 drive was calibrated using the Cannon S20 viscometer standard oil (State College, PA, USA). The MK500 drive was calibrated using the Cannon S200 viscometer oil. The tests were performed at two different temperatures (25 and 20 °C).

The RV 12 unit has only one torque head configuration only, the MK 150 unit. This unit was calibrated using both the S20 and S200 viscometer standard oils.

The torque heads are initially calibrated by the manufacturer and the full-scale torque associated with the head is stamped on the unit. Verification of the instrument is conducted by comparing the Newtonian viscosity value predicted by the instrument to the value provided by the standard oil manufacturer. Any difference between these two values can be attributed to inaccuracy in the full-scale torque of the head. A summary of the viscometer verification results is shown in Table 3.5.

Table 3.5: Viscometer Validation Summary

Drive	Spring Constant	Viscosity Error
MK 50	0.0043 N.m	±7.0%
MK 500	0.0450 N.m	±3.8%
MK 125	0.0148 N.m	±2.3%

The typical verification charts for the MK 50 and MK 500 configurations are shown in Figure 3.6 and Figure 3.7 respectively. A typical verification chart for the MK 150 is shown in Figure 3.8. Details of the verification tests can be found in Appendix B.

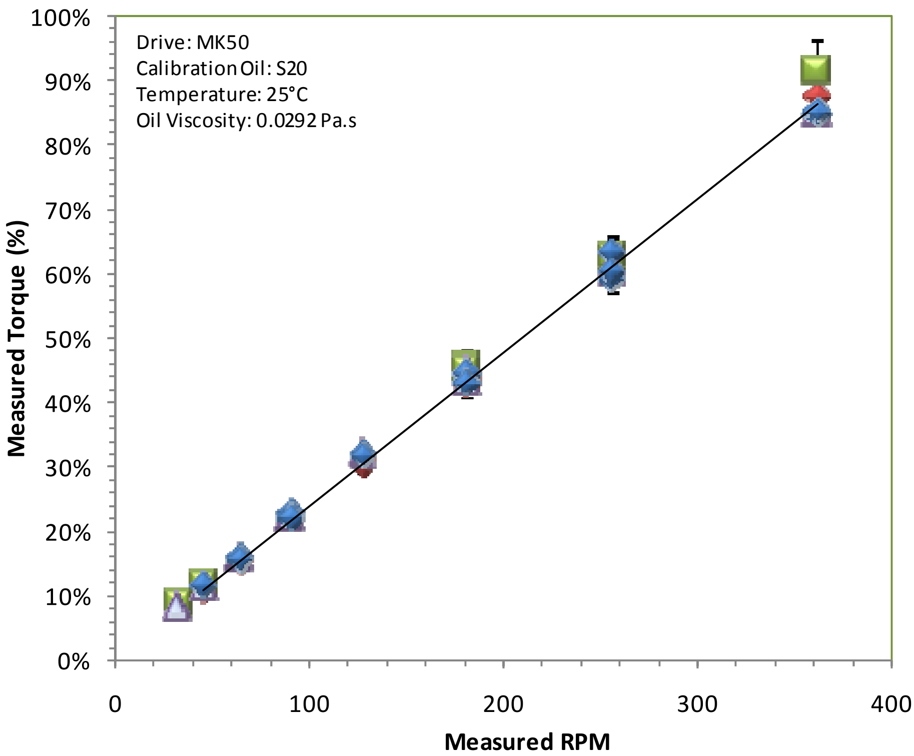

Figure 3.6: MK 50 Validation Curves

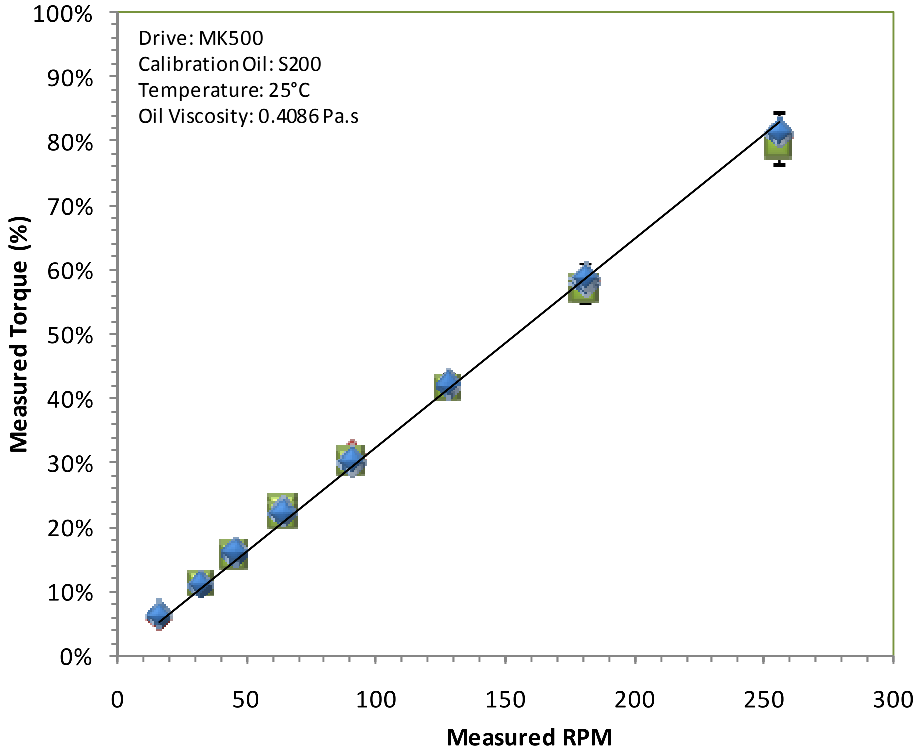

Figure 3.7: MK 500 Validation Curves

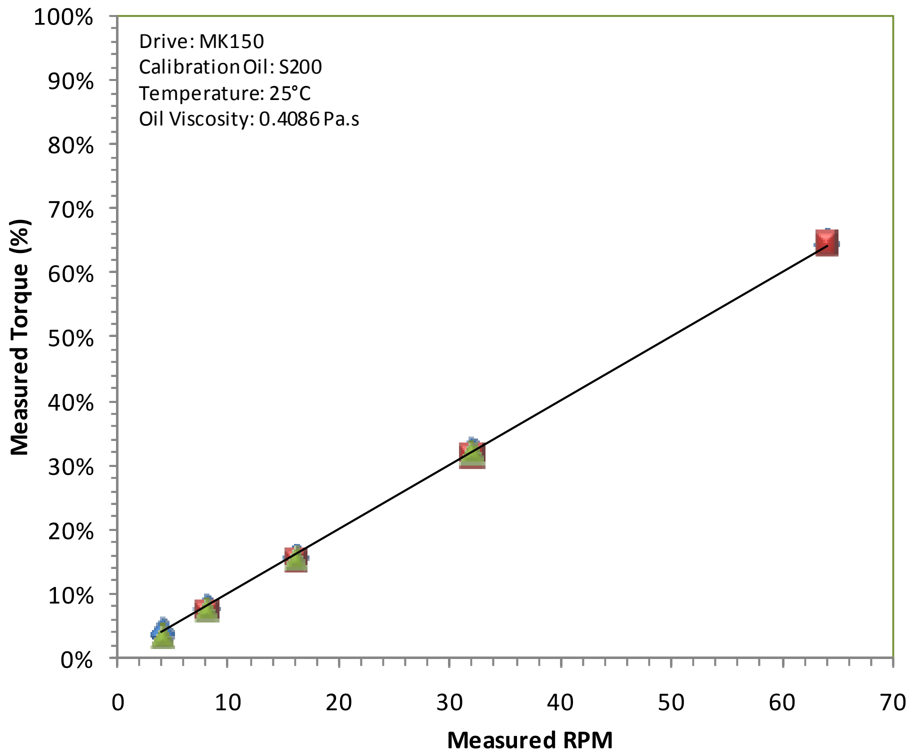

Figure 3.8: MK 150 Validation Curves

The verification results obtained with the standard fluid can be used to develop a correction function. This correction function is used in the software used to predict the rheological parameters from the viscometer measurements. As a result, the inaccuracy of the torque head can be compensated for.

For vane yield stress tests the FL10 and FL100 vanes were used. No calibration of these devices was necessary since the same drive was used as in the rotational viscometer tests.

3.3.2 Operation

Rotational viscometer tests

Based on the slurry rheology the viscometer minimum and maximum speed ranges are determined using Equations (2.15), (2.16), and (2.17) respectively. It is ensured that the predicted torque range expected falls within the viscometer head range.

The viscometer was zeroed with the spindle running at a midpoint speed for the required range, and the slurry then placed in the viscometer cup, and allowed to obtain constant temperature at maximum speed (for approximately 15 minutes). Once the torque value stabilised, measurements were taken, by decreasing the spindle speed, and taking the torque readings once the values had stabilised. Once minimum speed was reached the speed was again increased, and the process is repeated. Typically it took approximately 30 s for the torque values to stabilise at a speed. The torque values obtained at the same speed at the start and end of a test were compared to determine the effect of any time varying effects including particle settling. Typically, the total time per test was 24 minutes.

A typical rotational viscometer test is shown in Figure 3.9. The chart illustrates the operating rotational velocity range, as well as the appropriateness of the Bingham model fit. The test also indicates the typical time independent behaviour as the data set was obtained by running the same sample in up and down ramp rotational speeds.

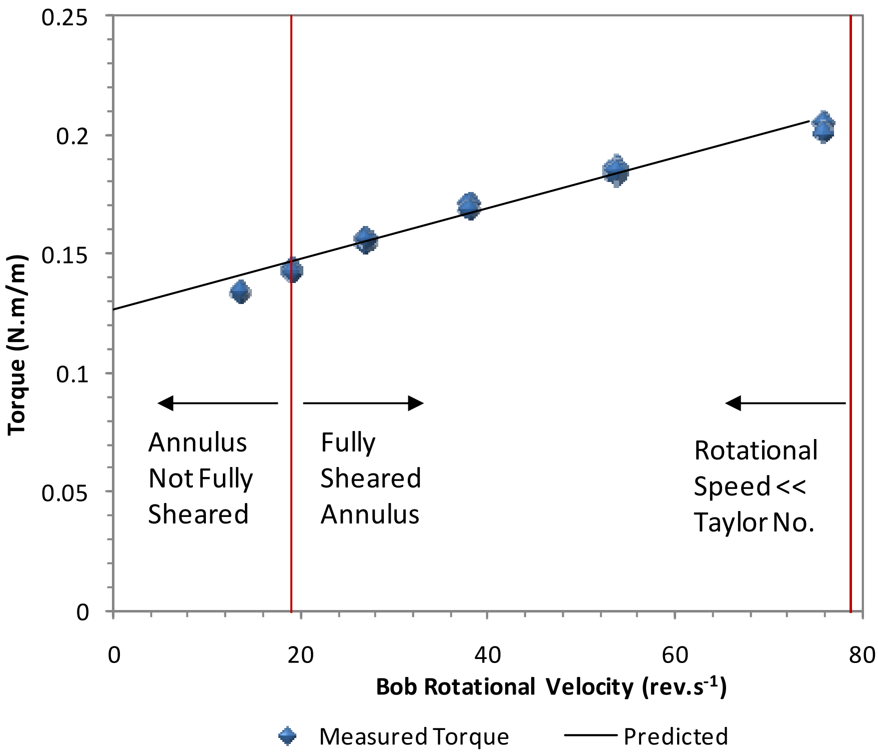

Figure 3.9: Typical Couette Viscometer Output Plot

Prior to a test series the viscometer was run at the minimum speed and the torque value was monitored to ensure that no settling took place. The onset of settling in the viscometer (resulting in fluctuations of the measured torque) however took significantly longer than the duration of a test. The shortest time of significant settling measured was in the order of 1 hour.

A typical data set obtained from a viscometer test is shown in Appendix A. Upon completion of the test, the slurry was discarded and all of the instrumentation was thoroughly cleaned.

Vane tests

A trial and error method was used to determine the appropriate choice of vane for a given slurry. The basis for selecting the vane was based on the full-scale torque generated in the test where torque values must fall within a range of 10 – 80% of maximum viscometer torque. This ensured that an accurate value was obtained.

The viscometer torque reading was zeroed at 0.01 rpm with the vane connected. Slurry was placed in a sufficiently large vessel. The diameter of the vessel must be greater twice the diameter of the vane and the height of the vessel must be greater than the sum of the vane diameter and height multiplied by two (Nyguyen and Boger, 1983). The vane was slowly immersed into the slurry to limit the degree of shearing. Once the vane was completely immersed the vane was rotated at 0.01 rpm (the peak torque is not influenced by the rotational rate, only the rate at which the torque increases), and the maximum torque reading registered (which corresponds to the yield point of the fluid) was noted. The vane was removed and the slurry sample was then lightly shaken in order to re-stabilise its structure. The measurement procedure was repeated two more times with the same slurry. The static (vane) yield stress presented in this study was the value obtained from averaging the three readings.

A typical vane test output is shown in Appendix A.

3.3.3 General test procedure and matrix

The viscometer test work procedure was as follows:

1. Makeup a fresh batch of Kaolin slurry using reverse osmosis water.

2. Determine the density and mass based composition of the homogenous slurry mixture.

3. Complete concentric cylinder and vane viscometer tests on the fresh sample. The correct viscometer drive configuration is determined by previous experience where the slurry density was used as guidance.

4. Obtain a 500 ml sample of the slurry and add the desired amount of sand. Mix the sample thoroughly.

5. Complete a concentric cylinder and vane viscometer test on this slurry mixture.

6. Take a sample of the slurry mixture containing the coarse particles for drying tests, and a second sample for density tests.

7. Using a 75 µm sieve, remove the coarse sand from the slurry and collect the carrier fluid.

8. Complete density tests, concentric cylinder and vane viscometer tests, and vane on the sieved Kaolin slurry.

9. Repeat the procedure outlined above for 5 different coarse particle concentrations (5%, 10%, 15% and 20% sand by total volume of mixture).

10. Repeat all the above for a range of Kaolin clay volume concentrations. Ranging from 16.7%$_v$ to 25%$_v$ Kaolin clay on a total slurry basis

11. Repeat the above process with all of the coarse particles identified for this study.

The test work matrix is shown in Table 3.6. It should be noted that all concentrations show in this table are on a volume basis.

Table 3.6: Test Work Matrix

Sand Concentration	Kaolin Concentration	17%	18%	19%	20%	21%	22%
Lane Mountain Sand	5%	✓	✓	✓	✓	✓	✓
	10%	✓	✓	✓	✓	✓	✓
	15%	✓	✓	✓	✓	✓	✓
	20%	✓	✓	✓	✓	✓	✓
Ottawa River Sand	5%	✓	✓	✓	✓	✗	✗
	10%	✓	✓	✓	✓	✗	✗
	15%	✓	✓	✓	✓	✗	✗
	20%	✓	✓	✓	✓	✗	✗
Quackenbush Glass	5%	✓	✓	✓	✓	✗	✗
	10%	✓	✓	✓	✓	✗	✗
	15%	✓	✓	✓	✓	✗	✗
	20%	✓	✓	✓	✓	✗	✗

4. RESULTS AND DISCUSSION

4.1 Introduction

Initial tests were aimed at determining the effect of coarse particle addition on the rheological parameters (Bingham yield stress and plastic viscosity) of the Kaolin slurries. Initially, the Lane Mountain sand was investigated. Repetitions were completed at all coarse particle fractions tested and at the highest and lowest Kaolin concentrations (16.8%$_v$ and 25.6%$_v$ respectively).

The coarse fraction was removed and the remaining Kaolin clay slurry was tested in order to determine if any physical change in the clay to water ratio or rheological parameters occurred during the sand addition. Upon completion of the Lane Mountain coarse fraction tests, the Ottawa sand was used, followed by the Glass beads. These tests focussed on determining the effect of coarse particle shape.

The coarse fraction was removed and the sieved Kaolin tested again in order to determine if any physical change (clay density, surface chemistry, etc) occurred during the sand addition. Upon completion of the Lane Mountain coarse fraction tests, the Ottawa sand was used, followed by the Glass beads.

The results of the Lane Mountain concentric cylinder and vane viscometer tests are shown in Table 4.1. The Ottawa sand and Quackenbush glass test results are summarised in Table 4.2 and Table 4.3 respectively. Detailed results for all the coarse materials are shown in Appendices D, E, and F.

Table 4.1: Lane Mountain Coaxial and Vane Viscometer Test Results

Test No.	**Clay Concentration (%v)**	**Sand Concentration (%v)**	**λ**	**Kaolin Only Dynamic Yield Stress, τ_{yB} (Pa)**	**Kaolin Only Plastic Viscosity, K_B (Pa.s)**	**Kaolin Only Static Yield Stress, τ_{yV} (Pa)**	**Bulk Kaolin Dynamic Yield Stress, τ_{yB} (Pa)**	**Bulk Kaolin Plastic Viscosity, K_B (Pa.s)**	**Bulk Kaolin Static Yield Stress, τ_{yV} (Pa)**	**Static Yield Stress Ratio**	**Dynamic Yield Stress Ratio**	**Plastic Viscosity Ratio**
LM-01	16.8%	7.8%	1.147	12.978	9.440E-03	6.137	15.759	9.450E-03	6.771	1.214	1.001	1.103
LM-02	16.8%	11.6%	1.565	12.978	9.440E-03	6.137	17.025	1.133E-02	7.323	1.312	1.201	1.193
LM-03	16.8%	21.4%	2.962	12.978	9.440E-03	6.137	32.644	2.292E-02	16.033	2.515	2.428	2.612
LM-04	16.8%	14.5%	1.912	12.978	9.440E-03	6.137	19.842	1.570E-02	9.437	1.529	1.664	1.538
LM-05	17.0%	14.9%	1.964	12.366	9.839E-03	6.034	22.687	1.698E-02	9.531	1.835	1.725	1.579
LM-06	16.9%	14.5%	1.911	14.440	9.510E-03	6.408	26.055	1.623E-02	10.673	1.804	1.706	1.666
LM-07	16.9%	19.9%	2.701	14.440	9.510E-03	6.408	31.374	1.893E-02	13.729	2.173	1.990	2.143
LM-08	16.9%	18.0%	2.400	14.440	9.510E-03	6.408	31.374	1.893E-02	11.933	2.173	1.990	1.862
LM-09	16.9%	21.3%	2.947	14.440	9.510E-03	6.408	37.199	2.281E-02	15.571	2.576	2.398	2.430
LM-10	20.6%	20.4%	2.782	40.202	1.773E-02	17.974	78.349	3.615E-02	33.287	1.949	2.039	1.852
LM-11	20.6%	10.6%	1.448	40.202	1.773E-02	17.974	52.811	2.444E-02	24.253	1.314	1.378	1.349
LM-12	20.6%	15.0%	1.979	40.202	1.773E-02	17.974	62.145	2.867E-02	28.078	1.546	1.617	1.562
LM-13	20.6%	14.2%	1.874	41.512	1.625E-02	17.640	62.226	2.684E-02	25.962	1.499	1.652	1.472
LM-14	20.6%	19.8%	2.679	41.512	1.625E-02	17.640	74.466	3.448E-02	36.990	1.794	2.122	2.097
LM-15	20.6%	7.7%	1.137	41.512	1.625E-02	17.640	51.968	1.979E-02	21.632	1.252	1.218	1.226
LM-16	20.6%	3.1%	0.652	41.512	1.625E-02	17.640	47.936	1.881E-02	19.716	1.155	1.157	1.118
LM-17	20.6%	5.3%	0.890	40.202	1.773E-02	17.974	46.164	2.082E-02	18.400	1.148	1.174	1.024
LM-18	22.5%	3.7%	0.719	57.162	1.938E-02	24.581	64.878	2.221E-02	28.951	1.135	1.146	1.178
LM-19	22.5%	10.1%	1.390	57.162	1.938E-02	24.581	73.898	2.304E-02	32.864	1.293	1.189	1.337
LM-20	22.5%	15.8%	2.083	57.162	1.938E-02	24.581	N/A	N/A	39.712	N/A	N/A	1.616
LM-21	22.5%	19.4%	2.621	57.162	1.938E-02	24.581	N/A	N/A	53.788	N/A	N/A	2.188

Test No.	Clay Concentration	Sand Concentration	λ	Kaolin Only Dynamic Yield Stress, τ_{yB}	Kaolin Only Plastic Viscosity, K_B	Kaolin Only Static Yield Stress, τ_{yV}	Bulk Kaolin Dynamic Yield Stress, τ_{yB}	Bulk Kaolin Plastic Viscosity, K_B	Bulk Kaolin Static Yield Stress, τ_{yV}	Static Yield Stress Ratio	Dynamic Yield Stress Ratio	Plastic Viscosity Ratio
LM-22	18.1%	5.0%	0.859	17.462	1.095E-02	8.967	20.182	1.102E-02	9.963	1.156	1.006	1.111
LM-23	18.1%	10.6%	1.444	17.462	1.095E-02	8.967	24.150	1.287E-02	11.133	1.383	1.175	1.242
LM-24	18.1%	15.2%	2.005	17.462	1.095E-02	8.967	29.830	1.737E-02	13.677	1.708	1.585	1.525
LM-25	18.1%	21.1%	2.912	17.462	1.095E-02	8.967	36.796	1.960E-02	17.630	2.107	1.789	1.966
LM-26	19.7%	6.2%	0.978	28.971	1.432E-02	13.138	31.965	1.409E-02	14.355	1.103	0.984	1.093
LM-27	19.7%	10.6%	1.452	28.971	1.432E-02	13.138	41.215	1.809E-02	16.232	1.423	1.263	1.236
LM-28	19.7%	15.6%	2.063	28.971	1.432E-02	13.138	48.394	2.205E-02	20.864	1.670	1.540	1.588
LM-29	19.7%	20.3%	2.775	28.971	1.432E-02	13.138	60.911	2.732E-02	29.869	2.102	1.908	2.274

Table 4.2: Ottawa Sand Coaxial and Vane Viscometer Test Results

Test No.	**Clay Concentration (%v)**	**Sand Concentration (%v)**	**λ**	**Kaolin Only Dynamic Yield Stress, τ_{yB} (Pa)**	**Kaolin Only Plastic Viscosity, K_B (Pa.s)**	**Kaolin Only Static Yield Stress, τ_{yV} (Pa)**	**Bulk Kaolin Dynamic Yield Stress, τ_{yB} (Pa)**	**Bulk Kaolin Plastic Viscosity, K_B (Pa.s)**	**Bulk Kaolin Static Yield Stress, τ_{yV} (Pa)**	**Static Yield Stress Ratio**	**Dynamic Yield Stress Ratio**	**Plastic Viscosity Ratio**
Ott-01	16.5%	5.6%	0.853	12.998	9.487E-03	7.371	13.156	1.023E-02	8.006	1.012	1.079	1.086
Ott-02	16.5%	9.3%	1.194	12.998	9.487E-03	7.371	13.475	1.122E-02	8.665	1.037	1.182	1.176
Ott-03	16.5%	13.6%	1.616	12.998	9.487E-03	7.371	16.208	1.104E-02	10.262	1.247	1.164	1.392
Ott-04	16.5%	19.4%	2.278	12.998	9.487E-03	7.371	20.509	1.609E-02	12.998	1.578	1.696	1.763
Ott-05	18.0%	5.8%	0.872	19.248	1.184E-02	9.810	19.971	1.251E-02	11.148	1.038	1.056	1.136
Ott-06	18.0%	11.2%	1.370	19.248	1.184E-02	9.810	22.663	1.356E-02	12.107	1.177	1.145	1.234
Ott-07	18.0%	15.8%	1.852	19.248	1.184E-02	9.810	24.815	1.471E-02	13.896	1.289	1.243	1.417
Ott-08	18.0%	20.4%	2.411	19.248	1.184E-02	9.810	32.147	1.746E-02	16.312	1.670	1.474	1.663
Ott-09	19.3%	5.6%	0.852	25.436	1.339E-02	12.748	27.417	1.411E-02	13.377	1.078	1.054	1.049
Ott-10	19.3%	10.5%	1.310	25.436	1.339E-02	12.748	31.034	1.548E-02	15.294	1.220	1.156	1.200
Ott-11	19.3%	16.8%	1.962	25.436	1.339E-02	12.748	32.834	1.757E-02	17.211	1.291	1.312	1.350
Ott-12	19.3%	21.3%	2.535	25.436	1.339E-02	12.748	39.079	1.954E-02	19.806	1.536	1.460	1.554
Ott-13	20.2%	5.0%	0.791	30.504	1.399E-02	16.412	33.279	1.421E-02	16.612	1.091	1.016	1.012
Ott-14	20.2%	11.1%	1.368	30.504	1.399E-02	16.412	36.447	1.498E-02	18.089	1.195	1.071	1.102
Ott-15	20.2%	15.8%	1.847	30.504	1.399E-02	16.412	42.108	1.616E-02	19.986	1.380	1.155	1.218
Ott-16	20.2%	21.0%	2.491	30.504	1.399E-02	16.412	51.822	2.132E-02	23.560	1.699	1.524	1.436
Ott-17	17.0%	10.8%	1.332	12.478	9.260E-03	7.587	14.429	1.049E-02	9.045	1.156	1.133	1.192
Ott-18	20.0%	15.9%	1.858	27.363	1.331E-02	14.954	42.113	1.649E-02	20.325	1.539	1.239	1.359

Table 4.3: Quackenbush Glass Coaxial and Vane Viscometer Test Results

Test No.	**Clay Concentration (%v)**	**Sand Concentration (%v)**	**λ**	**Kaolin Only Dynamic Yield Stress, τ_{yB} (Pa)**	**Kaolin Only Plastic Viscosity, K_B (Pa.s)**	**Kaolin Only Static Yield Stress, τ_{yV} (Pa)**	**Bulk Kaolin Dynamic Yield Stress, τ_{yB} (Pa)**	**Bulk Kaolin Plastic Viscosity, K_B (Pa.s)**	**Bulk Kaolin Static Yield Stress, τ_{yV} (Pa)**	**Static Yield Stress Ratio**	**Dynamic Yield Stress Ratio**	**Plastic Viscosity Ratio**
QG-01	16.5%	6.2%	0.872	10.654	8.083E-03	6.552	13.190	9.924E-03	7.986	1.238	1.228	1.219
QG-02	16.5%	10.3%	1.231	10.654	8.083E-03	6.552	12.506	9.770E-03	7.960	1.174	1.209	1.215
QG-03	16.5%	14.5%	1.625	10.654	8.083E-03	6.552	13.310	1.089E-02	8.772	1.249	1.347	1.339
QG-04	16.5%	18.9%	2.084	10.654	8.083E-03	6.552	15.479	1.301E-02	9.371	1.453	1.610	1.430
QG-05	17.9%	3.9%	0.667	15.430	9.604E-03	9.008	15.971	9.690E-03	9.484	1.035	1.009	1.053
QG-06	17.9%	9.1%	1.123	15.430	9.604E-03	9.008	17.367	1.169E-02	10.782	1.126	1.217	1.197
QG-07	17.9%	12.7%	1.453	15.430	9.604E-03	9.008	19.145	1.355E-02	11.181	1.241	1.411	1.241
QG-08	17.9%	20.1%	2.232	15.430	9.604E-03	9.008	21.615	1.597E-02	12.239	1.401	1.663	1.359
QG-09	19.3%	3.6%	0.636	22.820	1.197E-02	11.950	26.998	1.307E-02	13.098	1.183	1.092	1.096
QG-10	19.3%	10.9%	1.287	22.820	1.197E-02	11.950	27.966	1.434E-02	13.856	1.225	1.198	1.160
QG-11	19.3%	15.3%	1.706	22.820	1.197E-02	11.950	29.542	1.483E-02	15.074	1.295	1.238	1.261
QG-12	19.3%	23.6%	2.675	22.820	1.197E-02	11.950	35.318	1.778E-02	18.269	1.548	1.485	1.529
QG-13	20.3%	3.4%	0.614	28.168	1.424E-02	14.655	31.738	1.321E-02	14.395	1.127	0.927	0.982
QG-14	20.3%	12.3%	1.415	28.168	1.424E-02	14.655	38.870	1.610E-02	17.111	1.380	1.130	1.168
QG-15	20.3%	19.3%	2.132	28.168	1.424E-02	14.655	44.263	2.117E-02	21.923	1.571	1.486	1.496
QG-16	20.3%	17.0%	1.882	28.168	1.424E-02	14.655	44.461	2.073E-02	20.545	1.578	1.455	1.402

4.2 Particle Properties

The properties of the coarse particle were measured once each of the materials were screened to obtain the desired particle size distributions.

4.2.1 Particle density

The test results for the solids densities of the Lane Mountain and Ottawa Valley sands, glass beads, and kaolin clay are shown in Table 4.4. It is apparent that the particle density values are comparable and sufficiently similar for the purposes of this investigation. Three replicates of each property test were performed. These results compare well with both Supplier provided specifications and work done by Schaan et al. (2000).

Table 4.4: Solids Density Results

Material	**Solids Density**	**Solids Density (Schaan et al.)**
Sand (Lane Mountain)	2 596 kg/m³± 0.88%	2 655 kg/m³
Sand (Ottawa)	2 732 kg/m³± 0.87%	2 660 kg/m³
Glass Beads (Quackenbush)	2 432 kg/m³± 0.33%	2 440 kg/m³
Kaolin	2 734 kg/m³± 1.98%	-

4.2.2 Freely settled bed concentration

The test results for the freely settled bed concentrations of the sand and glass are shown in Table 4.5. The trends observed in the freely settled bed concentrations are as expected due to the increased sphericity of the Ottawa sand and glass beads compared to the Lane Mountain sand. It should be noted that these values compare well with work done by Schaan et al. (2000) on Lane Mountain sand, and Quackenbush glass. Three replicates were performed per material test.

Table 4.5: Freely Settled Bed Concentration Results

Material	**Freely Settled Bed Concentration**	**Freely Settled Bed Concentration (Schaan et al.)**
Sand (Lane Mountain)	51.2% ± 0.88%	50.5%
Sand (Ottawa)	57.8% ± 0.20%	57.5%
Glass Beads (Quackenbush)	61.2% ± 0.67%	62.2%
Kaolin	N/A	N/A

4.2.3 Particle size distribution

The particle size distributions (PSD's) of the coarse particles after the coarse and fine fractions have been removed are shown in Figure 4.1. These are the PSD's associated with the coarse particles used in all of the tests. All these PSD's were obtained by a combination of dry mechanical sieving and wet sieving. Note that these PSD's are based on averages of three tests for each coarse particle. Error bars reflect the standard deviation of the replicate experiments The PSD of the Kaolin clay particles is shown in Figure 4.2. Detailed results for each particle size distribution test are shown in Appendix C.

The particle size results are summarised in Table 4.6.

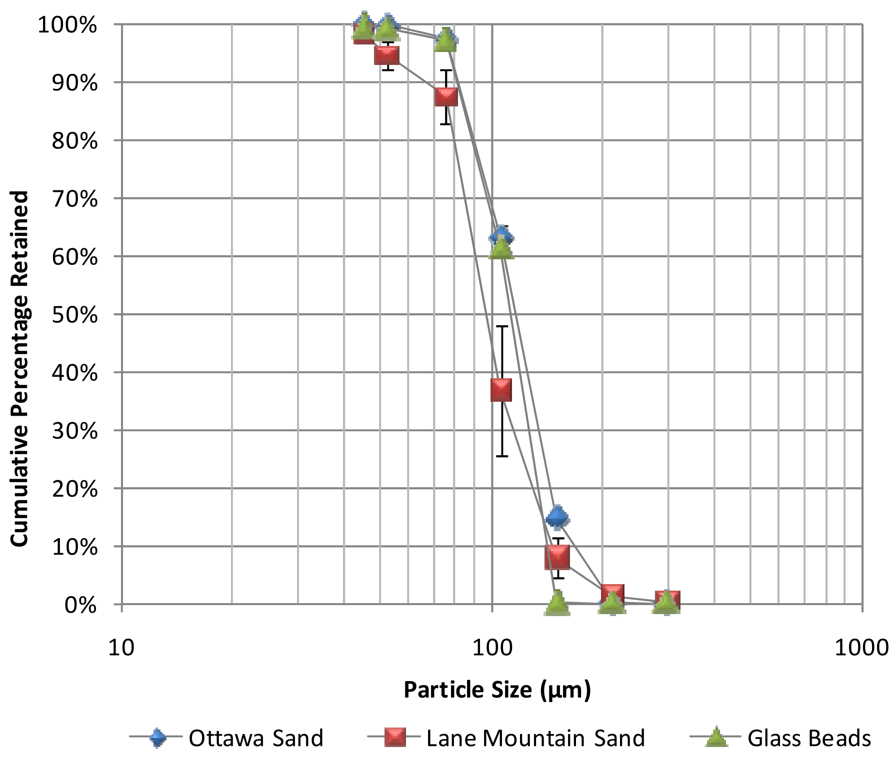

Figure 4.1: Coarse Particle PSD

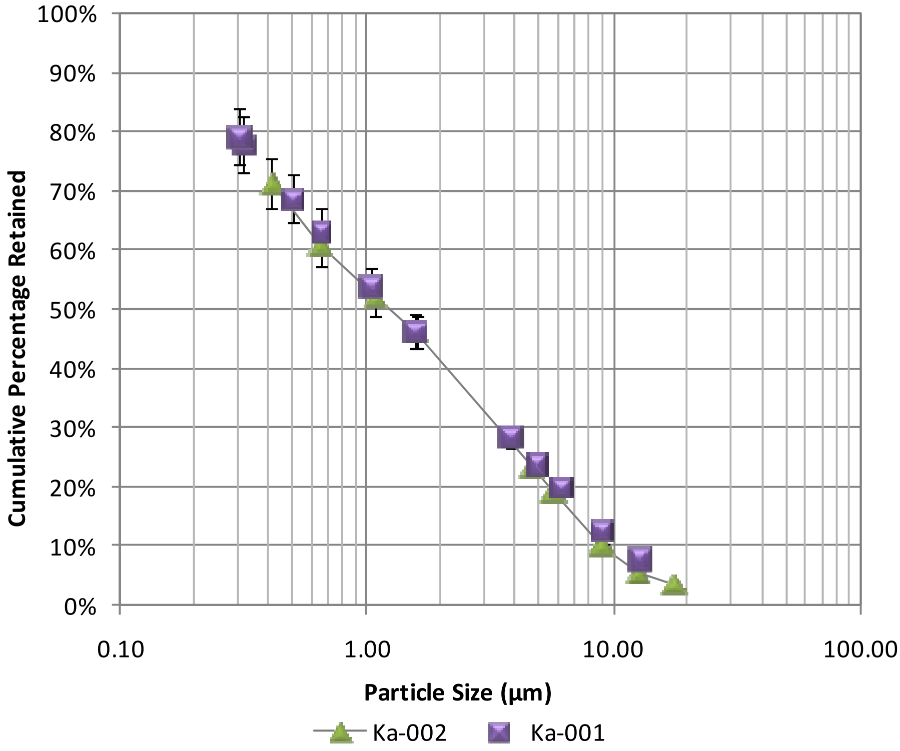

Figure 4.2: Kaolin PSD

Table 4.6: PSD Summary

Size	Sand (Lane Mountain)	Sand (Ottawa)	Glass Beads (Quackenbush)	Kaolin
d_{90} (µm)	167 µm ± 2.5%	159 µm ± 1.5%	142 µm ± 0.3%	10 µm ± 10.0%
d_{50} (µm)	117 µm ± 1.5%	108 µm ± 1.6%	113 µm ± 1.4%	1 µm ± 2.2%
d_{10} (µm)	81 µm ± 0.40%	72 µm ± 0.33%	80 µm ± 1.2%	0.2 µm ± 3.8%

4.2.4 pH Measurement

The pH level of the slurries composed of sand, glass and kaolin was measured using standard indicator paper. Mixtures of each were allowed to stand over a period of time after which the pH of the supernatant was measured. The purpose of these measurements was to determine the effect, if any, of the coarse solids fraction on the acidity/alkalinity of the mixture. For all the tests performed, reverse osmosis water was used as liquid phase. The results of these tests are shown in Table 4.7. Note that all tests have an experimental error in the pH readings of ± 5% as indicated by the manufacturer.

It is apparent from these results that the slurries composed of Kaolin clay, Kaolin clay and sand, do not indicate any shift in pH. Furthermore these mixtures show no shift in pH from the base case (reverse osmosis water), indicating that no noticeable change in acidity/alkalinity effects occurred over the time frame that the slurries were studied.

There were, however, large deviations of the observed pH when glass beads were added to the clay slurries. This pH shift caused by the glass would significantly alter the mixture rheology, as has been witnessed in past work performed by a number of researchers (Ancey and Jorrot, 2001, Michaels and Bolger, 1962, and Sumner et al. 2000).

It is important to note that the glass beads were not washed before they were used in the test. Following the addition of the glass beads, a steady decline in the pH of the aqueous phase was noted (from an initial value of approximately 9.5 to approximately 8.0) even though the mixture was only stirred occasionally. The observed gradual reduction in pH could be attributed to a reaction on the surface of the glass beads that diminishes as the surface and adjacent fluid come into equilibrium.

Conversely, the pH of the clay water slurry and glass bead mixture increased with time (from approximately 6.0 to 7.0). This could indicate some alternate ion exchange occurring between the water, clay particles and the glass beads. A similar trend was observed with the water washed glass. This could indicate that the active ions were continuously being replaced as they were replenished once the deionised water became saturated.

The effect of washing the glass beads with Hydrochloric Acid and Sulphuric Acid was also investigated. The glass beads were washed thoroughly with the acid, and allowed to stand overnight. The beads were then washed with distilled water until no further pH changes were observed. The beads were oven dried and placed in a beaker with distilled water, and the pH measured. An increase in pH was again observed. This could indicate that the active layers on the glass beads are being continuously replaced.

Furthermore, tests were performed by buffering the solutions with 1% HCl, of both the acid washed and unwashed beads. The pH of the glass only solutions again steadily increased even with buffering. However once Kaolin, and then buffer solution was added, the solution appeared to stabilise at the typical Kaolin concentration pH of 5.0. This was observed regardless of whether or not the beads were washed with acid beforehand. The unwashed glass beads were therefore used in the glass bead tests and an HCl solution added to maintain a constant pH level.

Table 4.7: pH Readings with Glass Bead and Water and Glass Beads and Slurry (Water and Kaolin Clay)

Time (min)	0	5	60	1440	2880	4320
Water Only	5.0	5.0	5.0	5.0	5.0	5.0
Slurry (Kaolin) Only	5.0	5.0	5.0	5.0	5.0	5.0
Water and Sand	5.0	5.0	5.0	5.0	5.0	5.0
Water and Glass	9.5	9.5	9.5	9.0	8.5	8.3
Slurry and Glass	6.5	6.5	6.5	6.5	7.0	7.0
Water Washed Glass	7.0	7.0	7.0	7.0	7.3	7.3
Acid Washed Glass	6.8	7.5	8.0	8.5	8.5	8.5
Glass + 1% HCl Buffer	4.5	5.0	5.0	5.5	6.0	6.8
Glass + Kaolin + 1% HCl Buffer	4.5	4.5	4.8	5.0	5.0	5.0
Acid Washed Glass + 1% HCl Buffer	4.5	4.5	4.8	5.2	5.5	5.8
Acid Washed Glass + Kaolin + 1% HCL Buffer	4.5	4.5	4.8	5.0	5.0	5.0

4.2.5 Photomicrographs

Photomicrographs taken of the Lane Mountain sand, Ottawa sand, and glass beads are presented in Figure 4.3 to Figure 4.5 respectively. One of the important observations from these plates is the difference in particle shape. The glass beads are very spherical whereas the Ottawa sand has a spheroid shape and the Lane Mountain sand grains have an angular shape. From the images, the glass beads are more uniform in size. All photos were taken at 10 × magnification.

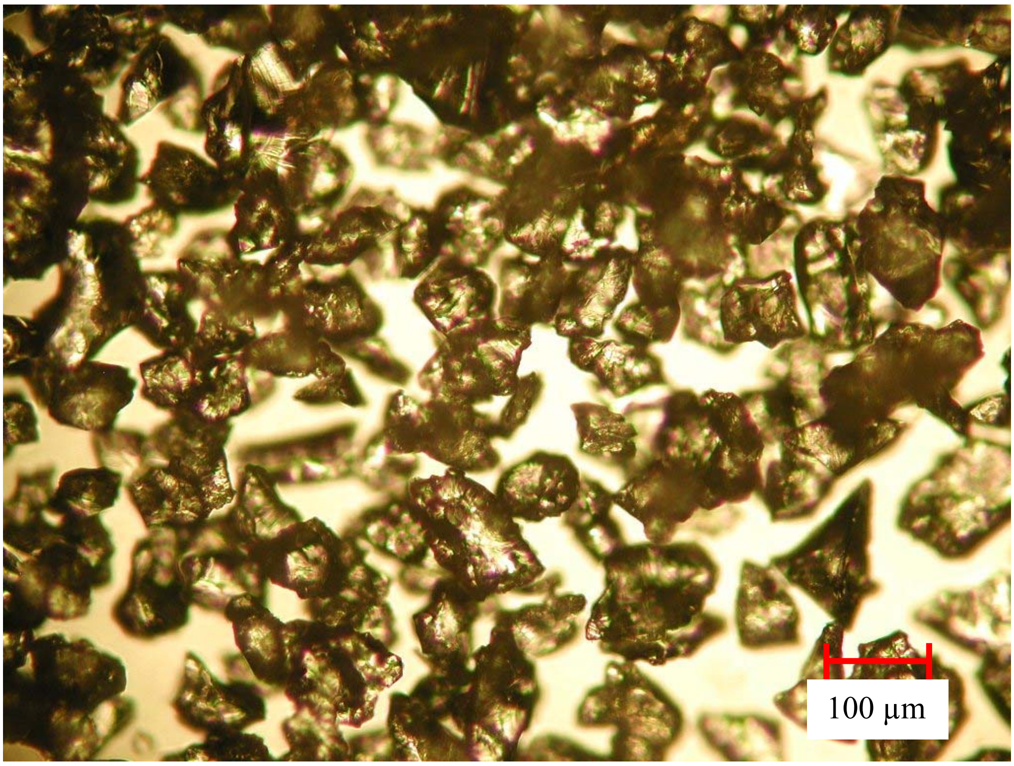

Figure 4.3: Lane Mountain Sand Photomicrograph

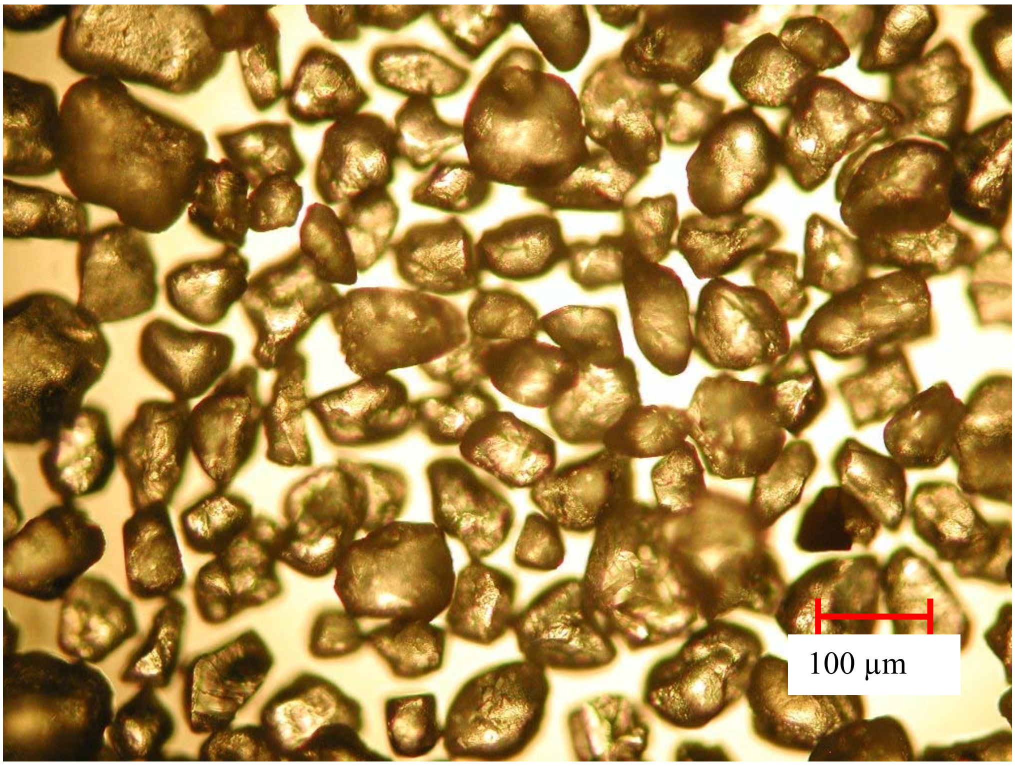

Figure 4.4: Ottawa Sand Photomicrograph

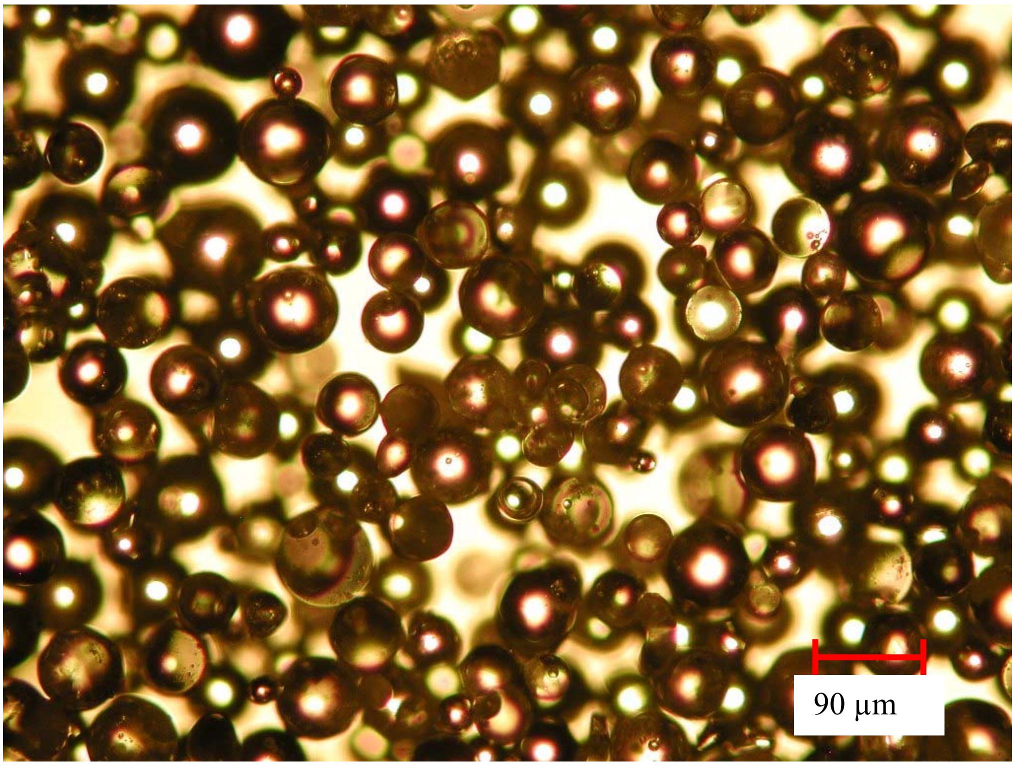

Figure 4.5: Glass Beads Photomicrograph

4.3 Parameter Testing

The dimensionless parameters and operational requirements discussed previously (in Section 2) are presented in this section. These are the Peclet number for Brownian effect, the hydrodynamic interaction parameters N, and T, and the maximum (from the Taylor number) and minimum (for complete shearing in the annulus) rotational speeds.

The summary of the test work parameters is shown in Table 4.8 to Table 4.10. It is apparent from the extremely high Peclet numbers that Brownian motion is negligible for all slurries tested based on the work of Ancey (2001). Furthermore, from the low N parameter numbers the research of Ancey would suggest that direct contacts between coarse particles would be negligible. This is further illustrated by the T parameter which is significantly less than 0.1, implying that direct contacts between coarse particles is negligible, and that the interstitial fluid therefore governs fluid rheology.

All rotational viscometer tests were performed between the maximum and minimum speeds presented in the tables.

Table 4.8: Lane Mountain Test Parameters

Test	Peclet No Eqn. (2.43)	Ancey, N Eqn. (2.44)	Ancey, T Eqn. (2.41)	Maximum Speed Eqn. (2.16) and (2.17)	Minimum Speed Eqn. (2.15)
LM-01	2.972E+07	2.548E-02	1.299E-07	1792 rpm	113 rpm
LM-02	2.972E+07	2.677E-02	1.772E-07	1494 rpm	101 rpm
LM-03	2.972E+07	1.597E-02	3.355E-07	739 rpm	96 rpm
LM-04	2.972E+07	2.264E-02	2.165E-07	1078 rpm	85 rpm
LM-05	2.832E+07	2.276E-02	2.319E-07	997 rpm	90 rpm
LM-06	3.307E+07	2.007E-02	2.180E-07	1043 rpm	108 rpm
LM-07	3.307E+07	1.803E-02	3.082E-07	895 rpm	112 rpm
LM-08	3.307E+07	1.976E-02	2.738E-07	895 rpm	112 rpm
LM-09	3.307E+07	1.651E-02	3.363E-07	742 rpm	110 rpm
LM-10	9.207E+07	8.165E-03	5.919E-07	468 rpm	146 rpm
LM-11	9.207E+07	8.836E-03	3.080E-07	693 rpm	146 rpm
LM-12	9.207E+07	8.556E-03	4.210E-07	591 rpm	146 rpm
LM-13	9.507E+07	9.107E-03	3.654E-07	631 rpm	157 rpm
LM-14	9.507E+07	7.275E-03	5.222E-07	491 rpm	146 rpm
LM-15	9.507E+07	9.172E-03	2.216E-07	855 rpm	177 rpm
LM-16	9.507E+07	8.707E-03	1.271E-07	900 rpm	172 rpm
LM-17	9.207E+07	9.974E-03	1.894E-07	813 rpm	150 rpm
LM-18	1.309E+08	6.482E-03	1.672E-07	762 rpm	197 rpm
LM-19	1.309E+08	6.814E-03	3.232E-07	735 rpm	217 rpm
LM-20	1.309E+08	6.464 E-03	4.842 E-07	N/A	N/A
LM-21	1.309E+08	5.159 E-03	6.096 E-07	N/A	N/A
LM-22	3.999E+07	1.647E-02	1.128E-07	1536 rpm	124 rpm
LM-23	3.999E+07	1.774E-02	1.897E-07	1316 rpm	127 rpm
LM-24	3.999E+07	1.650E-02	2.636E-07	975 rpm	116 rpm
LM-25	3.999E+07	1.483E-02	3.827E-07	864 rpm	127 rpm
LM-26	6.635E+07	1.272E-02	1.681E-07	1201 rpm	153 rpm
LM-27	6.635E+07	1.287E-02	2.495E-07	936 rpm	154 rpm
LM-28	6.635E+07	1.144E-02	3.545E-07	768 rpm	148 rpm
LM-29	6.635E+07	8.925E-03	4.768E-07	620 rpm	151 rpm

Table 4.9: Ottawa Sand Test Parameters

Test	Peclet No Eqn. (2.43)	Ancey, N Eqn. (2.44)	Ancey, T Eqn. (2.41)	Maximum Speed Eqn. (2.16) and (2.17)	Minimum Speed Eqn. (2.15)
Ott-01	2.977E+07	2.259E-02	9.878E-08	1654 rpm	87 rpm
Ott-02	2.977E+07	2.389E-02	1.383E-07	1510 rpm	81 rpm
Ott-03	2.977E+07	2.315E-02	1.872E-07	1534 rpm	99 rpm
Ott-04	2.977E+07	2.143E-02	2.639E-07	1052 rpm	86 rpm
Ott-05	4.408E+07	1.738E-02	1.261E-07	1354 rpm	108 rpm
Ott-06	4.408E+07	1.907E-02	1.980E-07	1248 rpm	113 rpm
Ott-07	4.408E+07	1.895E-02	2.677E-07	1151 rpm	114 rpm
Ott-08	4.408E+07	1.811E-02	3.486E-07	970 rpm	124 rpm
Ott-09	5.825E+07	1.523E-02	1.393E-07	1200 rpm	131 rpm
Ott-10	5.825E+07	1.552E-02	2.142E-07	1094 rpm	135 rpm
Ott-11	5.825E+07	1.628E-02	3.207E-07	964 rpm	126 rpm
Ott-12	5.825E+07	1.571E-02	4.143E-07	866 rpm	135 rpm
Ott-13	6.986E+07	1.248E-02	1.351E-07	1192 rpm	158 rpm
Ott-14	6.986E+07	1.377E-02	2.336E-07	1130 rpm	164 rpm
Ott-15	6.986E+07	1.403E-02	3.154E-07	1048 rpm	176 rpm
Ott-16	6.986E+07	1.340E-02	4.253E-07	794 rpm	164 rpm
Ott-17	2.858E+07	2.437E-02	1.506E-07	1614 rpm	93 rpm
Ott-18	6.266E+07	1.370E-02	3.020E-07	1026 rpm	172 rpm

Table 4.10: Quackenbush Glass Test Parameters

Test	Peclet No Eqn. (2.43)	Ancey, N Eqn. (2.44)	Ancey, T Eqn. (2.41)	Maximum Speed Eqn. (2.16) and (2.17)	Minimum Speed Eqn. (2.15)
QG-01	2.440E+07	2.148E-02	7.562E-08	1706 rpm	90 rpm
QG-02	2.440E+07	2.495E-02	1.068E-07	1733 rpm	86 rpm
QG-03	2.440E+07	2.582E-02	1.409E-07	1555 rpm	83 rpm
QG-04	2.440E+07	2.725E-02	1.808E-07	1301 rpm	80 rpm
QG-05	3.534E+07	1.757E-02	6.869E-08	1747 rpm	111 rpm
QG-06	3.534E+07	1.855E-02	1.157E-07	1448 rpm	100 rpm
QG-07	3.534E+07	2.001E-02	1.497E-07	1249 rpm	95 rpm
QG-08	3.534E+07	2.223E-02	2.300E-07	1060 rpm	91 rpm
QG-09	5.226E+07	1.340E-02	8.174E-08	1295 rpm	139 rpm
QG-10	5.226E+07	1.603E-02	1.653E-07	1181 rpm	132 rpm
QG-11	5.226E+07	1.661E-02	2.192E-07	1142 rpm	135 rpm
QG-12	5.226E+07	1.659E-02	3.436E-07	952 rpm	134 rpm
QG-13	6.451E+07	1.264E-02	9.384E-08	1282 rpm	162 rpm
QG-14	6.451E+07	1.392E-02	2.163E-07	1051 rpm	163 rpm
QG-15	6.451E+07	1.287E-02	3.259E-07	800 rpm	141 rpm
QG-16	6.451E+07	1.304E-02	2.876E-07	817 rpm	145 rpm

4.4 Rheological Characterisation of Kaolin

4.4.1 Kaolin only

The Kaolin only tests were performed with slurries containing only Kaolin Clay and Reverse Osmosis (RO) water. Tests were conducted with this slurry both at the beginning and the end of a test series. Repetitions were also performed on the Kaolin only slurries immediately after they were prepared.

The dynamic yield stress as a function of clay volume concentration for the Kaolin only slurries is shown in Figure 4.6 and the corresponding plastic viscosity plot is shown in Figure 4.7. The static vane yield stress results are plotted as a function of volume concentration of Kaolin in Figure 4.8. The error bars provided in the figures represent the experimental error which was estimated by conducting replicate experiments.

All of the rheological parameters were found to be strong functions of clay concentration. Strong correlations are found for all the relationships which accurately represent the concentration functionality associated with the rheological parameters. The values for the coefficients c and $K/_{d^2}$ from Equation (2.32) are of similar order as the values found by Ancey (2001) as shown in Table 4.11. The accuracy of the correlation for the dynamic yield stress is 8.2%, and 6.2% for the static yield stress.

Table 4.11: Kaolin Only Yield Stress Parameters

Parameter	Ancey (2001)	Static Yield Stress	Dynamic Yield Stress
c	5.15	4.10	3.60
$K/_{d^2}$	115 85	8 581	2 257

The correlation coefficient for the plastic viscosity is significantly higher than one (10.1) with an accuracy of 5.7%. According to Thomas (1963), this indicates that the solution is highly flocculated as it represents the volume of immobilized fluid relative to the volume of the solids.

The static yield stress is plotted as a function of the dynamic yield stress in Figure 4.9. Dzuy (1983) found that the ratio of the static yield stress to the dynamic yield stress was approximately 0.5 for TiO_2 suspensions. In this study, the ratio was found to be 0.47, as can be seen in Figure 4.9, which is in good agreement with the work of Dzuy.

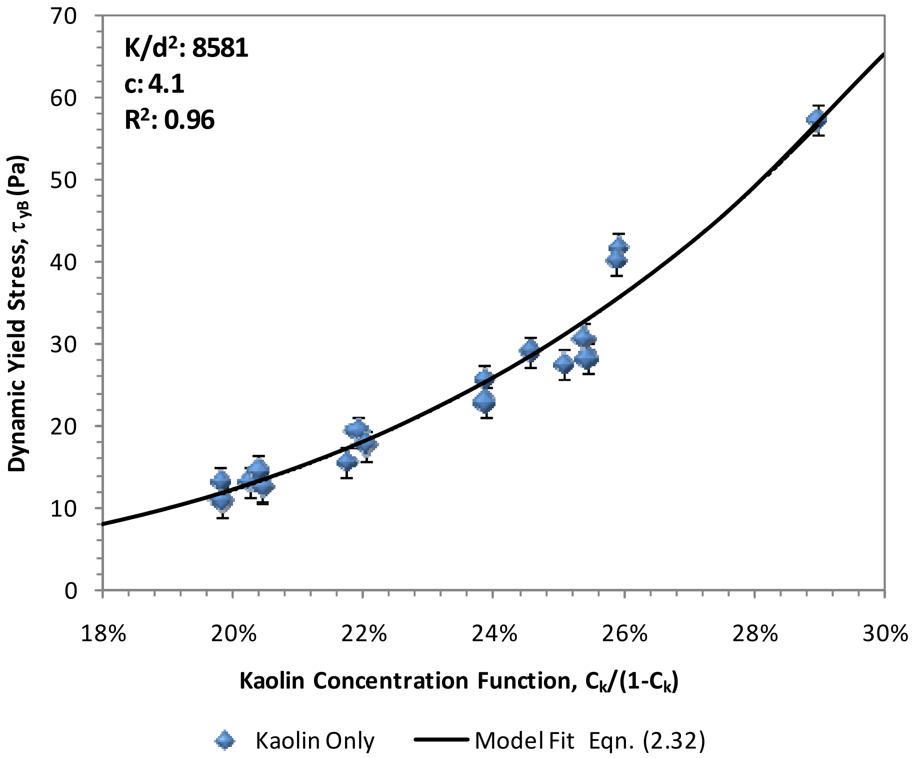

Figure 4.6: Dynamic Yield Stress as a Function of Kaolin Volume Concentration for Kaolin Only Slurries

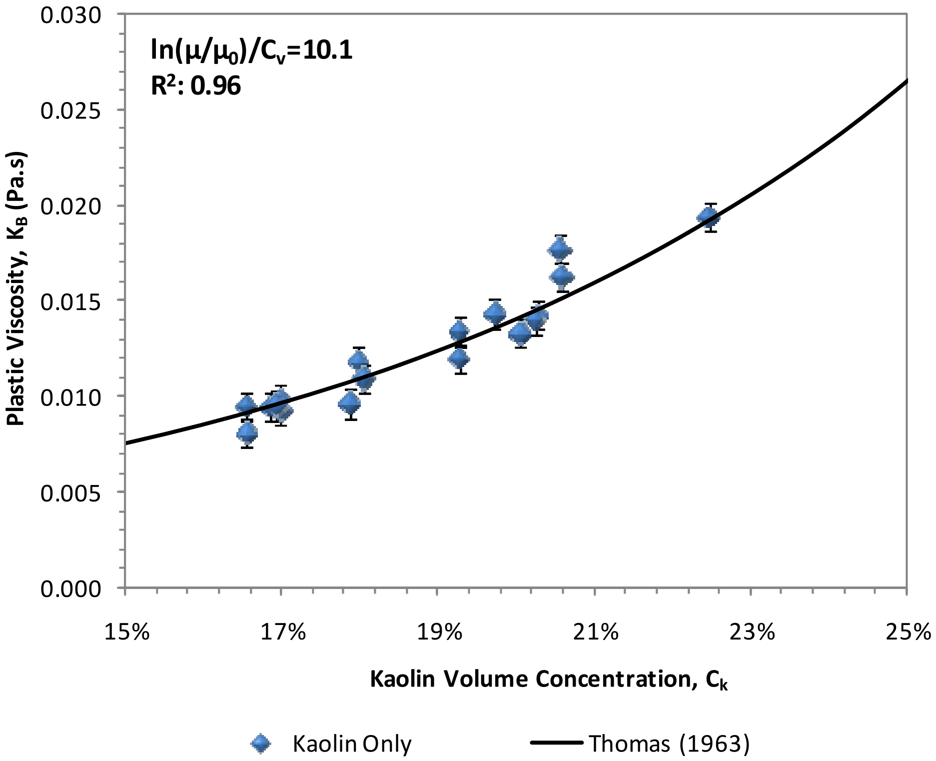

Figure 4.7: Plastic Viscosity as a Function of Kaolin Volume Concentration for Kaolin Only Slurries

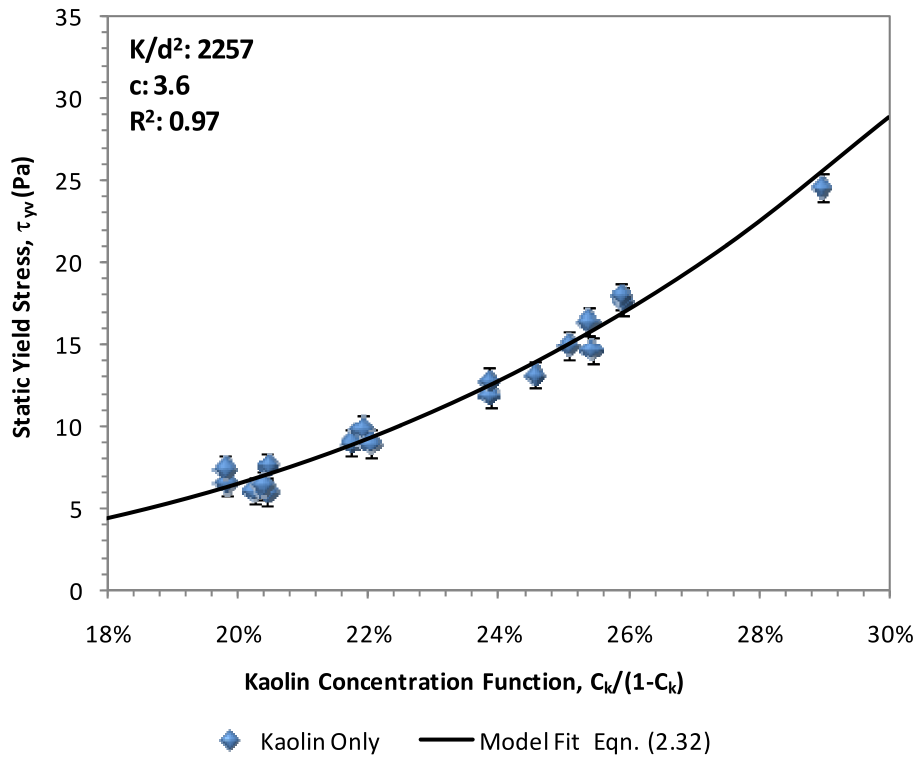

Figure 4.8: Static Yield Stress as a Function of Kaolin Volume Concentration for Kaolin Only Slurries

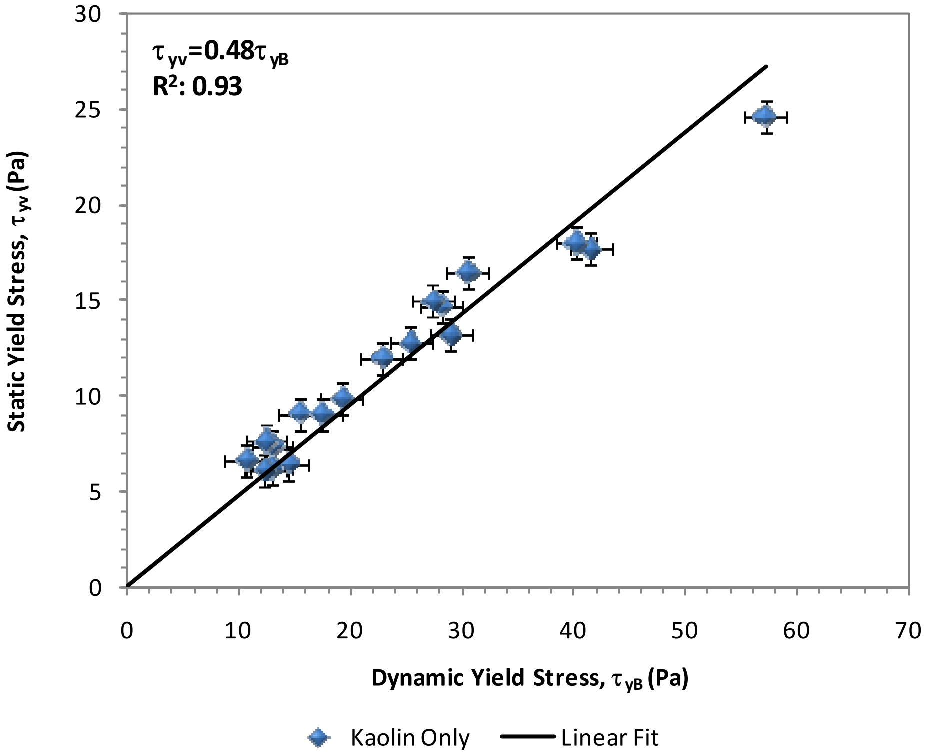

Figure 4.9: Static Yield Stress Versus Dynamic Yield Stress for Kaolin Only Slurries

4.4.2 Scalped Kaolin only slurries

Coarse sand was separated from coarse sand-Kaolin clay slurry samples by means of a 75 µm sieve. The resulting scalped kaolin slurry sample was tested with both with the vane and coaxial viscometer in order to ensure that the addition of the coarse particles did not influence the chemistry or alter the density, and consequently the rheology of the Kaolin clay-water carrier fluid.

Comparison of the dynamic yield stress obtained with the Kaolin clay slurry before and after the addition of coarse particles is shown in Figure 4.10. Based on a confidence limit of 95 %, the difference in the dynamic yield stress obtained with the slurry before the addition of coarse particles and after the particles were removed is not statistically significant. Consequently, the fitting parameters, c, and $K/_{d^2}$ have been modified to best represent the slurry both before the addition of coarse particles and after the particles were scalped. These parameters are now 3.8 and 5 610 respectively.

The plastic viscosities obtained with the Kaolin slurry before the addition of coarse particles and after the particles were scalped are shown in Figure 4.11. There is no statistical difference between the results obtained with the two slurries. The fitting parameter has again been adjusted to represent both sets optimally. Previously it was 10.1 and is now 12.3.

As with the dynamic yield stress, the difference between the static yield stress obtained with the clay slurry before the addition of coarse particles and after the particles were scalped was not statistically significant. The static yield stress comparison is illustrated in Figure 4.12. It should be noted that the fitting parameters have been adjusted in this figure based on the results obtained with the dynamic yield stress such that $c = 3.6$, and $K/_{d^2} = 2088$.

The static yield stress is still well represented as approximately ½ the Bingham yield stress as shown in Figure 4.13.

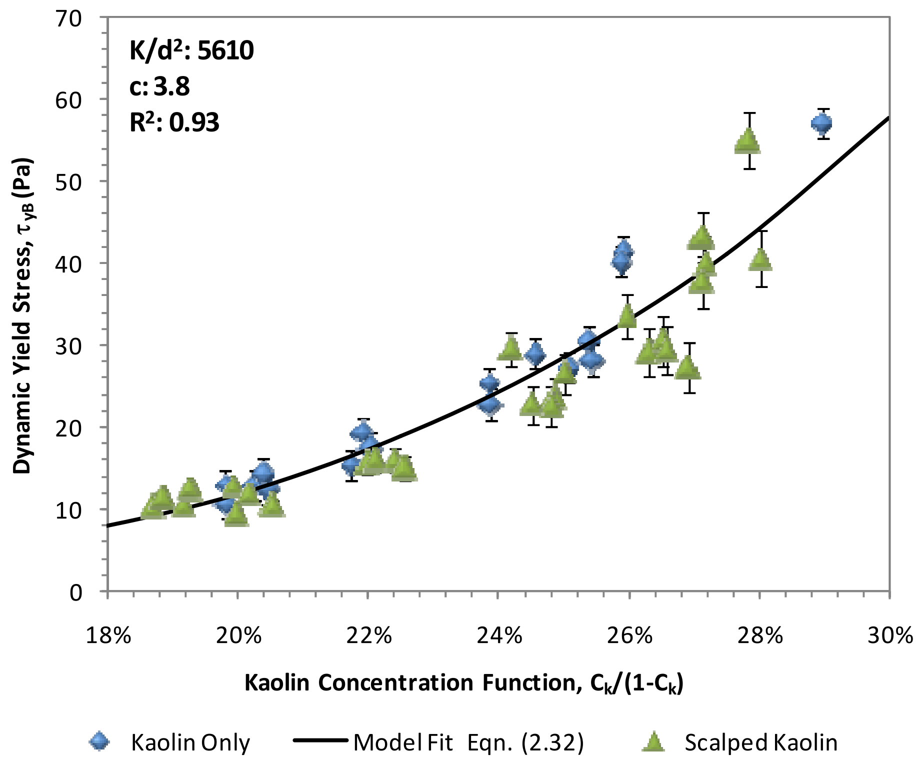

Figure 4.10: Dynamic Yield Stress as a Function of Kaolin Volume Concentration

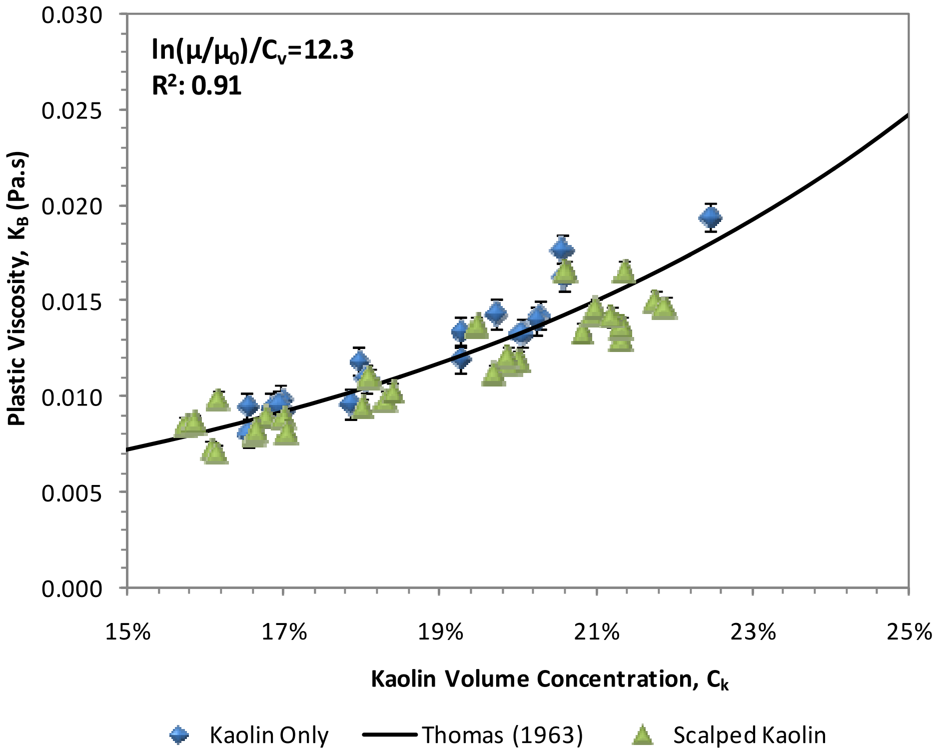

Figure 4.11: Plastic Viscosity as a Function of Kaolin Volume Concentration

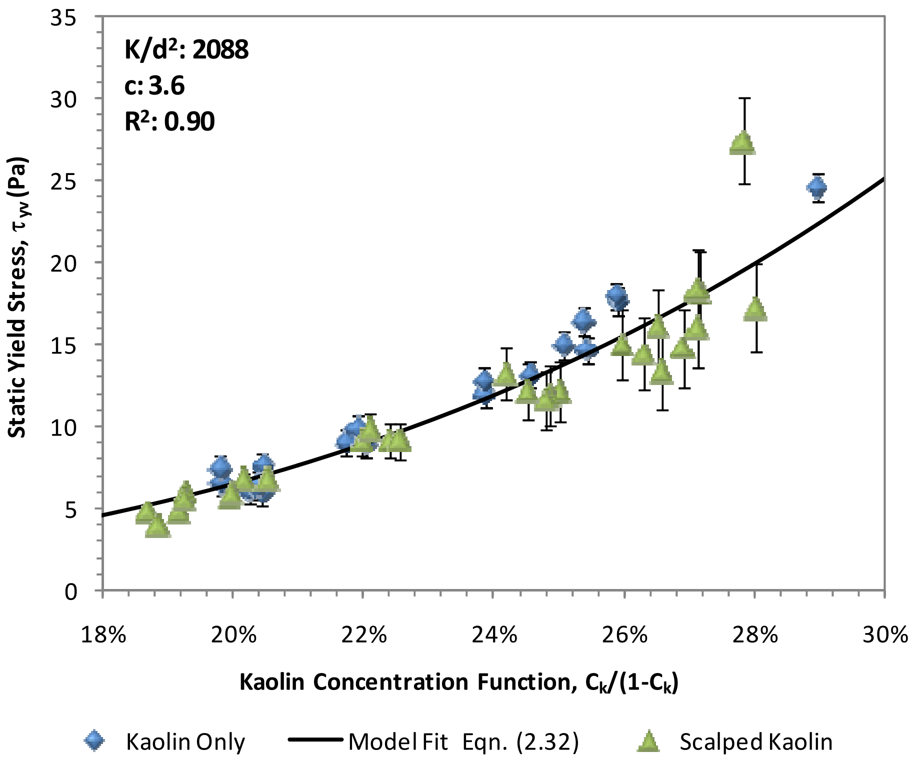

Figure 4.12: Static Yield Stress as a Function of Kaolin Volume Concentration

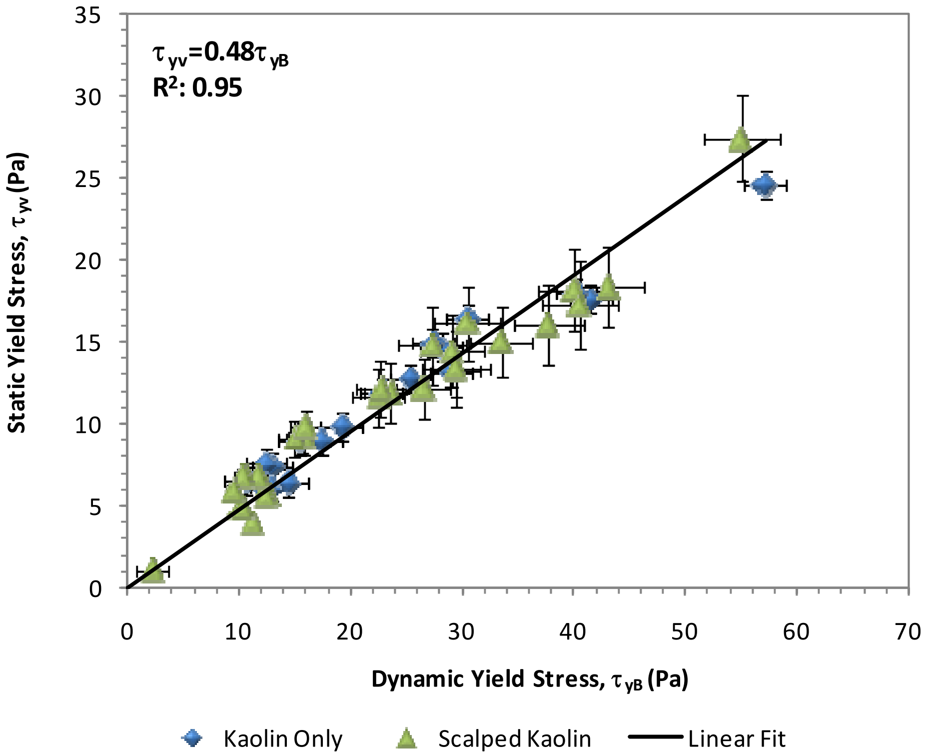

Figure 4.13: Static Yield Stress Versus. Dynamic Yield Stress

From the results presented in Figure 4.10 to Figure 4.13, it is apparent that there are no statistically significant changes in the rheological parameters tested. This is true of the Kaolin slurry before the addition of coarse particles and after the particles were scalped from the slurry based on a 95% level of confidence. It is therefore clear that the addition of the coarse fractions (both sand and glass) did not alter the rheological properties of the carrier fluid (clay-water). Consequently, the presence of the coarse fraction did not deplete the carrier fluid of water and there could not have been a significant additional removal of ions which would modify the rheology of the carrier fluid. The effect caused by the addition of the coarse fraction is therefore reversible.

4.5 Coarse Particle Addition Tests

4.5.1 Effect of coarse particle addition

For the entire range of slurries considered, the apparent viscosity of a clay slurry increased with the addition of coarse particles regardless of the type of coarse particle added. The mixtures continued to exhibit non-Newtonian behaviour over the shear rates and shear stresses tested and all of the rheological parameters (i.e. static and dynamic yield stress, plastic viscosity) increased in magnitude.

Bingham Dynamic yield stress

The dynamic yield stress is plotted as a function of the bulk concentration for Lane Mountain, Ottawa Sand, and Quackenbush glass beads are shown in Figure 4.14, Figure 4.15, and Figure 4.16, respectively. The Kaolin clay volume concentration associated with each data set is indicated on the chart.

It is apparent that the dynamic yield stress increases significantly, and that this change is statistically significant when compared with the experimental error which is represented by the error bars. It is also clear that the yield stress increase due to the presence of a coarse fraction is significantly less than the increase due to Kaolin only for the same change in volume fraction. Therefore the rheology of the clay-water carrier has the dominant role is determining the rheology of the mixture.

The results suggest that the slurry rheology is a function of the shape of the coarse particle.. It appears that the rate of increase in the dynamic yield stress of the slurry decreases with increasing sphericity or increasing $C_{v,max}$ (Lane Mountain → Ottawa → Quackenbush). This effect is illustrated in Figure 4.14 to Figure 4.17.

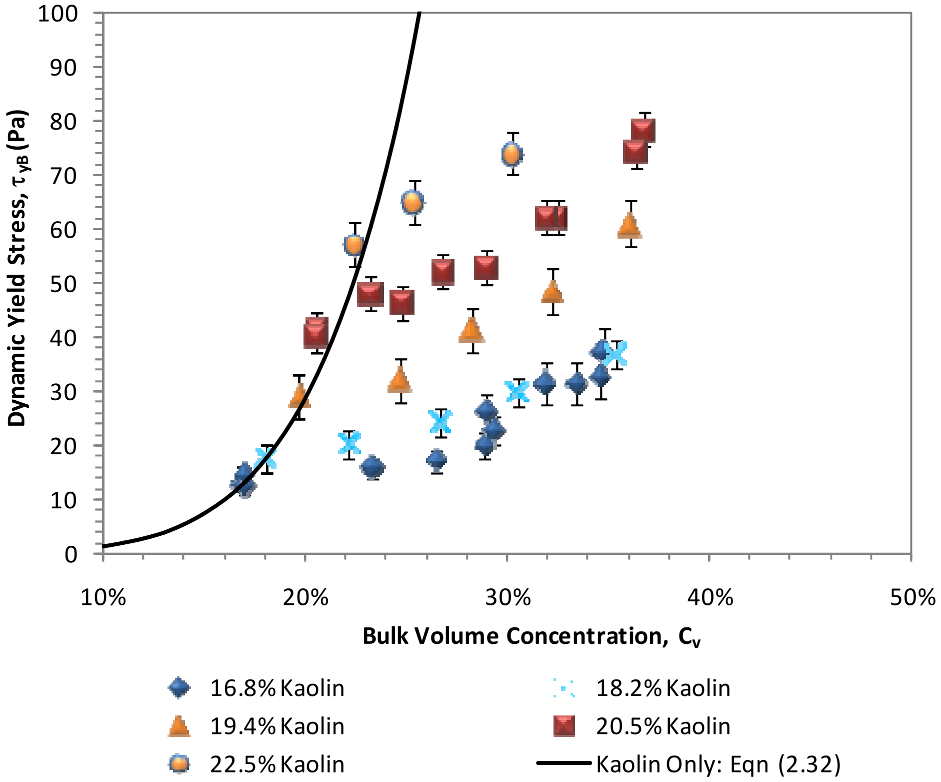

Figure 4.14: Dynamic Yield Stress as a Function of Bulk Volume Concentration for Lane Mountain Sand

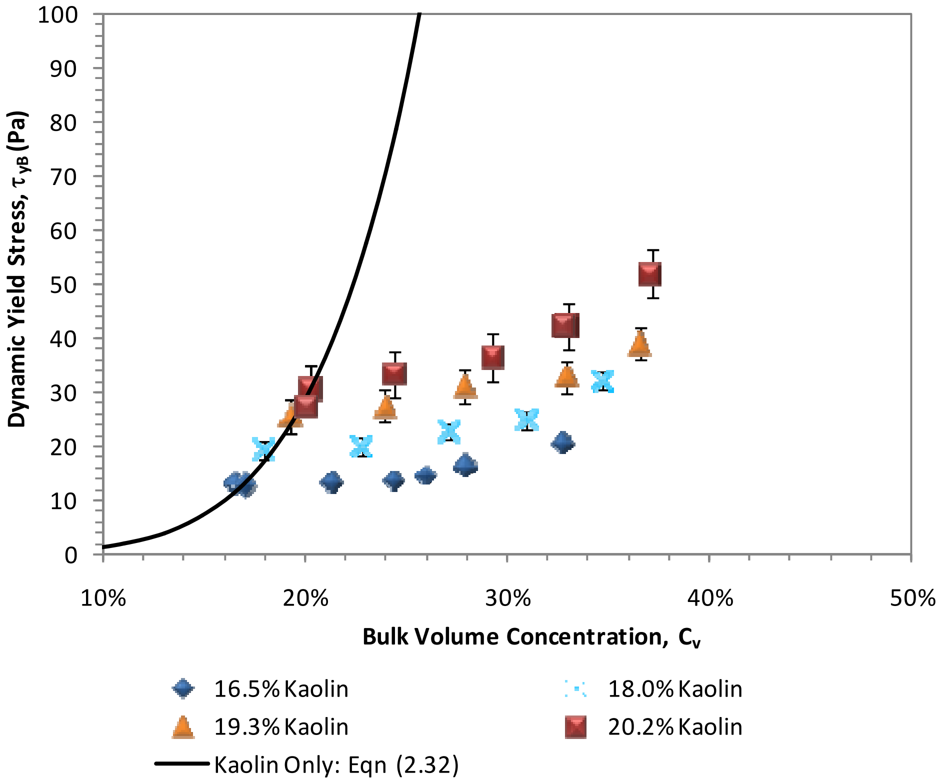

Figure 4.15: Dynamic Yield Stress as a Function of Bulk Volume Concentration for Ottawa River Sand

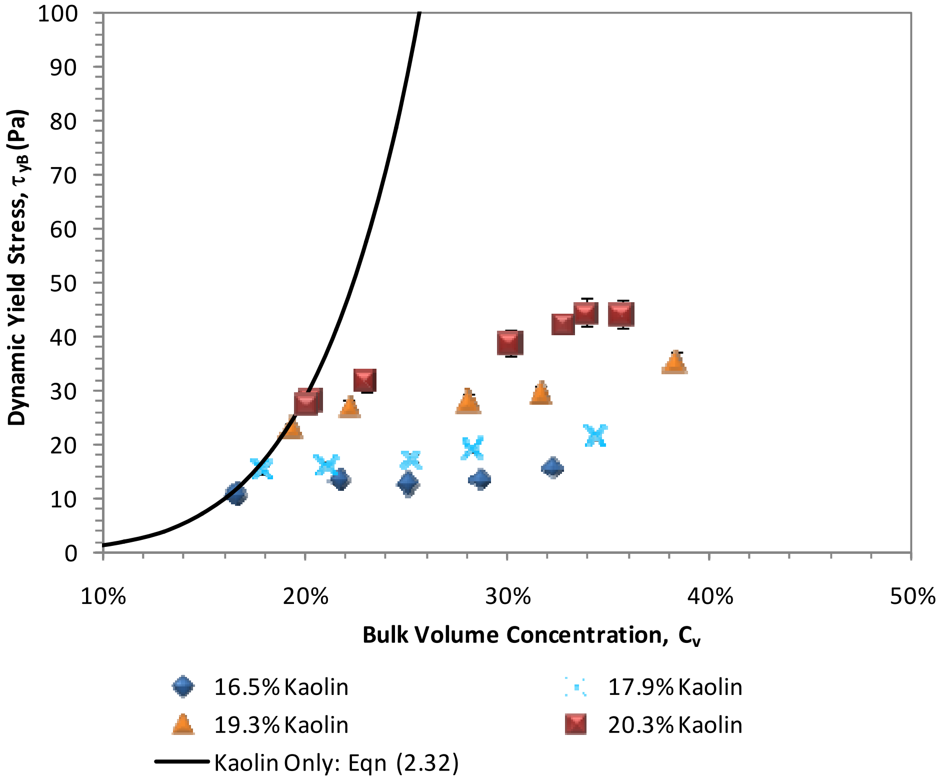

Figure 4.16: Dynamic Yield Stress as a Function of Bulk Volume Concentration for Quackenbush Glass

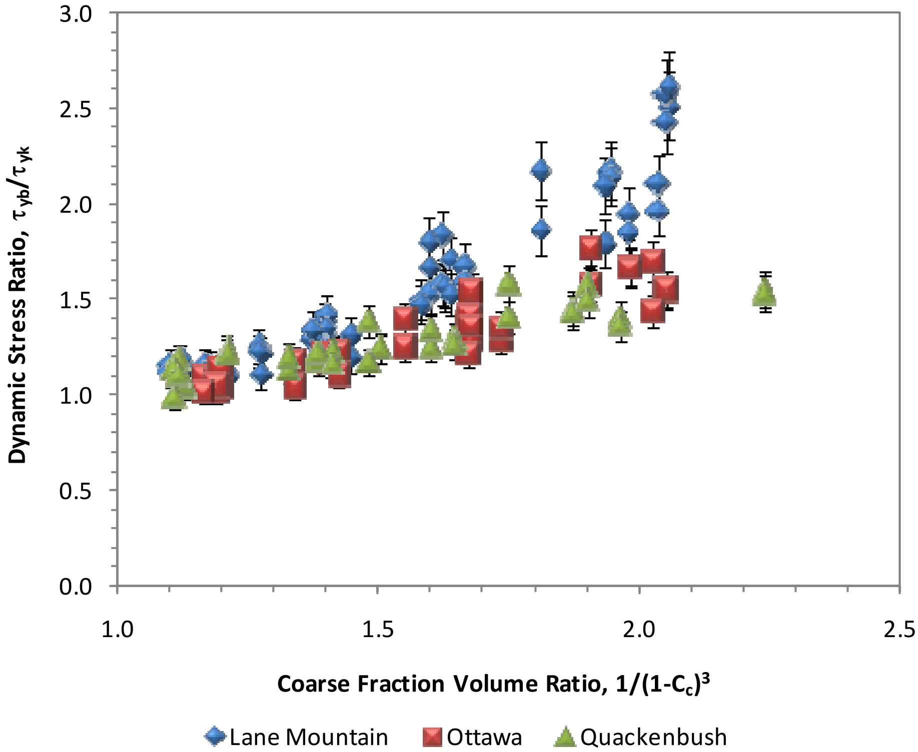

Figure 4.17: Dynamic Stress Ratios for all Coarse Materials Illustrating the Effect of Particle Shape

Bingham Plastic viscosity

The plastic viscosity as a function of the bulk volume concentration for Lane Mountain Sand, Ottawa Sand, and Quackenbush glass beads are shown in Figure 4.18, Figure 4.19, and Figure 4.20, respectively.

As with the dynamic yield stress, the plastic viscosity increases significantly, and this change is statistically significant based on the experimental error. The level the clay fraction is still the primary determinant of the magnitude of the plastic viscosity as was seen earlier with the dynamic yield stress. In addition, the decrease in plastic viscosity observed with the increase in sphericity, as is seen in Figure 4.21, is similar to what was observed earlier with the dynamic yield stress.

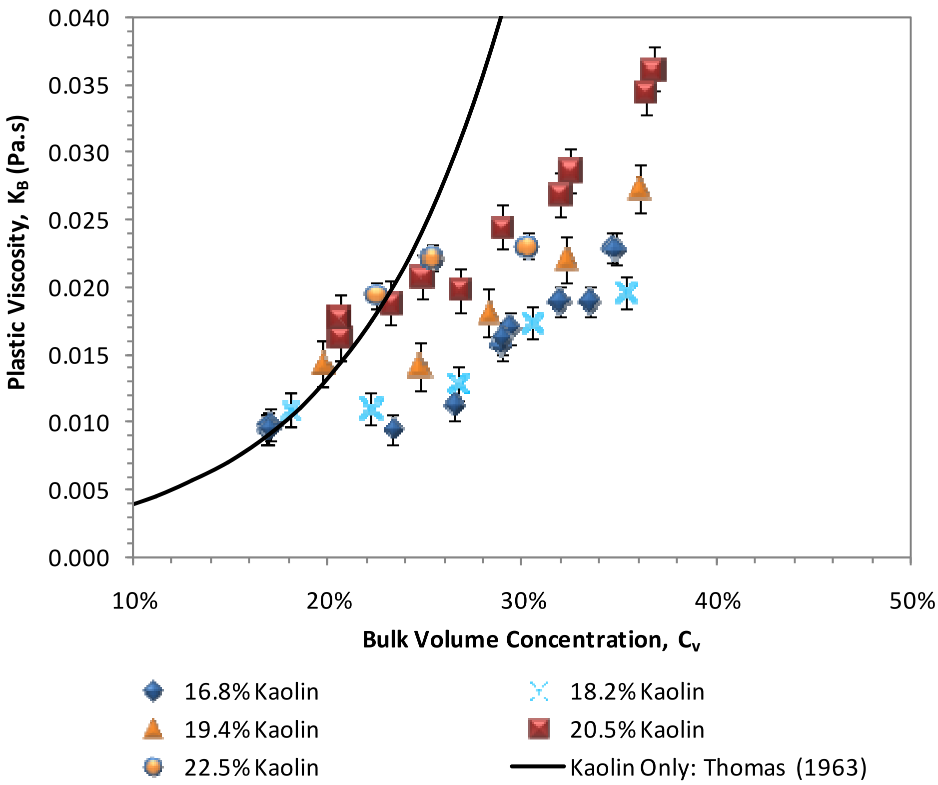

Figure 4.18: Plastic Viscosity as a Function of Bulk Volume Concentration for Lane Mountain Sand

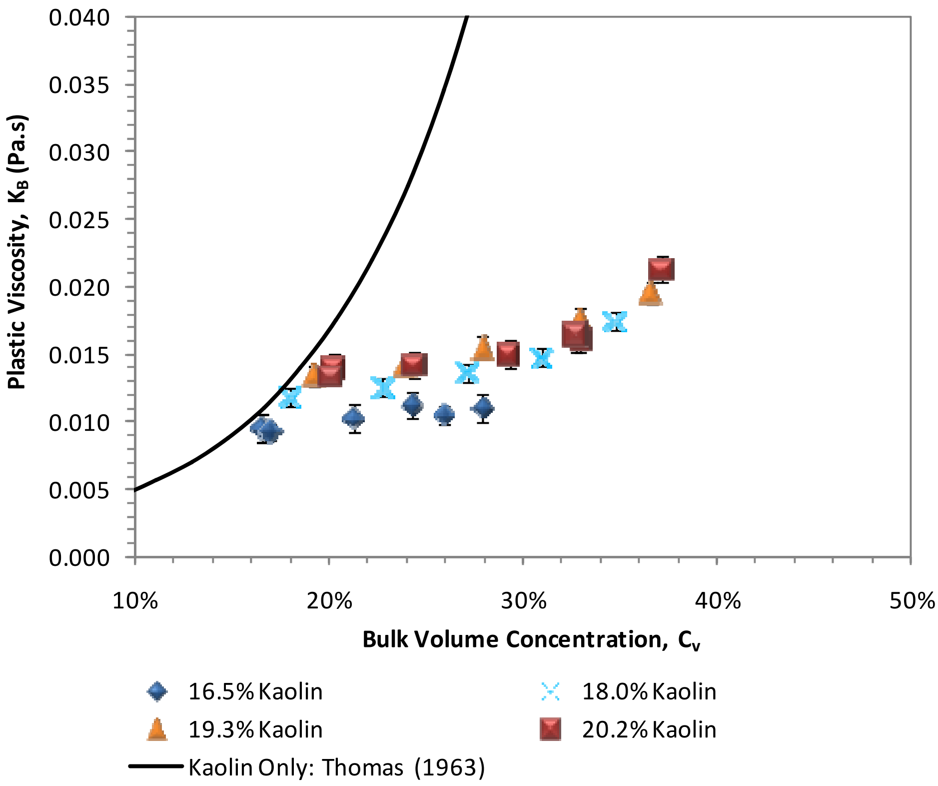

Figure 4.19: Plastic Viscosity as a Function of Bulk Volume Concentration for Ottawa River Sand

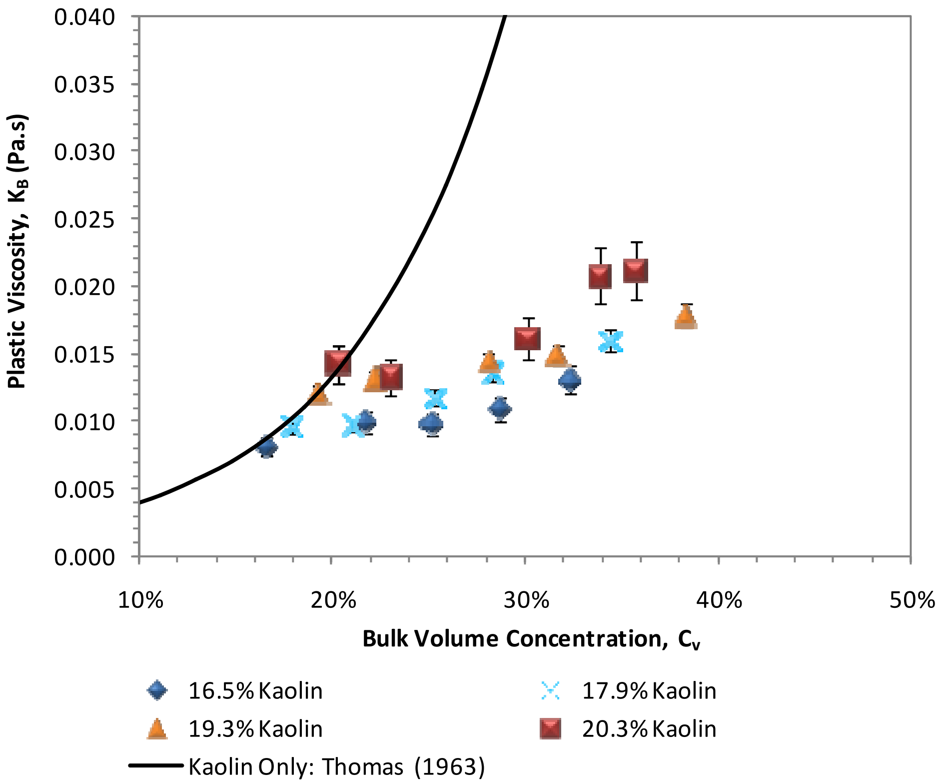

Figure 4.20: Plastic Viscosity as a Function of Bulk Volume Concentration for Quackenbush Glass

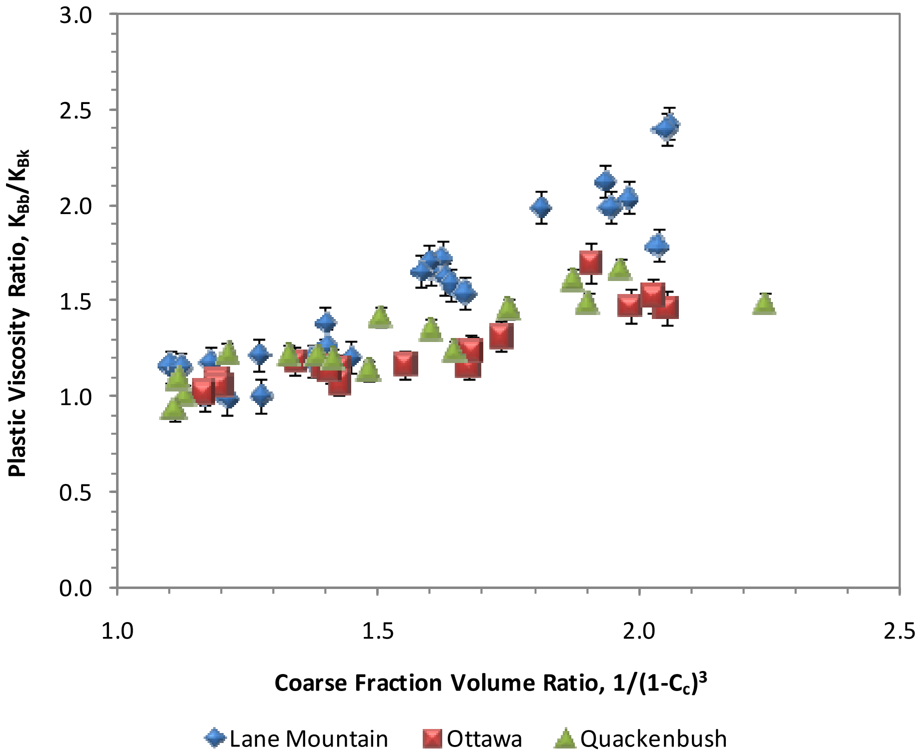

Figure 4.21: Plastic Viscosity Ratios for all Coarse Materials Illustrating the Effect of Particle Shape

Vane static yield stress

The static yield stress as a function of the bulk volume concentration for Lane Mountain, Ottawa Sand, and Quackenbush glass beads are shown in Figure 4.22, Figure 4.23, and Figure 4.24, respectively. It is apparent that the static yield stress increases significantly with bulk volume concentration. As was noted with the dynamic yield stress and plastic viscosity, the clay concentration is the dominant determinant of the slurry rheology. As was also noted earlier, the static yield stress increases with coarse particle concentration and decreases with increasing sphericity.

The relationship between the static and dynamic yield stress is shown in Figure 4.25. The same relationship for all coarse fractions is again followed as discussed in Section 4.4.1 and 4.4.2, namely the static yield stress is 48% of the dynamic yield stress, with an accuracy of 10.6%. This is an important observation. The addition of coarse particles affects both the static and dynamic yield stresses in the same way that the addition of Kaolin clay does. This suggests that the relative magnitude of the two yield stresses is not influenced by the relative motion of the coarse particles themselves.

This is since the static yield stress is obtained where no mixture motion occurs while the dynamic yield stress is obtained with the slurry being sheared using a rotating spindle. It would appear that the presence of coarse particles in the mixture has a similar effect on the static and dynamic yield stress values as the presence of clay flocs.

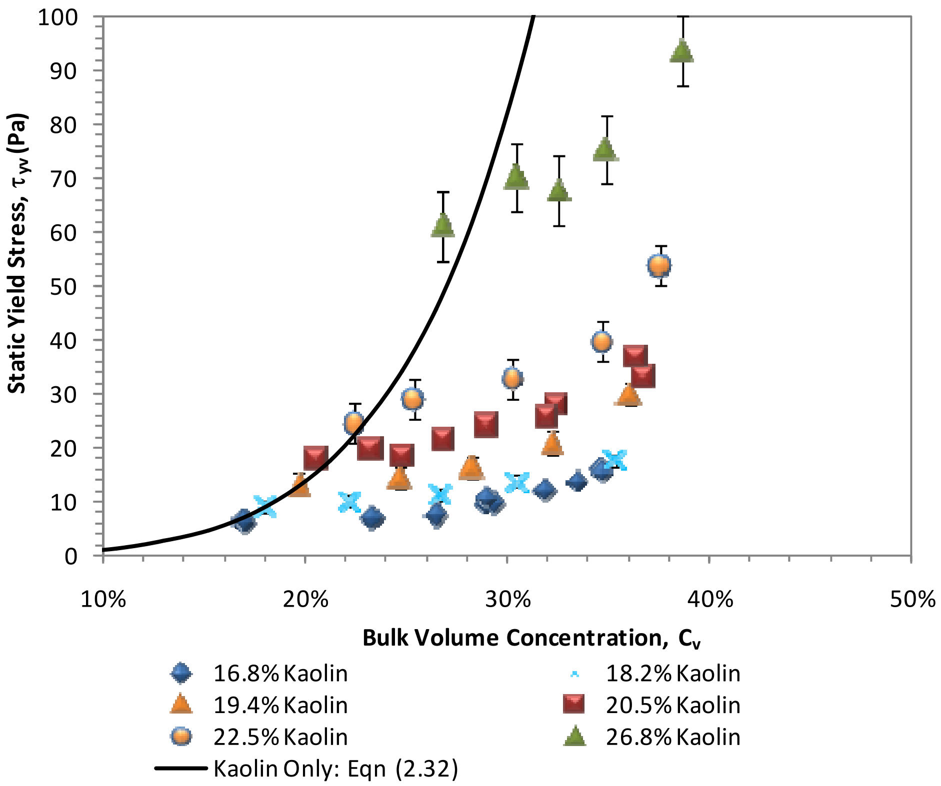

Figure 4.22: Static Yield Stress as a Function of Bulk Volume Concentration for Lane Mountain Sand

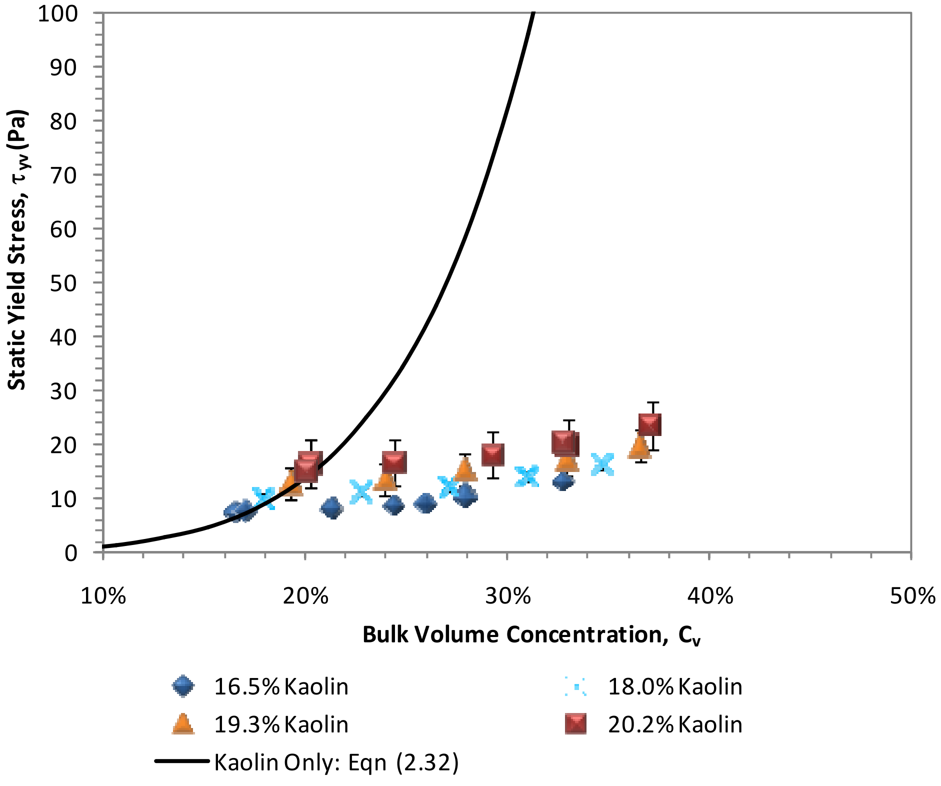

Figure 4.23: Static Yield Stress as a Function of Bulk Volume Concentration for Ottawa River Sand

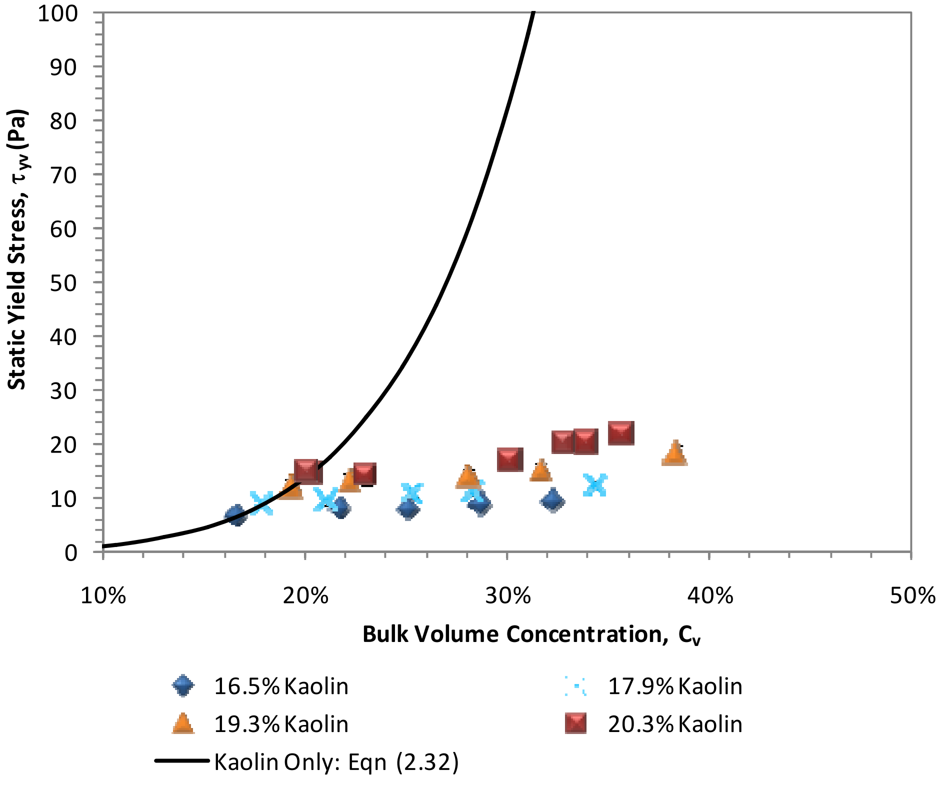

Figure 4.24: Static Yield Stress as a Function of Bulk Volume Concentration for Quackenbush Glass

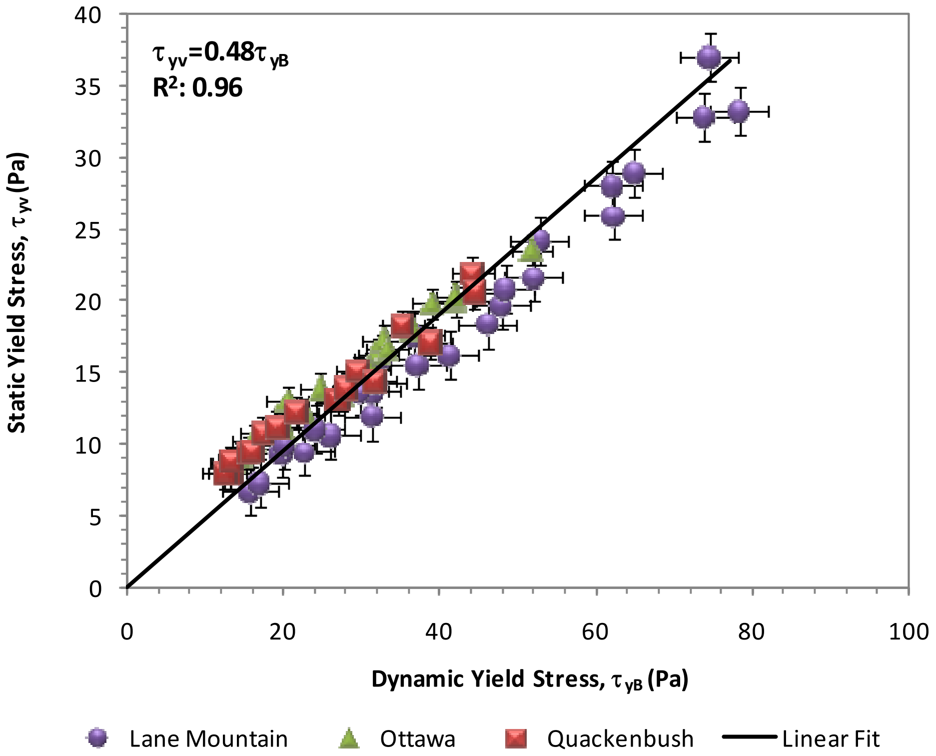

Figure 4.25: Static Yield Stress Versus. Dynamic Yield Stress for All Coarse Particles

4.5.2 *Evaluation of empirical and semi-empirical models*

Background

With a view to better understanding the effects observed in Section 4.5.1, the empirical and semi-empirical relationships discussed in Section 2.4.2 will be used to attempt to model the changes in rheological parameters noted in this study. Since it was determined in the previous section that both the static yield stress was proportional to the dynamic yield stress, these two parameters will be analysed in the same section.

Static and dynamic yield stress correlation: Wildemuth

Using the adapted Wildemuth relationship for the yield stress (Equation (2.51)) both the static and dynamic yield stresses have been modelled using the same constants since the two different yield stresses only differ by a proportionality constant (as discussed in the previous section). The Lane Mountain Bingham and vane yield stress results are shown in Figure 4.26 and Figure 4.27, respectively.

The average standard error for the correlation associated with the dynamic yield stress and the static yield stress is 11.3% and 4.4%, respectively. Similar results are obtained for the Ottawa sand and Quackenbush glass with averaged errors associated with the correlation ranging from 1.5% to 5.0% (see Figure 4.28 to Figure 4.31).

It is important to note that the slope of the correlating function obtained with the different types of coarse particles is independent of the clay fraction employed in the slurry (i.e. the correlation curves are parallel). This implies that, regardless of the Kaolin concentration in the slurry, the net increase in yield stress associated with the addition of coarse particles only related to the coarse fraction added.

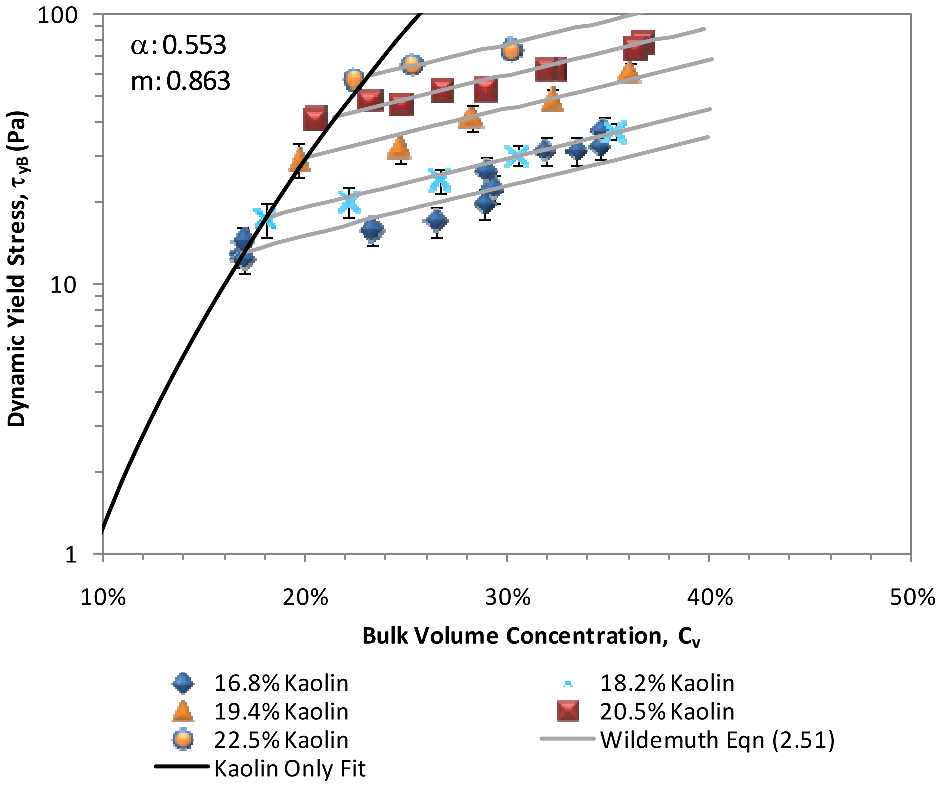

Figure 4.26: Wildemuth Correlation for Dynamic Yield Stress of Lane Mountain Sand

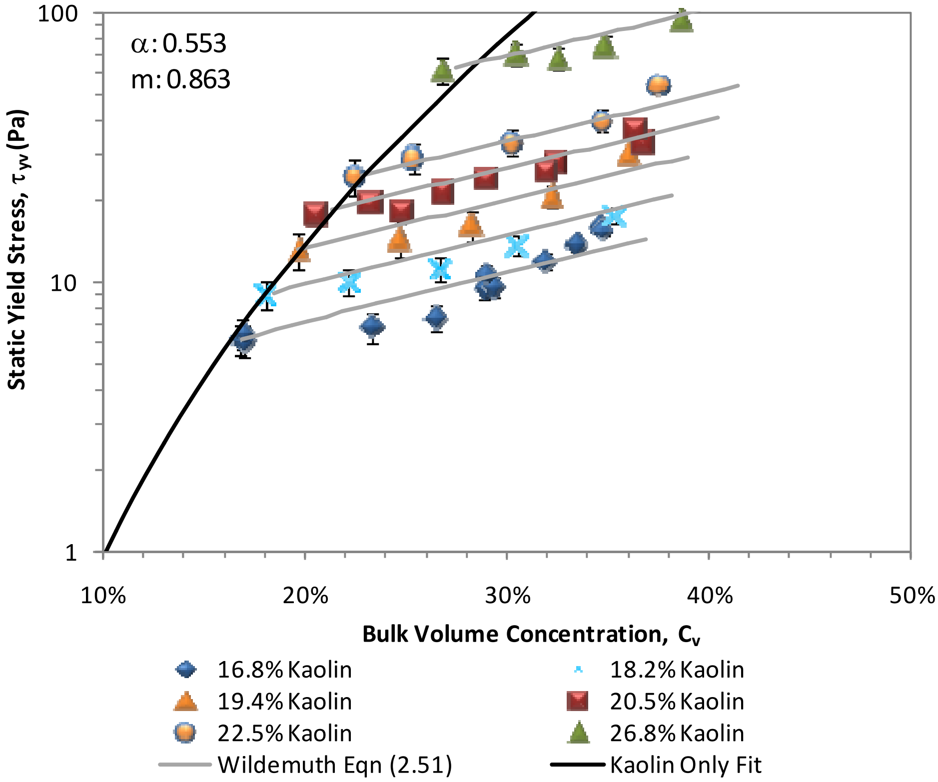

Figure 4.27: Wildemuth Correlation for Static Yield Stress of Lane Mountain Sand

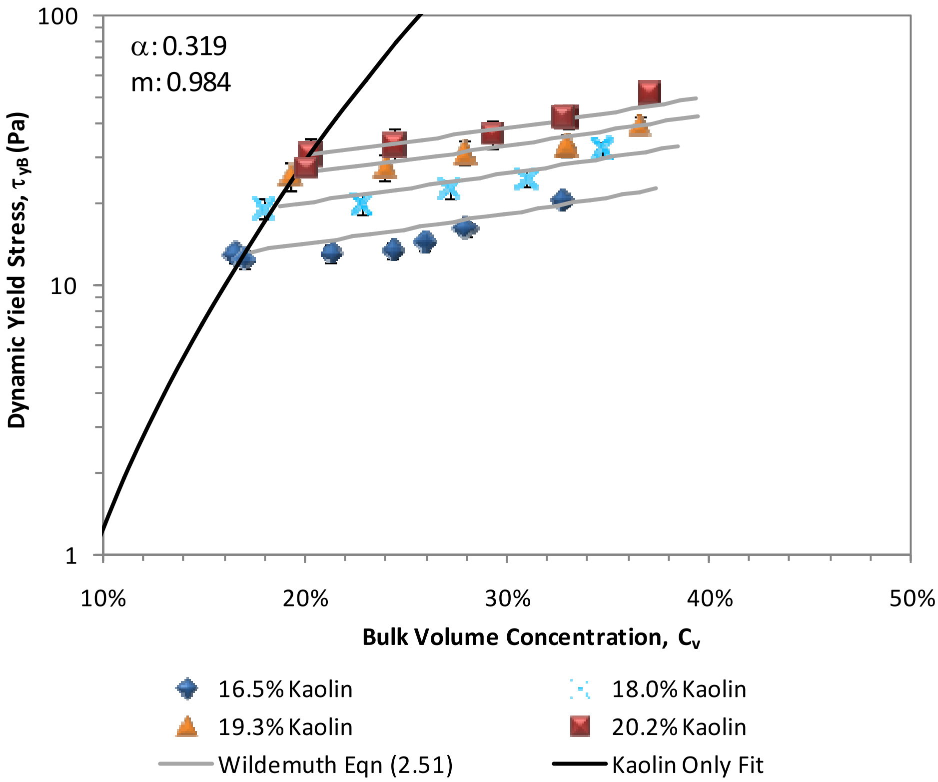

Figure 4.28: Wildemuth Correlation for Dynamic Yield Stress of Ottawa River Sand

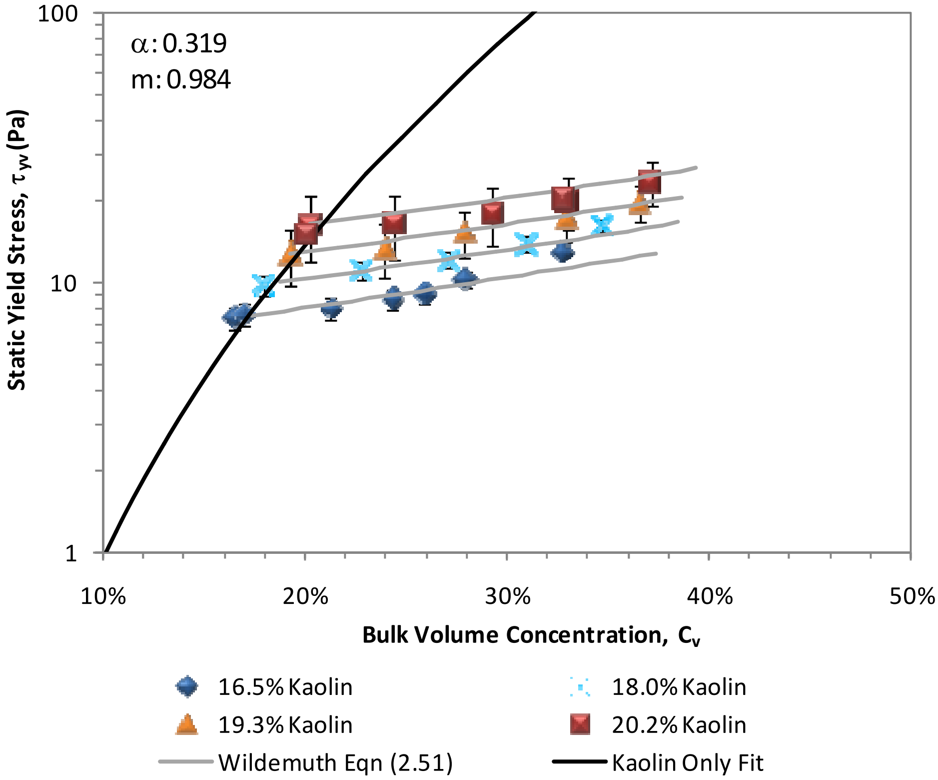

Figure 4.29: Wildemuth Correlation for Static Yield Stress of Ottawa River Sand

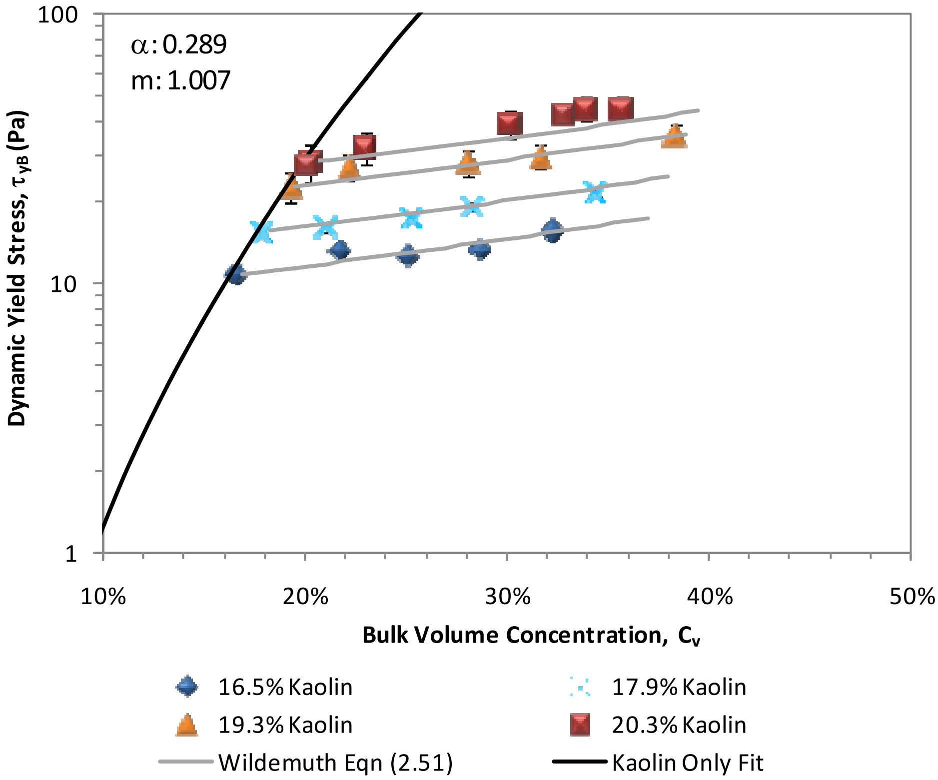

Figure 4.30: Wildemuth Correlation for Dynamic Yield Stress of Quackenbush Glass

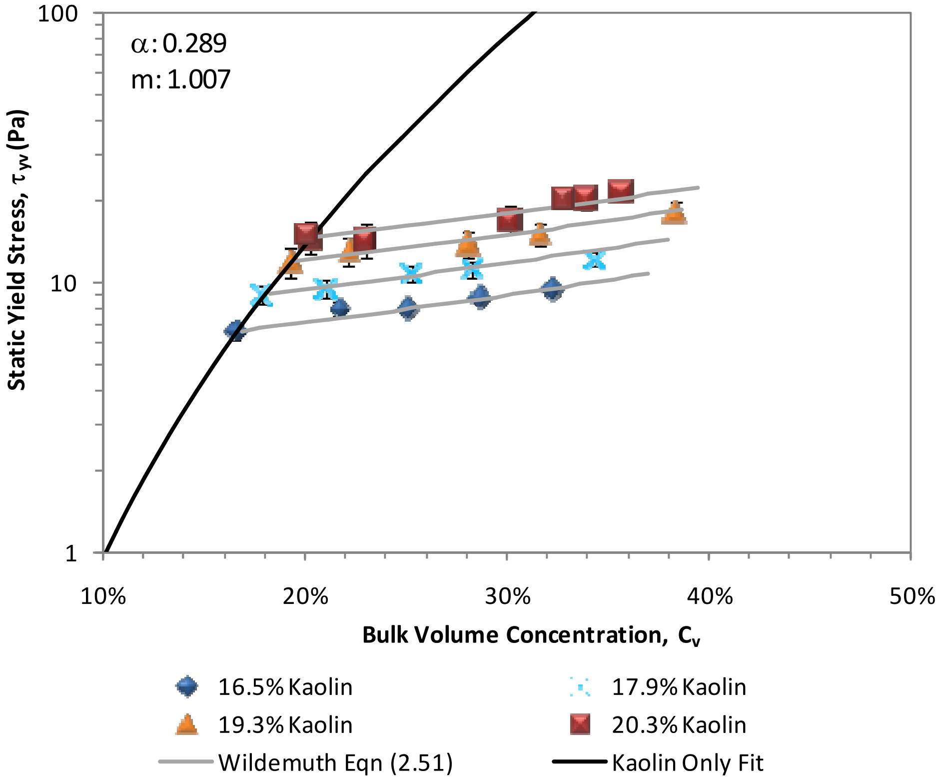

Figure 4.31: Wildemuth Correlation for Static Yield Stress of Quackenbush Glass

The modified Wildemuth equation provides a good correlation for the effect observed with the yield stress values. However, an empirical constant must be developed for each type of coarse particle. An equation which relates the empirical constant to characteristics of the particle is beyond the scope of this study.

Static and dynamic yield stress correlation: distance ratio

A more effective approach to developing a more general correlation would involve including a specific characteristic(s) associated with the type of coarse particles. The maximum settled bed concentration $C_{v,max}$ would represent a potential characteristic. For this reason, the bulk concentration in addition to the distance ratio, λ, has been shown to be an effective means of depicting variation in particle characteristics in earlier rheological parameter correlations.

Figure 4.32 presents an attempt to develop a function to predict the increase in static and dynamic yield stresses (from the original clay yield stresses) using the distance function. There is no statistical difference between the coarse fraction yield stress results (with a confidence limit of 95%), establishing the normalisation of the yield stresses by means of the incorporation of $C_{v,max}$. The average error in the correlation (±14%) is however significantly higher than errors from the adapted Wildemuth correlation.

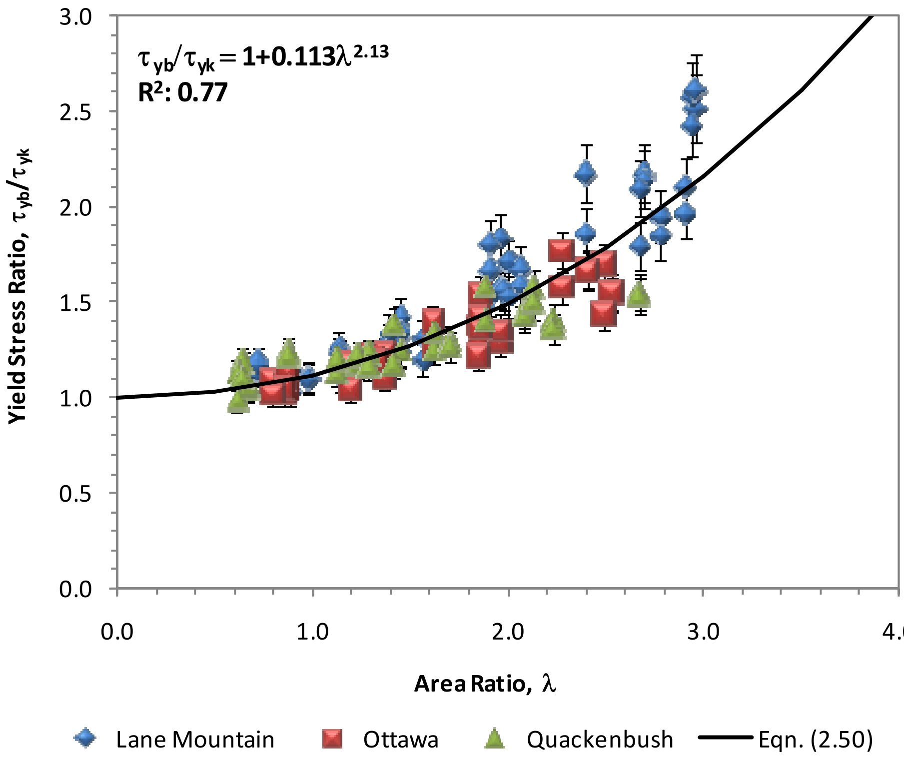

Figure 4.32: Yield Stress Increase as a Function of the Distance Ratio for Dynamic and Static Yield Stress

Static and dynamic yield stress correlation: A. Thomas correlation

The results presented in Figure 4.33 illustrate the ability of the Thomas (1999) equation, as described by Equation (2.48), to represent the yield stress data. Again, both the static and dynamic yield stress values are presented for each coarse material. As with the distance ratio relationship described in the previous section, the Thomas equation is capable of providing a reasonable representation of the data as is evidenced by the average standard errors of ±13%. The parameter value that gave the best fit, 1.94, is close to the value of 1.50 which obtained by Thomas (1999) in his investigation.

It is important to note that a significant deviation from the best fit correlation occurs at concentration ratio values greater than 40%. This could be explained by the effect of coarse particle interactions which would become more important at higher concentrations (higher collision frequencies).

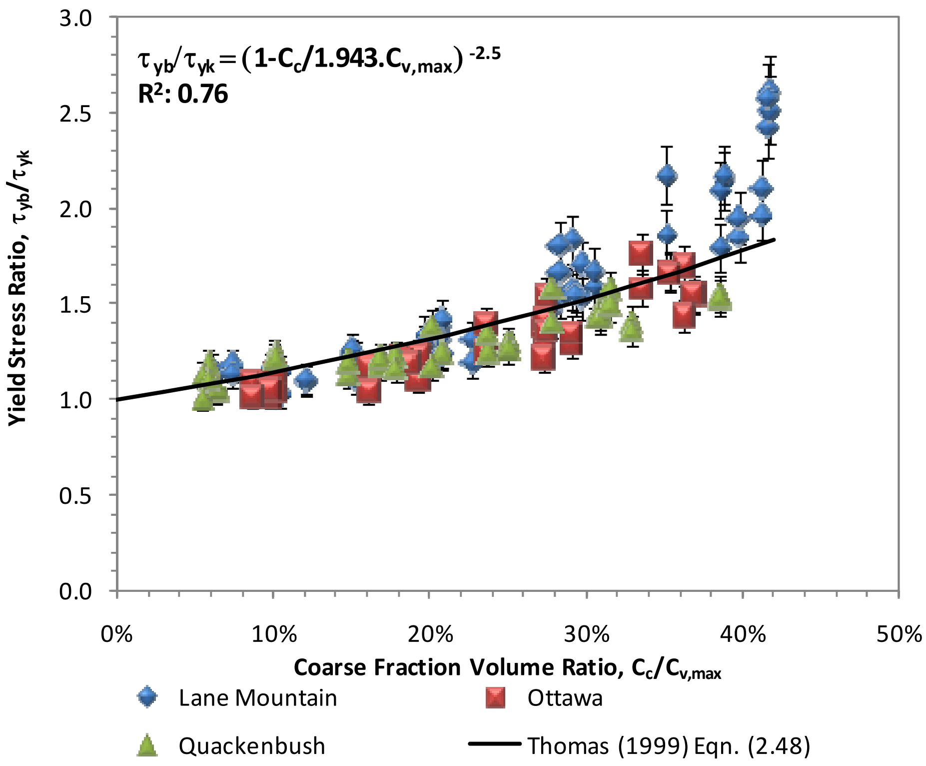

Figure 4.33: Yield Stress Increase as a Function of the Coarse Fraction Volume Ratio

Static and dynamic yield stress correlation: Zhou correlation

The approach developed by Zhou (1999) involves identifying a fictitious equivalent average particle radius, based on his equation (Equation (2.52)) which is capable of predicting the increase in yield stress. The equivalent mixture radius $\bar{r}$ would be expected to be inversely proportional to the Kaolin clay volume fraction since the fictitious particle size would approach the clay size as the Kaolin clay concentration increases. The equivalent radius would also be expected to be directly proportional to the coarse particle concentration because the fictitious radius will approach the coarse particle radius as maximum settled concentration limit is approached. This relationship is represented as follows:

$$\bar{r} \propto \frac{1}{C_k} \frac{C_c}{C_{v,max}}. \tag{4.1}$$

This relationship can be expanded to provide an equation for correlating the fictitious mixture radius from the mixture properties:

$$\bar{r} = A\left(\frac{1}{C_k}\right)^m \left(\frac{C_c}{C_{v,max}}\right)^n + B. \tag{4.2}$$

Where A, m, and n are correlation parameters to be determined by fitting measured data. The parameter B would be expected to be comparable to the average radius of the Kaolin clay particles based on the anticipated lower limit asymptote. By performing a series of linear regressions on the measured data, and the yield stress ratio data is used to determine the mixture radius, it was found that the experimental data could be well represented by Equation (4.2), as shown in Figure 4.34. The values for m and n are found to be 2 and 3 respectively. This is an interesting result since it corresponds with the function proposed by Thomas (1965) that the yield stress is a cubic function of concentration (see Section 2.3.1). The value for B of 1.389 corresponds to the average radius of the Kaolin clay particles used which is encouraging.

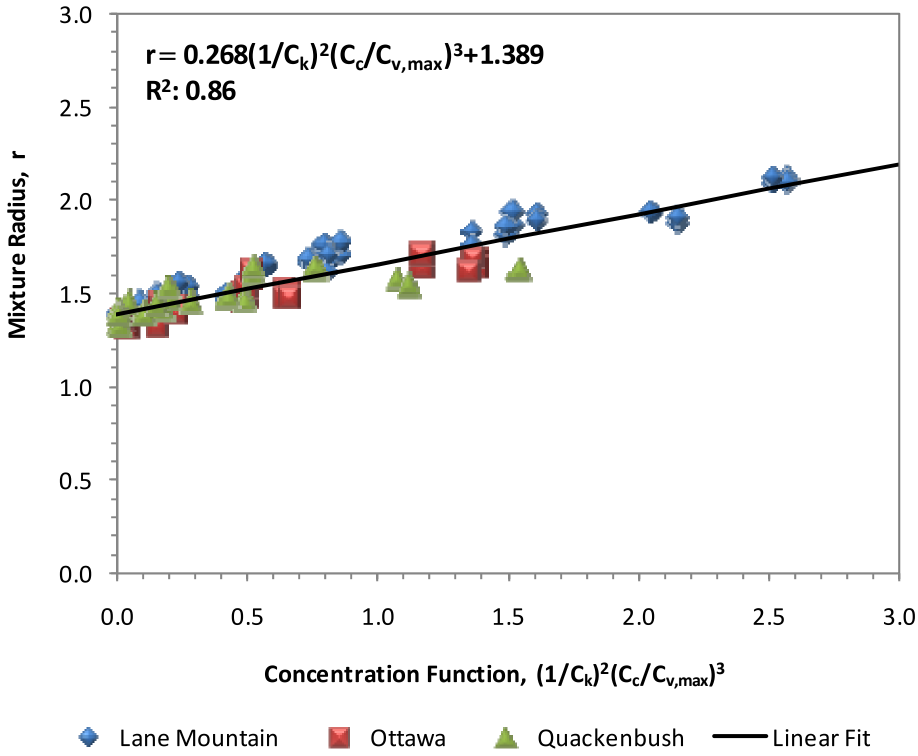

Figure 4.34: Mixture Radius as a Function of Kaolin and Coarse Volume Fraction

The increase in yield stress can be predicted using Equation (4.2) and the calculated mixture radius which is obtained from Equation (2.52). The ability of the correlation to predict all of the yield stress data is illustrated an average standard correlation error of ± 8.0% and is therefore capable of predicting the yield stress to significantly better than the previous empirical models described in the preceding sections.

Overall, satisfactory agreement has been found with a number of semi-empirical and empirical functions. The modified methods of Wildemuth and Zhou provided a better prediction of the yield stress ratios. The modified Zhou method is more suitable for use since characteristics of the coarse fraction types are incorporated by including the maximum settled bed concentration parameter.

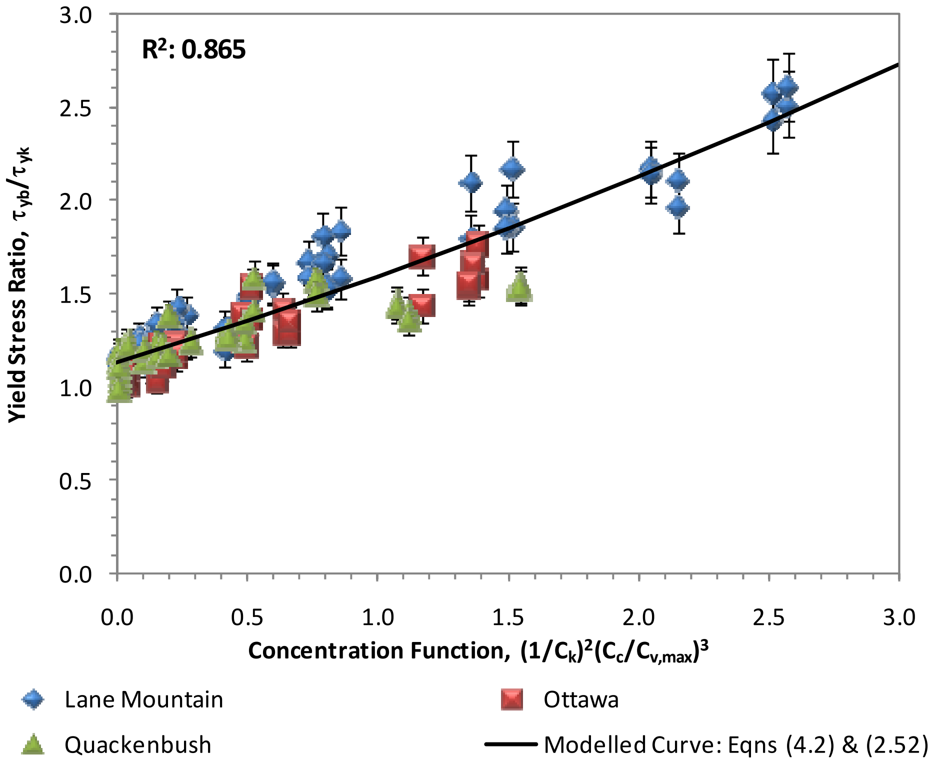

Figure 4.35: Yield Stress Ratio Predicted by a Modified Zhou Method

Plastic viscosity correlation: distance ratio

As with the yield stress ratio, the plastic viscosity ratio can also be represented in terms of the distance ratio, λ. This relationship is shown in Figure 4.36. It is apparent that the increase in Bingham viscosity is also best represented using the same correlation parameters with standard errors of ±10%. This implies, that should the distance ratio sufficiently explain the rheology increase due to the addition of the coarse particles, the rheology increase is constant for both yield stress and Bingham viscosity. A constant increase in rheology regardless of shear rate is therefore inferred.

Consider the Bingham relationship for shear stress determination (Equation (2.5)) defining both the Kaolin only and coarse particle mixtures:

$$\frac{\tau_{o,bulk}}{\tau_{o,kaolin}} = \frac{K_{B,bulk}\dot{\gamma} + \tau_{y,B,bulk}}{K_{B,kaolin}\dot{\gamma} + \tau_{y,B,kaolin}} \tag{4.3}$$

and since the increases in parameters are the same, we have:

$$\frac{\tau_{y,B,bulk}}{\tau_{y,B,kaolin}} = \Delta = \frac{K_{B,bulk}}{K_{B,kaolin}}$$

∴

$$\frac{\tau_{o,bulk}}{\tau_{o,kaolin}} = \Delta.$$

This effect is demonstrated in Figure 4.37. Note, that this effect was also observed by Thomas (1999) when he investigated sand concentrations over a range of only 0-to 25 $\%_v$.

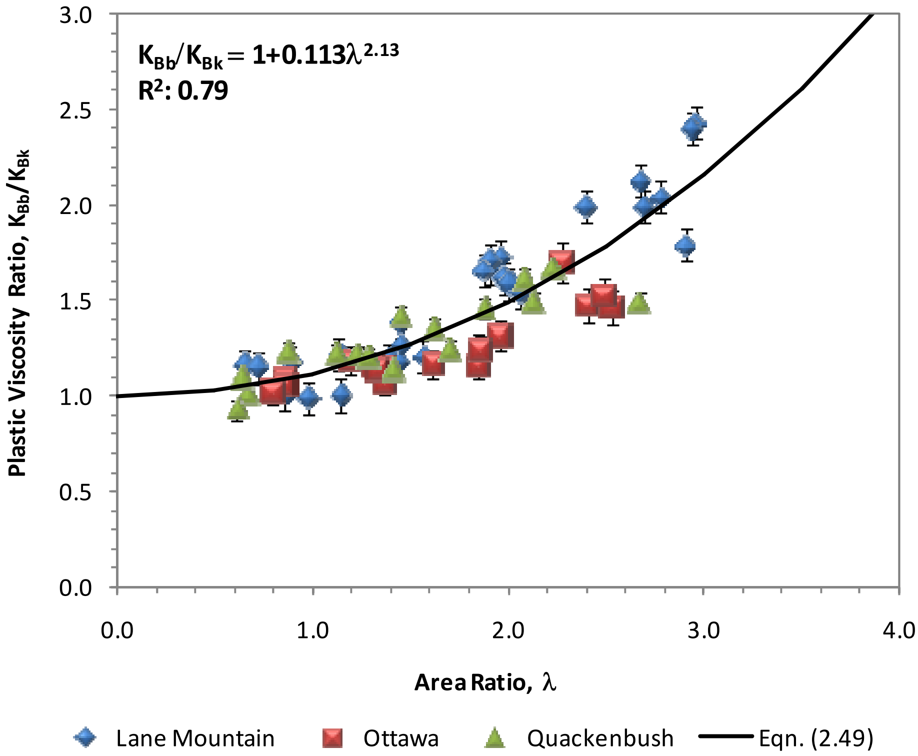

Figure 4.36: Yield Stress Increase as a Function of the Distance Ratio for Plastic Viscosity

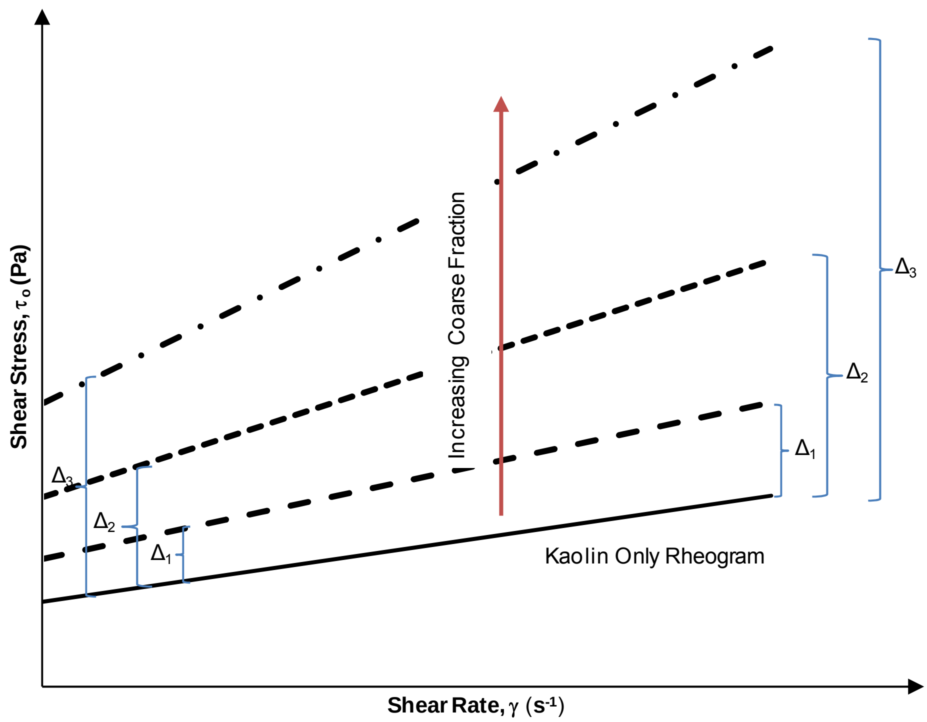

Figure 4.37: Illustration of Constant Rheology Increase

Plastic viscosity correlation: A. Thomas correlation

The Thomas (1999) relationship which was used earlier for the dynamic yield stress can be applied to the represent the behaviour of the plastic viscosity. In fact, it was found that the increase in plastic viscosity is very similar to the measured increase in yield stress as is shown in Figure 4.38. Indeed, an Analysis of Variance test on the plastic viscosity ratio and yield stress ratio's proves there is no statistical difference between the ratios within a confidence limit of 95%. Overall, good agreement is found (standard error ±10.3%) with this function and it may be deduced that the plastic viscosity ratio behaviour is well represented by this function.

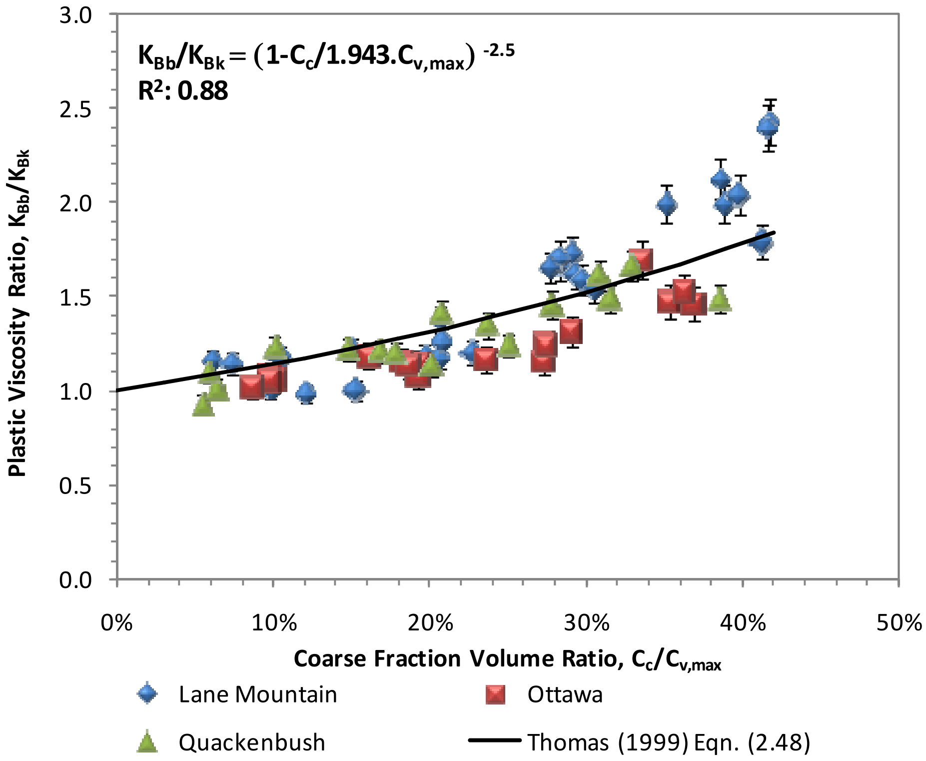

Figure 4.38: Plastic Viscosity Increase as a Function of the Coarse Fraction Volume Ratio

Plastic viscosity correlation: Chong correlation

The relationship of Chong (1971) (Equation (2.39)) for hard spheres in a Newtonian mixture can be used to describe the effect of coarse particle concentration on the plastic viscosity. The best fit of the data is shown in Figure 4.39. It is worth noting that if the power parameter in Equation (2.39) is reduced from 2 to 1 the error in the correlation is significantly reduced from ±21% to ±16%.

The application of this correlation was extended to the yield stress ratio data generated in this study. The ability of the correlation to represent the data is presented in Figure 4.39. The ability of the correlation to represent the data suggests that it can be further modified in order to best represent all the rheology data of this investigation. In this case, the power parameter becomes 1.5, as shown in Figure 4.40, and the average standard error is ±15.9%.

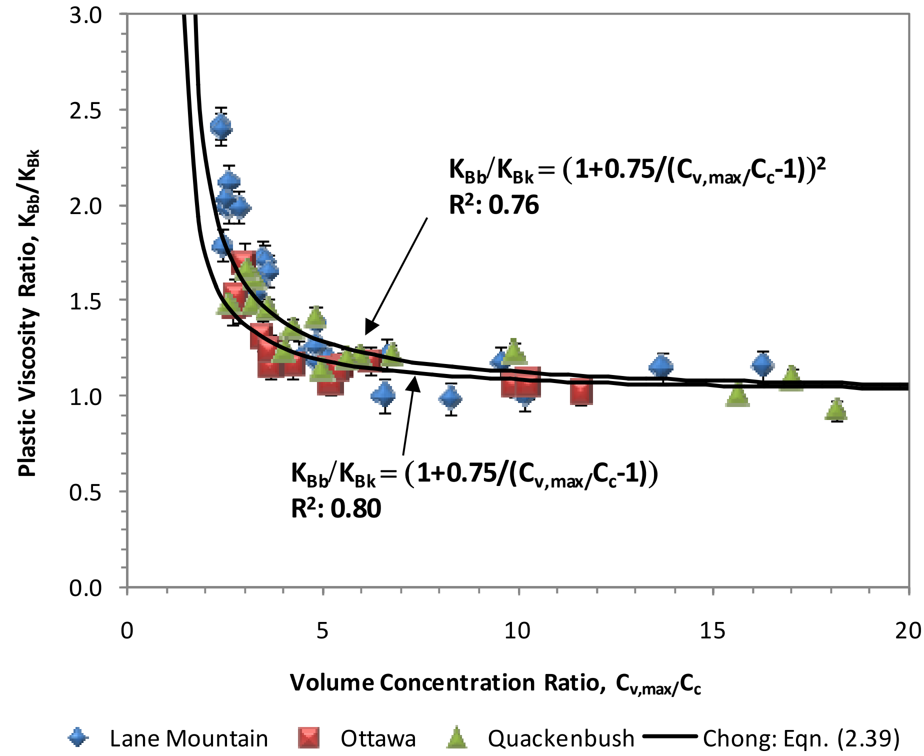

Figure 4.39: Plastic Viscosity Increase as a Function of the Coarse Fraction Volume Ratio

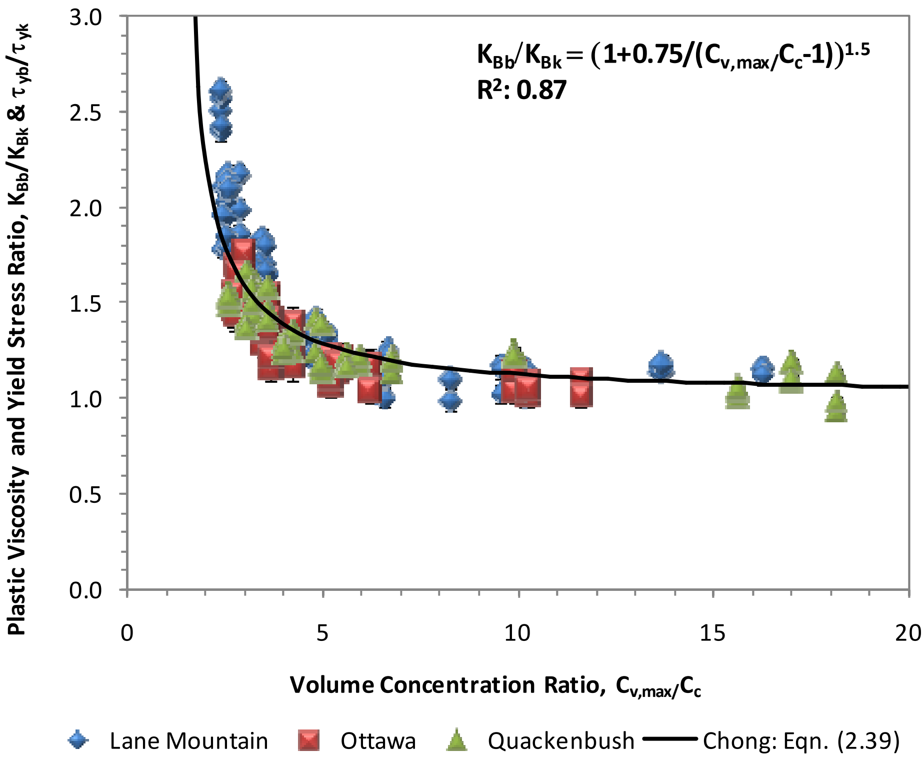

Figure 4.40: Plastic Viscosity and Yield Stress Increase as a Function of the Coarse Fraction Volume Ratio

4.5.3 *Colloidal and coarse particle interactions*

The empirical relationships in the previous section provide an acceptable means of predicting the changes in rheological parameters resulting from coarse particle addition. However, since the relationships are empirical, they do little to advance the understanding of the mechanisms causing the increase in the rheological parameters. Effects caused by hydrodynamic interactions were used in the development of some of the semi-empirical correlations. Hydrodynamic mechanisms may be important in explaining the observed behaviour based on the success of the correlations. However, the analysis performed in the previous sections does not clearly identify the phenomena causing the observed behaviour.

If there are any interactions between the clay floc structure and the coarse particles, the increase in the dynamic yield stress would be expected to be more than $1/(1 - C_c)^3$ based on the analysis of Sumner et al. (2000) (see Section 2.4.2), since this would imply that the coarse fraction is approaching the size of the flocculent. In that reference, it was suggested that such an increase would imply that the coarse fraction is approaching the size of the clay floc. The sizes of these flocs were estimated between 30 µm and 300 µm (Sumner et al., 2000).

Figure 4.41 illustrates how closely the dynamic yield stress and plastic viscosity follow a cubic concentration function. Based on a 95% level of confidence, the data is well represented by the cubic concentration function. Based on the explanation provided by Sumner et al., it would appear that the coarse particles and clay flocs are significantly different in size such that the effect of the coarse particle interaction within the floc structure may be ignored.

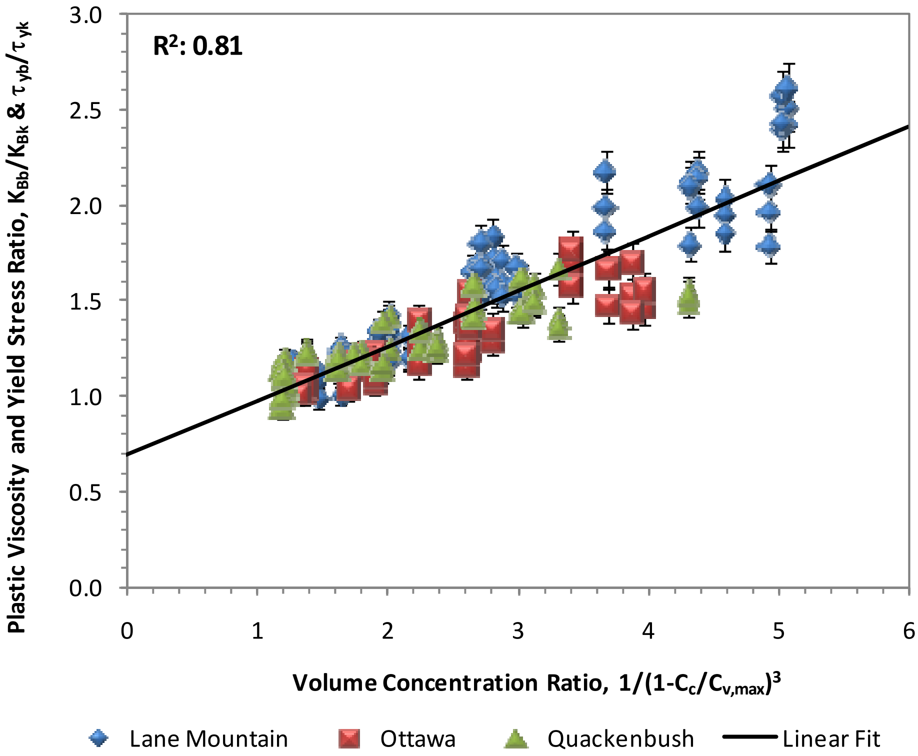

Figure 4.41: Plastic Viscosity and Yield Stress Increase as a Function of the Cubic Coarse Fraction Volume Ratio

Another possible explanation for the observed behaviour is fluid depletion. Two scenarios with regards to depletion may exist. These are depletion due to repulsion forces between the surface of the coarse particles and the flocs, or purely from geometric constraints. In order to estimate the importance of geometric effects, the floc size needs to be determined. Potanin (1996) provides the following equation for the estimating the size of a floc size based on a structure at equilibrium:

$$r_{floc} \sim r_k C_k^{-1/(3-d_f)}. \tag{4.4}$$

where $d_f = -\left({}^{3}/_{c} - 3\right)$, and c is determined from Equation (2.32). Based on the analysis performed in Section 4.4.1, the value for c determined with the results of this study was 3.6. This results in a value of 2.2 for d_f. The average floc size determined in this way is 5.6 μm which is comparable to value of the order of 7 μm which was determined by Ancey (2001). Equations (2.45) to (2.47) can be used to determine values of the yield stress can be determined for a modified Kaolin density.

The values determined in this way however drastically underestimate the yield stress (an illustration of this is seen in Figure 4.42). Ancey (2001) witnessed similar behaviour and consequently changed the depletion layer until more satisfactory results were obtained. He found values approximately 70 times higher than that predicted from geometric constraints. This may indicate that the structure of the formula is correct; however the theory may be inaccurate.

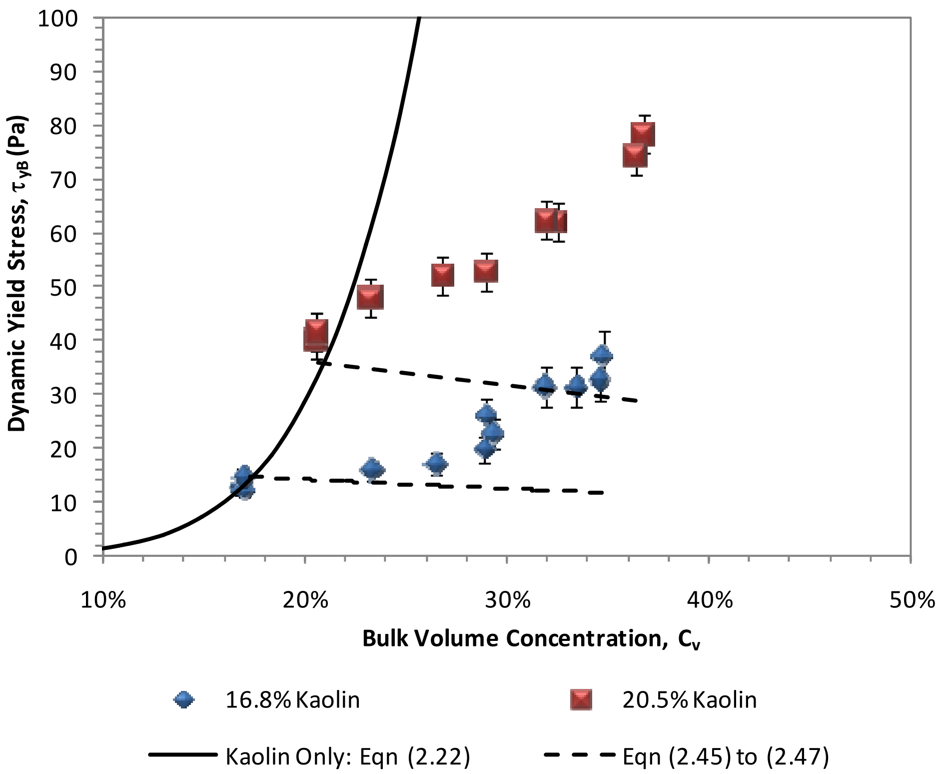

Figure 4.42: Dynamic Yield Stress Prediction with Geometrically Determined Depletion Layer Thickness

By adjusting the depletion layer thickness to be between 0.15 and 0.20 µm, it was possible to obtain reasonable predictions of the static and dynamic yield stress as is shown in Figure 4.43 and Figure 4.44. The average standard errors for these correlations are ±12.5% and ±10.2% respectively. As with Ancey, the fitted values of the depletion layer thickness are approximately 70 to 100 times larger than that predicted using the theoretical approach. As discussed earlier, this may suggest that the theory provides the correct form of the equation but does not accurately represent the physical behaviour. A depletion type effect could also be caused by repulsion forces or changes in floc structure due to the presence of the coarse particles. The latter is unlikely considering the range of volume concentrations tested in this project. Further investigation would be required to determine if surface repulsion effects could cause the measured behaviour.

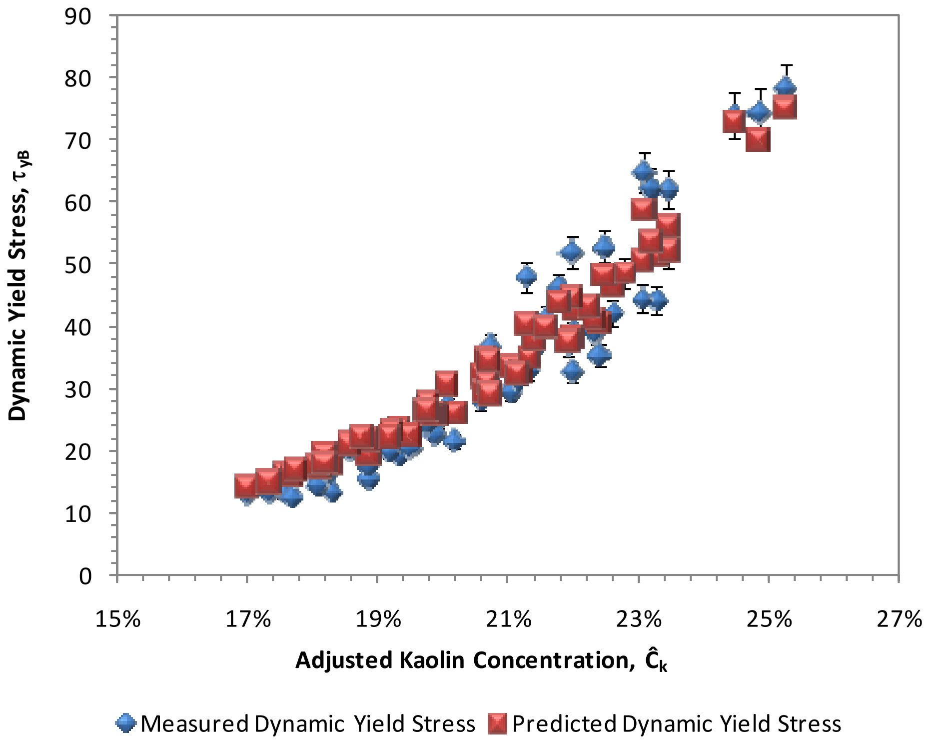

Figure 4.43: Dynamic Yield Stress Prediction with Optimised Depletion Layer Thickness

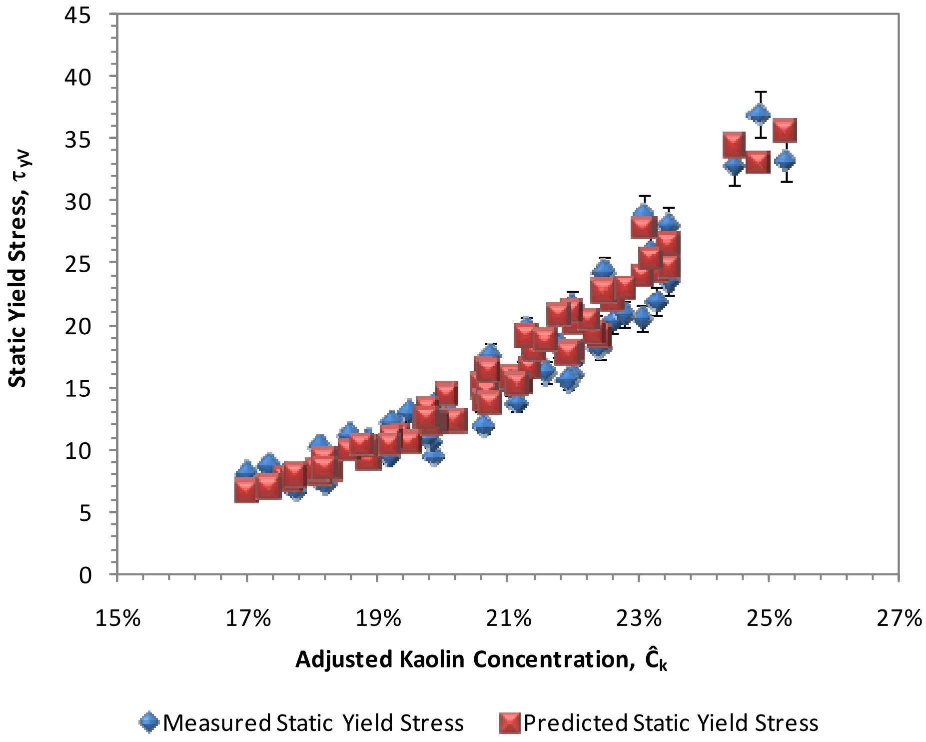

Figure 4.44: Static Yield Stress Prediction with Optimised Depletion Layer Thickness

Although good correlation was obtained for the Depletion Effect approach, the underlying mechanism on which this approach is based is not theoretically sound for reasons already mentioned. Another potential method for representing the effect of solids addition involves the development of an "effective" Kaolin concentration, which would take into account the experimentally observed increase in slurry rheology. The effective concentration represents clay concentration of a clay-only slurry which would give the same rheology as that observed with the clay-sand mixture. A residual concentration can also be defined which is the difference between the effective clay concentration and the clay concentration in the actual slurry. The residual concentration is therefore related to the effect on rheology resulting from the addition of coarse particles. It is believed that more meaningful deductions can be made using the effective/residual clay concentration approach. This approach assumes that a coarse particle acts, from a rheological standpoint, as a floc when it is added to the slurry. However, it is expected that since the coarse particle has a significantly lower charge to mass ratio than the flocs, the addition of these particles would not increase the rheology as significantly as a similarly sized floc.

As shown by Equation (2.32), the yield stress of a Kaolin only slurry is a function of the Kaolin concentration. It is now assumed that a Kaolin concentration (Kaolin only) exists which would have the same rheology as the Kaolin-coarse material slurry. This can be represented as follows for the static or dynamic yield stress:

$$\tau_{yc} = \mathrm{fn}(\mathrm{C_k}, \mathrm{C_c}). \tag{4.5}$$

Applying this argument to Equation (2.32), we now have:

$$\tau_{yc} = K\left(\frac{C_{k,adj}}{1 - C_{k,adj}}\right)^{c} \frac{1}{{d_p}^2}, \tag{4.6}$$

where the effective or adjusted Kaolin concentration, $C_{k,adj}$ is determined from the Kaolin only concentration, and a residual clay concentration, $\mathrm{C_{res}}$, is expected to be a function of the coarse solids fraction concentration, and shape of the coarse particle as shown below:

$$C_{k,adj} = C_k + \mathrm{C_{res}} = C_k + \mathrm{fn}(\mathrm{C_c}, \text{Particle Shape}) \tag{4.7}$$

The effective concentration for each coarse slurry test was found by determining the Kaolin only slurry concentration which best represented the dynamic yield stress of the coarse slurry. A plot of the residual concentration versus the coarse particle concentration is shown in Figure 4.45. Overall, the variation in residual concentration with coarse particle concentration appears to be quite linear. All of the linear trendlines go through the origin as would be expected. The correlation obtained with the spherical Quackenbush glass bead and rounded Ottawa sand are statistically equivalent (based on a 95% confidence limit). This is considered encouraging since the particle shapes (seen in the closeness of the $C_{v,max}$ values) of these materials are very similar. The concentration results and correlation obtained with the Lane Mountain sand are significantly different to the results obtained with the other coarse particles. There is insufficient data in this study to determine the relationship between particle shape and the residual concentration. It is recommended that this be considered in for future research projects. The results are however encouraging, enforcing the belief that coarse materials are similar in size to the flocs, and behave in a fashion similar to the addition of flocs.

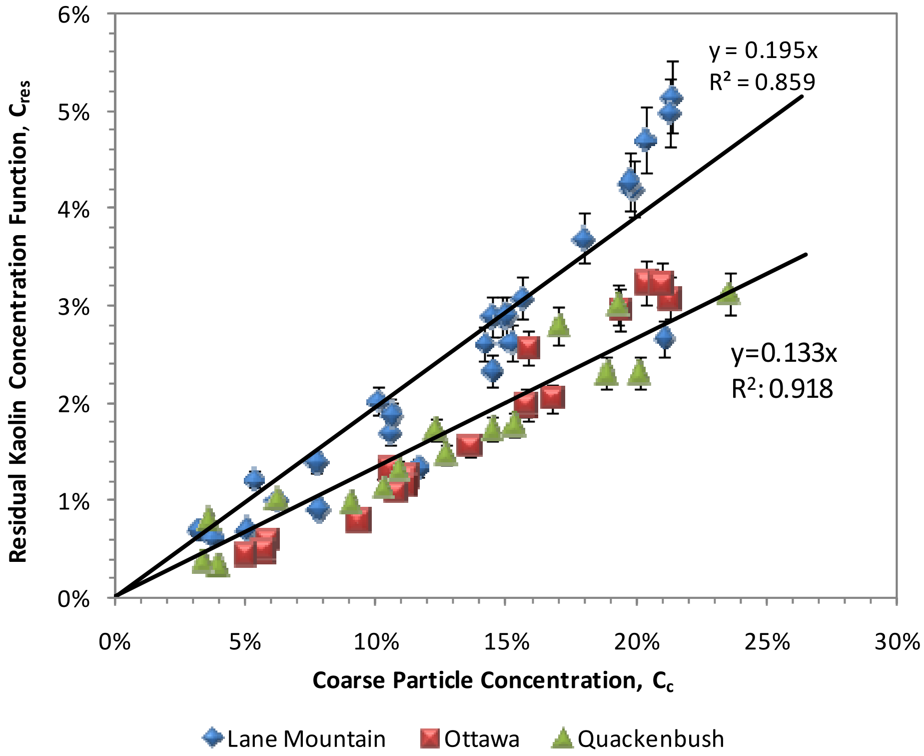

Figure 4.45: Residual Kaolin Concentration as a Function of the Coarse Particle Concentration

5. CASE STUDY

The purpose of this section is to illustrate the impact of the more accurate method of estimating rheological properties has on design decisions associated with a typical industrial application.

It is important to note that the slurries/materials used in this section have been purposefully chosen to be similar to the material properties of the substances used in this research project. This has been done in order to ensure that there is not a significant amount of extrapolation beyond the range of variables considered in the development of the model.

The systematic approach followed in the section reflects the typical procedure followed when designing a pumping system for an industrial application.

5.1 Design Criteria

5.1.1 Background

The operator of a Kaolin mine wishes to expand the mining operations. However, due to changes in the ore composition, a significant fraction of coarse sand material will have to be transported with the Kaolin clay from the mine face to the processing plant which represents a distance of 2.5 km.

The key design decision relates to the feasibility of conveying the clay-coarse particle mixture using the existing pumping system (with minor modifications if necessary) or whether an addition process step is required to separate of the coarse material at the ore face operations and transporting the two solids phases separately. With both scenarios, the sand has to be transported to the processing plant since it contains a significant amount of extractible minerals. The most efficient method of transporting the sand would be to convey it with the Kaolin slurry in the existing pumping system.

5.1.2 Operating properties

Operating properties of the existing and proposed systems have been estimated to be representative of a typical operation. The flow specifications are shown in Table 5.1.

Table 5.1: Case Study Flow Specifications

Operating Parameter	Current Specifications	Future Specifications
Solids Tonnage	80-100 t/h	140-160 t/h
Weight Concentration	42 - 46%	57%
Density	1 350 - 1 400 kg/m³	1 550 kg/m³
Sand Concentration	$0\%_v$	$15\%_v$

The system parameters are summarised in Table 5.2.

Table 5.2: Case Study System Specifications

Operating Parameter	Current Specifications	Future Specifications
Suction Level	1.5 m	
Discharge Level	20.0 m	
Pipe Size	155.0 mm	
Pipeline Length	2500 m	
No. of Operating Lines	1	
Operating Velocity	2.10 – 2.29 m/s	3.30 – 3.64 m/s
Pumping Pressure	1 591 – 2 968 kPa	To be determined
Pipeline Material	Mild steel	
Pump Type	Centrifugal	
No. Of Pumps	3	To be determined
Installed Motor/Pump	75 kW	To be determined

5.1.3 *Material properties*

The material properties were determined by the mine laboratory. They performed vane and coaxial (couette) viscometer tests on the Kaolin clay only slurries, and particle size and maximum packing concentration tests on some coarse sand samples. The density and size distribution properties of the solids are summarised in Table 5.3.

Table 5.3: Case Study Material Properties

Property	Value
Kaolin Solids Density	2 650 kg/m³
Sand Solids Density	2 600 kg/m³
Sand $C_{v,max}$	54.5%
Kaolin PSD: d_{90} d_{50} d_{10}	 13 µm 5.2 µm 1.5 µm
Sand PSD: d_{90} d_{50} d_{10}	 230 µm 190 µm 90 µm

5.2 Slurry Rheology

5.2.1 Kaolin rheology

The Kaolin rheology was determined from coaxial viscometer tests performed by the laboratory on the mine site. It was found that an exponential relationship best represented both the dynamic yield stress and plastic viscosity over the Kaolin clay concentration ranges tested. These relationships are described in Table 5.4. It should also be noted that the pipeline system presently operates under laminar conditions.

Table 5.4: Case Study Kaolin Rheological Properties

Parameter	Definition
Bingham Yield Stress	$\tau_y = 12\ 000 \left[\frac{C_K}{1 - C_K}\right]^{5.1}$
Bingham Viscosity	$K_B = 8.94 \times 10^{-4} e^{8.1 C_k}$
Applicable Kaolin Concentration	17.5 – 25.0 $\%_v$

5.2.2 Kaolin-sand rheology

The approach used in the design assumes that the addition of the coarse material results in a uniform increase in both the static and dynamic yield stress and plastic viscosity. In this example, no further information is known about the coarse sand mixture as the actual coarse material bearing ore has not yet been mined, and all tests to date have been based on a minimal amount of sample.

5.3 Design Basis

5.3.1 System pressure loss

Using a control volume as shown in Figure 5.1, the incompressible fluid Bernoulli equation can be applied to perform an energy balance over the section.

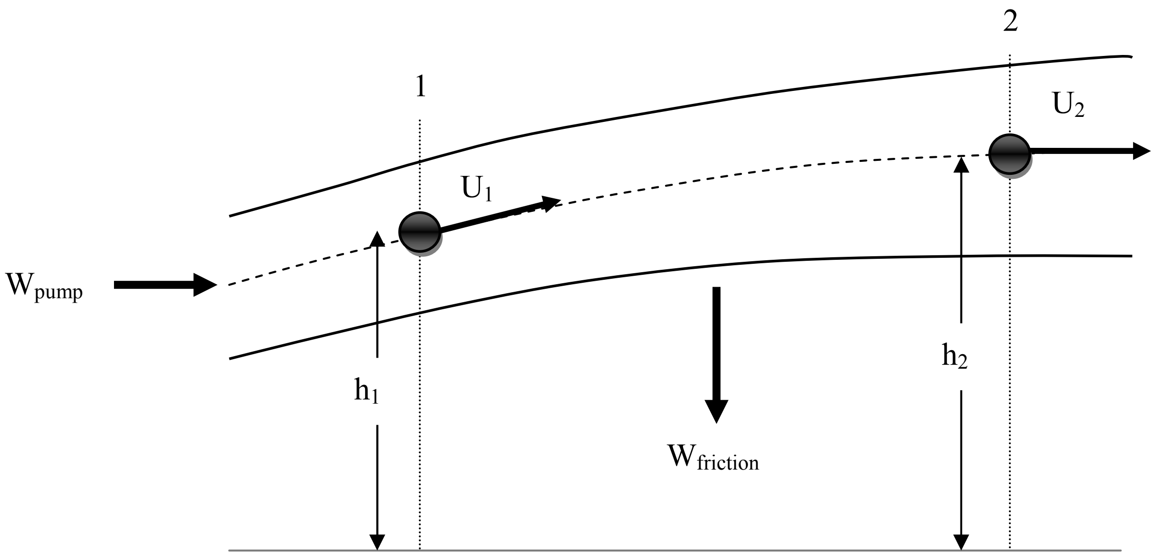

Figure 5.1: Control Volume for the Bernoulli Relationship

Using the notation in Figure 5.1, the Bernoulli relationship is expressed, in terms of metres of fluid, as:

$$\frac{{U_1}^2}{2g} + \mathrm{h}_1 + \frac{P_1}{\rho g} + \Delta H_{pump} = \frac{{U_2}^2}{2g} + \mathrm{h}_2 + \frac{P_2}{\rho g} + \Delta H_{friction}. \qquad (5.1)$$

The above equation is used to calculate the pumping head, ΔH_{pump}, requirements for the system.

The method to be used for determining the actual operating conditions is known as Nodal Analysis. Bernoulli's equation is used to generate a system curve, which represents the variation in pressure requirements of the pipeline system that occurs with variation in slurry volumetric flow rate. The pump curve, which is normally obtained from the pump manufacture, represents the variation in pressure developed by the pump when it operates over a range of volumetric flow rates. The intersection of the system and pump curve provides the operating pressure and flow rate of the pipeline system under steady state conditions.

5.3.2 *Laminar flow pressure loss*

A constitutive equation can be derived from first principles for laminar flow of a Bingham fluid in a circular pipe. This is the well-known Buckingham equation which relates the pipe pseudo-shear rate to wall shear stress (Shook and Roco, 1991):

$$\frac{8U}{D_{pipe}} = \frac{\tau_0}{K_B}\left[1 - \frac{4}{3}\frac{\tau_{y,B}}{\tau_0} + \frac{1}{3}\left(\frac{\tau_{y,B}}{\tau_0}\right)^4\right]. \tag{5.2}$$

Using Equation (5.2) the wall shear stress can be calculated if the rheological properties of the slurry, the pipeline dimensions and the velocity are known. The pressure gradient can be evaluated directly from the wall stress in pipelines as follows (Shook and Roco, 1991):

$$\frac{\Delta P}{\Delta L} = \tau_0 \frac{4}{D_{pipe}}. \tag{5.3}$$

5.3.3 *Turbulent flow pressure loss*

The Wilson & Thomas model (1985) was used to predict turbulent flow, as discussed in Section 2.2.3.

5.3.4 *Laminar/turbulent transition*

The laminar/turbulent transition is determined by the intersection method. In this method both the laminar and turbulent pressure losses are determined for a range of pipeline velocities. The critical (transitional) velocity is calculated as the point of intersection of these two curves.

5.3.5 *Pipeline roughness*

The piping used throughout is mild steel. The industry accepted value of roughness for mild steel is 100 µm.

5.3.6 Turbulent particle settling velocity

With slurry pipeline transport, it is important to ensure that none of the particles settle. If settling occurs, solids accumulate at the bottom of the pipe which could cause problems with the operation of the pipeline, such as blockages and significant pressure fluctuations. For the purposes of this case study, the Wilson and Judge (Wilson and Judge, 1976) relationship is used to determine the minimum operating velocity:

$$U_{dep} = \left[2 + 0.3\ log\left(\frac{d_{rep}}{D_{pipe}C_D}\right)\right]\sqrt{2gD_{pipe}(S_s - 1)}, \tag{5.4}$$

where C_D is the drag coefficient of the representative particle size.

5.3.7 Pump power calculation

The absorbed power in a slurry pump is determined from:

$$P_{abs} = 1.05\frac{\rho_m g Q_m H_m}{\eta}. \tag{5.5}$$

A factor of safety of 1.30 is used when selecting the motor size(Paterson & Cooke 2007).

5.4 Hydraulic Design

5.4.1 Kaolin only

The system curves for the current operation (Kaolin only) are shown in Figure 5.2. Note that a typical calculation illustrating the use of the models presented in this section is shown in Appendix G.

The system operates between points A and B as shown in Figure 5.2 when pumping Kaolin only. It should be noted that two pumps are required at point A, and three at point B. The absorbed powers at these points are 51 kW and 68 kW respectively.

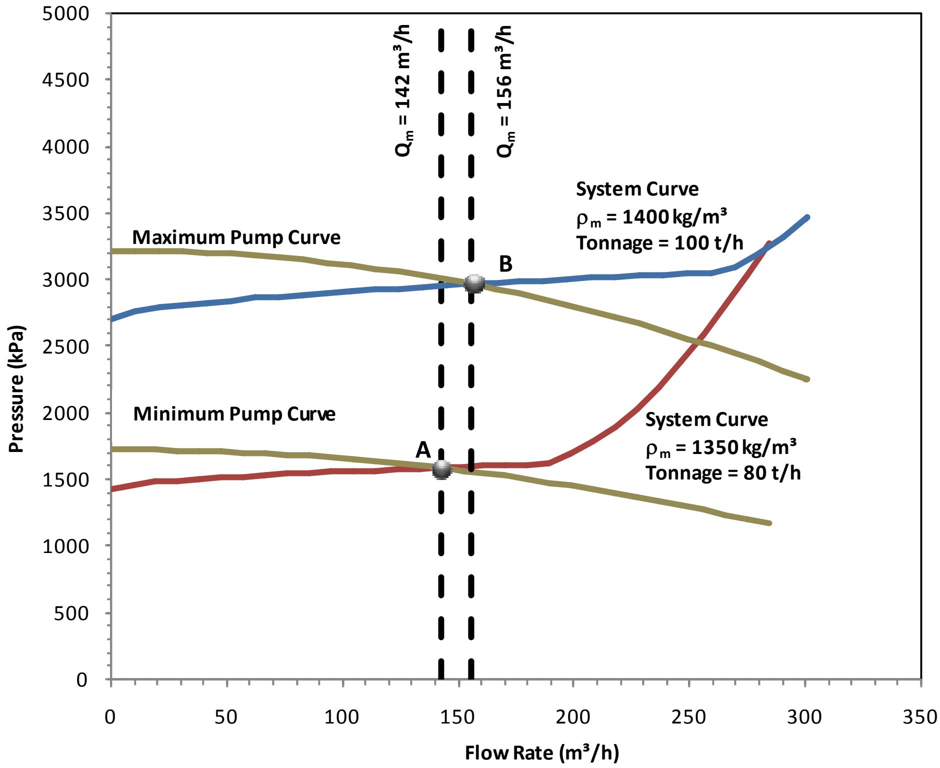

Figure 5.2: System Curves for Maximum and Minimum Pumping Head and Kaolin Only

5.4.2 Kaolin-sand

The effect on the slurry rheology caused by the addition of the coarse sand fraction to the Kaolin clay slurry is determined using the methods proposed in Sections 4.5.2 and 4.5.3. The Kaolin concentration in the mixture is determined from Equation (3.5). The resulting system curves for each of these methods at the highest density are shown in Figure 5.3.

Using the bulk concentration in the Kaolin rheology determination (Table 5.4) results in unrealistic rheological parameters, particularly in the case of the yield stress (τ_y = 408 Pa) as the Kaolin only concentration results in a yield stress of approximately 20 Pa. This is an extreme over-estimation of the rheological properties since it was shown in this research project that the rheological parameter increase due to presence of a coarse fraction is less than the increase due to clay only concentration.

Based on the results of this investigation, the addition of coarse sand particles always resulted in an increase in the apparent viscosity of the resulting slurry. For this reason, using the rheology associated with the Kaolin only slurry will result in an underestimation of the discharge pressure (point A = 1 801 kPa) since it was also shown that the addition of coarse fractions always increases the overall rheology. Therefore, the best representation of the actual system behaviour is believed to lie between points A and the rheology predicted by the use of the bulk concentration (i.e. where $\tau_y = 408$ Pa).

The Thomas and Separation Ratio methods (Equations (2.48) and (2.50)) provide similar discharge pressures at the high tonnage (Q_m = 181 m³/h) of 2 441 kPa and 2 503 kPa respectively.

The system curves obtained using the modified Zhou, Depletion and Residual concentration methods lie well below those obtained from other methods. The pumping pressures required for the Zhou and Depletion methods at 181 m³/h are 2 176 kPa and 1 816 kPa respectively. It is also clear that the Depletion method and the Kaolin only concentration produce very similar pressure requirements. The Depletion method therefore underestimates the increase in rheology in this case. Due to the lowered rheology predicted in this case the Deletion method predicts an operating point (point A') very close to the turbulent transition. Use of, and design for this inaccurate operating point could lead to severe operational problems.

Use of the Residual Model results in the highest predicted pressure requirements (point B' = 2 921 kPa). This is significantly higher than any of the other predictions; however this model is recommended in this design since it is based on more concrete theory, as opposed to empirical and semi-empirical relationships. It also represents the more conservative approach to the design of the system. This is more appropriate, since it is more acceptable, from a design standpoint to use methods which overestimate rather than underestimate system requirements.

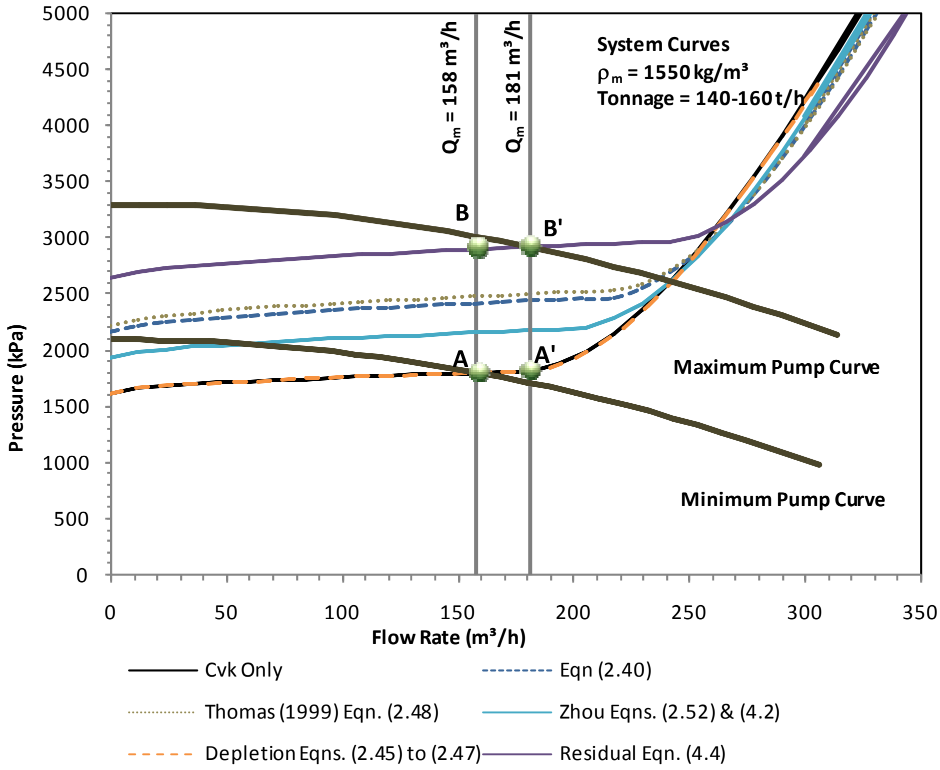

Figure 5.3: System Curves for the Kaolin-Sand Mixture at 1600 kg/m³

5.5 Effect of the Variation in Rheological Parameters

A summary of the predicted system outputs for each method is illustrated in Table 5.5. As mentioned in the previous section the Residual Model is recommended for this system. Clearly the other methods have significantly different absorbed powers (relating to predicted operating costs) and discharge pressures (relating to pumping costs). Further complications of selecting the inappropriate model may be the prediction of a flow regime change as shown in this example (in the case of the depletion method). This would cause major complications in pipeline selection, operation, and control.

The final system design recommendations based on the Residual Model are therefore the following:

- The future pipeline operates at velocities which are on average higher than the current pipeline velocities. Probable areas of wear should be monitored to ensure that no failures occur.

- The installed pumps are sufficiently sized to handle the future duty.
- The installed motors are not sufficient. Motor sizes have to be changed to 110 kW, and the adjustments made to the pumps if necessary.
- It is therefore feasible to convey the Kaolin-sand mixture to the plant.

Table 5.5: Summary of Models and System Outputs

Parameter	**Kaolin Only**	**Thomas**	**Separation Ratio**	**Zhou**	**Depletion**	**Residual Concentration**
Flow Rate	158 – 181 m^3/h					
Density	1 550 kg/m^3					
Pumping Pressure	1 815 kPa	2 503 kPa	2 441 kPa	2 176 kPa	1 816 kPa	2 921 kPa
Total Absorbed Power	147 kW	187 kW	196 kW	175 kW	147 kW	230 kW
No. Of Pumps	3	3	3	3	3	3
Installed Power/Pump	75 kW	90 kW	90 kW	90 kW	75 kW	110 kW

In this simplified example, it was shown that there could be large variation in pipeline design results due to not only the presence of coarse materials, but also in selecting the appropriate model used to represent the effect of coarse particles on the rheology. For design decisions it is generally best practise to select the most conservative model (i.e. the model predicting the highest pressure drop for a given volumetric flow rate, however experience must also be taken into consideration as illustrated in this example.

6. CONCLUSIONS

- The clay only slurries investigated in this research demonstrated time persistent rheological behaviour and measurements of slurries of the same composition were repeatable, as discussed in Sections 3.3.2 and 4.4.1.

- The yield stress (both static and dynamic) data is best correlated by means of the Zhou et al (1999) relationship (Equation (2.32)) as seen in Section 4.4. The average errors in the correlations are 8.2% and 6.2% for the dynamic and static yield stresses respectively. The plastic viscosity data is best correlated by means of the Thomas (1963) relationship. The average error of this correlation is 5.7%.

- Tests were done initially on clay only slurries. Coarse particles were added to the slurry then removed. The remaining clay only slurry exhibited the same rheological properties as the initial clay only slurry, as was shown in Section 4.4.2.

- The addition of coarse particles caused an increase in all of the rheological variables studied. In all cases the nature of the change to each of the parameters resembled the effect of adding clay to the rheological parameters of a clay only slurry. Furthermore, the effect of particle shape was found to have a significant effect on the rheological variables, particularly when the particle shape was angular in shape. This is discussed in detail in Section 4.5.

- With both the clay only slurries and clay and coarse sand slurries, a simple relationship existed between the static and dynamic yield stress. This effect was represented by the correlation $\tau_{yv} = 0.48\tau_{yB}$ which was capable of representing this behaviour to a prediction error of 10.6%. It is interesting to note that is evidence that wall slip was not important with the dynamic yield stress measurements.

- As shown in Section 4.5.1 the net change in rheological parameter caused by addition of coarse particles was not affected by the level of the clay fraction in the slurry. It should be noted that this is only applicable to the range of coarse particle and clay concentrations investigated in this study.

- Several correlations from the literature were investigated to determine their ability to predict the trend of the dynamic stress variation with coarse particle concentration, and were presented in Section 4.5.2. The Distance Ratio and Thomas correlation(s) were found to most accurately represent the behaviour and had prediction errors of 14% and 13% respectively.

- With respect to the plastic viscosity trend observed in this study, the Distance Ratio and Thomas correlations best represented the behaviour and were able to predict the results to a prediction error of 10% as seen in Section 4.5.2.

- A new correlation has been proposed, Residual Clay Concentration, which was capable of predicting the effect of coarse particle concentration on the dynamic yield stress with a prediction error of 8%. This model is presented in Section 4.5.3.

- Based on analysis of the results of a case study (see Section 5), the choice of correlation employed to predict the coarse particle concentration effect on the rheological parameters had a significant effect on the results. It is recommended that the Residual correlation be used since it gave the most conservative and/or accurate prediction.

7. RECOMMENDATIONS

- This study did not consider the effect of coarse particle size or size distribution. It is expected that these particle characteristics will have a significant effect on rheological behaviour and should be considered in future studies.

- The effect of particle shape on the rheological variables should be more thoroughly investigated.

- When coarse particle concentrations were increased to their highest values considered in this study, an anomalous effect was noted in the variation of the rheological variables. This may indicate a change in the dominant mechanisms controlling the slurry rheology and should be considered in future investigations.

- The addition of flocculants, including rheologically active ions, significantly impact on the slurry rheological parameters measured. The effect of flocculants on the rheological impact of coarse particle concentration variation would potentially give insight into the mechanisms associated with the observed increase in rheological parameters and would also be of industrial significance.

- Future work should include pipe loop tests and the use of rotational viscometers with a larger range of operation.

- It is recommended that further work be undertaken in order to investigate the influence of glass beads on slurry solutions, as this material altered the solution properties which had to be negated.

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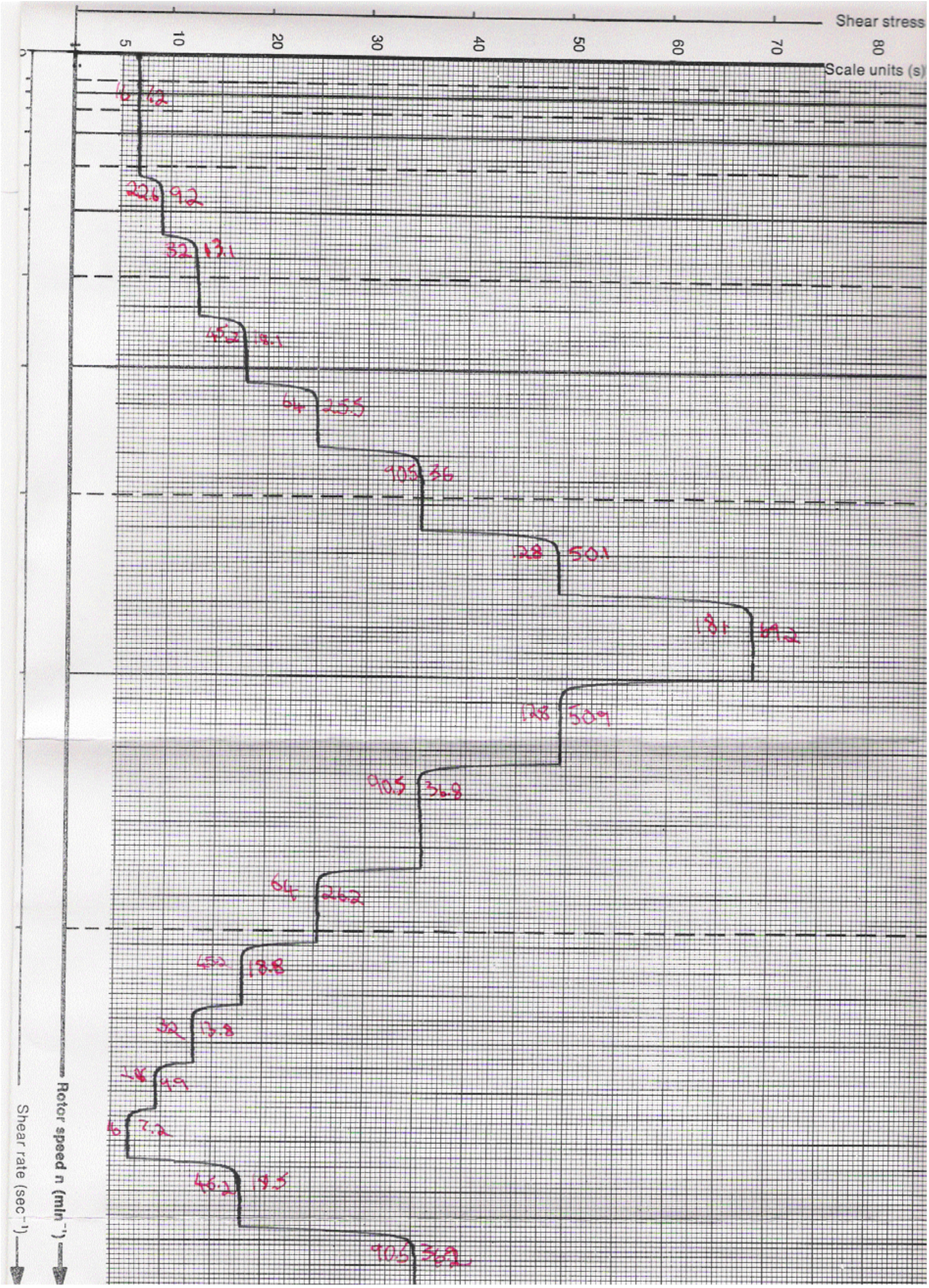
APPENDIX A: TYPICAL ROTATIONAL VISCOMETER OUTPUTS


Shear stress
Scale units (s)
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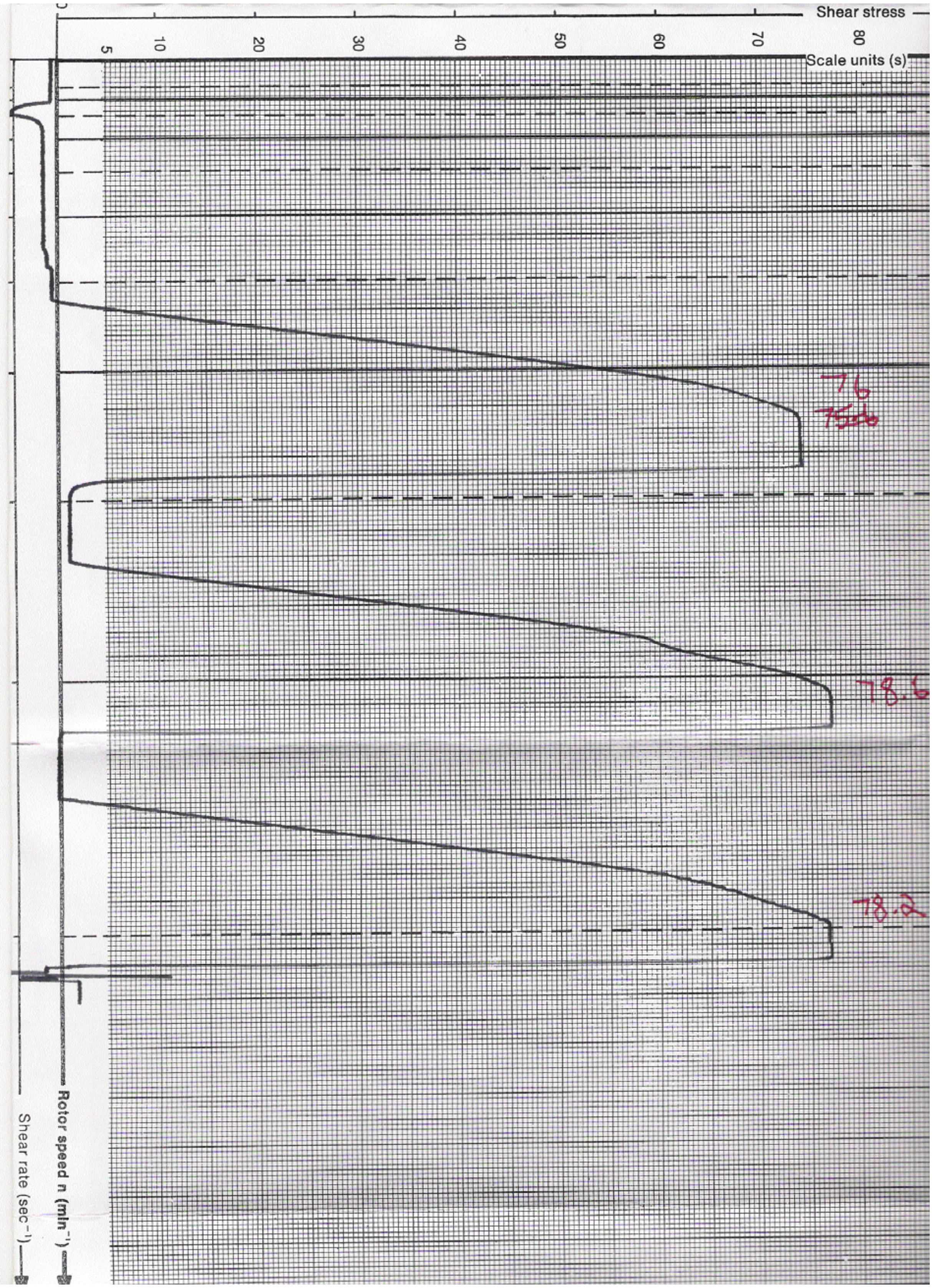
Rotor speed n (min⁻¹)
Shear rate (sec⁻¹)
16 7.2
22.6 9.2
32 13.1
45.2 18.1
64 25.5
90.5 36
128 50.1
181 69.2
128 50.9
90.5 36.8
64 26.2
45.2 18.8
32 13.8
22.6 9.9
16 7.2
45.2 18.5
90.5 36.2

Vane Test



Shear stress
Scale units (s)
5
10
20
30
40
50
60
70
80
76
75.6
78.6
78.2
Rotor speed n (min⁻¹)
Shear rate (sec⁻¹)

APPENDIX B: VALIDATION TESTS

VALIDATION TEST - 01

Test Details

Date	23/11/06
Test Number	Cal-50-2311-01
Substance	S20
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 50
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0043 N.m

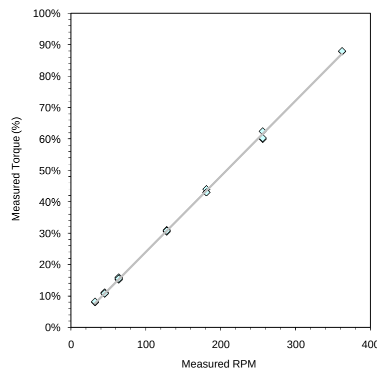
Fluid Details

Temperature	Viscosity
20.00 °C	0.0374 Pa.s
25.00 °C	0.0292 Pa.s

Viscosity @ Measured Temperature 0.0292 Pa.s

Measured Data

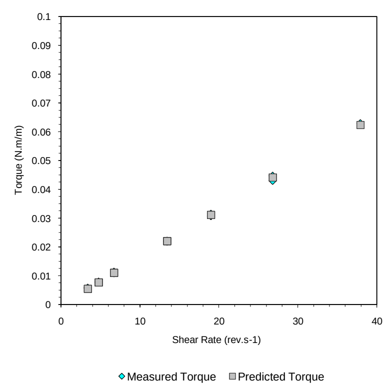
RPM	S
32.00	8.00%
45.20	10.80%
64.00	15.20%
128.00	30.50%
181.00	43.00%
256.00	60.00%
362.00	87.90%
256.00	62.50%
181.00	44.00%
128.00	31.00%
64.00	16.00%
45.20	11.20%
32.00	8.20%
45.20	10.90%
64.00	15.50%
128.00	30.80%
181.00	43.00%
256.00	60.30%
362.00	88.00%



Calculated Parameters

Calculated Viscosity	0.0292 Pa.s
Difference Between Measured & Calculated	0.00%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
3.35	5.73E-03	5.52E-03
4.73	7.74E-03	7.80E-03
6.70	1.09E-02	1.10E-02
13.40	2.18E-02	2.21E-02
18.95	3.08E-02	3.12E-02
26.81	4.30E-02	4.42E-02
37.91	6.30E-02	6.24E-02
26.81	4.48E-02	4.42E-02
18.95	3.15E-02	3.12E-02
13.40	2.22E-02	2.21E-02
6.70	1.15E-02	1.10E-02
4.73	8.02E-03	7.80E-03
3.35	5.87E-03	5.52E-03
4.73	7.81E-03	7.80E-03
6.70	1.11E-02	1.10E-02
13.40	2.21E-02	2.21E-02
18.95	3.08E-02	3.12E-02



VALIDATION TEST - 02

Test Details

Date	23/11/06
Test Number	Cal-50-2311-02
Substance	S20
Temperature	20.00 °C
ROTOVISCO RV	3
Measuring Head	MK 50
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0043 N.m

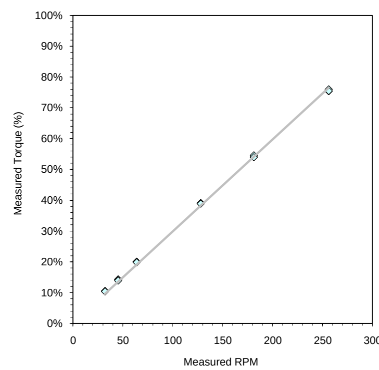
Fluid Details

Temperature	Viscosity
20.00 °C	0.0374 Pa.s
25.00 °C	0.0292 Pa.s

Viscosity @ Measured Temperature 0.0374 Pa.s

Measured Data

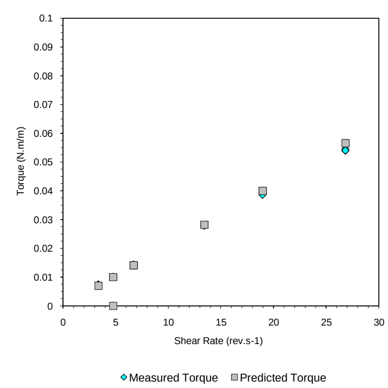
RPM	S
32.00	10.50%
45.20	14.30%
64.00	20.00%
128.00	39.00%
181.00	54.00%
256.00	75.30%
256.00	76.00%
181.00	54.50%
128.00	39.00%
64.00	20.00%
45.20	14.20%
32.00	10.30%
45.20	13.90%
64.00	19.80%
128.00	38.80%
181.00	53.90%
256.00	75.40%



Calculated Parameters

Calculated Viscosity	#VALUE!
Difference Between Measured & Calculated	#VALUE!

Angular Velocity (s^{-1})	Measured Torque (N.m)	Predicted Torque (N.m)
3.35	7.52E-03	7.07E-03
4.73	(N.m/m)	(N.m/m)
6.70	1.43E-02	1.41E-02
13.40	2.79E-02	2.83E-02
18.95	3.87E-02	4.00E-02
26.81	5.39E-02	5.66E-02
26.81	5.44E-02	5.66E-02
18.95	3.90E-02	4.00E-02
13.40	2.79E-02	2.83E-02
6.70	1.43E-02	1.41E-02
4.73	1.02E-02	9.99E-03
3.35	7.38E-03	7.07E-03
4.73	9.96E-03	9.99E-03
6.70	1.42E-02	1.41E-02
13.40	2.78E-02	2.83E-02
18.95	3.86E-02	4.00E-02
26.81	5.40E-02	5.66E-02



VALIDATION TEST - 03

Test Details

Date	24/11/06
Test Number	Cal-50-2411-01
Substance	S20
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 50
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0043 N.m

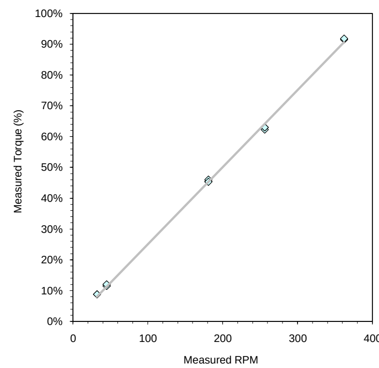
Fluid Details

Temperature	Viscosity
20.00 °C	0.0374 Pa.s
25.00 °C	0.0292 Pa.s

Viscosity @ Measured Temperature 0.0292 Pa.s

Measured Data

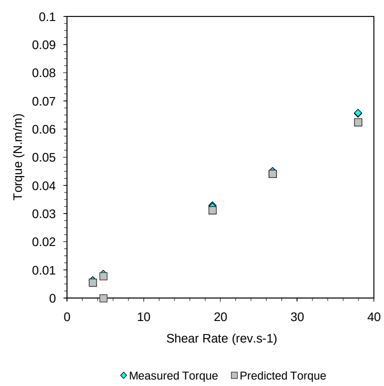
RPM	S
32.00	8.80%
45.20	11.50%
181.00	45.50%
256.00	62.20%
362.00	91.50%
256.00	63.00%
181.00	46.00%
256.00	63.00%
362.00	91.80%
45.20	12.00%
32.00	8.80%
181.00	45.30%



Calculated Parameters

Calculated Viscosity	#VALUE!
Difference Between Measured & Calculated	#VALUE!

Angular Velocity (s^{-1})	Measured Torque (N.m)	Predicted Torque (N.m)
3.35	6.30E-03	5.52E-03
4.73	(N.m/m)	(N.m/m)
18.95	3.26E-02	3.12E-02
26.81	4.46E-02	4.42E-02
37.91	6.55E-02	6.24E-02
26.81	4.51E-02	4.42E-02
18.95	3.30E-02	3.12E-02
26.81	4.51E-02	4.42E-02
37.91	6.58E-02	6.24E-02
4.73	8.60E-03	7.80E-03
3.35	6.30E-03	5.52E-03
18.95	3.25E-02	3.12E-02
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00



VALIDATION TEST - 04

Test Details

Date	24/11/06
Test Number	Cal-50-2411-02
Substance	S20
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 50
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0043 N.m

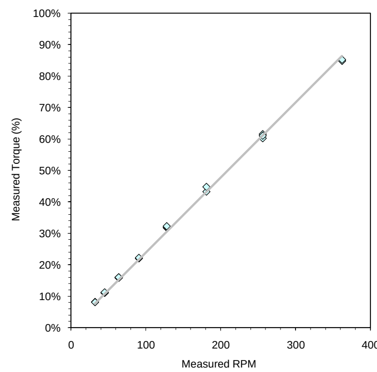
Fluid Details

Temperature	Viscosity
20.00 °C	0.0374 Pa.s
25.00 °C	0.0292 Pa.s

Viscosity @ Measured Temperature 0.0292 Pa.s

Measured Data

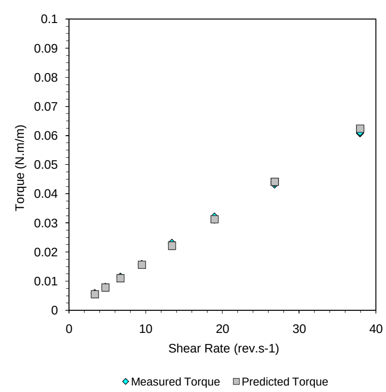
RPM	S
32.00	8.20%
45.20	11.00%
64.00	15.80%
90.50	22.00%
128.00	31.80%
181.00	43.30%
256.00	60.20%
362.00	84.80%
256.00	61.50%
181.00	44.80%
128.00	32.00%
90.50	22.20%
64.00	16.00%
45.20	11.30%
32.00	8.10%
64.00	16.00%
128.00	32.30%
256.00	61.00%
362.00	85.20%



Calculated Parameters

Calculated Viscosity	0.0289 Pa.s
Difference Between Measured & Calculated	0.83%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
3.35	5.87E-03	5.52E-03
4.73	7.88E-03	7.80E-03
6.70	1.13E-02	1.10E-02
9.48	1.58E-02	1.56E-02
13.40	2.28E-02	2.21E-02
18.95	3.10E-02	3.12E-02
26.81	4.31E-02	4.42E-02
37.91	6.07E-02	6.24E-02
26.81	4.41E-02	4.42E-02
18.95	3.21E-02	3.12E-02
13.40	2.29E-02	2.21E-02
9.48	1.59E-02	1.56E-02
6.70	1.15E-02	1.10E-02
4.73	8.10E-03	7.80E-03
3.35	5.80E-03	5.52E-03
6.70	1.15E-02	1.10E-02
13.40	2.31E-02	2.21E-02
26.81	4.37E-02	4.42E-02
37.91	6.10E-02	6.24E-02



VALIDATION TEST - 05

Test Details

Date	24/11/2006
Test Number	Cal-500-2411-01
Substance	S200
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 500
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0450 N.m

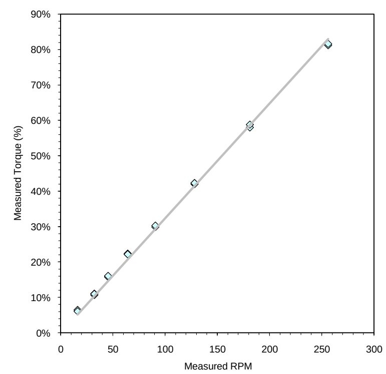
Fluid Details

Temperature	Viscosity
20.00 °C	0.589 Pa.s
25.00 °C	0.409 Pa.s

Viscosity @ Measured Temperature 0.409 Pa.s

Measured Data

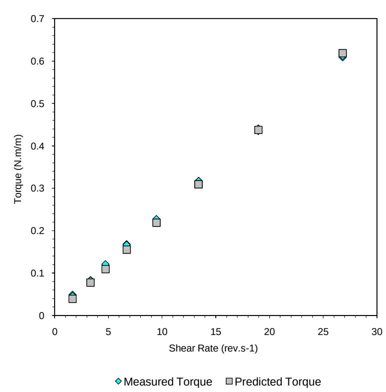
RPM	S
16.00	6.50%
32.00	10.70%
45.20	15.80%
64.00	22.20%
90.50	29.90%
128.00	42.00%
181.00	58.00%
256.00	81.20%
181.00	58.80%
128.00	42.30%
90.50	30.30%
64.00	22.40%
45.20	16.10%
32.00	11.10%
16.00	6.10%
32.00	11.00%
64.00	22.20%
128.00	42.30%
256.00	81.60%



Calculated Parameters

Calculated Viscosity	0.411 Pa.s
Difference Between Measured & Calculated	0.7%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
1.68	4.88E-02	3.87E-02
3.35	8.03E-02	7.73E-02
4.73	1.19E-01	1.09E-01
6.70	1.67E-01	1.55E-01
9.48	2.24E-01	2.19E-01
13.40	3.15E-01	3.09E-01
18.95	4.35E-01	4.37E-01
26.81	6.09E-01	6.19E-01
18.95	4.41E-01	4.37E-01
13.40	3.17E-01	3.09E-01
9.48	2.27E-01	2.19E-01
6.70	1.68E-01	1.55E-01
4.73	1.21E-01	1.09E-01
3.35	8.33E-02	7.73E-02
1.68	4.58E-02	3.87E-02
3.35	8.25E-02	7.73E-02
6.70	1.67E-01	1.55E-01
13.40	3.17E-01	3.09E-01
26.81	6.12E-01	6.19E-01



VALIDATION TEST - 06

Test Details

Date	24/11/2006
Test Number	Cal-500-2411-02
Substance	S200
Temperature	20.00 °C
ROTOVISCO RV	3
Measuring Head	MK 500
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0450 N.m

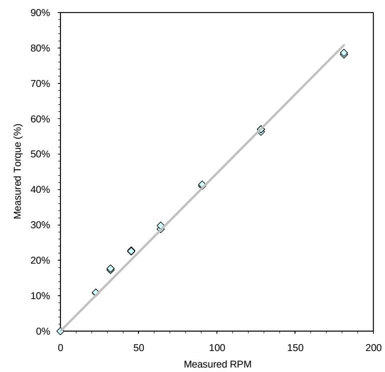
Fluid Details

Temperature	Viscosity
20.00 °C	0.589 Pa.s
25.00 °C	0.409 Pa.s

Viscosity @ Measured Temperature 0.589 Pa.s

Measured Data

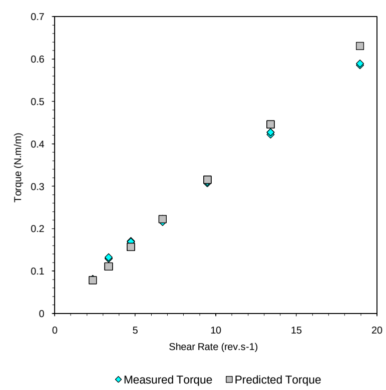
RPM	S
22.60	10.80%
32.00	17.30%
45.20	22.50%
64.00	28.80%
90.50	41.00%
128.00	56.30%
181.00	78.10%
128.00	57.00%
90.50	41.00%
64.00	29.80%
45.20	22.80%
32.00	17.30%
22.60	10.90%
32.00	17.70%
45.20	22.60%
90.50	41.40%
128.00	57.00%
181.00	78.60%
0.00	0.00%



Calculated Parameters

Calculated Viscosity 0.567 Pa.s
Difference Between Measured & Calculated 3.8%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
2.37	8.10E-02	7.87E-02
3.35	1.30E-01	1.11E-01
4.73	1.69E-01	1.57E-01
6.70	2.16E-01	2.23E-01
9.48	3.08E-01	3.15E-01
13.40	4.22E-01	4.46E-01
18.95	5.86E-01	6.30E-01
13.40	4.28E-01	4.46E-01
9.48	3.08E-01	3.15E-01
6.70	2.24E-01	2.23E-01
4.73	1.71E-01	1.57E-01
3.35	1.30E-01	1.11E-01
2.37	8.18E-02	7.87E-02
3.35	1.33E-01	1.11E-01
4.73	1.70E-01	1.57E-01
9.48	3.11E-01	3.15E-01
13.40	4.28E-01	4.46E-01
18.95	5.90E-01	6.30E-01
0.00	0.00E+00	0.00E+00



VALIDATION TEST - 07

Test Details

Date	24/11/2006
Test Number	Cal-500-2411-03
Substance	S200
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 500
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0450 N.m

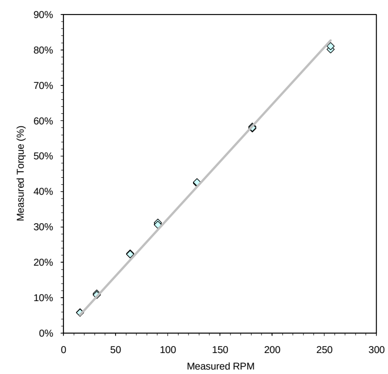
Fluid Details

Temperature	Viscosity
20.00 °C	0.589 Pa.s
25.00 °C	0.409 Pa.s

Viscosity @ Measured Temperature 0.409 Pa.s

Measured Data

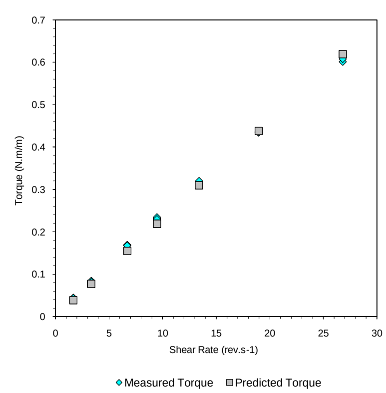
RPM	S
16.00	5.90%
32.00	10.90%
64.00	22.30%
90.50	30.80%
128.00	42.30%
181.00	57.80%
256.00	80.10%
181.00	58.30%
128.00	42.50%
90.50	31.20%
64.00	22.50%
32.00	11.20%
16.00	5.80%
32.00	10.80%
64.00	22.30%
90.50	30.60%
128.00	42.60%
181.00	58.00%
256.00	81.00%



Calculated Parameters

Calculated Viscosity	0.410 Pa.s
Difference Between Measured & Calculated	0.3%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
1.68	4.43E-02	3.87E-02
3.35	8.18E-02	7.73E-02
6.70	1.67E-01	1.55E-01
9.48	2.31E-01	2.19E-01
13.40	3.17E-01	3.09E-01
18.95	4.34E-01	4.37E-01
26.81	6.01E-01	6.19E-01
18.95	4.37E-01	4.37E-01
13.40	3.19E-01	3.09E-01
9.48	2.34E-01	2.19E-01
6.70	1.69E-01	1.55E-01
3.35	8.40E-02	7.73E-02
1.68	4.35E-02	3.87E-02
3.35	8.10E-02	7.73E-02
6.70	1.67E-01	1.55E-01
9.48	2.30E-01	2.19E-01
13.40	3.20E-01	3.09E-01
18.95	4.35E-01	4.37E-01
26.81	6.08E-01	6.19E-01



VALIDATION TEST - 08

Test Details

Date	21/02/07
Test Number	Cal-50-2102-02
Substance	S20
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 50
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0043 N.m

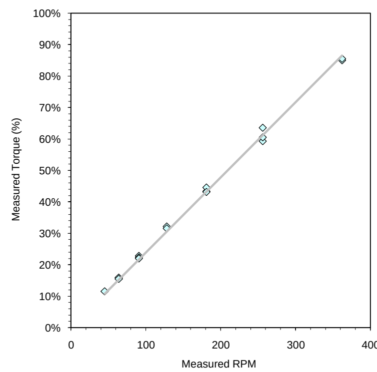
Fluid Details

Temperature	Viscosity
20.00 °C	0.037 Pa.s
25.00 °C	0.029 Pa.s

Viscosity @ Measured Temperature 0.029 Pa.s

Measured Data

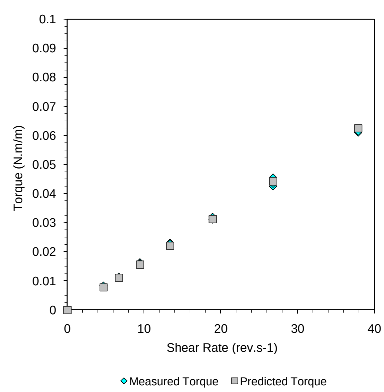
RPM	S
90.50	22.80%
181.00	43.40%
256.00	59.30%
362.00	85.00%
256.00	63.60%
181.00	44.60%
128.00	32.20%
90.50	22.30%
64.00	15.90%
45.20	11.60%
64.00	15.50%
90.50	22.00%
128.00	31.60%
181.00	43.20%
256.00	60.50%
362.00	85.50%



Calculated Parameters

Calculated Viscosity	0.029 Pa.s
Difference Between Measured & Calculated	0.73%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
9.48	1.63E-02	1.56E-02
18.95	3.11E-02	3.12E-02
26.81	4.25E-02	4.42E-02
37.91	6.09E-02	6.24E-02
26.81	4.56E-02	4.42E-02
18.95	3.20E-02	3.12E-02
13.40	2.31E-02	2.21E-02
9.48	1.60E-02	1.56E-02
6.70	1.14E-02	1.10E-02
4.73	8.31E-03	7.80E-03
6.70	1.11E-02	1.10E-02
9.48	1.58E-02	1.56E-02
13.40	2.26E-02	2.21E-02
18.95	3.09E-02	3.12E-02
26.81	4.33E-02	4.42E-02
37.91	6.13E-02	6.24E-02
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00



VALIDATION TEST - 09

Test Details

Date	21/02/2007
Test Number	Cal-500-2102-02
Substance	S200
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 500
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0450 N.m

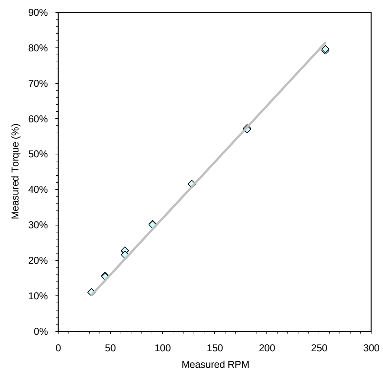
Fluid Details

Temperature	Viscosity
20.00 °C	0.589 Pa.s
25.00 °C	0.409 Pa.s

Viscosity @ Measured Temperature 0.409 Pa.s

Measured Data

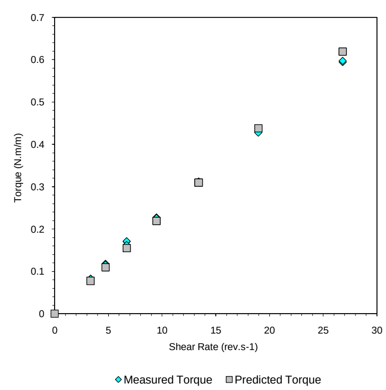
RPM	S
256.00	79.20%
181.00	57.30%
128.00	41.50%
90.50	30.30%
64.00	22.70%
45.20	15.70%
32.00	11.00%
45.20	15.40%
64.00	22.80%
90.50	30.10%
128.00	41.50%
181.00	57.00%
256.00	79.60%
128.00	41.60%
64.00	21.60%
32.00	11.00%



Calculated Parameters

Calculated Viscosity	0.403 Pa.s
Difference Between Measured & Calculated	1.3%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
26.81	5.94E-01	6.19E-01
18.95	4.30E-01	4.37E-01
13.40	3.11E-01	3.09E-01
9.48	2.27E-01	2.19E-01
6.70	1.70E-01	1.55E-01
4.73	1.18E-01	1.09E-01
3.35	8.25E-02	7.73E-02
4.73	1.16E-01	1.09E-01
6.70	1.71E-01	1.55E-01
9.48	2.26E-01	2.19E-01
13.40	3.11E-01	3.09E-01
18.95	4.28E-01	4.37E-01
26.81	5.97E-01	6.19E-01
13.40	3.12E-01	3.09E-01
6.70	1.62E-01	1.55E-01
3.35	8.25E-02	7.73E-02
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00



VALIDATION TEST - 10

Test Details

Date	24/04/2007
Test Number	Cal-150-2404-01
Substance	S200
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 150
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0147 N.m

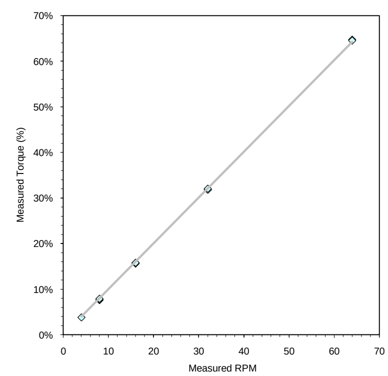
Fluid Details

Temperature	Viscosity
20.00 °C	0.589 Pa.s
25.00 °C	0.409 Pa.s

Viscosity @ Measured Temperature 0.409 Pa.s

Measured Data

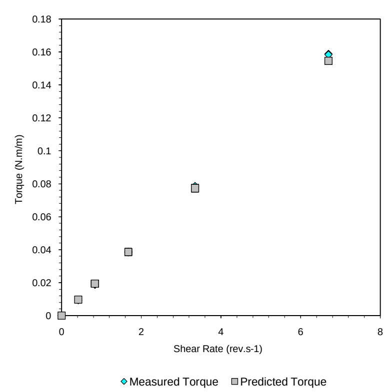
RPM	S
64.00	64.75%
32.00	31.85%
16.00	15.75%
8.00	7.60%
4.00	3.80%
8.00	7.70%
16.00	15.60%
32.00	31.80%
64.00	64.55%
32.00	32.05%
16.00	15.80%
8.00	7.90%



Calculated Parameters

Calculated Viscosity	0.417 Pa.s
Difference Between Measured & Calculated	1.9%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
6.70	1.59E-01	1.55E-01
3.35	7.81E-02	7.73E-02
1.68	3.86E-02	3.87E-02
0.84	1.86E-02	1.93E-02
0.42	9.32E-03	9.67E-03
0.84	1.89E-02	1.93E-02
1.68	3.83E-02	3.87E-02
3.35	7.80E-02	7.73E-02
6.70	1.58E-01	1.55E-01
3.35	7.86E-02	7.73E-02
1.68	3.88E-02	3.87E-02
0.84	1.94E-02	1.93E-02
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00



VALIDATION TEST - 11

Test Details

Date	24/04/2007
Test Number	Cal-150-2404-01
Substance	S200
Temperature	20.00 °C
ROTOVISCO RV	3
Measuring Head	MK 150
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0147 N.m

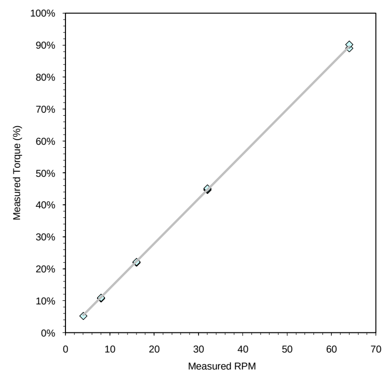
Fluid Details

Temperature	Viscosity
20.00 °C	0.589 Pa.s
25.00 °C	0.409 Pa.s

Viscosity @ Measured Temperature 0.589 Pa.s

Measured Data

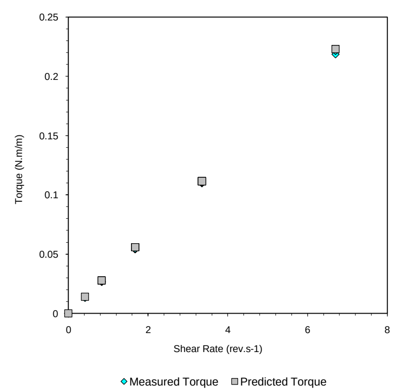
RPM	S
64.00	89.05%
32.00	44.70%
16.00	22.00%
8.00	10.80%
4.00	5.30%
8.00	10.80%
16.00	22.00%
32.00	44.90%
64.00	90.20%
32.00	45.20%
16.00	22.20%
8.00	11.00%



Calculated Parameters

Calculated Viscosity	0.580 Pa.s
Difference Between Measured & Calculated	1.4%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
6.70	2.18E-01	2.23E-01
3.35	1.10E-01	1.11E-01
1.68	5.40E-02	5.57E-02
0.84	2.65E-02	2.79E-02
0.42	1.30E-02	1.39E-02
0.84	2.65E-02	2.79E-02
1.68	5.40E-02	5.57E-02
3.35	1.10E-01	1.11E-01
6.70	2.21E-01	2.23E-01
3.35	1.11E-01	1.11E-01
1.68	5.45E-02	5.57E-02
0.84	2.70E-02	2.79E-02
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00



VALIDATION TEST - 12

Test Details

Date	25/04/2007
Test Number	Cal-150-2504-01
Substance	S20
Temperature	20.00 °C
ROTOVISCO RV	3
Measuring Head	MK 150
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0147 N.m

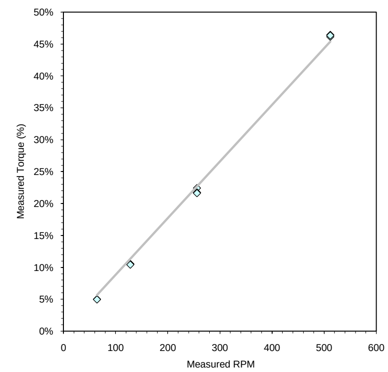
Fluid Details

Temperature	Viscosity
20.00 °C	0.037 Pa.s
25.00 °C	0.029 Pa.s

Viscosity @ Measured Temperature 0.037 Pa.s

Measured Data

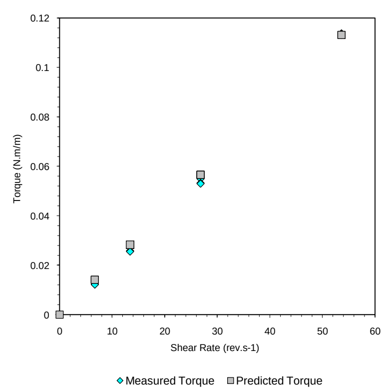
RPM	S
512.00	46.10%
256.00	22.40%
128.00	10.50%
64.00	5.00%
128.00	10.50%
256.00	21.70%
512.00	46.40%
256.00	21.70%
128.00	10.50%
64.00	4.95%
128.00	10.40%
256.00	21.60%
512.00	46.30%



Calculated Parameters

Calculated Viscosity	0.037 Pa.s
Difference Between Measured & Calculated	1.5%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
53.62	1.13E-01	1.13E-01
26.81	5.50E-02	5.66E-02
13.40	2.58E-02	2.83E-02
6.70	1.23E-02	1.41E-02
13.40	2.58E-02	2.83E-02
26.81	5.32E-02	5.66E-02
53.62	1.14E-01	1.13E-01
26.81	5.32E-02	5.66E-02
13.40	2.58E-02	2.83E-02
6.70	1.21E-02	1.41E-02
13.40	2.55E-02	2.83E-02
26.81	5.30E-02	5.66E-02
53.62	1.14E-01	1.13E-01
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00



VALIDATION TEST - 13

Test Details

Date	25/04/2007
Test Number	Cal-150-0405-05
Substance	S20
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 150
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0147 N.m

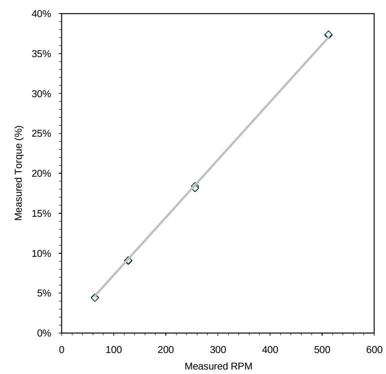
Fluid Details

Temperature	Viscosity
20.00 °C	0.037 Pa.s
25.00 °C	0.029 Pa.s

Viscosity @ Measured Temperature 0.029 Pa.s

Measured Data

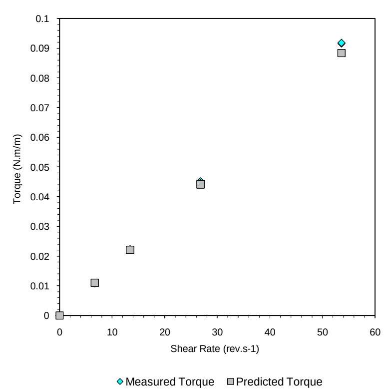
RPM	S
64.00	4.45%
128.00	9.05%
256.00	18.15%
512.00	37.30%
256.00	18.40%
128.00	9.05%
64.00	4.40%
128.00	9.10%
256.00	18.15%
512.00	37.40%



Calculated Parameters

Calculated Viscosity 0.030 Pa.s
Difference Between Measured & Calculated 2.9%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
6.70	1.09E-02	1.10E-02
13.40	2.22E-02	2.21E-02
26.81	4.45E-02	4.42E-02
53.62	9.15E-02	8.83E-02
26.81	4.51E-02	4.42E-02
13.40	2.22E-02	2.21E-02
6.70	1.08E-02	1.10E-02
13.40	2.23E-02	2.21E-02
26.81	4.45E-02	4.42E-02
53.62	9.18E-02	8.83E-02
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00



VALIDATION TEST - 14

Test Details

Date	30/05/2007
Test Number	Cal-150-3005-01
Substance	S200
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 150
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0147 N.m

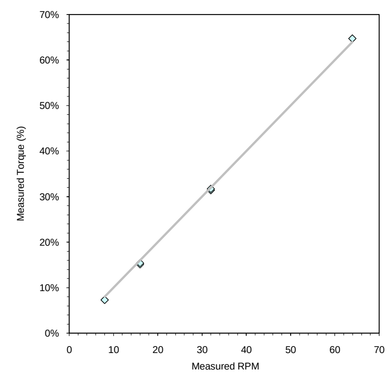
Fluid Details

Temperature	Viscosity
20.00 °C	0.589 Pa.s
25.00 °C	0.409 Pa.s

Viscosity @ Measured Temperature 0.409 Pa.s

Measured Data

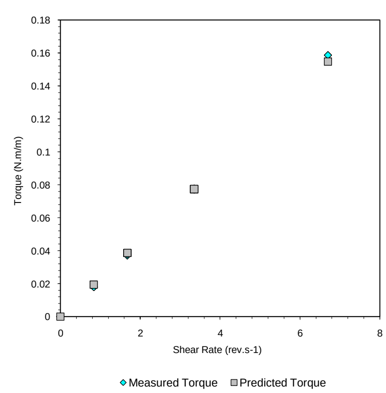
RPM	S
64.00	64.70%
32.00	31.40%
16.00	15.30%
8.00	7.30%
16.00	15.10%
32.00	31.40%
64.00	64.70%
32.00	31.70%
16.00	15.40%
8.00	7.30%



Calculated Parameters

Calculated Viscosity	0.415 Pa.s
Difference Between Measured & Calculated	1.5%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
6.70	1.59E-01	1.55E-01
3.35	7.70E-02	7.73E-02
1.68	3.75E-02	3.87E-02
0.84	1.79E-02	1.93E-02
1.68	3.70E-02	3.87E-02
3.35	7.70E-02	7.73E-02
6.70	1.59E-01	1.55E-01
3.35	7.78E-02	7.73E-02
1.68	3.78E-02	3.87E-02
0.84	1.79E-02	1.93E-02
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00



VALIDATION TEST - 15

Test Details

Date	30/05/2007
Test Number	Cal-150-3005-02
Substance	S200
Temperature	25.00 °C
ROTOVISCO RV	3
Measuring Head	MK 150
Sensor System	MV 1
Graphing Speed	50 s/cm

Viscometer Details

Spindle Length	0.060 m
Spindle Radius	0.020 m
Cup Radius	0.021 m
Spring Constant	0.0147 N.m

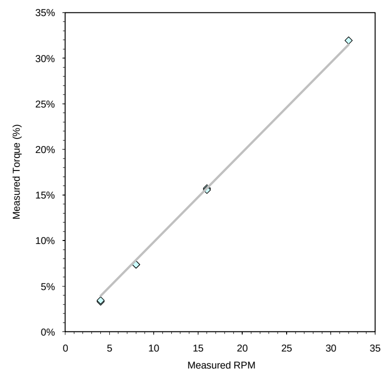
Fluid Details

Temperature	Viscosity
20.00 °C	0.589 Pa.s
25.00 °C	0.409 Pa.s

Viscosity @ Measured Temperature 0.409 Pa.s

Measured Data

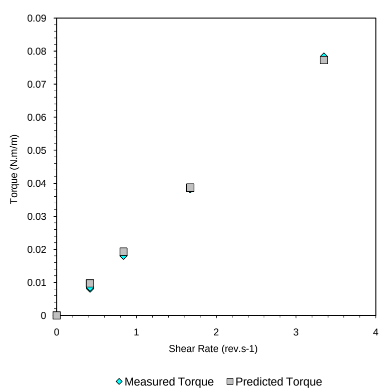
RPM	S
4.00	3.30%
8.00	7.37%
16.00	15.73%
32.00	31.97%
16.00	15.57%
8.00	7.37%
4.00	3.43%



Calculated Parameters

Calculated Viscosity	0.408 Pa.s
Difference Between Measured & Calculated	0.1%

Angular Velocity (s^{-1})	Measured Torque (N.m/m)	Predicted Torque (N.m/m)
0.42	8.10E-03	9.67E-03
0.84	1.81E-02	1.93E-02
1.68	3.86E-02	3.87E-02
3.35	7.84E-02	7.73E-02
1.68	3.82E-02	3.87E-02
0.84	1.81E-02	1.93E-02
0.42	8.42E-03	9.67E-03
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00
0.00	0.00E+00	0.00E+00



APPENDIX C: PARTICLE SIZE DISTRIBUTION TESTS

Lane Mountain - As Delivered

Date	**13/11/2006**
Test Name	**Sand-001-1311**
Notes	**Fresh Sand Samples**

Test Inputs

Mass of Pan With Sample	**206.41 g**
Mass of Pan Without Sample	**0.25 g**

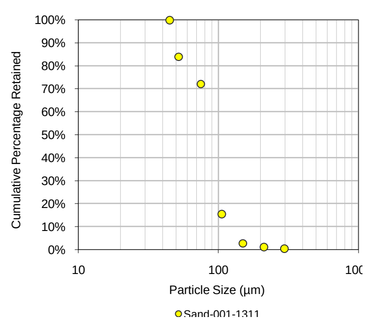
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	507.34 g	508.15 g
Size > 212 µm	506.39 g	507.71 g
Size > 150 µm	473.16 g	476.44 g
Size > 106 µm	511.26 g	537.10 g
Size > 75 µm	435.90 g	550.58 g
Size > 52 µm	494.55 g	518.54 g
Size > 45 µm	444.14 g	476.49 g
Pan	511.06 g	511.39 g

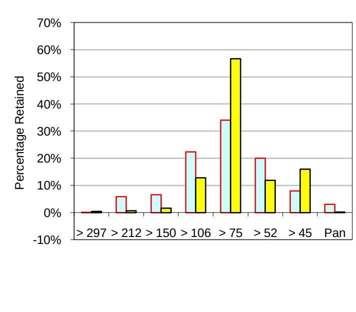
Test Outputs

Total Solids Added	**206.2 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.81 g	0.4%	0.4%
> 212	1.32 g	1.1%	0.7%
> 150	3.28 g	2.7%	1.6%
> 106	25.84 g	15.4%	12.8%
> 75	114.68 g	72.0%	56.6%
> 52	23.99 g	83.9%	11.8%
> 45	32.35 g	99.8%	16.0%
Pan	0.33 g	100.0%	0.2%
Total Solids	202.6 g		100%

Graphical Outputs





Lane Mountain - Scalped 1

Date	**22/11/2006**
Test Name	**Sand-001-2211**
Notes	**Sand Scalped @ 75 µm**

Test Inputs

Mass of Pan With Sample	**462.18 g**
Mass of Pan Without Sample	**255.92 g**

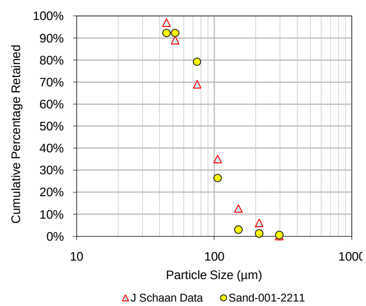
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	230.61 g	231.53 g
Size > 212 µm	231.41 g	233.02 g
Size > 150 µm	204.46 g	208.10 g
Size > 106 µm	256.18 g	304.14 g
Size > 75 µm	226.42 g	334.67 g
Size > 52 µm	241.83 g	268.65 g
Size > 45 µm		
Pan	0.00 g	15.89 g

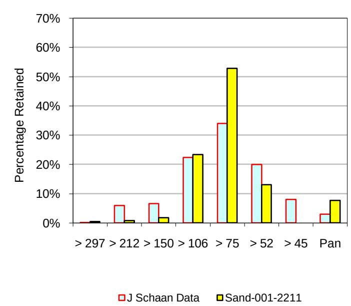
Test Outputs

Total Solids Added	**206.3 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.92 g	0.4%	0.4%
> 212	1.61 g	1.2%	0.8%
> 150	3.64 g	3.0%	1.8%
> 106	47.96 g	26.4%	23.4%
> 75	108.25 g	79.2%	52.8%
> 52	26.82 g	92.3%	13.1%
> 45	0.00 g	92.3%	0.0%
Pan	15.89 g	100.0%	7.7%
Total Solids	205.1 g		100%

Graphical Outputs





Lane Mountain - Scalped 2

Date	**28/11/2006**
Test Name	**Sand-001-2811**
Notes	**Sand Scalped @ 75 µm**

Test Inputs

Mass of Pan With Sample	**518.75 g**
Mass of Pan Without Sample	**314.24 g**

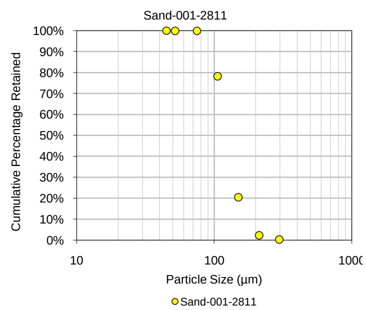
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	554.48 g	554.86 g
Size > 212 µm	511.27 g	515.33 g
Size > 150 µm	473.17 g	510.22 g
Size > 106 µm	506.37 g	623.63 g
Size > 75 µm	507.34 g	551.17 g
Size > 52 µm	514.02 g	514.21 g
Size > 45 µm	482.65 g	482.71 g
Pan	523.72 g	523.81 g

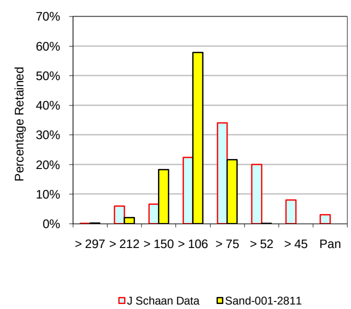
Test Outputs

Total Solids Added	**204.5 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.38 g	0.2%	0.2%
> 212	4.06 g	2.2%	2.0%
> 150	37.05 g	20.4%	18.3%
> 106	117.26 g	78.2%	57.8%
> 75	43.83 g	99.8%	21.6%
> 52	0.19 g	99.9%	0.1%
> 45	0.06 g	100.0%	0.0%
Pan	0.09 g	100.0%	0.0%
Total Solids	202.9 g		100%

Graphical Outputs





Lane Mountain - Scalped 3

Date	**17/5/2006**
Test Name	**Sand-001-1705**
Notes	**Sand Scalped @ 75 µm**

Test Inputs

Mass of Pan With Sample	**596.91 g**
Mass of Pan Without Sample	**365.53 g**

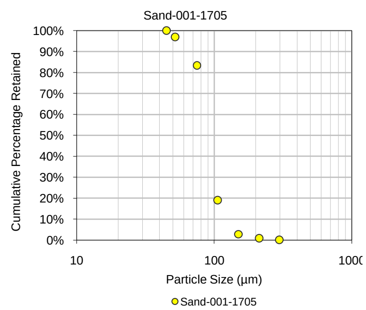
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	127.52 g	127.64 g
Size > 212 µm	127.53 g	129.36 g
Size > 150 µm	127.51 g	131.90 g
Size > 106 µm	127.53 g	164.64 g
Size > 75 µm	136.06 g	283.02 g
Size > 52 µm	128.77 g	159.74 g
Size > 45 µm	127.77 g	134.66 g
Pan	127.52 g	127.52 g

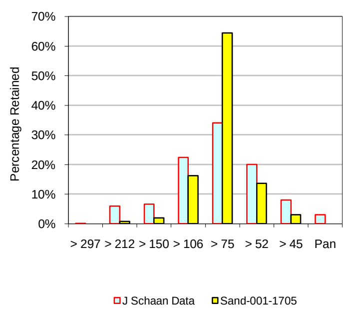
Test Outputs

Total Solids Added	**231.4 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.12 g	0.1%	0.1%
> 212	1.83 g	0.9%	0.8%
> 150	4.39 g	2.8%	1.9%
> 106	37.11 g	19.0%	16.3%
> 75	146.96 g	83.4%	64.4%
> 52	30.97 g	97.0%	13.6%
> 45	6.89 g	100.0%	3.0%
Pan	0.00 g	100.0%	0.0%
Total Solids	228.3 g		100%

Graphical Outputs





Ottawa Sand - As Delivered

Date	**20/03/07**
Test Name	**Ottawa-002-2103**
Notes	**As Delivered**

Test Inputs

Mass of Pan With Sample	**1828.85 g**
Mass of Pan Without Sample	**1585.46 g**

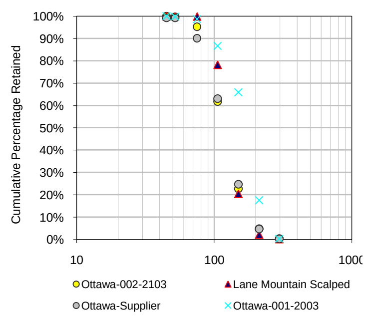
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	510.95 g	511.94 g
Size > 212 µm	508.07 g	518.50 g
Size > 150 µm	496.67 g	539.54 g
Size > 106 µm	519.11 g	612.27 g
Size > 75 µm	554.38 g	634.14 g
Size > 52 µm	482.55 g	493.31 g
Size > 45 µm	506.26 g	506.69 g
Pan	578.13 g	578.29 g

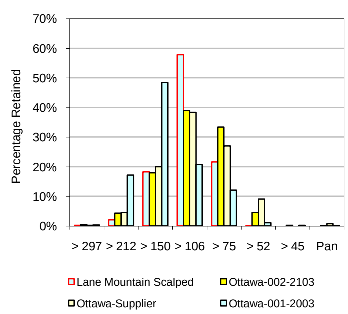
Test Outputs

Total Solids Added

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.99 g	0.4%	0.4%
> 212	10.43 g	4.8%	4.4%
> 150	42.87 g	22.8%	18.0%
> 106	93.16 g	61.8%	39.1%
> 75	79.76 g	95.2%	33.4%
> 52	10.76 g	99.8%	4.5%
> 45	0.43 g	99.9%	0.2%
Pan	0.16 g	100.0%	0.1%
Total Solids	238.6 g		100%

Graphical Outputs





Ottawa Sand - Scalped 1

Date	**23/04/2007**
Test Name	**Ottawa-003-2304**
Notes	**Scalped @ 75 and 212 µm**

Test Inputs

Mass of Pan With Sample	**411.69 g**
Mass of Pan Without Sample	**205.14 g**

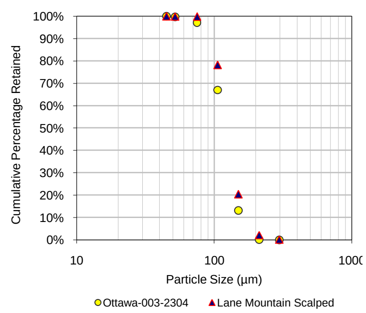
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	256.11 g	256.11 g
Size > 212 µm	256.11 g	256.27 g
Size > 150 µm	224.56 g	251.22 g
Size > 106 µm	243.43 g	353.59 g
Size > 75 µm	226.42 g	288.06 g
Size > 52 µm	226.01 g	231.35 g
Size > 45 µm	256.13 g	256.65 g
Pan	256.13 g	256.13 g

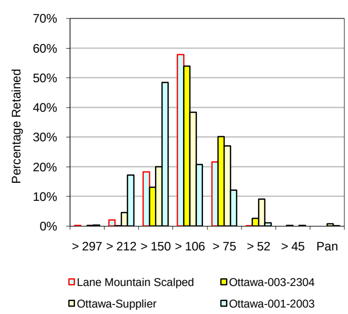
Test Outputs

Total Solids Added	**206.6 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.00 g	0.0%	0.0%
> 212	0.16 g	0.1%	0.1%
> 150	26.66 g	13.1%	13.0%
> 106	110.16 g	67.0%	53.9%
> 75	61.64 g	97.1%	30.1%
> 52	5.34 g	99.7%	2.6%
> 45	0.52 g	100.0%	0.3%
Pan	0.00 g	100.0%	0.0%
Total Solids	204.5 g		100%

Graphical Outputs





Ottawa Sand - Scalped 2

Date	**23/04/2007**
Test Name	**Ottawa-004-2404**
Notes	**Scalped @ 75 and 212 µm**

Test Inputs

Mass of Pan With Sample	**330.79 g**
Mass of Pan Without Sample	**116.18 g**

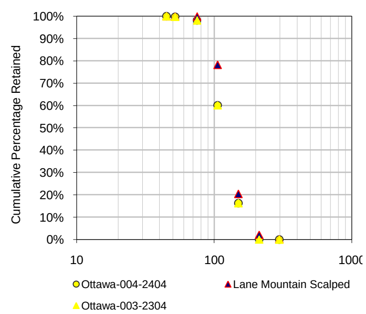
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	223.63 g	223.63 g
Size > 212 µm	223.63 g	223.73 g
Size > 150 µm	255.52 g	289.95 g
Size > 106 µm	226.01 g	319.24 g
Size > 75 µm	243.40 g	324.16 g
Size > 52 µm	224.58 g	228.10 g
Size > 45 µm	226.37 g	226.85 g
Pan	226.37 g	226.37 g

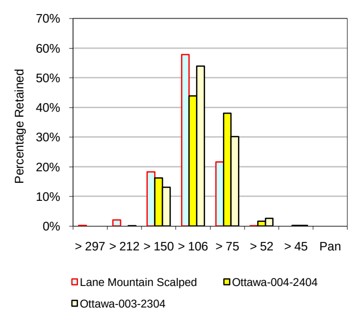
Test Outputs

Total Solids Added	**214.6 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.00 g	0.0%	0.0%
> 212	0.10 g	0.0%	0.0%
> 150	34.43 g	16.2%	16.2%
> 106	93.23 g	60.1%	43.9%
> 75	80.76 g	98.1%	38.0%
> 52	3.52 g	99.8%	1.7%
> 45	0.48 g	100.0%	0.2%
Pan	0.00 g	100.0%	0.0%
Total Solids	212.5 g		100%

Graphical Outputs





Ottawa Sand - Scalped 3

Date	**30/05/2007**
Test Name	**Ottawa-005-3005**
Notes	**Scalped @ 75 and 212 µm**

<u>Test Inputs</u>

Mass of Pan With Sample	**646.96 g**
Mass of Pan Without Sample	**445.61 g**

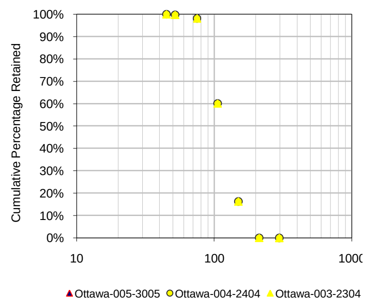
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	399.88 g	399.88 g
Size > 212 µm	399.62 g	399.88 g
Size > 150 µm	335.45 g	364.92 g
Size > 106 µm	326.40 g	422.46 g
Size > 75 µm	396.18 g	465.92 g
Size > 52 µm	319.56 g	325.41 g
Size > 45 µm	355.27 g	355.96 g
Pan	355.27 g	355.27 g

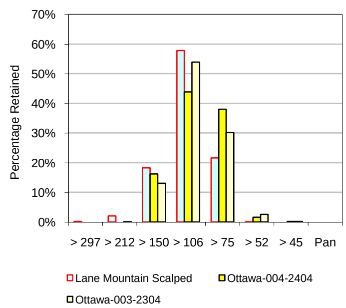
<u>Test Outputs</u>

Total Solids Added	**201.4 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.00 g	0.0%	0.0%
> 212	0.26 g	0.1%	0.1%
> 150	29.47 g	14.7%	14.6%
> 106	96.06 g	62.3%	47.5%
> 75	69.74 g	96.8%	34.5%
> 52	5.85 g	99.7%	2.9%
> 45	0.69 g	100.0%	0.3%
Pan	0.00 g	100.0%	0.0%
Total Solids	202.1 g		100%

<u>Graphical Outputs</u>





Quackenbush Glass Beads - As Delivered

Date	**16/04/2007**
Test Name	**Glass-001**
Notes	**As Delivered**

Test Inputs

Mass of Pan With Sample	**429.69 g**
Mass of Pan Without Sample	**152.42 g**

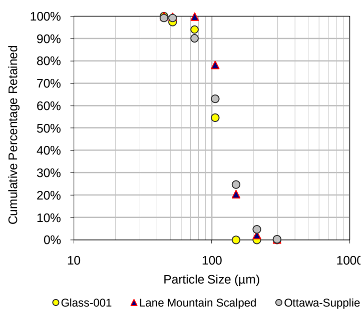
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	508.09 g	508.09 g
Size > 212 µm	508.09 g	508.09 g
Size > 150 µm	508.09 g	508.09 g
Size > 106 µm	508.09 g	658.19 g
Size > 75 µm	578.18 g	686.38 g
Size > 52 µm	511.17 g	520.20 g
Size > 45 µm	473.08 g	480.38 g
Pan	507.25 g	507.30 g

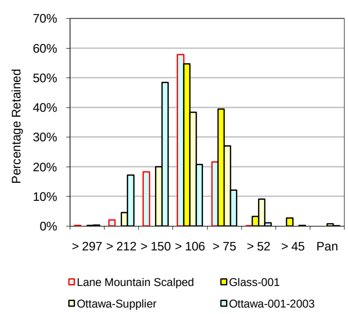
Test Outputs

Total Solids Added	**277.3 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.00 g	0.0%	0.0%
> 212	0.00 g	0.0%	0.0%
> 150	0.00 g	0.0%	0.0%
> 106	150.10 g	54.6%	54.6%
> 75	108.20 g	94.0%	39.4%
> 52	9.03 g	97.3%	3.3%
> 45	7.30 g	100.0%	2.7%
Pan	0.05 g	100.0%	0.0%
Total Solids	274.7 g		100%

Graphical Outputs





Quackenbush Glass Beads - Scalped 1

Date	**19/04/2007**
Test Name	**Glass-002**
Notes	**Scalped @ 75 µm**

Test Inputs

Mass of Pan With Sample	**661.37 g**
Mass of Pan Without Sample	**468.74 g**

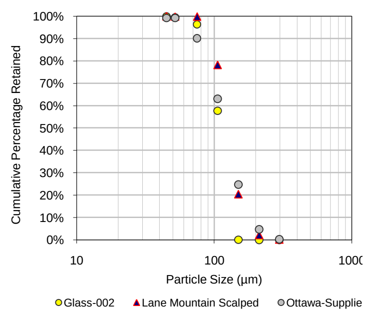
Size	**Pan Dry Mass**	**Pan and Solids Mass**
Size > 297 µm	**473.10 g**	**473.10 g**
Size > 212 µm	**473.10 g**	**473.10 g**
Size > 150 µm	**511.22 g**	**511.26 g**
Size > 106 µm	**496.65 g**	**606.74 g**
Size > 75 µm	**241.78 g**	**315.45 g**
Size > 52 µm	**256.11 g**	**262.10 g**
Size > 45 µm	**225.99 g**	**226.73 g**
Pan	**224.56 g**	**224.85 g**

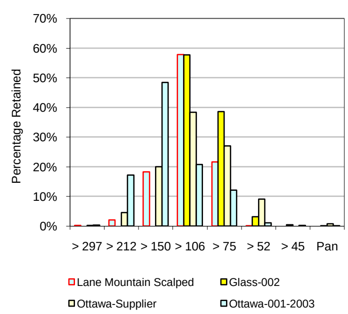
Test Outputs

Total Solids Added	**190.8 g**	192.63 g

Size	**Mass Retained**	**Cumulative % Retained**	**% Retained**
> 297	**0.00 g**	**0.0%**	**0.0%**
> 212	**0.00 g**	**0.0%**	**0.0%**
> 150	**0.04 g**	**0.0%**	**0.0%**
> 106	**110.09 g**	**57.7%**	**57.7%**
> 75	**73.67 g**	**96.3%**	**38.6%**
> 52	**5.99 g**	**99.5%**	**3.1%**
> 45	**0.74 g**	**99.8%**	**0.4%**
Pan	**0.29 g**	**100.0%**	**0.2%**
Total Solids	**190.8 g**		**100%**

Graphical Outputs





Quackenbush Glass Beads - Scalped 2

Date	**24/04/2007**
Test Name	**Glass-003**
Notes	**Scalped @ 75 µm**

Test Inputs

Mass of Pan With Sample	**461.69 g**
Mass of Pan Without Sample	**155.02 g**

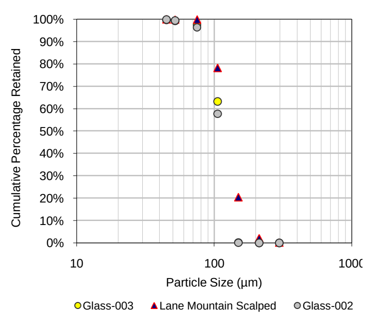
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	256.14 g	256.14 g
Size > 212 µm	256.14 g	256.15 g
Size > 150 µm	256.13 g	256.68 g
Size > 106 µm	256.18 g	448.69 g
Size > 75 µm	223.63 g	328.70 g
Size > 52 µm	127.71 g	132.58 g
Size > 45 µm	134.92 g	136.33 g
Pan	136.02 g	137.12 g

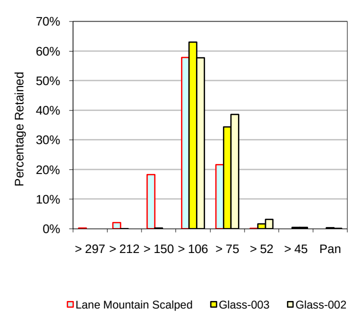
Test Outputs

Total Solids Added	**306.7 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.00 g	0.0%	0.0%
> 212	0.01 g	0.0%	0.0%
> 150	0.55 g	0.2%	0.2%
> 106	192.51 g	63.2%	63.0%
> 75	105.07 g	97.6%	34.4%
> 52	4.87 g	99.2%	1.6%
> 45	1.41 g	99.6%	0.5%
Pan	1.10 g	100.0%	0.4%
Total Solids	305.5 g		100%

Graphical Outputs





Quackenbush Glass Beads - Scalped 3

Date	**24/04/2007**
Test Name	**Glass-003**
Notes	**Scalped @ 75 µm**

Test Inputs

Mass of Pan With Sample	**517.58 g**
Mass of Pan Without Sample	**258.73 g**

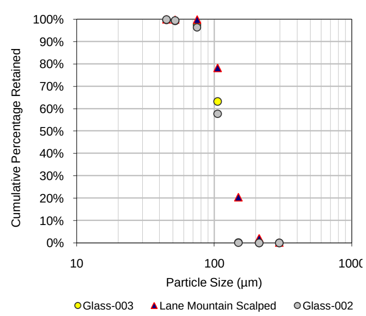
Size	Pan Dry Mass	Pan and Solids Mass
Size > 297 µm	412.44 g	412.44 g
Size > 212 µm	412.44 g	412.45 g
Size > 150 µm	425.15 g	425.34 g
Size > 106 µm	420.31 g	571.21 g
Size > 75 µm	347.86 g	443.51 g
Size > 52 µm	298.33 g	304.96 g
Size > 45 µm	278.00 g	281.15 g
Pan	289.28 g	289.76 g

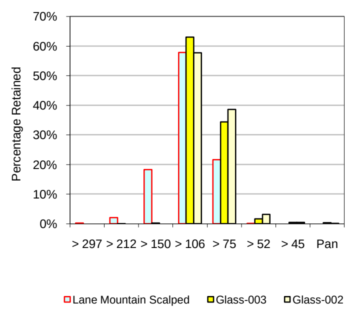
Test Outputs

Total Solids Added	**258.9 g**

Size	Mass Retained	Cumulative % Retained	% Retained
> 297	0.00 g	0.0%	0.0%
> 212	0.00 g	0.0%	0.0%
> 150	0.20 g	0.1%	0.1%
> 106	150.90 g	58.8%	58.7%
> 75	95.65 g	96.0%	37.2%
> 52	6.63 g	98.6%	2.6%
> 45	3.15 g	99.8%	1.2%
Pan	0.48 g	100.0%	0.2%
Total Solids	257.0 g		100%

Graphical Outputs



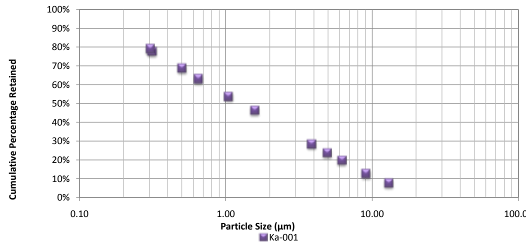


Kaolin - 001

Test	**Ka-001**
Solids Density	**2.734 t/m³**
Water Density	**0.998 t/m³**
Water Viscosity	**1 cP**

FRESH SLURRY

Crucible	**230.55**
Crucible & Slurry	**418.70**
Crucible & Solids	**235.78**
Weight Concentration	**2.78%**
Volume Concentration	**1.03%**



Sample	Hours (h)	Minutes (min)	Seconds (s)	Total Time (s)		Height (cm)	Particle Size (µm)	Mass of Crucible (g)	Slurry & Crucible (g)	Dry Clay & Crucible (g)	Solids Concentration (%w)	Percentage Finer Than
	N/A	N/A	N/A	N/A		N/A	N/A	**13.382**	**23.866**	**13.674**	2.79%	100%
1	**0**	**20**	**38**	1238		**19.88**	13.03	**13.150**	**23.490**	**13.416**	2.57%	92%
2	**0**	**41**	**21**	2481		**19.45**	9.10	**14.029**	**23.614**	**14.262**	2.43%	87%
3	**1**	**26**	**22**	5182		**18.95**	6.22	**12.366**	**21.908**	**12.579**	2.23%	80%
4	**2**	**13**	**22**	8002		**18.58**	4.96	**10.420**	**19.744**	**10.618**	2.12%	76%
5	**3**	**34**	**26**	12866		**18.22**	3.87	**13.253**	**22.637**	**13.440**	1.99%	72%
6	**21**	**9**	**15**	76155		**17.88**	1.58	**12.761**	**22.595**	**12.908**	1.49%	54%
7	**47**	**2**	**10**	169330		**17.45**	1.04	**12.363**	**23.243**	**12.503**	1.29%	46%
8	**118**	**20**	**5**	426005		**17.05**	0.65	**13.382**	**22.927**	**13.480**	1.03%	37%
9	**192**	**6**	**35**	691595		**16.48**	0.50	**13.152**	**22.674**	**13.235**	0.87%	31%
10	**479**	**16**	**15**	1725375		**16.15**	0.31	**12.365**	**22.093**	**12.425**	0.62%	22%
11	**501**	**16**	**35**	1804595		**15.75**	0.30	**12.766**	**23.079**	**12.826**	0.58%	21%

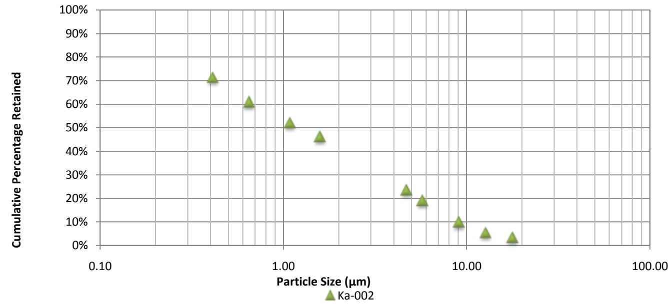
Kaolin - 002

TEST DETAILS

Test	**Ka-002**	
Solids Density	**2.734**	**t/m³**
Water Density	**0.998**	**t/m³**
Water Viscosity	**1**	**cP**

FRESH SLURRY

Crucible	**242.31**
Crucible & Slurry	**313.64**
Crucible & Solids	**244.19**
Weight Concentration	**2.64%**
Volume Concentration	**0.98%**



Sample	Hours (h)	Minutes (min)	Seconds (s)	Total Time (s)	Height (cm)	Particle Size (µm)	Mass of Crucible (g)	Slurry & Crucible (g)	Dry Clay & Crucible (g)	Solids Concentration (%w)	Percentage Finer Than
	N/A	N/A	N/A	N/A	N/A	N/A	**14.031**	**24.194**	**14.301**	2.66%	100%
1	**0**	**10**	**55**	655	**19.54**	17.76	**12.391**	**21.892**	**12.635**	2.57%	97%
2	**0**	**20**	**55**	1255	**19.15**	12.70	**12.606**	**22.912**	**12.865**	2.51%	95%
3	**0**	**40**	**10**	2410	**18.7**	9.06	**13.378**	**22.277**	**13.591**	2.39%	90%
4	**1**	**38**	**5**	5885	**18.39**	5.75	**14.278**	**24.042**	**14.488**	2.15%	81%
5	**2**	**23**	**15**	8595	**17.98**	4.70	**12.367**	**20.921**	**12.541**	2.03%	77%
6	**20**	**41**	**15**	74475	**17.65**	1.58	**13.148**	**22.583**	**13.283**	1.43%	54%
7	**43**	**12**	**10**	155530	**17.23**	1.08	**14.029**	**24.301**	**14.160**	1.28%	48%
8	**117**	**36**	**5**	423365	**16.80**	0.65	**12.387**	**21.238**	**12.479**	1.04%	39%
9	**284**	**59**	**20**	1025960	**16.43**	0.41	**12.794**	**21.715**	**12.862**	0.76%	29%

APPENDIX D: LANE MOUNTAIN SAND TESTS

LM-01

Test Details

Batch	12/12/2006		
Test Number	Kaol-1212		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0043 N.m	0.0043 N.m	0.0043 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1283 kg/m³	1335 kg/m³	1273 kg/m³
Weight Concentration	35.87%	42.66%	33.81%
Volume Concentration	16.84%	23.32%	15.74%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		7.8%	

Flow Properties

Bingham Yield Stress	12.98 Pa	15.76 Pa	10.11 Pa
Bingham Viscosity	0.009 Pa.s	0.009 Pa.s	0.008 Pa.s
Vane Yield Stress	6.14 Pa	6.77 Pa	4.78 Pa
Distance Ratio, l		1.1466	
Vane Yield Stress Ratio		1.1032	
Bingham Yield Stress Ratio		1.2143	
Bingham Viscosity Ratio		1.0011	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
6.2	3.36E-02	19.0	5.14E-02	19.0	3.57E-02
10.4	3.70E-02	26.8	5.61E-02	26.8	3.94E-02
14.6	4.00E-02	37.9	6.20E-02	37.9	4.41E-02
21.2	4.44E-02	53.6	6.98E-02	53.6	5.27E-02
30.0	4.96E-02	37.9	6.22E-02	37.9	4.50E-02
32.9	5.16E-02	26.8	5.63E-02	26.8	4.01E-02
30.4	5.06E-02	19.0	5.16E-02	19.0	3.61E-02
24.8	4.79E-02	9.5	4.46E-02	9.5	3.10E-02
16.6	4.38E-02	19.0	5.13E-02	19.0	3.58E-02
14.8	4.27E-02	26.8	5.62E-02	26.8	3.98E-02
13.8	4.03E-02	37.9	6.20E-02	37.9	4.46E-02
17.6	4.29E-02	0.0	0.00E+00	53.6	5.27E-02
22.1	4.46E-02	0.0	0.00E+00	0.0	0.00E+00
16.4	3.28E-02	0.0	0.00E+00	0.0	0.00E+00
5.0	1.77E-02	0.0	0.00E+00	0.0	0.00E+00
10.3	2.11E-02	0.0	0.00E+00	0.0	0.00E+00
1.7	8.42E-03	0.0	0.00E+00	0.0	0.00E+00
3.4	9.94E-03	0.0	0.00E+00	0.0	0.00E+00

LM-02

Test Details

Batch	12/12/2006		
Test Number	Kaol-14212		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0043 N.m	0.0043 N.m	0.0043 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1283 kg/m³	1403 kg/m³	1275 kg/m³
Weight Concentration	35.87%	47.73%	33.99%
Volume Concentration	16.84%	26.50%	15.85%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		11.6%	

Flow Properties

Bingham Yield Stress	12.98 Pa	17.03 Pa	11.20 Pa
Bingham Viscosity	0.009 Pa.s	0.011 Pa.s	0.009 Pa.s
Vane Yield Stress	6.14 Pa	7.32 Pa	3.93 Pa
Distance Ratio, l		1.5646	
Vane Yield Stress Ratio		1.1932	
Bingham Yield Stress Ratio		1.3119	
Bingham Viscosity Ratio		1.2007	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
6.2	3.36E-02	9.5	4.80E-02	19.0	3.90E-02
10.4	3.70E-02	19.0	5.64E-02	26.8	4.27E-02
14.6	4.00E-02	26.8	6.26E-02	37.9	4.75E-02
21.2	4.44E-02	37.9	6.99E-02	53.6	5.61E-02
30.0	4.96E-02	26.8	6.30E-02	37.9	4.83E-02
32.9	5.16E-02	19.0	5.75E-02	26.8	4.31E-02
30.4	5.06E-02	13.4	5.41E-02	19.0	3.93E-02
24.8	4.79E-02	9.4	5.01E-02	13.4	3.64E-02
16.6	4.38E-02	6.7	4.66E-02	9.5	3.30E-02
14.8	4.27E-02	13.4	5.37E-02	19.0	3.84E-02
13.8	4.03E-02	19.0	5.65E-02	26.8	4.21E-02
17.6	4.29E-02	26.8	6.18E-02	37.9	4.68E-02
22.1	4.46E-02	37.9	6.81E-02	53.6	5.65E-02
16.4	3.28E-02	0.0	0.00E+00	0.0	0.00E+00
5.0	1.77E-02	0.0	0.00E+00	0.0	0.00E+00
10.3	2.11E-02	0.0	0.00E+00	0.0	0.00E+00
1.7	8.42E-03	0.0	0.00E+00	0.0	0.00E+00
3.4	9.94E-03	0.0	0.00E+00	0.0	0.00E+00

LM-03

Test Details

Batch	19/12/2006		
Test Number	Kaol-1312		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 500	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0043 N.m	0.0043 N.m	0.0043 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1297 kg/m³	1506 kg/m³	1279 kg/m³
Weight Concentration	36.09%	52.88%	34.37%
Volume Concentration	16.84%	28.89%	16.08%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		14.5%	

Flow Properties

Bingham Yield Stress	12.98 Pa	19.84 Pa	10.36 Pa
Bingham Viscosity	0.009 Pa.s	0.016 Pa.s	0.007 Pa.s
Vane Yield Stress	6.14 Pa	9.44 Pa	4.86 Pa
Distance Ratio, l		1.9120	
Vane Yield Stress Ratio		1.5377	
Bingham Yield Stress Ratio		1.5290	
Bingham Viscosity Ratio		1.6636	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
6.2	3.36E-02	9.5	5.91E-02	19.0	3.50E-02
10.4	3.70E-02	13.4	6.41E-02	26.8	3.80E-02
14.6	4.00E-02	19.0	6.95E-02	37.9	4.25E-02
21.2	4.44E-02	13.4	6.49E-02	53.6	4.91E-02
30.0	4.96E-02	9.5	5.98E-02	53.6	5.03E-02
32.9	5.16E-02	6.7	5.62E-02	37.9	4.34E-02
30.4	5.06E-02	4.7	5.27E-02	26.8	3.88E-02
24.8	4.79E-02	6.7	5.59E-02	19.0	3.50E-02
16.6	4.38E-02	9.5	5.98E-02	13.4	3.33E-02
14.8	4.27E-02	13.4	6.41E-02	9.5	2.97E-02
13.8	4.03E-02	19.0	6.89E-02	13.4	3.35E-02
17.6	4.29E-02	0.0	0.00E+00	26.8	3.83E-02
22.1	4.46E-02	0.0	0.00E+00	37.9	4.20E-02
16.4	3.28E-02	0.0	0.00E+00	53.6	4.89E-02
5.0	1.77E-02	0.0	0.00E+00	0.0	0.00E+00
10.3	2.11E-02	0.0	0.00E+00	0.0	0.00E+00
1.7	8.42E-03	0.0	0.00E+00	0.0	0.00E+00
3.4	9.94E-03	0.0	0.00E+00	0.0	0.00E+00

LM-04

Test Details

Batch	12/12/2006		
Test Number	Kaol-1312		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 500	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0043 N.m	0.0450 N.m	0.0043 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1283 kg/m³	1553 kg/m³	1200 kg/m³
Weight Concentration	35.87%	58.00%	26.28%
Volume Concentration	16.84%	34.62%	11.54%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		21.4%	

Flow Properties

Bingham Yield Stress	12.98 Pa	32.64 Pa	2.26 Pa
Bingham Viscosity	0.009 Pa.s	0.023 Pa.s	0.004 Pa.s
Vane Yield Stress	6.14 Pa	16.03 Pa	1.07 Pa
Distance Ratio, l		2.9620	
Vane Yield Stress Ratio		2.6123	
Bingham Yield Stress Ratio		2.5154	
Bingham Viscosity Ratio		2.4278	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
6.2	3.36E-02	9.5	8.63E-02	19.0	1.00E-02
10.4	3.70E-02	13.4	9.75E-02	26.8	1.18E-02
14.6	4.00E-02	19.0	1.07E-01	37.9	1.38E-02
21.2	4.44E-02	26.8	1.22E-01	37.9	1.38E-02
30.0	4.96E-02	37.9	1.39E-01	26.8	1.15E-02
32.9	5.16E-02	53.6	1.58E-01	19.0	9.46E-03
30.4	5.06E-02	75.8	1.79E-01	13.4	8.81E-03
24.8	4.79E-02	53.6	1.60E-01	9.5	7.88E-03
16.6	4.38E-02	37.9	1.43E-01	19.0	9.89E-03
14.8	4.27E-02	26.8	1.26E-01	37.9	1.38E-02
13.8	4.03E-02	19.0	1.14E-01	0.0	0.00E+00
17.6	4.29E-02	13.4	1.04E-01	0.0	0.00E+00
22.1	4.46E-02	53.6	1.54E-01	0.0	0.00E+00
16.4	3.28E-02	13.4	1.01E-01	0.0	0.00E+00
5.0	1.77E-02	26.8	1.22E-01	0.0	0.00E+00
10.3	2.11E-02	37.9	1.36E-01	0.0	0.00E+00
1.7	8.42E-03	0.0	0.00E+00	0.0	0.00E+00
3.4	9.94E-03	0.0	0.00E+00	0.0	0.00E+00

LM-05

Test Details

Batch	17/01/2007		
Test Number	Kaol-1701		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 500	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0043 N.m	0.0450 N.m	0.0043 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1279 kg/m³	1485 kg/m³	1283 kg/m³
Weight Concentration	36.27%	52.50%	34.79%
Volume Concentration	16.97%	29.33%	16.16%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		14.9%	

Flow Properties

Bingham Yield Stress	12.37 Pa	22.69 Pa	12.37 Pa
Bingham Viscosity	0.010 Pa.s	0.017 Pa.s	0.010 Pa.s
Vane Yield Stress	6.03 Pa	9.53 Pa	5.99 Pa
Distance Ratio, l		1.9644	
Vane Yield Stress Ratio		1.5794	
Bingham Yield Stress Ratio		1.8346	
Bingham Viscosity Ratio		1.7254	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)
9.5	3.55E-02	19.0	8.10E-02	9.5	3.83E-02
13.4	3.90E-02	13.4	7.43E-02	13.4	4.08E-02
19.0	4.16E-02	26.8	8.55E-02	19.0	4.41E-02
26.8	4.73E-02	37.9	9.68E-02	26.8	4.67E-02
37.9	5.27E-02	53.6	1.09E-01	37.9	5.22E-02
53.6	6.22E-02	75.8	1.31E-01	53.6	6.09E-02
37.9	5.34E-02	53.6	1.11E-01	53.6	6.18E-02
26.8	4.84E-02	37.9	9.83E-02	37.9	5.24E-02
19.0	4.46E-02	19.0	8.48E-02	26.8	4.71E-02
13.4	4.14E-02	13.4	7.73E-02	19.0	4.41E-02
9.5	3.73E-02	19.0	8.33E-02	13.4	4.13E-02
19.0	4.33E-02	26.8	8.70E-02	9.5	3.85E-02
26.8	4.84E-02	37.9	9.60E-02	0.0	0.00E+00
37.9	5.39E-02	53.6	1.10E-01	0.0	0.00E+00
53.6	6.27E-02	75.8	1.34E-01	0.0	0.00E+00
0.0	0.00E+00	75.8	1.34E-01	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-06

Test Details

Batch	22/02/2007		
Test Number	Kaol-2202		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 500	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0043 N.m	0.0450 N.m	0.0043 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1299 kg/m³	1496 kg/m³	1290 kg/m³
Weight Concentration	35.66%	52.60%	35.18%
Volume Concentration	16.93%	28.96%	16.62%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		14.5%	

Flow Properties

Bingham Yield Stress	14.44 Pa	26.06 Pa	12.71 Pa
Bingham Viscosity	0.010 Pa.s	0.016 Pa.s	0.008 Pa.s
Vane Yield Stress	6.41 Pa	10.67 Pa	5.69 Pa
Distance Ratio, l		1.9109	
Vane Yield Stress Ratio		1.6658	
Bingham Yield Stress Ratio		1.8044	
Bingham Viscosity Ratio		1.7065	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)
53.6	6.52E-02	74.6	1.35E-01	53.6	5.82E-02
37.9	5.79E-02	53.6	1.21E-01	37.9	5.10E-02
26.8	5.28E-02	37.9	1.13E-01	26.8	4.60E-02
16.2	4.76E-02	26.8	9.75E-02	19.0	4.18E-02
11.4	4.42E-02	19.0	8.93E-02	13.4	4.00E-02
11.4	4.45E-02	13.4	8.25E-02	9.5	3.60E-02
16.2	4.67E-02	19.0	8.78E-02	13.4	3.98E-02
22.9	5.01E-02	26.8	9.53E-02	19.0	4.18E-02
32.4	5.50E-02	37.9	1.06E-01	26.8	4.53E-02
45.8	6.10E-02	53.6	1.18E-01	37.9	4.98E-02
45.8	6.20E-02	75.8	1.35E-01	53.6	5.76E-02
28.4	5.38E-02	53.6	1.22E-01	37.9	5.10E-02
14.2	4.64E-02	37.9	1.12E-01	19.0	4.26E-02
6.7	2.30E-02	26.8	9.75E-02	9.5	3.68E-02
4.7	2.17E-02	19.0	8.93E-02	0.0	0.00E+00
0.0	0.00E+00	13.4	8.18E-02	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-07

Test Details

Batch	22/02/2007		
Test Number	Kaol-2202		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 500	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0043 N.m	0.0450 N.m	0.0043 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1299 kg/m³	1570 kg/m³	1264 kg/m³
Weight Concentration	35.66%	57.69%	34.76%
Volume Concentration	16.93%	33.46%	16.14%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		19.9%	

Flow Properties

Bingham Yield Stress	14.44 Pa	31.37 Pa	12.50 Pa
Bingham Viscosity	0.010 Pa.s	0.019 Pa.s	0.007 Pa.s
Vane Yield Stress	6.41 Pa	13.73 Pa	5.54 Pa
Distance Ratio, l		2.7013	
Vane Yield Stress Ratio		2.1426	
Bingham Yield Stress Ratio		2.1727	
Bingham Viscosity Ratio		1.9901	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
53.6	6.52E-02	53.6	1.40E-01	53.6	5.46E-02
37.9	5.79E-02	75.8	1.56E-01	37.9	4.83E-02
26.8	5.28E-02	53.6	1.40E-01	26.8	4.46E-02
16.2	4.76E-02	37.9	1.23E-01	19.0	4.10E-02
11.4	4.42E-02	26.8	1.14E-01	13.4	3.85E-02
11.4	4.45E-02	19.0	1.01E-01	9.5	3.51E-02
16.2	4.67E-02	13.4	9.38E-02	13.4	3.88E-02
22.9	5.01E-02	19.0	1.01E-01	19.0	4.00E-02
32.4	5.50E-02	26.8	1.12E-01	26.8	4.33E-02
45.8	6.10E-02	37.9	1.20E-01	37.9	4.76E-02
45.8	6.20E-02	53.6	1.37E-01	53.6	5.43E-02
28.4	5.38E-02	75.8	1.56E-01	37.9	4.76E-02
14.2	4.64E-02	26.8	1.11E-01	19.0	4.01E-02
6.7	2.30E-02	13.4	9.30E-02	9.5	3.51E-02
4.7	2.17E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-08

Test Details

Batch	22/02/2007		
Test Number	Kaol-2202		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 500	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0043 N.m	0.0450 N.m	0.0043 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1299 kg/m³	1528 kg/m³	1264 kg/m³
Weight Concentration	35.66%	55.51%	34.76%
Volume Concentration	16.93%	31.88%	16.14%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		18.0%	

Flow Properties

Bingham Yield Stress	14.44 Pa	31.37 Pa	12.50 Pa
Bingham Viscosity	0.010 Pa.s	0.019 Pa.s	0.007 Pa.s
Vane Yield Stress	6.41 Pa	11.93 Pa	5.54 Pa
Distance Ratio, l		2.3999	
Vane Yield Stress Ratio		1.8623	
Bingham Yield Stress Ratio		2.1727	
Bingham Viscosity Ratio		1.9901	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
53.6	6.52E-02	53.6	1.37E-01	53.6	5.46E-02
37.9	5.79E-02	75.8	1.61E-01	37.9	4.83E-02
26.8	5.28E-02	53.6	1.43E-01	26.8	4.46E-02
16.2	4.76E-02	37.9	1.28E-01	19.0	4.10E-02
11.4	4.42E-02	26.8	1.19E-01	13.4	3.85E-02
11.4	4.45E-02	19.0	1.01E-01	9.5	3.51E-02
16.2	4.67E-02	13.4	9.38E-02	13.4	3.88E-02
22.9	5.01E-02	19.0	9.90E-02	19.0	4.00E-02
32.4	5.50E-02	26.8	1.13E-01	26.8	4.33E-02
45.8	6.10E-02	37.9	1.22E-01	37.9	4.76E-02
45.8	6.20E-02	53.6	1.40E-01	53.6	5.43E-02
28.4	5.38E-02	75.8	1.61E-01	37.9	4.76E-02
14.2	4.64E-02	37.9	1.28E-01	19.0	4.01E-02
6.7	2.30E-02	26.8	1.16E-01	9.5	3.51E-02
4.7	2.17E-02	13.4	9.68E-02	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-09

Test Details

Batch	22/02/2007		
Test Number	Kaol-2202		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 500	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0043 N.m	0.0450 N.m	0.0043 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1299 kg/m³	1582 kg/m³	1264 kg/m³
Weight Concentration	35.66%	58.84%	34.76%
Volume Concentration	16.93%	34.75%	16.14%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		21.3%	

Flow Properties

Bingham Yield Stress	14.44 Pa	37.20 Pa	12.50 Pa
Bingham Viscosity	0.010 Pa.s	0.023 Pa.s	0.007 Pa.s
Vane Yield Stress	6.41 Pa	15.57 Pa	5.54 Pa
Distance Ratio, l		2.9473	
Vane Yield Stress Ratio		2.4301	
Bingham Yield Stress Ratio		2.5761	
Bingham Viscosity Ratio		2.3983	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
53.6	6.52E-02	53.6	1.67E-01	53.6	5.46E-02
37.9	5.79E-02	75.8	1.89E-01	37.9	4.83E-02
26.8	5.28E-02	53.6	1.71E-01	26.8	4.46E-02
16.2	4.76E-02	37.9	1.52E-01	19.0	4.10E-02
11.4	4.42E-02	26.8	1.35E-01	13.4	3.85E-02
11.4	4.45E-02	19.0	1.23E-01	9.5	3.51E-02
16.2	4.67E-02	13.4	1.15E-01	13.4	3.88E-02
22.9	5.01E-02	19.0	1.19E-01	19.0	4.00E-02
32.4	5.50E-02	26.8	1.29E-01	26.8	4.33E-02
45.8	6.10E-02	37.9	1.46E-01	37.9	4.76E-02
45.8	6.20E-02	53.6	1.68E-01	53.6	5.43E-02
28.4	5.38E-02	75.8	1.95E-01	37.9	4.76E-02
14.2	4.64E-02	37.9	1.54E-01	19.0	4.01E-02
6.7	2.30E-02	26.8	1.35E-01	9.5	3.51E-02
4.7	2.17E-02	13.4	1.15E-01	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-10

Test Details

Batch	20/12/2006		
Test Number	Kaol-20%-2012-01		
Substance	Kaolin- Fresh Sample	Kaol-20%-2012-01	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 500	MK 500	MK 500
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0450 N.m	0.0450 N.m	0.0450 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1345 kg/m³	1619 kg/m³	1377 kg/m³
Weight Concentration	41.80%	61.01%	43.21%
Volume Concentration	20.56%	36.75%	21.77%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		20.4%	

Flow Properties

Bingham Yield Stress	40.20 Pa	78.35 Pa	61.30 Pa
Bingham Viscosity	0.018 Pa.s	0.036 Pa.s	0.020 Pa.s
Vane Yield Stress	17.97 Pa	33.29 Pa	27.41 Pa
Distance Ratio, l		2.7824	
Vane Yield Stress Ratio		1.8520	
Bingham Yield Stress Ratio		1.9489	
Bingham Viscosity Ratio		2.0389	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
11.2	1.09E-01	13.4	2.24E-01	13.4	1.72E-01
17.1	1.19E-01	19.0	2.40E-01	19.0	1.82E-01
24.2	1.28E-01	26.8	2.63E-01	26.8	1.97E-01
34.2	1.40E-01	37.9	2.89E-01	37.9	2.09E-01
48.4	1.54E-01	53.6	3.21E-01	53.6	2.24E-01
55.8	1.61E-01	75.8	3.60E-01	75.8	2.40E-01
52.1	1.59E-01	53.6	3.25E-01	53.6	2.24E-01
36.8	1.46E-01	37.9	2.91E-01	37.9	2.06E-01
26.0	1.35E-01	26.8	2.65E-01	26.8	1.90E-01
21.6	1.29E-01	19.0	2.45E-01	19.0	1.79E-01
19.7	1.26E-01	13.4	2.27E-01	13.4	1.67E-01
23.4	1.29E-01	19.0	2.41E-01	0.0	0.00E+00
33.7	1.40E-01	37.9	2.84E-01	0.0	0.00E+00
31.6	1.03E-01	75.8	3.49E-01	0.0	0.00E+00
12.6	4.73E-02	0.0	0.00E+00	0.0	0.00E+00
17.9	5.15E-02	0.0	0.00E+00	0.0	0.00E+00
24.9	5.85E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-11

Test Details

Batch	20/12/2006		
Test Number	Kaol-10%-2012-01		
Substance	Kaolin- Fresh Sample	Kaol-10%-2012-01	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 500	MK 500	MK 500
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0450 N.m	0.0450 N.m	0.0450 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1345 kg/m³	1484 kg/m³	1358 kg/m³
Weight Concentration	41.80%	52.24%	41.53%
Volume Concentration	20.56%	28.97%	20.62%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		10.6%	

Flow Properties

Bingham Yield Stress	40.20 Pa	52.81 Pa	33.55 Pa
Bingham Viscosity	0.018 Pa.s	0.024 Pa.s	0.017 Pa.s
Vane Yield Stress	17.97 Pa	24.25 Pa	15.00 Pa
Distance Ratio, l		1.4476	
Vane Yield Stress Ratio		1.3494	
Bingham Yield Stress Ratio		1.3136	
Bingham Viscosity Ratio		1.3783	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
11.2	1.09E-01	13.4	1.52E-01	13.4	9.68E-02
17.1	1.19E-01	19.0	1.59E-01	19.0	1.04E-01
24.2	1.28E-01	26.8	1.72E-01	26.8	1.12E-01
34.2	1.40E-01	37.9	1.88E-01	37.9	1.22E-01
48.4	1.54E-01	53.6	2.09E-01	53.6	1.39E-01
55.8	1.61E-01	75.8	2.36E-01	75.8	1.57E-01
52.1	1.59E-01	53.6	2.18E-01	53.6	1.43E-01
36.8	1.46E-01	37.9	2.00E-01	37.9	1.28E-01
26.0	1.35E-01	26.8	1.82E-01	26.8	1.18E-01
21.6	1.29E-01	19.0	1.68E-01	19.0	1.07E-01
19.7	1.26E-01	13.4	1.58E-01	13.4	9.90E-02
23.4	1.29E-01	19.0	1.66E-01	19.0	1.06E-01
33.7	1.40E-01	26.8	1.79E-01	37.9	1.25E-01
31.6	1.03E-01	37.9	1.97E-01	75.8	1.58E-01
12.6	4.73E-02	53.6	2.17E-01	0.0	0.00E+00
17.9	5.15E-02	75.8	2.44E-01	0.0	0.00E+00
24.9	5.85E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-12

Test Details

Batch	20/12/2006		
Test Number	Kaol-15%-2012-01		
Substance	Kaolin- Fresh Sample	Kaol-15%-2012-01	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 500	MK 500	MK 500
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0450 N.m	0.0450 N.m	0.0450 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1361 kg/m³	1550 kg/m³	1338 kg/m³
Weight Concentration	42.33%	56.54%	39.81%
Volume Concentration	20.56%	32.48%	19.48%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		15.0%	

Flow Properties

Bingham Yield Stress	40.20 Pa	62.14 Pa	29.52 Pa
Bingham Viscosity	0.018 Pa.s	0.029 Pa.s	0.014 Pa.s
Vane Yield Stress	17.97 Pa	28.08 Pa	13.20 Pa
Distance Ratio, l		1.9788	
Vane Yield Stress Ratio		1.5622	
Bingham Yield Stress Ratio		1.5458	
Bingham Viscosity Ratio		1.6167	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
11.2	1.09E-01	13.4	1.79E-01	13.4	8.55E-02
17.1	1.19E-01	19.0	1.92E-01	19.0	8.93E-02
24.2	1.28E-01	26.8	2.09E-01	26.8	9.98E-02
34.2	1.40E-01	37.9	2.21E-01	53.6	1.21E-01
48.4	1.54E-01	53.6	2.51E-01	75.8	1.35E-01
55.8	1.61E-01	75.8	2.81E-01	53.6	1.22E-01
52.1	1.59E-01	53.6	2.55E-01	26.8	1.04E-01
36.8	1.46E-01	37.9	2.33E-01	19.0	9.38E-02
26.0	1.35E-01	26.8	2.12E-01	13.4	8.78E-02
21.6	1.29E-01	19.0	1.95E-01	19.0	9.00E-02
19.7	1.26E-01	13.4	1.81E-01	75.8	1.36E-01
23.4	1.29E-01	19.0	1.92E-01	75.8	1.36E-01
33.7	1.40E-01	26.8	2.06E-01	0.0	0.00E+00
31.6	1.03E-01	37.9	2.26E-01	0.0	0.00E+00
12.6	4.73E-02	53.6	2.54E-01	0.0	0.00E+00
17.9	5.15E-02	75.8	2.85E-01	0.0	0.00E+00
24.9	5.85E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-13

Test Details

Batch	03/02/2007		
Test Number	Kaol-15%-0203-R		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 500	MK 500	MK 500
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.020 m	0.021 m
Spring Constant	0.0450 N.m	0.0043 N.m	0.0450 N.m
Vane Diameter	0.000 m	0.040 m	0.000 m
Vane Height	0.000 m	0.060 m	0.000 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1350 kg/m³	1552 kg/m³	1378 kg/m³
Weight Concentration	41.68%	56.26%	43.43%
Volume Concentration	20.59%	31.97%	21.89%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		14.2%	

Flow Properties

Bingham Yield Stress	41.51 Pa	62.23 Pa	40.55 Pa
Bingham Viscosity	0.016 Pa.s	0.027 Pa.s	0.015 Pa.s
Vane Yield Stress	17.64 Pa	25.96 Pa	17.23 Pa
Distance Ratio, l		1.8744	
Vane Yield Stress Ratio		1.4717	
Bingham Yield Stress Ratio		1.4990	
Bingham Viscosity Ratio		1.6519	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
64.7	1.69E-01	75.8	2.76E-01	75.8	1.70E-01
64.7	1.69E-01	53.6	2.50E-01	53.6	1.55E-01
45.8	1.55E-01	37.9	2.30E-01	37.9	1.41E-01
32.4	1.41E-01	26.8	2.10E-01	26.8	1.29E-01
22.9	1.30E-01	19.0	1.91E-01	19.0	1.22E-01
16.2	1.21E-01	13.4	1.76E-01	13.4	1.16E-01
16.2	1.21E-01	19.0	1.88E-01	19.0	1.24E-01
22.9	1.29E-01	26.8	2.05E-01	26.8	1.28E-01
32.4	1.40E-01	37.9	2.21E-01	37.9	1.39E-01
45.8	1.53E-01	53.6	2.44E-01	53.6	1.52E-01
64.7	1.67E-01	75.8	2.75E-01	75.8	1.67E-01
64.7	1.69E-01	53.6	2.48E-01	53.6	1.53E-01
32.4	1.41E-01	26.8	2.05E-01	26.8	1.28E-01
20.1	1.26E-01	13.4	1.76E-01	13.4	1.17E-01
6.7	5.85E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-14

Test Details

Batch	03/02/2007		
Test Number	Kaol-20%-0203-R		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 500	MK 500	MK 500
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.020 m
Spring Constant	0.0450 N.m	0.0450 N.m	0.0450 N.m
Vane Diameter	0.000 m	0.000 m	0.000 m
Vane Height	0.000 m	0.000 m	0.000 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1350 kg/m³	1618 kg/m³	1368 kg/m³
Weight Concentration	41.68%	60.75%	42.63%
Volume Concentration	20.59%	36.38%	21.33%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		19.8%	

Flow Properties

Bingham Yield Stress	41.51 Pa	74.47 Pa	37.74 Pa
Bingham Viscosity	0.016 Pa.s	0.034 Pa.s	0.013 Pa.s
Vane Yield Stress	17.64 Pa	36.99 Pa	16.04 Pa
Distance Ratio, l		2.6786	
Vane Yield Stress Ratio		2.0969	
Bingham Yield Stress Ratio		1.7939	
Bingham Viscosity Ratio		2.1217	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
64.7	1.69E-01	75.8	3.44E-01	53.6	1.42E-01
64.7	1.69E-01	53.6	3.09E-01	75.8	1.54E-01
45.8	1.55E-01	37.9	2.78E-01	53.6	1.42E-01
32.4	1.41E-01	26.8	2.52E-01	37.9	1.28E-01
22.9	1.30E-01	19.0	2.33E-01	26.8	1.19E-01
16.2	1.21E-01	13.4	2.17E-01	19.0	1.13E-01
16.2	1.21E-01	19.0	2.29E-01	13.4	1.04E-01
22.9	1.29E-01	26.8	2.47E-01	19.0	1.13E-01
32.4	1.40E-01	37.9	2.70E-01	26.8	1.19E-01
45.8	1.53E-01	53.6	2.96E-01	37.9	1.27E-01
64.7	1.67E-01	75.8	3.38E-01	53.6	1.39E-01
64.7	1.69E-01	53.6	3.03E-01	75.8	1.53E-01
32.4	1.41E-01	26.8	2.51E-01	37.9	1.28E-01
20.1	1.26E-01	13.4	2.18E-01	26.8	1.22E-01
6.7	5.85E-02	0.0	0.00E+00	13.4	1.04E-01
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-15

Test Details

Batch	03/02/2007		
Test Number	Kaol-7.5%-Vane-0203-01		
Substance	Kaolin- Fresh Sample	Kaolin- 7.5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 500	MK 500	MK 500
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.020 m
Spring Constant	0.0450 N.m	0.0450 N.m	0.0450 N.m
Vane Diameter	0.000 m	0.000 m	0.000 m
Vane Height	0.000 m	0.000 m	0.000 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1350 kg/m³	1465 kg/m³	1368 kg/m³
Weight Concentration	41.68%	50.17%	42.63%
Volume Concentration	20.59%	26.82%	21.33%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		7.7%	

Flow Properties

Bingham Yield Stress	41.51 Pa	51.97 Pa	37.74 Pa
Bingham Viscosity	0.016 Pa.s	0.020 Pa.s	0.013 Pa.s
Vane Yield Stress	17.64 Pa	21.63 Pa	16.04 Pa
Distance Ratio, l		1.1367	
Vane Yield Stress Ratio		1.2263	
Bingham Yield Stress Ratio		1.2519	
Bingham Viscosity Ratio		1.2178	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
64.7	1.69E-01	75.8	2.17E-01	53.6	1.42E-01
64.7	1.69E-01	53.6	1.98E-01	75.8	1.54E-01
45.8	1.55E-01	37.9	1.86E-01	53.6	1.42E-01
32.4	1.41E-01	26.8	1.68E-01	37.9	1.28E-01
22.9	1.30E-01	19.0	1.57E-01	26.8	1.19E-01
16.2	1.21E-01	13.4	1.45E-01	19.0	1.13E-01
16.2	1.21E-01	19.0	1.55E-01	13.4	1.04E-01
22.9	1.29E-01	26.8	1.65E-01	19.0	1.13E-01
32.4	1.40E-01	37.9	1.79E-01	26.8	1.19E-01
45.8	1.53E-01	53.6	1.98E-01	37.9	1.27E-01
64.7	1.67E-01	75.8	2.19E-01	53.6	1.39E-01
64.7	1.69E-01	53.6	2.03E-01	75.8	1.53E-01
32.4	1.41E-01	26.8	1.71E-01	37.9	1.28E-01
20.1	1.26E-01	13.4	1.49E-01	26.8	1.22E-01
6.7	5.85E-02	0.0	0.00E+00	13.4	1.04E-01
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-16

Test Details

Batch	03/02/2007		
Test Number	Kaol-5%-0203-R		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 500	MK 500	MK 500
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.020 m
Spring Constant	0.0450 N.m	0.0450 N.m	0.0450 N.m
Vane Diameter	0.000 m	0.040 m	0.000 m
Vane Height	0.000 m	0.060 m	0.000 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1350 kg/m³	1453 kg/m³	1368 kg/m³
Weight Concentration	41.68%	47.27%	42.63%
Volume Concentration	20.59%	23.21%	21.33%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		3.1%	

Flow Properties

Bingham Yield Stress	41.51 Pa	47.94 Pa	43.17 Pa
Bingham Viscosity	0.016 Pa.s	0.019 Pa.s	0.014 Pa.s
Vane Yield Stress	17.64 Pa	19.72 Pa	18.34 Pa
Distance Ratio, l		0.6519	
Vane Yield Stress Ratio		1.1176	
Bingham Yield Stress Ratio		1.1547	
Bingham Viscosity Ratio		1.1574	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
64.7	1.69E-01	75.8	2.06E-01	75.8	1.69E-01
64.7	1.69E-01	53.6	1.87E-01	53.6	1.59E-01
45.8	1.55E-01	37.9	1.72E-01	37.9	1.46E-01
32.4	1.41E-01	26.8	1.58E-01	26.8	1.34E-01
22.9	1.30E-01	19.0	1.44E-01	19.0	1.29E-01
16.2	1.21E-01	13.4	1.34E-01	13.4	1.16E-01
16.2	1.21E-01	19.0	1.43E-01	19.0	1.28E-01
22.9	1.29E-01	26.8	1.55E-01	26.8	1.34E-01
32.4	1.40E-01	37.9	1.69E-01	37.9	1.46E-01
45.8	1.53E-01	53.6	1.84E-01	53.6	1.56E-01
64.7	1.67E-01	75.8	2.02E-01	75.8	1.70E-01
64.7	1.69E-01	53.6	1.85E-01	53.6	1.58E-01
32.4	1.41E-01	26.8	1.57E-01	26.8	1.32E-01
20.1	1.26E-01	13.4	1.34E-01	13.4	1.16E-01
6.7	5.85E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-17

Test Details

Batch	20/12/2006		
Test Number	Kaol-5%-2012-01		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 500	MK 500	MK 500
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0450 N.m	0.0450 N.m	0.0450 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		51.2%	
Density	1345 kg/m³	1437 kg/m³	1371 kg/m³
Weight Concentration	41.80%	47.77%	42.63%
Volume Concentration	20.56%	24.81%	21.37%
Slurry pH	5.00	5.00	5.00
Sand Volume Concentration		5.3%	

Flow Properties

Bingham Yield Stress	40.20 Pa	46.16 Pa	40.04 Pa
Bingham Viscosity	0.018 Pa.s	0.021 Pa.s	0.017 Pa.s
Vane Yield Stress	17.97 Pa	18.40 Pa	18.17 Pa
Distance Ratio, l		0.8903	
Vane Yield Stress Ratio		1.0237	
Bingham Yield Stress Ratio		1.1483	
Bingham Viscosity Ratio		1.1744	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
11.2	1.09E-01	9.5	1.23E-01	13.4	1.14E-01
17.1	1.19E-01	13.4	1.32E-01	19.0	1.19E-01
24.2	1.28E-01	19.0	1.41E-01	26.8	1.28E-01
34.2	1.40E-01	26.8	1.52E-01	37.9	1.40E-01
48.4	1.54E-01	37.9	1.64E-01	53.6	1.56E-01
55.8	1.61E-01	53.6	1.83E-01	75.8	1.73E-01
52.1	1.59E-01	37.9	1.70E-01	53.6	1.59E-01
36.8	1.46E-01	26.8	1.57E-01	37.9	1.44E-01
26.0	1.35E-01	19.0	1.46E-01	26.8	1.35E-01
21.6	1.29E-01	13.4	1.37E-01	19.0	1.25E-01
19.7	1.26E-01	9.5	1.28E-01	13.4	1.16E-01
23.4	1.29E-01	13.4	1.36E-01	19.0	1.22E-01
33.7	1.40E-01	26.8	1.55E-01	26.8	1.34E-01
31.6	1.03E-01	53.6	1.85E-01	37.9	1.44E-01
12.6	4.73E-02	0.0	0.00E+00	53.6	1.58E-01
17.9	5.15E-02	0.0	0.00E+00	75.8	1.74E-01
24.9	5.85E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

LM-18

Test Details

Batch	04/05/2007		
Test Number	Ka-F-0405-01		
Substance	Kaolin- Fresh Sample	Kaolin-5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1402 kg/m³	1458 kg/m³
Weight Concentration	43.73%	48.91%
Volume Concentration	22.47%	25.37%
Slurry pH	5.00	5.00
Sand Volume Concentration		3.7%

Flow Properties

Bingham Yield Stress	57.16 Pa	64.88 Pa
Bingham Viscosity	0.019 Pa.s	0.022 Pa.s
Vane Yield Stress	24.58 Pa	28.95 Pa
Distance Ratio, l		0.7189
Vane Yield Stress Ratio		1.1777
Bingham Yield Stress Ratio		1.1350
Bingham Viscosity Ratio		1.1461

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
53.6	2.09E-01	53.6	2.40E-01	N/A	N/A
26.8	1.81E-01	26.8	2.06E-01	N/A	N/A
13.4	1.59E-01	13.4	1.80E-01	N/A	N/A
6.7	1.41E-01	6.7	1.59E-01	N/A	N/A
3.4	1.28E-01	3.4	1.44E-01	N/A	N/A
6.7	1.41E-01	6.7	1.58E-01	N/A	N/A
13.4	1.57E-01	13.4	1.78E-01	N/A	N/A
26.8	1.80E-01	26.8	2.04E-01	N/A	N/A
53.6	2.11E-01	53.6	2.38E-01	N/A	N/A
26.8	1.81E-01	26.8	2.06E-01	N/A	N/A
13.4	1.59E-01	13.4	1.79E-01	N/A	N/A
6.7	1.41E-01	6.7	1.59E-01	N/A	N/A
3.4	1.28E-01	3.4	1.44E-01	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

LM-19

Test Details

Batch	04/05/2007		
Test Number	Ka-F-0405-01		
Substance	Kaolin- Fresh Sample	Kaolin-10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1402 kg/m³	1508 kg/m³
Weight Concentration	43.73%	53.84%
Volume Concentration	22.47%	30.27%
Slurry pH	5.00	5.00
Sand Volume Concentration		10.1%

Flow Properties

Bingham Yield Stress	57.16 Pa	73.90 Pa
Bingham Viscosity	0.019 Pa.s	0.023 Pa.s
Vane Yield Stress	24.58 Pa	32.86 Pa
Distance Ratio, l		1.3899
Vane Yield Stress Ratio		1.3369
Bingham Yield Stress Ratio		1.2928
Bingham Viscosity Ratio		1.1885

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
53.6	2.09E-01	13.4	2.01E-01	N/A	N/A
26.8	1.81E-01	26.8	2.31E-01	N/A	N/A
13.4	1.59E-01	13.4	2.01E-01	N/A	N/A
6.7	1.41E-01	6.7	1.78E-01	N/A	N/A
3.4	1.28E-01	13.4	2.00E-01	N/A	N/A
6.7	1.41E-01	26.8	2.30E-01	N/A	N/A
13.4	1.57E-01	13.4	2.00E-01	N/A	N/A
26.8	1.80E-01	6.7	1.78E-01	N/A	N/A
53.6	2.11E-01	19.0	2.13E-01	N/A	N/A
26.8	1.81E-01	0.0	0.00E+00	N/A	N/A
13.4	1.59E-01	0.0	0.00E+00	N/A	N/A
6.7	1.41E-01	0.0	0.00E+00	N/A	N/A
3.4	1.28E-01	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

LM-20

Test Details

Batch	04/05/2007		
Test Number	Ka-F-0405-01		
Substance	Kaolin- Fresh Sample	Kaolin-15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1402 kg/m³	1559 kg/m³
Weight Concentration	43.73%	58.19%
Volume Concentration	22.47%	34.70%
Slurry pH	5.00	5.00
Sand Volume Concentration		15.8%

Flow Properties

Bingham Yield Stress	57.16 Pa	
Bingham Viscosity	0.019 Pa.s	
Vane Yield Stress	24.58 Pa	39.71 Pa
Distance Ratio, l		2.0825
Vane Yield Stress Ratio		1.6155
Bingham Yield Stress Ratio		0.0000
Bingham Viscosity Ratio		0.0000

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
53.6	2.09E-01	N/A	N/A	N/A	N/A
26.8	1.81E-01	N/A	N/A	N/A	N/A
13.4	1.59E-01	N/A	N/A	N/A	N/A
6.7	1.41E-01	N/A	N/A	N/A	N/A
3.4	1.28E-01	N/A	N/A	N/A	N/A
6.7	1.41E-01	N/A	N/A	N/A	N/A
13.4	1.57E-01	N/A	N/A	N/A	N/A
26.8	1.80E-01	N/A	N/A	N/A	N/A
53.6	2.11E-01	N/A	N/A	N/A	N/A
26.8	1.81E-01	N/A	N/A	N/A	N/A
13.4	1.59E-01	N/A	N/A	N/A	N/A
6.7	1.41E-01	N/A	N/A	N/A	N/A
3.4	1.28E-01	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A

LM-21

Test Details

Batch	04/05/2007		
Test Number	Ka-F-0405-01		
Substance	Kaolin- Fresh Sample	Kaolin-20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1402 kg/m³	1644 kg/m³
Weight Concentration	43.73%	62.07%
Volume Concentration	22.47%	37.52%
Slurry pH	5.00	5.00
Sand Volume Concentration		19.4%

Flow Properties

Bingham Yield Stress	57.16 Pa	
Bingham Viscosity	0.019 Pa.s	
Vane Yield Stress	24.58 Pa	53.79 Pa
Distance Ratio, l		2.6214
Vane Yield Stress Ratio		2.1882
Bingham Yield Stress Ratio		0.0000
Bingham Viscosity Ratio		0.0000

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)
53.6	2.09E-01	N/A	N/A	N/A	N/A
26.8	1.81E-01	N/A	N/A	N/A	N/A
13.4	1.59E-01	N/A	N/A	N/A	N/A
6.7	1.41E-01	N/A	N/A	N/A	N/A
3.4	1.28E-01	N/A	N/A	N/A	N/A
6.7	1.41E-01	N/A	N/A	N/A	N/A
13.4	1.57E-01	N/A	N/A	N/A	N/A
26.8	1.80E-01	N/A	N/A	N/A	N/A
53.6	2.11E-01	N/A	N/A	N/A	N/A
26.8	1.81E-01	N/A	N/A	N/A	N/A
13.4	1.59E-01	N/A	N/A	N/A	N/A
6.7	1.41E-01	N/A	N/A	N/A	N/A
3.4	1.28E-01	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A
0.0	0.00E+00	N/A	N/A	N/A	N/A

LM-22

Test Details

Batch	09/05/2007		
Test Number	Ka-F-0905-01		
Substance	Kaolin- Fresh Sample	Kaolin-5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1316 kg/m³	1379 kg/m³
Weight Concentration	37.49%	43.67%
Volume Concentration	18.05%	22.19%
Slurry pH	5.00	5.00
Sand Volume Concentration		5.0%

Flow Properties

Bingham Yield Stress	17.46 Pa	20.18 Pa
Bingham Viscosity	0.011 Pa.s	0.011 Pa.s
Vane Yield Stress	8.97 Pa	9.96 Pa
Distance Ratio, l		0.8585
Vane Yield Stress Ratio		1.1111
Bingham Yield Stress Ratio		1.1558
Bingham Viscosity Ratio		1.0062

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
40.2	7.03E-02	26.8	7.04E-02	N/A	N/A
40.2	7.21E-02	53.6	8.66E-02	N/A	N/A
20.1	5.89E-02	26.8	6.99E-02	N/A	N/A
10.1	5.08E-02	13.4	6.01E-02	N/A	N/A
5.0	4.56E-02	6.7	5.25E-02	N/A	N/A
10.1	5.16E-02	13.4	6.03E-02	N/A	N/A
20.1	5.95E-02	26.8	6.99E-02	N/A	N/A
40.2	7.24E-02	53.6	8.68E-02	N/A	N/A
26.8	3.80E-02	26.8	6.99E-02	N/A	N/A
13.4	3.08E-02	13.4	6.01E-02	N/A	N/A
6.7	2.70E-02	0.0	0.00E+00	N/A	N/A
3.4	2.39E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

LM-23

Test Details

Batch	09/05/2007		
Test Number	Ka-F-0905-01		
Substance	Kaolin- Fresh Sample	Kaolin-10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1316 kg/m³	1438 kg/m³
Weight Concentration	37.49%	49.13%
Volume Concentration	18.05%	26.70%
Slurry pH	5.00	5.00
Sand Volume Concentration		10.6%

Flow Properties

Bingham Yield Stress	17.46 Pa	24.15 Pa
Bingham Viscosity	0.011 Pa.s	0.013 Pa.s
Vane Yield Stress	8.97 Pa	11.13 Pa
Distance Ratio, l		1.4438
Vane Yield Stress Ratio		1.2416
Bingham Yield Stress Ratio		1.3830
Bingham Viscosity Ratio		1.1745

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)
40.2	7.03E-02	26.8	8.34E-02	N/A	N/A
40.2	7.21E-02	53.6	1.02E-01	N/A	N/A
20.1	5.89E-02	26.8	8.32E-02	N/A	N/A
10.1	5.08E-02	13.4	7.19E-02	N/A	N/A
5.0	4.56E-02	6.7	6.28E-02	N/A	N/A
10.1	5.16E-02	13.4	7.19E-02	N/A	N/A
20.1	5.95E-02	26.8	8.34E-02	N/A	N/A
40.2	7.24E-02	53.6	1.03E-01	N/A	N/A
26.8	3.80E-02	0.0	0.00E+00	N/A	N/A
13.4	3.08E-02	0.0	0.00E+00	N/A	N/A
6.7	2.70E-02	0.0	0.00E+00	N/A	N/A
3.4	2.39E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

LM-24

Test Details

Batch	09/05/2007		
Test Number	Ka-F-0905-01		
Substance	Kaolin- Fresh Sample	Kaolin-15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1316 kg/m³	1510 kg/m³
Weight Concentration	37.49%	54.07%
Volume Concentration	18.05%	30.51%
Slurry pH	5.00	5.00
Sand Volume Concentration		15.2%

Flow Properties

Bingham Yield Stress	17.46 Pa	29.83 Pa
Bingham Viscosity	0.011 Pa.s	0.017 Pa.s
Vane Yield Stress	8.97 Pa	13.68 Pa
Distance Ratio, l		2.0054
Vane Yield Stress Ratio		1.5253
Bingham Yield Stress Ratio		1.7083
Bingham Viscosity Ratio		1.5852

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
40.2	7.03E-02	26.8	1.04E-01	N/A	N/A
40.2	7.21E-02	53.6	1.31E-01	N/A	N/A
20.1	5.89E-02	26.8	1.05E-01	N/A	N/A
10.1	5.08E-02	13.4	9.13E-02	N/A	N/A
5.0	4.56E-02	6.7	7.95E-02	N/A	N/A
10.1	5.16E-02	13.4	9.00E-02	N/A	N/A
20.1	5.95E-02	26.8	1.06E-01	N/A	N/A
40.2	7.24E-02	53.6	1.31E-01	N/A	N/A
26.8	3.80E-02	26.8	1.06E-01	N/A	N/A
13.4	3.08E-02	13.4	9.00E-02	N/A	N/A
6.7	2.70E-02	0.0	0.00E+00	N/A	N/A
3.4	2.39E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

LM-25

Test Details

Batch	09/05/2007		
Test Number	Ka-F-0905-01		
Substance	Kaolin- Fresh Sample	Kaolin-20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1316 kg/m³	1565 kg/m³
Weight Concentration	37.49%	58.78%
Volume Concentration	18.05%	35.35%
Slurry pH	5.00	5.00
Sand Volume Concentration		21.1%

Flow Properties

Bingham Yield Stress	17.46 Pa	36.80 Pa
Bingham Viscosity	0.011 Pa.s	0.020 Pa.s
Vane Yield Stress	8.97 Pa	17.63 Pa
Distance Ratio, l		2.9116
Vane Yield Stress Ratio		1.9662
Bingham Yield Stress Ratio		2.1072
Bingham Viscosity Ratio		1.7888

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
40.2	7.03E-02	53.6	1.58E-01	N/A	N/A
40.2	7.21E-02	26.8	1.30E-01	N/A	N/A
20.1	5.89E-02	13.4	1.09E-01	N/A	N/A
10.1	5.08E-02	6.7	9.57E-02	N/A	N/A
5.0	4.56E-02	13.4	1.08E-01	N/A	N/A
10.1	5.16E-02	26.8	1.27E-01	N/A	N/A
20.1	5.95E-02	53.6	1.54E-01	N/A	N/A
40.2	7.24E-02	26.8	1.25E-01	N/A	N/A
26.8	3.80E-02	13.4	1.07E-01	N/A	N/A
13.4	3.08E-02	0.0	0.00E+00	N/A	N/A
6.7	2.70E-02	0.0	0.00E+00	N/A	N/A
3.4	2.39E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Test Details

Batch	16/05/2007		
Test Number	Ka-F-1605-01		
Substance	Kaolin- Fresh Sample	Kaolin-5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1340 kg/m³	1398 kg/m³
Weight Concentration	40.22%	46.22%
Volume Concentration	19.72%	24.69%
Slurry pH	5.00	5.00
Sand Volume Concentration		6.2%

Flow Properties

Bingham Yield Stress	28.97 Pa	31.96 Pa
Bingham Viscosity	0.014 Pa.s	0.014 Pa.s
Vane Yield Stress	13.14 Pa	14.36 Pa
Distance Ratio, l		0.9780
Vane Yield Stress Ratio		1.0927
Bingham Yield Stress Ratio		1.1033
Bingham Viscosity Ratio		0.9840

Raw Data

Fresh Tests		***Sand Tests***		***Sieved Tests***	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
53.6	1.20E-01	53.6	1.28E-01	N/A	N/A
26.8	9.87E-02	26.8	1.07E-01	N/A	N/A
13.4	8.57E-02	13.4	9.22E-02	N/A	N/A
6.7	7.61E-02	6.7	8.14E-02	N/A	N/A
13.4	8.56E-02	13.4	9.22E-02	N/A	N/A
26.8	9.85E-02	26.8	1.06E-01	N/A	N/A
53.6	1.20E-01	53.6	1.26E-01	N/A	N/A
26.8	9.91E-02	26.8	1.05E-01	N/A	N/A
13.4	8.65E-02	13.4	9.15E-02	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

LM-27

Test Details

Batch	16/05/2007		
Test Number	Ka-F-1605-01		
Substance	Kaolin- Fresh Sample	Kaolin-10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1340 kg/m³	1469 kg/m³
Weight Concentration	40.22%	51.26%
Volume Concentration	19.72%	28.25%
Slurry pH	5.00	5.00
Sand Volume Concentration		10.6%

Flow Properties

Bingham Yield Stress	28.97 Pa	41.22 Pa
Bingham Viscosity	0.014 Pa.s	0.018 Pa.s
Vane Yield Stress	13.14 Pa	16.23 Pa
Distance Ratio, l		1.4522
Vane Yield Stress Ratio		1.2356
Bingham Yield Stress Ratio		1.4226
Bingham Viscosity Ratio		1.2629

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
53.6	1.20E-01	53.6	1.65E-01	N/A	N/A
26.8	9.87E-02	26.8	1.38E-01	N/A	N/A
13.4	8.57E-02	13.4	1.18E-01	N/A	N/A
6.7	7.61E-02	6.7	1.04E-01	N/A	N/A
13.4	8.56E-02	13.4	1.16E-01	N/A	N/A
26.8	9.85E-02	26.8	1.35E-01	N/A	N/A
53.6	1.20E-01	53.6	1.63E-01	N/A	N/A
26.8	9.91E-02	26.8	1.36E-01	N/A	N/A
13.4	8.65E-02	13.4	1.17E-01	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

LM-28

Test Details

Batch	16/05/2007		
Test Number	Ka-F-1605-01		
Substance	Kaolin- Fresh Sample	Kaolin-15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1340 kg/m³	1534 kg/m³
Weight Concentration	40.22%	55.93%
Volume Concentration	19.72%	32.27%
Slurry pH	5.00	5.00
Sand Volume Concentration		15.6%

Flow Properties

Bingham Yield Stress	28.97 Pa	48.39 Pa
Bingham Viscosity	0.014 Pa.s	0.022 Pa.s
Vane Yield Stress	13.14 Pa	20.86 Pa
Distance Ratio, l		2.0628
Vane Yield Stress Ratio		1.5881
Bingham Yield Stress Ratio		1.6704
Bingham Viscosity Ratio		1.5396

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
53.6	1.20E-01	53.6	1.92E-01	N/A	N/A
26.8	9.87E-02	26.8	1.59E-01	N/A	N/A
13.4	8.57E-02	13.4	1.36E-01	N/A	N/A
6.7	7.61E-02	13.4	1.35E-01	N/A	N/A
13.4	8.56E-02	26.8	1.61E-01	N/A	N/A
26.8	9.85E-02	53.6	1.97E-01	N/A	N/A
53.6	1.20E-01	26.8	1.65E-01	N/A	N/A
26.8	9.91E-02	13.4	1.42E-01	N/A	N/A
13.4	8.65E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Test Details

Batch	16/05/2007		
Test Number	Ka-F-1605-01		
Substance	Kaolin- Fresh Sample	Kaolin-20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	12	12	12
Measuring Head	MK 150	MK 150	MK 150
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL100	FL100	FL100

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.022 m	0.022 m	0.022 m
Vane Height	0.016 m	0.016 m	0.016 m

Slurry Properties

Sand C_{max}		51.2%
Density	1340 kg/m³	1606 kg/m³
Weight Concentration	40.22%	60.25%
Volume Concentration	19.72%	36.04%
Slurry pH	5.00	5.00
Sand Volume Concentration		20.3%

Flow Properties

Bingham Yield Stress	28.97 Pa	60.91 Pa
Bingham Viscosity	0.014 Pa.s	0.027 Pa.s
Vane Yield Stress	13.14 Pa	29.87 Pa
Distance Ratio, l		2.7750
Vane Yield Stress Ratio		2.2736
Bingham Yield Stress Ratio		2.1024
Bingham Viscosity Ratio		1.9076

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)
53.6	1.20E-01	26.8	2.02E-01	N/A	N/A
26.8	9.87E-02	53.6	2.44E-01	N/A	N/A
13.4	8.57E-02	26.8	2.04E-01	N/A	N/A
6.7	7.61E-02	13.4	1.74E-01	N/A	N/A
13.4	8.56E-02	26.8	2.02E-01	N/A	N/A
26.8	9.85E-02	53.6	2.44E-01	N/A	N/A
53.6	1.20E-01	26.8	2.02E-01	N/A	N/A
26.8	9.91E-02	13.4	1.72E-01	N/A	N/A
13.4	8.65E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

APPENDIX E: OTTAWA SAND TESTS

Ott-01

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2205-01		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1280 kg/m³	1360 kg/m³
Weight Concentration	35.40%	42.23%
Volume Concentration	16.53%	21.28%
Slurry pH	5.00	5.00
Sand Volume Concentration		5.6%

Flow Properties

Bingham Yield Stress	13.00 Pa	13.16 Pa
Bingham Viscosity	0.009 Pa.s	0.010 Pa.s
Vane Yield Stress	7.37 Pa	8.01 Pa
Distance Ratio, l		0.8528
Vane Yield Stress Ratio		1.0862
Bingham Yield Stress Ratio		1.0121
Bingham Viscosity Ratio		1.0787

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)
40.2	5.62E-02	13.4	4.32E-02	N/A	N/A
40.2	5.58E-02	53.6	6.65E-02	N/A	N/A
20.1	4.49E-02	26.8	5.03E-02	N/A	N/A
10.1	3.89E-02	13.4	4.32E-02	N/A	N/A
10.1	3.92E-02	6.7	3.73E-02	N/A	N/A
20.1	4.50E-02	53.6	6.55E-02	N/A	N/A
40.2	5.59E-02	26.8	5.00E-02	N/A	N/A
40.2	5.57E-02	13.4	4.27E-02	N/A	N/A
20.1	4.55E-02	6.7	3.75E-02	N/A	N/A
6.7	2.07E-02	13.4	4.24E-02	N/A	N/A
3.4	1.82E-02	26.8	5.05E-02	N/A	N/A
0.0	0.00E+00	53.6	6.53E-02	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-02

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2205-01		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1280 kg/m³	1419 kg/m³
Weight Concentration	35.40%	46.78%
Volume Concentration	16.53%	24.34%
Slurry pH	5.00	5.00
Sand Volume Concentration		9.3%

Flow Properties

Bingham Yield Stress	13.00 Pa	13.48 Pa
Bingham Viscosity	0.009 Pa.s	0.011 Pa.s
Vane Yield Stress	7.37 Pa	8.67 Pa
Distance Ratio, l		1.1939
Vane Yield Stress Ratio		1.1756
Bingham Yield Stress Ratio		1.0367
Bingham Viscosity Ratio		1.182249481

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
40.2	5.62E-02	13.4	4.39E-02	N/A	N/A
40.2	5.58E-02	26.8	5.23E-02	N/A	N/A
20.1	4.49E-02	53.6	6.99E-02	N/A	N/A
10.1	3.89E-02	26.8	5.25E-02	N/A	N/A
10.1	3.92E-02	13.4	4.59E-02	N/A	N/A
20.1	4.50E-02	26.8	5.35E-02	N/A	N/A
40.2	5.59E-02	53.6	6.92E-02	N/A	N/A
40.2	5.57E-02	26.8	5.23E-02	N/A	N/A
20.1	4.55E-02	13.4	4.51E-02	N/A	N/A
6.7	2.07E-02	0.0	0.00E+00	N/A	N/A
3.4	1.82E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-03

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2205-01		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1280 kg/m³	1476 kg/m³
Weight Concentration	35.40%	51.26%
Volume Concentration	16.53%	27.94%
Slurry pH	5.00	5.00
Sand Volume Concentration		13.6%

Flow Properties

Bingham Yield Stress	13.00 Pa	16.21 Pa
Bingham Viscosity	0.009 Pa.s	0.011 Pa.s
Vane Yield Stress	7.37 Pa	10.26 Pa
Distance Ratio, l		1.6162
Vane Yield Stress Ratio		1.3923
Bingham Yield Stress Ratio		1.2470
Bingham Viscosity Ratio		1.1635

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)
40.2	5.62E-02	13.4	5.20E-02	N/A	N/A
40.2	5.58E-02	26.8	6.06E-02	N/A	N/A
20.1	4.49E-02	53.6	7.58E-02	N/A	N/A
10.1	3.89E-02	26.8	5.94E-02	N/A	N/A
10.1	3.92E-02	13.4	5.08E-02	N/A	N/A
20.1	4.50E-02	26.8	5.99E-02	N/A	N/A
40.2	5.59E-02	53.6	7.63E-02	N/A	N/A
40.2	5.57E-02	26.8	5.94E-02	N/A	N/A
20.1	4.55E-02	13.4	5.03E-02	N/A	N/A
6.7	2.07E-02	0.0	0.00E+00	N/A	N/A
3.4	1.82E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-04

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2205-01		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1280 kg/m³	1566 kg/m³
Weight Concentration	35.40%	57.14%
Volume Concentration	16.53%	32.76%
Slurry pH	5.00	5.00
Sand Volume Concentration		19.4%

Flow Properties

Bingham Yield Stress	13.00 Pa	20.51 Pa
Bingham Viscosity	0.009 Pa.s	0.016 Pa.s
Vane Yield Stress	7.37 Pa	13.00 Pa
Distance Ratio, l		2.2781
Vane Yield Stress Ratio		1.7634
Bingham Yield Stress Ratio		1.5778
Bingham Viscosity Ratio		1.6960

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
40.2	5.62E-02	13.4	6.28E-02	N/A	N/A
40.2	5.58E-02	53.6	1.03E-01	N/A	N/A
20.1	4.49E-02	26.8	7.95E-02	N/A	N/A
10.1	3.89E-02	13.4	6.75E-02	N/A	N/A
10.1	3.92E-02	26.8	7.95E-02	N/A	N/A
20.1	4.50E-02	53.6	1.02E-01	N/A	N/A
40.2	5.59E-02	26.8	7.97E-02	N/A	N/A
40.2	5.57E-02	13.4	6.75E-02	N/A	N/A
20.1	4.55E-02	0.0	0.00E+00	N/A	N/A
6.7	2.07E-02	0.0	0.00E+00	N/A	N/A
3.4	1.82E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-05

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2305-01		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1305 kg/m³	1382 kg/m³
Weight Concentration	37.71%	44.26%
Volume Concentration	17.97%	22.79%
Slurry pH	5.00	5.00
Sand Volume Concentration		5.8%

Flow Properties

Bingham Yield Stress	19.25 Pa	19.97 Pa
Bingham Viscosity	0.012 Pa.s	0.013 Pa.s
Vane Yield Stress	9.81 Pa	11.15 Pa
Distance Ratio, l		0.8719
Vane Yield Stress Ratio		1.1364
Bingham Yield Stress Ratio		1.0375
Bingham Viscosity Ratio		1.0563

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
40.2	7.75E-02	13.4	6.11E-02	N/A	N/A
40.2	7.85E-02	26.8	7.07E-02	N/A	N/A
20.1	6.42E-02	53.6	9.05E-02	N/A	N/A
10.1	5.59E-02	26.8	7.24E-02	N/A	N/A
10.1	5.61E-02	13.4	6.23E-02	N/A	N/A
20.1	6.48E-02	26.8	7.24E-02	N/A	N/A
40.2	7.70E-02	53.6	9.03E-02	N/A	N/A
40.2	7.84E-02	26.8	7.26E-02	N/A	N/A
20.1	6.43E-02	13.4	6.28E-02	N/A	N/A
6.7	3.01E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-06

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2305-01		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1305 kg/m³	1451 kg/m³
Weight Concentration	37.71%	49.91%
Volume Concentration	17.97%	27.15%
Slurry pH	5.00	5.00
Sand Volume Concentration		11.2%

Flow Properties

Bingham Yield Stress	19.25 Pa	22.66 Pa
Bingham Viscosity	0.012 Pa.s	0.014 Pa.s
Vane Yield Stress	9.81 Pa	12.11 Pa
Distance Ratio, l		1.3698
Vane Yield Stress Ratio		1.2342
Bingham Yield Stress Ratio		1.1774
Bingham Viscosity Ratio		1.1453

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
40.2	7.75E-02	13.4	6.89E-02	N/A	N/A
40.2	7.85E-02	53.6	1.00E-01	N/A	N/A
20.1	6.42E-02	26.8	8.19E-02	N/A	N/A
10.1	5.59E-02	13.4	6.97E-02	N/A	N/A
10.1	5.61E-02	26.8	8.19E-02	N/A	N/A
20.1	6.48E-02	53.6	1.00E-01	N/A	N/A
40.2	7.70E-02	26.8	8.12E-02	N/A	N/A
40.2	7.84E-02	13.4	6.97E-02	N/A	N/A
20.1	6.43E-02	0.0	0.00E+00	N/A	N/A
6.7	3.01E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-07

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2305-01		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1305 kg/m³	1536 kg/m³
Weight Concentration	37.71%	55.15%
Volume Concentration	17.97%	30.98%
Slurry pH	5.00	5.00
Sand Volume Concentration		15.8%

Flow Properties

Bingham Yield Stress	19.25 Pa	24.82 Pa
Bingham Viscosity	0.012 Pa.s	0.015 Pa.s
Vane Yield Stress	9.81 Pa	13.90 Pa
Distance Ratio, l		1.8518
Vane Yield Stress Ratio		1.4166
Bingham Yield Stress Ratio		1.2892
Bingham Viscosity Ratio		1.2427

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
40.2	7.75E-02	53.6	1.10E-01	N/A	N/A
40.2	7.85E-02	26.8	8.88E-02	N/A	N/A
20.1	6.42E-02	13.4	7.61E-02	N/A	N/A
10.1	5.59E-02	26.8	8.93E-02	N/A	N/A
10.1	5.61E-02	53.6	1.10E-01	N/A	N/A
20.1	6.48E-02	26.8	8.81E-02	N/A	N/A
40.2	7.70E-02	13.4	7.68E-02	N/A	N/A
40.2	7.84E-02	13.4	7.58E-02	N/A	N/A
20.1	6.43E-02	0.0	0.00E+00	N/A	N/A
6.7	3.01E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-08

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2305-01		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1305 kg/m³	1610 kg/m³
Weight Concentration	37.71%	59.55%
Volume Concentration	17.97%	34.74%
Slurry pH	5.00	5.00
Sand Volume Concentration		20.4%

Flow Properties

Bingham Yield Stress	19.25 Pa	32.15 Pa
Bingham Viscosity	0.012 Pa.s	0.017 Pa.s
Vane Yield Stress	9.81 Pa	16.31 Pa
Distance Ratio, l		2.4112
Vane Yield Stress Ratio		1.6628
Bingham Yield Stress Ratio		1.6701
Bingham Viscosity Ratio		1.4745

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
40.2	7.75E-02	13.4	9.74E-02	N/A	N/A
40.2	7.85E-02	53.6	1.37E-01	N/A	N/A
20.1	6.42E-02	26.8	1.13E-01	N/A	N/A
10.1	5.59E-02	13.4	9.71E-02	N/A	N/A
10.1	5.61E-02	26.8	1.13E-01	N/A	N/A
20.1	6.48E-02	53.6	1.37E-01	N/A	N/A
40.2	7.70E-02	26.8	1.13E-01	N/A	N/A
40.2	7.84E-02	13.4	9.71E-02	N/A	N/A
20.1	6.43E-02	0.0	0.00E+00	N/A	N/A
6.7	3.01E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-09

Test Details

Batch	22/05/2007		
Test Number	Ka-F-23405-01		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1337 kg/m³	1407 kg/m³
Weight Concentration	39.73%	46.06%
Volume Concentration	19.27%	23.96%
Slurry pH	5.00	5.00
Sand Volume Concentration		5.6%

Flow Properties

Bingham Yield Stress	25.44 Pa	27.42 Pa
Bingham Viscosity	0.013 Pa.s	0.014 Pa.s
Vane Yield Stress	12.75 Pa	13.38 Pa
Distance Ratio, l		0.8521
Vane Yield Stress Ratio		1.0493
Bingham Yield Stress Ratio		1.0779
Bingham Viscosity Ratio		1.0538

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
20.1	8.21E-02	13.4	8.07E-02	N/A	N/A
40.2	9.64E-02	26.8	9.32E-02	N/A	N/A
40.2	9.84E-02	53.6	1.14E-01	N/A	N/A
20.1	8.29E-02	26.8	9.54E-02	N/A	N/A
10.1	7.24E-02	13.4	8.29E-02	N/A	N/A
10.1	7.25E-02	26.8	9.54E-02	N/A	N/A
20.1	8.26E-02	53.6	1.14E-01	N/A	N/A
40.2	9.69E-02	26.8	9.57E-02	N/A	N/A
40.2	9.85E-02	13.4	8.34E-02	N/A	N/A
20.1	8.32E-02	0.0	0.00E+00	N/A	N/A
10.1	7.26E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-10

Test Details

Batch	22/05/2007		
Test Number	Ka-F-23405-01		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1337 kg/m³	1481 kg/m³
Weight Concentration	39.73%	51.42%
Volume Concentration	19.27%	27.92%
Slurry pH	5.00	5.00
Sand Volume Concentration		10.5%

Flow Properties

Bingham Yield Stress	25.44 Pa	31.03 Pa
Bingham Viscosity	0.013 Pa.s	0.015 Pa.s
Vane Yield Stress	12.75 Pa	15.29 Pa
Distance Ratio, l		1.3102
Vane Yield Stress Ratio		1.1997
Bingham Yield Stress Ratio		1.2201
Bingham Viscosity Ratio		1.1560

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
20.1	8.21E-02	13.4	9.25E-02	N/A	N/A
40.2	9.64E-02	26.8	1.05E-01	N/A	N/A
40.2	9.84E-02	53.6	1.28E-01	N/A	N/A
20.1	8.29E-02	26.8	1.07E-01	N/A	N/A
10.1	7.24E-02	13.4	9.32E-02	N/A	N/A
10.1	7.25E-02	26.8	1.07E-01	N/A	N/A
20.1	8.26E-02	53.6	1.28E-01	N/A	N/A
40.2	9.69E-02	26.8	1.07E-01	N/A	N/A
40.2	9.85E-02	13.4	9.27E-02	N/A	N/A
20.1	8.32E-02	0.0	0.00E+00	N/A	N/A
10.1	7.26E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-11

Test Details

Batch	22/05/2007		
Test Number	Ka-F-23405-01		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1337 kg/m³	1565 kg/m³
Weight Concentration	39.73%	57.24%
Volume Concentration	19.27%	32.96%
Slurry pH	5.00	5.00
Sand Volume Concentration		16.8%

Flow Properties

Bingham Yield Stress	25.44 Pa	32.83 Pa
Bingham Viscosity	0.013 Pa.s	0.018 Pa.s
Vane Yield Stress	12.75 Pa	17.21 Pa
Distance Ratio, l		1.9619
Vane Yield Stress Ratio		1.3500
Bingham Yield Stress Ratio		1.2908
Bingham Viscosity Ratio		1.3121

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
20.1	8.21E-02	13.4	9.74E-02	N/A	N/A
40.2	9.64E-02	26.8	1.14E-01	N/A	N/A
40.2	9.84E-02	53.6	1.39E-01	N/A	N/A
20.1	8.29E-02	26.8	1.15E-01	N/A	N/A
10.1	7.24E-02	13.4	1.00E-01	N/A	N/A
10.1	7.25E-02	26.8	1.15E-01	N/A	N/A
20.1	8.26E-02	53.6	1.38E-01	N/A	N/A
40.2	9.69E-02	26.8	1.15E-01	N/A	N/A
40.2	9.85E-02	13.4	9.94E-02	N/A	N/A
20.1	8.32E-02	0.0	0.00E+00	N/A	N/A
10.1	7.26E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-12

Test Details

Batch	22/05/2007		
Test Number	Ka-F-23405-01		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1337 kg/m³	1619 kg/m³
Weight Concentration	39.73%	60.92%
Volume Concentration	19.27%	36.60%
Slurry pH	5.00	5.00
Sand Volume Concentration		21.3%

Flow Properties

Bingham Yield Stress	25.44 Pa	39.08 Pa
Bingham Viscosity	0.013 Pa.s	0.020 Pa.s
Vane Yield Stress	12.75 Pa	19.81 Pa
Distance Ratio, l		2.5346
Vane Yield Stress Ratio		1.5536
Bingham Yield Stress Ratio		1.5364
Bingham Viscosity Ratio		1.4599

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)
20.1	8.21E-02	13.4	1.16E-01	N/A	N/A
40.2	9.64E-02	53.6	1.61E-01	N/A	N/A
40.2	9.84E-02	26.8	1.35E-01	N/A	N/A
20.1	8.29E-02	13.4	1.17E-01	N/A	N/A
10.1	7.24E-02	26.8	1.35E-01	N/A	N/A
10.1	7.25E-02	53.6	1.61E-01	N/A	N/A
20.1	8.26E-02	26.8	1.35E-01	N/A	N/A
40.2	9.69E-02	13.4	1.17E-01	N/A	N/A
40.2	9.85E-02	0.0	0.00E+00	N/A	N/A
20.1	8.32E-02	0.0	0.00E+00	N/A	N/A
10.1	7.26E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-13

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2805-01		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1356 kg/m³	1426 kg/m³
Weight Concentration	41.20%	47.07%
Volume Concentration	20.24%	24.39%
Slurry pH	5.00	5.00
Sand Volume Concentration		5.0%

Flow Properties

Bingham Yield Stress	30.50 Pa	33.28 Pa
Bingham Viscosity	0.014 Pa.s	0.014 Pa.s
Vane Yield Stress	16.41 Pa	16.61 Pa
Distance Ratio, l		0.7913
Vane Yield Stress Ratio		1.0122
Bingham Yield Stress Ratio		1.0910
Bingham Viscosity Ratio		1.0158

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
33.5	1.05E-01	13.4	9.40E-02	N/A	N/A
26.8	1.03E-01	26.8	1.08E-01	N/A	N/A
33.5	1.06E-01	53.6	1.31E-01	N/A	N/A
16.8	9.21E-02	26.8	1.10E-01	N/A	N/A
13.4	9.05E-02	13.4	9.62E-02	N/A	N/A
16.8	9.21E-02	26.8	1.10E-01	N/A	N/A
33.5	1.06E-01	53.6	1.31E-01	N/A	N/A
26.8	1.03E-01	26.8	1.11E-01	N/A	N/A
33.5	1.06E-01	13.4	9.57E-02	N/A	N/A
16.8	9.22E-02	0.0	0.00E+00	N/A	N/A
6.7	4.54E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-14

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2805-01		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1356 kg/m³	1478 kg/m³
Weight Concentration	41.20%	52.26%
Volume Concentration	20.24%	29.29%
Slurry pH	5.00	5.00
Sand Volume Concentration		11.1%

Flow Properties

Bingham Yield Stress	30.50 Pa	36.45 Pa
Bingham Viscosity	0.014 Pa.s	0.015 Pa.s
Vane Yield Stress	16.41 Pa	18.09 Pa
Distance Ratio, l		1.3678
Vane Yield Stress Ratio		1.1022
Bingham Yield Stress Ratio		1.1949
Bingham Viscosity Ratio		1.0710

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
33.5	1.05E-01	13.4	1.03E-01	N/A	N/A
26.8	1.03E-01	26.8	1.18E-01	N/A	N/A
33.5	1.06E-01	53.6	1.42E-01	N/A	N/A
16.8	9.21E-02	26.8	1.19E-01	N/A	N/A
13.4	9.05E-02	13.4	1.05E-01	N/A	N/A
16.8	9.21E-02	26.8	1.19E-01	N/A	N/A
33.5	1.06E-01	53.6	1.41E-01	N/A	N/A
26.8	1.03E-01	26.8	1.19E-01	N/A	N/A
33.5	1.06E-01	13.4	1.04E-01	N/A	N/A
16.8	9.22E-02	0.0	0.00E+00	N/A	N/A
6.7	4.54E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2805-01		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1356 kg/m³	1562 kg/m³
Weight Concentration	41.20%	57.18%
Volume Concentration	20.24%	32.98%
Slurry pH	5.00	5.00
Sand Volume Concentration		15.8%

Flow Properties

Bingham Yield Stress	30.50 Pa	42.11 Pa
Bingham Viscosity	0.014 Pa.s	0.016 Pa.s
Vane Yield Stress	16.41 Pa	19.99 Pa
Distance Ratio, l		1.8468
Vane Yield Stress Ratio		1.2178
Bingham Yield Stress Ratio		1.3804
Bingham Viscosity Ratio		1.1551

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
33.5	1.05E-01	26.8	1.38E-01	N/A	N/A
26.8	1.03E-01	53.6	1.61E-01	N/A	N/A
33.5	1.06E-01	26.8	1.36E-01	N/A	N/A
16.8	9.21E-02	13.4	1.18E-01	N/A	N/A
13.4	9.05E-02	26.8	1.35E-01	N/A	N/A
16.8	9.21E-02	53.6	1.59E-01	N/A	N/A
33.5	1.06E-01	26.8	1.34E-01	N/A	N/A
26.8	1.03E-01	13.4	1.17E-01	N/A	N/A
33.5	1.06E-01	0.0	0.00E+00	N/A	N/A
16.8	9.22E-02	0.0	0.00E+00	N/A	N/A
6.7	4.54E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-16

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2805-01		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1356 kg/m³	1627 kg/m³
Weight Concentration	41.20%	61.44%
Volume Concentration	20.24%	37.13%
Slurry pH	5.00	5.00
Sand Volume Concentration		21.0%

Flow Properties

Bingham Yield Stress	30.50 Pa	51.82 Pa
Bingham Viscosity	0.014 Pa.s	0.021 Pa.s
Vane Yield Stress	16.41 Pa	23.56 Pa
Distance Ratio, l		2.4905
Vane Yield Stress Ratio		1.4355
Bingham Yield Stress Ratio		1.6989
Bingham Viscosity Ratio		1.5243

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
33.5	1.05E-01	26.8	1.69E-01	N/A	N/A
26.8	1.03E-01	53.6	2.01E-01	N/A	N/A
33.5	1.06E-01	26.8	1.70E-01	N/A	N/A
16.8	9.21E-02	13.4	1.48E-01	N/A	N/A
13.4	9.05E-02	26.8	1.69E-01	N/A	N/A
16.8	9.21E-02	53.6	2.02E-01	N/A	N/A
33.5	1.06E-01	26.8	1.69E-01	N/A	N/A
26.8	1.03E-01	13.4	1.47E-01	N/A	N/A
33.5	1.06E-01	0.0	0.00E+00	N/A	N/A
16.8	9.22E-02	0.0	0.00E+00	N/A	N/A
6.7	4.54E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Ott-17

Test Details

Batch	30/05/2007		
Test Number	Ka-F-3005-16%		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1295 kg/m³	1437 kg/m³
Weight Concentration	35.84%	48.56%
Volume Concentration	16.98%	25.92%
Slurry pH	5.00	5.00
Sand Volume Concentration		10.8%

Flow Properties

Bingham Yield Stress	12.48 Pa	14.43 Pa
Bingham Viscosity	0.009 Pa.s	0.010 Pa.s
Vane Yield Stress	7.59 Pa	9.04 Pa
Distance Ratio, l		1.3320
Vane Yield Stress Ratio		1.1921
Bingham Yield Stress Ratio		1.1564
Bingham Viscosity Ratio		1.1326

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	3.95E-02	13.4	4.61E-02	N/A	N/A
26.8	4.66E-02	53.6	7.04E-02	N/A	N/A
53.6	6.11E-02	26.8	5.47E-02	N/A	N/A
26.8	4.71E-02	13.4	4.69E-02	N/A	N/A
13.4	4.02E-02	26.8	5.47E-02	N/A	N/A
6.7	3.58E-02	53.6	6.92E-02	N/A	N/A
13.4	3.97E-02	26.8	5.27E-02	N/A	N/A
26.8	4.78E-02	13.4	4.54E-02	N/A	N/A
53.6	6.08E-02	0.0	0.00E+00	N/A	N/A
26.8	4.66E-02	0.0	0.00E+00	N/A	N/A
13.4	4.05E-02	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

Test Details

Batch	30/05/2007		
Test Number	Ka-F-3005-20%		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		57.8%
Density	1344 kg/m³	1553 kg/m³
Weight Concentration	40.77%	56.78%
Volume Concentration	20.05%	32.74%
Slurry pH	5.00	5.00
Sand Volume Concentration		15.9%

Flow Properties

Bingham Yield Stress	27.36 Pa	42.11 Pa
Bingham Viscosity	0.013 Pa.s	0.016 Pa.s
Vane Yield Stress	14.95 Pa	20.33 Pa
Distance Ratio, l		1.8581
Vane Yield Stress Ratio		1.3591
Bingham Yield Stress Ratio		1.5391
Bingham Viscosity Ratio		1.2391

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	8.14E-02	13.4	1.20E-01	N/A	N/A
26.8	9.32E-02	26.8	1.39E-01	N/A	N/A
53.6	1.12E-01	53.6	1.62E-01	N/A	N/A
26.8	9.35E-02	26.8	1.35E-01	N/A	N/A
13.4	8.14E-02	13.4	1.18E-01	N/A	N/A
26.8	9.35E-02	26.8	1.36E-01	N/A	N/A
53.6	1.12E-01	53.6	1.60E-01	N/A	N/A
26.8	9.37E-02	26.8	1.35E-01	N/A	N/A
13.4	8.19E-02	13.4	1.18E-01	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A
0.0	0.00E+00	0.0	0.00E+00	N/A	N/A

APPENDIX F: QUACKENBUSH GLASS TESTS

QB-01

Test Details

Batch	14/06/2007		
Test Number	Ka-F-1406-01		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1284 kg/m³	1377 kg/m³	1294 kg/m³
Weight Concentration	35.22%	43.27%	35.81%
Volume Concentration	16.54%	21.70%	16.78%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		6.2%	

Flow Properties

Bingham Yield Stress	10.65 Pa	13.19 Pa	11.72 Pa
Bingham Viscosity	0.008 Pa.s	0.010 Pa.s	0.009 Pa.s
Vane Yield Stress	6.55 Pa	7.99 Pa	6.79 Pa
Distance Ratio, l		0.8719	
Vane Yield Stress Ratio		1.2189	
Bingham Yield Stress Ratio		1.2380	
Bingham Viscosity Ratio		1.2278	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)	Calculated Bob Speed (s^{-1})	Measured Torque (N.m/m)
20.1	3.84E-02	13.4	4.27E-02	13.4	3.90E-02
40.2	4.67E-02	26.8	5.10E-02	26.8	4.51E-02
40.2	4.66E-02	53.6	6.57E-02	53.6	5.81E-02
20.1	3.70E-02	26.8	4.96E-02	26.8	4.49E-02
20.1	3.78E-02	13.4	4.27E-02	13.4	3.75E-02
30.2	4.08E-02	26.8	4.98E-02	26.8	4.46E-02
20.1	3.72E-02	53.6	6.40E-02	53.6	5.72E-02
20.1	3.75E-02	26.8	4.88E-02	26.8	4.34E-02
26.8	2.67E-02	13.4	4.22E-02	13.4	3.66E-02
13.4	2.05E-02	0.0	0.00E+00	0.0	0.00E+00
6.7	1.74E-02	0.0	0.00E+00	0.0	0.00E+00
3.4	1.54E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-02

Test Details

Batch	14/06/2007		
Test Number	Ka-F-1406-01		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1284 kg/m³	1393 kg/m³	1298 kg/m³
Weight Concentration	35.22%	46.35%	36.17%
Volume Concentration	16.54%	25.12%	17.00%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		10.3%	

Flow Properties

Bingham Yield Stress	10.65 Pa	12.51 Pa	10.57 Pa
Bingham Viscosity	0.008 Pa.s	0.010 Pa.s	0.009 Pa.s
Vane Yield Stress	6.55 Pa	7.96 Pa	6.79 Pa
Distance Ratio, l		1.2313	
Vane Yield Stress Ratio		1.2148	
Bingham Yield Stress Ratio		1.1738	
Bingham Viscosity Ratio		1.208731643	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
20.1	3.84E-02	13.4	4.28E-02	13.4	3.53E-02
40.2	4.67E-02	26.8	4.96E-02	26.8	4.20E-02
40.2	4.66E-02	53.6	6.35E-02	53.6	5.47E-02
20.1	3.70E-02	53.6	6.26E-02	26.8	4.12E-02
20.1	3.78E-02	26.8	4.69E-02	13.4	3.41E-02
30.2	4.08E-02	13.4	4.05E-02	26.8	4.20E-02
20.1	3.72E-02	26.8	4.78E-02	53.6	5.45E-02
20.1	3.75E-02	53.6	6.11E-02	26.8	4.10E-02
26.8	2.67E-02	26.8	4.71E-02	13.4	3.41E-02
13.4	2.05E-02	13.4	3.88E-02	0.0	0.00E+00
6.7	1.74E-02	0.0	0.00E+00	0.0	0.00E+00
3.4	1.54E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-03

Test Details

Batch	14/06/2007		
Test Number	Ka-F-1406-01		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1284 kg/m³	1470 kg/m³	1298 kg/m³
Weight Concentration	35.22%	51.56%	36.22%
Volume Concentration	16.54%	28.65%	17.03%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		14.5%	

Flow Properties

Bingham Yield Stress	10.65 Pa	13.31 Pa	10.33 Pa
Bingham Viscosity	0.008 Pa.s	0.011 Pa.s	0.008 Pa.s
Vane Yield Stress	6.55 Pa	8.77 Pa	6.79 Pa
Distance Ratio, l		1.6249	
Vane Yield Stress Ratio		1.3388	
Bingham Yield Stress Ratio		1.2493	
Bingham Viscosity Ratio		1.3473	

Raw Data

Fresh Tests		***Sand Tests***		***Sieved Tests***	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
20.1	3.84E-02	13.4	4.50E-02	13.4	3.48E-02
40.2	4.67E-02	26.8	5.35E-02	26.8	4.07E-02
40.2	4.66E-02	53.6	6.95E-02	53.6	5.25E-02
20.1	3.70E-02	26.8	5.28E-02	26.8	3.97E-02
20.1	3.78E-02	13.4	4.42E-02	13.4	3.34E-02
30.2	4.08E-02	13.4	4.34E-02	13.4	3.29E-02
20.1	3.72E-02	26.8	5.03E-02	26.8	4.00E-02
20.1	3.75E-02	53.6	6.60E-02	53.6	5.08E-02
26.8	2.67E-02	26.8	5.00E-02	26.8	3.90E-02
13.4	2.05E-02	13.4	4.20E-02	13.4	3.26E-02
6.7	1.74E-02	0.0	0.00E+00	0.0	0.00E+00
3.4	1.54E-02	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-04

Test Details

Batch	14/06/2007		
Test Number	Ka-F-1406-01		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1284 kg/m³	1513 kg/m³	1292 kg/m³
Weight Concentration	35.22%	55.34%	35.60%
Volume Concentration	16.54%	32.29%	16.65%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		18.9%	

Flow Properties

Bingham Yield Stress	10.65 Pa	15.48 Pa	9.48 Pa
Bingham Viscosity	0.008 Pa.s	0.013 Pa.s	0.008 Pa.s
Vane Yield Stress	6.55 Pa	9.37 Pa	5.95 Pa
Distance Ratio, l		2.0844	
Vane Yield Stress Ratio		1.4302	
Bingham Yield Stress Ratio		1.4528	
Bingham Viscosity Ratio		1.6099	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
20.1	3.84E-02	13.4	5.12E-02	13.4	3.19E-02
40.2	4.67E-02	26.8	6.18E-02	26.8	3.82E-02
40.2	4.66E-02	53.6	8.10E-02	53.6	5.04E-02
20.1	3.70E-02	26.8	6.24E-02	26.8	3.74E-02
20.1	3.78E-02	13.4	5.13E-02	13.4	3.13E-02
30.2	4.08E-02	26.8	6.25E-02	26.8	3.73E-02
20.1	3.72E-02	53.6	7.95E-02	53.6	4.91E-02
20.1	3.75E-02	26.8	5.99E-02	26.8	3.75E-02
26.8	2.67E-02	13.4	4.96E-02	13.4	3.04E-02
13.4	2.05E-02	26.8	6.03E-02	0.0	0.00E+00
6.7	1.74E-02	53.6	7.92E-02	0.0	0.00E+00
3.4	1.54E-02	26.8	5.91E-02	0.0	0.00E+00
0.0	0.00E+00	13.4	5.00E-02	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-05

Test Details

Batch	13/06/2007		
Test Number	Ka-F-1306-01		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1305 kg/m³	1377 kg/m³	1315 kg/m³
Weight Concentration	37.40%	42.79%	37.79%
Volume Concentration	17.86%	21.07%	18.02%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		3.9%	

Flow Properties

Bingham Yield Stress	15.43 Pa	15.97 Pa	15.61 Pa
Bingham Viscosity	0.010 Pa.s	0.010 Pa.s	0.009 Pa.s
Vane Yield Stress	9.01 Pa	9.48 Pa	9.13 Pa
Distance Ratio, l		0.6665	
Vane Yield Stress Ratio		1.0528	
Bingham Yield Stress Ratio		1.0351	
Bingham Viscosity Ratio		1.0089	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	4.76E-02	13.4	5.03E-02	13.4	4.91E-02
26.8	5.57E-02	26.8	5.77E-02	26.8	5.57E-02
53.6	6.99E-02	53.6	7.14E-02	53.6	6.99E-02
26.8	5.59E-02	26.8	5.77E-02	26.8	5.57E-02
13.4	4.80E-02	13.4	4.93E-02	13.4	4.78E-02
26.8	5.58E-02	26.8	5.77E-02	26.8	5.67E-02
53.6	6.93E-02	53.6	7.09E-02	53.6	6.94E-02
26.8	5.52E-02	26.8	5.64E-02	26.8	5.52E-02
13.4	4.78E-02	13.4	4.81E-02	13.4	4.78E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-06

Test Details

Batch	13/06/2007		
Test Number	Ka-F-1306-01		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1305 kg/m³	1424 kg/m³	1320 kg/m³
Weight Concentration	37.40%	47.62%	38.24%
Volume Concentration	17.86%	25.29%	18.30%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		9.1%	

Flow Properties

Bingham Yield Stress	15.43 Pa	17.37 Pa	15.92 Pa
Bingham Viscosity	0.010 Pa.s	0.012 Pa.s	0.010 Pa.s
Vane Yield Stress	9.01 Pa	10.78 Pa	9.18 Pa
Distance Ratio, l		1.1229	
Vane Yield Stress Ratio		1.1969	
Bingham Yield Stress Ratio		1.1255	
Bingham Viscosity Ratio		1.2171	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	4.76E-02	13.4	5.45E-02	13.4	4.96E-02
26.8	5.57E-02	26.8	6.50E-02	26.8	5.74E-02
53.6	6.99E-02	53.6	8.19E-02	53.6	7.19E-02
26.8	5.59E-02	26.8	6.35E-02	26.8	5.64E-02
13.4	4.80E-02	13.4	5.42E-02	13.4	4.98E-02
26.8	5.58E-02	26.8	6.33E-02	26.8	5.77E-02
53.6	6.93E-02	53.6	8.05E-02	53.6	7.14E-02
26.8	5.52E-02	26.8	6.28E-02	26.8	5.69E-02
13.4	4.78E-02	13.4	5.37E-02	13.4	4.88E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-07

Test Details

Batch	13/06/2007		
Test Number	Ka-F-1306-01		
Substance	Kaolin- Fresh Sample	Kaolin- 115% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1305 kg/m³	1509 kg/m³	1322 kg/m³
Weight Concentration	37.40%	52.58%	38.39%
Volume Concentration	17.86%	28.30%	18.40%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		12.7%	

Flow Properties

Bingham Yield Stress	15.43 Pa	19.14 Pa	15.05 Pa
Bingham Viscosity	0.010 Pa.s	0.014 Pa.s	0.010 Pa.s
Vane Yield Stress	9.01 Pa	11.18 Pa	9.13 Pa
Distance Ratio, l		1.4527	
Vane Yield Stress Ratio		1.2412	
Bingham Yield Stress Ratio		1.2408	
Bingham Viscosity Ratio		1.4112	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	4.76E-02	13.4	6.06E-02	13.4	4.78E-02
26.8	5.57E-02	26.8	7.11E-02	26.8	5.59E-02
53.6	6.99E-02	53.6	9.22E-02	53.6	7.16E-02
26.8	5.59E-02	26.8	7.16E-02	26.8	5.64E-02
13.4	4.80E-02	13.4	6.11E-02	13.4	4.83E-02
26.8	5.58E-02	26.8	7.09E-02	26.8	5.57E-02
53.6	6.93E-02	53.6	9.10E-02	53.6	6.94E-02
26.8	5.52E-02	26.8	7.09E-02	26.8	5.35E-02
13.4	4.78E-02	13.4	5.96E-02	13.4	4.66E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-08

Test Details

Batch	13/06/2007		
Test Number	Ka-F-1306-01		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1305 kg/m³	1530 kg/m³	1317 kg/m³
Weight Concentration	37.40%	57.22%	37.92%
Volume Concentration	17.86%	34.40%	18.10%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		20.1%	

Flow Properties

Bingham Yield Stress	15.43 Pa	21.61 Pa	15.99 Pa
Bingham Viscosity	0.010 Pa.s	0.016 Pa.s	0.011 Pa.s
Vane Yield Stress	9.01 Pa	12.24 Pa	9.84 Pa
Distance Ratio, l		2.2319	
Vane Yield Stress Ratio		1.3587	
Bingham Yield Stress Ratio		1.4008	
Bingham Viscosity Ratio		1.6628	

Raw Data

Fresh Tests		***Sand Tests***		***Sieved Tests***	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	4.76E-02	13.4	6.65E-02	13.4	5.15E-02
26.8	5.57E-02	26.8	8.07E-02	26.8	5.96E-02
53.6	6.99E-02	53.6	1.05E-01	53.6	7.58E-02
26.8	5.59E-02	26.8	8.14E-02	26.8	5.91E-02
13.4	4.80E-02	13.4	6.75E-02	13.4	5.03E-02
26.8	5.58E-02	26.8	8.17E-02	26.8	5.91E-02
53.6	6.93E-02	53.6	1.06E-01	53.6	7.48E-02
26.8	5.52E-02	26.8	8.14E-02	26.8	5.91E-02
13.4	4.78E-02	13.4	6.80E-02	13.4	4.93E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-09

Test Details

Batch	22/05/2007		
Test Number	Ka-F-0806-01		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1327 kg/m³	1422 kg/m³	1350 kg/m³
Weight Concentration	39.74%	45.38%	40.86%
Volume Concentration	19.27%	22.19%	20.01%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		3.6%	

Flow Properties

Bingham Yield Stress	22.82 Pa	27.00 Pa	26.56 Pa
Bingham Viscosity	0.012 Pa.s	0.013 Pa.s	0.012 Pa.s
Vane Yield Stress	11.95 Pa	13.10 Pa	12.17 Pa
Distance Ratio, l		0.6362	
Vane Yield Stress Ratio		1.0961	
Bingham Yield Stress Ratio		1.1831	
Bingham Viscosity Ratio		1.0920	

Raw Data

Fresh Tests		***Sand Tests***		***Sieved Tests***	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	6.81E-02	13.4	7.78E-02	13.4	7.56E-02
26.8	7.84E-02	26.8	8.98E-02	26.8	8.73E-02
53.6	9.58E-02	53.6	1.11E-01	53.6	1.06E-01
26.8	7.97E-02	26.8	9.13E-02	26.8	8.86E-02
13.4	6.92E-02	13.4	7.95E-02	13.4	7.63E-02
26.8	7.96E-02	26.8	9.20E-02	26.8	8.88E-02
53.6	9.62E-02	53.6	1.11E-01	53.6	1.06E-01
26.8	7.90E-02	26.8	9.18E-02	26.8	8.81E-02
13.4	6.92E-02	13.4	7.85E-02	13.4	7.61E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-10

Test Details

Batch	22/05/2007		
Test Number	Ka-F-0806-01		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1327 kg/m³	1437 kg/m³	1348 kg/m³
Weight Concentration	39.74%	50.06%	40.69%
Volume Concentration	19.27%	28.09%	19.90%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		10.9%	

Flow Properties

Bingham Yield Stress	22.82 Pa	27.97 Pa	23.61 Pa
Bingham Viscosity	0.012 Pa.s	0.014 Pa.s	0.012 Pa.s
Vane Yield Stress	11.95 Pa	13.86 Pa	11.89 Pa
Distance Ratio, l		1.2869	
Vane Yield Stress Ratio		1.1596	
Bingham Yield Stress Ratio		1.2255	
Bingham Viscosity Ratio		1.1976	

Raw Data

Fresh Tests		***Sand Tests***		***Sieved Tests***	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	6.81E-02	13.4	8.12E-02	13.4	6.94E-02
26.8	7.84E-02	26.8	9.44E-02	26.8	8.02E-02
53.6	9.58E-02	53.6	1.18E-01	53.6	9.79E-02
26.8	7.97E-02	26.8	9.69E-02	26.8	7.97E-02
13.4	6.92E-02	13.4	8.27E-02	13.4	6.92E-02
26.8	7.96E-02	26.8	9.59E-02	26.8	8.00E-02
53.6	9.62E-02	53.6	1.17E-01	53.6	9.74E-02
26.8	7.90E-02	26.8	9.54E-02	26.8	8.02E-02
13.4	6.92E-02	13.4	8.19E-02	13.4	6.89E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-11

Test Details

Batch	22/05/2007		
Test Number	Ka-F-0806-01		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1327 kg/m³	1497 kg/m³	1347 kg/m³
Weight Concentration	39.74%	54.43%	40.66%
Volume Concentration	19.27%	31.66%	19.88%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		15.3%	

Flow Properties

Bingham Yield Stress	22.82 Pa	29.54 Pa	22.55 Pa
Bingham Viscosity	0.012 Pa.s	0.015 Pa.s	0.012 Pa.s
Vane Yield Stress	11.95 Pa	15.07 Pa	11.62 Pa
Distance Ratio, l		1.7062	
Vane Yield Stress Ratio		1.2615	
Bingham Yield Stress Ratio		1.2945	
Bingham Viscosity Ratio		1.2384	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	6.81E-02	13.4	8.59E-02	13.4	6.80E-02
26.8	7.84E-02	26.8	1.02E-01	26.8	7.80E-02
53.6	9.58E-02	53.6	1.24E-01	53.6	9.62E-02
26.8	7.97E-02	26.8	1.01E-01	26.8	7.80E-02
13.4	6.92E-02	13.4	8.59E-02	13.4	6.75E-02
26.8	7.96E-02	26.8	1.01E-01	26.8	7.78E-02
53.6	9.62E-02	53.6	1.22E-01	53.6	9.64E-02
26.8	7.90E-02	26.8	9.96E-02	26.8	7.80E-02
13.4	6.92E-02	13.4	8.54E-02	13.4	6.72E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-12

Test Details

Batch	22/05/2007		
Test Number	Ka-F-0806-01		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1327 kg/m³	1584 kg/m³	1344 kg/m³
Weight Concentration	39.74%	61.15%	40.38%
Volume Concentration	19.27%	38.33%	19.69%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		23.6%	

Flow Properties

Bingham Yield Stress	22.82 Pa	35.32 Pa	22.73 Pa
Bingham Viscosity	0.012 Pa.s	0.018 Pa.s	0.011 Pa.s
Vane Yield Stress	11.95 Pa	18.27 Pa	12.14 Pa
Distance Ratio, l		2.6746	
Vane Yield Stress Ratio		1.5288	
Bingham Yield Stress Ratio		1.5476	
Bingham Viscosity Ratio		1.4847	

Raw Data

Fresh Tests		***Sand Tests***		***Sieved Tests***	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	6.81E-02	13.4	1.02E-01	13.4	6.72E-02
26.8	7.84E-02	26.8	1.21E-01	26.8	7.68E-02
53.6	9.58E-02	53.6	1.48E-01	53.6	9.40E-02
26.8	7.97E-02	26.8	1.21E-01	26.8	7.73E-02
13.4	6.92E-02	13.4	1.03E-01	13.4	6.70E-02
26.8	7.96E-02	26.8	1.20E-01	26.8	7.73E-02
53.6	9.62E-02	53.6	1.46E-01	53.6	9.40E-02
26.8	7.90E-02	26.8	1.18E-01	26.8	7.68E-02
13.4	6.92E-02	13.4	1.01E-01	13.4	6.62E-02
0.0	0.00E+00	13.4	1.03E-01	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-13

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2805-01		
Substance	Kaolin- Fresh Sample	Kaolin- 5% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1347 kg/m³	1428 kg/m³	1364 kg/m³
Weight Concentration	41.25%	46.18%	42.07%
Volume Concentration	20.28%	23.00%	20.83%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		3.4%	

Flow Properties

Bingham Yield Stress	28.17 Pa	31.74 Pa	29.13 Pa
Bingham Viscosity	0.014 Pa.s	0.013 Pa.s	0.013 Pa.s
Vane Yield Stress	14.65 Pa	14.40 Pa	14.43 Pa
Distance Ratio, l		0.6140	
Vane Yield Stress Ratio		1.0180	
Bingham Yield Stress Ratio		1.1267	
Bingham Viscosity Ratio		0.9273	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	8.30E-02	26.8	1.04E-01	13.4	8.51E-02
26.8	9.53E-02	53.6	1.24E-01	26.8	9.54E-02
53.6	1.17E-01	26.8	1.04E-01	53.6	1.17E-01
26.8	9.71E-02	13.4	9.00E-02	26.8	9.79E-02
13.4	8.40E-02	26.8	1.04E-01	13.4	8.56E-02
26.8	9.67E-02	53.6	1.24E-01	26.8	9.76E-02
53.6	1.17E-01	26.8	1.04E-01	53.6	1.18E-01
26.8	9.73E-02	13.4	9.00E-02	26.8	9.84E-02
13.4	8.48E-02	0.0	0.00E+00	13.4	8.54E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-14

Test Details

Batch	22/05/2007		
Test Number	Ka-F-2805-01		
Substance	Kaolin- Fresh Sample	Kaolin- 10% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1347 kg/m³	1489 kg/m³	1366 kg/m³
Weight Concentration	41.25%	53.17%	42.27%
Volume Concentration	20.28%	30.13%	20.96%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		12.3%	

Flow Properties

Bingham Yield Stress	28.17 Pa	38.87 Pa	30.52 Pa
Bingham Viscosity	0.014 Pa.s	0.016 Pa.s	0.014 Pa.s
Vane Yield Stress	14.65 Pa	17.11 Pa	16.13 Pa
Distance Ratio, l		1.4151	
Vane Yield Stress Ratio		1.1676	
Bingham Yield Stress Ratio		1.3799	
Bingham Viscosity Ratio		1.1305	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	8.30E-02	26.8	1.27E-01	13.4	8.76E-02
26.8	9.53E-02	53.6	1.51E-01	26.8	1.01E-01
53.6	1.17E-01	26.8	1.27E-01	53.6	1.24E-01
26.8	9.71E-02	13.4	1.10E-01	26.8	1.03E-01
13.4	8.40E-02	13.4	1.08E-01	13.4	8.93E-02
26.8	9.67E-02	26.8	1.26E-01	26.8	1.03E-01
53.6	1.17E-01	53.6	1.52E-01	53.6	1.24E-01
26.8	9.73E-02	26.8	1.28E-01	26.8	1.03E-01
13.4	8.48E-02	13.4	1.10E-01	13.4	8.93E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-15

Test Details

Batch	04/06/2007		
Test Number	Ka-F-0406-01		
Substance	Kaolin- Fresh Sample	Kaolin- 15% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1347 kg/m³	1598 kg/m³	1367 kg/m³
Weight Concentration	41.25%	59.85%	42.31%
Volume Concentration	20.28%	35.69%	21.00%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		19.3%	

Flow Properties

Bingham Yield Stress	28.17 Pa	44.26 Pa	29.47 Pa
Bingham Viscosity	0.014 Pa.s	0.021 Pa.s	0.015 Pa.s
Vane Yield Stress	14.65 Pa	21.92 Pa	13.37 Pa
Distance Ratio, l		2.1322	
Vane Yield Stress Ratio		1.4959	
Bingham Yield Stress Ratio		1.5714	
Bingham Viscosity Ratio		1.4864	

Raw Data

Fresh Tests		***Sand Tests***		***Sieved Tests***	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	8.30E-02	13.4	1.25E-01	13.4	8.61E-02
26.8	9.53E-02	26.8	1.47E-01	26.8	9.91E-02
53.6	1.17E-01	53.6	1.81E-01	53.6	1.22E-01
26.8	9.71E-02	26.8	1.50E-01	26.8	1.01E-01
13.4	8.40E-02	13.4	1.28E-01	13.4	8.61E-02
26.8	9.67E-02	26.8	1.50E-01	26.8	9.96E-02
53.6	1.17E-01	53.6	1.81E-01	53.6	1.22E-01
26.8	9.73E-02	26.8	1.49E-01	26.8	1.01E-01
13.4	8.48E-02	13.4	1.28E-01	13.4	8.71E-02
0.0	0.00E+00	13.4	1.29E-01	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

QB-16

Test Details

Batch	04/06/2007		
Test Number	Ka-F-0406-01		
Substance	Kaolin- Fresh Sample	Kaolin- 20% Sand	Kaolin- Sieved
Temperature	25.00 °C	25.00 °C	25.00 °C
ROTOVISCO RV	3	3	3
Measuring Head	MK 50	MK 50	MK 50
Sensor System	MV 1	MV 1	MV 1
Graphing Speed	50 s/cm	50 s/cm	50 s/cm
Vane	FL10	FL10	FL10

Viscometer Details

Spindle Length	0.060 m	0.060 m	0.060 m
Spindle Radius	0.020 m	0.020 m	0.020 m
Cup Radius	0.021 m	0.021 m	0.021 m
Spring Constant	0.0147 N.m	0.0147 N.m	0.0147 N.m
Vane Diameter	0.040 m	0.040 m	0.040 m
Vane Height	0.060 m	0.060 m	0.060 m

Slurry Properties

Sand C_{max}		61.2%	
Density	1347 kg/m³	1597 kg/m³	1370 kg/m³
Weight Concentration	41.25%	58.70%	42.61%
Volume Concentration	20.28%	33.89%	21.20%
Slurry pH	4.60	4.60	4.60
Sand Volume Concentration		17.0%	

Flow Properties

Bingham Yield Stress	28.17 Pa	44.46 Pa	27.30 Pa
Bingham Viscosity	0.014 Pa.s	0.021 Pa.s	0.014 Pa.s
Vane Yield Stress	14.65 Pa	20.54 Pa	14.80 Pa
Distance Ratio, l		1.8819	
Vane Yield Stress Ratio		1.4019	
Bingham Yield Stress Ratio		1.5784	
Bingham Viscosity Ratio		1.4554	

Raw Data

Fresh Tests		*Sand Tests*		*Sieved Tests*	
Calculated Bob Speed (s^{-1})	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**	**Calculated Bob Speed (s^{-1})**	**Measured Torque (N.m/m)**
13.4	8.30E-02	26.8	1.49E-01	13.4	8.00E-02
26.8	9.53E-02	53.6	1.82E-01	26.8	9.22E-02
53.6	1.17E-01	26.8	1.49E-01	53.6	1.15E-01
26.8	9.71E-02	13.4	1.28E-01	26.8	9.47E-02
13.4	8.40E-02	26.8	1.49E-01	13.4	8.02E-02
26.8	9.67E-02	53.6	1.79E-01	26.8	9.35E-02
53.6	1.17E-01	26.8	1.48E-01	53.6	1.16E-01
26.8	9.73E-02	13.4	1.28E-01	26.8	9.44E-02
13.4	8.48E-02	0.0	0.00E+00	13.4	8.07E-02
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00
0.0	0.00E+00	0.0	0.00E+00	0.0	0.00E+00

APPENDIX G: TYPICAL CALCULATIONS FOR CASE STUDY

Calculations for Residual Concentration Model in Case Study Example

All system and material property inputs are as defined in Section 5. The results for this example are shown in Table G.1 to Table G.3.

Table G.1: System Specific Properties

	Value	**Calculation**
Design Tonnage, M_t	160 t/h	*Specified*
Solids Density, S_s	2.65	*Specified*
Slurry Density, S_m	1.55	*Specified*
Solids Weight Concentration, C_w	57.0%	$=\frac{S_s}{S_m}\left(\frac{S_m-1}{S_s-1}\right)$
Solids Volume Concentration, C_v	33.3%	$=\left(\frac{S_m-1}{S_s-1}\right)$
Percentage Fines, P_f	85%	*Specified*
Fines Volume Concentration, C_{vf}	21.6%	$=\left[\frac{C_v-(1-P_f)}{1-(1-P_f)}\right]$
Design Flow rate, Q_m	181 m^3/h	$=\frac{M_t}{S_S \cdot C_V}$
Pipeline Size, D_{pipe}	155 mm	*Specified*
Pipeline Roughness, k_{rough}	100 µm	*Specified*
Pipeline Length, L_{pipe}	2 500 m	*Specified*
Static Head, Δh	20 m	*Specified*

Table G.2: Rheological Parameter Properties

	Value	**Calculation**
Residual Kaolin Concentration, C_{res}	2.0%	$= 0.133 \cdot (1 - P_f)$
Adjusted Kaolin Concentration, $C_{k,adj}$	23.6%	$= C_{res} + C_{vf}$
Bingham Dynamic Yield Stress, $\tau_{y,B}$	34.7 Pa	$= 14000 \left(\frac{C_{k,adj}}{1 - C_{k,adj}}\right)^{5.1}$
Bingham Dynamic Viscosity, K_B	6.03 mPa.s	$= 8.94 \times 10^{-4} (C_{k,adj})^{8.1}$

Table G.3: System Operating Properties

	Value	**Calculation**
Average Velocity, U	2.67 m/s	$= \frac{Q_m}{3600 \cdot \pi \cdot 0.25 \cdot {D_{pipe}}^2}$
Pseudo-Shear Rate, $8U/D_{pipe}$	137.8 s^{-1}	$= \frac{8U}{D_{pipe}}$
Laminar Wall Shear Stress (iterative), $\tau_{o, lam}$	38.8 Pa	$\frac{8U}{D_{pipe}} = \frac{\tau_0}{K_B}\left[1 - \frac{4}{3}\frac{\tau_{y,B}}{\tau_0} + \frac{1}{3}\left(\frac{\tau_{y,B}}{\tau_0}\right)^4\right]$ $\therefore 137.8 = \frac{\tau_0}{0.006}\left[1 - \frac{4.93}{\tau_0} + \frac{1}{3}\left(\frac{34.7}{\tau_0}\right)^4\right]$
Non-Newtonian Reynolds Number, Re	10 6255	$= \frac{1000 \cdot S_m \cdot U \cdot D_{pipe}}{K_B}$
Turbulent Wall Shear Stress (iterative), $\tau_{o, turb}$	28.6 Pa	Step 1: Calculate Fanning Friction Factor, f Colebrooke-White formula (iterative): $\frac{-1}{\sqrt{f}} = 4 \cdot \ln\left(\frac{k_{rough}}{3.7 \cdot D_{pipe}} + \frac{1.26}{\sqrt{f} \cdot Re}\right)$ Step 2: Calculate turbulent wall shear stress, $\tau_{0,turb}$: $= 0.5 \cdot U^2 \cdot \sqrt{f} \cdot 1000 \cdot S_m$ Step 3: Iteratively solve for τ_0 (see Section 2.2.3) $U = V_N + 2.5\left[\sqrt{\frac{\tau_0}{\rho}} \ln \frac{\left(1 - \frac{\tau_y}{\tau_0}\right)}{\left(1 + \frac{\tau_y}{\tau_0}\right)} + \frac{\tau_y}{\tau_0}\left(14.1 + 1.25\frac{\tau_y}{\tau_0}\right)\right]$
Flow Regime	Laminar	$\tau_{0,lam} > \tau_{0,turb}$
Pumping Pressure Required, P_{pump}	2 933 kPa	$= 15\frac{U^2}{2g}1000 \cdot S_m + \Delta h + \frac{4 \cdot \tau_o}{D_{pipe}} L_{pipe}$