A RHEOLOGICAL INVESTIGATION OF THREE SOUTH AFRICAN GOLD MINE PULPS

by

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SYNOPSIS

A method is described which enables the user to determine the rheological parameters of a fast settling slurry using conventional viscometric measuring equipment. The effect of concentration, temperature and pH on these parameters is investigated. The results agree with those obtained by previous workers using different viscometers. However, this method allows a more detailed characterization of all the properties. A literature survey was carried out and two semi-empirical correlations were found, which allow the effect of either concentration, temperature or pH on the rheological parameters to be investigated.

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This thesis is dedicated to

Sheenagh

without whom this project would never
have been completed.

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NOMENCLATURE

η^*, η_S, η_{susp} = viscosity of suspension

ϕ = volume fraction

ϕ_m = maximum attainable concentration

η_{rel} = viscosity index defined as

$$\frac{\text{viscosity of suspension}}{\text{viscosity of liquid at same temperature}}$$

a = diameter of sphere

d = diameter of couette apparatus

h = distance between spheres

ψ_{21} = concentration of volume fraction ϕ_2 in liquid excluding the volume occupied by ϕ_1

V = volume of solids or liquid

ν = kinematic viscosity

τ = shear stress

γ = shear rate

η = apparent viscosity of a non-Newtonian system

ω = angular velocity

n = flow behaviour index

K = consistency index

= projected value of τ at a shear rate of 1 $\sec^{-1}$

T = torque

L_e = effective length

d_S/d_B = ratio of spindle diameter to beaker diameter

N = rpm

R = dial reading

S = spring constant of viscometer

D_p = diameter of particle

U_t, V_0 = terminal settling velocity

V_c = hindered settling velocity

ρ_S, ρ = density of solid and liquid respectively

ε = void fraction = $1 - \phi$

ρ_w = density of water.

CHAPTER 1

INTRODUCTION

The revived interest in both the development of the resin-in-pulp extraction of uranium and processes involving the transfer of heat between slurries has initiated this study of the rheological properties of mineral ore slurries.

The determination of these properties is complicated by two interacting factors viz., non-Newtonian behaviour and settling of slurries in normal viscometric flow apparatus. This led previous workers on slurries to believe that they could not measure the rheological properties and thus they were satisfied to measure a value which was proportional to the effective viscosity. The investigations that utilized this "proportionality" to characterise a suspension usually were interested only in the effect of one parameter, viz. concentration or temperature, on the viscosity of the suspension.

This research program has approached the problem of determining the rheological properties in a different manner, utilizing the fact that the theory of non-Newtonian liquids has progressed to the point where the rheological properties of a non-Newtonian slurry can be described once certain properties have been measured using a conventional viscometer. This viscometer can only be used if the problem of settling can be eliminated otherwise a new rheometer, which can prevent this settling, will have to be designed and built.

Once the measurement of the rheological properties is possible, the power required to pump or agitate a slurry may be calculated. The effect of finer ground pulp, changes in ambient temperature, flocculating agents, etc., on the rheological properties may be determined with a higher degree of accuracy than ever before.

Thus the aims of this research program were :

1. To investigate the feasibility of determining the rheological properties of mine pulps using a commercially available spindle-in-fluid viscometer.

2. To determine if any of the available theories derived from either fundamental or semi-empirical studies could describe the rheological properties of a slurry.

A brief summary of the work undertaken is given in this chapter. Chapter 2 contains a review of the pertinent literature on the theories of viscosity of suspensions and on the experimental work performed in this field. Various theoretical equations that have been proposed are tabulated in Table 2.1 in two forms, viz. (i) the original equations as derived by the authors and (ii) as Taylor expansions for comparative purposes. This is necessary as each equation has been derived differently and thus varies in its final form, although inherently similar.

In Chapter 3 there is a discussion of the various viscometers used for investigating slurries. The theory, which describes the use of a rotating bob viscometer for the measurement of the rheological properties of non-Newtonian slurries, is also outlined and justified. The following chapter contains a detailed description of the apparatus and an account of the experimental work done. A discussion of the effect of settling within the viscometer during viscometric measurements and the relative effect of this can also be found in this chapter.

The manipulation of the data and the analysis of the results is discussed in Chapter 5. The results obtained, for the variables investigated, viz. concentration, temperature, pH and the effect of bentonite are presented. Two correlations are also presented which fit the data and describe the effect of concentration on the viscosity index. The last chapter contains the conclusions and recommendations for further study drawn from this project.

CHAPTER 2

REVIEW OF THEORETICAL AND EXPERIMENTAL STUDIES ON THE VISCOSITY OF SUSPENSIONS

2.1 THEORETICAL PREDICTIONS

2.1.1 Theory for infinitely dilute suspensions

The classical theory on the viscosity of suspensions at infinite dilution is due to Einstein [1]. He considered the motion of a liquid to be the superposition of three separate motions, viz.: a rigid translation, a rigid rotation and a pure shear along the three principal axes of stress. The first two motions are not affected by the presence of any particles since the fluid acts as a rigid body, but the third motion is modified by the presence of these particles. It is the perturbation due to these particles that causes an increase in the viscosity.

Einstein considered the simple model of small rigid spheres of equal density in an incompressible liquid where the size of the particles was assumed to be large enough to allow the surrounding liquid to be treated as a continuum and the equations of motion to be applied.

The velocity components of the liquid in a differential fluid element can be represented by the first terms of a Taylor expansion about the origin. If a small sphere is placed in that region, the change in the velocity component, about the origin, can be calculated, assuming that no slip occurs at the interface between the particle and the surrounding liquid. Using this as one of the boundary conditions Einstein was able to obtain a solution for the equations of motion. Placing a second concentric sphere of infinitely greater radius about the first, the energy dissipated per unit time can be calculated. Summing the contribution of all the spheres in that region, the viscosity of an infinitely diluted suspension is:

$$\eta^* = \eta(1 + 2{,}5\ \phi) \tag{2-1}$$

where η^* = viscosity of the suspension
η = viscosity of the liquid
and ϕ = volume fraction of the suspension
occupied by the spherical particles. This derivation is based on the assumption that the distance between the particles is infinitely greater than the radius of the particles and all the particles are of equal radius.

Experimental verification of Equation (2-1) has been undertaken by various workers including Einstein with inconclusive results with regard to the numerical value of the constant, often referred to as the "Einstein factor".

2.1.2 Viscosity at finite concentration

Several workers have undertaken an extension of Einstein's work in order to predict the viscosity of suspensions of particles at finite concentration.

Guth and Simha [2] found that repeating Einstein's derivation without the simplifying assumption of no wall effects resulted, for the case of couette flow, in:

$$\eta_{rel} = 1 + 2{,}5\ (1 + \frac{15}{16}\,\frac{a}{d})\,\phi \tag{2-2}$$

where a = diameter of sphere
and d = diameter of couette apparatus.

Gold [3] repeated Einstein's derivation without any simplifying assumptions and found

$$\eta_{rel} = 1 + 2{,}5\ \phi + 14{,}1\ \phi^2 + \ldots. \tag{2-3}$$

The possibility of aggregation and direct collision of particles has not been considered in the above theories. Burgers [4] and Saito [5] considered these factors and when combined with long range interactions found

$$\eta_{rel} = 1 + 2{,}5\ \phi + 12{,}6\ \phi^2 + \ldots \qquad (2\text{-}4)$$

These equations have been verified experimentally by Smith [6] and by Eirich [7] for suspensions of spheres up to concentrations of 6 percent by volume.

De Bruijn [8] attempted several methods of calculating the long range hydrodynamic interaction among spheres. The first of these was semi-empirical where the most important physical variable was taken to be the relative fluidity, equal to $1/\eta_{rel}$. This was assumed to be given exactly by a quadratic in ϕ with coefficients such that η_{rel} was predicted by Einstein's equation at very low concentration and as ϕ approached 0,74, the maximum attainable concentration for cubic packing of spheres, the viscosity became infinite.

$$\frac{1}{\eta_{rel}} = 1 - 2{,}5\ \phi + 1{,}55\ \phi^2 \qquad (2\text{-}5)$$

In a subsequent calculation, which only considered the volume excluded, he obtained:

$$\frac{1}{\eta_{rel}} = \frac{1 - \phi}{(1+1{,}5\phi)} \qquad (2\text{-}6)$$

It should be noted that references 2 to 8 cited above have not been consulted in their original form but are reported as discussed by Frish and Simha in their review article "The viscosity of colloidal suspensions and macromolecular solutions" [43].

Vand [9] estimated the increased viscosity from the addition of a volume fraction of spheres to a dilute suspension by neglecting the interaction of the particles and obtained:

$$\frac{d\ \eta_{rel}}{\eta_{rel}} = 2{,}5\ d\ \phi$$

or

$$\eta_{rel} = \exp\ (2{,}5\ \phi) \qquad (2\text{-}7)$$

He also calculated the concentration dependence of suspensions of spheres in couette streaming, similar to that undertaken by Guth and Simha. He used successive reflections of the hydrodynamic disturbance from two spheres to satisfy the boundary condition on the surface of a sphere and obtained

$$\ln \eta_{rel} = \frac{2{,}5\ \phi}{1 - \left(\frac{39}{64}\right)\phi} \qquad (2\text{-}8)$$

Vand has also presented an extensive treatment of the effect of collisions for a suspension of spheres in which he neglected, as a first approximation, the effect of Brownian motion on this process. This yielded:

$$\eta_{rel} = 1 + 2{,}5\ \phi + 7{,}35\ \phi^2 + \ldots. \qquad (2\text{-}9)$$

2.1.3 Concentrated suspensions

Vand [9], Roscoe [10] and Brinkman [11] each attempted to obtain a solution to the problem of the effect of concentration on the viscosity of a concentrated suspension on a purely theoretical basis. They each, individually, showed that a suspension of small spheres acts as a homogeneous liquid of increased viscosity and also that if larger spheres were added to the suspension in concentrations lower than that of the small spheres, the increase in viscosity should be given by the Einstein equation. This process could also be repeated for still larger spheres.

Considering that the volume of added spheres increases the total volume of the suspension, the incremental viscosity is

$$\frac{d\eta}{d\phi} = \frac{2{,}5\ \eta}{1 - \phi} \qquad (2\text{-}10)$$

so that upon integration it becomes:

$$\eta_{rel} = (1 - \phi)^{-2,5} \tag{2-11}$$

The assumption that a suspension of small spheres would act towards larger spheres as a homogeneous liquid of equal viscosity, has been shown to be valid by Fidleris and Whitmore [12] even when the relative difference in the diameters of the two fractions of spheres is very small. Richardson and Meikle [13] in their study of hindered settling came to the same conclusion as Fidleris and Whitmore and used this assumption to solve the problem of hindered settling for two size fractions with differing densities.

Roscoe [10] extended this argument to a concentrated suspension of equal sized spheres by assuming that any aggregates formed act as larger spheres, immobilizing liquid within them, thereby increasing the effective concentration by $3\sqrt{2}/\pi$ in the limit. Thus

$$\eta_{rel} = (1 - 1,35\ \phi)^{-2,5} \tag{2-12}$$

Mooney [14] treated the addition of successive spheres in a different manner. He considered two quantities of spheres of equal radii, where the addition of the first quantity would increase the viscosity by a factor $H(\phi_1) = \frac{\eta_1}{\eta_0}$. This factor H must reduce to Einstein's relationship for the relative viscosity at small values of ϕ_1. If the second fraction ϕ_2 is added there will be a further increase in the viscosity of the liquid not occupied by the fraction ϕ_1. This increase in viscosity can be represented by:

$$\eta_2 = \eta_1\ H(\psi_{21}) \tag{2-13}$$

where $$\psi_{21} = \frac{\phi_2}{(1 - K\phi_1)} \tag{2-14}$$

is the concentration of ϕ_2 in the remaining liquid, allowance being made for a crowding factor, K. But, as this crowding is mutual, the addition of the second set of particles will also reduce the free volume available to the first set.

Therefore the effective volume concentration of the first set is

$$\psi_{12} = \frac{\phi_1}{(1 - K\phi_2)} \tag{2-15}$$

To take account of this effect, $H(\phi_1)$ was replaced by $H(\psi_{12})$. The product of $H(\psi_{12})$ and $H(\psi_{21})$ gives the viscosity of the suspension of total concentration $(\phi_1 + \phi_2)$ and hence is equal to $H(\phi_1 + \phi_2)$.

Thus

$$H(\phi_1 + \phi_2) = \frac{\eta_{12}}{\eta_0} = H(\psi_{12}) \times H(\psi_{21})$$

$$= H\left(\frac{\phi_1}{1 - K\phi_2}\right) \times H\left(\frac{\phi_2}{1 - K\phi_1}\right) \tag{2-16}$$

It was found that this functional equation was satisfied if H has the form:

$$H(\phi) = \exp\left(\frac{2{,}5\ \phi}{1 - K\phi}\right) \tag{2-17}$$

The constant 2,5 was chosen to agree with Einstein's equation for very dilute solutions. The value of K is equal to $1/\phi_{max}$ and should lie between 1,35 and 1,91 which are the values for hexagonal and cubic packing respectively.

Frankel and Acrivos [15] calculated the rate of energy dissipation in a concentrated suspension by assuming that each solid particle moved with the average velocity of the surrounding liquid. Thus the solid spheres could be considered as fluid elements with regard to their instantaneous motion, but it was still possible to investigate the hydrodynamic interaction among particles in relative motion, and in close proximity to one another.

The viscous dissipation of energy is related to the effective viscosity by Einstein's [1] method. This dissipation arises primarily from the flow within the narrow gap separating the various solid spheres from one another. Within each gap this flow is due to the relative motion of two spheres and can be resolved into a component along their line of centres and a component normal to that line. In general, both components have to be considered, but the dominant term in the asymptotic form is due solely to the relative movement of the first type. Thus the asymptotic solution of the rate of viscous dissipation of energy in either half-space can be expressed as

$$E \sim 3\pi\mu W^2 a\left[\frac{a}{h}\right] \tag{2-18}$$

An identical result could have been obtained by considering the asymptotic solution of the classical problem of flow between two parallel discs, narrowly separated, and approaching each other at a constant velocity.

The effective viscosity of a suspension can be defined as the ratio of the rates of work being performed by the stresses at the boundaries of an apparatus containing, respectively, either the suspension in question or an equivalent volume of pure liquid. This definition is consistent with the usual experimental methods for determining viscosity, viz. couette viscometry. Using the above definition and Equation 2-18 Frankel and Acrovos derived an equation of the form

$$\eta_{rel} = c'\left(\frac{(\phi/\phi_m)^{1/3}}{1 - (\phi/\phi_m)^{1/3}}\right) \tag{2-19}$$

as $\phi/\phi_m \to 1$,

where ϕ_m = maximum obtainable concentration

and c' = constant determined to be 9/8.

The Root-Reciprocal relationship of Clarke, reviewed in Beazley [16], which predicted a linear relationship between the root reciprocal of viscosity and weight percent of solids for deflocculated clays, approached the problem of particle interaction in a different manner.

In shearing motion, solids and liquid particles move relative to each other, and it is unimportant whether the particles are considered to be stationary with the liquid moving or vice versa. At a higher concentration of solids, the movement of liquid relative to the clay can be considered as a particular example of the capillary flow of liquid through pores, whose apparent radii, r, are determined by the amount of liquid free to flow. If a volume fraction, V, immobilizes a volume of water, KV, by hydrodynamic processes, the water free to move is:

$$\begin{aligned} V_0 &= 1 - V - KV \\ &= 1 - V(1 + K) \qquad (2\text{-}20) \end{aligned}$$

If the pores are assumed to be of equal diameter, N in number and of length, L, then the volume they contain is $N\pi R^2L$. When equated to V_0 the following is obtained:

$$N \cdot \pi r^2 L = 1 - V(1 + K)$$

$$\therefore \qquad r^2 = \frac{1 - V(1 + K)}{\pi NL} \qquad (2\text{-}21)$$

In capillary flow, the resistance to the flow is proportional to R^{-4} and this determines the apparent viscosity of the system. Hence the suspension viscosity is:

$$\eta_S \propto \frac{(\pi NL)}{(1 - V(1 + K))^2} \qquad (2\text{-}22)$$

Inverting and taking roots

$$\frac{1}{\sqrt{\eta_S}} \propto \frac{1 - V(1 + K)}{\pi NL} \qquad (2\text{-}23)$$

or

$$\frac{1}{\sqrt{\eta_S}} \propto A - BV \qquad (2\text{-}24)$$

2.2 EXPERIMENTAL WORK ON SLURRIES

The experimental work performed on slurries utilized two basic types of viscometers, viz. a capillary viscometer and a rotational viscometer. The theory of these viscometers is discussed in Chapter 3. As these viscometers vary considerably in their modes of operation and the experimental results obtained require different methods of analysis, it has been decided to discuss the experimental work done using these viscometers in separate sections.

2.2.1 Capillary Viscometers

De Vaney and Shelton [17] investigated typical coal slurries and the usage of heavy media such as finely ground suspensions of sand, clay, magnetite, galena, ferrosilicon and lead to separate coal from shale. Their interest lay in the efficiency of these separating devices. For comparison of the efficiency of these separating media they needed to know the viscosity. Realizing that these media were non-Newtonian they set about developing a viscometer which, although unable to measure the apparent viscosity accurately, would give an approximate indication of the viscosity. This indication they called the "consistency" of the media and named their viscometer a "consistometer". The "consistometer" consisted of a graduated glass cylinder 3,8 cm in diameter and 16,5 cm in length, which held 200 cm^3 of pulp. The pulp was stirred by an impeller which was provided with three sets of arms to keep the material in suspension. A discharge tube was attached to the glass cylinder which had a 2,64 mm I.D. and a 16,5 cm length. After being stirred, the pulp was allowed to flow through the discharge tube until a steady flow was achieved, at which stage the time required for the flow of 100 cm^3 was recorded.

For heavy medium suspensions, which have an appreciable viscosity, the volumetric flow rate can be closely approximated by the following:

$$Q = \frac{\nu\pi g d^4 t h}{128\mu L} \qquad (2\text{-}25)$$

where t = time in seconds
d = diameter of tube in cm
L = length of tube in cm
h = head, in cm of liquid
ν = density in g/cm^3.

Using this equation for their analysis, the results indicated

(i) an exponential relationship between effective viscosity and specific gravity;

(ii) an increase in effective viscosity for decreasing particle size;

(iii) a critical point, 23 percent by volume of solids, below which the exponential curve could be approximated by a linear relationship between the effective viscosity and specific gravity. This was found to hold for different pulps ranging from quartz, S.G. 2,65, to lead, S.G. 11,3;

(iv) a decrease in apparent viscosity for increasing temperature, over the range, 3,5 to 35 degrees Centigrade.

Shack, Dean and Malloy [18] in their investigation of the apparent viscosity of some common minerals, examined three different types of viscometers: (i) a conventional torsion-type electroviscometer; (ii) a torsion-type viscometer which measures the viscosity using a calibrated coil spring; (iii) the "consistometer" used by De Vaney and Shelton.

Their research was a qualitative observation of the influence of the viscosity of a mineral ore suspension on flotation, thickening, filtering and other mineral dressing unit operations. For this purpose the "consistometer" was found to be adequate.

Samples of natural quartz, ortho-clase feldspar, muscovite mica, calcite, gypsum and pyrex laboratory glass were accurately classified into six different sizes, viz. 5, 10, 20, 30, 40 and 50 microns. These were then mixed with distilled water and tests were run as described in the section on De Vaney and Shelton.

The results of Shack, Dean and Malloy generally agreed with those of De Vaney and Shelton as they obtained exponential type relationships for the effective viscosity versus the solids concentration in the pulp for each of the materials investigated. A plot of apparent viscosity versus particle size, however, deviated markedly from that found by De Vaney and Shelton - a maximum was reached at approximately 20 microns after which, with decreasing size, the effective viscosity fell off again.

They reached the conclusion that (i) the frequent high viscosity of ground ore pulps was not due to the presence of finely ground quartz, feldspar, mica, calcite or gypsum, (ii) pulps with heterogeneous mixture of sizes had viscosity intermediate between the maximum and the minimum value for the individual fractions composing the mixture and (iii) the viscosity of a mineral pulp was not a simple function of particle size and pulp solids. This last conclusion was based on their observation, reported above, of the effect on the viscosity when decreasing the particle size.

Marsden [19] investigated five South African mine slurries. He utilized the same "consistometer" as described by De Vaney and Shelton [17]. The work was carried out at the following temperatures: between 5 and 13 degrees Centigrade, at 50°C and at 75°C with pH levels of 9; 6 and 2.

The results obtained were similar to those of De Vaney and Shelton. A slow increase in apparent viscosity with increasing concentration until a critical point was reached after which a small increase in concentration caused a large increase in viscosity, i.e. behaviour such as would be predicted by an exponential relationship between η_{rel} and ϕ.

The results of the pH tests indicated that at any given density, the viscosity decreased as the pulp was acidified, but that both acid and alkali pulps were very viscous at high densities.

The temperature results indicated that with an acid pulp there was a normal decrease in effective viscosity with increasing temperature, but that with alkaline pulps, above their critical density, an increase in the viscosity was achieved with temperatures above 50°C. This is thought to be the first reported "inversion" of the rheological properties of concentrated slurries and was attributed to the high proportion of colloidal matter in the slurries. Tests were run on the identical slurries using a viscometer which imparted a large shear rate to the sample by the use of sound waves. The results obtained were significantly lower than those obtained for the "consistometer" and this was attributed to shear thinning behaviour. Another conclusion drawn was that "all the slurries investigated show a similar relationship between apparent viscosity and density. It should be noted that, despite the general similarity in shape of the curves, the variation in the critical region may result in significant practical differences". In other words Marsden felt that it was not possible to obtain a general correlation for all pulps as the viscosity-density relationship is also dependent on the composition of each pulp.

A systematic study of variables affecting viscosity and pipeline flow for concentrated slurries was made by Shaheen [20]. The significant variables were found to be: volume fraction of particles, shear rate, particle size and L/D ratios. His review of the literature revealed that none of the theory available considered any of these variables except volume fraction. Shear rate, particle size and particle size distribution were assumed to have a negligible effect on the viscosity.

Shaheen found that Mooney's [14] equation incorporated a crowding factor although it ignored all the other variables. It seemed reasonable that the major variable in this concept should be the volume fraction and therefore that these other variables should be incorporated elsewhere. Therefore, the equation that he proposed, and used, to correlate his data was

$$\eta_{rel} = \exp\left(\frac{2{,}5\ \phi}{1 - \alpha\phi^{n}} \right) \tag{2-26}$$

where α = adjustable factor accounting for various variables,
and n = constant.

The rheometric instrument used in this study was a type of capillary viscometer. It consisted of a straight capillary tube section, used with the following accessories: a cathetometer for checking alignment, a Moyno pump for slurry transport, a number of pressure supply accessories, a microscope and mixing equipment. The slurry used in the experiment was prepared by mixing styrene divinylbenzene beads with distilled water. The density of the solids was 1,053 g/cm^3 so that settling was almost non-existent.

The viscosity was calculated using the Mooney-Rabinowitz equation. Non-Newtonian behaviour was encountered for slurries with a volume fraction between 0,2 and 0,47. However, above and below this point the slurries were Newtonian. Working at two size ranges, 57,0 μm and 135,5 μm, Shaheen found that at the same volume fraction the relative viscosity was greater for the 135,5 μm particles than for the 57,0 μm particles. Studying a mixture of these two sizes, he determined that the viscosity of the mixture went through a minimum at a volume fraction of approximately 0,25 of small particles. He suggested that the first addition of small particles acted as a lubricant to facilitate the rotation of the large particles and that this lead to a direct reduction in the relative slurry viscosity. Further additions of small particles resulted in an increase in the relative viscosity.

The modified equation which Shaheen suggested for a mixture of particles thus became:

$$\frac{\mu_S \text{ mixture}}{\mu_0} = \exp\left(\frac{2{,}5\ \phi_1}{1 - \alpha_1 \phi_1^{0{,}5}}\right) \cdot \exp\left(\frac{2{,}5\ \phi_2}{1 - \alpha_2 \phi_2^{0{,}5}}\right) \qquad (2\text{-}27)$$

where

$$\alpha_1 = 0{,}6 \left(\frac{D_{p_1}^{2}\ K\ \rho_0}{\mu_0}\right)^{-0{,}445} \left(\frac{D_{p_1}}{D}\right)^{0{,}57} \qquad (2\text{-}28)$$

$$\alpha_2 = 0{,}6 \left(\frac{D_{p_2}^{2}\ K\ \rho_0}{\mu_0}\right)^{-0{,}445} \cdot \left(\frac{D_{p_2}}{D}\right)^{0{,}57} \qquad (2\text{-}29)$$

This equation could only hold for discrete particle sizes and not for a continuous distribution of sizes.

2.2.2 Rotational Viscometers

Clyde Orr and Dallavalle [21] investigated heat transfer media composed of suspensions of powdered solids in water or ethylene glycol. One of the criteria required was the viscosity of the solution. Using a modified Saybolt viscometer, they found an empirical expression to describe their results which were plotted as fluidity (reciprocal of viscosity) versus volume percent solids. The equation was of the form:

$$\mu_S = \frac{\mu_L}{\left(1 - \frac{x_V}{x_{V_0}}\right)^{1{,}8}} \qquad (2\text{-}30)$$

where μ_S, μ_L = viscosity of suspension and liquid respectively,

and x_V = volume fraction of suspension

x_{V_0} = volume fraction at zero fluidity.

Their results showed fair agreement with Equation 2-30 for concentrations below 20 percent by volume, but deviated as concentration increased. They concluded that the expression was adequate for their heat-transfer correlations. This equation, however, was not recommended for pipe-line design or similar work requiring precise measurement of the viscosity.

Clarke [22] studied the viscosity of coarse settling suspensions using quartz, glass and polymethylmethacrylate in water. He felt that two significant factors had been overlooked in previous work, viz., the effect of shear rate and slip between coarse particles and smooth measuring surfaces.

To counteract the effect of settling, a concentric-cylinder, Feranti viscometer was modified by the addition of an impeller, four vertical and four horizontal baffles and grooves cut into the cylinder wall. The rotating impeller maintained the suspension with the help of the baffles which were so placed that rotational circulation was minimized and top-to-bottom circulation encouraged. The grooves prevented slip occurring between the particles and the cylinder walls but were large enough not to trap particles and hence prevent natural settling.

Clarke found that the rate of increase in the viscosity with concentration was dependent on the density, shape, size distribution, degree of roughness of the particle, and on the shear rate. A "critical point" was observed at a concentration of approximately 25 percent by volume for granular materials. The critical concentration was found to vary according to the type of solids used, i.e. between 15 percent and 40 percent by volume for glass rods and polymethylmethacralate respectively.

The value of viscosity recorded for a given concentration was generally higher than that reported in the literature. This was attributed to slip and plug flow occurring during measurements of viscosity by other viscometric means. Most of the suspensions studied by Clarke were shear thickening in nature but again this varied according to the suspension and was felt by Clarke to be due to four factors, viz. concentration, anisometry of shape, size and density of particle, which increased both the force and the frequency of the interactions.

The viscosity of the quartz suspension increased regularly with increased particle size, 30 to 180 microns, at all concentrations and at all shear rates. Increases in viscosity were also found with increasing density. This indicates that the viscosity is influenced by the inertia of the particle.

The results obtained by Clarke need to be examined carefully, due to the modifications that he made to his viscometer. Van Wazer [23] in his book on viscometers advocated that grooves be cut in the cylinder walls to eliminate slip between rough particles and smooth measuring surfaces. This permits a more accurate measurement of the viscosity of a suspension and Clarke found that this improved accuracy caused an increase in the measured value of the viscosity relative to other reported values for similar suspensions.

The viscosity of Clarke's suspension was measured while the agitator was rotating at 400 rpm which was the minimum speed to maintain the suspension. This rotation created a top to bottom circulation but nowhere is it reported whether the effect of this circulation on normal viscometric flow was investigated or taken into account. In fact he still used the manufacturer's calculated shear rates, after having completely altered their original bob. These last facts could be the reason why he is the only worker on suspension to have obtained shear thickening behaviour over the entire concentration range investigated.

The Research laborators of Anglo American Corporation [24] investigated the effect of concentration and particle size on the viscosity and on the leaching rate of a pulp containing copper using a Brookfield Synchro-Lectric viscometer, which measures the drag on a spindle rotating in a fluid. Pulp viscosity was taken over a range of pulp specific gravity from 1,1 to 1,6. The specific gravity of the liquid was varied by the addition of copper sulphate.

The main interest of the report lay in the determination of the "critical point", i.e. the point at which the linear relationship between viscosity and concentration ceased to hold. The data reported showed that an increase in the liquid specific gravity raised the value of the pulp specific gravity at which the critical point appeared. From the results of four experiments at different liquid specific gravity, a logarithmic correlation was predicted for critical pulp specific gravity as a function of liquid pulp specific gravity and solids specific gravity. However, due to the scatter of the four points, the validity of this correlation is doubtful.

The work done with two different sized particles, 60 and 35 microns, indicated that the range, over which the linear relationship held, increased with an increase in the particle size.

Beazley [16] worked on fourteen commercial kaolin clays to examine the validity of the root-reciprocal viscosity relationship (section 2.1.3) over a wide range of solids. This relationship is used by the research laboratories of Pochin and Co., England, as a basis for their routine control work. The original work was done by Clarke in 1948 and is reviewed in Beazley. The investigation was carried out using a cone-and-plate viscometer. The plots of the root-reciprocal of viscosity versus weight or volume fractions yielded linear curves for all the clays investigated. He concluded that, as a first approximation, this relationship held for a wide range of clays.

Beazley also found that a plot of viscosity versus concentration could be divided into three sections, Figure 2.1.

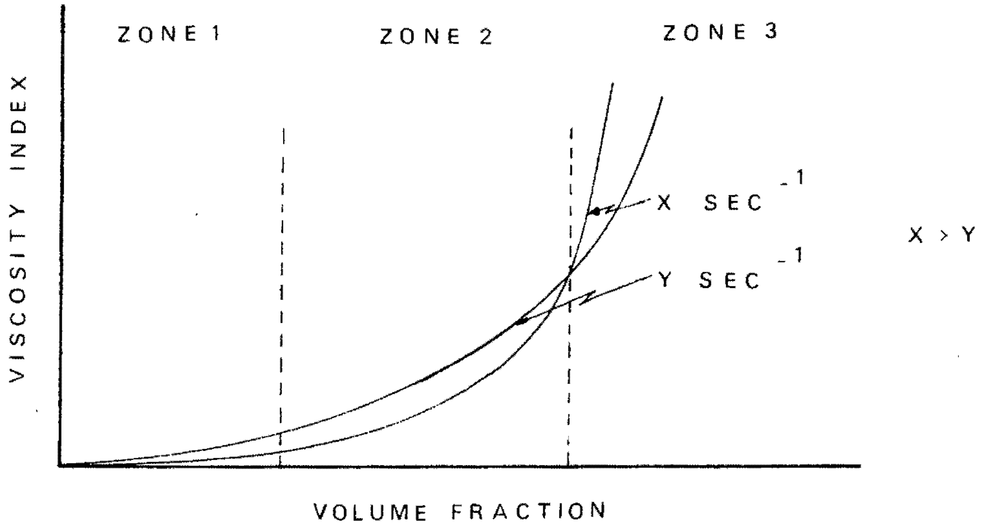


FIGURE 2.1 THE EFFECT OF CONCENTRATION AND SHEAR RATE ON THE VISCOSITY

The effect of concentration is different in each zone and the reason for this difference is explained as follows.

In zone 1 the particles are far apart and only distort the flow lines of the water when they move. The viscosity in this zone is described by the Einstein equation and exists for concentration of solids up to a volume fraction of 0,2 depending on the type of clay.

In the second zone, not only is the flow path of the water distorted by flow past each clay particle but, as the particles are very close together, the flow lines around each particle interact with each other and cause a large increase in the viscosity. Further, the particles in this zone can be sufficiently close together to give rise to significant interparticle forces, against which the particles have to move.

The last zone is determined by increasing mechanical interparticle interference and hindrance, and shows shear thickening behaviour. The particles achieve the highest concentration possible which still gives the system the characteristics of a suspension.

Beazley correlated all his data using an extension of Mooney's [14] equation

$$\eta_{rel} = \exp\left(\frac{A\,\phi}{1 - K\phi}\right) \qquad (2\text{-}31)$$

He found that above a volume fraction of 0,47 the clay became shear thickening and thus used a four term equation

$$\eta_{rel} = \exp\left(\frac{A_1\phi}{1 - K_1\phi}\right) \cdot \exp\left(\frac{A_2\phi}{1 - K_2\phi}\right) \qquad (2\text{-}32)$$

to fit his data over the entire concentration range.

Van der Walt and Fourie [25] in their investigation of dense-medium processes for the cleaning of coal, modified a Stormer viscometer to determine the yield stresses and apparent viscosity of the suspensions. They described a method whereby the viscosity versus volume fraction curves could be plotted. Their curves were exponential in nature. However, they did not present any theory nor did they attempt to correlate their experimental results.

2.3 CONCLUSIONS

The equations that predict the effect of concentration on the viscosity of a suspension have been derived either theoretically, semi-empirically or experimentally and thus the resulting forms are completely different. In order to be able to compare them it was thus necessary to convert them all to a common basis. Use was made of Taylor expansions to present the equations in the form of

$$\eta_{rel} = a_0 + a_1\phi + a_2\phi^2 + a_3\phi^3 + \ldots. \qquad (2\text{-}33)$$

The equations are listed in Table 2.1.

TABLE 2.1

Relationships for Relative Viscosity as; $\eta_{rel} = a_0+a_1\phi+a_2\phi^2+a_3\phi^3+a_4\phi^4 ....$

WORKER	REF.	EQUATION	COEFFICIENTS IN EXPANSION				
			a_0	a_1	a_2	a_3	a_4
Einstein	1	$\eta_{rel} = 1+2,5\phi$	1	2,5	0	0	0
Gold	3	$\eta_{rel} = 1+2,5\left(1 + \frac{5}{16}\frac{a}{d}\right)\phi$	1	2,5	14,1	+	+
Burgers and Saito	4,5	$\eta_{rel} = 1+2,5\phi+12,6\phi^2 + ...$	1	2,5	12,6	+	+
De Bruijn	8	$\frac{1}{\eta_{rel}} = 1-2,5\phi+1,55\phi$	1	2,5	4,7	0	0
De Bruijn	8	$\frac{1}{\eta_{rel}} = \frac{(1-\phi)}{(1+1,5\phi)}$	1	2,5	2,5	+	+
Vand	9	$\eta_{rel} = \exp(2,5\phi)$	1	2,5	3,125	2,604	1,627
Vand	9	$\eta_{rel} = \exp\left[\frac{2,5\phi}{1- \frac{39}{64}\phi}\right]$	1	2,5	4,65	+	+
Vand	9	$\eta_{rel} = 1+2,5\phi+7,35\phi^2 + ...$	1	2,5	7,35	+	+
Vand, Roscoe & Brinkman	9,10,11	$\eta_{rel} = (1-\phi)^{-2,5}$	1	2,5	4,375	6,562	9,023
Roscoe	10	$\eta_{rel} = (1-1,35)^{-2,5}$	1	3,375	7,973	16,143	29,947
Mooney	14	$\eta_{rel} = \exp\left(\frac{2,5\phi}{1-K\phi}\right)$ for K=1,35	1	2,5	6,5	7,116	+
Mooney	14	$\eta_{rel} = \exp\left(\frac{2,5\phi}{1-K\phi}\right)$ for K=1,91	1	2,5	7,9	26,404	+
Shaheen	20	$\eta_{rel} = \exp\left(\frac{2,5\phi}{1-a\phi\ n}\right)$ for n=0,5	$1+2,5\phi+1,935a^2\phi^2+(3,906a+24,435a^3+11,166a^4)\phi^3+...$				
Frankel & Acrivos	15	$\eta_{rel} = \frac{9}{8}\left(\frac{(\phi/\phi_m)^{1/3}}{1-(\phi/\phi_m)^{1/3}}\right)$ for ϕ_m=0,74	$1,156\phi^{1\ 3}+1,222\phi^{2\ 3}+1,35\phi+1,49\phi^{4\ 3}+ ....$				

As can be seen from this table the value of "a_1" is 2,5 in most of the equations. This is as a result of the fact that all the equations follow on from Einstein's original equation for dilute suspensions, which is

$$\eta_{rel} = 1 + 2,5\ \phi \qquad (2\text{-}34)$$

Thereafter the value of the constants differ from equation to equation depending on which simplifying assumptions were made when deriving the equation.

All the experimental work performed on slurries has utilized either a capillary or a rotational viscometer. The results obtained by each worker are presented and discussed in a qualitative manner, but the following two conclusions can be drawn from these discussions. (i) There exists an exponential relationship between the viscosity index and the concentration, and (ii) there is a direct relationship between the size of the particles and the viscosity. The relationship between particle size and viscosity is not a simple one and various workers have obtained different, and in some cases the direct opposite, results. De Vaney and Shelton [17] found an increase in the viscosity for decreasing particle size. Shack, Dean and Malloy [18] predicted a parabolic relationship, where the viscosity increased with decreasing particle size until a maximum was reached at approximately 20 microns after which the viscosity decreased. Shaheen [20] studied two size fractions and found that the viscosity was greatest for the larger particles but when studying a mixture of these two particles he found that the viscosity of the mixture decreased when small particles were first added but then increased with the further addition of small particles. He has suggested that the smaller particles first act as lubricants to the larger ones before they contribute to the viscosity. Clarke [22] found that the viscosity increased with increasing particle size.

The results obtained by Clarke can possibly be discounted as a result of the modifications that he made to his viscometer (section 2.2.2). The results obtained by the other workers indicate that (i) the viscosity increases with decreasing particle size (ii) the viscosity of a mixture of only two sizes goes through a minimum before starting to increase and (iii) for a continuous size distribution of particles the viscosity increases with decreasing particle size.

Although these are a number of theoretical equations which predict the viscosity of a suspension of spherical particles, it is not possible to justify the use of one above another as each equation has an error associated with it. These equations are also derived for use with idealistic situations, i.e. equal sized spherical particles, and thus it is evident that more work is required on suspensions in order to be able to predict the effect of concentration, size of particles, shear rate, etc., on the viscosity of a suspension of non-ideal particles, i.e. non-spherical, rough particles of different sizes.

CHAPTER 3

THEORY OF VISCOMETERS

3.1 INTRODUCTION

Two types of viscometers have been used in all previous work on slurries, the capillary and the rotational (sections 2.2.1 and 2.2.2).

The use of a capillary viscometer, similar to the "consistometer" used by De vaney and Shelton [17], was considered for this study, but rejected for the following reasons:

(i) the effect of swirl on the viscosity is unknown;
(ii) settling of the pulp during measurements;
(iii) migration of particles to the centre of the tube;
(iv) blockages of the tube.

In order to maintain a homogeneous suspension, De Vaney and Shelton [17] used a paddle which rotated in the reservoir of the viscometer. The swirl, induced by this rotating motion, has to stop before any measurement can be made. This is necessary as the effect on the viscosity determination of swirling flow through a capillary tube is unknown. If this swirl is allowed to die out before any measurement is taken, the suspension will no longer be homogeneously suspended while entering the discharge tube.

Repetti and Leonard [26] have also found that spheres in a suspension flowing down a capillary tube migrate to the centre. This results in a layer of liquid at the wall and a plug of suspension in the centre of the tube. The viscosity measured for this system is very much lower than the actual viscosity, due to this effective slip.

The particles found in a pulp are irregular in shape and the possibility of aggregation of the particles with subsequent blockages of the tube can not be ruled out.

These facts, plus the uncertainty of the shear rate being exerted on the pulp as a result of its non-Newtonian behaviour, are the reasons why the "consistometer" was not used.

Three rotational vicometers were considered for this investigation - the cone-and-plate, concentric cylinder and spindle-in-fluid viscometers.

Both the Brookfield [27] and the Haake [28] cone-and-plate viscometers require only a small sample, 1,5 and 0,5 mℓ respectively, for analysis. Difficulties were envisaged in obtaining a true representation of the pulp with such a small sample. It was also impossible to see whether settling was taking place within the sample cup. The danger also existed that, due to the abrasiveness of the pulp, the apex of the cone would be damaged after prolonged use. Thus this viscometric apparatus could not be used.

The concentric cylinder viscometer is used to determine the viscosity of homogeneous non-Newtonian liquids but its use is limited when dealing with suspensions. Normally, a sample, once placed in the viscometer, is not removed until the entire run is completed. However, if the sample settles out, as experimentation with a Haake viscometer confirmed, it means that after each reading is completed, the sample will have to be removed, the viscometer cleaned and another sample placed in it. This technique will require a large number of samples of the same concentration which is extremely difficult to achieve in practice.

Clarke [22] has suggested various modifications to be made to this attachment (section 2.2.2) in order to enable it to measure the viscosity of a settling non-Newtonian suspension. These modifications necessitate major alterations of the existing viscometer and it was felt that this could not be motivated until all the other possibilities had been ruled out, as doubt has been cast on the validity of the measurement made after the modifications have been carried out (section 2.2.2).

The work done by Rosen [29,30] on non Newtonian emulsions and Anglo American Research Laboratories [24] on copper extraction, suggested the use of a Brookfield [27] spindle-in-fluid viscometer. Preliminary experimentation and calculations, section 4.3.4, indicated that this viscometer, used in conjunction with an external stirrer, could be used for determining the viscosity of settling non-Newtonian suspensions. The theory of this viscometer is explained in the next section, while the experimental apparatus can be found in section 4.2.

3.2 ADAPTATION OF THE THEORY OF THE VISCOMETER TO NON-NEWTONIAN SYSTEMS

A simple theory has been presented by Rosen [29,30], who investigated agglomerates in silicone emulsions, for the determination of the rheological properties of a power-law non-Newtonian liquid. He used a Brookfield Synchro-Lectric [27] viscometer which rotates a spindle in the liquid at a constant speed and measures the torque necessary to overcome the resulting viscous drag. This torque is measured by a copper-beryllium spring which, for a given speed and spindle, produces a deflection on the dial of the instrument. This deflection is proportional to the viscosity.

For a Newtonian liquid the viscosity is obtained by multiplying the dial reading by a suitable "factor" obtained from a "factor finder" supplied with the instrument. Since apparent viscosity varies with shear rate in non-Newtonian liquids, a one-point viscosity measurement is insufficient to describe their flow properties. A power-law non-Newtonian liquid is one which can be characterized by a value of the apparent viscosity at a specific shear rate and an index which describes the deviation from Newtonian behaviour.

To determine the apparent viscosity, η, of a non-Newtonian liquid it is necessary to calculate both the shear stress, τ, and the shear rate, $\dot{\gamma}$, since,

$$\eta = - \frac{\tau}{\dot{\gamma}} \tag{3-1}$$

For a cup of large diameter, the shear rate at the surface of a cylindrical spindle may be calculated by assuming a model of an infinitely long cylinder in an infinite sea of fluid. For such a situation Krieger and Maron [31] have shown that

$$\dot{\gamma} = 2 \frac{d\omega}{d \ln\tau} \tag{3-2}$$

where ω = angular velocity in radius per second,

τ = shear stress at the surface of the spindle in dynes per cm^2,

and $\dot{\gamma}$ = shear rate, sec^{-1}

The details of the Krieger and Maron derivation are given in Appendix A.

From Equation 3-2, it can be shown that

$$\dot{\gamma} = - 2 \omega \frac{d \ln\omega}{d \ln\tau} \tag{3-3}$$

Equation 3-3 is valid for any liquid that does not have a yield stress.

The rheological equation of state for a power-law liquid can be expressed as

$$\tau = - K |\dot{\gamma}|^{n-1} \dot{\gamma} \tag{3-4}$$

where K = projected value of τ at a shear rate of 1 sec^{-1}

and n = flow behaviour index.

Taking logarithms and differentiating Equation 3-4 with respect to $\dot{\gamma}$ yields:

$$n = d \ln\tau / d \ln\dot{\gamma} \tag{3-5}$$

The shear thinning index, STI, can be defined as:

$$\mathrm{STI} - d \ln\omega / d \ln\tau \qquad (3\text{-}6)$$

It can be shown that for a power-law liquid STI is a constant and

$$\mathrm{STI} = 1/n \qquad (3\text{-}7)$$

The angular velocity, ω, is directly proportional to the rotational speed and the shear stress, τ, is a function of dial reading. From Equation 3-5, 3-6 and 3-7 the slope of a plot of log (rpm) versus log (dial reading) is the shear thinning index, STI.

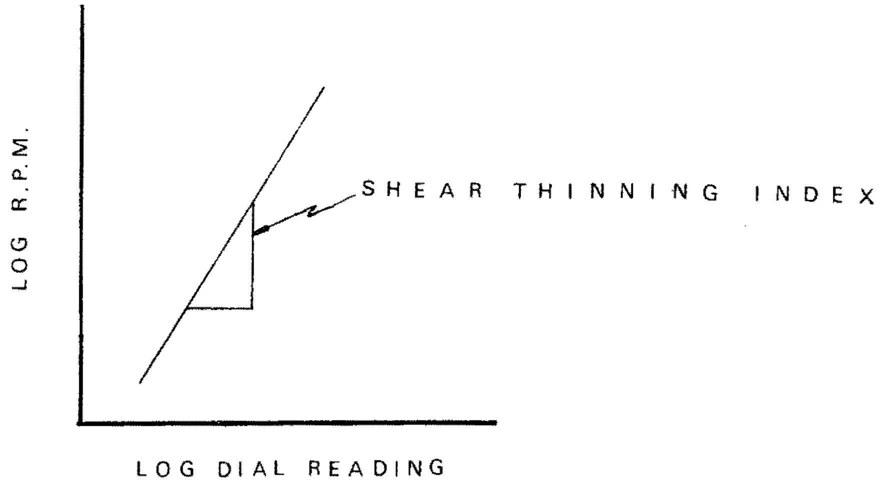


FIGURE 3.1 A PLOT OF ROTATIONAL SPEED VERSUS DIAL READING

The shear rate, $\dot{\gamma}$, may be obtained at any rotational speed by rewriting Equation 3-3 as

$$\dot{\gamma} = - K_1 \times \mathrm{STI} \qquad (3\text{-}8)$$

where $K_1 = \frac{\pi}{15} \times \mathrm{rpm}$.

The shear stress, τ, may be obtained from the general expression for a cylinder rotating in a cup [32] which is

$$\tau = T/2\pi r^2 \; L_e \qquad (3-9)$$

where T = torque in dyne-cm, obtained by multiplying the dial deflection by the spring constant of the viscometer divided by one hundred,

r = radius of the cylinder in centimeters,

and L_e = the "effective length" in centimeters.

$$\therefore \quad \tau = \frac{\text{Dial Reading x spring constant / 100}}{2\pi \;\; (\text{radius})^2 \;\; (\text{effective length})} \qquad (3-10)$$

The viscosity, η, can be obtained by dividing Equation 3-10 by Equation 3-8 and obtaining

$$\eta = K_2 \text{ x Dial reading / STI} \qquad (3-11)$$

where $K_2 = \dfrac{\text{spring constant of viscometer}}{2\pi r^2 \cdot \text{"effective length"} \cdot K_1}$

As a cylinder of finite length is used, rather than one of infinite length assumed in the model, an "effective length" is required which accounts for the drag on the top and the bottom of the cylinders. The determination of this effective length is described in section 4.3.3.

As has been shown above the rheological properties of a power-law liquid can be defined completely by one apparent vixcosity, η, at a specific shear rate, $\dot{\gamma}$, and the flow behaviour index, n. The shear rate, $\dot{\gamma}$, can be expressed as a linear function of the angular velocity, ω, as

$$|\dot{\gamma}| = \kappa \; \omega \qquad (3-12)$$

Rearranging Equations 3-3, 3-6 and 3-12, it can be shown that the slope of a plot of log (viscosity) versus log (shear rate) can be expressed in terms of the shear thinning index as

$$\frac{d\ \ln\eta}{d\ \ln\dot{\gamma}} = \frac{1 - STI}{STI} \qquad (3\text{-}13)$$

Therefore, knowing the value of the viscosity at any shear rate and the shear thinning index it is possible to plot the entire shear rate versus viscosity rheogram as shown in Figure 3.2.

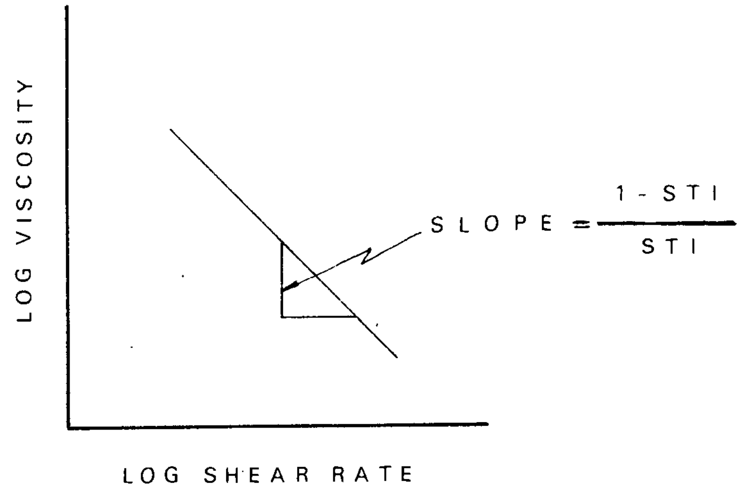


FIGURE 3.2 RHEOGRAM OF SHEAR RATE VERSUS VISCOSITY

Thus, once the STI is obtained, as shown in Figure 3.1, and the value of the viscosity is calculated at a specific shear rate, it is possible to predict the apparent viscosity at any shear rate using either Equation 3-13 or a plot of log (viscosity) versus log (shear rate) as shown in Figure 3.2.

CHAPTER 4

EXPERIMENTAL WORK AND APPARATUS

4.1 INTRODUCTION

A typical gold mine reduction plant generates 3 pulps of different pH when extracting both gold and uranium. These are: a pulp consisting of freshly milled ore, pH 6,8 to 7,2, containing both uranium and gold; an acid pulp, pH 2,8 containing only gold as all the uranium has been removed using a liquid-extraction process; and an alkali pulp, pH 10,8, containing neither gold nor uranium.

The effect of concentration and temperature on the viscosity of these three pulps was investigated using the method described in section 4.5.1. The pulps obtained for investigation were: a neutral and an acid pulp from West Driefontein and an alkali pulp from West Rand Consolidated. As each pulp was at a different pH, it is only possible to infer the effect of pH on the viscosity of a pulp. This is discussed in section 5.3.3.

In order to maintain a homogeneous suspension, it was necessary to add an external stirrer to the normal viscometric apparatus. The effect of this modification is examined in section 4.3.2. A new spindle had to be built as well in order to extend the range of the viscometer and the calibration of this spindle is described in section 4.3.3. The method used for determining the pulp and solids densities is described in section 4.3.5.

4.2 APPARATUS

The apparatus used in all the work was a Brookfield Synchro-Lectric LVT model [27]. This is an eight speed (0,3; 0,6; 1,5; 3; 6; 12; 30 and 60 rpm) rotational viscometer which rotates a cylinder or disk and measures the torque necessary to overcome the viscous drag. The guard supplied with the viscometer for use with Newtonian liquids was not used in these experiments.

Three spindles were used to enable the viscometer to measure the viscosity of the pulps over the entire concentration range. Two of these spindles are commercially available (LV Model Cylindrical Spindles [27]), whereas the third had to be specially built. This was done by designing a perspex sleeve which slipped on to one of the spindles thereby creating a new one. The use of an o-ring allowed the sleeve to slip on and off, but once on, permitted no relative movement between the spindle and the sleeve, even when the viscometer exerted its maximum torque.

Schematic drawing of all 3 spindles are shown in Figure 4.1 and the major dimensions are listed in Table 4.1.

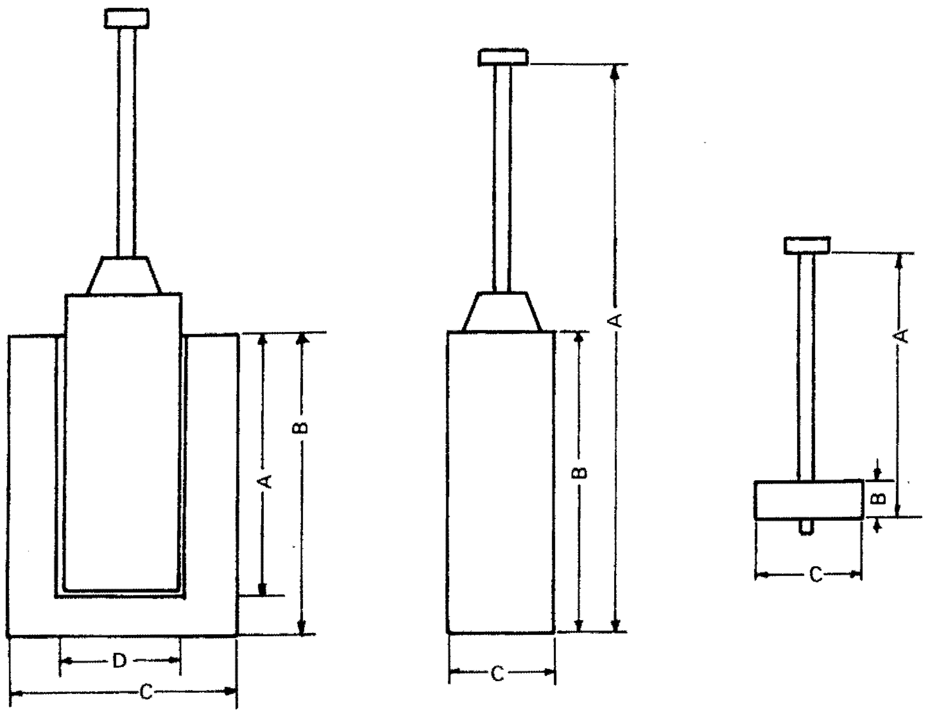


FIGURE 4.1 SCHEMATIC DRAWINGS OF THE 3 SPINDLES

TABLE 4.1 DIMENSIONS OF SPINDLES WITH REFERENCE TO FIG.4.1

Spindle Dimension	0	1	2
A	6,51	8,12	3,17
B	6,81	6,53	0,68
C	3,79	1,87	1,84
D	1,89	-	-

For temperature control, the beaker containing the pulp was immersed in a jacket through which water was pumped. The temperature of this water was controlled by both a heating element and a cooling coil which gave an effective range of 8 to 50°C. Temperature variations within this range were less than 0,2°C. The heating element used was a labotec model no.103 and the cooling coil was a Fryka-Kaltetechnic DLK 300.

Beakers of two sizes were used - a 600 mℓ beaker when spindle 1 or 2 was attached and a 1 litre beaker for spindle 0. A table of all the dimensions and clearances is shown in Table 4.2.

TABLE 4.2 DIMENSION AND CLEARANCE IN BEAKERS

Spindle	Beaker	d_S/d_B	Clearance from bottom
0	1 000	0,361	5,3 cm
1	600	0,2113	2,43 cm
2	600	0,2079	7,38 cm

Air agitation in a mini pachuca tank was used to initially suspend the pulp. Concentration was determined using a specific gravity bottle and a standard laboratory magnetic stirrer was used for mixing.

A schematic drawing of the experimental apparatus is shown in Figure 4.2 and one of the viscometer is shown in Figure 4.3.

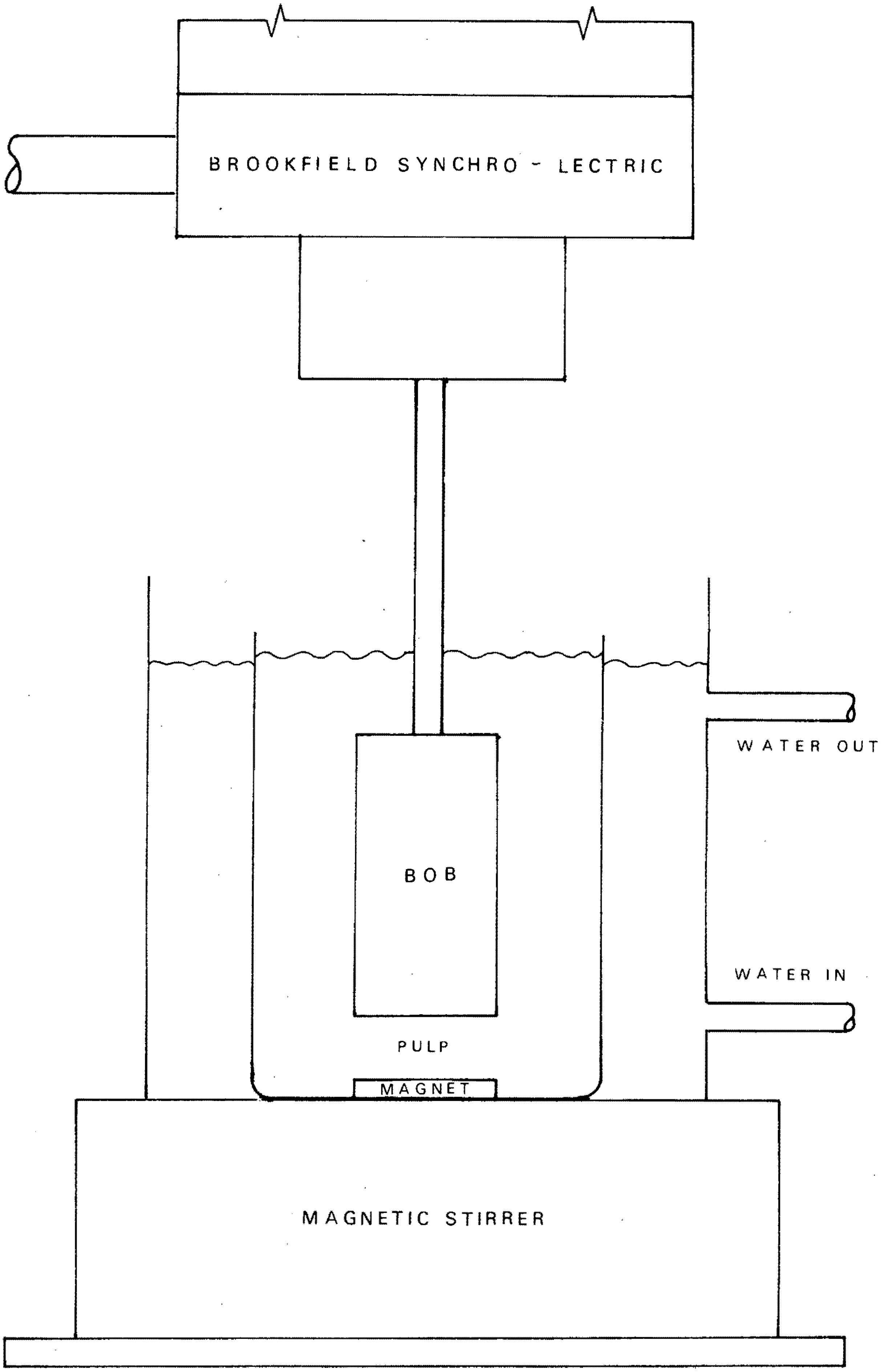
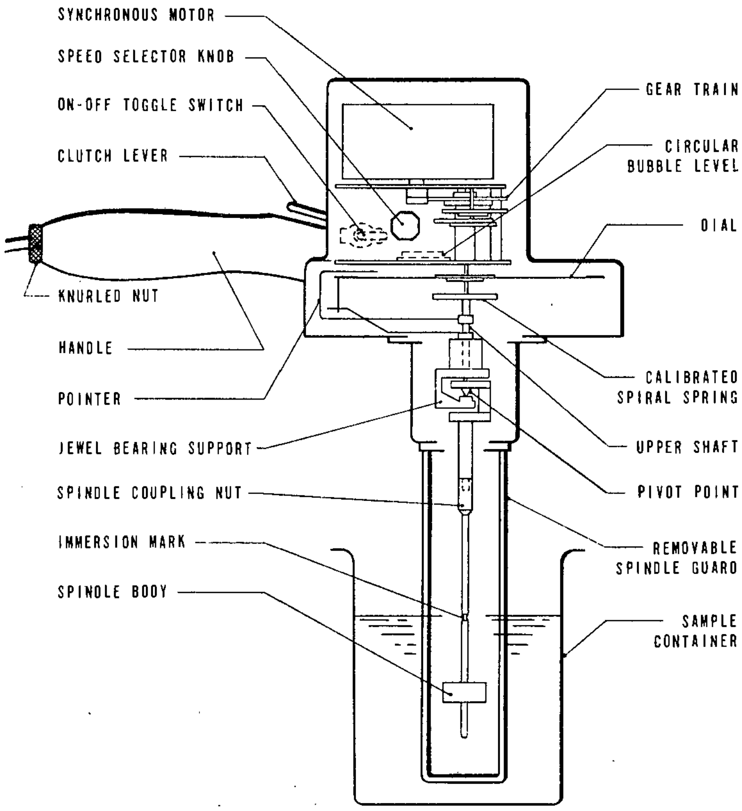


FIGURE 4.2 SCHEMATIC DRAWING OF THE EXPERIMENTAL APPARATUS



SCHEMATIC DRAWING OF THE
BROOKFIELD SYNCHRO-LECTRIC VISCOMETER

4.3 EXPERIMENTAL WORK

4.3.1 Experimental technique

A beaker containing a homogeneous sample of pulp of known concentration, previously determined by the use of a specific gravity bottle (section 4.3.5) was placed in a water jacket fixed above a magnetic stirrer, which was then switched on. The viscometer was then placed in position and the spindle immersed to a pre-set depth, determined by a notch on the spindle. A special laboratory stand, available from the manufacturers [27], was used to ensure that the viscometer was level and remained in the same horizontal plane for the duration of the experimental run. The temperature regulator was set to the required temperature and the pulp allowed to reach steady state.

The experimental data was obtained by selecting a speed of rotation for the viscometer and noting the deflection of the pointer on the dial. Due to the construction of this particular viscometer, the dial pointer oscillated before settling down. The readings taken were those at steady state, indicated by no change in the dial reading for three successive rotations. A minimum of three readings were taken at each rotational speed. The magnetic stirrer was used to resuspend the pulp after each reading. Section 4.3.2 has a discussion on the effects of the magnetic stirrer.

These readings were repeated for each selected speed of rotation. It was not possible to use the full speed range of the instrument in all cases because (i) the lower speeds caused no deflection of the pointer, (ii) accuracy could not be obtained at the lower speeds and (iii) the time to damp out the oscillations of the pointer exceeded the settling time of the suspension.

This last fact requires further explanation. As stated earlier the construction of this viscometer caused the needle to oscillate before settling down to a constant reading. However, as the pulp was settling all the time, a reading was only taken when the pointer had remained constant for three successive rotations of the viscometer. Although this reading was taken at a quasi steady state, reproducible results were obtained. However, by the time the needle stopped oscillating at the lower speeds, even this "steady state" could not be attained and the pointer moved lower and lower on each rotation. The effect of this quasi steady state on the viscosity is explained in section 4.3.4.

Working within these limitations, readings were taken at as many rotational speeds as possible, usually four but never less than three. After the run had been completed, a new temperature was selected and after equilibrium had been reached, the procedure was repeated. Normally three to four temperatures, in the range 8 to 30 degrees Centigrade were investigated for each concentration.

The above represents only the lower half of the temperature range found on a typical mine but, as a result of problems caused by evaporation, namely increasing concentration (section 5.3.2) it was decided, that for this first investigation, this would be adequate.

4.3.2 The effect of agitation by a stirrer

In order to ensure that the viscosity of a homogeneous suspension was being measured, it was necessary to resuspend the pulp by means of a magnetic stirrer before each reading. There are two ways of taking a measurement once the pulp is uniformly suspended, viz. (i) switching the viscometer on when the swirling induced by the stirrer has ceased and (ii) switching the viscometer on before switching the stirrer off.

In the first method a visual observation was made of the pulp movement and when this had ceased, the viscometer was switched on. The pointer oscillated for 6 to 8 revolutions before settling down to a constant value. It remained constant for a number of revolutions before changing, presumably due to the settling of the pulp. The reading was taken at a steady value. The variation of the dial reading with time is shown in Table 4.3.

TABLE 4.3 VARIATION OF DIAL READING WITH TIME (METHOD 1)

No.of revs.	Dial reading	No.of revs.	Dial reading
2	50,9	14	31,2
4	25,1	16	30,8
6	31,5	18	30,0
8	31,2	20	28,8
10	31,2	22	28,0
12	31,2	24	

In the second method, the viscometer was switched on before the agitator was switched off which resulted in the needle oscillating for 14 to 16 revolutions before settling down to the same value as before. This is shown in Table 4.4.

TABLE 4.4 VARIATION OF DIAL READING WITH TIME (METHOD 2)

No.of revs.	Dial reading	No.of revs.	Dial reading
2	0	16	35,6
4	0	18	31,0
6	0	20	31,4
8	55,3	22	31,4
10	15,8	24	31,4
12	45,3	26	31,4
14	20,8	28	31,0

Although the same end result was reached, the first method is much simpler and was used for the rest of the experiments performed. The method used, therefore, does not influence the results. Two further queries arose, however, from these results, (i) whether the results obtained were reproducible and (ii) whether the time and intensity of agitation affected the readings obtained.

The results obtained were reproducible as can be seen from a typical run shown in Table 4.5. This reproducibility indicates that the pulp was uniformly suspended before each reading was taken and that the proposed quasi steady state existed.

TABLE 4.5 A TYPICAL RUN (RUN 12)

Speed	Dial reading	Speed	Dial reading
3	21,8	12	28,6
3	22,1	30	33,2
3	22,0	30	33,3
6	23,6	30	33,2
6	23,9	60	39,8
6	23,9	60	39,9
12	28,6	60	39,7
12	28,5		

In order to evaluate whether the mode of agitation had any effect on the readings, a run was performed varying either the speed of the agitator or the length of time the pulp was agitated with the following results.

TABLE 4.6 THE EFFECT OF THE AGITATOR ON THE DIAL READING

Speed	Time of Agitation	Dial reading
½	30 sec	47,2
¾	30 sec	47,8
full	30 sec	46,8
½	1 min	47,2
½	3 min	48,0
½	30 min	47,0

The results show that allowing either parameter to vary has no effect on the reading. Thus it does not matter what type of agitator is used to resuspend the pulp provided that it does not interfere with the operation of the viscometer.

The possibility that the behaviour of the pulp was time dependent was investigated by performing the following experiment. Each successive reading was taken at an increased shear rate until the maximum shear rate was reached. The procedure was then reversed. The results obtained are shown in Table 4.7.

TABLE 4.7 READING TAKEN AT INCREASING AND DECREASING SHEAR RATE (RUN 15)

Speed	Dial reading	Speed	Dial reading
3	75,5	12	93,6
3	75,0	6	83,2
6	85,0	3	83,0
6	83,0	3	74,2
6	84,0	3	74,0
12	93,5	1,5	68,0
12	93,8	1,5	67,0

For the same shear rate, the results obtained are similar and are independent of whether it was taken while the shear rate was increasing or decreasing, which proves that the pulp cannot be time dependent.

4.3.3 Calibration of spindles

Before a spindle could be used it was necessary to calibrate it in order to determine the "end effects". This is necessary as the mathematical model which determines the viscosity of a liquid using a spindle, assumes an infinitely long cylinder and therefore does not take into account the drag on the ends of the spindle. This is allowed for by using an "effective length" instead of the actual length of the spindle. For commercial spindles the "effective length" is given [27], however, it is necessary to determine the "effective length" of a new spindle experimentally.

The method, recommended by Rosen [29], was used, which is based on the following theory. The viscosity of a Newtonian liquid determined with the aid of a Brookfield viscometer is

$$\mu = K_2 \times R \qquad (4\text{-}1)$$

where R = dial reading

and $$K = \frac{S}{2\pi r^2 \times L_e \times K_1} \qquad (4\text{-}2)$$

where S is the spring constant = 673,7 dyne.cm for the Brookfield LVT [27]

r = radius of spindle attached

$$K_1 = \frac{\pi}{15} \times N \qquad (4\text{-}3)$$

N = rpm

L_e = effective length

.: from Equations 4-1, 4-2, and 4-3

$$L_e = \frac{15 \times S}{2\pi r^2 \times \pi \times N} \times \frac{R}{\mu}$$

$$.: \quad L_e = \frac{C_1}{r^2 \times N} \times \frac{R}{\mu} \qquad (4\text{-}4)$$

.: the true viscosity is

$$\mu = \frac{C_1}{r^2 \times N \times L_e} \qquad (4\text{-}5)$$

However, if L_e is not known, an apparent viscosity μ^* can be calculated using the actual length of the spindle as

$$\mu^* = \frac{C_1}{r^2 \times N} \times \frac{R}{L} \qquad (4\text{-}6)$$

Dividing Equation 4-6 by Equation 4-5

$$\frac{L_e}{L} = \frac{\mu^*}{\mu}$$

$$\therefore \quad L_e = \frac{\mu^* \times L}{\mu} \tag{4-7}$$

Therefore the effective length, L_e, can be calculated by measuring the length of the spindle, determining μ^* experimentally, using the Brookfield viscometer, and knowing the true viscosity, μ, from some other measurement.

The experimental method used was as follows: The viscosity of a Newtonian oil was accurately determined with the aid of a laboratory Oswald viscometer, which had previously been calibrated using 90 percent w/w glycerol in water. The results obtained were:

Specific gravity of oil = 0,879 g/cc
The average time to flow through the Oswald
  viscometer = 79 secs
Calibrated factor for this Oswald = 0,373489 $\frac{\text{cm}^2}{\text{sec}^2}$

$$\therefore \text{ viscosity of oil} = o{,}373489 \times 0{,}879 \times 79$$
$$= 25{,}95 \text{ mPa·s}$$

The viscosity of oil determined by the Brookfield viscometer using the actual length in the calculation is

$$\mu = 38{,}804 \text{ mPa·s}$$

$$\therefore \quad \text{effective length} = \frac{38{,}804 \times 6{,}835}{25{,}95}$$

$$= 10{,}1168 \text{ cm}$$

As a check on this method, the effective length of a commercial spindle, no.1, was determined. The result was an effective length of 7,494 cm, compared with 7,493 cm, quoted by the manufacturers, Brookfield Laboratories [27]. Thus the method is applicable and the effective length obtained was used in all the calculations. Appendix G contains the results used to determine the effective length of the spindles.

4.3.4 Calculation of settling rate of pulp and the effect of settling on Viscometric Measurements

This section of the thesis has been deleted
and should be ignored.

order to answer this, it is necessary to be able to calculate the rate of settling of a suspension and the contribution that each particle makes to the viscosity.

Richardson and Zaki [33] have derived an equation which predicts the rate of hindered settling of a particle once the terminal settling velocity is known. From this, the rate of settling of the suspension can be calculated.

Shaheen [20] has derived an equation which calculates the viscosity of a suspension which has only two particle sizes, i.e. a discrete particle analysis. Thus the contribution of each fraction of particles to the total viscosity of the suspension can be calculated. In order to use this fact, it is necessary to divide a continuous size distribution into two fractions. Analysis of the size distribution of the acid pulp, shown in Table E.2, Appendix F, showed the existence of two natural peaks, one with its midpoint at 76,5 microns and one at 30,0 microns. This division yielded that 12 percent of the particles had a size of 76,5 microns and 88 percent of the particles had a size of 30,0 microns.

Thus, using the above facts, it is possible to calculate the rate of settling of a suspension and the contribution that each particle makes to the viscosity, which is done as follows:

The terminal settling velocity for a particle, from Stoke's law, is

$$U_t = \frac{D_p{}^2(\rho_s - \rho)g}{18\ \mu} \qquad (4\text{-}8)$$

where D_p = particle diameter

ρ_s, ρ = density of solid and liquid respectively

μ = viscosity of liquid

Therefore the terminal settling velocity for each peak, settling in water at 20,2°C is

$$U_{t_1} = \frac{(76,5 \times 10^{-6})^2 (2,5938 - 0,998) \times 10^3 \times 9,8}{18 \times 10^{-3}}$$

$$= 0,00508 \text{ m/s}$$

and

$$U_{t_2} = \frac{(30 \times 10^{-6})^2 \ (2,5938 - 0,998) \times 10^3 \times 9,8}{18 \times 10^{-3}}$$

$$= 0,00078 \text{ m/s}$$

A check on the Reynolds number revealed that both particles were settling within the region for which Stoke's law was valid.

$$N_{Re_1} = \frac{U_t D\rho}{\mu}$$

$$= 0,38897$$

and $$N_{Re_2} = 0,0234$$

Richardson and Zaki [33] have derived the following equation for particles settling as a hindered mass

$$V_c = V_0 \ \varepsilon^{0,45} \tag{4-9}$$

where V_c = hindered settling velocity

V_0 = terminal settling velocity for a single particle

ε = void fraction = 1 - volume fraction.

The terminal settling velocities were calculated for each fraction at several values of the total solids concentrations. These are tabulated in Table 4.8.

TABLE 4.8 SETTLING VELOCITIES FOR HINDERED SETTLING

Volume fraction solids	ε	V_{c_1} m/s	V_{c_2} m/s
0,0	1,0	0,00508	0,00078
0,1	0,9	0,00484	0,00074
0,2	0,8	0,00459	0,00071
0,3	0,7	0,00433	0,00066
0,4	0,6	0,00404	0,00062

The values show that the settling rate of the heavier particles is so large that, even for a high concentration, these particles settle almost immediately and that any viscosity measurement made would not incorporate their contribution. The lighter particles settle much more slowly and thus the measured viscosity is only due to the contribution of these lighter particles. This means that the viscosity contributed to the suspension by 12 percent of the particles is not being measured and it is interesting to establish what effect this contribution would have on the viscosity.

Shaheen [20] has derived an equation which predicts the viscosity of a suspension as

$$\eta_{rel} = \exp\left(\frac{A\ \phi}{1 - \alpha\phi^n}\right) \qquad (4\text{-}10)$$

where A = constant determined experimentally = 2,5
n, α = constants for the suspension.

He has also derived an expression to predict the viscosity of a suspension with two fractions of different sized particles as

$$\eta_{rel} = \exp\left(\frac{A\phi_1}{1 - \alpha_1\phi_2{}^{n_1}}\right) \cdot \exp\left(\frac{A\phi_2}{1 - \alpha_2\phi_2{}^{n_2}}\right) \quad (4\text{-}11)$$

In order to determine the effect of neglecting the heavier particles, the viscosity of a suspension was calculated using Equation 4-11 for a total volume fraction of 30 percent.

$$\eta_{rel_1} = \exp\left(\frac{5{,}5\ \phi}{1 - \alpha\phi^n}\right)$$

$$= 1{,}3217$$

and $\eta_{rel_2} = 26{,}645$

.: $\eta_{rel_{susp}} = 1{,}3217 \times 26{,}645$

$$= 35{,}217$$

The actual viscosity was calculated using Equation 4-10 and the result is

$$\eta_{rel} = 51{,}57$$

Two facts emerge from these calculations; (i) even though a discrete size distribution was assumed, the viscosity calculated agrees very well with the actual viscosity and (ii) it will be possible to calculate the contribution of either fraction of particles to the total viscosity.

It was found that the heavier fraction contributes only 3,7 percent of the total viscosity of the suspension. This error is well within the accuracy of the experiment used to determine the viscosity. In practice the suspension settles far slower than was predicted and thus the time that the quasi steady state exists is very much longer than estimated. The heavier particles also settle slower than estimated and thus the error in determining the viscosity is probably less than the 3,7 percent predicted.

~~In conclusion it can be stated that once the suspension was uniformly suspended, it remained so for the entire period over which the measurement was taken. Settling did take place but, as has been proved above, this has a negligible effect on the viscosity of the suspension. These points prove that the method described in section 4.3.1 for the determination of a suspension of fine material, such as found in a gold mine pulp, is valid.~~

4.3.5 The determination of pulp and solid densities

In order to determine the pulp density a specific gravity bottle was used. Temperature effects were eliminated by determining the density of water at ambient temperature immediately before determining the density of the pulp:

$$\rho_{\text{pulp}} = \frac{F - C}{D - C} \tag{4-12}$$

where F = mass of specific gravity bottle plus pulp

C = mass of specific gravity bottle plus water

D = mass of empty specific gravity bottle.

In order to calculate the volume occupied by the solids in the pulp it was necessary first to determine the density of the solids, which was done as follows [34]: The pulp was washed three times in distilled water to remove dissolved solids; then filtered; dried at 120°C for three hours; then powdered and dried for a further 24 hour period at 100°C.

The dried solids were allowed to cool to ambient temperature and a previously weighed specific gravity bottle was filled with solids such that one third of the volume was occupied by these solids. The bottle was then weighed and distilled water added to wet the solids before being placed in a vacuum for a further 24 hours. This expelled any air trapped between the solid particles and allowed the water to take their place. The bottle was then topped up and weighed. The density of the solids is then determined as follows: The specific gravity bottle has a volume of

$$\frac{C - D}{\rho_W} \text{ cm}^3$$

where ρ_w = density of water at ambient temperature.

The volume of water in the mixture was $\frac{A - E}{\rho_W}$ cm^3

where A = specific gravity bottle + 1/3 solids + water
E = specific gravity bottle + 1/3 solids

.: the volume that the pulp occupied was

$$\frac{C - D}{\rho_W} - \frac{A - E}{\rho_W} \qquad V_{SG} \text{ cm}^3$$

The mass of solids was $\left(E - D\right)$g

.: the density of the solids was $\rho_S = \frac{E - D}{V_{SG}} \frac{g}{cm^3}$

The mass and volume fraction was determined as follows:

The specific gravity of the pulp

$$= \frac{\text{mass of pulp in } V_{sg}}{\text{mass of water in } V_{SG}}$$

$$= \frac{(\text{mass of water + mass of solid) in } V_{SG}}{\text{mass of water in } V_{SG}}$$

$$= \frac{(\text{volume of water x } \rho_w \text{ + volume of solids x } \rho_S) \text{ in } V_{SG}}{\text{vol of water x } \rho_w \text{ in } V_{SG}}$$

but $\rho_w x + \rho_S y$ = mass of pulp (4-13)

where x = volume of water in pulp
and y = volume of solids in pulp

and $x + y = V_{SG}$ (4-14)

$$x + y = \frac{\text{mass of water}}{\rho_w} \tag{4-15}$$

Rearranging Equation 4-15

$$x = \frac{\text{mass of water}}{\rho_w} - y \tag{4-16}$$

Substituting Equation 4-16 in Equation 4-13

$$\left(\frac{\text{mass of water}}{\rho_w} - y\right) \rho_w + \rho_S\, y = \text{mass of pulp}$$

Rearranging

$$y = \frac{\text{mass of pulp} - \text{mass of water}}{\rho_S - \rho_w} \tag{4-17}$$

$$\therefore \quad \text{mass \%} = \frac{y \times \rho_S}{\text{mass of pulp}} \tag{4-18}$$

$$= \frac{(\text{mass of pulp} - \text{mass of water}) \times \rho_S}{\text{mass of pulp} \times (\rho_S - \rho_w)}$$

$$= \frac{(\text{S.G.} - 1) \times \rho_S}{\rho_S - \rho_w} \times 100 \tag{4-19}$$

$$\text{and volume \%} = y/V_{SG} \tag{4-20}$$

$$= \frac{\text{mass of pulp} - \text{mass of water}}{\rho_S - \rho_w} \cdot \frac{\rho_w}{\text{mass of water}}$$

$$= \text{S.G.} \times \frac{\rho_w}{\rho_S} \times \text{mass \%} \tag{4-21}$$

CHAPTER 5

DISCUSSION AND RESULTS

5.1 ANALYSIS OF RESULTS

For each experimental run the following data were recorded:- Rotational speeds, the corresponding dial reading, the temperature and the spindle attached to the viscometer. The data are then processed as follows: The shear thinning index is obtained by statistically fitting the best straight line (section 5.2) through the data plotted as log (dial reading) versus log (rotational speed) and measuring the slope of this line. The shear rate, shear stress and the apparent viscosity can now be calculated using Equations 3-8, 3-10 and 3-11, the experimental data, and the shear thinning index (section 3.2).

In order to be able to correlate and compare the results it is necessary to convert each apparent viscosity, which is at a different shear rate, to a common shear rate, which is done by using Equation 3-13.

5.2 STATISTICAL ANALYSIS OF DATA

It was necessary to make two changes to the method used by Rosen [29] to analyse his data in order to fit the best straight line through the experimental data, using the standard least squares linear formula. These were (i) to transpose the coordinates of the graph used to determine the shear thinning index and (ii) the addition of a weighting factor to the data.

Rosen obtained the shear thinning index from the slope of a plot of log (rpm) on the y-axis versus log (dial reading) on the x-axis. For the Brookfield viscometer the dial reading is the dependent variable while the rotational speed, which is pre-set for each reading is the independent variable. For statistical purposes it is necessary to plot the dependent variable on the y-axis in order that any experimental error in determining this dependent variable is allowed for in the equations used to fit the data.

As can be seen it was necessary to transpose the coordinates of this graph. The slope of the graph thus obtained is the reciprocal of the shear thinning index.

Any data obtained with the aid of a mechanical device has an error associated with it which is either a constant relative error, i.e. all the data have the same accuracy, or a constant absolute error, i.e. the larger the numerical value of the data the greater its accuracy. The latter is the case for the Brookfield viscometer which has an absolute error of 1 percent of full scale reading throughout the range [27]. Thus it is necessary to weight statisticcally the readings obtained, as the larger the numerical value of the dial reading the greater is its accuracy.

The use of logarithmic scales, in order to obtain the shear thinning index, Figure 3-1, results in a weighting taking place of the lower dial readings [35,36,37], i.e. of the data which are less accurate. Thus it is necessary to weight the data for two reasons, viz. (i) to emphasize the more accurate results and (ii) to counteract the weighting resulting from the use of logarithmic scales.

The following weighting method was applied: Every point was entered into the "least squares" formula a number of times which was proportional to the numerical value of the dependent variable, e.g. for a dial reading of 3, the point was entered 3 times whereas for a dial reading of 80, the point was entered 80 times. This weighted the data in favour of the larger more accurate points and gave a fit which had nearly equal absolute errors [35,36,37].

5.3 DISCUSSION OF RESULTS

5.3.1 The effect of concentration on the rheological parameters of the pulps

In order to compare experimental results at a common shear rate it is necessary to obtain the shear thinning index. This is done as described in section 5.2 and typical plots of log (dial reading) versus log (rpm) for all three pulps are shown in Figures 5.1, 5.2 and 5.3. The shear thinning index can now be used to convert the apparent viscosity to a common shear rate using either Equation (3-13) or Figure 3.2. Typical plots of apparent viscosity versus shear rate for all three pulps are shown in Figures 5.4, 5.5 and 5.6.

The results obtained from these graphs are shown in Tables 5.1, 5.2 and 5.3. These tables also contain all the data necessary to completely describe any particular experiment, i.e. the maximum shear rate, GAMMA (MAX), the corresponding viscosity, ETA (MAX), the temperature and the spindle used. All the experimental data obtained are listed in Appendix B.

All the pulps were found to be shear thinning, i.e. the shear thinning index was always greater than 1,0 over the entire concentration range investigated, viz. 0,17 to 0,43 volume fraction. The shear thinning index for the experiments is shown in Tables 5.1, 5.2 and 5.3.

Similar results, to those obtained during this research program, had also been found by Marsden [19], who was the first South African to investigate the rheological parameters of gold mine pulps. He used two viscometers, which imparted different shear rates when measuring the viscosity of the pulp, and found that at the same concentration, the apparent viscosity was lower when using the viscometer which imparted the higher shear rate. He concluded that the pulps were shear thinning.

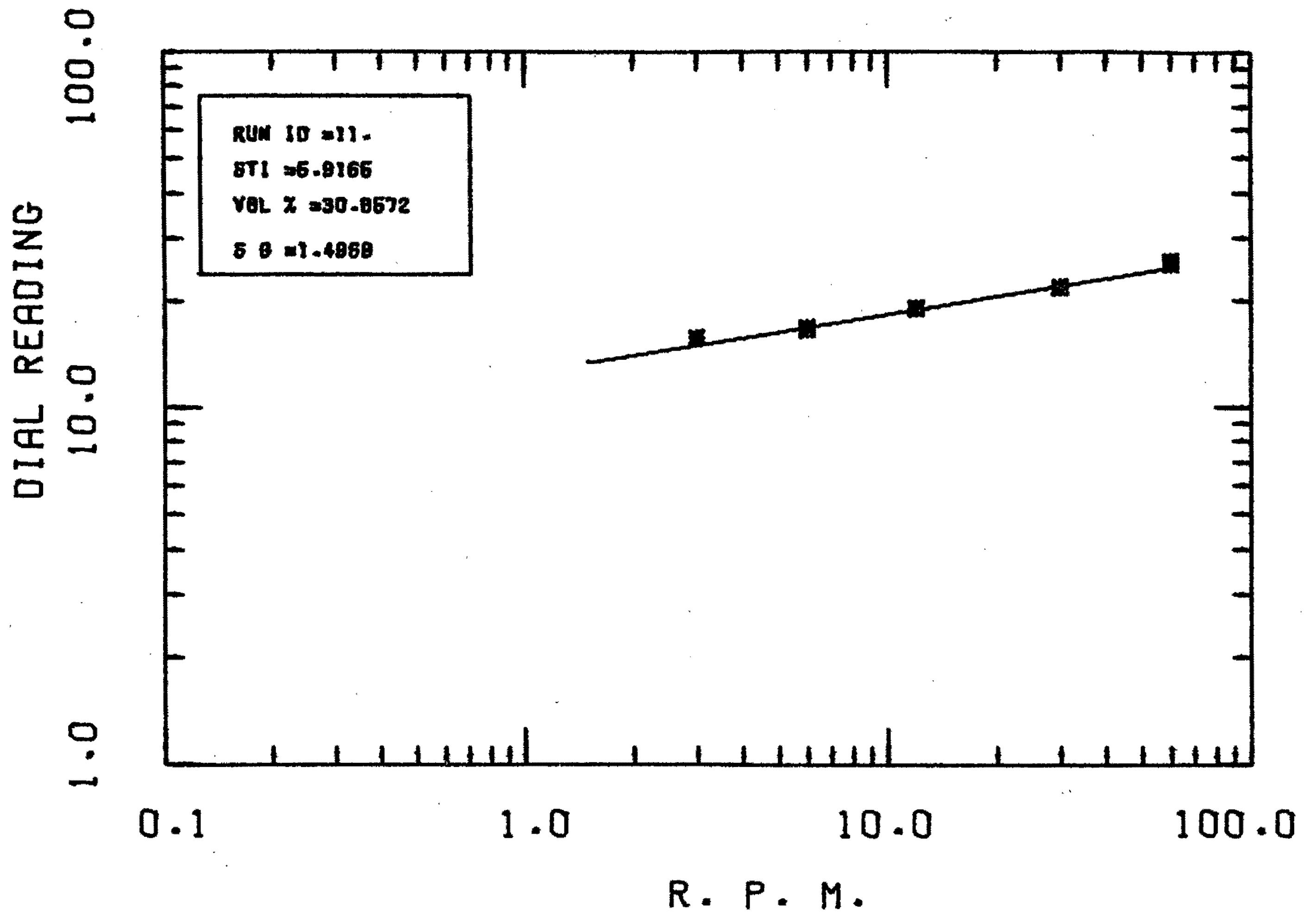


FIG. 5.1 DIAL READING vs ROTATIONAL SPEED

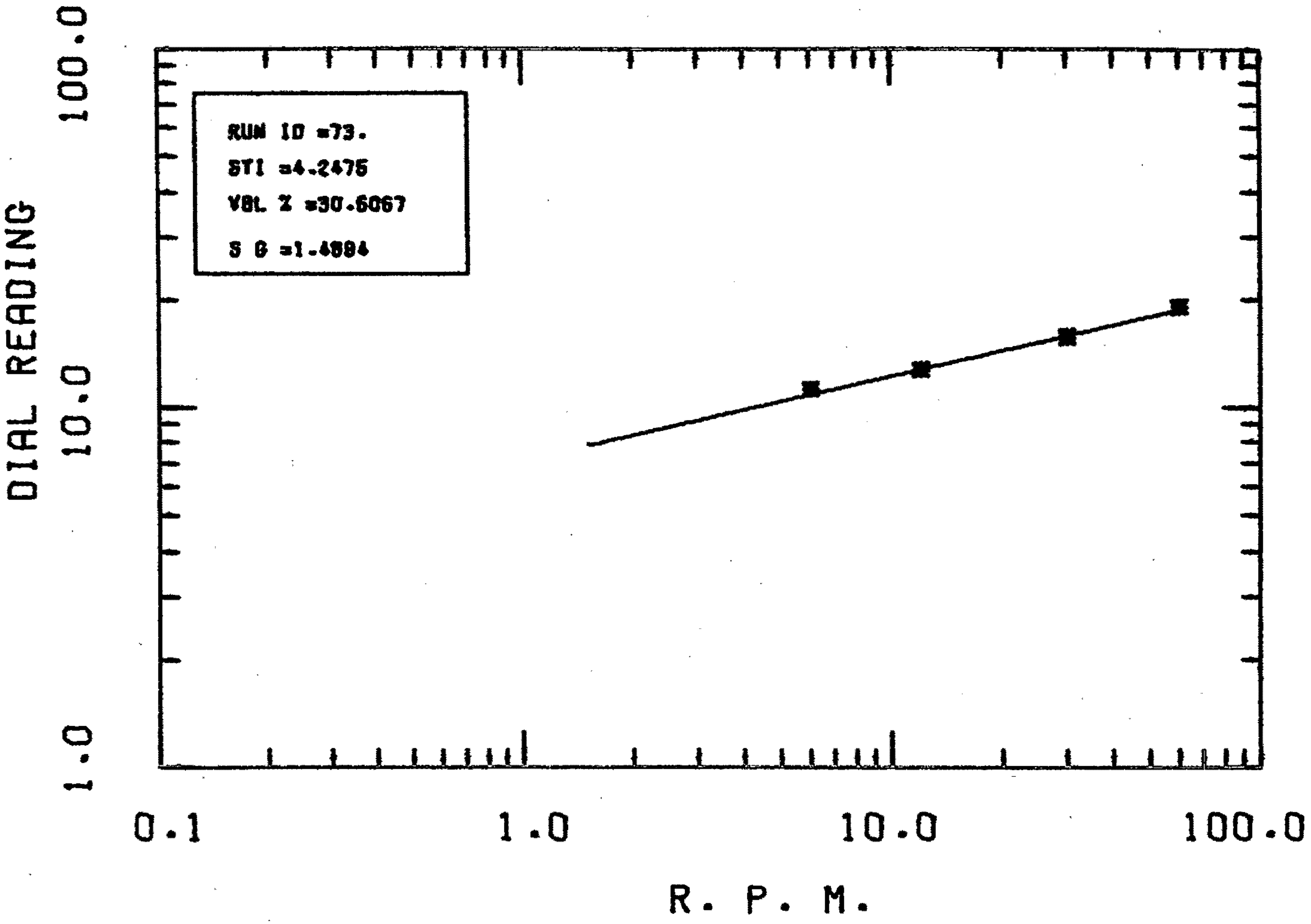


FIG. 5.2 DIAL READING vs ROTATIONAL SPEED

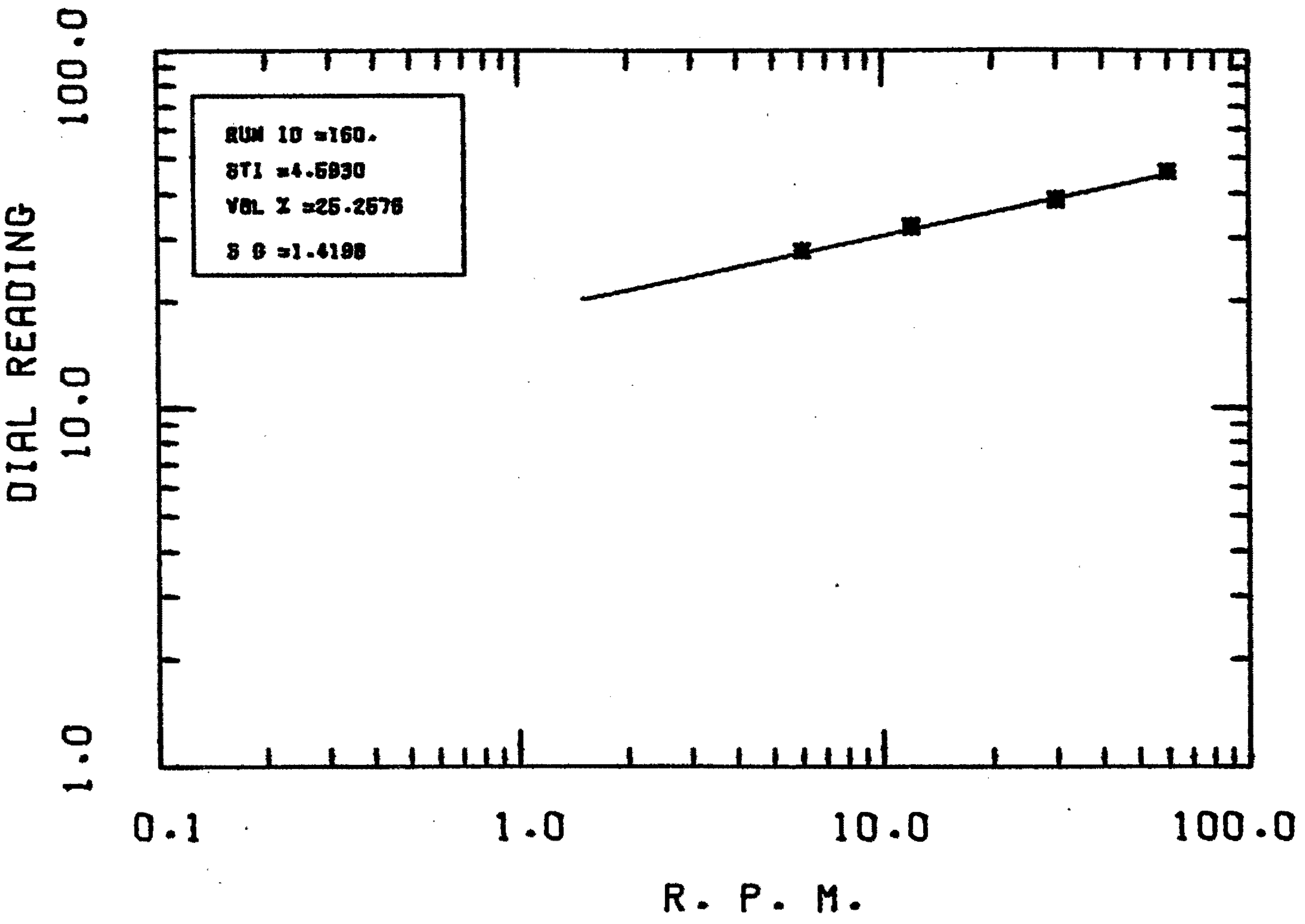


FIG. 5.3 DIAL READING vs ROTATIONAL SPEED

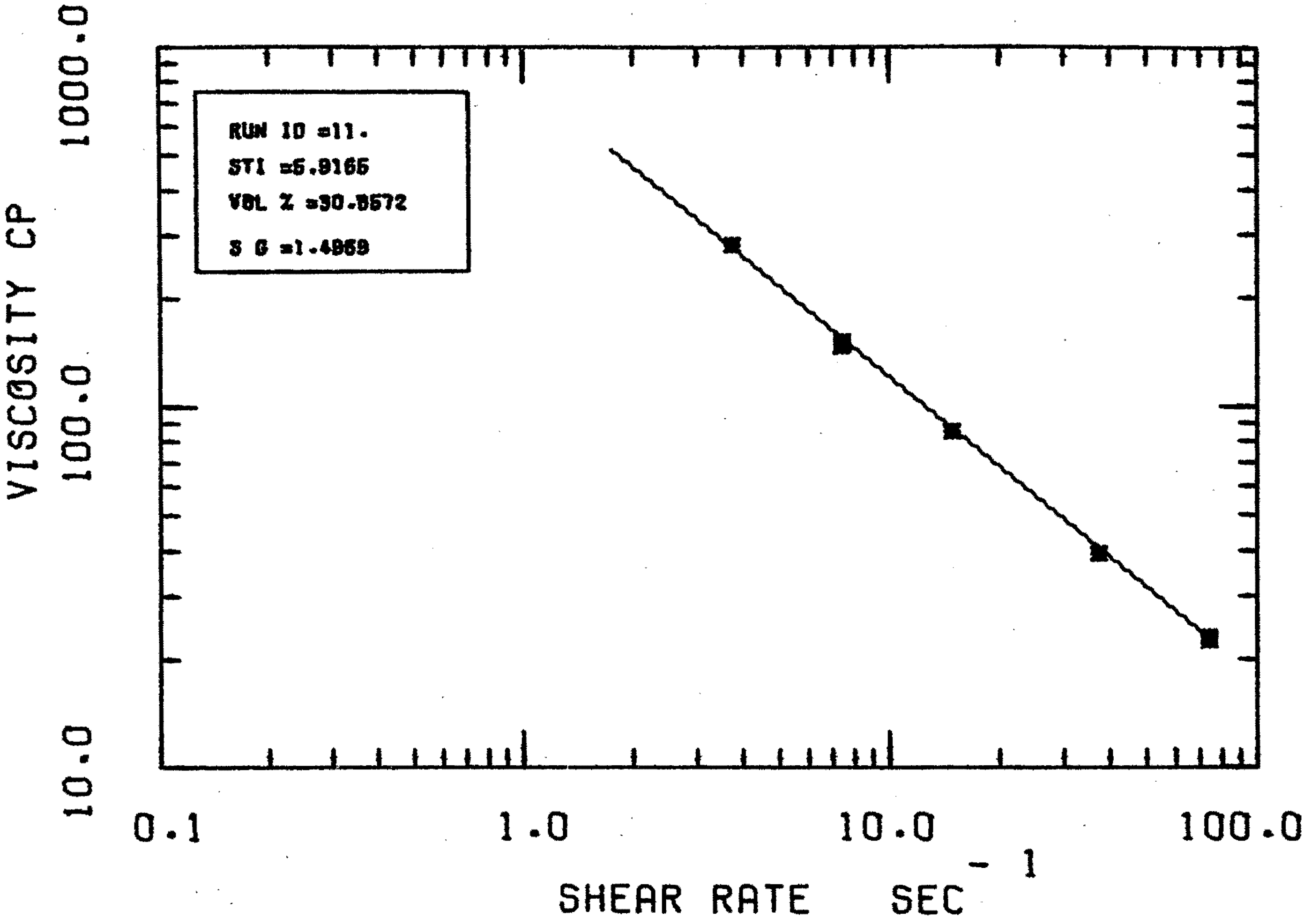


FIG. 5.4 VISCØSITY vs SHEAR RATE

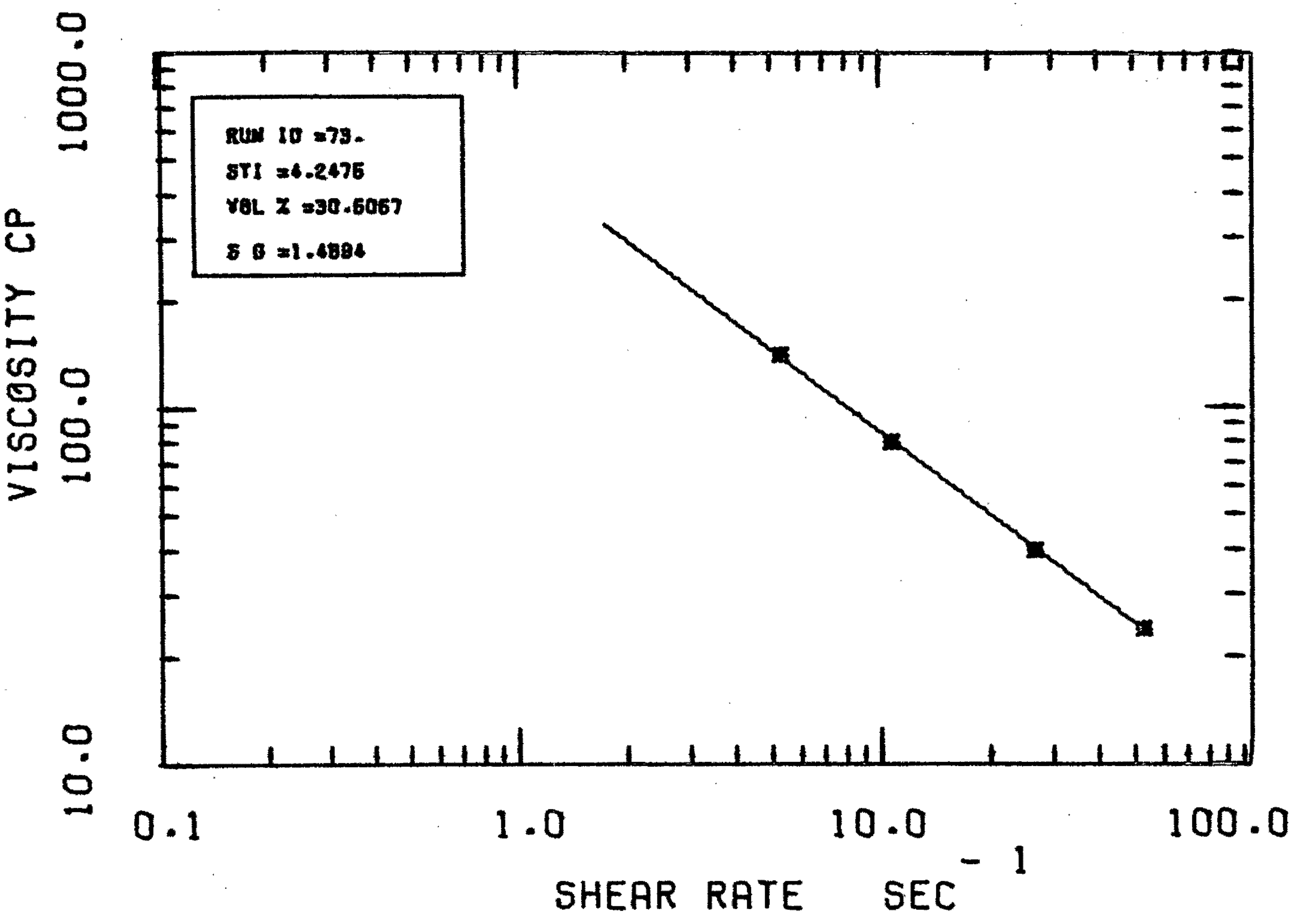


FIG. 5.5 VISCOSITY vs SHEAR RATE

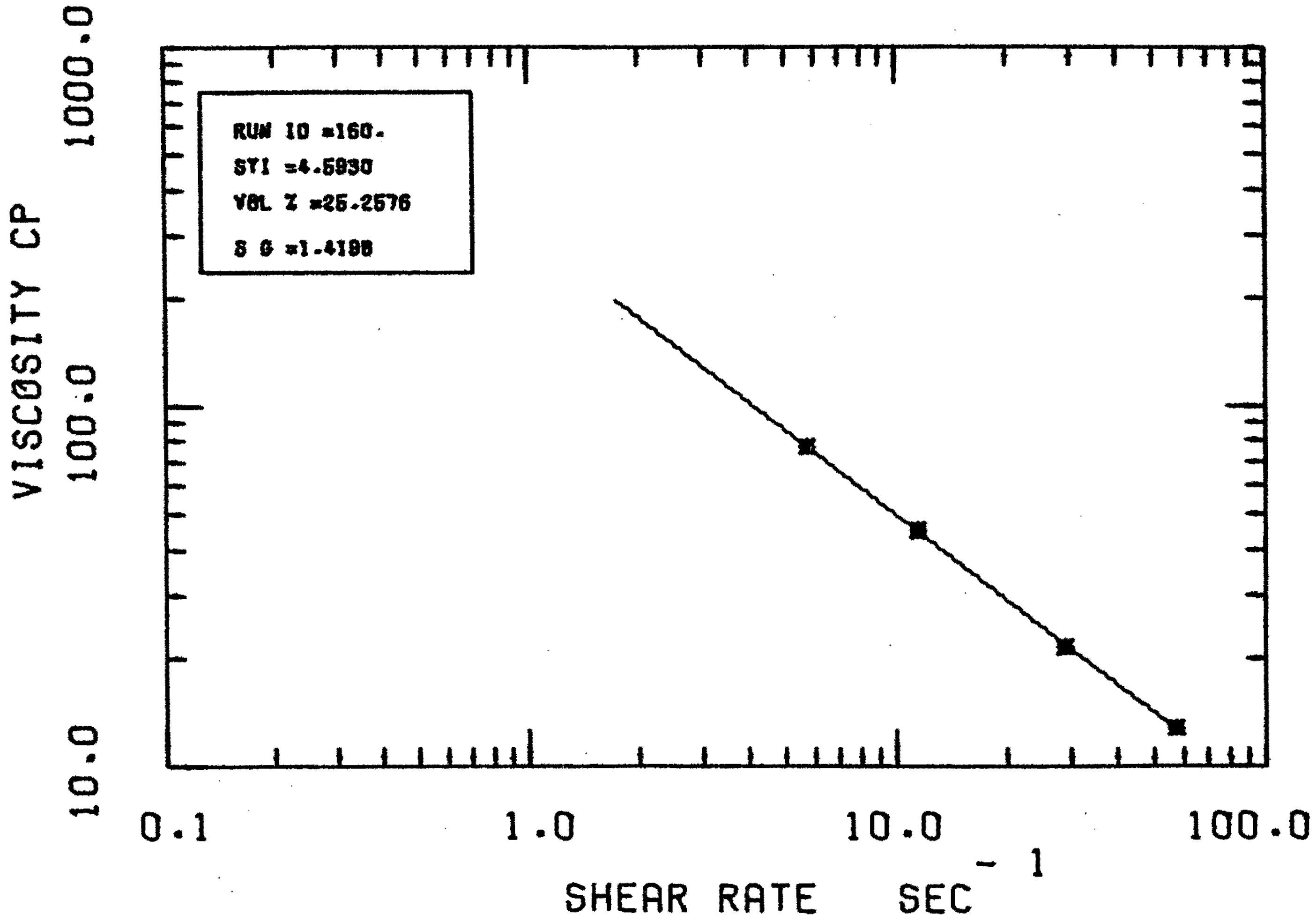


FIG. 5.6 VISCOSITY vs SHEAR RATE

TABLE 5.1

PULP A

NO	S.G.	TEMP	S.T.I.	GAMMA(MAX)	ETA(MAX)	SPINDLE
-2	1.361	25.0	4.720	59.31	8.99	1
3	1.500	25.0	6.460	81.18	39.93	2
5	1.420	25.0	5.371	67.49	14.10	1
-8	1.238	25.0	1.101	13.83	13.05	″
9	1.299	25.0	1.835	23.05	11.76	″
10	1.315	25.0	3.741	47.01	6.65	1
11	1.497	25.0	5.916	74.35	22.79	2
12	1.399	25.0	4.948	62.17	10.32	1
-13	1.341	25.0	4.626	29.05	9.42	0
-14	1.341	25.0	4.026	25.30	12.62	1
-15	1.361	25.3	6.265	15.75	17.41	2
-16	1.320	30.0	2.375	29.85	9.24	1
-17	1.320	38.0	2.462	30.94	9.09	1
18	1.382	23.5	4.862	61.10	9.53	1
19	1.382	35.0	6.264	79.74	7.37	1
20	1.382	40.2	6.660	83.69	7.02	1
21	1.433	25.9	5.669	71.23	13.97	1
22	1.433	32.7	7.009	38.08	12.01	1
23	1.481	18.0	6.245	78.48	19.76	1
24	1.481	21.6	6.656	83.64	18.64	1
25	1.481	24.6	6.964	87.51	18.00	1
26	1.481	26.8	7.530	94.62	16.78	1
27	1.578	19.4	6.998	87.94	45.94	2
28	1.578	23.0	7.212	90.62	46.02	2
29	1.578	24.5	7.168	90.07	46.30	2
30	1.578	28.2	7.048	88.56	47.69	2
31	1.537	12.7	6.223	78.20	37.79	2
32	1.537	15.2	6.652	83.60	35.78	2
33	1.537	21.5	7.314	91.90	32.07	2
34	1.537	25.5	7.297	91.70	32.40	2
35	1.537	30.0	7.365	92.54	32.43	2
36	1.496	11.9	8.487	21.33	294.97	1
37	1.496	11.4	5.533	69.52	25.92	2
38	1.496	17.8	6.078	76.38	23.59	2
39	1.496	25.7	6.742	84.71	21.31	2
40	1.592	10.4	7.010	88.09	62.72	2
41	1.592	17.3	6.978	87.69	62.02	2
42	1.592	25.8	5.742	72.15	75.46	2
43	1.592	30.1	5.444	68.41	81.08	2
44	1.586	10.4	5.998	75.37	65.53	2
45	1.586	17.2	6.132	77.06	63.77	2
46	1.586	24.9	5.543	69.65	71.09	2
47	1.586	31.2	5.084	63.89	81.13	2
48	1.565	11.4	6.532	82.08	46.75	2
49	1.565	17.2	7.011	88.10	44.99	2
50	1.565	22.3	6.180	77.66	51.57	2
51	1.565	28.6	5.771	72.51	55.67	2

TABLE 5.2

PULP B

NO	S.G.	TEMP	S.T.I.	GAMMA(MAX)	ETA(MAX)	SPINDLE
59	1.449	25.4	5.053	63.50	16.30	1
60	1.449	28.5	4.914	61.75	16.84	1
61	1.277	21.4	2.158	13.56	7.35	0
62	1.277	25.0	2.173	13.66	7.35	0
63	1.277	27.5	2.208	13.87	7.20	0
64	1.360	19.0	3.127	39.29	8.82	1
65	1.360	21.5	3.484	43.78	8.11	1
66	1.360	25.6	3.524	44.28	7.87	1
67	1.360	30.3	3.641	45.75	7.53	1
68	1.397	18.9	3.789	47.62	11.49	1
69	1.397	22.0	4.129	51.89	10.84	1
70	1.397	25.4	4.160	52.27	10.54	1
71	1.397	30.1	4.229	53.13	10.25	1
72	1.489	8.8	3.637	45.70	26.39	2
73	1.489	14.8	4.248	63.37	23.71	2
74	1.489	18.9	4.395	55.22	22.69	2
75	1.489	26.4	4.740	59.56	20.35	2
76	1.548	8.8	4.294	53.96	44.40	2
77	1.548	13.8	4.787	60.16	39.35	2
78	1.548	22.8	4.863	61.11	38.15	2
79	1.548	30.1	5.087	63.92	35.75	2
80	1.530	11.1	4.229	53.14	33.76	2
81	1.530	15.4	4.773	59.98	29.58	2
82	1.530	22.5	5.155	64.79	26.94	2
83	1.530	30.8	5.252	65.99	26.08	2
84	1.561	12.8	3.934	49.43	50.76	2
85	1.561	15.8	4.322	54.31	46.28	2
86	1.561	22.9	4.530	56.92	44.00	2
87	1.561	30.1	4.641	58.32	42.30	2
88	1.623	10.4	4.206	52.86	106.03	2
89	1.623	17.9	5.125	64.40	84.76	2
90	1.623	26.1	4.839	60.81	89.98	2
91	1.623	30.6	4.887	61.42	89.52	2
92	1.507	10.8	3.978	49.99	26.96	1
93	1.507	15.4	4.225	53.09	24.94	1
94	1.507	22.6	4.564	57.36	23.05	1
95	1.507	32.3	4.908	61.67	21.87	1
96	1.461	11.4	3.326	41.80	19.92	1
97	1.461	15.2	3.599	45.22	18.11	1
98	1.461	19.7	3.665	46.05	17.75	1
99	1.566	10.2	3.195	40.15	54.10	2
100	1.566	18.5	4.430	55.66	39.73	2
101	1.566	22.3	4.631	58.19	39.62	2
102	1.566	30.7	4.633	58.22	39.97	2
103	1.628	11.0	3.632	45.64	104.80	2
104	1.628	21.2	4.275	53.72	99.20	2
105	1.628	29.9	4.515	56.73	91.35	2
106	1.653	11.1	3.943	49.55	130.23	2
107	1.653	16.8	4.343	54.57	116.01	2
108	1.653	25.3	4.453	55.95	118.10	2
109	1.653	31.5	4.294	26.98	223.34	2
110	1.568	10.6	3.534	44.41	41.63	2
111	1.568	18.7	3.783	47.54	37.55	2
112	1.568	28.5	3.943	49.54	37.02	2
113	1.568	32.3	4.211	52.92	36.00	2

TABLE 5.3

PULP C

NO	S.G.	TEMP	S.T.I.	GAMMA(MAX)	ETA(MAX)	SPINDLE
115	1.462	11.1	4.719	59.30	23.36	1
116	1.462	15.9	5.070	63.71	21.53	1
117	1.462	24.9	5.366	67.43	20.08	1
118	1.462	30.1	5.773	72.55	18.96	1
119	1.494	12.2	4.331	54.43	29.00	2
120	1.494	17.1	4.930	61.96	24.91	2
121	1.494	24.9	5.215	65.53	23.14	2
122	1.494	30.7	5.549	69.73	21.53	2
123	1.537	11.4	4.632	58.21	38.90	2
124	1.537	17.6	4.914	61.74	35.86	2
125	1.537	26.1	4.642	58.34	37.91	2
126	1.537	30.4	4.551	57.18	39.18	2
127	1.589	10.6	4.111	51.66	74.33	2
128	1.589	18.5	4.300	54.04	68.50	2
129	1.589	25.9	4.343	54.58	66.97	2
130	1.599	30.2	4.067	51.10	73.20	2
131	1.622	11.5	4.295	53.97	100.59	2
132	1.622	16.8	4.950	62.21	95.24	2
133	1.622	21.6	5.088	63.93	79.57	2
134	1.622	28.0	4.306	54.10	91.93	2
135	1.648	10.4	4.263	53.57	117.40	2
136	1.648	18.3	3.738	46.97	133.74	2
137	1.648	25.2	3.711	46.64	132.87	2
138	1.648	30.1	3.471	43.62	141.47	2
139	1.641	10.2	4.027	50.60	124.10	2
140	1.641	17.0	3.904	49.06	122.94	2
141	1.641	24.7	3.962	49.79	130.91	2
142	1.641	30.9	3.435	43.46	143.28	2
143	1.620	10.6	3.748	47.10	98.16	2
144	1.620	17.6	4.138	52.00	96.73	2
145	1.620	24.6	4.031	50.66	90.43	2
146	1.620	31.2	3.746	47.08	102.36	2
147	1.535	10.7	4.242	53.30	44.58	2
148	1.535	21.9	5.738	72.10	30.83	2
149	1.535	28.4	5.687	71.46	35.39	2
150	1.492	10.3	4.314	54.21	25.81	2
151	1.492	17.7	4.679	58.80	22.51	2
152	1.492	26.1	4.845	60.88	20.79	2
153	1.492	31.3	4.517	56.76	22.14	2
154	1.443	10.7	4.066	51.10	19.12	1
155	1.443	19.3	4.696	59.02	15.99	1
156	1.443	24.7	4.724	59.37	15.32	1
157	1.443	30.2	4.616	58.00	15.33	1
158	1.420	10.8	3.913	49.17	15.03	1
159	1.420	17.4	4.435	55.74	13.50	1
160	1.420	24.2	4.593	57.72	12.76	1
161	1.420	30.6	4.856	61.02	11.41	1
162	1.408	10.6	3.817	47.96	14.12	1
163	1.408	16.9	3.978	49.99	12.99	1
164	1.408	23.8	4.065	51.08	11.77	1
165	1.408	30.3	4.163	52.31	11.06	1
166	1.390	11.0	3.458	43.46	11.76	1
167	1.390	18.3	3.583	45.03	10.60	1
168	1.390	25.6	3.626	45.56	9.90	1
169	1.390	30.9	4.049	50.88	8.49	1

Working with kaolin clays, Beazley [16] found shear thickening behaviour at concentrations greater than 0,46 volume fraction, while below this the pulp was shear thinning. The highest attainable concentration using the apparatus described in section 4.2 was 0,43 volume fraction and thus this anomaly, found by Beazley, cannot be validated.

Clarke [22], using the equipment described in section 2.2.2, reported shear thickening behaviour for the entire concentration range of the pulps he investigated. These results are directly opposite to the results obtained in this study. However, due to the radical modifications that he made to his agitator and the possibility of secondary flows introduced by baffles in the sample cup (section 2.2.2), the shear rates that he used were possibly incorrect. He admits to using the manufacturer's given shear rate after completely changing their original bob, which is possibly the reason why he is the only worker on slurries to have obtained shear thickening behaviour over the entire concentration range.

In order to investigate the effect of concentration on the viscosity index, the experimental data were fitted to a number of correlations. Only two correlations have been found which allow the effect of concentration, shear rate and temperature on the viscosity index to be investigated. These are the equations of Shaheen [20] and Beazley [16].

Shaheen proposed an equation of the form:

$$\eta_{rel} = \exp\left(\frac{A\ \phi}{1 - \alpha\phi^n}\right) \qquad (5\text{-}1)$$

where $A = 2,5$

α, n are constants.

The value of A was determined empirically and the numerical value of 2,5 is fortuitous and is not related in any way to the "Einstein factor". Investigation proved that, although

Equation 5-1 was not extremely sensitive to changes in the value of "A", a three constant equation gave an overall smaller standard deviation, i.e. a better fit, than the two constant equation which had a fixed numerical value for A. Sophisticated search techniques are available for determining the best fit using three constants, e.g. the Nelder and Mead simplex technique [38], but as Equation 5-1 was not sensitive to "A", a simple iterative process was used.

The constants were determined as follows:

$$\eta_{rel} = \exp\left(\frac{A\ \phi}{1 - \alpha\phi^n}\right)$$

$$\ln\ \eta_{rel} = \frac{A\ \phi}{1 - \alpha\phi^n}$$

$$1 - \alpha\phi^n = \frac{A\ \phi}{\ln\ \eta_{rel}}$$

$$\alpha\phi^n = 1 - \frac{A\ \phi}{\ln\ \eta_{rel}}$$

$$\therefore \quad \ln\ \alpha + n\ \ln\ \phi = \ln\left(1 - \frac{A\ \phi}{\ln\ \eta_{rel}}\right) \qquad (5\text{-}2)$$

Plotting log (volume fraction) versus a function of volume fraction and viscosity index yields the values of n and α for a particular value of "A". "A" was allowed to vary from 0,1 to 19,5 with increments of 0,1. This was repeated for various values of temperature and shear rate. The values of the constants chosen were those that yielded the smallest standard deviation. The value of A, n and α are shown in Table 5.4 for various values of temperature and shear rate.

TABLE 5.4

VALUES OF A, n AND α USING EQUATION 5-1

Pulp	Shear rate sec^{-1}	temperature ^{o}C	A	α	n
A	40	15	0,1	0,99641	0,00436
		20	4,7	0,83919	0,27288
		25	7,6	0,76962	0,57972
		30	9,5	0,77521	0,93309
	20	15	0,1	0,99582	0,00284
		20	0,1	0,99527	0,00212
		25	0,1	0,99491	0,00160
		30	14,3	0,50357	0,47692
	80	15	3,3	1,00635	0,36195
		20	5,9	1,18068	0,89011
		25	7,4	1,50639	1,39337
		30	8,4	1,95747	1,84940
B	40	15	0,1	0,99637	0,00513
		20	0,3	0,98738	0,01311
		25	4,8	0,83030	0,32012
		30	7,0	0,80365	0,61625
	20	15	0,1	0,99503	0,00231
		20	5,0	0,75770	0,19633
		25	8,6	0,62887	0,53943
		30	10,3	0,61307	0,86765
	80	15	8,2	37,72589	5,63888
		20	0,1	0,99836	0,00808
		25	0,1	0,99742	0,00690
		30	2,9	0,94554	0,25481
C	40	15	11,2	7,71078	3,87444
		20	11,9	2,03687	2,43995
		25	11,6	4,89816	3,13220
		30	11,9	2,00971	2,20313
	20	15	13,1	0,52298	0,76664
		20	13,4	0,49096	0,63206
		25	13,7	0,47023	0,53213
		30	14,0	0,45588	0,45452
	80	15	9,4	8,51805	4,16878
		20	9,8	8,93007	4,29333
		25	10,1	7,09081	4,08978
		30	10,4	6,66752	4,07750

TABLE 5.5

VALUES OF A AND K USING EQUATION 5-3

Pulp	shear rate sec^{-1}	temperature °C	A	K
A	40	15	7,3492	1,1545
		20	8,1896	1,0204
		25	8,9486	0,9044
		30	9,6426	0,8021
	20	15	9,2799	0,9702
		20	10,3427	0,8149
		25	11,2897	0,6821
		30	12,1461	0,5661
	80	15	5,5100	1,3735
		20	6,1608	1,2575
		25	6,7564	1,1562
		30	7,3067	1,0661
B	40	15	6,1916	1,2831
		20	6,8394	1,1683
		25	7,4380	1,0666
		30	7,9954	0,9753
	20	15	8,3902	0,9782
		20	9,1563	0,8632
		25	9,8589	0,7614
		30	10,5088	0,6702
	80	15	4,1924	1,6281
		20	4,7295	1,5110
		25	5,2292	1,4076
		30	5,6974	1,3148
C	40	15	8,2960	0,9112
		20	8,6167	0,8926
		25	8,9240	0,8720
		30	9,2183	0,8504
	20	15	11,0112	0,5655
		20	11,4203	0,5397
		25	11,8079	0,5131
		30	12,1760	0,4864
	80	15	5,9273	1,2635
		20	6,1802	1,2485
		25	6,4243	1,2311
		30	6,6597	1,2124

The correlation used by Beazley which is an extension of Mooney's [14] equation, was also tried. The equation is

$$\eta_{rel} = \exp\left(\frac{A\ \phi}{1 - K\phi}\right) \tag{5-3}$$

The variable A and K were obtained as follows:

$$\ln \eta_{rel} = \frac{A\ \phi}{1 - K\phi}$$

$$\frac{1}{\ln \eta_{rel}} = \frac{1 - K\phi}{A\ \phi}$$

$$\therefore \quad \frac{1}{\ln \eta_{rel}} = \frac{1}{A\phi} - \frac{K}{A} \tag{5-4}$$

Plotting the log of the reciprocal of the viscosity index versus the reciprocal of the volume fraction yields the values of A and K. These values are shown in Table 5.5.

A comparison of the standard deviation for these two equation is shown in Table 5.6

TABLE 5.6

A COMPARISON OF THE STANDARD DEVIATION USING EITHER EQUATION 5-1 OR 5-3

Pulp	Shear rate sec^{-1}	Temp. ^{o}C	η_{rel} minimum	η_{rel} maximum	S.D. Eqn.5-1	S.D. Eqn.5-3
A	40	20	11,30	149,39	4,2	8,80
		30	12,91	186,84	4,085	11,22
	20	15	17,23	219,39	8,026	11,04
		20	18,69	248,50	7,289	12,74
	80	20	6,83	89,82	2,558	7,17
B	40	20	7,61	123,63	6,778	4,70
		30	9,74	154,82	7,705	4,11
	20	15	6,068	194,88	12,082	10,82
		20	11,14	220,98	12,684	10,26
	80	20	5,19	69,18	4,284	2,56
C	40	20	4,12	155,04	4,038	16,98
		30	5,017	200,18	4,588	10,76
	20	15	5,278	224,37	6,227	25,13
		20	5,97	263,49	5,931	20,99
	80	20	2,85	91,23	2,417	18,99

As can be seen from Table 5.6 Equation 5-1 has a smaller standard deviation for Pulp A and C whilst Equation 5-3 has a smaller standard deviation for Pulp B. All the results obtained during the course of the project were used to obtain these results and no "smoothing" techniques were applied. If "smoothing" techniques were applied to the data, i.e. the points that lie outside a specified confidence limit are ignored, better results would have been obtained but would not have been more meaningful. For illustrative purposes the constraints in Equations 5-1 and 5-3 have been replaced by numerical values. These values are for Pulp B at a shear rate of 40 $\sec^{-1}$ and a temperature of 20°C.

$$\eta_{rel} = \exp \frac{0,3\ \phi}{1 - 0,987\ \phi^{0,013}} \qquad (5\text{-}1)$$

and

$$\eta_{rel} = \exp \frac{8,19\ \phi}{1 - 1,02\ \phi} \qquad (5\text{-}3)$$

The conclusions that can be drawn from Tables 5.6 are (i) if computer analysis is available both Equations 5-1 and 5-3 should be used to fit the data and Equation 5-1 should be used as a 3 constant equation, (ii) if computer analysis is not available, graphical techniques should be used and Equation 5-1 should be a two constant equation as it is not particularly sensitive to "A", (iii) as can be seen, once the equation is found which has the smallest standard deviation for a particular pulp it can be used for the entire range of concentration, temperature and shear rate that will be encountered and (iv) the fact that both the equations are exponential indicates that the results obtained do describe the effect of concentration on the apparent viscosity as this result has been reported by many previous workers [14,15,16,17,18,19,20,21,22,23].

Thus it is possible to describe the effect of concentration on the apparent viscosity using Equation 5-1 or 5-3.

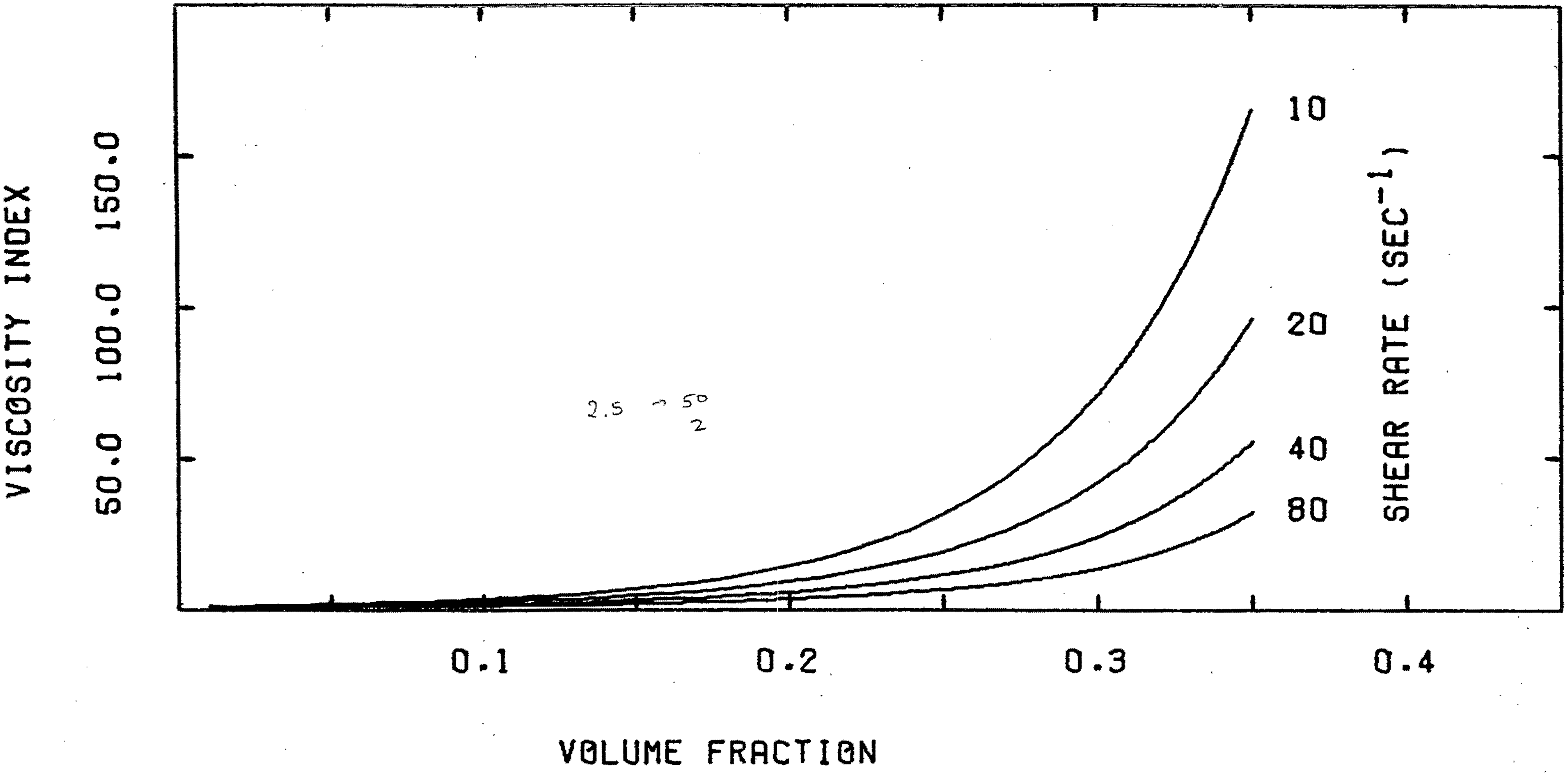
These equations also allow the effect of the two parameters, i.e. temperature and shear rate to be investigated. The effect of shear rate on Equation 5-1 or 5-3 can be seen in Figures 5.7 and 5.8.

5.3.2 The effect of Temperature on the rheological properties of mine pulps

The effect of temperature on the viscous parameters, K and n, of all three pulps was investigated. The temperature was kept constant as described in section 4.3.1. The range of temperature chosen for the study was 10 to 30^{o} Centigrade but extremes of 8^{o}C and 35^{o}C were also recorded. This represents only the lower half of the normal temperature range used on a South African gold mine extraction plant. Higher temperatures could not be investigated as evaporation took place which resulted in an increase in the concentration and invalid results. Thus it was decided that for this initial investigation, the above temperature range would suffice.

Normally when investigating the effect of two variables, i.e. concentration and temperature, a factorial design is performed. This calculates the minimum number of experiments necessary to investigate all the effects of the variables. However, this could not be done for these experiments as setting the thermo-regulator of the temperature bath to the same temperature resulted in a different pulp temperature for various concentrations. This meant that, in order to correlate the results at the same temperature, linear interpolation had to be used.

It was found that there was a linear relationship between viscosity index and the temperature of the pulp which is shown in Figure 5.9. As can be seen, increasing the concentration of the pulp increases the slope of the curve monotonically. Thus it is possible to use this relationship to predict the viscosity of the pulp at any temperature.



$2.5 \rightarrow \frac{50}{2}$

FIG. 5.7 THE EFFECT OF SHEAR RATE ON THE VISCOSITY INDEX USING EQUATION 5-1

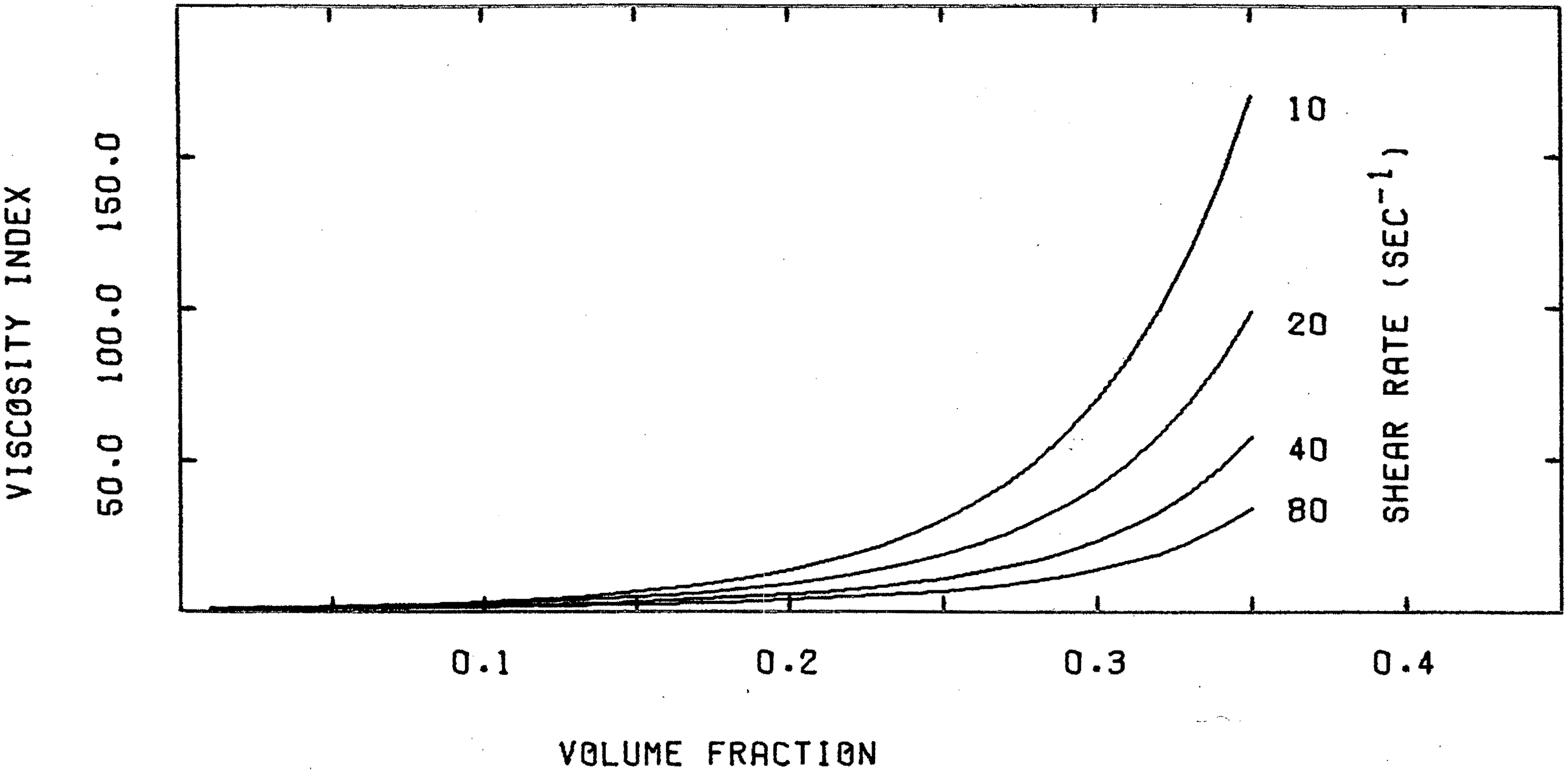


FIG. 5.8 THE EFFECT OF SHEAR RATE ON THE VISCOSITY INDEX USING EQUATION 5-3

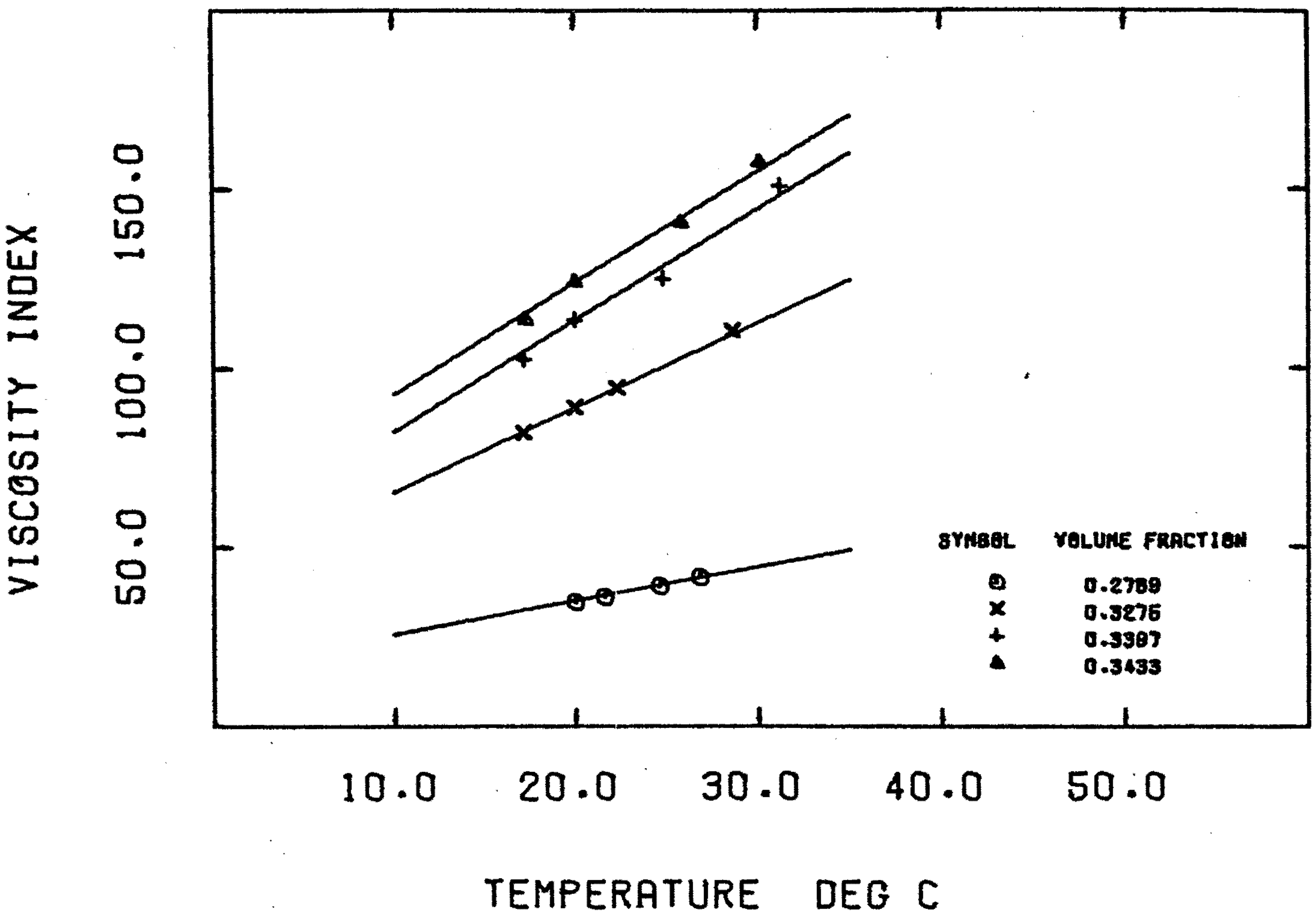


FIG. 5.9 THE DEPENDENCE ØF VISCØSITY ØN TEMPERATURE

In order to calculate the effect of temperature on the rheological properties of a non-Newtonian liquid it is necessary to decide on two points, viz. (i) a common basis on which to compare the variables, i.e. shear rate or shear stress and (ii) which variables to compare, i.e. the power-law variables K and n or the viscosity index, η_{rel}. A literature survey revealed that no work had ever been done on the effect of temperature on the rheological properties of a slurry and thus, as no precedent existed, it was decided to report the effect of temperature on all three variables, K, n and the viscosity index, at a common shear rate and the effect of temperature on the viscosity index at both a common shear rate and shear stress.

Typical plots of K, n and viscosity index versus temperature at a common shear rate are shown in Figures 5.10, 5.11 and 5.12. Viscosity index versus temperature at a common shear stress is shown in Figure 5.13. These graphs are plotted for Pulp B but are typical of all the pulps. The coordinates of the graph were chosen to give the best linear relationship between the variables investigated and temperature, i.e. the best straight line plot. Other combinations were also chosen but did not give better results.

As stated earlier and as can be seen from the graphs, the temperature range studied was rather limited and therefore no firm prediction can be made as to the effect of temperature on the rheological properties of the pulps.

The results, however, do seem to indicate that there is a change in the effect of temperature on the parameter investigated with increasing temperature, i.e. above a certain concentration the rheological properties no longer decrease with increasing temperature but increase. A tentative explanation for this is as follows: It has been suggested [39,40] that for a molecule in a Newtonian liquid to take part in liquid flow it must acquire sufficient

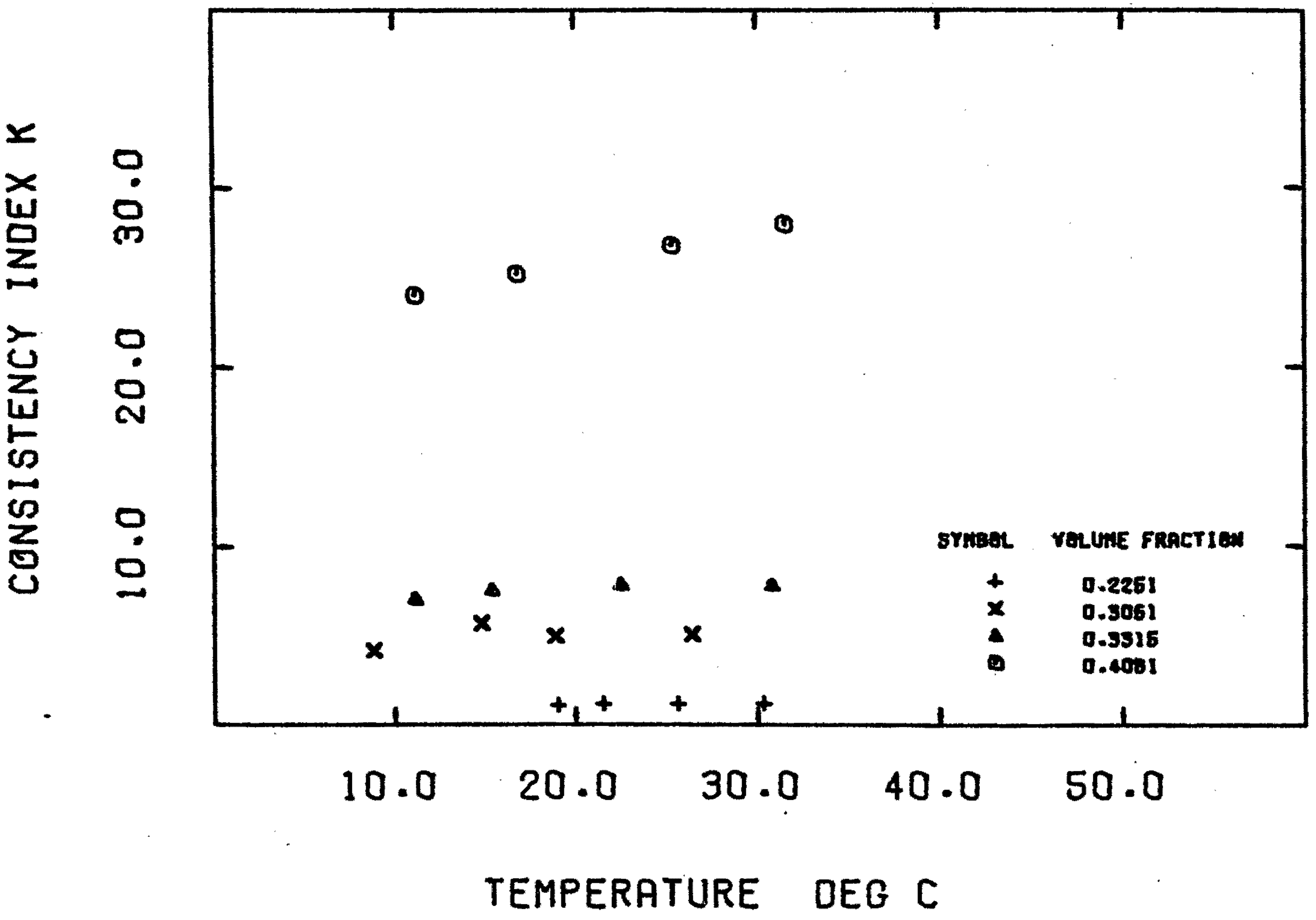


FIG. 5.10 THE DEPENDENCE OF THE CONSISTENCY INDEX ON TEMPERATURE

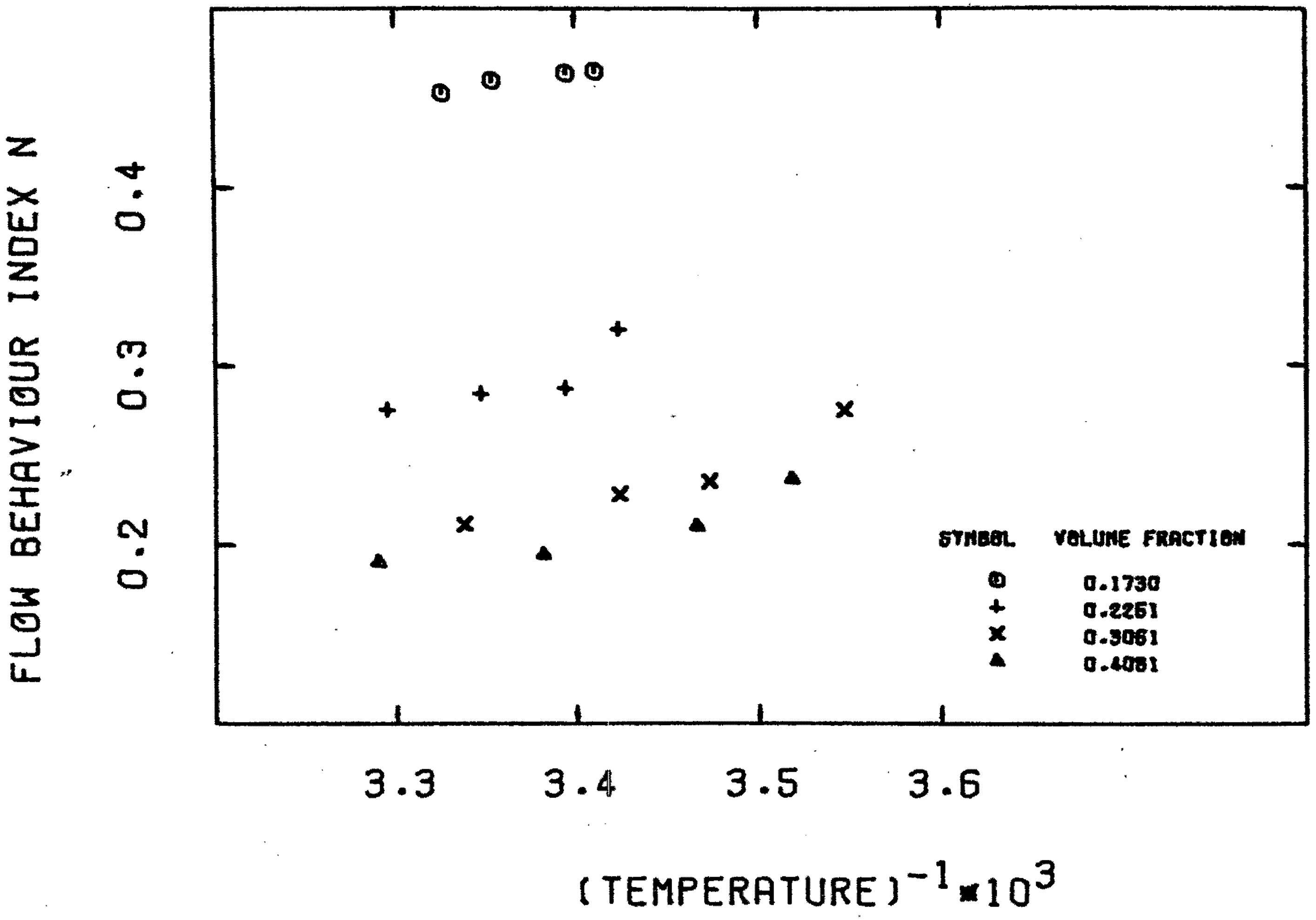


FIG. 5.11 THE DEPENDENCE OF THE FLOW BEHAVIOUR INDEX ON TEMPERATURE

$\frac{1}{T}$ E3 = 3.5

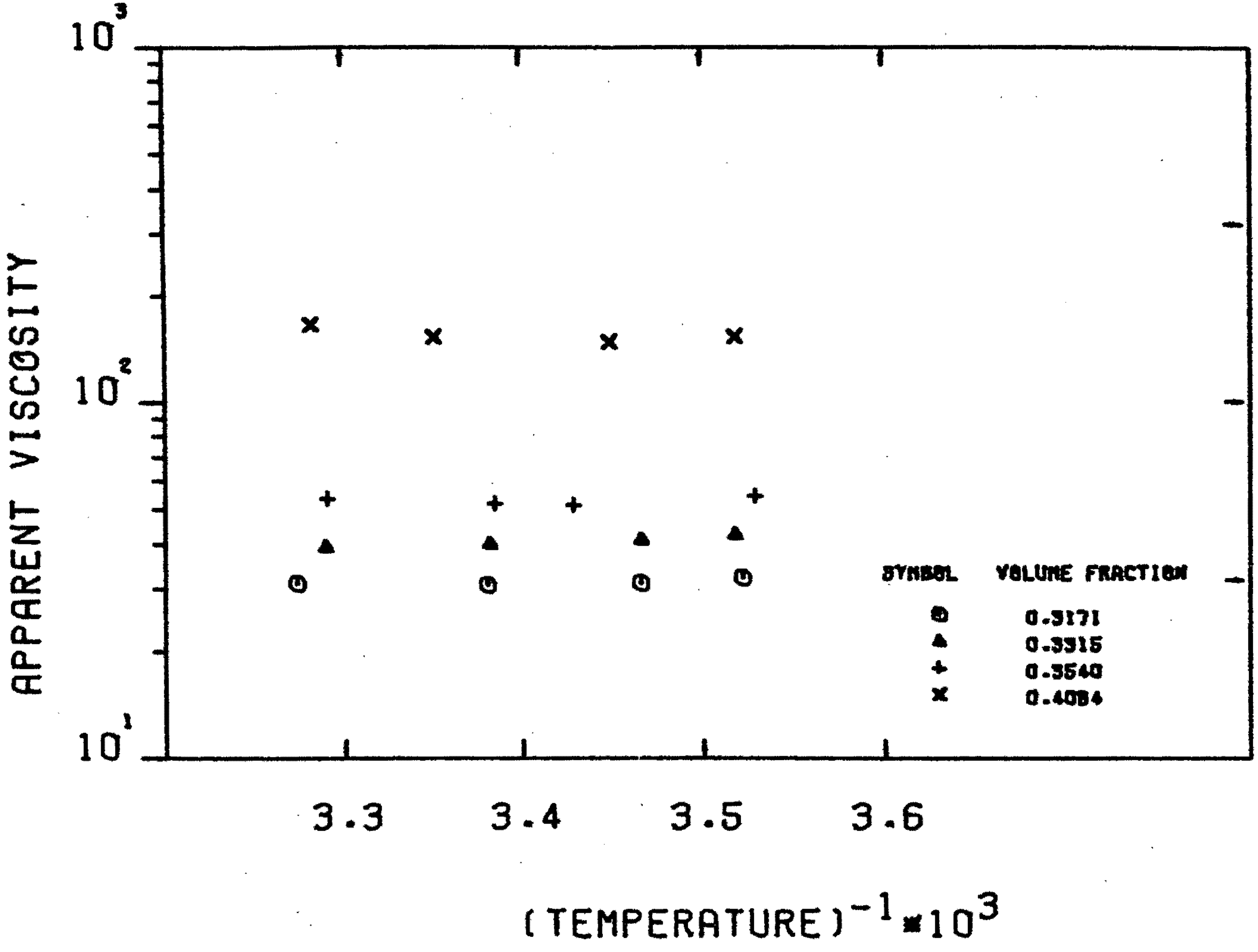


FIG. 5.12 THE EFFECT OF TEMPERATURE ON THE APPARENT VISCOSITY AT A COMMON SHEAR RATE

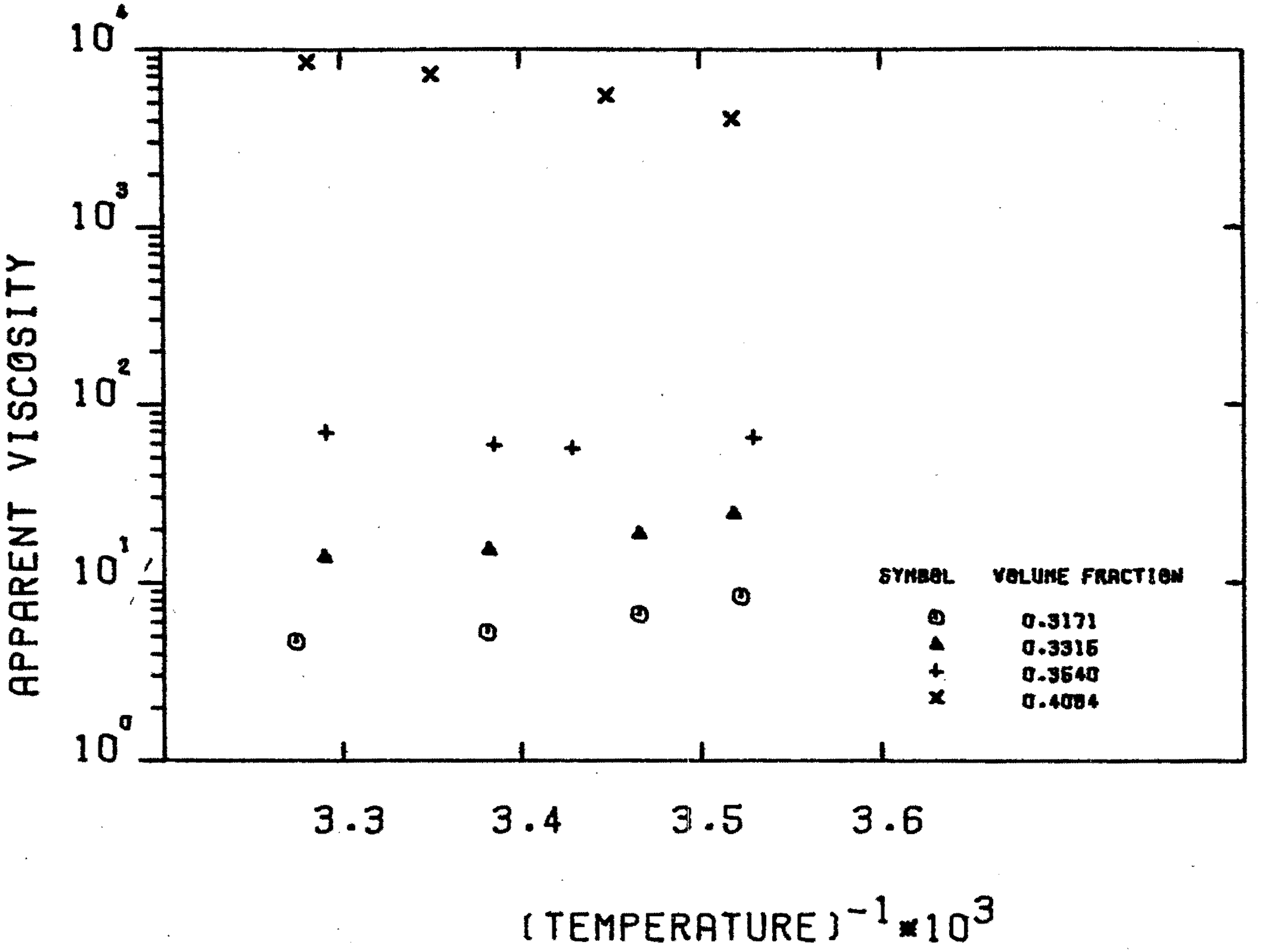


FIG. 5.13 THE EFFECT OF TEMPERATURE ON THE APPARENT VISCOSITY AT A COMMON SHEAR STRESS

energy to push aside the molecules which surround it. Similarly, in a non-Newtonian slurry the particles must acquire sufficient energy to be able to move. However, the particles also need energy to be able to shear past other particles and energy is also dissipated in particle-to-particle collisions. Thus, as the temperature is increased, and the shear rate is kept constant, the particles acquire more energy, but as the concentration is increased, particle interaction and hindrance increase and start to predominate causing an increase in the measured parameter rather than a decrease.

This reversal, of the rheological properties, of a concentrated slurry has also been found by Marsden [19] who stated that his findings, that the viscosity of a concentrated alkaline pulp increased with increasing temperature, were the first reported "inversion" of the rheological properties of a slurry. Thus, in conclusion, the effect of temperature on the rheological properties can not be stated, due to the small temperature range investigated but it would seem that increasing concentration will cause an "inversion" of these properties, i.e. an increase in the parameters with increasing temperature. It is suggested that further work be done on this problem using a larger temperature range than was used in this project.

5.3.3 pH significance

Normal mine operations generate three pulps of different pH. (i) A neutral pulp which has a pH of 6,8 - 7,2. This is formed by the addition of water to freshly milled mine ore, (ii) an acid pulp ± pH 2,3 found in the uranium extraction plant which is acidified by the addition of concentrated sulphuric acid and (iii) an alkali pulp of pH 10,8 found in the gold extraction plant basified by the addition of slaked lime.

The three pulps all exhibit similar exponential curves of viscosity index versus concentration (section 5.3.1). Within experimental error the alkali and the neutral pulp both lie on the same curve, whereas, the curve of the acid pulp lies well below these.

The difference in the curves is thought to be due to the presence of an ionic cloud surrounding the individual particles. The pH of the pulp will influence the size of this cloud and thus the ease with which particles can move past each other. Presumably the ionic cloud is unaffected by going from basic to neutral but is reduced in acid. The size of this cloud will have a large effect on the value of the viscosity.

The increase in viscosity found in changing from an acid to an alkali pulp is encountered in normal mine operations [41]. Curves of all three pulps can be seen in Figures 5.14, 5.15 and 5.16.

5.3.4 Bentonite Investigation

In order to test further the applicability of the method used to determine the rheological properties of a pulp, a short investigation was carried out on the effect of the presence of bentonite in a pulp.

Commercially pure bentonite was suspended in water and then added to prepared samples of neutral pulp. The concentration of the suspended bentonite was chosen to give a pulp density of approximately 0,1925 volume fraction and a bentonite concentration of approximately 0,5; 1,0 and 1,5 percent w/w. The viscous parameter of the modified pulp were then determined in the same manner as for a normal pulp described in section 4.3.1.

The results are shown in Figure 5.17 where it can be seen that the addition of only 0,5 percent w/w bentonite to the pulp caused a large increase in the apparent viscosity of the pulp. Further additions of bentonite caused

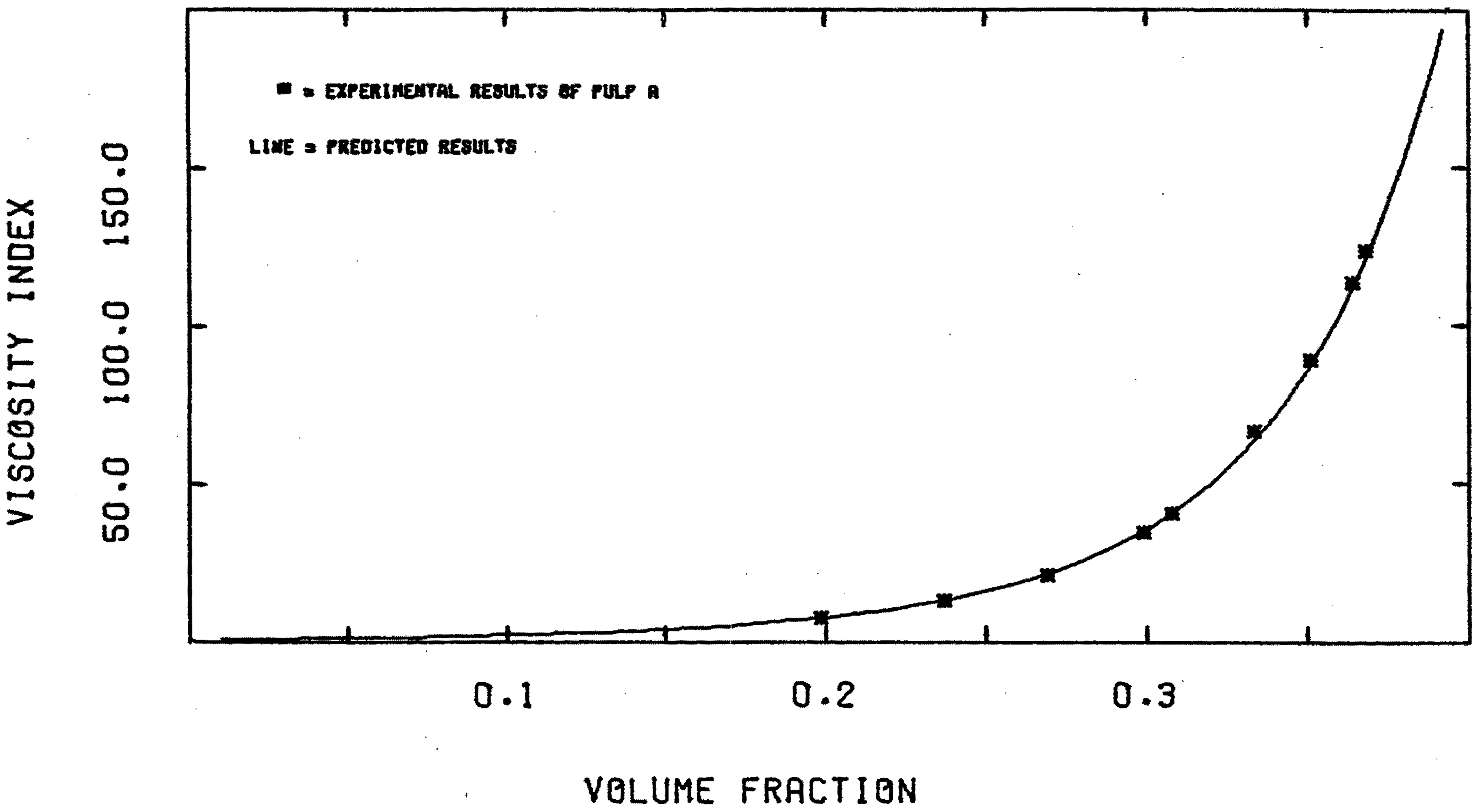


FIG. 5.14 A COMPARISON OF EXPERIMENTAL AND PREDICTED RESULTS

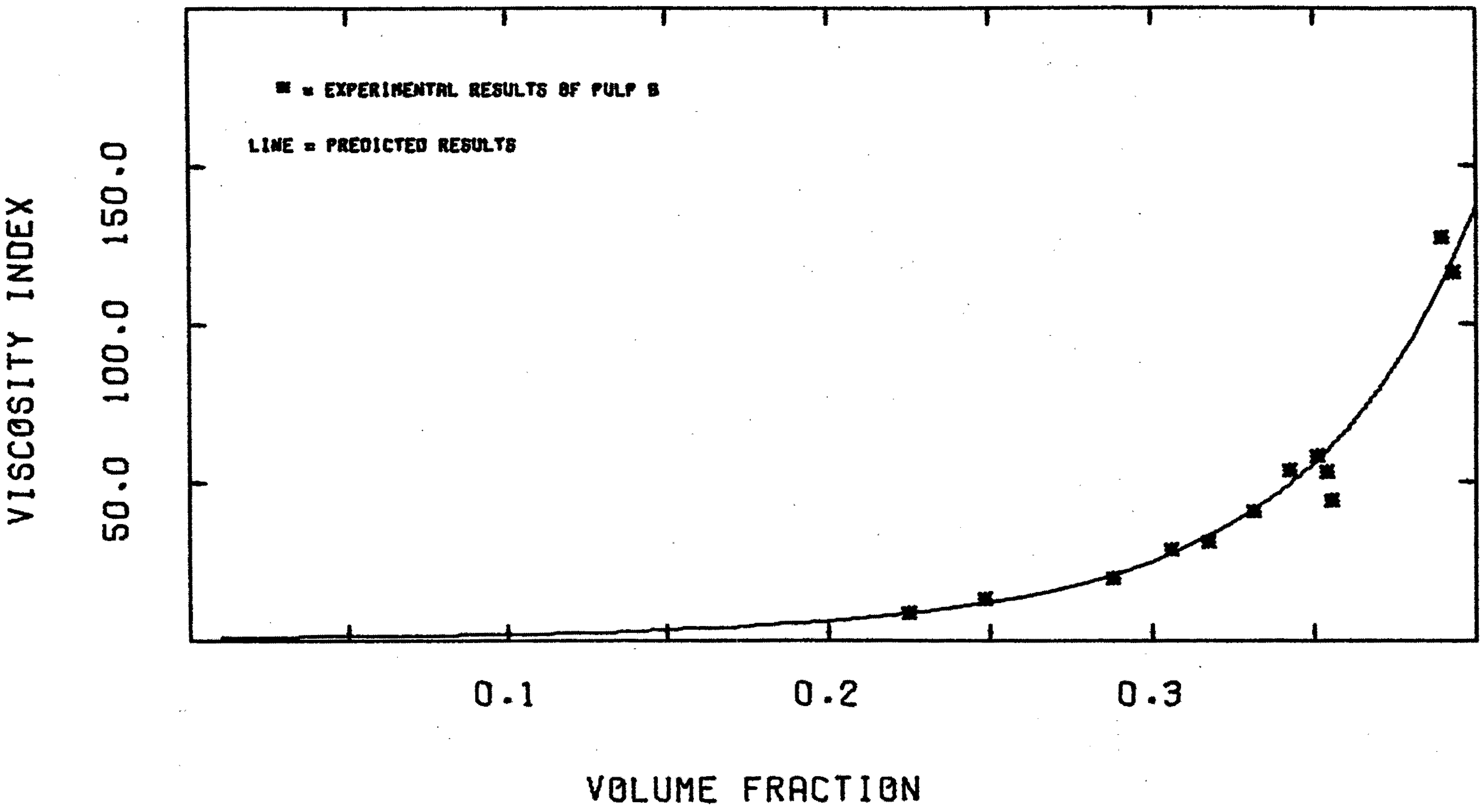


FIG. 5.15 A COMPARISON OF EXPERIMENTAL AND PREDICTED RESULTS

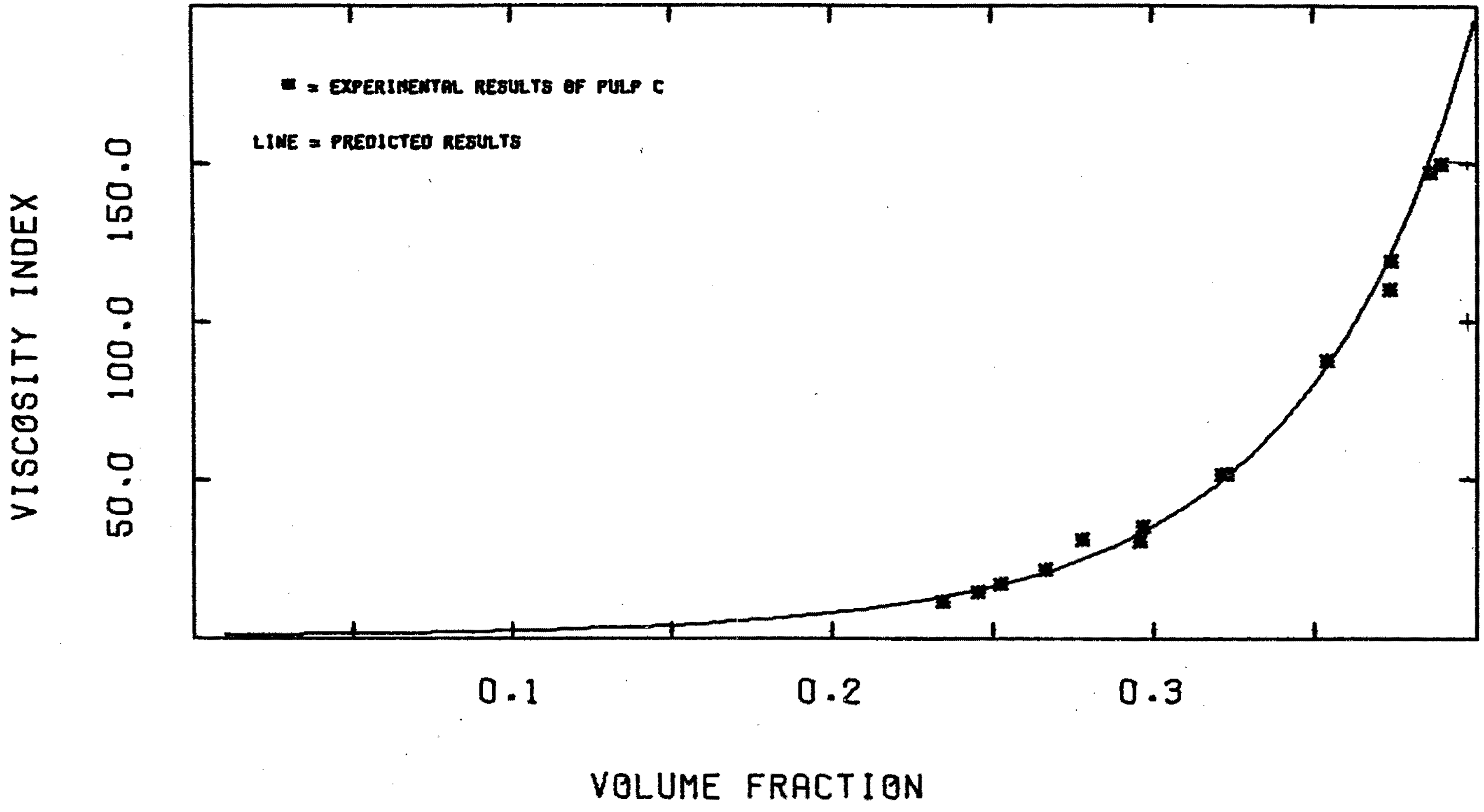


FIG. 5.16 A COMPARISON OF EXPERIMENTAL AND PREDICTED RESULTS

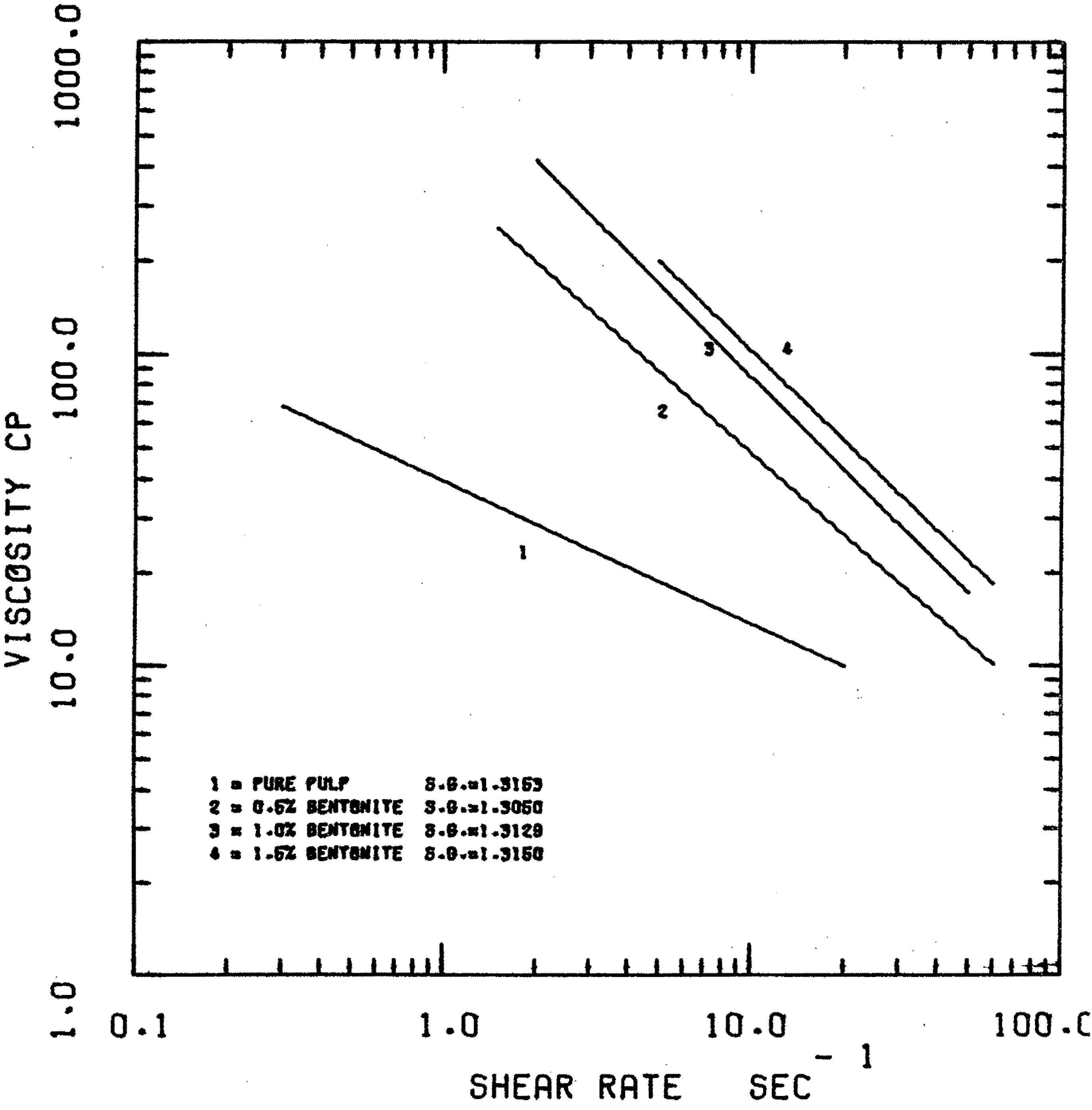


FIG. 5.17 THE EFFECT OF BENTONITE ADDITION

additional increases in the viscosity. However, the relative increase decreased with increasing bentonite concentration. Selected results are shown in Table 5.9.

TABLE 5.9

THE EFFECT OF THE ADDITION OF BENTONITE ON THE APPARENT VISCOSITY OF THE PULP

S.G.	Temp.	% Bentonite	Apparent viscosity at a shear rate of 20 sec^{-1}
1,3191	25°C	0,0	9,84
1,3050	25,1°C	0,5	26,09
1,3129	25,0°C	1,0	42,73
1,315	24,9°C	1,5	52,58

Shack, Dean and Malloy [18] have studied the effect of the addition of bentonite to a clay and found similar results to those reported here. A possible reason for this is that bentonite can absorb large amounts of water [42]. Thus the first addition of bentonite to the pulp results in the adsorption or immobilization of most of the "free" water available with a resultant large increase in the viscosity. Shack et al. found that bentonite could adsorb thirteen times its own weight in water onto its surface.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This research project has shown that it is feasible to investigate the rheological properties of a mine pulp using a conventional viscometer. However, it was necessary to modify the viscometer in order to avoid settling taking place during viscometric measurements and it was found that a normal laboratory magnetic stirrer could be used to keep the pulp in suspension.

A literature survey revealed that there are no fundamental equations which describe the effect of concentration, temperature or shear rate on the rheological properties with any degree of accuracy. Two semi empirical correlations, however, have been presented which describe these effects; viz. Shaheen [20] equation.

$$\eta_{rel} = \exp \frac{A\ \phi}{1 - \alpha\phi^{n}} \qquad (5\text{-}1)$$

and that of Beazley [16]

$$\eta_{rel} = \exp \frac{A\ \phi}{1 - K\phi} \qquad (5\text{-}3)$$

An experimental procedure is outlined in section 4.3.1 which enables the determination of the rheological properties of a mine pulp. This method was developed with a view to its application in the routine determination of the rheological properties of a mine pulp using commercially available equipment.

It was not possible to investigate fully the effect of temperature on the rheological properties and it is suggested that further work be done, utilizing a wider range of temperature, in order to describe the effect of temperature on these rheological parameters in more detail.

Thus the aims of this research project have been satisfied and a new method has been developed which can determine the rheological properties of a mine pulp.

REFERENCES

1. Einstein, A., Ann Physic, 17, 549, (1905); 19, 289, 371, (1906); 34, 591, (1911).

2. Guth,E. and Simha, R., Kolloid-z, 74, 266, (1936). (as reported in reference 32)

3. Gold, O., Dissertation, Vienna,1937. (as reported in reference 32)

4. Burgers, J.M., Unpublished. (as reported in reference 32.)

5. Saito, N., 'Concentration dependence of the viscosity of high polymer solutions', J. Phys. Soc. (Japan), 5, 4, (1950).

6. Smith, H.F., Rubber Chem. and Technol., 15, 301, (1942).

7. Eirich, F., Kolloid-Z, 81, 7, (1937).

8. De Bruijn, H., "The viscosity of suspension of spherical particles", Rec. Trav.Chim., 61, 863, (1942).

9. Vand, V., "Viscosities of solutions and suspensions. 1, 2 & 3", J. Phys. Colloid Chem., 52, 277, 300, 314, (1948).

10. Roscoe, R., "The viscosity of suspensions of rigid spheres", Brit. J. Appl. Phys., 3, 267, (1952).

11. Brinkman, H.C., "The viscosity of concentrated suspensions and solutions", J. Chem. Phys., 20, 571, (1952).

12. Fidleris, V. and Whitmore, R.L., "The physical interaction of spherical particles in suspensions", Rheol. Acta., 1, 573, (1961).

13. Richardson, J.F. and Meikle, R.A., "Sedimentation and fluidization Part III", Trans. Instn Chem. Engrs, 39, 348-356, (1961).

14. Mooney, M., "The viscosity of a concentrated suspension of spherical particles", J. Colloid Sci., 6, 162, (1951).

15. Frankel, N.A. and Arcivos, A., "On the viscosity of a concentrated suspension of solid spheres", Chem. Eng. Sci., 22, 847, (1967).

16. Beazley, K.M., "Viscosity concentration relationships in deflocculated kaolin suspensions", J. Coll. Sci., 41, k, 105, Oct., (1972).

17. De Vaney, F.D. and Shelton, S.M., "Report of investigation - properties of suspension medium for float and sink concentration," Bureau of Mines, No.3469, May, (1940).

18. Schack, C.H., Dean, K.C. and Molloy, S.M., "Measurement and nature of the apparent viscosity of water suspensions of some common minerals", Bureau of Mines Report No.5334, May, (1957).

19. Marsden, D.D., "The effect of pH, temperature and density on the kinematic viscosity of some South African mine pulps." J. South African Inst. Min and Metall. 62 391 - 398 (1962).

20. Shaheen, E.I., "Rheological study of viscosity and pipeline flow of concentrated slurries", Powder Technol., 5, 245, (1971/72).

21. Clyde Orr, Jr. and Dallavalle, J.M., "Heat transfer properties of liquid-solid suspensions", C.E.P. Symposium Series, 50, 9, 29, (1954).

22. Clarke, B., "Rheology of coarse settling suspensions", Trans. Instn Chem. Engrs, 45, T251, (1967).

23. Van Wazer, J.R. et al., "Viscosity and Flow Measurement", Interscience Publishers, N.Y., (1963) p.94.

24. Anglo American Research Laboratories, Private Communication.

25. Van der Walt, P.J. and Fourie, A.M., "Determination of the viscosity of unstable industrial suspensions with the aid of a Stormer viscometer", J. of S.A. Institute of Mining and Metallurgy, 57, 709, July, (1957).

26. Repetti, R.V. and Leonard, E.F., "Physical basis for the axial accumulation of red blood cells", Chem. Engng Prog. Symposium Series - Chemical Engineering in Medicine, 62, 66, 80-87, (1966).

27. Brookfield Engineering Laboratories, Stoughton Massachusetts, U.S.A.

28. Gebrüder Haake, 1 Berlin 37, Goerzallee 249, West Germany.

29. Rosen, M.R., "A rheogram template for power-law fluids", J. of Colloid and Interface Science, 36, 3, July, (1971).

30. Rosen, M.R., "A rheogram template for power-law fluids - II, rapid rheological characterization in a coaxial cylinder", J. of Colloid and Interface Science, 39, 2, May, (1972).

31. Krieger, I.M. and Maron, S.H., "Direct determination of the flow curves of non-Newtonian liquids", J. Applied Physics, 23, 1, 147-149, (1952).

32. Van Wazer, J.R. et al., "Viscosity and Flow Measurements", Interscience Publishers, N.Y.(1963) p.58.

33. Richardson, J.F. and Zaki, W.N., "Sedimentation and fluidization Part I", Trans. Instn Chem. Engrs, 32, 35-51, (1954).

34. Rigby, R.G., Private Communication.

35. Pennington, R.H., "Introductory Computer Methods and Numerical Analysis", Macmillan, New York (1965).

36. Himmelblau, D.M., "Process Analysis by Statistical Methods", John Wiley & Sons, U.S.A. (1970).

37. Boydell, D.W., Private Communication.

38. Nelder, J.A. and Mead, R., "A simplex method for function minimization", Computer J., 7, 308-313, (1965).

39. Glasstone, S. and Lewis, D., "Elements of Physical Chemistry", Macmillan, Netherlands, (1968).

40. Barrow, G.M., "Physical Chemistry", McGraw-Hill, Tokyo, (1966).

41. Blyvooruitzicht Gold Mining Company, Private Communication.

42. American Colloid Company, Private Communication.

43. Frisch, H.L., and R. Simha, "The viscosity of colloidal suspensions and macromelecular solutions," in Eirich, F.R., "Rheology, Theory and Application" Vol. I, Academic Press, New York. (1956)

APPENDIX A

THE DIRECT DETERMINATION OF THE FLOW CURVES OF NON-NEWTONIAN LIQUIDS:

Krieger and Maron [31] considered a concentric cylinder viscometer of bob length L and radius R_1 and a cup of radius R_2. They assumed that the cup rotated with an angular velocity, Ω, while a torque, T, was exerted on the bob to hold it stationary. With laminar flow, the velocity gradient at a distance r from the axis of rotation is

$$\frac{dV}{dy} = -r d\omega/dr \qquad \text{A-1}$$

where ω = angular velocity of the fluid at distance r.

The shear stress is given by the expression

$$\tau = T/2\pi r^2 L \qquad \text{A-2}$$

The flow behaviour of non-Newtonian liquids is described by a functional relationship between the velocity gradient, dV/dy, and the shear stress, τ, as

$$\frac{dV}{dy} = g(\tau) \qquad \text{A-3}$$

Substituting for $\frac{dV}{dy}$ and τ from Equations A-1 and A-2, Equation A-3 becomes

$$-r\frac{d\omega}{dr} = g(T/2\pi r^2 L) \qquad \text{A-4}$$

Further, since $dr/r = - d\tau/2\tau$, Equation A-1 may be transformed to

$$d\omega = \tfrac{1}{2}\, g(\tau)\, \frac{d\tau}{\tau} \qquad \text{A-5}$$

which on integration between the bob, where $\omega = 0$ and $\tau = \tau_1 = T/2\pi R_1{}^2 L$, and the cup, where $\omega = \Omega$ and $\tau = \tau_2 = T/2\pi R_2{}^2 L$, gives

$$\Omega = \tfrac{1}{2} \int_{\tau_1}^{\tau_2} \frac{g(\tau)}{\tau}\, d\tau \qquad \text{A-6}$$

Substituting $\frac{R_2{}^2}{R_1{}^2} = \frac{\tau_1}{\tau_2} = s^2$, Equation A-6 becomes

$$\Omega = \tfrac{1}{2} \int_{s^2\tau_2}^{\tau_2} \frac{g(\tau)}{\tau}\, d\tau \qquad \text{A-7}$$

On differentiating Ω with respect to τ_2, the following equation is obtained

$$\frac{d\Omega}{dF_2} = \tfrac{1}{2}\; \frac{g(\tau_2)}{\tau_2} - \frac{s^2 g(s^2\tau_2)}{s^2\tau_2}$$

$$= \frac{1}{2\tau_2}\quad g(\tau_2) - g(\tau_1) \qquad \text{A-8}$$

For the special case of a finite bob rotating in a cup of infinite radius, $\tau_2 = 0$, Equation A-7 reduces to

$$\Omega = \tfrac{1}{2} \int_{\tau_1}^{0} \frac{g(\tau)\; d\tau}{\tau} \qquad \text{A-9}$$

Differentiation of Equation A-9 with respect to τ_1 gives

$$g(\tau_1) = - 2d\Omega/d \ln \tau \qquad \text{A-10}$$

hence $g(\tau_1)$ could be found from a plot of Ω versus $\ln \tau_1$.

TABLE A 1

RUN 2

	PULP A	TEMP.=25.0	SPINDLE 1	S.G.=1.361
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
1.5	14.6	1.48	2.35	158.77
1.5	14.7	1.48	2.37	159.86
1.5	15.1	1.48	2.43	164.21
3.0	16.4	2.97	2.64	89.17
3.0	16.6	2.97	2.68	90.26
3.0	16.5	2.97	2.66	89.72
.6	13.9	.59	2.24	377.90
.6	14.0	.59	2.26	380.61
6.0	18.4	5.93	2.97	50.02
6.0	18.6	5.93	3.00	50.57
6.0	8.9	5.93	1.43	24.20
6.0	19.0	5.93	3.06	51.65
12.0	22.8	11.86	3.68	30.99
12.0	22.8	11.86	3.68	30.99
12.0	23.0	11.86	3.71	31.26
30.0	27.6	29.65	4.45	15.01
30.0	27.6	29.65	4.45	15.01
30.0	27.6	29.65	4.45	15.01
60.0	33.6	59.31	5.42	9.13
60.0	32.9	59.31	5.30	8.94
60.0	32.6	59.31	5.26	8.86

TABLE A 2

RUN 3

	PULP A	TEMP.=25.0	SPINDLE 2	S.G.=1.500
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	30.3	4.06	20.18	497.29
3.0	30.5	4.06	20.32	500.58
6.0	34.0	8.12	22.65	279.01
6.0	34.2	8.12	22.78	280.65
6.0	34.0	8.12	22.65	279.01
12.0	37.0	16.24	24.65	151.81
12.0	37.2	16.24	24.81	152.84
12.0	37.3	16.24	24.85	153.04
30.0	43.5	40.59	28.98	71.39
30.0	43.2	40.59	28.78	70.90
30.0	42.5	40.59	28.31	69.75
60.0	49.0	81.18	32.64	40.21
60.0	48.0	81.18	31.98	39.39
60.0	48.6	81.18	32.38	39.88

TABLE A 3

RUN 5

	PULP A	TEMP.=25.0	SPINDLE 1	S.G.=1.420
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	34.5	3.37	5.56	164.85
3.0	34.5	3.37	5.56	164.85
6.0	37.3	6.75	6.01	89.11
6.0	36.9	6.75	5.95	88.16
6.0	36.9	6.75	5.95	88.16
12.0	42.5	13.50	6.85	50.77
12.0	42.8	13.50	6.90	51.13
12.0	42.4	13.50	6.84	50.65
30.0	49.5	33.74	7.98	23.65
30.0	49.7	33.74	8.01	23.75
30.0	49.8	33.74	8.03	23.80
60.0	59.6	67.49	9.61	14.24
60.0	58.5	67.49	9.43	13.98
60.0	59.0	67.49	9.51	14.10

TABLE A 4

RUN 8

	PULP A	TEMP.=25.0	SPINDLE 0	S.G.=1.238
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	3.7	.69	.11	15.66
3.0	4.0	.69	.12	16.93
3.0	3.5	.69	.10	14.82
3.0	4.0	.69	.12	16.93
3.0	4.0	.69	.12	16.93
6.0	8.2	1.38	.24	17.36
6.0	8.0	1.38	.23	16.93
6.0	8.2	1.38	.24	17.36
12.0	14.6	2.77	.43	15.45
12.0	14.3	2.77	.42	15.13
12.0	14.8	2.77	.43	15.66
30.0	29.3	6.92	.86	12.40
30.0	29.0	6.92	.85	12.28
30.0	28.7	6.92	.84	12.15
60.0	62.4	13.83	1.83	13.21
60.0	60.5	13.83	1.77	12.81
60.0	62.0	13.83	1.82	13.12
60.0	60.6	13.83	1.77	12.83
60.0	61.6	13.83	1.80	13.04

TABLE A 5

RUN 9

PULP A TEMP.=25.0 SPINDLE 0 S.G.=1.299

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	17.2	1.15	.50	43.70
3.0	16.7	1.15	.49	42.43
3.0	16.8	1.15	.49	42.68
6.0	27.0	2.31	.79	34.30
6.0	26.8	2.31	.78	34.04
6.0	27.0	2.31	.79	34.30
12.0	38.7	4.61	1.13	24.58
12.0	39.2	4.61	1.15	24.90
12.0	39.1	4.61	1.14	24.83
30.0	58.2	11.53	1.70	14.79
30.0	57.9	11.53	1.70	14.71
30.0	57.5	11.53	1.68	14.61
60.0	93.0	23.05	2.72	11.81
60.0	92.7	23.05	2.71	11.77
60.0	92.0	23.05	2.69	11.69

TABLE A 6

RUN 10

PULP A TEMP.=25.0 SPINDLE 1 S.G.=1.315

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	10.7	4.70	1.73	36.70
6.0	10.9	4.70	1.76	37.39
6.0	10.6	4.70	1.71	36.36
12.0	11.6	9.40	1.87	19.83
12.0	12.0	9.40	1.93	20.58
12.0	11.7	9.40	1.89	20.06
30.0	15.2	23.50	2.45	10.43
30.0	14.9	23.50	2.40	10.22
30.0	15.5	23.50	2.50	10.63
60.0	19.6	47.01	3.16	6.72
60.0	19.2	47.01	3.10	6.59
60.0	19.4	47.01	3.13	6.65

TABLE A 7

RUN 11

PULP A TEMP.=25.0 SPINDLE 2 S.G.=1.497

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	15.6	3.72	10.39	279.56
3.0	15.6	3.72	10.39	279.56
6.0	16.4	7.43	10.93	146.95
6.0	16.6	7.43	11.06	148.74
6.0	16.8	7.43	11.19	150.53
12.0	19.0	14.87	12.66	85.12
12.0	18.9	14.87	12.59	84.67
12.0	19.0	14.87	12.66	85.12
30.0	21.8	37.17	14.52	39.07
30.0	21.6	37.17	14.39	38.71
30.0	21.6	37.17	14.39	38.71
60.0	25.6	74.35	17.05	22.94
60.0	25.1	74.35	16.72	22.49
60.0	25.6	74.35	17.05	22.94

TABLE A 8

RUN 12

PULP A TEMP.=25.0 SPINDLE 1 S.G.=1.399

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	21.8	3.11	3.51	113.07
3.0	22.1	3.11	3.56	114.63
3.0	22.0	3.11	3.55	114.11
6.0	23.6	6.22	3.81	61.20
6.0	23.9	6.22	3.85	61.98
6.0	23.9	6.22	3.85	61.98
12.0	28.6	12.43	4.61	37.09
12.0	28.5	12.43	4.60	36.96
12.0	28.6	12.43	4.61	37.09
30.0	33.2	31.09	5.35	17.22
30.0	33.3	31.09	5.37	17.27
30.0	33.2	31.09	5.35	17.22
60.0	39.8	62.17	6.42	10.32
60.0	39.9	62.17	6.43	10.35
60.0	39.7	62.17	6.40	10.30

TABLE A 9

RUN 13

PULP A TEMP.=25.0 SPINDLE 0 S.G.=1.341

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
1.5	48.6	1.45	1.42	97.98
3.0	54.2	2.91	1.59	54.63
6.0	64.6	5.81	1.89	32.56
12.0	72.6	11.62	2.13	18.30
30.0	94.0	29.05	2.75	9.48
1.5	49.5	1.45	1.45	99.79
3.0	56.5	2.91	1.65	56.95
6.0	64.5	5.81	1.89	32.51
12.0	73.4	11.62	2.15	18.50
30.0	92.8	29.05	2.72	9.35

TABLE A 10

RUN 14

PULP A TEMP.=25.0 SPINDLE 1 S.G.=1.341

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
30.0	19.8	25.30	3.19	12.62
12.0	16.1	10.12	2.60	25.66
60.0	24.3	50.59	3.92	7.74
30.0	19.8	25.30	3.19	12.62
12.0	15.8	10.12	2.55	25.18
6.0	13.6	5.06	2.19	43.34
6.0	13.6	5.06	2.19	43.34

TABLE A 11

RUN 15

PULP A TEMP.=25.3 SPINDLE 2 S.G.=1.361

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	75.5	3.94	50.30	1277.70
3.0	75.0	3.94	49.96	1269.24
6.0	85.0	7.87	56.62	719.24
6.0	84.0	7.87	55.96	710.77
12.0	93.5	15.75	62.29	395.58
12.0	93.8	15.75	62.49	396.85
12.0	93.6	15.75	62.35	396.00
6.0	83.2	7.87	55.42	704.00
6.0	83.0	7.87	55.29	702.31
3.0	74.2	3.94	49.43	1255.70
3.0	74.0	3.94	49.30	1252.32
1.5	68.0	1.97	45.30	2301.55
1.5	67.0	1.97	44.63	2267.71

TABLE A 12

RUN 16

PULP A TEMP.=30.0 SPINDLE 1 S.G.=1.320

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	25.6	1.49	4.13	276.56
3.0	25.2	1.49	4.06	272.24
6.0	36.6	2.98	5.90	197.70
6.0	36.6	2.98	5.90	197.70
12.0	48.0	5.97	7.74	129.64
12.0	48.0	5.97	7.74	129.64
12.0	47.5	5.97	7.66	128.29
30.0	67.0	14.92	10.80	72.38
30.0	66.8	14.92	10.77	72.16
60.0	94.4	29.85	15.22	50.99
60.0	94.0	29.85	15.16	50.77

TABLE A 13

RUN 17

	PULP A	TEMP.=38.0	SPINDLE 1	S.G.=1.320
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	27.0	1.55	4.35	281.42
3.0	26.8	1.55	4.32	279.34
6.0	38.5	3.09	6.21	200.64
6.0	38.0	3.09	6.13	198.04
12.0	50.5	6.19	8.14	131.59
12.0	50.6	6.19	8.16	131.85
30.0	68.0	15.47	10.96	70.88
30.0	69.0	15.47	11.12	71.92
30.0	68.8	15.47	11.09	71.71
60.0	96.0	30.94	15.48	50.03
60.0	96.0	30.94	15.48	50.03

TABLE A 14

RUN 18

	PULP A	TEMP.=23.5	SPINDLE 1	S.G.=1.382
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
60.0	36.0	61.10	5.80	9.50
60.0	36.2	61.10	5.84	9.55
30.0	30.2	30.55	4.87	15.94
30.0	30.2	30.55	4.87	15.94
12.0	25.0	12.22	4.03	32.99
12.0	25.0	12.22	4.03	32.99
6.0	22.5	6.11	3.63	59.38
6.0	22.3	6.11	3.60	58.85
3.0	19.2	3.05	3.10	101.34
3.0	19.5	3.05	3.14	102.92

TABLE A 15

RUN 19

	PULP A	TEMP.=35.0	SPINDLE 1	S.G.=1.382
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	22.3	3.94	3.60	91.33
3.0	22.5	3.94	3.63	92.15
6.0	24.4	7.87	3.93	49.96
6.0	24.0	7.87	3.87	49.14
12.0	26.6	15.75	4.29	27.23
12.0	26.3	15.75	4.24	26.93
30.0	30.8	39.37	4.97	12.61
30.0	30.6	39.37	4.93	12.53
60.0	36.0	78.74	5.80	7.37
60.0	36.0	78.74	5.80	7.37

TABLE A 16

RUN 20

	PULP A	TEMP.=40.2	SPINDLE 1	S.G.=1.382
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	23.6	4.18	3.81	90.93
3.0	23.4	4.18	3.77	90.16
6.0	25.2	8.37	4.06	48.55
6.0	25.1	8.37	4.05	48.36
12.0	27.8	16.74	4.48	26.78
12.0	28.0	16.74	4.51	26.97
30.0	32.1	41.84	5.18	12.37
30.0	32.4	41.84	5.22	12.48
60.0	36.4	83.69	5.87	7.01
60.0	36.5	83.69	5.88	7.03

TABLE A 17

RUN 21

PULP A TEMP.=25.9 SPINDLE 1 S.G.=1.433

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	36.6	3.56	5.90	165.69
3.0	36.6	3.56	5.90	165.69
6.0	39.7	7.12	6.40	89.86
6.0	39.8	7.12	6.42	90.09
12.0	45.2	14.25	7.29	51.15
12.0	45.5	14.25	7.34	51.49
30.0	52.3	35.62	8.43	23.68
30.0	52.8	35.62	8.51	23.90
60.0	61.6	71.23	9.93	13.94
60.0	61.8	71.23	9.96	13.99

TABLE A 18

RUN 22

PULP A TEMP.=32.7 SPINDLE 1 S.G.=1.433

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	43.5	4.40	7.01	159.26
3.0	43.0	4.40	6.93	157.43
6.0	45.7	8.81	7.37	83.66
6.0	45.3	8.81	7.30	82.92
12.0	50.4	17.62	8.13	46.13
12.0	50.6	17.62	8.16	46.31
30.0	57.4	44.04	9.25	21.01
30.0	57.6	44.04	9.29	21.09
60.0	65.6	88.08	10.58	12.01
60.0	65.6	88.08	10.58	12.01

TABLE A 19

RUN 23

	PULP A	TEMP.=18.0	SPINDLE 1	S.G.=1.481
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	59.8	3.92	9.64	245.72
3.0	59.8	3.92	9.64	245.72
6.0	64.6	7.85	10.42	132.72
6.0	64.8	7.85	10.45	133.13
12.0	70.8	15.70	11.42	72.73
12.0	70.8	15.70	11.42	72.73
30.0	82.4	39.24	13.29	33.86
30.0	82.4	39.24	13.29	33.86
60.0	96.2	78.48	15.51	19.76
60.0	96.2	78.48	15.51	19.76

TABLE A 20

RUN 24

	PULP A	TEMP.=21.6	SPINDLE 1	S.G.=1.481
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	62.0	4.18	10.00	239.04
3.0	62.0	4.18	10.00	239.04
6.0	66.2	8.36	10.67	127.62
6.0	66.3	8.36	10.69	127.81
12.0	72.3	16.73	11.66	69.69
12.0	72.3	6.73	11.66	69.69
30.0	83.6	1.82	13.48	32.23
30.0	83.4	41.82	13.45	32.15
60.0	96.7	83.64	15.59	18.64
60.0	96.6	83.64	15.57	18.62

TABLE A 21

RUN 25

PULP A TEMP.=24.6 SPINDLE 1 S.G.=1.481

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	64.1	4.38	10.33	236.19
3.0	63.6	4.38	10.25	234.35
6.0	68.3	8.75	11.01	125.83
6.0	68.1	8.75	10.98	125.47
12.0	74.0	17.50	11.93	68.17
12.0	74.2	17.50	11.96	68.35
30.0	85.1	43.76	13.72	31.36
30.0	84.9	43.76	13.69	31.28
60.0	97.6	87.51	15.74	17.98
60.0	97.8	87.51	15.77	18.02

TABLE A 22

RUN 26

PULP A TEMP.=26.8 SPINDLE 1 S.G.=1.481

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	66.6	4.73	10.74	226.98
3.0	66.5	4.73	10.72	226.64
6.0	70.8	9.46	11.42	120.65
6.0	70.6	9.46	11.38	120.31
12.0	76.4	18.92	12.32	65.10
12.0	76.4	18.92	12.32	65.10
30.0	87.1	47.31	14.04	29.68
30.0	87.2	47.31	14.06	29.72
60.0	98.4	94.62	15.87	16.77
60.0	98.5	94.62	15.88	16.79

TABLE A 23

RUN 27

PULP A   TEMP.=19.4   SPINDLE 2   S.G.=1.578

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	39.6	4.40	26.38	599.96
3.0	39.8	4.40	26.51	602.99
6.0	42.5	8.79	28.31	321.95
6.0	42.6	8.79	28.38	322.71
12.0	47.6	17.59	31.71	180.29
12.0	46.0	17.59	30.64	174.23
12.0	47.2	17.59	31.44	178.78
30.0	53.2	43.97	35.44	80.60
30.0	53.2	43.97	35.44	80.60
60.0	60.4	87.94	40.24	45.75
60.0	60.9	87.94	40.57	46.13

TABLE A 24

RUN 28

PULP A   TEMP.=23.0   SPINDLE 2   S.G.=1.578

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	40.8	4.53	27.18	599.84
3.0	40.8	4.53	27.18	599.84
6.0	45.4	9.06	30.24	333.74
6.0	45.5	9.06	30.31	334.47
12.0	49.6	18.12	33.04	182.31
12.0	49.4	18.12	32.91	181.57
30.0	55.6	45.31	37.04	81.74
30.0	55.0	45.31	36.64	80.86
60.0	62.6	90.62	41.70	46.02
60.0	62.6	90.62	41.70	46.02

TABLE A 25

RUN 29

PULP A | TEMP.=24.5 | SPINDLE 2 | S.G.=1.578

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	40.8	4.50	27.18	603.54
3.0	40.8	4.50	27.18	603.54
6.0	45.8	9.01	30.51	338.75
6.0	45.4	9.01	30.24	335.79
6.0	45.6	9.01	30.38	337.27
12.0	49.5	18.01	32.98	183.06
12.0	49.6	18.01	33.04	183.43
30.0	56.2	45.03	37.44	83.13
30.0	56.2	45.03	37.44	83.13
60.0	62.6	90.07	41.70	46.30
60.0	62.6	90.07	41.70	46.30

TABLE A 26

RUN 30

PULP A | TEMP.=28.2 | SPINDLE 2 | S.G.=1.578

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	40.7	4.43	27.11	612.28
3.0	40.7	4.43	27.11	612.28
6.0	46.2	8.86	30.78	347.51
6.0	46.7	8.86	31.11	351.27
12.0	50.9	17.71	33.91	191.43
12.0	50.7	17.71	33.77	190.68
30.0	56.3	44.28	37.51	84.70
30.0	56.8	44.28	37.84	85.45
60.0	62.6	88.56	41.70	47.09
60.0	63.6	88.56	42.37	47.84
60.0	63.6	88.56	42.37	47.84
60.0	63.8	88.56	42.50	47.99

TABLE A 27

RUN 31

PULP A   TEMP.=12.7   SPINDLE 2   S.G.=1.537

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	27.6	3.91	18.39	470.24
3.0	27.4	3.91	18.25	466.83
3.0	27.4	3.91	18.25	466.83
6.0	29.8	7.82	19.85	253.86
6.0	30.1	7.82	20.05	256.41
6.0	30.2	7.82	20.12	257.27
12.0	33.3	15.64	22.18	141.84
12.0	33.6	15.64	22.38	143.12
12.0	33.2	15.64	22.12	141.41
30.0	38.9	39.10	25.91	66.28
30.0	38.2	39.10	25.45	65.08
30.0	38.4	39.10	25.58	65.42
60.0	44.5	78.20	29.64	37.91
60.0	44.2	78.20	29.44	37.65
60.0	44.4	78.20	29.58	37.82

TABLE A 28

RUN 32

PULP A   TEMP.=15.2   SPINDLE 2   S.G.=1.537

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
60.0	44.8	83.60	29.84	35.70
60.0	45.0	83.60	29.98	35.86
30.0	38.5	41.80	25.65	61.36
30.0	38.7	41.80	25.78	61.68
12.0	33.7	16.72	22.45	134.28
12.0	34.4	16.72	22.92	137.06
12.0	34.1	16.72	22.72	135.87
6.0	31.3	8.36	20.85	249.43
6.0	31.1	8.36	20.72	247.83
3.0	28.5	4.18	18.99	454.22
3.0	28.4	4.18	18.92	452.63

TABLE A 29

RUN 33

RPM	PULP A DIAL READING	TEMP.=21.5 SHEAR RATE	SPINDLE 2 SHEAR STRESS	S.G.=1.537 EFFECTIVE VISCOSITY
3.0	29.6	4.60	19.72	429.11
3.0	29.2	4.60	19.45	423.31
6.0	31.6	9.19	21.05	229.05
6.0	31.6	9.19	21.05	229.05
12.0	34.6	18.38	23.05	125.40
12.0	34.8	18.38	23.18	126.12
30.0	39.1	45.95	26.05	56.68
30.0	38.9	45.95	25.91	56.39
60.0	44.3	91.90	29.51	32.11
60.0	44.2	91.90	29.44	32.04

TABLE A 30

RUN 34

RPM	PULP A DIAL READING	TEMP.=25.6 SHEAR RATE	SPINDLE 2 SHEAR STRESS	S.G.=1.537 EFFECTIVE VISCOSITY
3.0	29.8	4.58	19.85	432.99
3.0	29.4	4.58	19.59	427.17
6.0	32.3	9.17	21.52	234.66
6.0	32.4	9.17	21.58	235.38
12.0	35.5	18.34	23.65	128.95
12.0	35.3	18.34	23.52	128.23
30.0	40.2	45.85	26.78	58.41
30.0	40.2	45.85	26.78	58.41
60.0	44.6	91.70	29.71	32.40
60.0	44.6	91.70	29.71	32.40

TABLE A 31

RUN 35

RPM	PULP A DIAL READING	TEMP.=30.0 SHEAR RATE	SPINDLE 2 SHEAR STRESS	S.G.=1.537 EFFECTIVE VISCOSITY
3.0	29.6	4.63	19.72	426.14
3.0	29.6	4.63	19.72	426.14
6.0	32.9	9.25	21.92	236.82
6.0	33.2	9.25	22.12	238.98
12.0	36.4	18.51	24.25	131.01
12.0	36.2	18.51	24.12	130.29
30.0	40.6	46.27	27.05	58.45
30.0	39.8	46.27	26.51	57.30
60.0	45.0	92.54	29.98	32.39
60.0	45.1	92.54	30.04	32.46

TABLE A 32

RUN 36

RPM	PULP A DIAL READING	TEMP.=11.9 SHEAR RATE	SPINDLE 1 SHEAR STRESS	S.G.=1.496 EFFECTIVE VISCOSITY
3.0	80.3	5.33	12.95	242.79
3.0	80.2	5.33	12.93	242.49
6.0	86.4	10.67	13.93	130.62
6.0	86.5	10.67	13.95	130.77
12.0	94.3	21.33	15.20	71.28
12.0	94.6	21.33	15.25	71.51

TABLE A 33

RUN 37

	PULP A	TEMP.=11.4	SPINDLE 2	S.G.=1.496
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	15.8	3.48	10.53	302.78
3.0	15.7	3.48	10.46	300.86
6.0	17.5	6.95	11.66	167.68
6.0	17.6	6.95	11.72	168.64
12.0	19.3	13.90	12.86	92.46
12.0	19.4	13.90	12.92	92.94
30.0	23.0	34.76	15.32	44.08
30.0	22.9	34.76	15.26	43.88
60.0	27.1	69.52	18.05	25.97
60.0	27.0	69.52	17.99	25.87

TABLE A 34

RUN 38

	PULP A	TEMP.=17.8	SPINDLE 2	S.G.=1.496
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	16.5	3.82	10.99	287.81
3.0	16.5	3.82	10.99	287.81
6.0	18.3	7.64	12.19	159.60
6.0	18.2	7.64	12.12	158.73
12.0	20.6	15.28	13.72	89.83
12.0	20.3	15.28	13.52	88.52
30.0	23.5	38.19	15.65	40.99
30.0	23.5	38.19	15.65	40.99
60.0	27.0	76.38	17.99	23.55
60.0	27.1	76.38	18.05	23.64

TABLE A 35

RUN 39

PULP A TEMP.=25.7 SPINDLE 2 S.G.=1.496

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	17.5	4.24	11.66	275.23
3.0	17.4	4.24	11.59	273.65
6.0	18.9	8.47	12.59	148.62
6.0	18.7	8.47	12.46	147.05
12.0	20.6	16.94	13.72	80.99
12.0	20.6	16.94	13.72	80.99
30.0	23.6	42.36	15.72	37.12
30.0	23.7	42.36	15.79	37.27
60.0	27.0	84.71	17.99	21.23
60.0	27.2	84.71	18.12	21.39

TABLE A 36

RUN 40

PULP A TEMP.=10.4 SPINDLE 2 S.G.=1.592

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	53.8	4.40	35.84	813.70
3.0	53.4	4.40	35.57	807.65
6.0	59.7	8.81	39.77	451.47
6.0	59.9	8.81	39.90	452.98
12.0	66.0	17.62	43.97	249.56
12.0	65.6	17.62	43.70	248.04
30.0	73.5	44.05	48.96	111.17
30.0	73.4	44.05	48.90	111.01
60.0	82.4	88.09	54.89	62.31
60.0	83.2	88.09	55.42	62.92
60.0	83.2	88.09	55.42	62.92

TABLE A 37

RUN 41

	PULP A	TEMP.=17.3	SPINDLE 2	S.G.=1.592
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	53.2	4.38	35.44	808.34
3.0	51.2	4.38	34.11	777.95
6.0	60.1	8.77	40.04	456.59
6.0	59.6	8.77	39.70	452.79
12.0	64.8	17.54	43.17	246.15
12.0	65.4	17.54	43.57	248.43
30.0	73.6	43.84	49.03	111.83
30.0	73.2	43.84	48.76	111.22
60.0	81.3	87.69	54.16	61.76
60.0	81.8	87.69	54.49	62.14
60.0	81.8	87.69	54.49	62.14

TABLE A 38

RUN 42

	PULP A	TEMP.=25.8	SPINDLE 2	S.G.=1.592
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	44.6	3.61	29.71	823.55
3.0	44.3	3.61	29.51	818.01
6.0	59.8	7.22	39.84	552.11
6.0	59.8	7.22	39.84	552.11
12.0	66.2	14.43	44.10	305.60
12.0	66.3	14.43	44.17	306.06
30.0	74.6	36.08	49.70	137.75
30.0	74.3	36.08	49.50	137.20
60.0	81.3	72.15	54.16	75.06
60.0	81.9	72.15	54.56	75.62
60.0	82.0	72.15	54.63	75.71

TABLE A 39

RUN 43

PULP A TEMP.=30.1 SPINDLE 2 S.G.=1.592

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	43.8	3.42	29.18	853.01
3.0	42.0	3.42	27.98	817.96
6.0	59.5	6.84	39.64	579.39
6.0	60.1	6.84	40.04	585.23
12.0	66.8	13.68	44.50	325.24
12.0	67.4	13.68	44.90	328.16
12.0	67.6	13.68	45.03	329.13
30.0	75.8	34.21	50.50	147.62
30.0	74.6	34.21	49.70	145.28
30.0	75.0	34.21	49.96	146.06
60.0	83.2	68.41	55.42	81.02
60.0	83.2	68.41	55.42	81.02
60.0	83.4	68.41	55.56	81.21

TABLE A 40

RUN 44

PULP A TEMP.=10.4 SPINDLE 2 S.G.=1.586

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	44.6	3.77	29.71	788.44
3.0	44.4	3.77	29.58	784.91
6.0	50.8	7.54	33.84	449.02
6.0	50.7	7.54	33.77	448.14
12.0	56.2	15.07	37.44	248.38
12.0	57.2	15.07	38.10	252.80
12.0	56.2	15.07	37.44	248.38
30.0	65.4	37.68	43.57	115.62
30.0	64.6	37.68	43.03	114.20
30.0	65.1	37.68	43.37	115.08
60.0	74.4	75.37	49.56	65.76
60.0	73.5	75.37	48.96	64.97
60.0	74.5	75.37	49.63	65.85

TABLE A 41

RUN 45

PULP A   TEMP.=17.2   SPINDLE 2   S.G.=1.586

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	43.8	3.85	29.18	757.27
3.0	44.0	3.85	29.31	760.73
6.0	52.1	7.71	34.71	450.39
6.0	52.1	7.71	34.71	450.39
12.0	57.9	15.41	38.57	250.26
12.0	57.9	15.41	38.57	250.26
30.0	65.6	38.53	43.70	113.42
30.0	65.3	38.53	43.50	112.90
30.0	65.6	38.53	43.70	113.42
60.0	73.9	77.06	49.23	63.88
60.0	74.0	77.06	49.30	63.97
60.0	73.4	77.06	48.90	63.45

TABLE A 42

RUN 46

PULP A   TEMP.=24.8   SPINDLE 2   S.G.=1.586

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	40.4	3.48	26.91	772.78
3.0	40.4	3.48	26.91	772.78
6.0	52.4	6.97	34.91	501.16
6.0	52.4	6.97	34.91	501.16
12.0	58.8	13.93	39.17	281.18
12.0	58.8	13.93	39.17	281.18
30.0	66.4	34.83	44.23	127.01
30.0	66.0	34.83	43.97	126.25
30.0	66.5	34.83	44.30	127.20
60.0	74.2	69.65	49.43	70.97
60.0	74.4	69.65	49.56	71.16
60.0	74.4	69.65	49.56	71.16

TABLE A 43

RUN 47

PULP A TEMP.=31.2 SPINDLE 2 S.G.=1.506

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	38.6	3.19	25.71	804.99
3.0	38.6	3.19	25.71	804.99
6.0	54.3	6.39	36.17	566.21
6.0	54.9	6.39	36.57	572.46
12.0	62.2	12.78	41.44	324.29
12.0	62.2	12.78	41.44	324.29
30.0	70.2	31.94	46.76	146.40
30.0	70.2	31.94	46.76	146.40
60.0	78.0	63.89	51.96	81.33
60.0	77.8	63.89	51.83	81.13
60.0	77.6	63.89	51.69	80.92

TABLE A 44

RUN 48

PULP A TEMP.=11.4 SPINDLE 2 S.G.=1.565

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	36.0	4.10	23.98	584.33
3.0	36.4	4.10	24.25	590.82
6.0	40.5	8.21	26.98	328.69
6.0	40.5	8.21	26.98	328.69
12.0	44.3	16.42	29.51	179.76
12.0	44.2	16.42	29.44	179.36
30.0	50.4	41.04	33.57	81.81
30.0	50.4	41.04	33.57	81.81
60.0	57.6	82.08	38.37	46.75
60.0	57.6	82.08	38.37	46.75
60.0	57.6	82.08	38.37	46.75

TABLE A 45

RUN 49

	PULP A	TEMP.=17.2	SPINDLE 2	S.G.=1.565
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	37.6	4.41	25.05	568.60
3.0	38.4	4.41	25.58	580.70
6.0	42.6	8.81	28.38	322.11
6.0	45.6	8.81	30.38	344.79
12.0	46.3	17.62	30.84	175.04
12.0	46.2	17.62	30.78	174.66
30.0	52.6	44.05	35.04	79.54
30.0	52.6	44.05	35.04	79.54
60.0	59.2	88.10	39.44	44.76
60.0	59.6	88.10	39.70	45.06
60.0	60.0	88.10	39.97	45.37
60.0	59.2	88.10	39.44	44.76

TABLE A 46

RUN 50

	PULP A	TEMP.=22.3	SPINDLE 2	S.G.=1.565
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	36.2	3.88	24.12	621.03
3.0	36.0	3.88	23.98	617.60
6.0	42.6	7.77	28.38	365.41
6.0	42.5	7.77	28.31	364.56
12.0	47.1	15.53	31.38	202.01
12.0	46.5	15.53	30.98	199.43
30.0	53.2	38.83	35.44	91.27
30.0	53.6	38.83	35.71	91.95
60.0	60.0	77.66	39.97	51.47
60.0	60.4	77.66	40.24	51.81
60.0	60.0	77.66	39.97	51.47
60.0	60.1	77.66	40.04	51.55

TABLE A 47

RUN 51

PULP A TEMP.=28.6 SPINDLE 2 S.G.=1.565

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	34.7	3.63	23.12	637.57
3.0	33.6	3.63	22.38	617.36
6.0	42.7	7.25	28.45	392.28
6.0	42.8	7.25	28.51	393.20
12.0	47.7	14.50	31.78	219.11
12.0	47.6	14.50	31.71	218.65
30.0	53.9	36.26	35.91	99.03
30.0	54.2	36.26	36.11	99.59
60.0	60.7	72.51	40.44	55.76
60.0	60.5	72.51	40.30	55.58
60.0	60.6	72.51	40.37	55.67
60.0	60.6	72.51	40.37	55.67

TABLE A 48

RUN 59

PULP B TEMP.=25.4 SPINDLE 1 S.G.=1.449

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
3.0	36.4	3.17	5.87	184.85
3.0	36.3	3.17	5.85	184.34
6.0	40.0	6.35	6.45	101.57
6.0	39.7	6.35	6.40	100.80
12.0	45.2	12.70	7.29	57.38
12.0	45.2	12.70	7.29	57.38
30.0	56.1	31.75	9.05	28.49
30.0	55.6	31.75	8.96	28.24
30.0	55.6	31.75	8.96	28.24
60.0	64.4	63.50	10.38	16.35
60.0	64.6	63.50	10.42	16.40
60.0	63.6	63.50	10.25	16.15

TABLE A 49

RUN 60

PULP B TEMP.=28.5 SPINDLE 1 S.G.=1.449

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	40.8	6.17	6.58	106.54
6.0	40.4	6.17	6.51	105.49
12.0	45.7	12.35	7.37	59.67
12.0	45.6	12.35	7.35	59.54
30.0	56.1	30.87	9.05	29.30
30.0	56.2	30.87	9.06	29.35
30.0	56.2	30.87	9.06	29.35
60.0	64.0	61.75	10.32	16.71
60.0	64.4	61.75	10.38	16.82
60.0	64.3	61.75	10.37	16.79

TABLE A 50

RUN 61

PULP B TEMP.=21.4 SPINDLE 0 S.G.=1.277

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	15.8	1.91	.46	24.24
6.0	16.4	1.91	.48	25.16
12.0	22.7	3.82	.66	17.41
12.0	22.1	3.82	.65	16.95
12.0	22.2	3.82	.65	17.03
30.0	34.0	9.54	1.00	10.43
30.0	34.1	9.54	1.00	10.46
30.0	34.0	9.54	1.00	10.43
60.0	67.3	19.09	1.97	10.32
60.0	67.8	19.09	1.99	10.40
60.0	66.8	19.09	1.96	10.25

TABLE A 51

RUN 62

	PULP B	TEMP.=25.0	SPINDLE 0	S.G.=1.277
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	16.6	2.73	.49	17.80
6.0	16.2	2.73	.47	17.37
12.0	22.3	5.46	.65	11.95
12.0	22.4	5.46	.66	12.01
12.0	22.4	5.46	.66	12.01
30.0	34.4	13.66	1.01	7.38
30.0	34.2	13.66	1.00	7.33
30.0	34.2	13.66	1.00	7.33

TABLE A 52

RUN 64

	PULP B	TEMP.=19.0	SPINDLE 1	S.G.=1.360
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	10.2	3.93	1.64	41.86
6.0	10.1	3.93	1.63	41.45
12.0	13.1	7.86	2.11	26.88
12.0	12.8	7.86	2.06	26.26
12.0	13.1	7.86	2.11	26.88
30.0	17.2	19.65	2.77	14.12
30.0	16.9	19.65	2.72	13.87
30.0	17.1	19.65	2.76	14.03
60.0	21.3	39.29	3.43	8.74
60.0	21.6	39.29	3.48	8.86
60.0	21.6	39.29	3.48	8.86

TABLE A 53

RUN 65

	PULP B	TEMP.=21.5	SPINDLE 1	S.G.=1.360
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	11.6	4.38	1.87	42.72
6.0	11.4	4.38	1.84	41.98
12.0	13.6	8.76	2.19	25.04
12.0	13.6	8.76	2.19	25.04
12.0	13.6	8.76	2.19	25.04
30.0	17.4	21.89	2.81	12.82
30.0	17.4	21.89	2.81	12.82
30.0	17.4	21.89	2.81	12.82
60.0	22.1	43.78	3.56	8.14
60.0	22.1	43.78	3.56	8.14
60.0	21.9	43.78	3.53	8.06

TABLE A 54

RUN 66

	PULP B	TEMP.=25.6	SPINDLE 1	S.G.=1.360
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	11.1	4.43	1.79	40.42
6.0	11.4	4.43	1.84	41.51
12.0	13.5	8.86	2.18	24.58
12.0	13.7	8.86	2.21	24.94
12.0	13.6	8.86	2.19	24.76
30.0	17.5	22.14	2.82	12.74
30.0	17.4	22.14	2.81	12.67
30.0	17.4	22.14	2.81	12.67
60.0	21.6	44.28	3.48	7.87
60.0	21.6	44.28	3.48	7.87
60.0	21.6	44.28	3.48	7.87

TABLE A 55

RUN 67

	PULP B	TEMP.=30.3	SPINDLE 1	S.G.=1.360
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	11.2	4.57	1.81	39.47
6.0	11.7	4.57	1.89	41.24
12.0	13.6	9.15	2.19	23.97
12.0	13.6	9.15	2.19	23.97
12.0	13.6	9.15	2.19	23.97
30.0	17.3	22.87	2.79	12.19
30.0	17.3	22.87	2.79	12.19
30.0	17.3	22.87	2.79	12.19
60.0	21.6	45.75	3.48	7.61
60.0	20.6	45.75	3.32	7.26
60.0	21.6	45.75	3.48	7.61
60.0	21.7	45.75	3.50	7.65

TABLE A 56

RUN 68

	PULP B	TEMP.=18.9	SPINDLE 1	S.G.=1.397
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	18.2	4.76	2.93	61.63
6.0	18.4	4.76	2.97	62.30
12.0	22.3	9.52	3.60	37.75
12.0	22.1	9.52	3.56	37.42
12.0	22.2	9.52	3.58	37.58
30.0	27.3	23.81	4.40	18.49
30.0	27.2	23.81	4.39	18.42
30.0	27.3	23.81	4.40	18.49
60.0	34.0	47.62	5.48	11.51
60.0	34.0	47.62	5.48	11.51
60.0	33.8	47.62	5.45	11.44

TABLE A 57

RUN 69

	PULP B	TEMP.=22.0	SPINDLE 1	S.G.=1.397
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	19.8	5.19	3.19	61.53
6.0	20.0	5.19	3.22	62.15
12.0	23.1	10.38	3.72	35.89
12.0	23.1	10.38	3.72	35.89
12.0	23.1	10.38	3.72	35.89
30.0	28.2	25.94	4.55	17.53
30.0	28.1	25.94	4.53	17.46
30.0	28.0	25.94	4.51	17.40
60.0	34.6	51.89	5.58	10.75
60.0	34.8	51.89	5.61	10.81
60.0	34.6	51.89	5.58	10.75

TABLE A 58

RUN 70

	PULP B	TEMP.=25.4	SPINDLE 1	S.G.=1.397
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	19.6	5.23	3.16	60.46
6.0	19.6	5.23	3.16	60.46
12.0	23.1	10.45	3.72	35.63
12.0	23.0	10.45	3.71	35.47
12.0	22.9	10.45	3.69	35.32
30.0	27.6	26.14	4.45	17.03
30.0	28.0	26.14	4.51	17.27
30.0	28.0	26.14	4.51	17.27
60.0	34.3	52.27	5.53	10.58
60.0	34.1	52.27	5.50	10.52
60.0	34.1	52.27	5.50	10.52

TABLE A 59

RUN 71

PULP B
TEMP.=30.1
SPINDLE 1
S.G.=1.397

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	19.7	5.31	3.18	59.78
6.0	19.6	5.31	3.16	59.47
12.0	22.6	10.63	3.64	34.29
12.0	22.8	10.63	3.68	34.59
12.0	22.7	10.63	3.66	34.44
30.0	27.6	26.57	4.45	16.75
30.0	27.4	26.57	4.42	16.63
30.0	27.5	26.57	4.43	16.69
60.0	33.7	53.13	5.43	10.23
60.0	33.7	53.13	5.43	10.23
60.0	33.9	53.13	5.47	10.29

TABLE A 60

RUN 72

PULP B
TEMP.= 8.8
SPINDLE 2
S.G.=1.489

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	9.7	4.57	6.46	141.40
6.0	9.4	4.57	6.26	137.03
6.0	9.8	4.57	6.53	142.86
12.0	11.2	9.14	7.46	81.63
12.0	11.4	9.14	7.59	83.09
12.0	11.4	9.14	7.59	83.09
30.0	14.4	22.85	9.59	41.98
30.0	14.5	22.85	9.66	42.27
30.0	14.6	22.85	9.73	42.57
60.0	17.9	45.70	11.92	26.09
60.0	18.1	45.70	12.06	26.39
60.0	18.1	45.70	12.06	26.39

TABLE A 61

RUN 73

	PULP B	TEMP.=14.8	SPINDLE 2	S.G.=1.489
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	11.2	5.34	7.46	139.79
6.0	11.2	5.34	7.46	139.79
12.0	12.7	10.67	8.46	79.25
12.0	12.7	10.67	8.46	79.25
12.0	12.7	10.67	8.46	79.25
30.0	15.7	26.69	10.46	39.19
30.0	15.7	26.69	10.46	39.19
30.0	15.8	26.69	10.53	39.44
60.0	19.0	53.37	12.66	23.71
60.0	19.0	53.37	12.66	23.71
60.0	19.0	53.37	12.66	23.71

TABLE A 62

RUN 74

	PULP B	TEMP.=18.9	SPINDLE 2	S.G.=1.489
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	11.2	5.52	7.46	135.11
6.0	11.2	5.52	7.46	135.11
12.0	12.8	11.04	8.53	77.20
12.0	12.7	11.04	8.46	76.60
12.0	12.8	11.04	8.53	77.20
30.0	15.7	27.61	10.46	37.88
30.0	15.8	27.61	10.53	38.12
30.0	15.7	27.61	10.46	37.88
60.0	18.8	55.22	12.52	22.68
60.0	18.6	55.22	12.39	22.44
60.0	18.8	55.22	12.52	22.68

TABLE A 63

RUN 75

PULP B   TEMP.=26.4   SPINDLE 2   S.G.=1.489

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	11.2	5.96	7.46	125.26
6.0	11.3	5.96	7.53	126.38
12.0	12.8	11.91	8.53	71.58
12.0	12.7	11.91	8.46	71.02
12.0	12.7	11.91	8.46	71.02
30.0	15.3	29.78	10.19	34.22
30.0	15.4	29.78	10.26	34.45
30.0	15.3	29.78	10.19	34.22
60.0	18.1	59.56	12.06	20.24
60.0	18.2	59.56	12.12	20.35
60.0	18.2	59.56	12.12	20.35

TABLE A 64

RUN 76

PULP B   TEMP.= 8.8   SPINDLE 2   S.G.=1.548

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	21.2	5.40	14.12	261.74
6.0	21.2	5.40	14.12	261.74
6.0	20.8	5.40	13.86	256.80
12.0	24.1	10.79	16.05	148.77
12.0	24.2	10.79	16.12	149.39
12.0	24.1	10.79	16.05	148.77
30.0	29.4	26.98	19.59	72.60
30.0	29.4	26.98	19.59	72.60
30.0	29.4	26.98	19.59	72.60
60.0	35.9	53.96	23.92	44.32
60.0	35.9	53.96	23.92	44.32
60.0	36.1	53.96	24.05	44.57

TABLE A 65

RUN 77

PULP B TEMP.=13.8 SPINDLE 2 S.G.=1.548

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	22.0	6.02	14.66	243.62
6.0	21.7	6.02	14.46	240.30
6.0	21.8	6.02	14.52	241.41
12.0	24.4	12.03	16.25	135.10
12.0	24.5	12.03	16.32	135.65
12.0	24.4	12.03	16.25	135.10
30.0	29.2	30.08	19.45	64.67
30.0	29.1	30.08	19.39	64.45
30.0	29.2	30.08	19.45	64.67
60.0	35.0	60.16	23.32	38.76
60.0	35.4	60.16	23.58	39.20
60.0	35.3	60.16	23.52	39.09

TABLE A 66

RUN 78

PULP B TEMP.=22.8 SPINDLE 2 S.G.=1.548

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	22.3	6.11	14.86	243.10
6.0	21.8	6.11	14.52	237.65
6.0	22.0	6.11	14.66	239.83
12.0	24.2	12.22	16.12	131.90
12.0	24.2	12.22	16.12	131.90
12.0	24.3	12.22	16.19	132.45
30.0	29.6	30.55	19.72	64.54
30.0	29.4	30.55	19.59	64.10
30.0	29.6	30.55	19.72	64.54
60.0	34.8	61.11	23.18	37.94
60.0	35.2	61.11	23.45	38.37
60.0	35.0	61.11	23.32	38.15

TABLE A 67

RUN 79

	PULP B	TEMP.=30.1	SPINDLE 2	S.G.=1.548
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	22.3	6.39	14.86	232.41
6.0	21.7	6.39	14.46	226.16
6.0	22.0	6.39	14.66	229.29
12.0	24.3	12.78	16.19	126.63
12.0	24.4	12.78	16.25	127.15
12.0	24.3	12.78	16.19	126.63
30.0	27.9	31.96	18.59	58.16
30.0	29.4	31.96	19.59	61.28
30.0	28.9	31.96	19.25	60.24
30.0	28.3	31.96	18.85	58.99
30.0	28.9	31.96	19.25	60.24
60.0	33.5	63.92	22.32	34.91
60.0	34.6	63.92	23.05	36.06
60.0	34.5	63.92	22.98	35.96
60.0	34.4	63.92	22.92	35.85
60.0	34.5	63.92	22.98	35.96

TABLE A 68

RUN 80

	PULP B	TEMP.=11.1	SPINDLE 2	S.G.=1.530
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	15.5	5.31	10.33	194.30
6.0	15.8	5.31	10.53	198.06
6.0	15.8	5.31	10.53	198.06
12.0	18.0	10.63	11.99	112.82
12.0	18.0	10.63	11.99	112.82
12.0	18.2	10.63	12.12	114.08
30.0	22.4	26.57	14.92	56.16
30.0	22.4	26.57	14.92	56.16
30.0	22.4	26.57	14.92	56.16
60.0	26.8	53.14	17.85	33.60
60.0	26.9	53.14	17.92	33.72
60.0	27.1	53.14	18.05	33.97

TABLE A 69

RUN 81

PULP B TEMP.=15.4 SPINDLE 2 S.G.=1.530

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	16.4	6.00	10.93	182.16
6.0	16.5	6.00	10.99	183.27
6.0	16.5	6.00	10.99	183.27
12.0	18.6	12.00	12.39	103.30
12.0	18.6	12.00	12.39	103.30
12.0	18.6	12.00	12.39	103.30
30.0	22.2	29.99	14.79	49.32
30.0	22.3	29.99	14.86	49.54
30.0	22.4	29.99	14.92	49.76
60.0	26.6	59.98	17.72	29.55
60.0	26.6	59.98	17.72	29.55
60.0	26.7	59.98	17.79	29.66

TABLE A 70

RUN 82

PULP B TEMP.=22.5 SPINDLE 2 S.G.=1.530

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	16.8	6.48	11.19	172.75
6.0	16.9	6.48	11.26	173.78
6.0	16.7	6.48	11.12	171.73
12.0	18.8	12.96	12.52	96.66
12.0	19.0	12.96	12.66	97.69
12.0	18.7	12.96	12.46	96.15
30.0	22.3	32.39	14.86	45.86
30.0	22.4	32.39	14.92	46.07
30.0	22.4	32.39	14.92	46.07
60.0	26.1	64.78	17.39	26.84
60.0	26.3	64.78	17.52	27.04
60.0	26.2	64.78	17.45	26.94

TABLE A 71

RUN 83

	PULP B	TEMP.=30.8	SPINDLE 2	S.G.=1.530
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	16.7	6.60	11.12	168.58
6.0	16.7	6.60	11.12	168.58
6.0	16.7	6.60	11.12	168.58
12.0	18.7	13.20	12.46	94.39
12.0	18.7	13.20	12.46	94.39
12.0	18.7	13.20	12.46	94.39
30.0	22.2	33.00	14.79	44.82
30.0	22.1	33.00	14.72	44.62
30.0	22.2	33.00	14.79	44.82
60.0	26.1	65.99	17.39	26.35
60.0	25.6	65.99	17.05	25.84
60.0	25.8	65.99	17.19	26.04

TABLE A 72

RUN 84

	PULP B	TEMP.=10.8	SPINDLE 2	S.G.=1.561
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	21.2	4.94	14.12	285.70
6.0	21.3	4.94	14.19	287.05
6.0	21.3	4.94	14.19	287.05
12.0	24.3	9.89	16.19	163.74
12.0	24.3	9.89	16.19	163.74
12.0	24.4	9.89	16.25	164.41
30.0	31.2	24.72	20.78	84.09
30.0	31.6	24.72	21.05	85.17
30.0	31.4	24.72	20.92	84.63
60.0	37.5	49.43	24.98	50.54
60.0	37.8	49.43	25.18	50.94
60.0	37.7	49.43	25.11	50.81

TABLE A 73

RUN 85

PULP B TEMP.=15.8 SPINDLE 2 S.G.=1.561

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	22.4	5.43	14.92	274.76
6.0	22.4	5.43	14.92	274.76
6.0	22.4	5.43	14.92	274.76
12.0	25.2	10.86	16.79	154.55
12.0	25.1	10.86	16.72	153.94
12.0	25.2	10.86	16.79	154.55
30.0	31.4	27.15	20.92	77.03
30.0	31.6	27.15	21.05	77.52
30.0	31.4	27.15	20.92	77.03
60.0	37.9	54.31	25.25	46.49
60.0	37.7	54.31	25.11	46.24
60.0	37.6	54.31	25.05	46.12

TABLE A 74

RUN 86

PULP B TEMP.=22.9 SPINDLE 2 S.G.=1.561

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	23.0	5.69	15.32	269.16
6.0	22.8	5.69	15.19	266.82
6.0	22.7	5.69	15.12	265.65
12.0	25.7	11.38	17.12	150.38
12.0	25.9	11.38	17.25	151.55
12.0	25.7	11.38	17.12	150.38
30.0	32.2	28.46	21.45	75.36
30.0	31.9	28.46	21.25	74.66
30.0	31.9	28.46	21.25	74.66
60.0	37.6	56.92	25.05	44.00
60.0	37.6	56.92	25.05	44.00
60.0	37.6	56.92	25.05	44.00

TABLE A 75

RUN 87

PULP B TEMP.=30.1 SPINDLE 2 S.G.=1.561

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	23.1	5.83	15.39	263.86
6.0	22.7	5.83	15.12	259.30
6.0	22.5	5.83	14.99	257.01
12.0	25.5	11.66	16.99	145.64
12.0	25.6	11.66	17.05	146.21
12.0	25.7	11.66	17.12	146.78
30.0	31.7	29.16	21.12	72.42
30.0	31.6	29.16	21.05	72.19
30.0	31.7	29.16	21.12	72.42
60.0	37.1	58.32	24.71	42.38
60.0	36.9	58.32	24.58	42.15
60.0	37.1	58.32	24.71	42.38

TABLE A 76

RUN 88

PULP B TEMP.=10.4 SPINDLE 2 S.G.=1.623

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	48.1	5.29	32.04	606.20
6.0	48.2	5.29	32.11	607.46
6.0	48.2	5.29	32.11	607.46
12.0	58.0	10.57	38.64	365.49
12.0	58.6	10.57	39.04	369.27
12.0	58.6	10.57	39.04	369.27
30.0	71.2	26.43	47.43	179.47
30.0	71.2	26.43	47.43	179.47
30.0	71.4	26.43	47.56	179.97
60.0	84.1	52.86	56.02	105.99
60.0	84.1	52.86	56.02	105.99
60.0	84.2	52.86	56.09	106.12

TABLE A 77

RUN 89

	PULP B	TEMP.=17.8	SPINDLE 2	S.G.=1.623
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	55.5	6.44	36.97	574.11
6.0	51.4	6.44	34.24	531.70
6.0	50.6	6.44	33.71	523.43
12.0	58.6	12.88	39.04	303.09
12.0	58.4	12.88	38.90	302.06
12.0	58.4	12.88	38.90	302.06
30.0	69.8	32.20	46.50	144.41
30.0	70.2	32.20	46.76	145.24
30.0	69.8	32.20	46.50	144.41
60.0	82.2	64.40	54.76	85.03
60.0	81.6	64.40	54.36	84.41
60.0	82.0	64.40	54.63	84.82

TABLE A 78

RUN 90

	PULP B	TEMP.=26.1	SPINDLE 2	S.G.=1.623
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	50.8	6.08	33.84	556.55
6.0	50.4	6.08	33.57	552.16
6.0	50.6	6.08	33.71	554.36
12.0	60.2	12.16	40.10	329.76
12.0	59.6	12.16	39.70	326.48
12.0	59.4	12.16	39.57	325.38
30.0	71.4	30.40	47.56	156.45
30.0	71.3	30.40	47.50	156.23
30.0	70.3	30.40	46.83	154.04
60.0	82.4	60.81	54.89	90.27
60.0	81.6	60.81	54.36	89.40
60.0	82.4	60.81	54.89	90.27

TABLE A 79

RUN 91

PULP B TEMP.=30.6 SPINDLE 2 S.G.=1.623

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	51.3	6.14	34.17	556.43
6.0	51.2	6.14	34.11	555.35
6.0	50.6	6.14	33.71	548.84
12.0	60.7	12.28	40.44	329.20
12.0	59.7	12.28	39.77	323.77
12.0	60.2	12.28	40.10	326.48
30.0	71.2	30.71	47.43	154.46
30.0	70.9	30.71	47.23	153.81
30.0	71.4	30.71	47.56	154.89
60.0	82.3	61.42	54.83	89.27
60.0	82.9	61.42	55.22	89.92
60.0	82.4	61.42	54.89	89.38

TABLE A 80

RUN 92

PULP B TEMP.=10.8 SPINDLE 1 S.G.=1.507

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	46.7	5.00	7.53	150.63
6.0	46.8	5.00	7.55	150.95
6.0	46.8	5.00	7.55	150.95
12.0	55.4	10.00	8.93	89.34
12.0	55.4	10.00	8.93	89.34
12.0	55.6	10.00	8.96	89.67
30.0	69.1	24.99	11.14	44.58
30.0	68.9	24.99	11.11	44.45
30.0	68.8	24.99	11.09	44.38
60.0	83.4	49.99	13.45	26.90
60.0	83.8	49.99	13.51	27.03
60.0	83.6	49.99	13.48	26.96

TABLE A 81

RUN 93

PULP B TEMP.=15.4 SPINDLE 1 S.G.=1.507

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	47.4	5.31	7.64	143.95
6.0	47.8	5.31	7.71	145.16
6.0	47.6	5.31	7.67	144.56
12.0	55.4	10.62	8.93	84.12
12.0	55.6	10.62	8.96	84.43
12.0	55.6	10.62	8.96	84.43
30.0	68.1	26.55	10.98	41.36
30.0	68.3	26.55	11.01	41.48
30.0	68.2	26.55	11.00	41.42
60.0	82.1	53.09	13.24	24.93
60.0	82.2	53.09	13.25	24.96
60.0	82.1	53.09	13.24	24.93

TABLE A 82

RUN 94

PULP B TEMP.=22.6 SPINDLE 1 S.G.=1.507

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	49.5	5.74	7.98	139.15
6.0	49.4	5.74	7.96	138.87
6.0	49.4	5.74	7.96	138.87
12.0	57.1	11.47	9.21	80.26
12.0	57.1	11.47	9.21	80.26
12.0	57.2	11.47	9.22	80.40
30.0	68.6	28.68	11.06	38.57
30.0	69.1	28.68	11.14	38.85
30.0	69.2	28.68	11.16	38.90
60.0	82.0	57.36	13.22	23.05
60.0	82.2	57.36	13.25	23.11
60.0	81.8	57.36	13.19	22.99

TABLE A 83

RUN 95

PULP B TEMP.=32.3 SPINDLE 1 S.G.=1.507

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	52.4	6.17	8.45	136.99
6.0	52.2	6.17	8.42	136.47
6.0	52.2	6.17	8.42	136.47
12.0	59.4	12.33	9.58	77.65
12.0	59.8	12.33	9.64	78.17
12.0	59.9	12.33	9.66	78.30
30.0	71.2	30.84	11.48	37.23
30.0	71.2	30.84	11.48	37.23
30.0	71.4	30.84	11.51	37.33
60.0	83.6	61.67	13.48	21.86
60.0	83.6	61.67	13.48	21.86
60.0	83.7	61.67	13.50	21.88

TABLE A 84

RUN 96

PULP B TEMP.=11.4 SPINDLE 1 S.G.=1.461

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	26.0	4.18	4.19	100.29
6.0	26.0	4.18	4.19	100.29
6.0	26.2	4.18	4.22	101.06
12.0	30.8	8.36	4.97	59.40
12.0	30.5	8.36	4.92	58.83
12.0	31.0	8.36	5.00	59.79
30.0	40.1	20.90	6.47	30.94
30.0	40.2	20.90	6.48	31.01
30.0	40.2	20.90	6.48	31.01
60.0	51.5	41.80	8.30	19.87
60.0	51.4	41.80	8.29	19.83
60.0	52.0	41.80	8.38	20.06

TABLE A 85

RUN 97

	PULP B	TEMP.=15.2	SPINDLE 1	S.G.=1.461
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	27.0	4.52	4.35	96.27
6.0	26.8	4.52	4.32	95.56
6.0	27.0	4.52	4.35	96.27
12.0	31.6	9.04	5.09	56.34
12.0	31.4	9.04	5.06	55.98
12.0	31.6	9.04	5.09	56.34
30.0	40.1	22.61	6.47	28.60
30.0	40.2	22.61	6.48	28.67
30.0	40.2	22.61	6.48	28.67
60.0	50.7	45.22	8.17	18.08
60.0	50.9	45.22	8.21	18.15
60.0	50.8	45.22	8.19	18.11

TABLE A 86

RUN 98

	PULP B	TEMP.=19.7	SPINDLE 1	S.G.=1.461
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	27.1	4.61	4.37	94.88
6.0	27.1	4.61	4.37	94.88
6.0	27.2	4.61	4.39	95.23
12.0	32.1	9.21	5.18	56.19
12.0	31.7	9.21	5.11	55.49
12.0	32.3	9.21	5.21	56.54
30.0	40.4	23.03	6.51	28.29
30.0	41.2	23.03	6.64	28.85
30.0	40.6	23.03	6.55	28.43
60.0	50.8	46.05	8.19	17.79
60.0	50.7	46.05	8.17	17.75
60.0	50.6	46.05	8.16	17.72

TABLE A 87

RUN 99

PULP B TEMP.=10.2 SPINDLE 2 S.G.=1.566

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	16.0	4.01	10.66	265.50
6.0	16.0	4.01	10.66	265.50
6.0	16.1	4.01	10.73	267.16
12.0	19.4	8.03	12.92	160.96
12.0	19.4	8.03	12.92	160.96
12.0	19.4	8.03	12.92	160.96
30.0	26.6	20.07	17.72	88.28
30.0	26.4	20.07	17.59	87.61
30.0	26.3	20.07	17.52	87.28
60.0	32.3	40.15	21.52	53.60
60.0	32.5	40.15	21.65	53.93
60.0	33.0	40.15	21.98	54.76

TABLE A 88

RUN 100

PULP B TEMP.=18.5 SPINDLE 2 S.G.=1.566

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	20.1	5.57	13.39	240.55
6.0	19.8	5.57	13.19	236.96
6.0	19.8	5.57	13.19	236.96
12.0	22.6	11.13	15.06	135.24
12.0	22.6	11.13	15.06	135.24
12.0	22.7	11.13	15.12	135.83
30.0	28.4	27.83	18.92	67.98
30.0	28.2	27.83	18.79	67.50
30.0	27.8	27.83	18.52	66.54
60.0	33.1	55.66	22.05	39.61
60.0	33.1	55.66	22.05	39.61
60.0	33.4	55.66	22.25	39.97

TABLE A 89

RUN 101

	PULP B	TEMP.=22.3	SPINDLE 2	S.G.=1.566
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	20.6	5.82	13.72	235.82
6.0	20.6	5.82	13.72	235.82
6.0	20.5	5.82	13.66	234.67
12.0	23.5	11.64	15.65	134.51
12.0	23.6	11.64	15.72	135.08
12.0	23.6	11.64	15.72	135.08
30.0	28.9	29.10	19.25	66.17
30.0	28.6	29.10	19.05	65.48
30.0	28.6	29.10	19.05	65.48
60.0	33.7	58.19	22.45	38.58
60.0	33.7	58.19	22.45	38.58
60.0	33.8	58.19	22.52	38.69

TABLE A 90

RUN 102

	PULP B	TEMP.=30.7	SPINDLE 2	S.G.=1.566
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	21.4	5.82	14.26	244.85
6.0	21.2	5.82	14.12	242.56
6.0	21.2	5.82	14.12	242.56
12.0	24.2	11.64	16.12	138.44
12.0	24.4	11.64	16.25	139.58
12.0	24.6	11.64	16.39	140.73
30.0	29.6	29.11	19.72	67.73
30.0	29.4	29.11	19.59	67.28
30.0	29.6	29.11	19.72	67.73
60.0	35.1	58.22	23.38	40.16
60.0	34.9	58.22	23.25	39.93
60.0	34.8	58.22	23.18	39.82

TABLE A 91

RUN 103

	PULP B	TEMP.=11.0	SPINDLE 2	S.G.=1.628
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	38.2	4.56	25.45	557.58
6.0	38.0	4.56	25.31	554.66
6.0	37.8	4.56	25.18	551.74
12.0	46.7	9.13	31.11	340.82
12.0	46.4	9.13	30.91	338.64
12.0	46.4	9.13	30.91	338.64
30.0	59.8	22.82	39.84	174.57
30.0	59.8	22.82	39.84	174.57
30.0	60.1	22.82	40.04	175.45
60.0	72.1	45.64	48.03	105.24
60.0	71.7	45.64	47.76	104.66
60.0	71.6	45.64	47.70	104.51

TABLE A 92

RUN 104

	PULP B	TEMP.=21.2	SPINDLE 2	S.G.=1.628
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	42.7	5.37	28.45	529.48
6.0	42.3	5.37	28.18	524.52
6.0	41.7	5.37	27.78	517.08
12.0	48.8	10.74	32.51	302.56
12.0	49.3	10.74	32.84	305.66
12.0	48.8	10.74	32.51	302.56
30.0	61.4	26.86	40.90	152.27
30.0	61.4	26.86	40.90	152.27
30.0	61.6	26.86	41.04	152.77
60.0	71.8	53.72	47.83	89.03
60.0	71.9	53.72	47.90	89.16
60.0	72.1	53.72	48.03	89.40

TABLE A 93

RUN 105

	PULP B	TEMP.=29.9	SPINDLE 2	S.G.=1.628
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	47.2	5.67	31.44	554.23
6.0	46.7	5.67	31.11	548.36
6.0	46.0	5.67	30.64	540.14
12.0	54.6	11.35	36.37	320.56
12.0	54.6	11.35	36.37	320.56
12.0	54.6	11.35	36.37	320.56
30.0	66.2	28.37	44.10	155.47
30.0	66.8	28.37	44.50	156.88
30.0	66.8	28.37	44.50	156.88
60.0	78.0	56.73	51.96	91.59
60.0	77.8	56.73	51.83	91.35
60.0	77.6	56.73	51.69	91.12

TABLE A 94

RUN 106

	PULP B	TEMP.=11.1	SPINDLE 2	S.G.=1.653
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	53.9	4.95	35.91	724.65
6.0	54.0	4.95	35.97	726.00
6.0	53.9	4.95	35.91	724.65
12.0	63.8	9.91	42.50	428.88
12.0	64.0	9.91	42.63	430.22
12.0	64.3	9.91	42.83	432.24
30.0	79.9	24.77	53.23	214.84
30.0	79.3	24.77	52.83	213.23
30.0	80.3	24.77	53.49	215.92
60.0	96.6	49.55	64.35	129.87
60.0	97.1	49.55	64.68	130.54
60.0	96.9	49.55	64.55	130.28

TABLE A 95

RUN 107

	PULP B	TEMP.=16.8	SPINDLE 2	S.G.=1.653
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	56.2	5.46	37.44	686.03
6.0	56.1	5.46	37.37	684.81
6.0	55.4	5.46	36.91	676.27
12.0	65.2	10.91	43.43	397.95
12.0	65.2	10.91	43.43	397.95
12.0	65.8	10.91	43.83	401.61
30.0	80.4	27.29	53.56	196.29
30.0	80.4	27.29	53.56	196.29
30.0	80.4	27.29	53.56	196.29
60.0	94.1	54.57	62.69	114.87
60.0	95.4	54.57	63.55	116.45
60.0	95.6	54.57	63.69	116.70

TABLE A 96

RUN 108

	PULP B	TEMP.=25.3	SPINDLE 2	S.G.=1.653
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	58.1	5.60	38.70	691.71
6.0	59.2	5.60	39.44	704.80
6.0	59.2	5.60	39.44	704.80
12.0	69.9	11.19	46.56	416.10
12.0	69.9	11.19	46.56	416.10
12.0	69.3	11.19	46.17	412.52
30.0	84.7	27.98	56.42	201.68
30.0	85.1	27.98	56.69	202.63
30.0	84.3	27.98	56.16	200.73
60.0	99.0	55.95	65.95	117.86
60.0	99.6	55.95	66.35	118.58
60.0	99.0	55.95	65.95	117.86

TABLE A 97

RUN 109

PULP B TEMP.=31.5 SPINDLE 2 S.G.=1.653

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	61.6	5.40	41.04	760.44
6.0	62.6	5.40	41.70	772.78
6.0	61.6	5.40	41.04	760.44
12.0	74.0	10.79	49.30	456.76
12.0	74.2	10.79	49.43	457.99
12.0	74.0	10.79	49.30	456.76
30.0	90.8	26.98	60.49	224.18
30.0	89.6	26.98	59.69	221.22
30.0	90.7	26.98	60.42	223.93
30.0	90.8	26.98	60.49	224.18

TABLE A 98

RUN 110

PULP B TEMP.=10.6 SPINDLE 2 S.G.=1.568

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	14.6	4.44	9.73	219.01
6.0	14.4	4.44	9.59	216.01
6.0	14.5	4.44	9.66	217.51
12.0	17.4	8.88	11.59	130.51
12.0	17.6	8.88	11.72	132.01
12.0	17.4	8.88	11.59	130.51
30.0	22.6	22.20	15.06	67.80
30.0	22.5	22.20	14.99	67.50
30.0	22.4	22.20	14.92	67.20
30.0	22.6	22.20	15.06	67.80
60.0	27.7	44.41	18.45	41.55
60.0	27.9	44.41	18.59	41.85
60.0	27.6	44.41	18.39	41.40
60.0	27.8	44.41	18.52	41.70

TABLE A 99

RUN 111

	PULP B	TEMP.=18.7	SPINDLE 2	S.G.=1.568
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	14.5	4.75	9.66	203.18
6.0	14.6	4.75	9.73	204.58
6.0	14.6	4.75	9.73	204.58
12.0	17.4	9.51	11.59	121.91
12.0	17.4	9.51	11.59	121.91
12.0	17.4	9.51	11.59	121.91
30.0	21.9	23.77	14.59	61.37
30.0	22.0	23.77	14.66	61.65
30.0	21.9	23.77	14.59	61.37
60.0	26.8	47.54	17.85	37.55
60.0	26.9	47.54	17.92	37.69
60.0	26.7	47.54	17.79	37.41

TABLE A 100

RUN 112

	PULP B	TEMP.=28.5	SPINDLE 2	S.G.=1.568
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	15.5	4.95	10.33	208.42
6.0	15.4	4.95	10.26	207.07
6.0	15.4	4.95	10.26	207.07
12.0	18.0	9.91	11.99	121.02
12.0	18.1	9.91	12.06	121.69
12.0	18.1	9.91	12.06	121.69
30.0	22.9	24.77	15.26	61.58
30.0	22.8	24.77	15.19	61.32
30.0	23.0	24.77	15.32	61.85
60.0	27.6	49.54	18.39	37.11
60.0	27.4	49.54	18.25	36.84
60.0	27.6	49.54	18.39	37.11

TABLE A 101

RUN 113

PULP B TEMP.=32.3 SPINDLE 2 S.G.=1.568

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	16.7	5.29	11.12	210.22
6.0	16.4	5.29	10.93	206.44
6.0	16.6	5.29	11.06	208.96
12.0	19.4	10.58	12.92	122.10
12.0	19.5	10.58	12.99	122.73
12.0	19.5	10.58	12.99	122.73
30.0	24.3	26.46	16.19	61.18
30.0	24.1	26.46	16.05	60.67
30.0	24.2	26.46	16.12	60.93
60.0	28.6	52.92	19.05	36.00
60.0	28.4	52.92	18.92	35.75
60.0	28.8	52.92	19.19	36.25

TABLE A 102

RUN 115

PULP C TEMP.=11.1 SPINDLE 1 S.G.=1.462

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	53.4	7.01	8.61	122.84
6.0	52.8	7.01	8.51	121.46
6.0	52.7	7.01	8.50	121.23
12.0	60.0	14.02	9.67	69.01
12.0	60.0	14.02	9.67	69.01
12.0	60.6	14.02	9.77	69.70
12.0	60.6	14.02	9.77	69.70
30.0	73.2	35.05	11.80	33.68
30.0	72.2	35.05	11.64	33.22
30.0	73.2	35.05	11.80	33.68
30.0	72.2	35.05	11.64	33.22
60.0	73.2	70.09	11.80	16.84
60.0	72.8	70.09	11.74	16.75
60.0	85.9	70.09	13.85	19.76
60.0	85.9	70.09	13.85	19.76

TABLE A 103

RUN 116

	PULP C	TEMP.=15.9	SPINDLE 1	S.G.=1.462
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	54.0	6.44	8.71	135.30
6.0	54.5	6.44	8.79	136.55
6.0	54.1	6.44	8.72	135.55
12.0	60.9	12.87	9.82	76.29
12.0	62.0	12.87	10.00	77.67
12.0	62.0	12.87	10.00	77.67
30.0	73.1	32.18	11.79	36.63
30.0	73.1	32.18	11.79	36.63
30.0	72.9	32.18	11.75	36.53
60.0	85.2	64.35	13.74	21.35
60.0	84.8	64.35	13.67	21.25
60.0	85.2	64.35	13.74	21.35

TABLE A 104

RUN 117

	PULP C	TEMP.=24.9	SPINDLE 1	S.G.=1.462
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	54.6	6.74	8.80	130.55
6.0	54.5	6.74	8.79	130.31
6.0	55.0	6.74	8.87	131.50
12.0	62.2	13.49	10.03	74.36
12.0	62.2	13.49	10.03	74.36
12.0	62.0	13.49	10.00	74.12
30.0	73.4	33.72	11.83	35.10
30.0	73.2	33.72	11.80	35.00
30.0	73.6	33.72	11.87	35.20
30.0	74.0	33.72	11.93	35.39
60.0	84.4	67.43	13.61	20.18
60.0	83.5	67.43	13.46	19.96
60.0	84.1	67.43	13.56	20.11
60.0	84.0	67.43	13.54	20.08

TABLE A 105

RUN 118

	PULP C	TEMP.=30.1	SPINDLE 1	S.G.=1.462
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
12.0	64.6	14.51	10.42	71.79
12.0	64.6	14.51	10.42	71.79
12.0	64.5	14.51	10.40	71.67
12.0	64.6	14.51	10.42	71.79
30.0	74.6	36.27	12.03	33.16
30.0	74.2	36.27	11.96	32.98
30.0	74.2	36.27	11.96	32.98
30.0	74.2	36.27	11.96	32.98
60.0	85.8	72.55	13.83	19.07
60.0	84.6	72.55	13.64	18.80
60.0	85.3	72.55	13.75	18.96
60.0	85.6	72.55	13.80	19.02

TABLE A 106

RUN 119

	PULP C	TEMP.=12.2	SPINDLE 2	S.G.=1.494
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	13.8	5.44	9.19	168.90
6.0	13.9	5.44	9.26	170.12
6.0	13.8	5.44	9.19	168.90
12.0	16.3	10.89	10.86	99.75
12.0	16.4	10.89	10.93	100.36
12.0	16.4	10.89	10.93	100.36
30.0	19.6	27.21	13.06	47.98
30.0	19.8	27.21	13.19	48.47
30.0	20.0	27.21	13.32	48.96
60.0	23.7	54.43	15.79	29.01
60.0	23.8	54.43	15.85	29.13
60.0	23.6	54.43	15.72	28.88

TABLE A 107

RUN 120

	PULP C	TEMP.=17.1	SPINDLE 2	S.G.=1.494
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	14.4	6.20	9.59	154.83
6.0	14.8	6.20	9.86	159.13
6.0	14.6	6.20	9.73	156.98
12.0	16.4	12.39	10.93	88.17
12.0	16.4	12.39	10.93	88.17
12.0	16.4	12.39	10.93	88.17
30.0	19.8	30.98	13.19	42.58
30.0	19.8	30.98	13.19	42.58
30.0	19.8	30.98	13.19	42.58
60.0	23.2	61.96	15.46	24.95
60.0	23.1	61.96	15.39	24.84
60.0	23.2	61.96	15.46	24.95

TABLE A 108

RUN 121

	PULP C	TEMP.=24.9	SPINDLE 2	S.G.=1.494
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	14.8	6.55	9.86	150.45
6.0	14.8	6.55	9.86	150.45
6.0	14.4	6.55	9.59	146.38
12.0	16.6	13.11	11.06	84.37
12.0	16.5	13.11	10.99	83.86
12.0	16.6	13.11	11.06	84.37
30.0	19.7	32.77	13.12	40.05
30.0	19.8	32.77	13.19	40.26
30.0	19.7	32.77	13.12	40.05
60.0	22.9	65.53	15.26	23.28
60.0	22.8	65.53	15.19	23.18
60.0	22.6	65.53	15.06	22.97

TABLE A 109

RUN 122

	PULP C	TEMP.=30.7	SPINDLE 2	S.G.=1.494
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	15.0	6.97	9.99	143.30
6.0	14.9	6.97	9.93	142.34
6.0	14.9	6.97	9.93	142.34
12.0	16.7	13.95	11.12	79.77
12.0	16.7	13.95	11.12	79.77
12.0	16.8	13.95	11.19	80.25
30.0	19.6	34.87	13.06	37.45
30.0	20.2	34.87	13.46	38.60
30.0	19.8	34.87	13.19	37.83
60.0	22.4	69.73	14.92	21.40
60.0	22.4	69.73	14.92	21.40
60.0	22.8	69.73	15.19	21.78

TABLE A 110

RUN 123

	PULP C	TEMP.=11.4	SPINDLE 2	S.G.=1.537
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	20.6	5.82	13.72	235.76
6.0	20.8	5.82	13.86	238.05
6.0	20.8	5.82	13.86	238.05
12.0	24.1	11.64	16.05	137.91
12.0	23.9	11.64	15.92	136.76
12.0	24.1	11.64	16.05	137.91
30.0	29.8	29.10	19.85	68.21
30.0	30.0	29.10	19.98	68.67
30.0	29.8	29.10	19.85	68.21
60.0	33.6	58.21	22.38	38.45
60.0	34.0	58.21	22.65	38.91
60.0	34.1	58.21	22.72	39.03

TABLE A 111

RUN 124

	PULP C	TEMP.=17.6	SPINDLE 2	S.G.=1.537
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	20.7	6.17	13.79	223.33
6.0	20.9	6.17	13.92	225.49
6.0	21.1	6.17	14.06	227.65
12.0	23.8	12.35	15.85	128.39
12.0	24.0	12.35	15.99	129.47
12.0	23.7	12.35	15.79	127.85
30.0	29.2	30.87	19.45	63.01
30.0	28.8	30.87	19.19	62.14
30.0	29.2	30.87	19.45	63.01
60.0	33.4	61.74	22.25	36.04
60.0	33.2	61.74	22.12	35.82
60.0	33.1	61.74	22.05	35.71

TABLE A 112

RUN 125

	PULP C	TEMP.=26.1	SPINDLE 2	S.G.=1.537
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	20.6	5.83	13.72	235.24
6.0	20.4	5.83	13.59	232.95
6.0	20.6	5.83	13.72	235.24
12.0	22.3	11.67	14.86	127.33
12.0	23.2	11.67	15.46	132.46
12.0	23.1	11.67	15.39	131.89
30.0	28.6	29.17	19.05	65.32
30.0	28.8	29.17	19.19	65.78
30.0	28.8	29.17	19.19	65.78
60.0	33.1	58.34	22.05	37.80
60.0	33.1	58.34	22.05	37.80
60.0	33.4	58.34	22.25	38.14

TABLE A 113

RUN 126

PULP C TEMP.=30.4 SPINDLE 2 S.G.=1.537

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	20.6	5.72	13.72	239.98
6.0	20.6	5.72	13.72	239.98
6.0	20.6	5.72	13.72	239.98
12.0	23.3	11.44	15.52	135.72
12.0	23.1	11.44	15.39	134.55
12.0	23.3	11.44	15.52	135.72
30.0	29.7	28.59	19.79	69.20
30.0	30.2	28.59	20.12	70.36
30.0	28.6	28.59	19.05	66.64
60.0	33.8	57.18	22.52	39.38
60.0	33.7	57.18	22.45	39.26
60.0	33.4	57.18	22.25	38.91

TABLE A 114

RUN 127

PULP C TEMP.=10.6 SPINDLE 2 S.G.=1.589

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	33.2	5.17	22.12	428.08
6.0	33.4	5.17	22.25	430.66
6.0	33.3	5.17	22.18	429.37
12.0	38.4	10.33	25.58	247.57
12.0	38.7	10.33	25.78	249.50
12.0	38.2	10.33	25.45	246.28
30.0	49.5	25.83	32.98	127.65
30.0	49.0	25.83	32.64	126.36
30.0	49.8	25.83	33.17	128.43
60.0	58.2	51.66	38.77	75.04
60.0	57.4	51.66	38.24	74.01
60.0	57.2	51.66	38.10	73.75
60.0	57.8	51.66	38.50	74.53

TABLE A 115

RUN 128

	PULP C	TEMP.=18.5	SPINDLE 2	S.G.=1.589
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	33.0	5.40	21.98	406.82
6.0	32.7	5.40	21.78	403.12
6.0	33.0	5.40	21.98	406.82
12.0	37.6	10.81	25.05	231.76
12.0	37.6	10.81	25.05	231.76
12.0	37.4	10.81	24.91	230.53
30.0	47.8	27.02	31.84	117.85
30.0	47.6	27.02	31.71	117.36
30.0	47.2	27.02	31.44	116.37
60.0	55.7	54.04	37.11	68.67
60.0	55.7	54.04	37.11	68.67
60.0	55.3	54.04	36.84	68.17

TABLE A 116

RUN 129

	PULP C	TEMP.=25.9	SPINDLE 2	S.G.=1.589
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	32.6	5.46	21.72	397.90
6.0	32.6	5.46	21.72	397.90
6.0	32.5	5.46	21.65	396.68
12.0	37.6	10.92	25.05	229.46
12.0	37.3	10.92	24.85	227.63
12.0	37.3	10.92	24.85	227.63
30.0	46.4	27.29	30.91	113.27
30.0	47.8	27.29	31.84	116.68
60.0	54.9	54.58	36.57	67.01
60.0	54.7	54.58	36.44	66.76
60.0	55.0	54.58	36.64	67.13

TABLE A 117

RUN 130

	PULP C	TEMP.=30.2	SPINDLE 2	S.G.=1.589
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	31.9	5.11	21.25	415.87
6.0	32.1	5.11	21.38	418.47
6.0	32.1	5.11	21.38	418.47
12.0	37.7	10.22	25.11	245.74
12.0	37.8	10.22	25.18	246.39
12.0	38.6	10.22	25.71	251.61
30.0	49.7	25.55	33.11	129.58
30.0	49.2	25.55	32.78	128.28
30.0	49.8	25.55	33.17	129.84
60.0	56.7	51.10	37.77	73.92
60.0	55.3	51.10	36.84	72.09
60.0	55.8	51.10	37.17	72.74
60.0	56.8	51.10	37.84	74.05

TABLE A 118

RUN 131

	PULP C	TEMP.=11.5	SPINDLE 2	S.G.=1.622
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	46.6	5.40	31.04	575.15
6.0	46.9	5.40	31.24	578.85
6.0	47.3	5.40	31.51	583.79
12.0	58.2	10.79	38.77	359.16
12.0	58.2	10.79	38.77	359.16
12.0	58.4	10.79	38.90	360.39
30.0	71.4	26.99	47.56	176.25
30.0	70.2	26.99	46.76	173.29
30.0	71.4	26.99	47.56	176.25
60.0	80.8	53.97	53.83	99.73
60.0	82.4	53.97	54.89	101.70
60.0	81.3	53.97	54.16	100.34

TABLE A 119

RUN 132

PULP C TEMP.=16.8 SPINDLE 2 S.G.=1.622

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	49.6	6.22	33.04	531.16
6.0	50.3	6.22	33.51	538.65
6.0	50.1	6.22	33.37	536.51
12.0	57.4	12.44	38.24	307.34
12.0	56.8	12.44	37.84	304.13
12.0	58.1	12.44	38.70	311.09
30.0	69.6	31.10	46.37	149.07
30.0	68.4	31.10	45.57	146.50
30.0	69.2	31.10	46.10	148.21
60.0	78.4	62.21	52.23	83.96
60.0	80.0	62.21	53.29	85.67
60.0	80.4	62.21	53.56	86.10

TABLE A 120

RUN 133

PULP C TEMP.=21.6 SPINDLE 2 S.G.=1.622

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	49.1	6.39	32.71	511.59
6.0	49.6	6.39	33.04	516.80
6.0	48.2	6.39	32.11	502.22
12.0	55.2	12.79	36.77	287.58
12.0	55.3	12.79	36.84	288.10
12.0	55.6	12.79	37.04	289.66
30.0	67.8	31.97	45.17	141.29
30.0	67.8	31.97	45.17	141.29
30.0	67.6	31.97	45.03	140.87
60.0	76.1	63.93	50.70	79.29
60.0	76.8	63.93	51.16	80.02
60.0	76.2	63.93	50.76	79.40

TABLE A 121

RUN 134

PULP C   TEMP.=28.0   SPINDLE 2   S.G.=1.622

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	42.2	5.41	28.11	519.59
6.0	42.6	5.41	28.38	524.52
6.0	42.7	5.41	28.45	525.75
12.0	54.4	10.82	36.24	334.90
12.0	53.0	10.82	35.31	326.28
12.0	54.4	10.82	36.24	334.90
30.0	69.4	27.05	46.23	170.90
60.0	74.3	54.10	49.50	91.48
60.0	74.8	54.10	49.83	92.10
60.0	73.5	54.10	48.96	90.50
60.0	75.8	54.10	50.50	93.33
60.0	74.9	54.10	49.90	92.22

TABLE A 122

RUN 135

PULP C   TEMP.=10.4   SPINDLE 2   S.G.=1.648

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	53.6	5.36	35.71	666.58
6.0	55.0	5.36	36.64	683.99
6.0	53.2	5.36	35.44	661.61
12.0	67.0	10.71	44.63	416.61
12.0	68.2	10.71	45.43	424.07
12.0	69.2	10.71	46.10	430.29
30.0	85.8	26.78	57.16	213.41
30.0	80.8	26.78	53.83	200.97
30.0	82.8	26.78	55.16	205.94
60.0	95.0	53.57	63.29	118.14
60.0	93.4	53.57	62.22	116.15
60.0	94.8	53.57	63.15	117.90

TABLE A 123

RUN 136

PULP C   TEMP.=18.3   SPINDLE 2   S.G.=1.648

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	48.8	4.70	32.51	692.12
6.0	50.2	4.70	33.44	711.98
6.0	49.6	4.70	33.04	703.47
12.0	65.4	9.39	43.57	463.78
12.0	63.8	9.39	42.50	452.43
12.0	65.4	9.39	43.57	463.78
30.0	80.8	23.48	53.83	229.20
30.0	81.4	23.48	54.23	230.90
30.0	82.8	23.48	55.16	234.87
30.0	84.2	23.48	56.09	238.84
60.0	93.9	46.97	62.55	133.18
60.0	95.1	46.97	63.35	134.88
60.0	93.2	46.97	62.09	132.18
60.0	95.0	46.97	63.29	134.74

TABLE A 124

RUN 137

PULP C   TEMP.=25.2   SPINDLE 2   S.G.=1.648

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	50.9	4.66	33.91	727.02
6.0	48.7	4.66	32.44	695.60
6.0	49.7	4.66	33.11	709.88
12.0	60.4	9.33	40.24	431.36
12.0	62.2	9.33	41.44	444.21
12.0	61.5	9.33	40.97	439.21
30.0	79.3	23.32	52.83	226.53
30.0	81.8	23.32	54.49	233.68
30.0	78.7	23.32	52.43	224.82
60.0	92.9	46.64	61.89	132.69
60.0	94.8	46.64	63.15	135.41
60.0	91.8	46.64	61.15	131.12
60.0	92.6	46.64	61.69	132.26

TABLE A 125

RUN 138

PULP C   TEMP.=30.1   SPINDLE 2   S.G.=1.648

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	45.6	4.36	30.38	696.39
6.0	44.6	4.36	29.71	681.12
6.0	45.9	4.36	30.58	700.97
12.0	64.7	8.72	43.10	494.04
12.0	62.8	8.72	41.84	479.53
12.0	64.7	8.72	43.10	494.04
30.0	80.4	21.81	53.56	245.57
30.0	78.4	21.81	52.23	239.46
30.0	81.0	21.81	53.96	247.40
60.0	91.1	43.62	60.69	139.13
60.0	92.0	43.62	61.29	140.50
60.0	94.8	43.62	63.15	144.78

TABLE A 126

RUN 139

PULP C   TEMP.=10.2   SPINDLE 2   S.G.=1.641

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	51.8	5.06	34.51	681.92
6.0	52.1	5.06	34.71	685.87
6.0	53.1	5.06	35.37	699.04
12.0	66.8	10.12	44.50	439.70
12.0	64.9	10.12	43.23	427.19
12.0	65.8	10.12	43.83	433.11
30.0	81.8	25.30	54.49	215.37
30.0	81.7	25.30	54.43	215.11
30.0	80.6	25.30	53.69	212.21
60.0	95.4	50.60	63.55	125.59
60.0	92.8	50.60	61.82	122.17
60.0	94.6	50.60	63.02	124.54

TABLE A 127

RUN 140

PULP C TEMP.=17.0 SPINDLE 2 S.G.=1.641

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	48.1	4.91	32.04	653.15
6.0	48.7	4.91	32.44	661.30
6.0	48.8	4.91	32.51	662.66
12.0	62.9	9.81	41.90	427.06
12.0	62.4	9.81	41.57	423.67
12.0	63.2	9.81	42.10	429.10
30.0	76.6	24.53	51.03	208.03
30.0	74.8	24.53	49.83	203.14
30.0	72.8	24.53	48.50	197.71
60.0	90.8	49.06	60.49	123.30
60.0	90.8	49.06	60.49	123.30
60.0	90.0	49.06	59.95	122.21

TABLE A 128

RUN 141

PULP C TEMP.=24.7 SPINDLE 2 S.G.=1.641

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	48.7	4.98	32.44	651.62
6.0	50.4	4.98	33.57	674.37
6.0	50.4	4.98	33.57	674.37
12.0	62.6	9.96	41.70	418.80
12.0	63.5	9.96	42.30	424.82
12.0	63.4	9.96	42.23	424.15
30.0	79.2	24.89	52.76	211.94
30.0	80.2	24.89	53.43	214.62
30.0	79.8	24.89	53.16	213.55
60.0	90.0	49.79	59.95	120.42
60.0	91.0	49.79	60.62	121.76
60.0	90.1	49.79	60.02	120.56

TABLE A 129

RUN 142

	PULP C	TEMP.=30.9	SPINDLE 2	S.G.=1.641
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	44.6	4.32	29.71	688.41
6.0	44.3	4.32	29.51	683.78
6.0	44.4	4.32	29.58	685.32
12.0	64.5	8.63	42.97	497.78
12.0	64.3	8.63	42.83	496.24
12.0	63.2	8.63	42.10	487.75
30.0	81.6	21.58	54.36	251.90
60.0	92.4	43.16	61.55	142.62
60.0	88.8	43.16	59.16	137.06
60.0	96.5	43.16	64.28	148.95
60.0	93.6	43.16	62.35	144.47

TABLE A 130

RUN 143

	PULP C	TEMP.=10.6	SPINDLE 2	S.G.=1.620
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	37.2	4.71	24.78	526.14
6.0	37.6	4.71	25.05	531.80
6.0	37.8	4.71	25.18	534.62
12.0	46.4	9.42	30.91	328.13
12.0	45.8	9.42	30.51	323.89
12.0	45.8	9.42	30.51	323.89
30.0	60.2	23.55	40.10	170.29
30.0	59.8	23.55	39.84	169.16
30.0	59.2	23.55	39.44	167.46
60.0	69.4	47.10	46.23	98.16
60.0	69.6	47.10	46.37	98.44
60.0	69.2	47.10	46.10	97.87

TABLE A 131

RUN 144

	PULP C	TEMP.=17.6	SPINDLE 2	S.G.=1.620
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	38.2	5.20	25.45	489.40
6.0	39.2	5.20	26.11	502.21
6.0	38.6	5.20	25.71	494.52
12.0	46.6	10.40	31.04	298.51
12.0	46.7	10.40	31.11	299.15
12.0	46.6	10.40	31.04	298.51
30.0	58.8	26.00	39.17	150.66
30.0	58.3	26.00	38.84	149.38
30.0	57.8	26.00	38.50	148.10
60.0	68.6	52.00	45.70	87.89
60.0	66.1	52.00	44.03	84.68
60.0	68.4	52.00	45.57	87.63

TABLE A 132

RUN 145

	PULP C	TEMP.=24.6	SPINDLE 2	S.G.=1.620
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	37.8	5.07	25.18	497.07
6.0	38.5	5.07	25.65	506.28
6.0	38.4	5.07	25.58	504.96
12.0	47.4	10.13	31.58	311.66
12.0	48.4	10.13	32.24	318.23
12.0	48.4	10.13	32.24	318.23
30.0	59.2	25.33	39.44	155.70
30.0	60.2	25.33	40.10	158.33
30.0	59.5	25.33	39.64	156.49
60.0	69.1	50.66	46.03	90.87
60.0	68.6	50.66	45.70	90.21
60.0	68.6	50.66	45.70	90.21

TABLE A 133

RUN 146

	PULP C	TEMP.=31.2	SPINDLE 2	S.G.=1.620
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	37.4	4.71	24.91	529.25
6.0	39.1	4.71	26.05	553.30
6.0	37.8	4.71	25.18	534.91
12.0	50.2	9.42	33.44	355.19
12.0	50.8	9.42	33.84	359.43
12.0	49.4	9.42	32.91	349.53
30.0	62.1	23.54	41.37	175.75
30.0	63.2	23.54	42.10	178.87
30.0	63.5	23.54	42.30	179.72
60.0	71.7	47.08	47.76	101.46
60.0	73.1	47.08	48.70	103.44
60.0	72.2	47.08	48.10	102.17

TABLE A 134

RUN 147

	PULP C	TEMP.=10.7	SPINDLE 2	S.G.=1.535
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	20.6	5.33	13.72	257.46
6.0	21.1	5.33	14.06	263.70
6.0	20.8	5.33	13.86	259.96
12.0	23.9	10.66	15.92	149.35
12.0	24.2	10.66	16.12	151.22
12.0	24.4	10.66	16.25	152.47
30.0	30.2	26.65	20.12	75.49
30.0	30.4	26.65	20.25	75.99
30.0	30.2	26.65	20.12	75.49
60.0	35.6	53.30	23.72	44.49
60.0	36.2	53.30	24.12	45.24
60.0	35.2	53.30	23.45	43.99

TABLE A 135

RUN 148

PULP C TEMP.=21.9 SPINDLE 2 S.G.=1.535

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	22.7	7.21	15.12	209.73
6.0	22.4	7.21	14.92	206.96
6.0	22.4	7.21	14.92	206.96
12.0	24.7	14.42	16.45	114.10
12.0	24.2	14.42	16.12	111.79
12.0	24.3	14.42	16.19	112.26
30.0	28.7	36.05	19.12	53.03
30.0	28.7	36.05	19.12	53.03
30.0	28.8	36.05	19.19	53.22
60.0	33.6	72.10	22.38	31.04
60.0	33.1	72.10	22.05	30.58
60.0	33.4	72.10	22.25	30.86

TABLE A 136

RUN 149

PULP C TEMP.=28.4 SPINDLE 2 S.G.=1.535

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	21.9	7.15	14.59	204.15
6.0	21.6	7.15	14.39	201.35
6.0	21.6	7.15	14.39	201.35
12.0	24.7	14.29	16.45	115.12
12.0	24.2	14.29	16.12	112.79
12.0	24.2	14.29	16.12	112.79
30.0	28.4	35.73	18.92	52.95
30.0	28.3	35.73	18.85	52.76
30.0	28.2	35.73	18.79	52.58
60.0	32.6	71.46	21.72	30.39
60.0	32.6	71.46	21.72	30.39
60.0	32.6	71.46	21.72	30.39

TABLE A 137

RUN 150

PULP C TEMP.=10.3 SPINDLE 2 S.G.=1.492

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	12.2	5.42	8.13	149.92
6.0	12.3	5.42	8.19	151.15
6.0	12.3	5.42	8.19	151.15
12.0	14.6	10.84	9.73	89.71
12.0	14.7	10.84	9.79	90.32
12.0	14.6	10.84	9.73	89.71
30.0	17.7	27.10	11.79	43.50
30.0	18.2	27.10	12.12	44.73
30.0	18.2	27.10	12.12	44.73
60.0	21.0	54.21	13.99	25.81
60.0	21.1	54.21	14.06	25.93
60.0	20.9	54.21	13.92	25.68

TABLE A 138

RUN 151

PULP C TEMP.=17.7 SPINDLE 2 S.G.=1.492

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	12.2	5.88	8.13	138.22
6.0	12.0	5.88	7.99	135.96
6.0	12.1	5.88	8.06	137.09
12.0	14.2	11.76	9.46	80.44
12.0	14.4	11.76	9.59	81.57
12.0	14.3	11.76	9.53	81.01
30.0	17.4	29.40	11.59	39.43
30.0	17.5	29.40	11.66	39.65
30.0	17.2	29.40	11.46	38.97
60.0	19.7	58.80	13.12	22.32
60.0	19.9	58.80	13.26	22.55
60.0	20.0	58.80	13.32	22.66

TABLE A 139

RUN 152

PULP C | TEMP.=26.1 | SPINDLE 2 | S.G.=1.492

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	11.7	6.09	7.79	128.03
6.0	11.5	6.09	7.66	125.84
6.0	11.6	6.09	7.73	126.94
12.0	14.2	12.18	9.46	77.69
12.0	14.0	12.18	9.33	76.60
12.0	14.2	12.18	9.46	77.69
30.0	16.6	30.44	11.06	36.33
30.0	16.8	30.44	11.19	36.77
30.0	16.5	30.44	10.99	36.11
60.0	18.9	60.88	12.59	20.68
60.0	18.9	60.88	12.59	20.68
60.0	19.2	60.88	12.79	21.01

TABLE A 140

RUN 153

PULP C | TEMP.=31.3 | SPINDLE 2 | S.G.=1.492

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	11.5	5.68	7.66	134.98
6.0	11.2	5.68	7.46	131.45
6.0	11.3	5.68	7.53	132.63
12.0	13.4	11.35	8.93	78.64
12.0	13.3	11.35	8.86	78.05
12.0	13.6	11.35	9.06	79.81
30.0	16.8	28.38	11.19	39.44
30.0	16.7	28.38	11.12	39.20
30.0	16.5	28.38	10.99	38.73
60.0	19.0	56.76	12.66	22.30
60.0	19.0	56.76	12.66	22.30
60.0	18.6	56.76	12.39	21.83

TABLE A 141

RUN 154

	PULP C	TEMP.=10.7	SPINDLE 1	S.G.=1.443
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	34.4	5.11	5.55	108.55
6.0	34.6	5.11	5.58	109.18
6.0	34.9	5.11	5.63	110.12
12.0	40.3	10.22	6.50	63.58
12.0	40.1	10.22	6.47	63.27
12.0	40.0	10.22	6.45	63.11
30.0	50.9	25.55	8.21	32.12
30.0	50.6	25.55	8.16	31.93
30.0	50.5	25.55	8.14	31.87
60.0	60.6	51.10	9.77	19.12
60.0	60.6	51.10	9.77	19.12
60.0	60.6	51.10	9.77	19.12

TABLE A 142

RUN 155

	PULP C	TEMP.=18.3	SPINDLE 1	S.G.=1.443
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	35.4	5.90	5.71	96.71
6.0	36.5	5.90	5.88	99.72
6.0	35.9	5.90	5.79	98.08
12.0	40.6	11.80	6.55	55.46
12.0	41.0	11.80	6.61	56.01
12.0	40.9	11.80	6.59	55.87
30.0	49.4	29.51	7.96	26.99
30.0	49.4	29.51	7.96	26.99
30.0	49.3	29.51	7.95	26.94
60.0	58.4	59.02	9.42	15.95
60.0	58.6	59.02	9.45	16.01
60.0	58.6	59.02	9.45	16.01

TABLE A 143

RUN 156

PULP C TEMP.=24.7 SPINDLE 1 S.G.=1.443

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	34.7	5.94	5.59	94.24
6.0	34.8	5.94	5.61	94.51
6.0	34.8	5.94	5.61	94.51
12.0	39.2	11.87	6.32	53.23
12.0	39.4	11.87	6.35	53.50
12.0	39.2	11.87	6.32	53.23
30.0	47.6	29.68	7.67	25.86
30.0	47.5	29.68	7.66	25.80
30.0	47.2	29.68	7.61	25.64
60.0	56.7	59.37	9.14	15.40
60.0	56.1	59.37	9.05	15.24
60.0	56.4	59.37	9.09	15.32

TABLE A 144

RUN 157

PULP C TEMP.=30.8 SPINDLE 1 S.G.=1.443

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	33.7	5.80	5.43	93.68
6.0	34.1	5.80	5.50	94.79
6.0	33.2	5.80	5.35	92.29
12.0	38.5	11.60	6.21	53.51
12.0	38.1	11.60	6.14	52.95
12.0	38.1	11.60	6.14	52.95
30.0	46.8	29.00	7.55	26.02
30.0	47.2	29.00	7.61	26.24
30.0	46.6	29.00	7.51	25.91
60.0	55.3	58.00	8.92	15.37
60.0	55.1	58.00	8.88	15.32
60.0	55.0	58.00	8.87	15.29

TABLE A 145

RUN 158

	PULP C	TEMP.=10.8	SPINDLE 1	S.G.=1.420
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	26.2	4.92	4.22	85.91
6.0	26.7	4.92	4.30	87.55
6.0	27.1	4.92	4.37	88.86
12.0	31.9	9.83	5.14	52.30
12.0	31.9	9.83	5.14	52.30
12.0	32.1	9.83	5.18	52.63
30.0	39.5	24.59	6.37	25.90
30.0	39.8	24.59	6.42	26.10
30.0	39.8	24.59	6.42	26.10
60.0	48.1	49.17	7.76	15.77
60.0	48.4	49.17	7.80	15.87
60.0	48.3	49.17	7.79	15.84

TABLE A 146

RUN 159

	PULP C	TEMP.=17.4	SPINDLE 1	S.G.=1.420
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	27.6	5.57	4.45	79.84
6.0	27.7	5.57	4.47	80.13
6.0	27.7	5.57	4.47	80.13
12.0	32.2	11.15	5.19	46.57
12.0	32.3	11.15	5.21	46.72
12.0	32.4	11.15	5.22	46.86
30.0	38.9	27.87	6.27	22.51
30.0	39.2	27.87	6.32	22.68
30.0	39.1	27.87	6.30	22.62
60.0	46.7	55.74	7.53	13.51
60.0	46.4	55.74	7.48	13.42
60.0	46.9	55.74	7.56	13.57

TABLE A 147

RUN 160

	PULP C	TEMP.=24.2	SPINDLE 1	S.G.=1.420
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	27.4	5.77	4.42	76.54
6.0	27.4	5.77	4.42	76.54
6.0	27.4	5.77	4.42	76.54
12.0	32.1	11.54	5.18	44.84
12.0	32.3	11.54	5.21	45.12
12.0	32.4	11.54	5.22	45.26
30.0	38.1	28.86	6.14	21.29
30.0	38.4	28.86	6.19	21.45
30.0	38.4	28.86	6.19	21.45
60.0	45.7	57.72	7.37	12.77
60.0	45.6	57.72	7.35	12.74
60.0	45.7	57.72	7.37	12.77

TABLE A 148

RUN 161

	PULP C	TEMP.=30.6	SPINDLE 1	S.G.=1.420
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	27.0	6.10	4.35	71.34
6.0	26.9	6.10	4.34	71.08
6.0	26.9	6.10	4.34	71.08
12.0	31.5	12.20	5.08	41.62
12.0	30.5	12.20	4.92	40.30
12.0	29.4	12.20	4.74	38.84
30.0	36.8	30.51	5.93	19.45
30.0	36.4	30.51	5.87	19.24
30.0	36.4	30.51	5.87	19.24
60.0	43.2	61.02	6.97	11.41
60.0	43.2	61.02	6.97	11.41
60.0	43.2	61.02	6.97	11.41

TABLE A 149

RUN 162

PULP C TEMP.=10.6 SPINDLE 1 S.G.=1.408

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	22.9	4.80	3.69	76.98
6.0	23.0	4.80	3.71	77.32
6.0	23.0	4.80	3.71	77.32
12.0	26.8	9.59	4.32	45.05
12.0	27.6	9.59	4.45	46.39
12.0	27.4	9.59	4.42	46.05
30.0	34.1	23.98	5.50	22.93
30.0	34.3	23.98	5.53	23.06
30.0	34.4	23.98	5.55	23.13
60.0	42.0	47.96	6.77	14.12
60.0	41.9	47.96	6.76	14.09
60.0	42.1	47.96	6.79	14.15

TABLE A 150

RUN 163

PULP C TEMP.=16.9 SPINDLE 1 S.G.=1.408

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	22.3	5.00	3.60	71.93
6.0	22.6	5.00	3.64	72.90
6.0	22.6	5.00	3.64	72.90
12.0	27.0	10.00	4.35	43.54
12.0	26.6	10.00	4.29	42.90
12.0	27.2	10.00	4.39	43.87
30.0	33.8	24.99	5.45	21.80
30.0	33.5	24.99	5.40	21.61
30.0	33.6	24.99	5.42	21.68
60.0	40.4	49.99	6.51	13.03
60.0	40.3	49.99	6.50	13.00
60.0	40.1	49.99	6.47	12.93

TABLE A 151

RUN 164

	PULP C	TEMP.=23.8	SPINDLE 1	S.G.=1.408
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	21.2	5.11	3.42	66.91
6.0	21.2	5.11	3.42	66.91
6.0	21.1	5.11	3.40	66.60
30.0	31.2	25.54	5.03	19.70
30.0	31.6	25.54	5.09	19.95
30.0	31.4	25.54	5.06	19.82
60.0	37.6	51.08	6.06	11.87
60.0	37.3	51.08	6.01	11.77
60.0	37.0	51.08	5.97	11.68

TABLE A 152

RUN 165

	PULP C	TEMP.=30.3	SPINDLE 1	S.G.=1.408
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	20.2	5.23	3.26	62.26
6.0	20.3	5.23	3.27	62.57
6.0	20.4	5.23	3.29	62.88
12.0	25.0	10.46	4.03	38.53
12.0	24.8	10.46	4.00	38.22
12.0	25.0	10.46	4.03	38.53
30.0	30.2	26.16	4.87	18.62
30.0	29.8	26.16	4.80	18.37
30.0	30.0	26.16	4.84	18.49
60.0	35.7	52.31	5.76	11.00
60.0	36.1	52.31	5.82	11.13
60.0	35.9	52.31	5.79	11.06

TABLE A 153

RUN 166

	PULP C	TEMP.=11.0	SPINDLE 1	S.G.=1.390
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	16.2	4.35	2.61	60.11
6.0	15.8	4.35	2.55	58.62
6.0	16.0	4.35	2.58	59.36
12.0	20.3	8.69	3.27	37.66
12.0	20.3	8.69	3.27	37.66
12.0	20.0	8.69	3.22	37.10
30.0	24.8	21.73	4.00	18.40
30.0	25.4	21.73	4.10	18.85
30.0	25.3	21.73	4.08	18.77
60.0	31.9	43.46	5.14	11.84
60.0	31.6	43.46	5.09	11.72
60.0	31.6	43.46	5.09	11.72

TABLE A 154

RUN 167

	PULP C	TEMP.=18.3	SPINDLE 1	S.G.=1.390
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	15.2	4.50	2.45	54.43
6.0	16.2	4.50	2.61	58.01
6.0	15.1	4.50	2.43	54.07
12.0	18.8	9.01	3.03	33.66
12.0	18.6	9.01	3.00	33.30
12.0	18.7	9.01	3.02	33.48
30.0	23.4	22.51	3.77	16.76
30.0	23.6	22.51	3.81	16.90
30.0	23.6	22.51	3.81	16.90
60.0	29.7	45.03	4.79	10.63
60.0	29.6	45.03	4.77	10.60
60.0	29.5	45.03	4.76	10.56

TABLE A 155

RUN 168

	PULP C	TEMP.=25.6	SPINDLE 1	S.G.=1.390
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	14.1	4.56	2.27	49.89
6.0	14.8	4.56	2.39	52.37
6.0	14.7	4.56	2.37	52.02
12.0	18.5	9.11	2.98	32.73
12.0	18.4	9.11	2.97	32.55
12.0	18.4	9.11	2.97	32.55
30.0	22.7	22.78	3.66	16.07
30.0	23.1	22.78	3.72	16.35
30.0	22.8	22.78	3.68	16.14
60.0	28.4	45.56	4.58	10.05
60.0	27.9	45.56	4.50	9.87
60.0	27.6	45.56	4.45	9.77

TABLE A 156

RUN 169

	PULP C	TEMP.=30.9	SPINDLE 1	S.G.=1.390
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	15.2	5.09	2.45	48.17
6.0	14.9	5.09	2.40	47.22
6.0	15.4	5.09	2.48	48.80
12.0	18.2	10.18	2.93	28.84
12.0	18.0	10.18	2.90	28.52
12.0	17.6	10.18	2.84	27.89
30.0	22.3	25.44	3.60	14.13
30.0	22.5	25.44	3.63	14.26
30.0	22.3	25.44	3.60	14.13
60.0	26.3	50.88	4.24	8.33
60.0	27.6	50.88	4.45	8.75
60.0	26.5	50.88	4.27	8.40

TABLE B 1

RUN 52

PULP A TEMP.=25.0 SPINDLE 1 S.G.=1.313

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
12.0	55.0	259.70	8.87	3.41
12.0	54.0	259.70	8.71	3.35
12.0	54.1	259.70	8.72	3.36
30.0	52.3	649.25	8.43	1.30
30.0	52.4	649.25	8.45	1.30
30.0	52.0	649.25	8.38	1.29
60.0	55.2	1298.51	8.90	.69
60.0	55.2	1298.51	8.90	.69
60.0	55.2	1298.51	8.90	.69
60.0	55.2	1298.51	8.90	.69

TABLE B 2

RUN 53

PULP A TEMP.=25.5 SPINDLE 1 S.G.=1.313

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
60.0	52.0	175.43	8.38	4.78
60.0	53.1	175.43	8.56	4.88
60.0	52.5	175.43	8.46	4.82
60.0	53.6	175.43	8.64	4.93
60.0	52.0	175.43	8.38	4.78
60.0	53.4	175.43	8.61	4.91
30.0	49.2	87.72	7.93	9.04
30.0	49.2	87.72	7.93	9.04
12.0	47.2	35.09	7.61	21.69
12.0	47.3	35.09	7.63	21.74

TABLE B 3

RUN 54

	PULP A	TEMP.=25.0	SPINDLE 1	S.G.=1.288
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
12.0	33.7	24.89	5.43	21.83
12.0	33.7	24.89	5.43	21.83
30.0	36.2	62.22	5.84	9.38
30.0	36.2	62.22	5.84	9.38
60.0	39.1	124.44	6.30	5.07
60.0	39.3	124.44	6.34	5.09
60.0	40.3	124.44	6.50	5.22
60.0	39.4	124.44	6.35	5.10

TABLE B 4

RUN 55

	PULP A	TEMP.=25.0	SPINDLE 1	S.G.=1.305
RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	29.3	10.06	4.72	46.98
6.0	29.8	10.06	4.80	47.78
12.0	32.2	20.11	5.19	25.81
12.0	31.8	20.11	5.13	25.49
12.0	32.0	20.11	5.16	25.65
30.0	35.4	50.28	5.71	11.35
30.0	35.4	50.28	5.71	11.35
30.0	35.2	50.28	5.68	11.29
60.0	39.2	100.57	6.32	6.28
60.0	39.6	100.57	6.38	6.35
60.0	39.6	100.57	6.38	6.35

TABLE B 3

RUN 54

PULP A TEMP.=25.0 SPINDLE 1 S.G.=1.288

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
12.0	33.7	24.89	5.43	21.83
12.0	33.7	24.89	5.43	21.83
30.0	36.2	62.22	5.84	9.38
30.0	36.2	62.22	5.84	9.38
60.0	39.1	124.44	6.30	5.07
60.0	39.3	124.44	6.34	5.09
60.0	40.3	124.44	6.50	5.22
60.0	39.4	124.44	6.35	5.10

TABLE B 4

RUN 55

PULP A TEMP.=25.0 SPINDLE 1 S.G.=1.305

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	29.3	10.06	4.72	46.98
6.0	29.8	10.06	4.80	47.78
12.0	32.2	20.11	5.19	25.81
12.0	31.8	20.11	5.13	25.49
12.0	32.0	20.11	5.16	25.65
30.0	35.4	50.28	5.71	11.35
30.0	35.4	50.28	5.71	11.35
30.0	35.2	50.28	5.68	11.29
60.0	39.2	100.57	6.32	6.28
60.0	39.6	100.57	6.38	6.35
60.0	39.6	100.57	6.38	6.35

TABLE B 5

RUN 56

PULP A TEMP.=24.9 SPINDLE 1 S.G.=1.315

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
60.0	73.1	301.50	11.79	3.91
60.0	73.4	301.50	11.83	3.93
60.0	72.6	301.50	11.71	3.88
30.0	71.0	150.75	11.45	7.59
30.0	71.1	150.75	11.46	7.60
30.0	70.8	150.75	11.42	7.57

TABLE C 1

RUN 57

PULP A | TEMP.=25.0 | SPINDLE 1 | S.G.=1.327

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
12.0	9.6	6.33	1.55	24.47
12.0	9.6	6.33	1.55	24.47
30.0	13.6	15.82	2.19	13.86
30.0	13.6	15.82	2.19	13.86
60.0	18.1	31.63	2.92	9.23
60.0	18.1	31.63	2.92	9.23
60.0	18.2	31.63	2.93	9.28

TABLE C 2

RUN 58

PULP A | TEMP.=26.1 | SPINDLE 1 | S.G.=1.335

RPM	DIAL READING	SHEAR RATE	SHEAR STRESS	EFFECTIVE VISCOSITY
6.0	21.6	5.95	3.48	58.53
6.0	21.6	5.95	3.48	58.53
12.0	25.8	11.90	4.16	34.95
12.0	25.2	11.90	4.06	34.14
30.0	29.2	29.75	4.71	15.82
30.0	29.4	29.75	4.74	15.93
30.0	29.4	29.75	4.74	15.93
60.0	35.7	59.50	5.76	9.67
60.0	35.5	59.50	5.72	9.62
60.0	35.6	59.50	5.74	9.65

APPENDIX F

SIZE DISTRIBUTION

TABLE E1

PULP A

Size (microns)	Percent
+ 149	0,2
+ 105 - 149	3,5
+ 74 - 105	9,9
+ 53 - 74	7,8
+ 37 - 53	9,0
+ 34,3 - 37	13,0
+ 24,7 - 34,3	10,3
+ 16,7 - 24,7	8,6
+ 12,8 - 16,7	5,0
- 12,8	32,7
	100,0

TABLE E2

PULP B

Size (microns)	Percent
+ 150	0,4
+ 100 - 150	2,6
+ 53 - 100	16,9
+ 39 - 53	6,0
+ 29 - 39	10,5
+ 20 - 29	11,2
+ 13 - 20	9,7
+ 10 - 13	6,0
- 10	36,7
	100,0

APPENDIX G

DETERMINATION OF THE EFFECTIVE LENGTH OF THE SPINDLES

TABLE F1

SPINDLE 0

Viscosity of oil = 25,95 mPa.s

RPM	DIAL READING
1,5	2,6
3,0	5,6
6,0	11,4
12,0	22,0
30,0	55,7
60,0	+100,0

TABLE F2

SPINDLE 1

Viscosity of oil = 88,7 mPa.s

RPM	DIAL READING
3,0	3,0
6,0	7,0
12,0	13,8
30,0	34,6
60,0	69,0

TABLE F3

SPINDLE 2

Viscosity of oil = 990 mPa.s

RPM	DIAL READING
0,6	2,9
1,5	5,4
3,0	10,7
6,0	21,3
12,0	41,7
30,0	+100,0