RHEOLOGY OF NON-NEWTONIAN SLURRIES
USING A
STORMER VISCOMETER

By

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A thesis submitted to the faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science.

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ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Dr. R. R. Faddick for his help and guidance, Prof. E. Shimoda for his help, Dr. J. O. Golden and Dr. G. P. Martins for acting as committee members, Mr. Keith Linck for permission to use the regression program "SNAP", and to the Colorado School of Mines Foundation for supporting this research. The author would also like to thank Mr. R. C. Cornwall for performing part of the experiments, and Dr. R. R. Faddick and the CSM Rheology Lab for permission to use the data. The data provided by the CSM Rheology Lab have been indicated in the text, wherever data have been listed.

NOMENCLATURE

A	Stormer viscometer constant (gm-sec/cp)
D	diameter of spindle (cm)
h	height of spindle immersed (cm)
K'	constant in the Geddes-Dawson analysis ($cc^{-1}sec^{-2}$)
L	length of spindle (cm)
L_e	effective length of spindle, which is the sum of the length of the spindle and the end-effects of the viscometer (cm)
n	rotational speed of the spindle (rev/sec)
n'	slope of the logarithmic plot of torque T vs. rotational speed n
n''	dn'/d (ln T)
PC	percent correction to be applied to the driving weight to account for turbulence
R_s, R_b	radius of spindle or bob (cm)
R_c	radius of cup (cm)
S	ratio of the cup radius to the spindle radius
T	torque (dyne-cm)
t	time for 100 revolutions (sec)
W	driving weight (gm)
W_c	portion of driving weight required to overcome viscous resistance (gm)
$(\dot{\gamma})_{app}$	shear rate determined by dividing the shear stress by the viscosity (sec^{-1})

$(\dot{\gamma})_{baf}$	shear rate determined by assuming the gap between the spindle and the cup to be uniform and equal to the gap between the baffle and the spindle (sec^{-1})
$(\dot{\gamma})_{cup}$	shear rate calculated by assuming the gap between the cup and spindle to be uniform and equal to the difference in radii (sec^{-1})
τ	shear stress ($dyne/cm^2$)
ρ	fluid density (gm/cc)
ρ_s	solids density (gm/cc)
μ	absolute viscosity (cp)
μ_f	an apparent constant value of viscosity attained by a slurry as the rotational speed of the viscometer is increased
μ_s	approximate viscosity of a slurry read from the Newtonian calibration chart (cp)
Ω	angular velocity of spindle (radians/sec)

ABSTRACT

The objective of the present research was to analyse the Stormer viscometer data on slurries gathered by the CSM Rheology Lab. Significant steps have been taken towards the goal of generating rheograms. The behaviour of different slurries has been compared using psuedo-rheograms developed from the available experimental data.

Data taken with Newtonian fluids using a Stormer viscometer have been used to analyse the behaviour of the instrument. Corrections have been made for turbulence caused by high shearing rates. A method has been devised to calculate the shear rate from the values obtained by using equations available for instruments of simpler geometry.

Data taken with non-Newtonian slurries have not been amenable to complete analysis. An approximate correction has been made for turbulence effects. However, it has not been possible to calculate the shear rates. Psuedo-rheograms of corrected driving weight vs. revolutions per second have been plotted for comparative purposes, using aqueous slurries of coal, limestone, and some metallic ores.

The steady value of the approximate viscosity of a slurry (μ_f) generally increases as concentration increases. The value of μ_f decreases as temperatures increases. The yield value is independent of temperature when all other factors are constant. It is dependent on concentration. The change in yield value with concentration is gradual for finer particle slurries, and abrupt at some particular volumetric concentration for coarser particle slurries. The volumetric concentration at which the yield value changes abruptly is suspected

to be dependent on particle size, the ratio of the solids density to liquid density and possibly by the nature of the solids. The behaviour of the slurries is influenced to a large extent by the nature of the particles. This is evident when different slurries, like uranium tailings, taconite, copper ore and limestone, are compared.

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INTRODUCTION

Slurry pipeline design requires a knowledge of the rheological properties of the solid-liquid mixture that has to be transported. Heterogeneous slurries tend to settle, and this hampers viscometric measurements. Hence any viscometer being used to study the coarser slurries must counteract the tendency of the particles to settle. An external stirring device may be used for the purpose of keeping the particles in suspension, or the viscometer may be designed to provide the stirring action itself.

A rheological study involves the conversion of viscometric measurements to meaningful quantities, such as shear stress and shear rate (or related quantities). This would facilitate the comparison of the behaviour of slurries and also the calculation of pressure drops in pipelines. The conversions are fairly simple if the readings are taken in the laminar region and if the geometry of the viscometer is uncomplicated.

The Stormer viscometer has certain advantages when it comes to handling heterogeneous slurries. It is designed to provide a stirring action without the help of an external device. It can handle coarser slurries than most other concentric cylinder rotational viscometers or capillary viscometers. An additional advantage over capillary viscometers is that the Stormer viscometer is commercially available, whereas capillary viscometers have to be custom-built. The Stormer viscometer can be used in the higher shear rate regions where pipeline flow generally occurs. Lastly, the instrument is inexpensive.

The CSM Rheology Lab has gathered extensive experimental data on slurries using a Stormer viscometer. The present work was aimed at generating rheograms with the available data. However, certain analytical problems arose because of the geometric complexity of the instrument. Shear rate equations were not available for the Stormer viscometer, and corrections had to be made for turbulence before the shear stress could be calculated. The attempts to overcome the difficulties in calculating the shear stress and shear rate have been partially successful. Even though true rheograms have not been generated, psuedo-rheograms can be, and these are useful in comparing the behaviour of the slurries. In particular, the effect of temperature, and concentration (weight or volumetric) can be clearly seen by tabulating the information from the psuedo-rheograms. It is also possible to see that the physical properties of the solids, like particle density and particle size, affect slurry rheology. However, the effect of the individual factors is not evident from the available data.

LITERATURE SURVEY

The survey covers the following topics:

i) Rigorous mathematical methods to calculate shear stress and shear rate,

ii) studies on the rheology of slurries, and

iii) studies using the Stormer viscometer.

Shear Stress and Shear Rate:

The methods used to calculate shear stress and shear rate in instruments of simple geometry are fairly well established. The quantities are generally calculated at the spindle surface.

The shear stress at the spindle surface is given by (1)

$$\tau = T/2\pi R_s^2 L, \qquad (1)$$

where τ = shear stress (dynes/cm^2),

T = torque (dyne-cm),

R_s = spindle radius (cm),

and L = spindle length (cm).

This equation does not correct for end-effect. End-effect can be included by substituting L_e for L in equation (1). The effective length can be determined by using a Newtonian fluid of known viscosity.(2)

$$L_e = T/2\pi R_s^2 \mu(\dot{\gamma}), \qquad (2)$$

where L_e = effective length (cm),

μ = viscosity (poise),

and $\dot{\gamma}$ = shear rate (sec^{-1}).

It is assumed that the end-effect is identical for both Newtonian fluids and non-Newtonian slurries. Equation (2) would be useless for instruments in which the shear rate cannot be readily calculated. For such instruments it is necessary to use other methods.

Lindsley and Fischer (3) have described the single spindle method of Searle. This involves filling the cup to various heights and taking readings. The height h, is plotted against the product W*t, the weight and the time for 100 revolutions, respectively. The intercept of the line on the height axis gives the correction to be applied to the spindle length for end-effect. However, this method gives only the bottom end-effect. In the Stormer viscometer, the top end-effect has also to be considered. The method has to be modified slightly for this reason.

Rosen (4) has described a method to calculate the end-effect in a Brookfield viscometer. This also assumes that the shear rate can be determined readily.

The shear rate equations for a concentric cylinder viscometer depend on the geometry of the instrument. For instruments with a cup of infinite radius the equation is (5)

$$\dot{\gamma} = -2d\Omega/d(\ln\tau) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

where Ω = the angular velocity of the spindle (radians/sec). Where the cup radius is not very large compared to the spindle radius (i.e., where S, the ratio of the cup radius to the spindle radius is less than 1.2), the equation of Krieger-Maron-Elrod (5) can be used. They have shown that the shear rate can be obtained from an infinite series which can be approximated by

$$(\dot{\gamma}) = \frac{4\pi n}{1-S^{-2}} \left\{ 1+\frac{S^2-1}{2S^2}(1+\tfrac{2}{3}\ln S)\left(\frac{1}{n'}-1\right) + \frac{S^2-1}{6S^2}(\ln S)\left[\left(\frac{1}{n'}-1\right)^2 + \frac{d\left(\frac{1}{n'}-1\right)}{d(\log T)} + \ldots\right]\right\} \ldots(4)$$

where n' is the slope of the logarithmic plot of T vs. n.

In a later paper, Krieger (6) has shown that the shear rate can be expressed as a power-law approximation plus a correction that can be readily calculated.

$$\dot{\gamma} = \frac{2n'\Omega}{1-S^{-2n'}}\left[1 + \frac{n''}{n'^2}\ f(2n'\ln S)\right], \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where n" = the second derivative of the logarithmic plot of T vs. n, and $f(t) = \frac{t^2}{12}\left(1 - \frac{t}{2} + \frac{t^2}{15} + \ldots\right)$.

It is evident that none of these methods can be directly applied to the Stormer viscometer.

Slurry Rheology using other Viscometers:

Schack *et al.* (7) have made a detailed study to establish the dependence of viscosity on pulp density, particle size, crystallinity and cleavage. They have used an orifice type viscometer with a mechanical stirrer. They measured the time required for a given volume of the slurry to flow out of the viscometer, and read off the viscosity from a standard viscosity vs. time plot. Such a procedure may be employed for Newtonian fluids, whose viscosities do not depend on the shear rate. However, for suspensions which may be non-Newtonian, this procedure may lead to erroneous results. The viscosity of a slurry must be specified at a particular shear rate. Since the readings on different slurries may have been taken at different shear rates, it would be incorrect to compare the viscosities read off a calibration chart, as the authors have done.

Govier *et al.* (8) have studied the rheology of water suspensions of finely subdivided magnetite, galena and ferrosilicon. They have used the Fann rotational viscometer for their studies. To calculate shear rates they have multiplied the rotor speed by a constant factor. This may be done in the case of Newtonian fluids. However, for non-Newtonian fluids, characteristic of most mineral slurries, it is necessary to use the Krieger equations.

Studies with the Stormer Viscometer:

Geddes and Dawson (9) were among the first to consider the Stormer viscometer for the study of non-Newtonian fluids. They postulated that the curvature towards the weight axis of a W vs. 1/t plot for Newtonian fluids was due to turbulence and attempted to correct for this effect. However, the method suggested by them is suspect. (The details are discussed later). Also there is no evidence that they did any work on non-Newtonian fluids.

Fourie *et al.* (10) have also tried to correct for kinetic effects. They have generated plots of W vs. 1/t for slurries. Such plots are probably sufficient for Newtonian fluids and Bingham plastic fluids. They have not explained the method they used to predict pipeline pressure losses from the psuedo-rheograms generated, but claim that the predictions tally well with real-life pipeline data.

Smith (11) has made use of extensive pipeline data to determine the factors to convert the slope of the W vs. 1/t plot to the coefficient of rigidity (slope of the shear stress vs. shear rate plot for a

Bingham fluid) and the intercept to the yield stress. The method should work well because of the amount of experimental data used to determine the conversion factors, but the method is good only for Bingham plastic fluids, specifically limestone or cement slurries.

EXPERIMENTAL WORK

Apparatus:

The Stormer viscometer is shown in Figure 1-a. It consists of a baffled cup (Figure 1-b) which should be placed in a constant temperature bath. The bath temperature can be controlled by circulating water (hot or cold as necessary) through a helical coil immersed in the bath. The cup has a provision for inserting a thermometer to measure the temperature of the sample. The cup-bath arrangement is supported on a platform which can be raised or lowered as necessary. A stop is provided to bring the cup to the same height for each reading.

The spindle is suspended from a shaft that can be driven by a weight through a pulley arrangement. The spindle design is shown in Figure 1-c. With its open bottom and perforated top, it provides a pumping action that reduces the settling of slurries. A dial is provided to count the number of revolutions. A brake mechanism is provided to stop the free fall of the driving weight.

Newtonian Fluid Data:

A set of experiments were run initially using Newtonian fluids of known viscosities. The cup was filled with sufficient fluid to cover the spindle completely. The temperature of the fluid was maintained at 25 ± .5C. A known driving weight was used and the brake released. The time for 100 revolutions was noted. The experiment was repeated thrice for each driving weight and the three readings

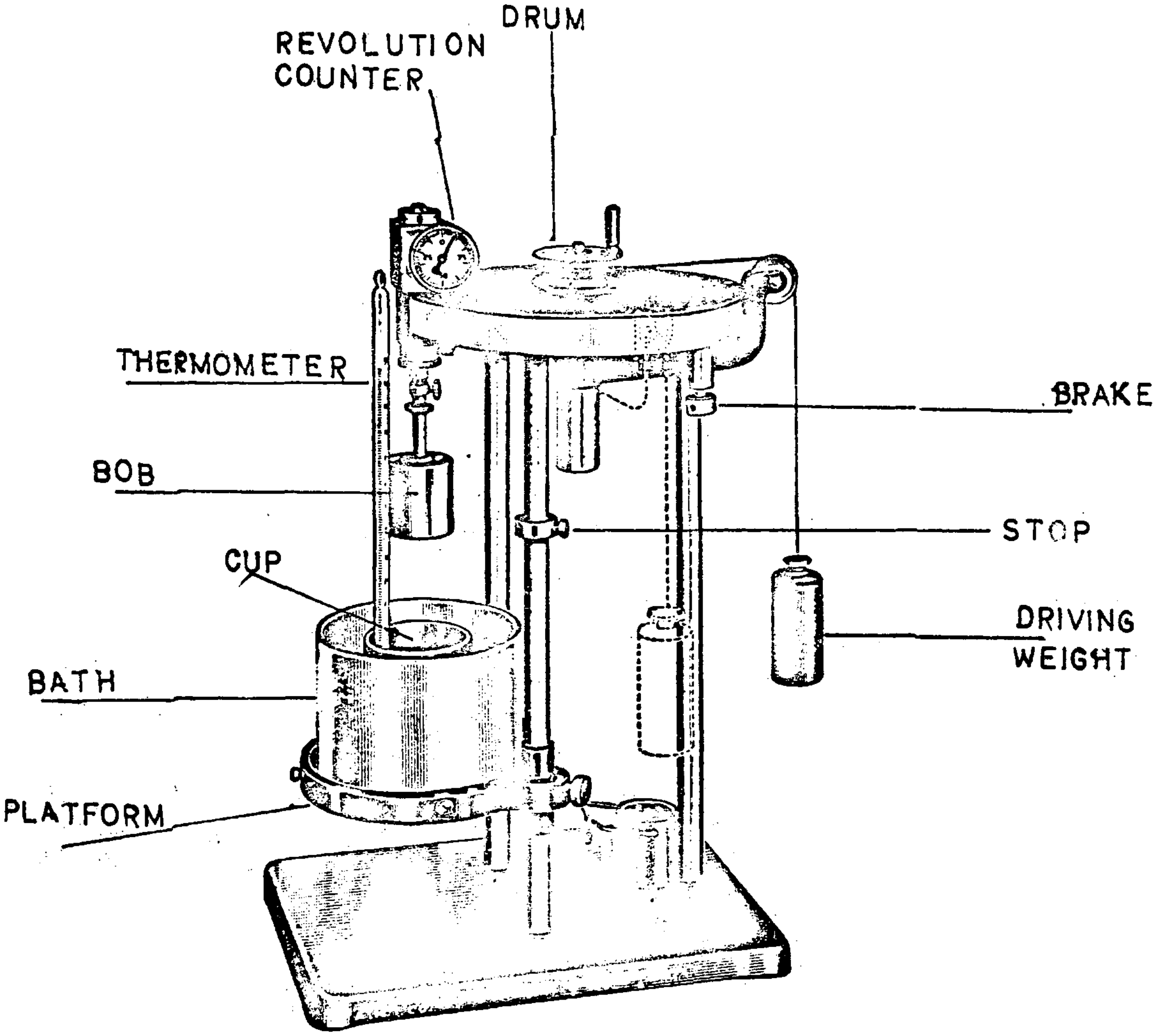

FIGURE 1a. The Stormer Viscometer (11)

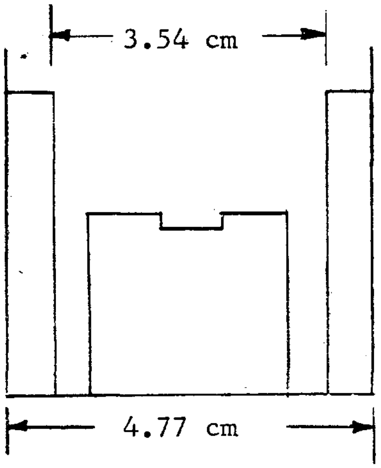

FIGURE 1b. Cross-Section of Cup

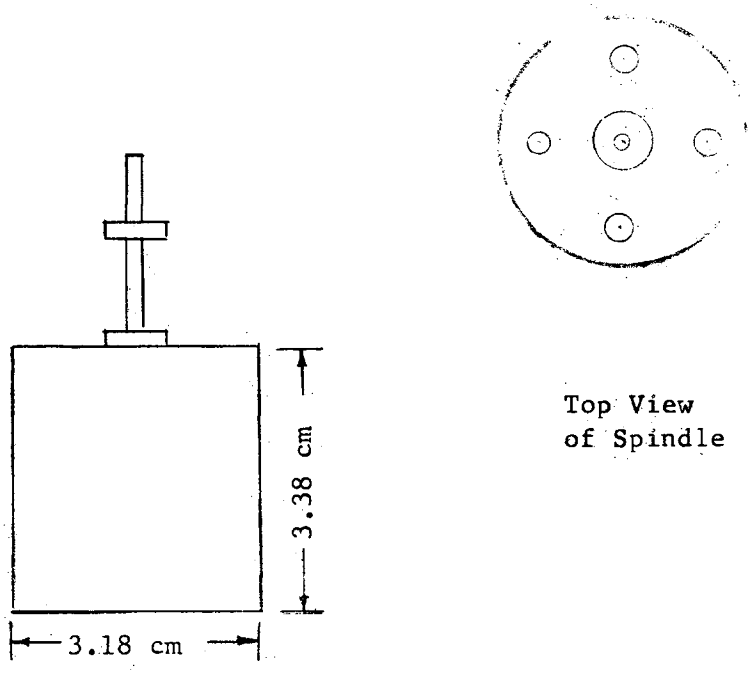

FIGURE 1c. The Modified Stormer Spindle

were averaged.

The Newtonian fluid data have been used to draw the calibration charts. The data are listed in Appendix Ia and the calibration charts are shown in Appendix Ib.

Determination of the End-Effect:

The cup was filled with a fluid of known viscosity. The spindle was immersed to a particular height in the fluid and readings were taken using a few different weights. The experiment was repeated at various depths of immersion including full immersion. The product W*t (W = driving weight, and t = time for 100 revolutions) was plotted against h, the height of immersion. The end-effect was determined graphically as shown in Figure 2. The derivation in Appendix II shows why this procedure gives the end-effect. The end-effect so determined includes both the top and the bottom effect. The prime data are listed in Table 1.

It should be mentioned that the product W*t will be a constant for a given height only if the readings are taken in the laminar region. This can be ensured by using fluids of fairly high viscosity. If the product W*t is not a constant for a given depth of immersion, it is necessary to correct for turbulence. The method for correcting for turbulence is discussed later.

The end-effect of the viscometer was determined to be 1.42 cm, using a fluid of nominal viscosity, 500 cp. Experiments were also performed with a fluid of nominal viscosity 1000 cp. There was a slight scatter in the data. Depending on how the line is drawn, the total end-effect would lie between 1 cm and 1.4 cm. This magnitude of difference is small compared to the total effective length, L_e (about 5%). The value of the viscometer end-effect used in further calculations is 1.42 cm.

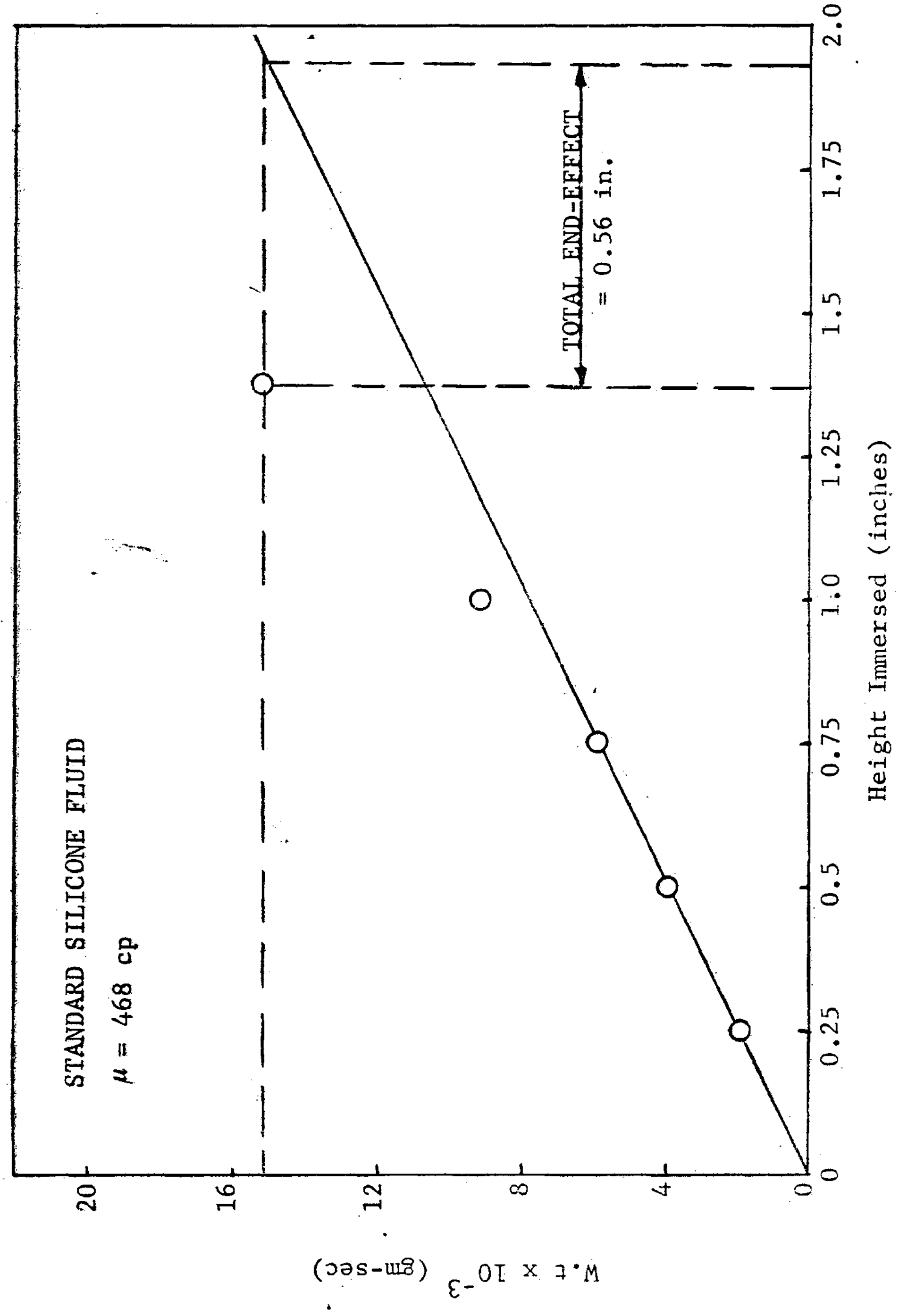

FIGURE 2. Determination of End-Effect

TABLE 1

END-EFFECT DATA

Viscosity: 468 cp

Temperature: 25 ± .5C

Height Immersed (h) inches	Weight (W) gms	Time for 100 Revs (t) sec	Weight x Time (Wxt) gms-sec
0.25 in.	15	119.2	1788
(0.635 cm)	25	73.0	1825
	35	52.8	1848
	45	41.4	1862
0.50	35	108.8	3808
(1.27)	45	84.6	3807
	55	67.8	3728
	65	58.2	3782
0.75	65	91.0	5914
(1.905)	75	78.8	5910
	85	71.4	6068
	95	62.8	5966
1.00	95	96.6	9177
(2.54)	115	79.0	9085
	135	67.2	9072
	145	62.8	9106
1.37	145	105.5	15224
(3.38)	200	75.2	15040
Full Immersion	250	62.0	15500
	300	50.8	15240

Analysis of Newtonian Fluid Data:

The objective of this study was to generate rheograms, or psuedo-rheograms, for slurries which would help in comparing mineral slurry behaviour. Data taken with Newtonian fluids have been used to analyse the behaviour of the instrument. The analysis indicates that certain empirical relations hold for shear stress and shear rate in a Stormer viscometer for Newtonian fluids.

Shear Stress:

The general equation for calculating the shear stress on a cylindrical spindle is given by (1)

$$\tau_b = \frac{T}{(2\pi R_b L_e)R_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

The torque, T, transmitted to the fluid by the spindle can be calculated by using the equation (12)

$$T = \frac{1.425 \times 981}{11} \times W_c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where W_c is the weight required to overcome viscous resistance, 11 is the gear ratio and 1.425 is the radius of the drum in cm. The end-effect can be determined as explained earlier. The W vs. 1/t plots for various Newtonian fluids (Figs. 3a, 3b) show a curvature towards the weight axis, which is thought to be due to turbulence. If so, W must be corrected for this effect before the shear stress can be calculated.

The equation for the dynamic viscosity of a Newtonian fluid in a Stormer viscometer is given by (9, 10)

$$\mu = (W*t)/A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

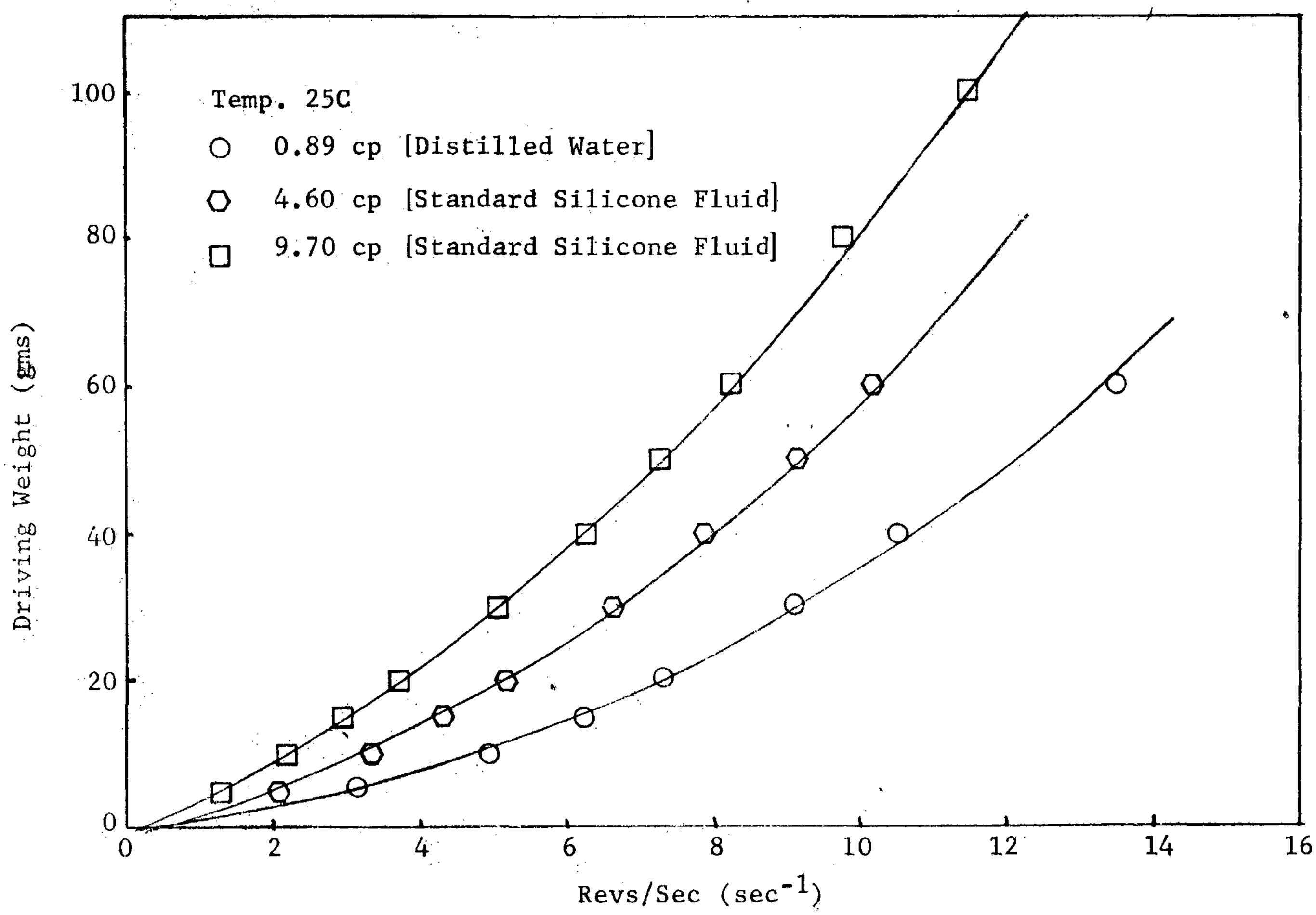

FIGURE 3a. Driving Weight vs. Rotational Speed for the Stormer Viscometer

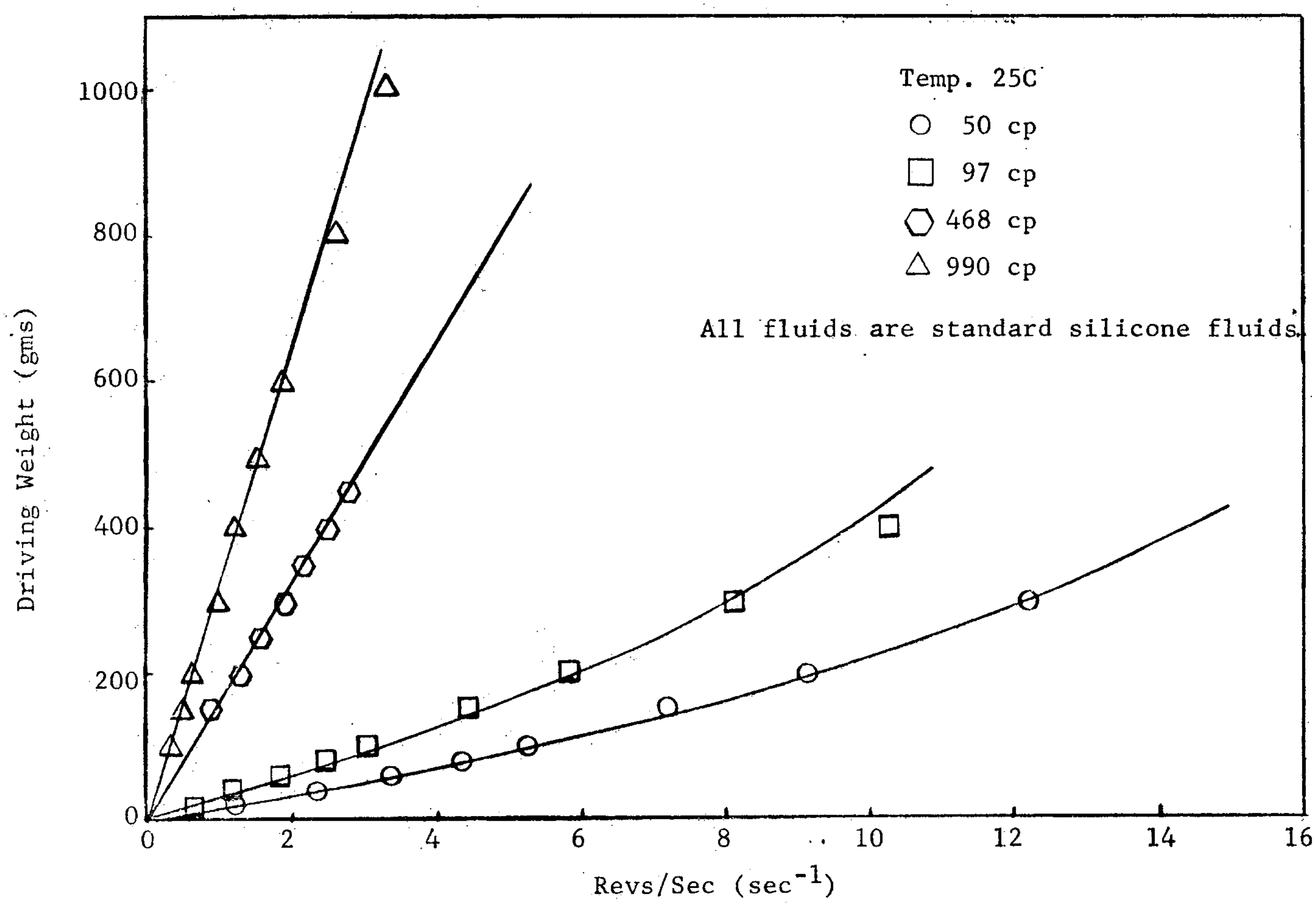

FIGURE 3b. Driving Weight vs. Rotational Speed for the Stormer Viscometer

where W = driving weight used (gms),

t = time taken for 100 revolutions (sec),

and A = the instrument constant (gm-sec/cp).

This equation is valid only if the readings are taken in the laminar region. Geddes and Dawson (9), realizing that the readings may have been taken in the turbulent region, suggested a modified equation to account for the kinetic effects.

$$\mu = t(W - (K'\rho/t^2))/A \qquad (9)$$

where K' = a constant ($cc^{-1}sec^{-2}$)

and ρ = density of fluid (gm/cc).

The correction to the weight term is based on physical reasoning. The authors argue that correction for kinetic energy effects should be proportional to the kinetic energy imparted to the fluid during the shearing. However, the substitution of actual data yields very poor results. The equation indicates that for a given instrument any two readings made with a fluid at a fixed temperature should give the same value of the constant, K'. Calculation of K' values shows that this is not the case. K' values were calculated for the readings taken by Geddes and Dawson. The range of the values for K' was from -81,000 to +146,000 $cc^{-1}sec^{-2}$. It is inappropriate to consider these numbers as a constant. The authors appear to have averaged the values obtained with a fluid of 6.3 poise viscosity. The range of the K' values for this fluid alone were from 12,560 to 41,280 $cc^{-1}sec^{-2}$.

The K' values for data taken in the CSM Rheology Laboratory ranged from -19,500 to 84,000 $cc^{-1}sec^{-2}$. Consequently, although the idea of correcting for turbulence was retained, it was decided to disregard the Geddes-Dawson method.

A look at the W vs. 1/t plots reveals that the curves for fluids of higher viscosities are essentially straight. This suggests that the readings taken with these fluids have been taken in the laminar region. Hence the value of the instrument constant, A, can be calculated using these readings.

$$A = W*t/\mu \tag{10}$$

The value of the instrument constant was calculated to be 31.7 gm-sec/cp using the readings taken with a standardized silicone fluid of nominal viscosity equal to 1000 cp at 25C.

The W vs. 1/t plot for the fluid of nominal viscosity 500 cp is also a straight line, which means that the readings are taken in the laminar region. The instrument constant calculated with these readings was 33.0 gm-sec/cp, which is slightly higher than the previous value. This is probably due to minor fluctuations in temperature during the experiments. The value of A calculated with the 1000 cp nominal viscosity fluid has been used for further calculations.

Working backwards, W_c, the weight required to overcome the viscous resistance can be calculated in all cases.

$$W_c = \mu A/t \tag{11}$$

Since W is the weight used, the percent correction, PC, is given by

$$PC = \frac{(W-W_c)}{W} \times 100 \tag{12}$$

The percent correction has been calculated for all readings.

The Reynolds number of the spindle is given by

$$(N_{Re})_{sp} = D^2 n \rho/\mu \tag{13}$$

Figure 4,($(N_{Re})_{sp}$) vs. PC, shows that some relationship exists. For values of $(N_{Re})_{sp}$ less than 10, the percent correction does not exceed 7%. Although, this is estimated to be slightly larger than the range of experimental error, it has been decided to exclude these data points while correlating $(N_{Re})_{sp}$ and PC, because they appear to be random. The equation for percent correction in terms of $(N_{Re})_{sp}$ greater than 10 was determined by regression. The curve-fitting was done on a digital computer.

The relationship is given by

$$PC = 68.8 - 49.92\,(\ln(N_{Re})) + 11.17\,(\ln(N_{Re}))^2 - .60(\ln(N_{Re}))^3 \ldots\ldots(14)$$

The coefficient of correlation for the fit was 0.99.

Since W_c, the driving weight required to overcome the viscous resistance, is known for all the readings and also the effective length, L_e, for the instrument, it is possible to calculate the shear stress at the spindle surface for each reading, using equations (6) and (7). The values of shear stress have been determined and listed in Table 2.

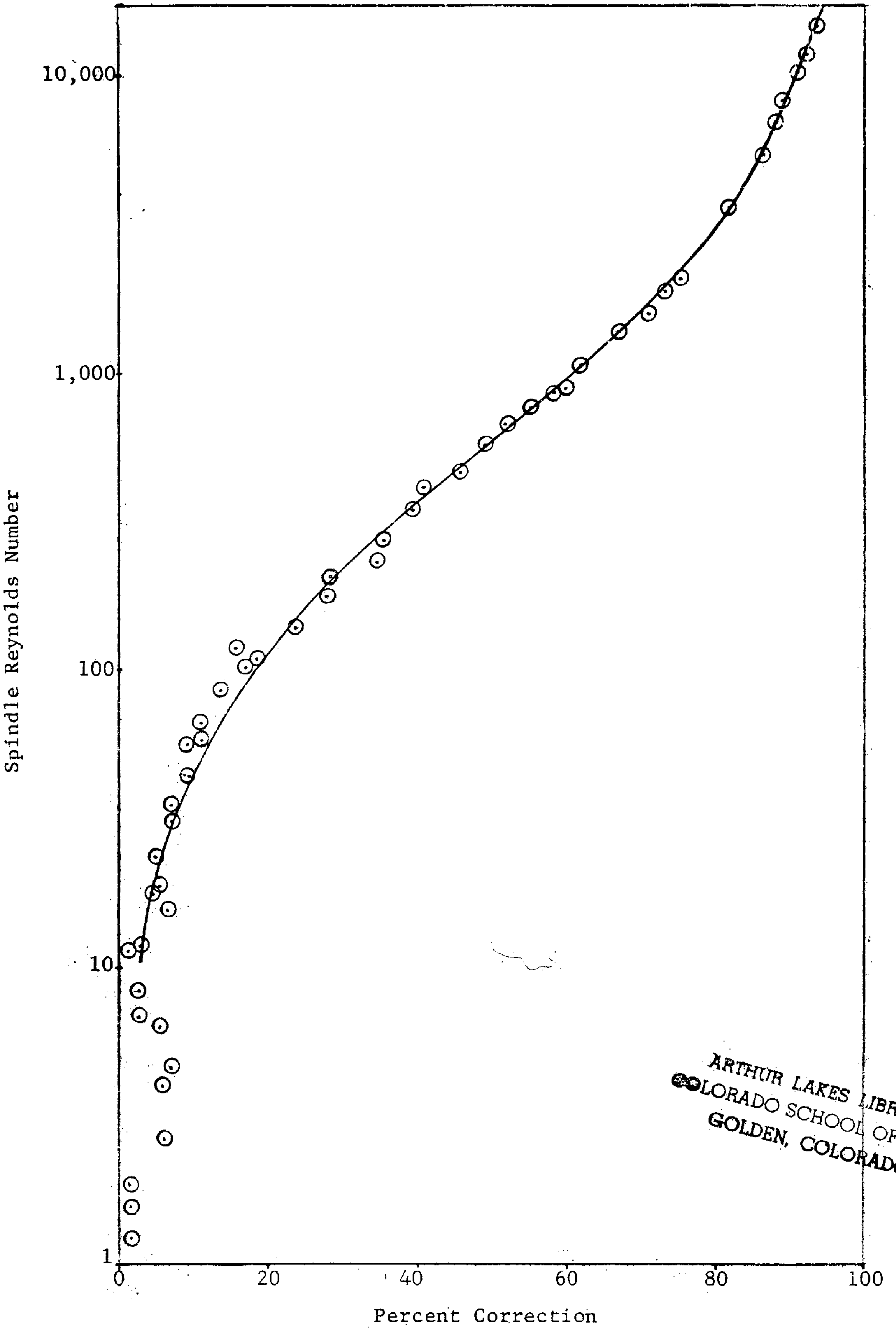

FIGURE 4. Spindle Reynolds Number vs. Percent Correction for Turbulence

TABLE 2

SHEAR STRESS FOR NEWTONIAN FLUIDS

Viscosity Standards cp	Weight (W) gms	Corrected Weight (W_c) gms	Shear Stress (τ) dynes/cm^2
0.89	5	0.90	0.86
	10	1.38	1.32
	15	1.76	1.68
	20	2.07	1.98
	30	2.58	2.47
	40	2.98	2.85
	60	3.73	3.57
4.6	5	2.97	2.84
	10	4.84	4.63
	15	6.26	5.99
	20	7.56	7.24
	30	9.66	9.25
	40	11.48	10.99
	50	13.38	12.81
	60	14.88	14.25
10.3	5	4.22	4.04
	10	7.18	6.87
	15	9.66	9.25
	20	12.09	11.57
	30	16.41	15.71
	40	20.41	19.54
	50	23.66	22.65
	60	26.98	25.83
	80	32.01	30.65
	100	37.53	35.94
50.0	10	9.72	9.30
	15	14.29	13.68
	20	19.10	18.29
	30	27.90	26.71
	40	36.69	35.13
	50	45.42	43.49
	60	53.37	51.11
	80	68.91	65.99
	100	82.98	79.46
	150	114.03	109.20

TABLE 2 (Cont.)

Viscosity Standards	Weight (W) gms	Corrected Weight (W_c) gms	Shear Stress (τ) dynes/cm^2
97.0	15	14.05	13.45
	20	18.83	18.03
	30	30.72	29.42
	40	37.50	35.91
	50	46.95	44.96
	60	56.42	54.03
	80	75.37	72.18
	100	93.18	89.23
	150	137.27	131.46
468.0	150	140.75	134.79
	200	186.61	178.71
	250	231.44	221.64
	300	277.82	266.06
	350	323.92	310.21
	400	369.04	353.42
	450	414.40	396.86
990.0	100	98.53	94.36
	150	146.79	140.57
	200	200.02	191.55
	300	298.03	285.41
	400	394.26	377.57
	500	493.44	472.55
	600	593.25	568.14
	800	828.05 *	793.00
	1000	1056.67 *	1011.94

* Corrected weights should not exceed original driving weights used. The two data points marked are suspect. It is possible that there was a slight error in noting the time for 100 revolutions. An error of about half a second is sufficient to explain the discrepancy in each case.

Shear Rate:

The geometry of the viscometer precludes direct calculation of the shear rate. However, it is possible to get an idea of the value of the shear rate by dividing the shear stress by the known viscosity. This will be denoted by $(\dot{\gamma})_{app}$ in further discussions.

A value of the shear rate can also be obtained by assuming that the gap between the cup and the spindle is uniform and equal to the difference in radii. This will be denoted by $(\dot{\gamma})_{cup}$. The ratio $(\dot{\gamma})_{app}/(\dot{\gamma})_{cup}$ was determined for all the readings. The mean of the ratios was calculated to be 1.374. At the 95% level of significance, the confidence interval for the mean ranged from 1.322 to 1.426.

Similarly a value of shear rate was obtained assuming the gap to be uniform and equal to the gap between the spindle and the baffle. This value is denoted by $(\dot{\gamma})_{baf}$. The ratio $(\dot{\gamma})_{app}/(\dot{\gamma})_{baf}$ was determined for all the readings and the mean of the ratios was calculated to be .463. The confidence interval for the mean at the 95% significance level was between .462 and .464.

The values of $(\dot{\gamma})_{app}$, $(\dot{\gamma})_{cup}$ and $(\dot{\gamma})_{baf}$ determined for individual readings have been listed in Table 3. The ratios $(\dot{\gamma})_{app}/(\dot{\gamma})_{baf}$ and $(\dot{\gamma})_{app}/(\dot{\gamma})_{cup}$ have also been reported in the same table.

Evidently, for a Newtonian fluid of known viscosity $(\dot{\gamma})_{baf}$ or $(\dot{\gamma})_{cup}$ can be calculated and multiplied by the appropriate constant to get the value of the shear rate. However, the same procedure cannot be followed for calculating the shear rates for slurries.

TABLE 3

SHEAR RATE FOR NEWTONIAN FLUIDS

Viscosity cp	Time for 100 revs sec	$(\dot{\gamma})_{app}$ sec^{-1}	$(\dot{\gamma})_{baf}$ sec^{-1}	$\frac{(\dot{\gamma})_{app}}{(\dot{\gamma})_{baf}}$	$(\dot{\gamma})_{cup}$ sec^{-1}	$\frac{(\dot{\gamma})_{app}}{(\dot{\gamma})_{cup}}$
0.89	31.4	96.8	209.1	0.463	71.7	1.350
	20.5	148.4	320.3	0.463	109.8	1.352
	16.1	189.3	407.9	0.464	139.8	1.354
	13.7	222.7	479.4	0.465	164.3	1.355
	11.0	277.6	597.0	0.465	204.7	1.356
	9.5	320.6	691.3	0.464	237.0	1.353
	7.6	401.3	864.1	0.464	296.3	1.355
4.6	49.1	61.8	133.7	0.462	45.8	1.348
	30.1	100.7	218.2	0.462	74.8	1.347
	23.3	130.3	281.8	0.462	96.6	1.348
	19.3	157.3	340.3	0.463	116.6	1.349
	15.1	201.1	434.9	0.462	149.1	1.349
	12.7	239.0	517.1	0.462	177.3	1.348
	10.9	278.5	602.5	0.462	206.6	1.348
	9.8	309.7	670.1	0.462	229.7	1.348
10.3	77.4	39.2	84.8	0.462	29.0	1.349
	45.5	66.7	144.3	0.462	49.4	1.349
	33.8	89.8	194.3	0.462	66.6	1.348
	27.0	112.4	243.2	0.462	83.4	1.348
	19.9	152.5	330.0	0.462	113.1	1.348
	16.0	189.7	410.4	0.462	140.7	1.348
	13.8	219.9	475.9	0.462	163.1	1.348
	12.1	250.8	542.8	0.462	186.1	1.348
	10.2	297.6	643.9	0.462	220.7	1.348
	8.7	348.9	754.9	0.462	258.8	1.348
50.0	163.3	18.6	40.2	0.463	13.7	1.350
	110.9	27.3	59.2	0.462	20.3	1.348
	83.0	36.5	79.1	0.462	27.1	1.348
	56.8	53.4	115.6	0.462	39.6	1.348
	43.2	70.2	152.0	0.462	52.1	1.348
	34.9	86.9	188.1	0.462	64.5	1.348
	29.7	102.2	221.1	0.462	75.8	1.348
	23.0	131.9	285.5	0.462	97.9	1.348
	19.1	158.9	343.8	0.462	117.9	1.348
	13.9	218.4	472.5	0.462	162.0	1.348

TABLE 3 (Cont.)

Viscosity cp	Time for 100 revs sec	$(\dot{\gamma})_{app}$ sec^{-1}	$(\dot{\gamma})_{baf}$ sec^{-1}	$\frac{(\dot{\gamma})_{app}}{(\dot{\gamma})_{baf}}$	$(\dot{\gamma})_{cup}$ sec^{-1}	$\frac{(\dot{\gamma})_{app}}{(\dot{\gamma})_{cup}}$
97.0	218.5	13.8	30.0	0.461	10.3	1.346
	163.3	18.5	40.2	0.462	13.7	1.348
	109.9	30.3	59.7	0.508	20.4	1.480
	82.0	37.0	80.0	0.462	27.4	1.348
	65.5	46.3	100.2	0.462	34.3	1.348
	54.5	55.7	120.5	0.462	41.3	1.348
	40.8	74.4	160.9	0.462	55.1	1.348
	33.0	91.9	199.0	0.462	68.2	1.348
	22.4	135.5	293.2	0.462	100.5	1.348
468.0	106.5	28.8	61.6	0.467	21.1	1.362
	79.5	38.1	82.6	0.462	28.3	1.348
	64.1	47.3	102.4	0.462	35.1	1.348
	53.4	56.8	122.9	0.462	42.1	1.348
	45.9	66.2	143.0	0.463	49.0	1.351
	40.2	75.5	163.3	0.462	56.0	1.348
	35.7	84.7	183.9	0.461	63.0	1.344
990.0	318.5	9.5	20.0	0.462	7.0	1.348
	213.8	14.2	30.7	0.462	10.5	1.348
	156.9	19.3	41.8	0.462	14.3	1.348
	105.3	28.8	62.3	0.462	21.3	1.348
	79.6	38.1	82.5	0.462	28.2	1.348
	63.6	47.7	103.2	0.462	35.4	1.348
	52.9	57.3	124.1	0.462	42.5	1.348
	37.9	80.1	173.2	0.462	59.4	1.348
	29.7	102.2	221.1	0.462	75.8	1.348

Slurry Data:

The experiments on slurries were conducted in the same way, except that periodic checks were made to see if any settling had occurred. Also the slurry concentration was determined at the beginning and at the end of the experiments to monitor evaporation of the liquid phase. Invariably some solids tend to adhere to the walls causing some thinning of the fluid. The concentration determination also ensured that the fluid had not thinned out too much during the course of the experiments or that excessive settling of solids had not occurred.

Analysis of Slurries:

As in the case of Newtonian fluids, a correction must be applied to the driving weight, W, to account for turbulence. Only then can the shear stress be calculated. The percent correction vs. the spindle Reynolds number plot developed using Newtonian fluids of standard viscosity can be used only if the spindle Reynolds number is available. Since the slurry viscosity at the shear rate of the reading is not known, it is not possible to calculate the spindle Reynolds number.

It should be noted that the calibration plots (time for 100 revolutions vs. viscosity, for different uncorrected weights) given in Appendix Ib cannot be used to give the viscosity.

If the viscosities of two liquids are equal, (for a given shear stress) then the shear rates will be equal, and not the values for revolutions per second, unless both liquids are Newtonian. In the case under consideration, the calibration plots are drawn using data taken with Newtonian fluids, and second fluid, the slurry is non-Newtonian. Hence it would be incorrect to use the calibration charts directly, except to get approximate values of viscosities.

Since, there is no way to determine the viscosity of the slurry at the shear rate of the reading, it has been decided to use the value read off the calibration plots to correct for turbulence. Obviously, this correction will only be approximate. A more rigorous approach has been discussed under suggestions for further work. It involves a tedious trial and error procedure.

Attempts to devise a method to calculate the shear rate have not been very successful. It is possible to calculate the quantities $(\dot{\gamma})_{cup}$ and $(\dot{\gamma})_{baf}$ using the Krieger equation(6). However, no method is available to convert them into shear rates. The multiplication factors developed for Newtonian fluids cannot be used for slurries.

Hence only psuedo-rheograms (W_c vs. 1/t plots) have been generated for slurries. It is possible to predict pipeline pressure losses for limestone-in-water slurries using the method of Smith(11). It is also possible to compare the behaviour of slurries quantitatively. Such comparisons reveal the effect of particle size, temperature and concentration. The discussion of results contains information inferred from the psuedo-rheograms.

Table 4 is a sample of the slurry data. Figures 5a, 5b, 5c, and 5d are representative psuedo-rheograms for slurries. The complete mineral slurry data bank is listed in Appendix III.

TABLE 4

SLURRY DATA[**]

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 16.0% Vol Conc: 12.36%

Temperature: 10.4C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity * (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	42.2	3.2	2.28	2.37
10	26.8	3.4	3.82	3.73
15	20.3	3.0	4.68	4.93
20	17.0	3.1	5.76	5.88
30	13.2	2.9	7.20	7.58
40	11.1	2.8	8.48	9.01

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.00 Solids SG: 1.35

Wt Conc: 24.5% Vol Conc: 19.37%

Temperature: 10.6C

5	74.6	9.5	3.81	1.34
10	38.4	7.6	5.99	2.60
15	27.5	6.9	7.74	3.64
20	22.0	6.6	9.29	4.55
30	16.8	6.6	12.41	5.95
40	13.9	6.4	14.93	7.19
50	11.9	6.6	17.56	8.40
60	10.6	6.7	20.02	9.43

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* Viscosity values read from Newtonian calibration charts in Appendix Ib.

[**] Slurry data obtained from CSM Rheology Lab.

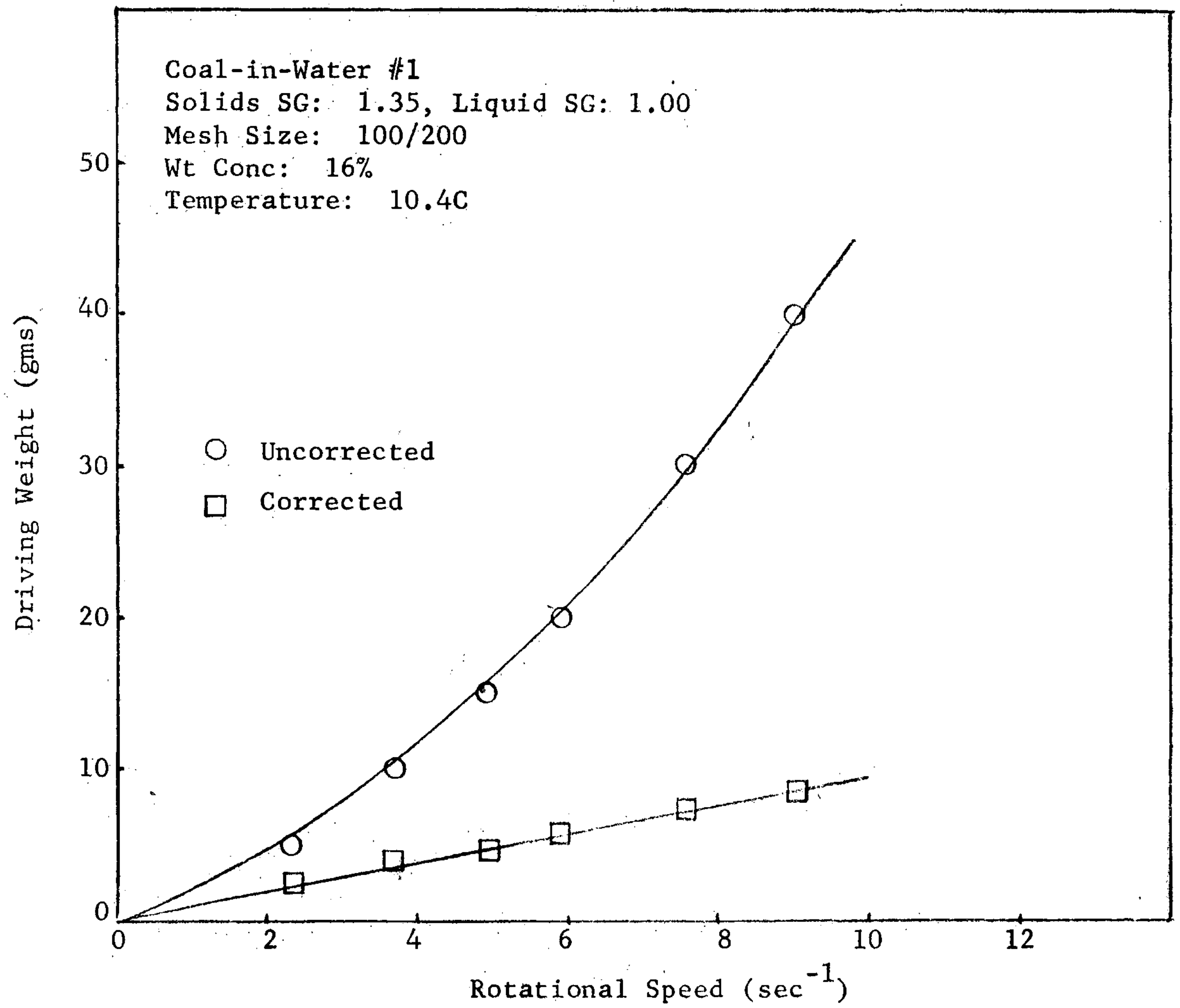

FIGURE 5a. Psuedo-Rheograms for Slurries

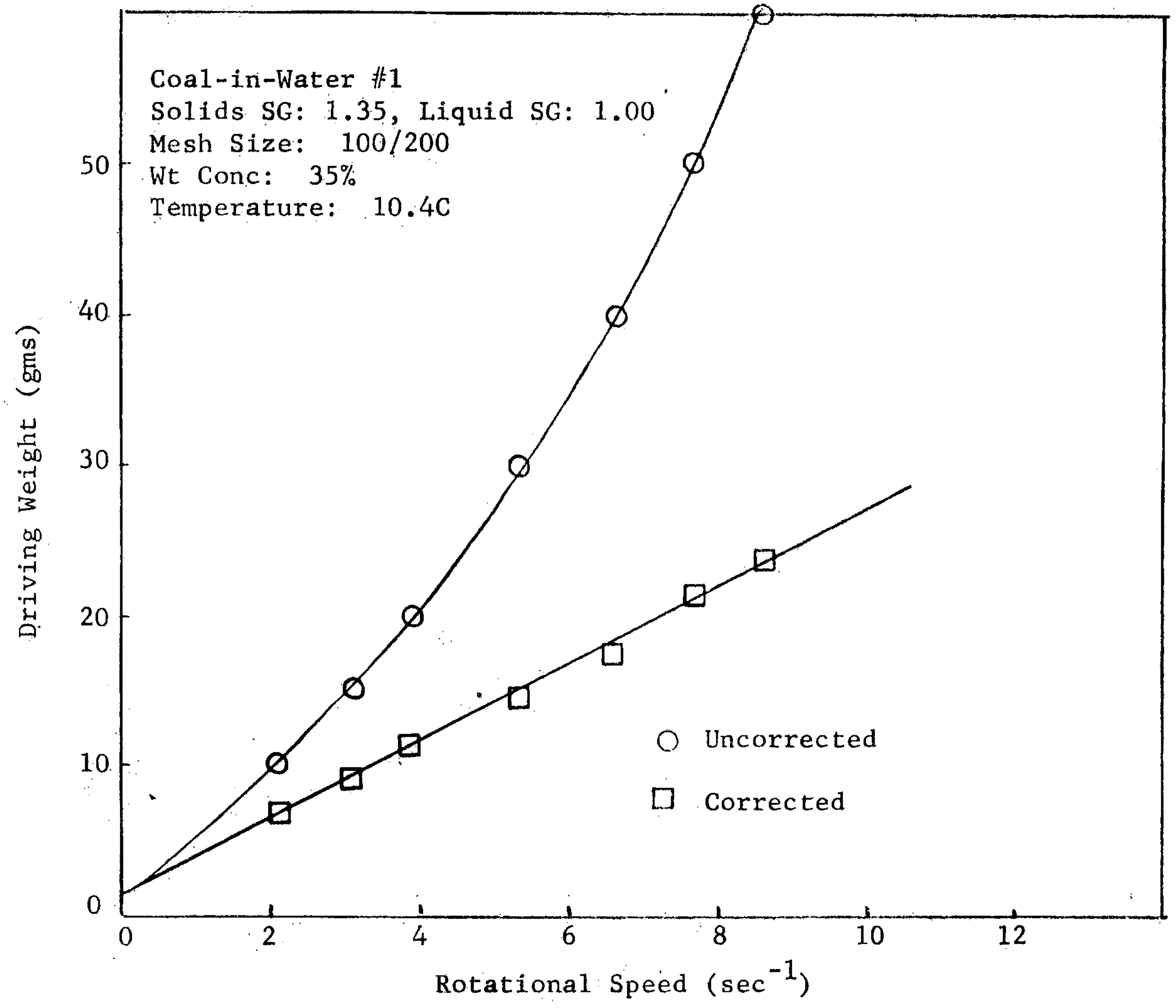

FIGURE 5b. Psuedo-Rheograms for Slurries

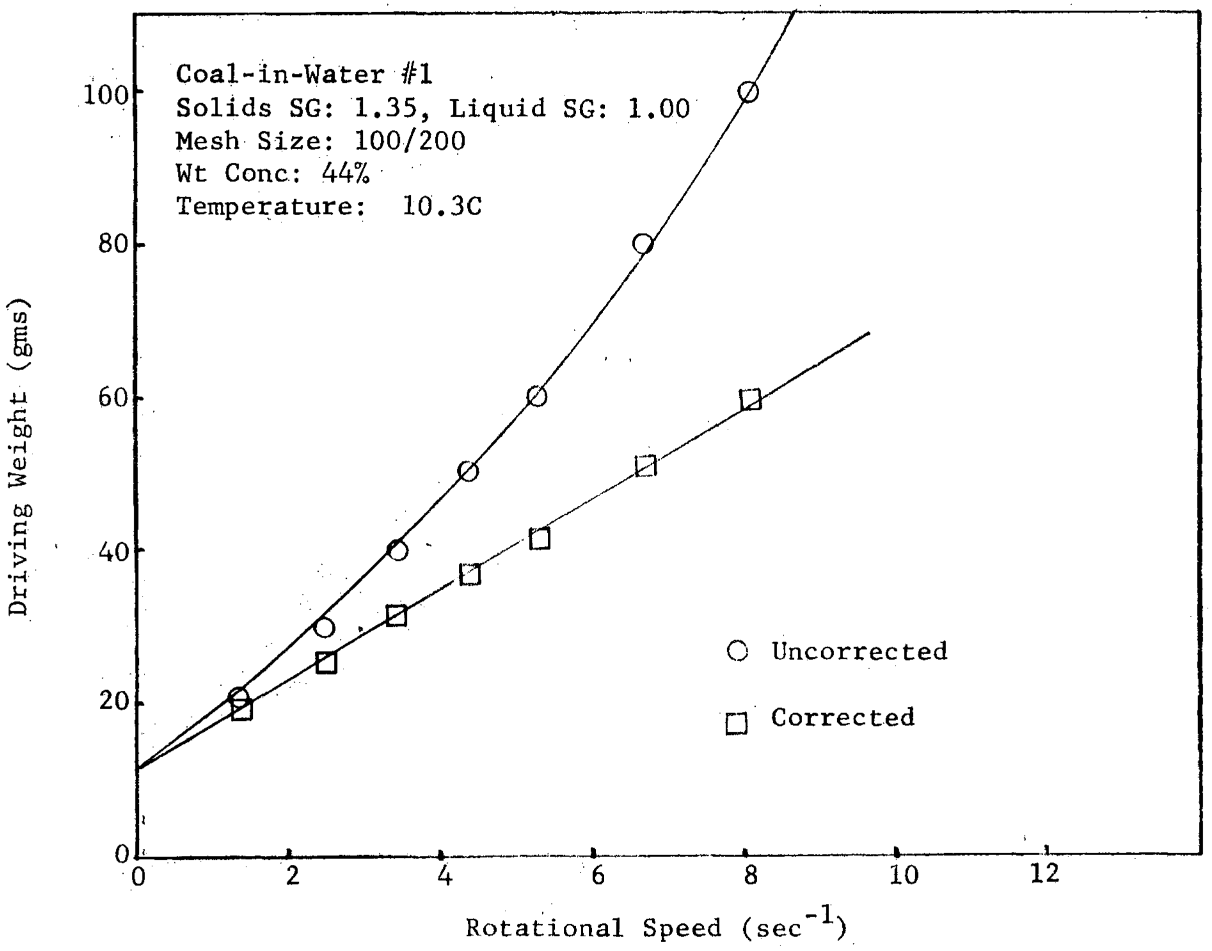

FIGURE 5c. Psuedo-Rheograms for Slurries

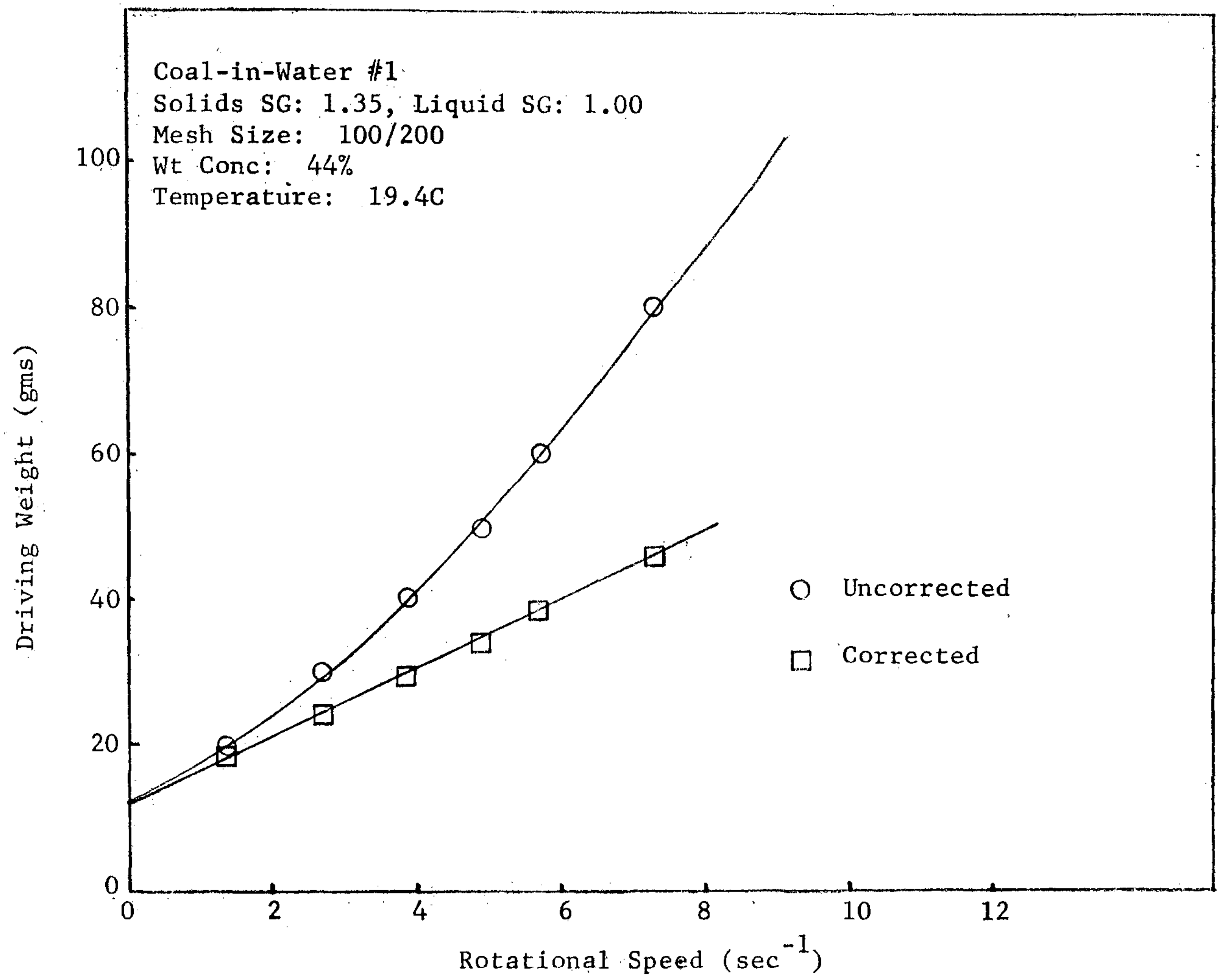

FIGURE 5d. Psuedo-Rheograms for Slurries

RESULTS

Newtonian Fluids:

i) The equation relating the percent correction to be applied to the driving weight to account for turbulence and the spindle Reynolds number is given by

$$PC = 68.8 - 49.92\,(\ln(N_{Re})) + 11.17\,(\ln(N_{Re}))^2 - .60\,(\ln(N_{Re}))^3$$

for $10 < (N_{Re})_{sp} < 20{,}000$.

ii) The total end-effect of the spindle is 1.42 cm.

iii) The ratios $(\dot{\gamma})_{app}/(\dot{\gamma})_{cup}$ and $(\dot{\gamma})_{app}/(\dot{\gamma})_{baf}$ are constants at $1.374 \pm .052$ and $.463 \pm .001$ respectively, for Newtonian fluids.

Slurries:

i) As the rotational speed of the viscometer is increased, the approximate viscosity of the slurry (read from the calibration charts in Appendix Ib) attains a steady value, μ_f. (Table 4)

ii) All other factors being constant, an increase in concentration will increase the value of μ_f. (Table 5)

iii) All other factors being constant, an increase in temperature causes the value of μ_f to decrease. (Table 5)

iv) The yield value increases with an increase in concentration, for a given slurry. The rate of change of yield value with concentration begins to increase rapidly at some particular volumetric concentration. (Table 6)

v) There is no appreciable change in yield value with changes in temperature for a given slurry. (Table 6)

vi) The physical properties of the solids, like particle density and particle size, affect the rheological behaviour of the slurries. The effect of the individual factors is not evident from the available data.

Table 7 is a complete compilation of results.

TABLE 5

Effect of Concentration and Temperature on μ_f

Slurry: Coal-in-water #1

Mesh Size: 100/200

Vol Conc	Temp (C)			
	10.6	19.4	29.9	39.3
12.36	2.8	2.2	1.6	1.2
19.37	6.7	6.0	3.9	4.0
28.5	9.0	7.6	6.1	5.2
36.9	24.5	20.0	15.0	13.0
46.5	64.0	56.0	80.0*	44.0

* It is suspected that the approximate viscosity of the slurry had not attained the steady value.

TABLE 6

Effect of Concentration and Temperature on Yield Value

Slurry: Coal-in-water #1

Mesh Size: 100/200

Vol Conc	Temp (C)			
	10.6	19.4	29.9	39.3
12.36	0	0	0	0
19.37	1.0	2.0	0	0
28.5	1.0	1.0	0	1.0
36.9	12.0	12.0	11.0	12.0
46.5	55.0	60.0	60.0	70.0

TABLE 7

<u>Results</u>

Slurry	ρ_s/ρ_1	Mesh Size	Wt Conc	Vol Conc	Temp (C)	Yield (gms)	μ_f (cp)
Coal-in-water #1	1.35	100/200	16.0	12.3	10.6	0	2.8
			24.5	19.3	10.6	1.0	6.7
			35.0	28.5	10.5	1.0	9.0
			44.1	36.8	10.3	12.0	24.5
			54.0	46.5	10.8	55.0	64.0
			16.0	12.3	19.2	0	2.2
			24.5	19.3	19.4	2.0	6.0
			35.0	28.5	19.5	1.0	7.6
			44.1	36.8	19.4	12.0	20.0
			54.0	46.5	19.3	60.0	56.0
			16.0	12.3	29.3	0	1.6
			24.5	19.3	29.8	0	3.9
			35.0	28.5	29.8	0	6.1
			44.1	36.8	29.7	11.0	15.0
			54.0	46.5	30.0	60.0	80.0
			16.0	12.3	38.7	0	1.2
			24.5	19.3	39.0	0	4.0
			35.0	28.5	39.3	1.0	5.2
			44.1	36.8	39.7	12.0	13.0
			54.0	46.5	39.6	70.0	44.0
	1.35	200/0	14.6	11.2	12.0	0	2.7
			24.7	19.6	10.0	3.0	5.1
			34.7	28.2	10.4	8.0	10.3

TABLE 7 (Cont.)

Slurry	ρ_s/ρ_1	Mesh Size	Wt Conc	Vol Conc	Temp (C)	Yield (gms)	μ_f (cp)
Coal-in-water #1	1.35	200/0	45.2	37.9	10.6	40.0	41.0
			49.4	41.9	10.3	70.0	100.0
			14.6	11.2	19.4	0	2.3
			24.7	19.6	19.7	2.0	3.9
			34.7	28.2	19.7	10.0	8.0
			45.2	37.9	19.7	45.0	32.0
			49.4	41.9	19.9	70.0	82.0
			14.6	11.2	30.0	0	1.2
			24.7	19.6	30.0	3.0	2.2
			34.7	28.2	29.7	10.0	7.0
			45.2	37.9	29.9	45.0	31.0
			49.4	41.9	29.7	70.0	70.0
			14.6	11.2	39.5	0	1.2
			24.7	19.6	39.8	2.0	3.1
			34.7	28.2	39.8	10.0	6.0
			45.2	37.9	40.1	50.0	23.0
			49.4	41.9	40.1	65.0	42.0
Coal-in-water #2	1.51	-65	33.5	24.9	24.1	1.0	5.0
			39.5	30.1	23.7	0	9.5
			45.3	35.4	24.7	0	21.0
			50.2	40.0	24.8	13.0	40.0
			54.2	44.2	24.7	50.0	75.0
Coal-in-water #3	1.38	-100	46.8	38.7	25.0	45.0	23.0
Coal-in-water #4	1.45	-65	37.3	29.3	25.0	28.0	65.0
			40.5	31.9	19.4	30.0	125.0

TABLE 7 (Cont.)

Slurry	ρ_s/ρ_1	Mesh Size	Wt Conc	Vol Conc	Temp (C)	Yield (gms)	μ_f (cp)
Coal-in-crude oil	1.91	100/200	35.0	22.0	27.2	0	20.0
			46.5	31.2	26.8	60.0	51.0
			48.0	32.6	26.7	60.0	212.0
			35.0	22.0	15.7	0	36.0
			45.8	30.6	15.8	20.0	135.0
			48.0	32.6	15.8	40.0	112.0
			35.4	23.1	8.4	0	80.0
			46.5	31.3	8.5	70.0	355.0
			48.2	32.8	8.5	100.0	252.0
Coal-in-glycerine	1.09	6/10	10.0	9.3	26.1	0	1.4
			15.0	13.9	26.0	0	2.0
			25.0	23.5	25.6	0	3.0
Cement-in-water	2.49	-100	58.0	35.7	27.2	82.0	80.0
			58.0	35.7	16.3	82.0	42.0
			58.0	35.7	9.9	76.0	55.0
			62.0	39.6	26.7	152.0	56.0
			62.0	39.6	16.4	170.0	70.0
			62.0	39.6	9.9	170.0	70.0
			68.0	46.0	25.9	500.0	360.0
			68.0	46.0	17.0	450.0	280.0
			68.0	46.0	9.9	550.0	340.0
Gypsum fly-ash-in-water #1	2.474		80.1	14.8	21.0	28.0	14.0
#2	2.474		30.0	14.8	21.0	28.0	14.0

TABLE 7 (Cont.)

Slurry	ρ_s/ρ_1	Mesh Size	Wt Conc	Vol Conc	Temp (C)	Yield (gms)	μ_f (cp)
Taconite tailings-in-water	3.03	-	72.3	46.3	21.0	20.0	175.0
Copper ore-in-water	2.69		36.3	17.5	25.4	8.0	8.0
			39.0	19.2	25.4	12.0	10.0
Uranium tailings-in-water	2.576	-65	30.5	14.5	5.5	25.0	13.0
			30.5	14.5	19.8	25.0	9.5
			35.4	17.5	25.1	28.0	15.0
			39.8	20.4	25.0	29.0	18.0
			44.5	23.7	25.0	48.0	24.0
Salt-in-brine	Slurry SG: 1.2	-80	40.0	-	26.8	0	3.0
			40.0	-	35.0	0	2.7
			50.0	-	26.8	0	3.3
			50.0	-	35.0	0	2.6
			60.0	-	26.8	0	3.0
			60.0	-	35.0	0	2.6
			70.0	-	26.8	0	3.1
			70.0	-	35.0	0	2.8
Fluid coke-in-water	1.6	-48	18.2	12.2	26.0	2.0	3.2
			32.9	23.4	27.0	4.0	5.0
			49.2	37.7	27.0	4.0	10.0

DISCUSSION OF RESULTS

The analysis of Newtonian fluid data has yielded two very important results. The first is that a definite relationship exists between the correction to be applied to account for turbulence and the spindle Reynolds number. This relationship is to be expected. Reynolds number is the ratio of inertial forces to viscous forces. The portion of the driving weight required to overcome the inertial forces must bear some relationship to the Reynolds number. However, the form of the equation obtained by regression has no physical basis.

The second important result is that the shear rate calculated by dividing the shear stress by the viscosity ($(\dot{\gamma})_{app}$) is related to the shear rates calculated by assuming uniform gaps ($(\dot{\gamma})_{baf}$ and $(\dot{\gamma})_{cup}$). This relationship is purely empirical. It was anticipated that the value of $(\dot{\gamma})_{app}$ would lie between the values of $(\dot{\gamma})_{baf}$ and $(\dot{\gamma})_{cup}$. It was an intuitive guess and proved to be right. Also, the fact that the ratios, $(\dot{\gamma})_{app}/(\dot{\gamma})_{cup}$ and $(\dot{\gamma})_{app}/(\dot{\gamma})_{baf}$, are constant (Table 3) establishes conclusively that the three quantities are inter-related.

The difficulties involved in analysing slurry data have already been discussed. However, it is possible to apply approximate corrections to account for turbulence effects and then draw the corrected plots. These corrected plots are useful for comparing the behaviour of slurries. The comparisons have to be based on rheological parameters or related quantities. In the present analysis, one rheological parameter, the yield value, is available. It can also be seen that the approximate viscosities of the slurries (read from the Newtonian calibration charts) attain a steady value, μ_f, as the rotational speed of the viscometer increases. This quantity can also be used as a basis for comparison.

The behaviour of the approximate viscosity of the slurry with increasing rotational speed gives some clue to the nature of the slurry. It seems reasonable to assume that the ratio of the shear stress to shear rate will decrease with decreasing μ_s, although the value of the slurry viscosity is approximate. When the value of μ_s is almost constant with increasing rotational speed, as it is for some dilute coal-in-water and salt-in-brine slurries, then the slurries are probably Newtonian, with a viscosity of μ_s. If the value of μ_s starts at a high value and then reduces as the rotational speed increases, the slurry is obviously non-Newtonian. Just on the basis of the trend of μ_s with rotational speed it is not possible to further classify the slurry as psuedoplastic, Bingham plastic or dilatant. However, it can be stated that the slope of the rheogram cannot exceed unity.

The effects of various factors on the yield value and μ_f are of importance to the practical rheologist. The effects of temperature and concentration are most obvious. An increase in temperature, with all other factors held constant, causes μ_f to decrease. (Table 5) The decrease in the value of μ_f is gradual. Changes in temperature do not effect the yield value, if other factors are not changed. The existence of a yield value is evidence of interaction between particles - physical interaction or interaction due to surface effects - that must be broken up before the slurry will begin to flow. The physical interaction depends on volumetric concentration and container geometry. The surface effects or any other type of interaction, if any are present, are unaffected by temperature. This would explain the independence of temperature and the yield value.

The effect of concentration on μ_f and the yield value is interesting. An increase in concentration, with all other factors held constant generally causes μ_f to increase. The increase is gradual for finer slurries (coal-in-water #1, 200/0 mesh) but is fairly abrupt at a particular concentration by volume for coarser slurries (coal-in-water #2, -65 mesh). The change in yield value with concentration follows a similar pattern. The volumetric concentration at which the abrupt change in properties occurs is slightly different for differnt slurries (~40% for the coal-in-water slurry #2, -65 mesh and ~36% for coal-in-water slurry #1, 100/200 mesh). This may be due to the difference in particle sizes or due to the differences in densities (coal-in-water #2, 1.51, coal-in-water #1, 1.36), or due to differences in chemical compositions.

It is very difficult to compare the other aqueous slurries because the data were taken at different concentrations. It was believed that the yield value would increase with an increase in the ratio of solids density to liquid density. This is not true. Taconite tailings ($\rho_s/\rho_1 = 3.03$) has a yield value less than that of uranium tailings ($\rho_s/\rho_1 = 2.58$), although it has a very much higher volumetric concentration (46% for taconite, 20% for uranium tailings).

The fact that the taconite tailings were very much finer may be respondible. It can also be seen that cement-in-water slurries exhibit very high values of μ_f. This is believed to be due to the high clay content of the slurries.

Most of the statements concerning the effects of temperature and concentration have been based on the data on the coal-in-water slurries. The data available on the other slurries are not extensive. However, the available data do not generally contradict the conclusions.

CONCLUSIONS

The present work has revealed certain useful facts about the Stormer viscometer and also about the slurries studied. The major point established about the instrument is that although the Stormer viscometer cannot be analysed rigorously, it is possible to develop empirical relations to help in the interpretation of rheological quantities. An equation has been developed to account for turbulence in the instrument. The equation relates the percent correction to be applied to correct for turbulence and the spindle Reynolds number. It has been proven that, for Newtonian fluids, the shear rate of the instrument at a given rotational speed is proportional to the shear rate value calculated by assuming uniform gaps.

The slurry data were analysed by applying approximate corrections for turbulence and then plotting psuedo-rheograms of W_c vs. $1/t$. An analysis of the psuedo-rheograms has established the effects of temperature and concentration (volumetric or weight) on the rheological behaviour of slurries.

An increase in temperature causes μ_f (the apparent constant value of viscosity attained by a slurry as the rotational speed increases) to decrease. Temperature has no appreciable effect on the yield value. Concentration affects both the value of μ_f and the yield value. An increase in concentration increases both quantities. The rate at which μ_f or the yield value changes with concentration depends on the particle size.

The fact that taconite at a volumetric concentration of 46% has a lower yield value than uranium tailings at 20% volumetric concentration may be due to the difference in particle size. The behaviour of cement-in-water slurries, which exhibits very high viscosities, is probably due to high clay content.

RECOMMENDATIONS FOR FURTHER WORK

The results of the present work are encouraging enough to warrant further research. A possible method to overcome the difficulties encountered in the analysis of slurries is described here.

It may be recalled that the first weakness in the analysis was the lack of knowledge of the viscosity of the slurry at the shear rate of the reading. The calibration charts were used to get an approximate value to aid in the calculation of the spindle Reynolds number. If a method were available to determine the correct viscosity of the slurry at the shear rate of the reading, it would be possible to apply the proper correction to the driving weight. Also, the actual shear rate can be determined by dividing the shear stress by the correct viscosity.

A possible trial and error method exists to determine the correct viscosity of the slurry at the shear rate of the reading. It involves the use of modified calibration charts, which can be generated using Newtonian fluid data. The modified calibration plots would have viscosity plotted against $(\dot{\gamma})_{cup}$ for different driving weights. A second set of plots would have viscosity against $(\dot{\gamma})_{baf}$ for different driving weights.

The procedure would involve using the original calibration charts (Appendix Ia) to get an initial viscosity. These could be used to calculate values of $(\dot{\gamma})_{cup}$ and $(\dot{\gamma})_{baf}$ as was done in the present work. The values of $(\dot{\gamma})_{cup}$ $(\dot{\gamma})_{baf}$ could be used to give new values of viscosities from the modified calibration charts. It should be noted that there will be two values of viscosity for each reading, at this stage.

The trial and error procedure could be carried out as shown in the flow-chart overleaf. The viscosities calculated for each reading by the two alternate routes are expected to converge to the same value. This value will represent the viscosity of the slurry, and may be used to determine the necessary rheological quantities.

The additional experimental work required for the analysis described above would extend the modified calibration charts into the necessary regions of $(\dot{\gamma})_{cup}$ and $(\dot{\gamma})_{baf}$. It would help further if standard liquids with viscosities between 100 and 500 cp, and 500 and 1000 cp were used. This would enable the development of better calibration plots (both the original and the modified) instead of the straight line approximations being used at present over large regions.

The method described is undoubtedly tedious. However, it is hoped that some obvious correlation between the correct shear rate and $(\dot{\gamma})_{cup}$ and $(\dot{\gamma})_{baf}$ would surface. If it did, a simple method would be available to generate rheograms for slurries. If it did not, the trial-and-error procedure would have to be used.

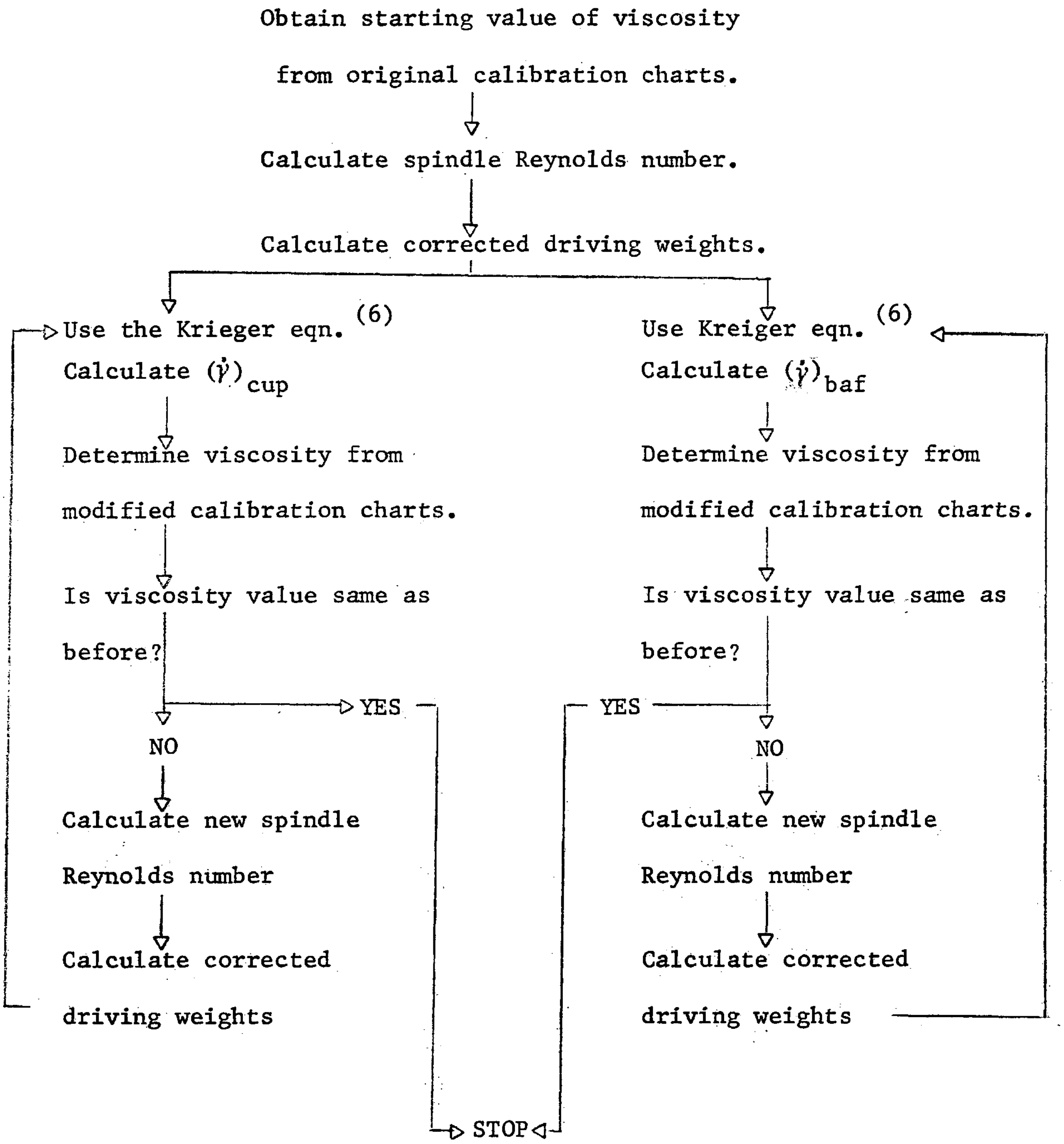

FIGURE 6. Flow-Chart for Trial-and-Error Method

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APPENDIX Ia

Newtonian Fluid Data *

The fluid of viscosity 0.89 cp is distilled water. All the other fluids are standardised silicone fluids supplied by the Brookfield Company.

Temperature: 25 ± .5C

Viscosity cp	Weight (W) gms	Time for 100 revs (t) sec	Revolutions/sec (n) sec^{-1}
.89	5	31.4	3.13
	10	20.5	4.88
	15	16.1	6.21
	20	13.7	7.30
	30	11.0	9.09
	40	9.5	10.53
	60	7.6	13.50
4.60	5	49.1	2.04
	10	30.1	3.32
	15	23.3	4.29
	20	19.3	5.18
	30	15.1	6.62
	40	12.7	7.88
	50	10.9	9.17
	60	9.8	10.20
10.30	5	77.4	1.29
	10	45.5	2.20
	15	33.8	2.96
	20	27.0	3.70
	30	19.9	5.02
	40	16.0	6.25
	50	13.8	7.25
	60	12.1	8.26
	80	10.2	9.80
	100	8.7	11.50

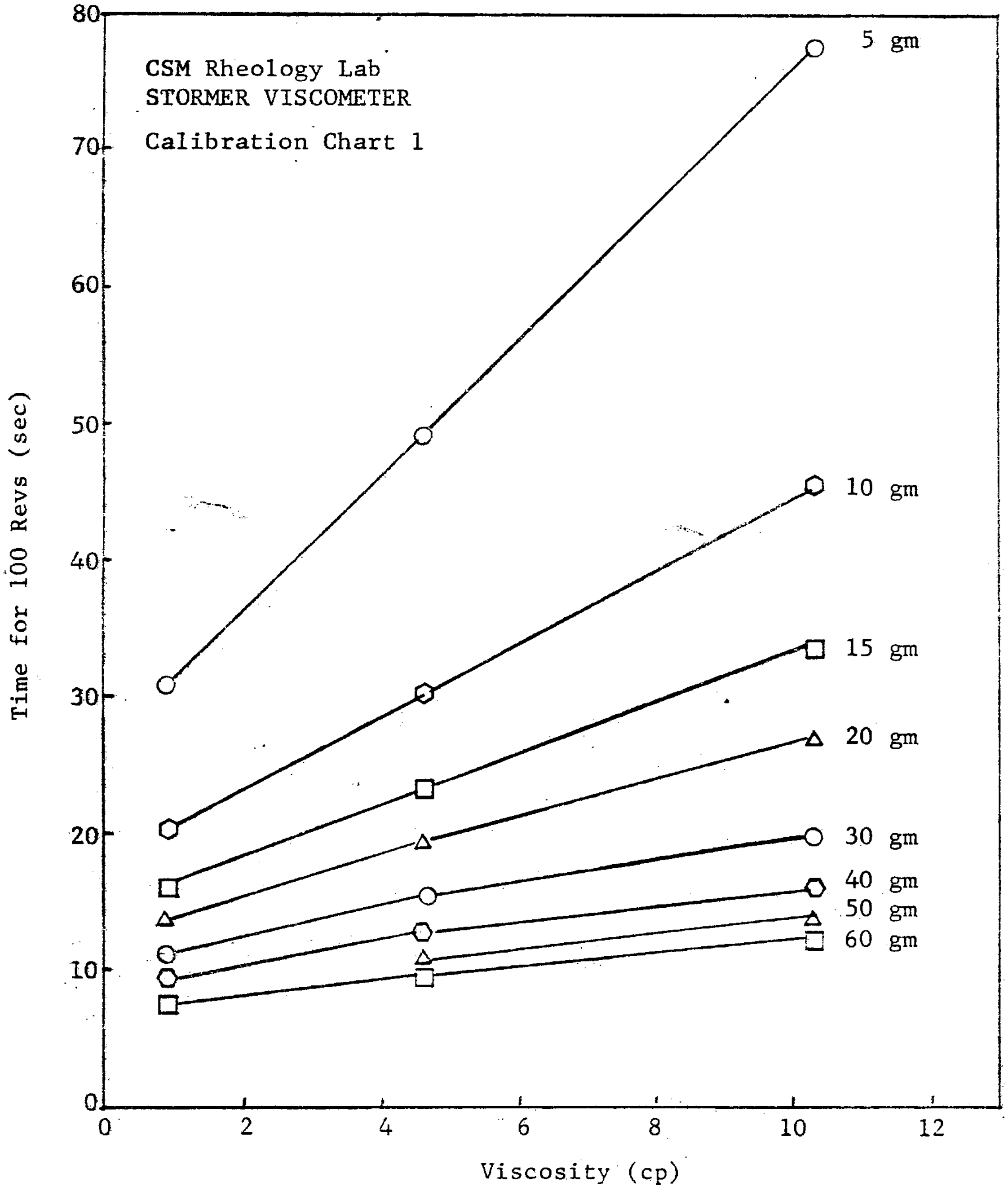
---

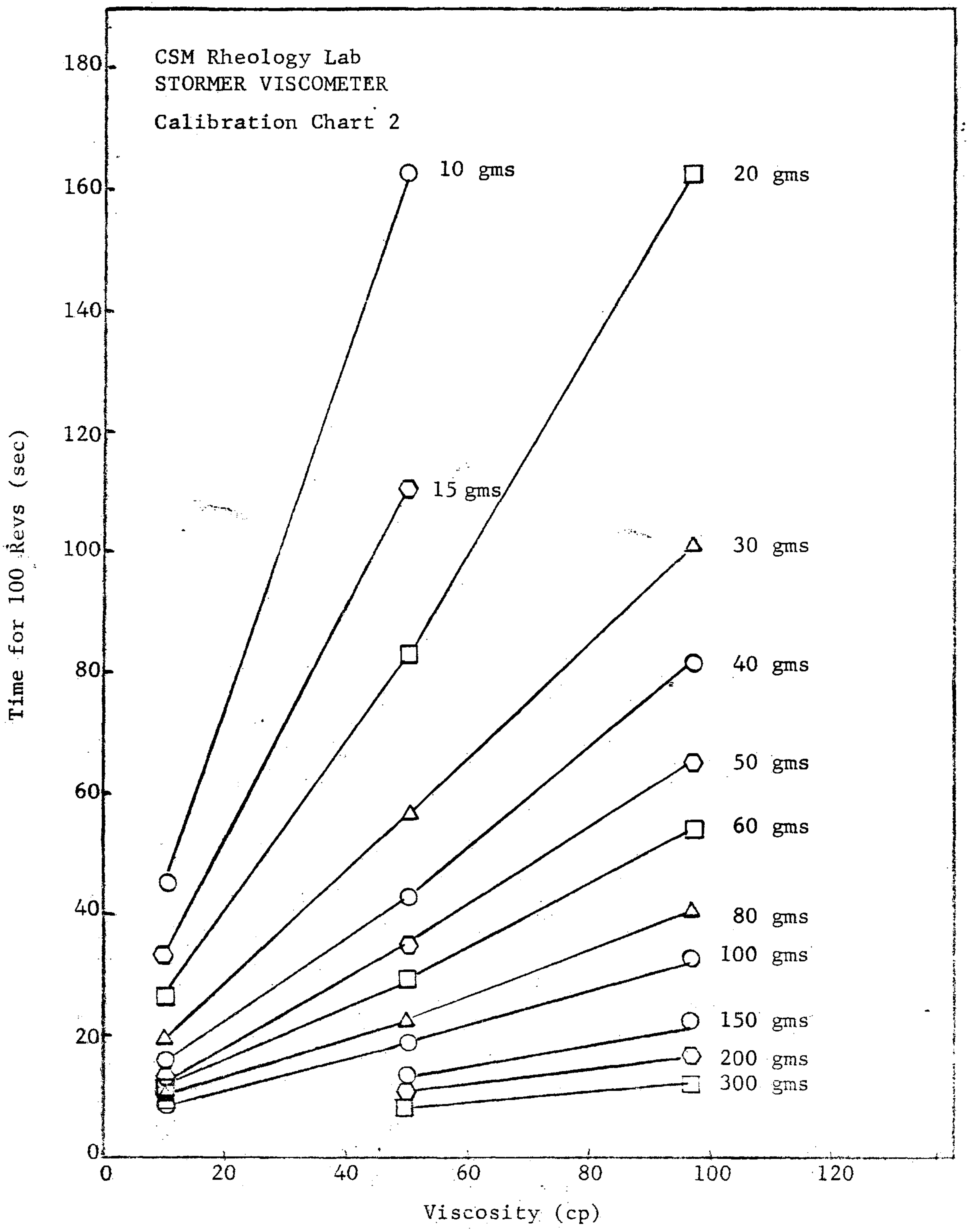
* Data with the fluid of viscosity 468 cp were taken by the author. The rest were provided by the CSM Rheology Lab.

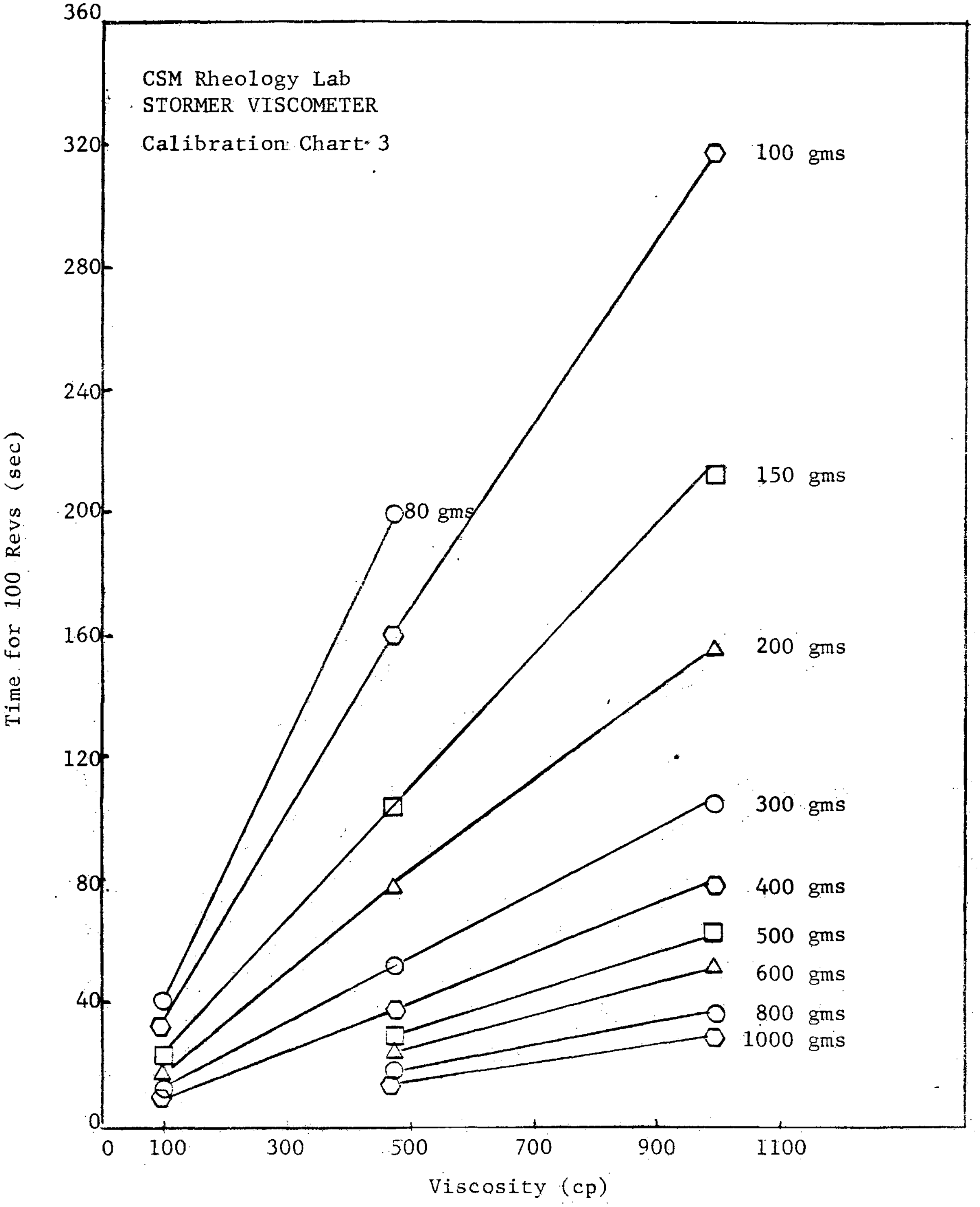
Viscosity cp	Weight (W) gms	Time for 100 revs (t) sec	Revolutions/sec (n) sec^{-1}
50.0	10	163.1	0.61
	15	110.9	0.92
	20	83.0	1.20
	30	56.8	1.76
	40	43.2	2.31
	50	34.9	2.87
	60	29.7	3.37
	80	23.0	4.35
	100	19.1	5.24
	150	13.9	7.20
97.0	15	218.9	0.46
	20	163.3	0.61
	30	109.1	0.92
	40	82.0	1.22
	50	65.5	1.52
	60	54.4	1.84
	80	40.8	2.45
	100	33.0	3.03
	150	22.4	4.46
	200	17.1	5.85
468.0	150	106.4	0.94
	200	79.5	1.26
	250	64.1	1.56
	300	53.4	1.87
	350	45.9	2.19
	400	40.8	2.49
	450	35.7	2.80
990.0	100	318.5	0.31
	150	213.8	0.47
	200	156.9	0.63
	300	105.3	0.95
	400	79.6	1.25
	500	63.6	1.57
	600	52.9	1.89
	800	37.9	2.64
	1000	29.7	3.37

Appendix Ib.

Calibration Charts for the Stormer Viscometer




CSM Rheology Lab
STORMER VISCOMETER
Calibration Chart 2
10 gms
15 gms
20 gms
30 gms
40 gms
50 gms
60 gms
80 gms
100 gms
150 gms
200 gms
300 gms
Time for 100 Revs (sec)
Viscosity (cp)
0
20
40
60
80
100
120
140
160
180
0
20
40
60
80
100
120


CSM Rheology Lab
STORMER VISCOMETER
Calibration Chart 3
Time for 100 Revs (sec)
Viscosity (cp)
0
40
80
120
160
200
240
280
320
360
0
100
300
500
700
900
1100
80 gms
100 gms
150 gms
200 gms
300 gms
400 gms
500 gms
600 gms
800 gms
1000 gms

APPENDIX II

End-Effect Determination

Assumptions:

i) All readings are taken in the laminar region.
ii) The fluids are Newtonian.
iii) The bob is open at the bottom.
iv) End-effect due to the peripheral edge is negligible.

Method:

A specific volume of liquid is added into the cup. The bob is immersed to a specific height, h, and readings taken. Three to four weights are generally used, and three readings are taken with each weight. The height is then changed and the procedure repeated. Readings are taken at four or five heights. One of the heights must correspond to the case in which the spindle is completely immersed.

The end-effect is determined by plotting the height immersed against the product W[illegible]t. All the points except the one obtained with the spindle completely immersed will lie on a straight line. This straight line is drawn. The point on the straight line which has the same W[illegible]t product as the reading with the spindle completely immersed is located. The spindle height corresponding to this point is noted. It gives the sum of spindle height, the top end-effect, and the bottom end-effect.

Theory:

$$\mu = (\text{Shear Stress}/\text{Shear Rate}) \qquad (1)$$

Shear Stress (12) = Torque/(Shearing area x moment arm)

$$= W \times (1.425 \times 981/11)/(2\pi R_b)R_b L_e$$

$$= K_1 W/L_e,$$

where K_1 is a constant = $(1.425 \times 981/11)/2\pi R_b^{2}$.

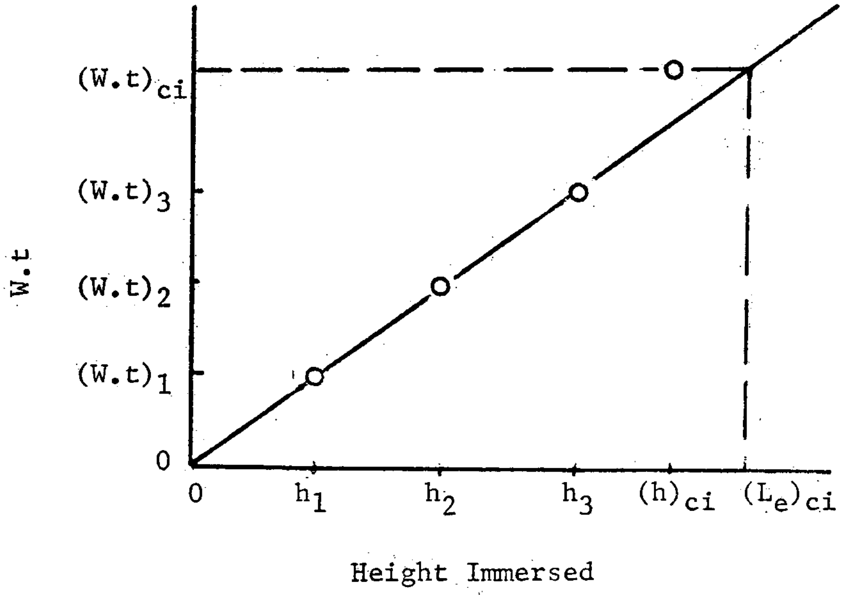
Shear Rate (1) = $4\pi n/(1-S^{-2})$

$$= 4\pi \quad \times 100/t(1-S^{-2})$$

$$= K_2/t,$$

where K_2 is a constant = $4\pi \times 100/(1-S^{-2})$.

(The subscript $_{ci}$ denotes completely immersed.)



$$\mu = \frac{K_1W}{L_e} \times \frac{t}{K_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For the Stormer viscometer (9),

$$\mu = W*t/A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Comparing equations (2) and (3),

$$\therefore \qquad A = \frac{K_2L_e}{K_1}$$

$$\frac{A}{L_e} \text{ is a constant.}$$

For a fluid of constant viscosity $W*t \propto A$

$$\therefore \qquad \frac{W*t}{L_e} \text{ is a constant.}$$

Hence a plot of L_e vs. $W*t$ should give a straight line passing through the origin.

$$\text{Also } \frac{(W*t)_1}{(L_e)_1} = \frac{(W*t)_2}{(L_e)_2} = \ldots\ldots = \frac{(W*t)_{ci}}{(L_e)_{ci}}{}^{*} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

For the reading with height of immersion equal to h_1, no end-effect is present.

$\therefore$ $(L_e)_1$ = height of spindle immersed = h_1,

Similarly, $(L_e)_2 = h_2$

$(L_e)_3 = h_3$.

These points are sufficient to establish the relationship between $W*t$ and L_e. On the plot, they can be joined to give a straight line.

Now $(L_e)_{ci} = (h)_{ci} + (\text{end-effects})_{top + bottom}$.

The readings taken with the spindle completely immersed has been plotted at the co-ordinates $(h_{ci}, W*t)$. Hence, it does not lie on

---

* Subscript $_{ci}$ denotes completely immersed.

the plot relating $W*t$ and L_e.

It is easy to determine $(L_e)_{ci}$, because it is known from equation 4 that it should lie on the straight line and $(W*t)_{ci}$ corresponding to it is known. $(L_e)_{ci}$ shown in the plot is the sum of the spindle height and the top and bottom end-effects.

APPENDIX III

Mineral Slurry Data Bank**

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 16.0% Vol Conc: 12.36%

Temperature: 10.4C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity * (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	42.2	3.2	2.28	2.37
10	26.8	3.4	3.82	3.73
15	20.3	3.0	4.68	4.93
20	17.0	3.1	5.76	5.88
30	13.2	2.9	7.20	7.58
40	11.1	2.8	8.48	9.01

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.00 Solids SG: 1.35

Wt Conc: 24.5% Vol Conc: 19.37%

Temperature: 10.6C

5	74.6	9.5	3.81	1.34
10	38.4	7.6	5.99	2.60
15	27.5	6.9	7.74	3.64
20	22.0	6.6	9.29	4.55
30	16.8	6.6	12.41	5.95
40	13.9	6.4	14.93	7.19
50	11.9	6.6	17.56	8.40
60	10.6	6.7	20.02	9.43

* Viscosity values read from Newtonian calibration charts in Appendix Ib.

** Data on pages 62-91 were provided by the CSM Rheology Lab.

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.00 Solids SG: 1.35

Wt Conc: 35.0% Vol Conc: 28.5%

Temperature: 10.45C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
10	47.4	10.7	6.98	2.11
15	32.8	9.8	9.18	3.05
20	26.1	10.0	11.44	3.83
30	18.7	9.3	14.80	5.35
40	15.2	8.7	17.64	6.58
50	13.0	9.5	21.41	7.69
60	11.7	9.0	23.91	8.55

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.00 Solids SG: 1.35

Wt Conc: 44.1% Vol Conc: 36.88%

Temperature: 10.3C

20	71.3	41.6	18.76	1.40
30	39.9	32.2	25.36	2.51
40	29.2	29.5	31.39	3.42
50	22.8	27.8	36.64	4.39
60	18.8	25.7	41.04	5.32
80	14.9	24.0	50.20	6.71
100	12.4	24.5	59.63	8.06

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 54.0% Vol Conc: 46.51%

Temperature: 10.8C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
80	78.8	183.0	73.83	1.27
100	45.5	126.0	96.61	2.20
150	22.0	97.0	135.74	4.55
200	14.4	75.0	163.14	6.94
300	9.3	64.0	214.93	10.75

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 16.0% Vol Conc: 12.36%

Temperature: 19.2C

5	40.4	2.8	2.11	2.48
10	25.8	2.9	3.47	3.88
15	19.5	2.7	4.32	5.13
20	16.1	2.6	5.06	6.21
30	12.6	2.3	6.10	7.94
40	10.6	2.2	7.14	9.43

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 24.5% Vol Conc: 19.37%

Temperature: 19.4C

5	87.0	11.0	4.05	1.15
10	38.3	7.6	5.99	2.61
15	27.2	6.8	7.67	3.68
20	21.2	6.0	8.79	4.72
30	16.5	6.2	11.96	6.06
40	13.7	6.0	14.37	7.30

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 35.0% Vol Conc: 28.5%

Temperature: 19.5C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
10	39.4	8.0	6.08	2.54
15	30.3	8.2	8.44	3.30
20	23.6	7.7	10.04	4.24
30	17.4	7.4	13.08	5.75
40	14.5	7.4	16.08	6.90

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 44.1% Vol Conc: 36.88%

Temperature: 19.4C

20	71.6	41.7	18.77	1.40
30	37.0	29.0	24.58	2.70
40	26.2	25.5	29.68	3.82
50	20.5	24.2	34.44	4.88
60	17.5	23.0	38.99	5.71

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 54% Vol Conc: 46.51%

Temperature: 19.3C

80	71.6	165.0	75.35	1.40
100	44.1	130.0	96.61	2.27
150	20.3	85.0	132.08	4.93
200	13.0	63.0	154.31	7.69

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 16.0% Vol Conc: 12.36%

Temperature: 29.3C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	36.9	2.1	1.76	2.71
10	24.0	2.1	2.81	4.17
15	18.4	2.1	3.62	5.43
20	15.5	2.1	4.36	6.45
30	12.0	2.0	5.45	8.33
40	10.1	1.6	5.81	9.90

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 24.6% Vol Conc: 19.5%

Temperature: 29.8C

5	55.1	5.8	3.08	1.81
10	30.2	4.6	4.56	3.31
20	18.8	4.3	7.12	5.32
30	14.3	4.0	8.93	6.99
50	10.4	3.9	12.25	9.62

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 35.0% Vol Conc: 28.5%

Temperature: 29.8C

10	38.3	7.6	5.93	2.61
20	21.3	6.1	8.75	4.69
30	16.2	6.1	11.61	6.17
40	13.4	5.7	13.65	7.46
50	11.7	6.1	16.48	8.55
60	10.2	6.1	18.39	9.80

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 44.1% Vol Conc: 36.9%

Temperature: 29.7C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
20	49.8	25.0	16.82	2.01
30	28.8	20.3	21.55	3.47
40	20.9	17.4	25.23	4.78
50	17.2	17.0	29.45	5.81
60	15.0	16.5	33.40	6.67

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids: 1.35

Wt Conc: 54% Vol Conc: 46.5%

Temperature: 30C

100	64.3	190.0	93.88	1.56
150	30.6	88.0	139.18	3.27
200	19.1	105.0	179.69	5.24
300	10.9	80.0	234.70	9.17

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 16% Vol Conc: 12.36%

Temperature: 38.7C

5	35.0	1.7	1.54	2.86
10	22.8	1.9	2.58	4.39
15	17.8	1.7	3.13	5.62
20	14.9	1.7	3.75	6.71
30	11.7	1.6	4.71	8.55
40	9.8	1.2	5.05	10.20

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 24.5% Vol Conc: 19.4%

Temperature: 39.0C

Driving Weight (W) gms	Time for 100 revs (t) sec.	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	61.9	7.1	3.38	1.62
10	31.2	5.1	4.82	3.21
20	18.9	4.4	7.22	5.29
30	14.4	4.1	9.08	6.94
50	10.2	4.7	13.49	9.80
60	9.2	4.0	13.88	10.87

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 35.0% Vol Conc: 28.5%

Temperature: 39.3C

10	36.1	6.8	5.60	2.77
15	25.8	6.1	7.11	3.88
20	20.7	5.6	8.33	4.83
30	15.8	5.4	10.82	6.33
50	11.1	5.2	14.72	9.01

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 44.1% Vol Conc: 36.9%

Temperature: 39.7C

20	51.0	27.5	17.15	1.96
30	28.0	19.5	21.19	3.57
40	20.0	16.0	24.25	5.00
50	16.6	16.5	28.81	6.02
60	14.7	16.3	33.02	6.80
80	11.5	13.0	36.75	8.70

Slurry: Coal-in-water #1 Mesh Size: 100/200

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 54% Vol Conc: 46.5%

Temperature: 39.6C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec $^{-1}$
100	75.1	217.0	90.78	1.33
150	32.8	145.0	144.33	3.05
200	20.4	117.0	183.34	4.90
300	11.5	80.0	237.30	8.70
400	7.8	44.0	245.83	12.82

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 14.6% Vol Conc: 11.16%

Temperature: 12.0C

5	46.7	4.1	2.61	2.14
10	27.0	3.5	3.89	3.70
15	20.5	3.3	4.95	4.88
20	17.2	3.4	6.11	5.81
40	11.1	2.9	8.68	9.01
60	8.6	2.7	10.70	11.63

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 24.7% Vol Conc: 28.24%

Temperature: 10.0C

5	82.1	11.0	4.01	1.22
10	35.4	6.6	5.56	2.82
15	25.4	5.9	7.06	3.94
20	20.2	5.4	8.21	4.95
30	15.6	5.1	10.60	6.41
40	12.8	4.6	12.09	7.81

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 34.7% Vol Conc: 28.2%

Temperature: 10.4C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
15	56.6	22.2	12.69	1.77
20	37.4	17.8	14.92	2.67
30	23.9	15.0	18.99	4.18
40	18.4	14.0	22.79	5.43
60	12.7	12.2	28.28	7.87
80	10.2	10.3	31.86	9.80

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 45.2% Vol Conc: 37.9%

Temperature: 10.6C

60	78.1	160.0	56.08	1.28
80	37.1	83.0	75.24	2.70
100	25.0	70.0	88.54	4.00
150	14.0	52.0	113.42	7.14
200	10.3	45.0	135.13	9.71
300	7.2	41.0	177.04	13.89

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 49.4% Vol Conc: 41.8%

Temperature: 10.3C

100	187.0	560.0	36.03	0.53
150	60.4	270.0	135.95	1.66
200	31.7	180.0	193.24	3.15
300	15.3	118.0	266.29	6.54
400	10.0	100.0	322.38	10.00

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 14.6% Vol Conc: 11.16%

Temperature: 19.4C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	41.2	3.0	2.19	2.43
10	25.6	2.9	3.46	3.91
15	19.4	2.7	4.32	5.15
20	16.2	2.6	5.09	6.17
30	12.6	2.3	6.11	7.94
50	9.3	2.4	8.71	10.75

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 24.7% Vol Conc: 19.55%

Temperature: 19.7C

5	77.4	10.1	3.89	1.29
10	32.2	5.5	5.02	3.11
15	23.2	4.7	6.16	4.31
20	18.9	4.4	7.22	5.29
30	14.4	4.1	9.08	6.94
50	10.3	3.9	12.18	9.71

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 34.7% Vol Conc: 28.2%

Temperature: 19.7C

15	57.4	22.5	12.75	1.74
20	35.2	16.2	14.38	2.84
30	22.3	13.1	17.82	4.48
40	16.7	11.0	20.17	5.99
50	13.9	10.8	23.27	7.19

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 45.2% Vol Conc: 37.92%

Temperature: 10.6C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
60	72.5	150.0	56.77	1.38
80	36.4	86.0	75.33	2.75
100	23.5	65.0	86.84	4.26
150	13.0	46.0	108.29	7.69
200	9.4	38.5	125.83	10.64

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 49.4% Vol Conc: 41.9%

Temperature: 19.9C

100	177.5	530.0	41.02	0.56
150	53.4	235.0	140.31	1.87
200	27.4	155.0	191.68	3.65
300	13.2	100.0	254.12	7.58
400	8.5	82.0	298.63	11.76

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 14.6% Vol Conc: 11.16%

Temperature: 30.0C

5	39.7	2.6	2.03	2.52
10	24.3	2.4	3.05	4.12
15	18.5	2.2	3.74	5.41
20	15.5	2.2	4.49	6.45
30	12.0	1.8	5.13	8.33
40	10.2	1.8	6.23	9.80
50	8.9	1.0	5.92	11.24

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 24.7% Vol Conc: 19.55%

Temperature: 30.0C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	62.8	7.2	3.41	1.59
10	31.1	5.0	4.77	3.22
15	22.2	4.2	5.72	4.50
20	18.2	4.0	6.76	5.49
30	13.8	3.2	7.72	7.25
40	11.4	3.1	9.03	8.77

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 34.7% Vol Conc: 28.24%

Temperature: 29.7C

15	54.1	20.8	12.45	1.85
20	32.9	14.5	13.73	3.04
30	20.6	11.2	16.45	4.85
40	15.6	9.5	18.51	6.41
50	12.8	8.5	20.24	7.81

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 45.2% Vol Conc: 37.92%

Temperature: 29.9C

60	89.5	190.0	53.94	1.12
80	38.7	91.5	75.98	2.58
100	23.8	66.0	87.20	4.20
150	12.6	44.0	106.26	7.94
200	8.9	35.0	120.09	11.24
300	6.3	31.0	153.03	15.87

Slurry: Coal-in-water #1

Mesh Size: 200/0

Liquid SG: 1.0

Solids SG: 1.35

Wt Conc: 49.2%

Vol Conc: 41.9%

Temperature: 29.7C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
100	147.8	432.0	57.00	0.68
150	45.5	200.0	143.66	2.20
200	23.4	133.0	188.08	4.27
300	11.6	78.0	237.06	8.62
400	7.8	70.0	281.40	12.82

Slurry: Coal-in-water #1

Mesh Size: 200/0

Liquid SG: 1.0

Solids SG: 1.35

Wt Conc: 14.6%

Vol Conc: 11.16%

Temperature: 39.5C

5	37.0	2.1	1.77	2.70
10	23.2	2.0	2.69	4.31
15	17.8	1.8	3.25	5.62
20	15.0	1.8	3.91	6.67
30	11.6	1.4	4.37	8.62

Slurry: Coal-in-water #1

Mesh Size: 200/0

Liquid SG: 1.0

Solids SG: 1.35

Wt Conc: 24.7%

Vol Conc: 19.5%

Temperature: 39.8C

5	63.3	7.4	3.44	1.58
10	30.5	4.8	4.66	3.28
15	22.2	4.2	5.72	4.50
20	17.9	3.7	6.43	5.59
30	13.6	3.2	7.66	7.35
40	11.3	3.1	8.98	8.85
50	9.8	3.0	10.11	10.20

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 34.7% Vol Conc: 28.2%

Temperature: 39.8C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
15	53.2	20.3	12.36	1.88
20	32.0	14.0	13.50	3.13
30	20.2	10.9	16.18	4.95
40	15.1	9.0	17.86	6.62
50	12.7	8.0	19.61	7.87
60	11.0	7.5	21.29	9.09

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 45.2% Vol Conc: 37.9%

Temperature: 40.1C

60	49.1	87.0	57.55	2.04
80	25.2	56.0	68.63	3.97
100	17.2	43.0	75.88	5.81
150	10.1	31.0	90.21	9.90
200	7.8	27.0	104.93	12.82
300	5.5	23.0	128.13	18.18

Slurry: Coal-in-water #1 Mesh Size: 200/0

Liquid SG: 1.0 Solids SG: 1.35

Wt Conc: 49.4% Vol Conc: 41.97%

Temperature: 40.1C

80	107.2	250.0	65.73	0.93
100	51.8	150.0	96.36	1.93
150	20.3	87.0	132.76	4.93
200	12.5	63.0	153.48	8.00
300	7.4	42.0	179.33	13.51

Slurry: Coal-in-water #2 Mesh Size: -65

Liquid SG: 1.0 Solids SG: 1.51

Wt Conc: 33.48% Vol Conc: 24.99%

Temperature: 24.1C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	64.8	7.6	3.44	1.54
10	34.5	6.3	5.32	2.90
15	25.5	5.9	6.91	3.92
20	20.7	5.6	8.23	4.83
30	15.9	5.4	10.72	6.29
50	11.5	5.6	15.40	8.70

Slurry: Coal-in-water #2 Mesh Size: -65

Liquid SG: 1.0 Solids SG: 1.51

Wt Conc: 39.45% Vol Conc: 30.14%

Temperature: 23.7C

10	43.0	9.3	6.45	2.33
15	31.9	9.3	8.81	3.13
20	25.5	9.2	10.84	3.92
30	18.8	9.0	14.37	5.32
50	13.3	9.4	21.07	7.52
80	10.4	10.0	31.00	9.62

Slurry: Coal-in-water #2 Mesh Size: -65

Liquid SG: 1.0 Solids SG: 1.51

Wt Conc: 45.3% Vol Conc: 35.42%

Temperature: 24.7C

15	52.2	20.0	12.12	1.92
20	39.0	19.0	15.04	2.56
40	22.2	20.0	26.40	4.50
60	16.0	20.0	35.86	6.25
80	13.2	21.0	45.60	7.58

Slurry: Coal-in-water #2 Mesh Size: -65

Liquid SG: 1.0 Solids SG: 1.51

Wt Conc: 50.2% Vol Conc: 40.03%

Temperature: 24.8C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
40	42.4	49.0	35.93	2.36
50	34.4	50.0	43.79	2.91
60	27.6	46.0	50.07	3.62
80	20.3	42.0	61.79	4.93
100	16.4	40.0	72.75	6.10
150	11.8	39.0	99.44	8.47

Slurry: Coal-in-water #2 Mesh Size: -65

Liquid SG: 1.0 Solids SG: 1.51

Wt Conc: 54.5% Vol Conc: 44.23%

Temperature: 24.7C

100	45.0	132.0	96.59	2.22
150	23.5	100.0	136.43	4.26
200	16.3	90.0	170.50	6.13
300	10.3	80.0	229.14	9.71
400	8.3	75.0	286.02	12.05

Slurry: Coal-in-water #3 Mesh Size: -100

Liquid SG: 1.0 Solids SG: 1.38

Wt Conc: 46.8% Vol Conc: 38.9%

Temperature: 25.0C

60	42.3	74.2	56.45	2.36
80	22.4	48.5	65.48	4.46
100	15.4	36.5	70.85	6.49
150	9.7	28.0	85.72	10.31
200	7.5	25.0	99.93	13.33
300	5.5	23.0	127.39	18.18

Slurry: Coal-in-water #4 Mesh Size: -65

Liquid SG: 1.0 Solids SG: 1.45

Wt Conc: 37.3% Vol Vonc: 29.3%

Temperature: 25.0C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
50	77.6	100.0	48.17	1.29
60	50.3	89.0	57.66	1.99
80	33.5	78.0	74.18	2.99
100	25.9	73.0	89.45	3.86
150	16.5	66.0	123.15	6.06
200	12.8	65.0	155.72	7.81

Slurry: Coal-in-water #4 Mesh Size: -65

Liquid SG: 1.0 Solids SG: 1.45

Wt Conc: 40.5% Vol Conc: 31.9%

Temperature: 19.4C

100	61.8	183.0	94.40	1.62
150	36.0	157.0	144.92	2.78
200	25.6	145.0	190.38	3.91
300	16.6	135.0	273.52	6.02
400	12.5	135.0	351.90	8.00

Slurry: Coal-in-crude oil Mesh Size: 100/200

Liquid SG: 0.84 Solids SG: 1.60

Wt Conc: 35.0% Vol Conc: 22.0%

Temperature: 27.2C

10	66.6	17.4	8.47	1.50
15	44.5	15.9	11.57	2.25
20	35.1	16.0	14.64	2.85
40	21.2	18.0	26.47	4.72
50	18.0	18.7	31.90	5.56
60	16.0	19.0	37.12	6.25

Slurry: Coal-in-crude oil Mesh Size: 100/200

Liquid SG: 0.84 Solids SG: 1.60

Wt Conc: 46.5% Vol Conc: 31.2%

Temperature: 26.8C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
50	46.7	68.5	47.33	2.14
60	38.3	66.2	55.74	2.61
80	29.5	67.5	72.46	3.39
100	24.1	67.0	88.18	4.15
150	16.3	65.0	123.67	6.13
200	12.1	61.0	153.42	8.26

Slurry: Coal-in-crude oil Mesh Size: 100/200

Liquid SG: 0.84 Solids SG: 1.60

Wt Conc: 48.0% Vol Conc: 32.6%

Temperature: 26.7C

150	91.6	410.0	150.00	1.09
200	59.3	350.0	200.00	1.69
300	35.1	300.0	283.65	2.85
400	24.5	290.0	385.81	4.08
500	18.5	230.0	480.31	5.41

Slurry: Coal-in-crude oil Mesh Size: 100/200

Liquid SG: 0.84 Solids SG: 1.60

Wt Conc: 35.0% Vol Conc: 22.0%

Temperature: 15.7C

15	100.0	44.7	14.47	1.00
20	73.0	42.8	18.99	1.37
30	48.6	41.5	27.42	2.06
40	36.4	40.0	35.10	2.75
50	30.5	42.2	43.08	3.28
60	25.9	41.8	50.26	3.86

Slurry: Coal-in-crude oil Mesh Size: 100/200

Liquid SG: 0.84 Solids SG: 1.60

Wt Conc: 45.8% Vol Conc: 30.59%

Temperature: 15.8C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
80	97.5	230.0	80.00	1.03
100	76.6	220.0	100.00	1.31
150	44.2	176.0	144.22	2.26
200	31.6	160.0	193.11	3.16
300	20.3	150.0	283.09	4.93
400	14.9	150.0	367.20	6.71

Slurry: Coal-in-crude oil Mesh Size: 100/200

Liquid SG: 0.84 Solids SG: 1.60

Wt Conc: 48.0% Vol Conc: 32.59%

Temperature: 15.8C

100	65.6	172.0	100.00	1.52
150	37.4	149.0	144.97	2.67
200	25.1	133.0	189.74	3.98
300	15.4	122.0	269.54	6.49
400	11.3	115.0	340.97	8.85

Slurry: Coal-in-crude oil Mesh Size: 100/200

Liquid SG: 0.84 Solids SG: 1.60

Wt Conc: 36.4% Vol Conc: 23.06%

Temperature: 8.4C

80	44.2	140.0	77.26	2.26
100	34.3	100.0	95.41	2.92
150	22.5	98.0	138.29	4.44
200	16.8	95.0	177.53	5.95
300	11.4	87.0	247.07	8.77

Slurry: Coal-in-crude oil   Mesh Size: 100/200

Liquid SG: 0.84   Solids SG: 1.60

Wt Conc: 46.5%   Vol Conc: 31.28%

Temperature: 8.4C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
150	142.6	650.0	150.00	0.70
200	97.7	600.0	200.00	1.02
300	54.6	480.0	300.00	1.83
400	37.6	448.0	400.00	2.66
500	28.1	412.0	500.00	3.56

Slurry: Coal-in-crude oil   Mesh Size: 100/200

Liquid SG: 0.84   Solids SG: 1.60

Wt Conc: 48.2%   Vol Conc: 32.76%

Temperature: 8.5C

200	80.5	475.0	200.00	1.24
300	45.8	375.0	300.00	2.18
400	30.6	300.0	381.82	3.27
500	22.9	285.0	483.02	4.37
600	18.4	275.0	579.17	5.43

Slurry: Coal-in-glycerine   Mesh Size: 6/10

Liquid SG: 1.25   Solids SG: 1.36

Wt Conc: 10.0%   Vol Conc: 9.26%

Temperature: 26.1C

5	34.2	1.5	1.28	2.92
10	22.4	1.6	2.06	4.46
15	17.5	1.6	2.67	5.71
20	14.8	1.6	3.23	6.76
30	11.6	1.4	3.99	8.62
40	10.0	1.4	5.03	10.00

Slurry: Coal-in-glycerine Mesh Size: 6/10

Liquid SG: 1.25 Solids SG: 1.36

Wt Conc: 15.0% Vol Conc: 13.95%

Temperature: 26.0C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	36.8	2.0	1.56	2.72
10	24.8	2.5	2.83	4.03
15	18.4	2.1	3.23	5.43
20	15.3	2.0	3.74	6.54
30	12.0	1.6	4.31	8.33

Slurry: Coal-in-glycerine Mesh Size: 6/10

Liquid SG: 1.25 Solids SG: 1.36

Wt Conc: 25.0% Vol Conc: 23.45%

Temperature: 25.6C

5	49.1	4.4	2.53	2.04
10	28.2	3.9	3.79	3.55
15	21.3	3.7	4.82	4.69
20	17.7	3.5	5.64	5.65
30	13.7	3.2	6.93	7.3
40	11.6	3.2	8.36	8.62

Slurry: Cement-in-water Mesh Size: -100

Liquid SG: 1.0 Solids SG: 2.49

Wt Conc: 58.0% Vol Conc: 35.67%

Temperature: 27.2C

100	28.5	84.0	88.68	3.51
125	15.7	45.0	87.21	6.37
150	11.3	36.0	89.07	8.85
175	9.6	32.0	94.40	10.42
200	8.2	30.0	99.28	12.20

Slurry: Cement-in-water   Mesh Size: -100

Liquid SG: 1.0   Solids SG: 2.49

Wt Conc: 58.0%   Vol Conc: 35.67%

Temperature: 16.3C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
100	50.6	145.0	96.58	1.98
125	23.6	80.0	107.07	4.24
150	15.5	60.0	111.97	6.45
175	11.5	44.0	111.22	8.70
200	9.7	42.0	118.81	10.31

Slurry: Cement-in-water   Mesh Size: -100

Liquid SG: 1.0   Solids SG: 2.49

Wt Conc: 58.0%   Vol Conc: 35.67%

Temperature: 9.9C

150	23.8	105.0	133.70	4.20
175	17.1	82.0	142.36	5.85
200	14.5	80.0	156.70	6.90
225	11.4	56.0	152.80	8.77
250	10.0	55.0	162.82	10.00

Slurry: Cement-in-water   Mesh Size: -100

Liquid SG: 1.0   Solids SG: 2.49

Wt Conc: 62.0%   Vol Conc: 39.6%

Temperature: 26.7C

200	27.9	160.0	188.56	3.58
250	13.5	86.0	194.39	7.41
300	8.8	56.0	187.02	11.36

Slurry: Cement-in-water Mesh Size: -100

Liquid SG: 1.0 Solids SG: 2.49

Wt Conc: 62.0% Vol Conc: 39.6%

Temperature: 16.4C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
200	36.2	210.0	193.15	2.76
225	20.9	140.0	203.74	4.77
250	15.0	102.0	205.27	6.67
275	12.0	80.0	205.00	8.33
300	10.0	75.0	210.52	10.00

Slurry: Cement-in-water Mesh Size: -100

Liquid SG: 1.0 Solids SG: 2.49

Wt Conc: 62.0% Vol Conc: 39.6%

Temperature: 9.9C

200	36.5	235.0	193.33	2.74
250	16.9	105.0	210.69	5.92
300	11.8	92.0	229.92	8.47
350	8.6	75.0	235.93	11.63
400	7.3	70.0	252.13	13.70

Slurry: Cement-in-water Mesh Size: -100

Liquid SG: 1.0 Solids SG: 2.49

Wt Conc: 68.0% Vol Conc: 46.04%

Temperature: 25.9C

550	49.6	840.0	550.00	2.02
600	29.2	460.0	574.53	3.42
650	22.4	445.0	628.03	4.46
700	15.5	360.0	667.09	6.45

Slurry: Cement-in-water

Mesh Size: -100

Liquid SG: 1.0

Solids SG: 2.49

Wt Conc: 68.0%

Vol Conc: 46.04%

Temperature: 17.0C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
500	39.4	605.0	500.00	2.54
550	25.2	425.0	530.83	3.97
600	19.3	360.0	577.40	5.18
650	13.3	280.0	600.18	7.52

Slurry: Cement-in-water

Mesh Size: -100

Liquid SG: 1.0

Solids SG: 2.49

Wt Conc: 68.0%

Vol Conc: 46.04%

Temperature: 9.9C

600	44.0	825.0	600.00	2.27
650	25.6	510.0	623.43	3.91
700	20.8	430.0	676.62	4.81
750	17.2	380.0	720.00	5.81
800	13.3	340.0	751.22	7.52

Slurry: Gypsum fly ash-in-water

Mesh Size: Not Known

Liquid SG: 1.0

Solids SG: 2.47

Wt Conc: 30.12%

Vol Conc: 14.83%

Temperature: 21.0C

30	72.0	66.0	28.81	1.39
40	31.9	33.2	32.22	3.13
50	20.3	23.2	33.25	4.93
60	16.1	19.8	35.45	6.21
80	12.0	15.6	39.02	8.33
100	9.4	14.0	42.08	10.64

Slurry: Gypsum fly ash-in-water Mesh Size: Not Known

Liquid SG: 1.0 Solids SG: 2.47

Wt Conc: 30.07% Vol Conc: 14.83%

Temperature: 21.0C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
30	81.0	71.0	28.99	1.23
40	33.2	35.5	33.25	3.01
50	20.4	23.2	33.89	4.90
60	15.6	13.0	30.94	6.41
80	11.8	14.5	38.63	8.47

Slurry: Taconite tailings-in-water Mesh Size: Not Known

Liquid SG: 1.0 Solids SG: 3.03

Wt Conc: 72.3% Vol Conc: 46.27%

Temperature: 21.0C

100	72.0	213.0	95.79	1.39
150	44.2	195.0	144.65	2.26
200	32.5	190.0	190.16	3.08
300	25.1	212.0	282.33	3.98
400	16.7	188.0	356.36	5.99

Slurry: Uranium tailings-in-water Mesh Size: -65

Liquid SG: 1.0 Solids SG: 2.58

Wt Conc: 30.5% Vol Conc: 14.55%

Temperature: 5.5C

30	56.8	50.4	27.84	1.76
40	27.1	26.8	29.67	3.69
50	18.8	20.0	31.04	5.32
60	15.4	18.2	33.86	6.49
80	11.2	13.0	35.05	8.93
100	9.4	13.0	40.55	10.64
150	7.0	13.0	52.84	14.29

Slurry: Uranium tailings-in-water Mesh Size: -65

Liquid SG: 1.0 Solids SG: 2.58

Wt Conc: 30.5% Vol Conc: 14.55%

Temperature: 19.8C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
30	41.2	33.5	25.31	2.43
40	22.4	19.6	26.01	4.46
50	16.2	15.4	27.08	6.17
60	13.0	10.0	25.02	7.69
80	10.0	9.0	28.03	10.00

Slurry: Uranium tailings-in-water Mesh Size: -65

Liquid SG: 1.0 Solids SG: 2.58

Wt Conc: 35.4% Vol Conc: 17.54%

Temperature: 25.1C

40	32.1	34.0	32.12	3.12
50	21.1	24.8	33.80	4.74
60	16.5	20.2	35.43	6.06
80	12.1	16.0	38.83	8.26
100	9.8	15.0	43.29	10.20

Slurry: Uranium tailings-in-water Mesh Size: -65

Liquid SG: 1.0 Solids SG: 2.58

Wt Conc: 39.8% Vol Conc: 20.42%

Temperature: 25.0C

40	43.3	48.5	35.55	2.31
50	26.0	32.5	37.76	3.85
60	19.4	27.0	40.18	5.15
80	13.9	21.5	45.01	7.19
100	11.0	20.0	50.33	9.09
150	7.9	18.0	63.02	12.66
200	6.2	16.0	70.94	16.13

Slurry: Uranium tailings-in-water Mesh Size: -65

Liquid SG: 1.0 Solids SG: 2.58

Wt Conc: 44.5% Vol Conc: 23.74%

Temperature: 25.0C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
60	41.5	72.5	55.35	2.41
80	20.6	43.0	60.53	4.85
100	14.4	32.5	64.13	6.94
150	9.3	26.5	77.66	10.75
200	7.2	24.0	89.91	13.89

Slurry: Copper ore-in-water Mesh Size: Not Known

Liquid SG: 1.0 Solids SG: 2.69

Wt Conc: 36.3% Vol Conc: 17.48%

Temperature: 25.4C

15	43.1	14.2	10.53	2.32
20	28.3	11.3	11.59	3.53
30	18.8	10.3	14.48	5.32
40	14.9	8.2	15.83	6.71
50	12.7	8.0	18.12	7.87
60	11.4	8.4	21.12	8.77

Slurry: Copper ore-in-water Mesh Size: Not Known

Liquid SG: 1.0 Solids SG: 2.69

Wt Conc: 39.0% Vol Conc: 19.2%

Temperature: 25.4C

20	45.7	23.5	15.89	2.19
30	22.6	13.53	17.00	4.42
40	18.3	14.0	21.30	5.46
50	13.8	11.0	21.60	7.25
60	12.0	10.0	23.31	8.33
80	10.2	10.0	28.74	9.80

Slurry: Salt-in-brine　　Mesh Size: -80

Slurry SG: 1.2　　Wt Conc: 40%

Temperature: 26.8C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	41.3	3.0	2.06	2.42
10	26.4	3.2	3.44	3.79
15	20.6	3.3	4.60	4.85
20	17.1	3.2	5.44	5.85
30	13.7	3.1	7.05	7.30
40	11.2	3.0	8.17	8.93
50	9.8	3.0	9.43	10.20
60	8.8	3.0	10.61	11.36

Slurry: Salt-in-brine　　Mesh Size: -80

Slurry SG: 1.2　　Wt Conc: 40%

Temperature: 35.0C

5	40.0	2.7	1.94	2.50
10	26.0	3.1	3.35	3.85
15	20.0	3.0	4.30	5.00
20	16.5	2.8	4.94	6.06
30	13.1	2.9	6.60	7.63
40	10.9	2.5	7.21	9.17
50	9.6	2.8	8.93	10.42
60	8.7	2.7	9.90	11.49

Slurry: Salt-in-brine　　Mesh Size: -80

Slurry SG: 1.2　　Wt Conc: 50%

Temperature: 26.8C

5	41.4	3.0	2.06	2.42
10	26.9	3.4	3.57	3.72
15	20.6	3.3	4.60	4.85
20	17.4	3.4	5.69	5.75
30	13.9	3.4	7.51	7.19
40	11.3	3.1	8.38	8.85
50	9.9	3.1	9.67	10.10
60	9.0	3.3	11.38	11.11

Slurry: Salt-in-brine   Mesh Size: -80

Slurry SG: 1.2   Wt Conc: 50%

Temperature: 35.0C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	39.3	2.6	1.89	2.54
10	25.1	2.7	3.06	3.98
15	19.3	2.6	3.89	5.18
20	16.3	2.7	4.80	6.13
30	13.0	2.7	6.29	7.69
40	10.7	2.2	6.61	9.35

Slurry: Salt-in-brine   Mesh Size: -80

Slurry SG: 1.2   Wt Conc: 60%

Temperature: 26.8C

5	40.9	2.9	2.02	2.44
10	26.4	3.2	3.44	3.79
15	20.5	3.2	4.51	4.88
20	17.0	3.1	5.33	5.88
40	11.3	3.0	8.22	8.85
50	9.9	3.0	9.48	10.10

Slurry: Salt-in-brine   Mesh Size: -80

Slurry SG: 1.2   Wt Conc: 60%

Temperature: 35.0C

5	39.4	2.6	1.89	2.54
10	25.6	2.9	3.21	3.91
15	19.9	2.9	4.21	5.03
20	16.5	2.8	4.94	6.06
30	12.8	2.4	5.81	7.81
40	11.0	2.6	7.42	9.09
50	9.7	2.7	8.80	10.31
60	8.5	2.6	9.57	11.76

Slurry: Salt-in-brine Mesh Size: -80

Slurry SG: 1.2 Wt Conc: 70%

Temperature: 26.8C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
5	41.1	3.0	2.06	2.43
10	26.6	3.3	3.50	3.76
15	20.6	3.2	4.53	4.85
20	17.4	3.4	5.69	5.75
30	13.4	3.1	6.96	7.46
40	11.2	3.1	8.34	8.93
50	9.8	3.0	9.43	10.20
60	8.9	3.1	10.89	11.24

Slurry: Salt-in-brine Mesh Size: -80

Slurry SG: 1.2 Wt Conc: 70%

Temperature: 35.0C

5	39.8	2.7	1.93	2.51
10	25.6	2.9	3.21	3.91
15	19.8	2.8	4.11	5.05
20	16.8	2.9	5.09	5.95
30	12.9	2.6	6.12	7.75
40	10.8	2.5	7.17	9.26
50	9.7	2.8	8.99	10.31

Slurry: Fluid coke-in-water	Mesh Size: -48

Liquid SG: 1.0	Solids SG: 1.60

Wt Conc: 18.2%	Vol Conc: 12.2%

Temperature: 26C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
15	22.6	4.2	5.76	4.42
20	17.8	3.8	6.49	5.62
25	14.0	2.4	5.46	7.14
30	13.2	3.0	7.23	7.58
35	12.0	2.8	7.65	8.33
50	10.0	3.2	10.61	10.00

Slurry: Fluid coke-in-water	Mesh Size: -48

Liquid SG: 1.0	Solids SG: 1.60

Wt Conc: 32.9%	Vol Conc: 23.4%

Temperature: 27C

20	17.6	3.5	5.98	5.68
40	11.6	3.4	9.27	8.62
60	10.4	6.2	18.38	9.62
80	9.2	5.5	21.44	10.87
100	7.6	5.0	22.68	13.16
150	5.8	5.0	28.91	17.24

Slurry: Fluid coke-in-water Mesh Size: -48

Liquid SG: 1.0 Solids SG: 1.60

Wt Conc: 49.2% Vol Conc: 37.7%

Temperature: 27C

Driving Weight (W) gms	Time for 100 revs (t) sec	Approximate Viscosity (μ_s) cp	Corrected Driving Wt (W_c) gms	Rotational Speed (n) sec^{-1}
35	18.0	10.5	17.10	5.56
50	12.0	7.0	16.94	8.33
100	8.8	10.0	34.69	11.36
150	6.6	10.0	44.76	15.15
200	5.2	10.0	52.23	19.23