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SRC-WATER SLURRY RHEOLOGY

Final Technical Report

By
K. C. Tewari

February 1984

Work Performed Under Contract No. AC05-78OR03054

International Coal Refining Company
Allentown, Pennsylvania

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FINAL TECHNICAL REPORT:
SRC-WATER SLURRY RHEOLOGY

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for the
UNITED STATES DEPARTMENT OF ENERGY
Office of Solvent-Refined Coal Products
under Contract DE-AC05-78-OR-03054

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ABSTRACT

SRC-water slurries exhibit properties that qualify them for use as fuel in conventional oil-fired combustion facilities. However, to date, the slurries tested have shown storage instability, which requires constant agitation and recirculation to avoid sedimentation in the storage tanks. High viscosities of the material being evaluated hampered the test performance. A program was instituted to better understand the variables responsible for viscosity and static stability of these slurries. Effective additives and concentrations were determined. This report presents laboratory data demonstrating that solid concentration, particle size distribution, additive concentration, and slurry preparation technique influence the viscosity and stability characteristics of an SRC-water slurry.

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INTRODUCTION

As mixtures of solid, deashed Solvent-Refined Coal (SRC) and water, SRC-water slurries exhibit properties that qualify them as a power-generating fuel for use in conventional oil-designed facilities. The slurry concept provides a means of firing more than 70 wt % solid fuel with minimum modification of oil designed facilities and with the additional benefit of utilizing the storage, handling, and transportation capabilities of the existing fuel oil supply infrastructure.

To be a technically viable replacement for fuel oil, an SRC-water slurry must resemble oil as closely as possible in all aspects of usage, i.e., storage, transportation, handling, and combustion. Combustion tests on SRC-water slurry were successfully conducted at Pittsburgh Energy Technology Center (DOE/PETC) during January 1983 (1). Approximately 20,000 gal of SRC-water slurry, containing about 66 wt % of solid pulverized to 90% minus 200 mesh, were test-fired in the 700-hp (30 MM Btu/hr fuel input) oil-designed watertube package boiler. The steady-state duration tests, conducted at full boiler load with 600°F air preheat, resulted in an average carbon conversion efficiency of 98.9%. The average boiler efficiency of 81.8% was comparable to that achieved when burning No. 6 fuel oil (81.9%). Although overall results showed that SRC-water slurry is a viable alternative for fuel oil in oil-designed boilers, no information is available with regard to preparation, stability, and flow characteristics of SRC-water slurry fuels. The slurry used in PETC combustion tests, which contained 0.5 wt % Lomar D dispersant (a sodium salt of highly polymerized naphthalene sulfonate), showed storage instability and required constant agitation and recirculation in the storage tank to avoid sedimentation.

To identify effective additives and understand the basic variables responsible for slurry stability, a literature search was performed on the preparation of coal-water slurries. A review of the literature revealed that the rheology and stability of coal-water dispersion, a loosely dispersed flocculated network, depend on several variables such as solid concentration, particle size, temperature, and chemical additives used as dispersants and stabilizers. Proper selection of particle

size and dispersant leads to a pseudoplastic slurry of low viscosity. Anionic surfactants as dispersants are best suited for use in coal-water slurries (2-6). Slurry stability can be further improved by the addition of a stabilizer and conversion of the slurry to a Bingham fluid (3, 7).

This report summarizes the laboratory test results which demonstrate that SRC-water slurry with an additive concentration of less than 1.0 wt %, ^{*} can be successfully prepared with optimal stability and maximum energy (Btu/lb) content.

OBJECTIVES

The objectives of this work are:

- ° To identify commercially available viscosity-reducing dispersants and stabilizers.
- ° To develop and establish the slurry preparation technique.
- ° To evaluate quantitatively and to optimize the solid concentration, particle size distribution, additive concentration, and temperature based on the viscosity and stability characteristics of the slurry.
- ° To determine the flow characteristics of optimized slurries.

EXPERIMENTAL PROCEDURE

Materials

Based on the information on coal-water slurries and the results of preliminary screening tests on various commercially available additives, the following chemical additives were found to be suitable for the preparation of SRC-water slurries:

- ° Dispersant A-23 (Diamond Shamrock Corp.)

As an ammonium salt, A-23 is an anionic, high-molecular-weight, condensed polynuclear hydrocarbon. It is available in

^{*} All weight percents are based on the weight of SRC.

liquid form at 42-45% solids and also as a tan fine powder that readily dissolves in water.

Stabilizer CW-23 (Diamond Shamrock Corp.)

This proprietary anionic, dark, reddish-brown liquid of 55% activity is completely soluble in water.

Two SRC deashed solid samples used in this investigation were acquired from Wilsonville through International Coal Refining Company. The sample marked "SRC(A)" was taken from Wilsonville Run 235. SRC(A) was pulverized and sieved into various particle sizes ranging from 100% minus 100 mesh to 100% minus 200 mesh. The sample marked "SRC(B)" was an "industrial" pulverized sample of 80% minus 200 mesh. The ultimate analysis and heating value for each sample are listed in Table 1. Additional data on the size distribution used for the test and a cross-reference for the tables and figures are provided in the Appendix.

Slurry Preparation

The SRC-water slurry was prepared by first adding the dispersant and stabilizer to deionized water at ambient temperature in the desired quantities based on the weight of SRC to be subsequently added. The requisite quantity of pulverized SRC was then gradually added to the water-additive composition under mechanical stirring and intermittent 30-sec sonic agitation. After complete addition of the desired SRC quantity, the mixture was again subjected to sonic agitation for 1 to 3 min, depending on the solid content of the mixture, followed by mechanical stirring for 1 hr.

The sonic agitation helped to break the SRC agglomerates to primary particles, leading to a stabilized mixture of reduced viscosity. The ultrasonic radiation was produced by an ultrasonic horn manufactured by Branson Sonic Power (a Smith Kline Company), Danbury, Connecticut. Because the instrument was "tuned" to generate sound at a frequency of 20 KHz, the frequency of the wave was not a variable; however, the power output could be adjusted. Sonication of the slurries was performed at a medium power output level by placing the tip of the horn just below the surface of the slurry in the mixing vessel.

Viscosity Measurement

Viscosities of the slurries at different shear rates were determined using a conventional concentric cylinder rotational viscometer, the Haake Rotovisco, an instrument that has been used by several researchers working on coal-water mixtures. The MVI and MVII sample systems with the appropriate measuring head were used for these measurements. Unless otherwise stated, all measurements were performed at ambient temperature (75-78°F) using fresh sample for each run. To improve repeatability, a standard preshearing treatment (2 min at 117 sec^{-1}) was given to each sample to remove the effects of the ill-defined shear history acquired during the sample loading. Following this pre-shear, the flow curve was determined for a 2-min period to evaluate time dependency at each increasing shear rate step. In some cases a Brookfield viscometer (LVT) was also used to measure viscosities at 30 rpm.

Static Stability

Settling rates were determined to screen additives for effectiveness and to evaluate static stability of slurries in order to optimize the additive concentration and particle size distribution. Freshly prepared slurry samples, each of approximately 60 mL, were placed in 2-oz flat-bottom glass jars and allowed to settle. The initial height of the slurry was measured, and the jars were then carefully capped and placed in an oven at 78°F. At regular intervals, the height, h_1 , of the sediment at the bottom of the jars was measured by gently inserting into the jars a thin white graduated plastic ruler as far as the hard-packed sediment layer. Measurements were made until no further increase in the height, h_2 at time t_∞ , could be detected and a clean water layer appeared over the settled solids. Percent settled was calculated using the settling ratio as follows:

$$\text{Percent settled} = \frac{h_1}{h_2} \times 100$$

RESULTS AND DISCUSSION

Both viscosity and settling data were used to evaluate the SRC-water slurry system. Preliminary results during the development of the

slurry preparation technique and screening of additives revealed the following:

- A dispersant is necessary to prepare an SRC-water slurry having a solid content greater than 55 wt % to avoid viscosities exceeding 1,000 cp which is the nominal upper limit for pumping purposes.
- Slurries having water contents exceeding about 60%, even with additives, are highly unstable.
- Slurries having solid contents greater than 60 wt % are viscous and show dilatant behavior, i.e., viscosity increases as the rate of shear increases.
- A sonication and mixing technique helps to prevent dilatant behavior and to reduce viscosity.
- An increase in solid concentration increases the static stability of the slurry.
- Stability and viscosity characteristics change drastically as the solid content is increased above 65 wt %.
- Stabilizers affect both stability and viscosity of the slurry.
- Addition of incompatible dispersants and stabilizers can adversely affect the stability of the slurry.
- Particle size distribution affects both stability and viscosity of the slurry.

In this study, the effects of the following parameters were examined: (a) concentration of solids, (b) particle size distribution, (c) dispersant concentration, (d) stabilizer concentration, and (e) ultrasonic radiation. Evaluations were performed on slurries having solid concentrations equal to or greater than 55 wt %.

Table 2 lists the viscosity of the optimized SRC-water slurries as a function of solid concentration and shear rate. Also shown is the time-dependent behavior at each applied shear rate. The SRC(A) sample used for the preparation of these slurries had a particle size distribution of 100% minus 170 mesh. The optimized dispersant A-23 and stabilizer CW-23 concentrations were 0.5 and 0.25 wt %, respectively. Figures 1 and 2 summarize, respectively, the interpolated viscosity at a

shear rate of 500 sec^{-1} as a function of SRC solid concentration and shear time. The variation of slurry viscosity with shear rate at shear times of 30 and 120 sec is summarized in Figure 3. It can be seen from the data that:

- ° At a given shear rate and shear time, a dramatic increase in slurry viscosity occurs as the solid concentration is increased above 63 wt %.
- ° At a given shear rate and solid concentration, slurry viscosity as a function of shear time decreases and then levels out as the time of shear increases. This decrease in viscosity with shear time is more prominent at low shear rates and solid concentrations equal to or greater than 65 wt %; (high solids concentrations require a higher shear time to level out).
- ° An increase in the concentration of SRC solid increases the shear thinning (pseudoplastic) characteristics of the slurry, particularly at low shear times of less than 90 sec.
- ° At a shear time of 120 sec (higher for slurries greater than 65 wt % solid), SRC-water slurries exhibit Newtonian behavior (viscosity independent of shear rate) in the range of shear rates studied.

Particle Size Distribution Effect

Sample SRC(A) was pulverized and sieved into three particle sizes with distributions of -100 + 170 mesh, -170 + 200 mesh, and -200 mesh. Each of these three samples was then used to prepare a slurry of 60 wt % solid content with 0.5 wt % dispersant A-23 and 0.15 wt % stabilizer CW-23 concentrations. To evaluate the effect of particle size distribution, both static stability and viscosity of each slurry at 78°F was determined. The settling rates were measured by the method described previously. Viscosities were determined using a Brookfield LVT viscometer at 30 rpm. The results are listed in Table 3 and summarized in Figures 4 and 5.

Figure 4 shows that the viscosity of the slurry increases with a decrease in particle size. This may be due to the increase in the

number of particles with decreasing particle size for a given concentration, which corresponds to a decrease in the interparticle distance and an increase in the surface area of the particles. Consequently, the particle-particle and particle-fluid interactions would be enhanced. The overall result would be to increase the viscosity of the suspension as the particle size decreases, since more energy would be dissipated during viscous flow of the suspension.

Figure 5 shows that the particle size distribution of -170 + 200 mesh provides optimum static stability in the suspension. As can be seen in Table 3, the percents sedimentation after 4 hr in slurries with particle sizes of -100 + 170 mesh, -170 + 200 mesh, and -200 mesh were 83.3, 12.8, and 40.0, respectively. The distribution of -170 + 200 mesh is too narrow for practical use with commercial pulverizer systems. Therefore, based on the above settling data, a particle size distribution of 100% minus 170 mesh was chosen for maximum solid loading and optimization of SRC-water slurries.

To evaluate the effect of solids concentration in the slurry on settling rates, a freshly pulverized SRC(A) sample having a particle size of 100% minus 170 mesh was used to prepare slurries of 65 and 70 wt % solids with 0.5 wt % dispersant A-23 and 0.25 wt % stabilizer CW-23 concentrations. The settling data on these slurries are listed in Table 4 and summarized in Figure 6. To further substantiate the particle size effect, also shown are the stability data on a 65 wt % SRC-water slurry having a particle size distribution of -150 + 170 mesh. The results indicate that an increase in the amount of solid in the slurry increases the static stability of the slurry or decreases the settling rate. Settling at high solids concentration is marked by a low initial settling rate, but increases as a function of storage time to reach a maximum value. The effect of increased particle size distribution is to decrease the static stability of the slurry, leading to a high initial settling rate.

Optimization of Dispersant Concentration

Dispersants are used to minimize viscosity and reduce the interparticle network structure. Electrochemistry controls the level of

surface charge on each particle enough to effect mutual repulsion and suspend the particles at the maximum separation distance allowed by the water content. This minimizes the particle collision frequency in shear, which therefore minimizes viscosity.

To evaluate the dispersant A-23 concentration effect on the stability and viscosity of the suspension, slurries of 65 wt % SRC(A) sample having an optimized particle size of 100% minus 170 mesh were prepared with 0.25 wt % stabilizer CW-23 and dispersant A-23 concentrations varying from 0.1 to 0.5 wt %. Table 5 and Figure 7 show the correlation between Haake viscosities and weight percent dispersant of a 65 wt % SRC-water slurry. Since, as shown previously, a 65 wt % slurry at a shear time of 120 sec shows Newtonian behavior, it is evident from Figure 7 that in order to approach a near minimum viscosity slurry, a dispersant concentration of 0.3-0.5 wt % is required.

Table 6 lists the stability test results obtained on 65 wt % slurries having dispersant A-23 concentrations of 0.1 and 0.5 wt %. The increase in the amount of dispersant A-23 decreases the initial settling rate of the slurry.

Based on the above results, a dispersant A-23 concentration of 0.3-0.5 wt % was considered optimum for the preparation of a more stable reduced-viscosity SRC-water slurry.

Optimization of Stabilizer Concentration

Stabilizers are used to improve slurry stability. Two sets of experiments were performed to evaluate and optimize the effect of stabilizer CW-23 on the stability and viscosity of SRC-water slurries. One set of experiments involved the use of commercially pulverized SRC, sample SRC(B), having a particle size distribution of 80% minus 200 mesh. Slurries of 60 wt % SRC content were prepared with 0.5 wt % dispersant A-23 and with stabilizer CW-23 concentrations ranging between 0 and 0.3 wt %. The settling rates of the slurries were determined by the method described previously. Viscosities were measured using a Brookfield LVT viscometer at 30 rpm. The results are listed in Table 7, and summarized in Figures 8 and 9. As can be seen from Figure 8, due to the large number of particles of less than minus 200 mesh, the overall stability of the slurry without the stabilizer was low. Conversely, the

presence of stabilizer enhances the static stability of the slurries. The settling rate decreases with the increase in stabilizer concentration. A decrease in settling rate of about 60% can be achieved by the addition of 0.3 wt % stabilizer CW-23.

Figure 9 shows the effect of stabilizer concentration on the Brookfield viscosity of the slurry. It is interesting to note that the thinning characteristic of the stabilizer reverses at concentrations greater than 0.25 wt %, indicating the optimum concentration of stabilizer CW-23 for SRC-water slurries.

To substantiate the above results, another set of experiments was performed using the optimized particle size distribution of 100% minus 170 mesh, and the optimized dispersant A-23 concentration of 0.5 wt %. The solid loading was increased to 65 wt %. The slurries were prepared using the SRC(A) sample with a particle size distribution of 100% minus 170 mesh. The viscosities were measured at ambient temperature, 78°F, using a Haake Rotovisco concentric cylinder viscometer in the manner described previously. The stabilizer CW-23 concentration was varied between 0.0 and 0.4 wt %. The results are listed in Tables 8 and 9. Figure 10 summarizes the effect of stabilizer concentration on the settling rate of the slurry. Figures 8 and 10 show that the static stability of the slurry significantly increases with the use of optimized particle size distribution and increased solid loading. Further, the rate of settling decreases with an increase in stabilizer concentration. Settling at stabilizer concentrations equal to or greater than 0.25 wt % is marked by a low initial settling rate, but increases as a function of storage time to reach a maximum value. The data summarized in Figure 10 substantiate the results described previously. Table 9 and Figure 11 describe the effect of stabilizer concentration on slurry viscosity. The results support the data reported in Figure 9 that the viscosity reducing characteristics of stabilizer CW-23 reverse at concentrations greater than 0.25 wt %.

A balance between the viscosity reduction and stabilization characteristics of CW-23 suggests a concentration of 0.25 wt % as optimum for the preparation of SRC-water slurries.

Sonication Effect

As mentioned earlier, SRC-water slurries with solid loading greater than 60 wt % were highly viscous and showed dilatant behavior. Sonication was found to break the SRC agglomerates to primary particles, leading to a stabilized mixture of reduced viscosity. Table 10 summarizes the effect of sonication on the thinning characteristics of SRC-water slurries having optimized particle size distribution and additive concentrations. Sonication times required for thinning the slurry vary with the solid content of the slurry. As depicted in Figure 12, the viscosity of the slurry decreases with the time of sonication, leading to a slurry of minimized viscosity. The viscosity values were measured at the highest shear rate and at a shear time of 120 sec.

Temperature Effect

To evaluate the temperature effect, the viscosity of a 65 wt % SRC-water optimized slurry was measured at 78 and 99°F. The results are shown in Table 11. Within the narrow temperature range evaluated, the viscosity of the slurry is independent of temperature.

CONCLUSIONS

- ° Chemical additives are required to prepare SRC-water slurries with solid concentrations greater than 55 wt %.
- ° Diamond Shamrock's Dispersant A-23 and Stabilizer CW-23 are highly effective additives for SRC-water slurries having a solids content greater than 55 wt %.
- ° Slurries with greater than 60 wt % solid are viscous and show dilatant behavior (i.e., viscosity increases as the rate of shear increases) unless special mixing techniques are used.
- ° An intermittent sonication and mechanical mixing technique prevents dilatant behavior of the slurries and produces homogeneous mixtures with reduced viscosity.
- ° Viscosity and static stability of the slurry depend on solid content, particle size distribution, additive concentration, and ultrasonic radiation applied during the preparation of the slurry.

- ° An increase in solid content increases the viscosity, static stability, and shear thinning (pseudoplastic) characteristics of the slurries.

- ° Slurries show a time-dependent behavior at each applied shear rate. At shear times greater than 120 sec, slurries of up to 65 wt % solids exhibit Newtonian behavior.

- ° A dramatic increase in slurry viscosity occurs as solid loading is increased above 63 wt %.

- ° The viscosity of the slurry increases with a decrease in particle size. A particle size distribution of 100% between -170 +200 mesh provides optimum static stability to SRC-water slurry.

- ° An increase in the amount of dispersant A-23 decreases the initial settling rate of the slurry. A dispersant A-23 optimum concentration of 0.5 wt %, based on the weight of SRC, is required for a near minimum viscosity slurry.

- ° The presence of stabilizer CW-23 in the slurry enhances static stability. CW-23 also acts as a thinner, but the viscosity reducing characteristics reverse at concentrations greater than 0.25 wt %.

- ° The optimum concentrations of 0.3-0.5 and 0.25 wt % of A-23 and CW-23, respectively, are required for the preparation of sufficiently stable and reduced viscosity SRC-water slurries having an optimized particle size distribution of 100% minus 170 mesh.

- ° Reasonably stable and homogeneous slurries with a solid content greater than 70 wt % and viscosity less than 1,000 cP can be prepared by using optimized concentrations of additives as well as particle size distribution and a sonication technique.

- ° Some amount of agitation or recirculation will be required to avoid settling during long-term storage.

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Table 1
Properties of SRC Solid Fuel

Ultimate analysis (wt %)	SRC(A)	SRC(B)
C	86.20	86.16
H	5.99	5.82
O	4.61	4.78
N	2.12	2.16
S	1.02	0.95
Ash	0.06	0.13
Heating value (Btu/lb)	15,482	15,400

Table 2

Viscosity of Optimized SRC-Water Slurries^a

SRC solid concentration (wt %)	Shear rate (sec ⁻¹)	Viscosity (cP) at shear time (sec)			
		30	60	90	120
55	468	83	74	69	63
	936	72	69	66	63
	1,404	65	63	62	61
62	468	100	91	82	75
	936	85	81	78	75
	1,404	79	77	75	74
65	468	201	179	160	147
	936	180	165	154	144
	1,404	169	160	154	149
70	180	514	485	447	428
	540	476	447	425	409

^aConcentration of Dispersant A-23, 0.5 wt % and of Stabilizer CW-23, 0.25 wt %.

Table 3

Particle Size Distribution Effect^a

Particle size	Brookfield viscosity at 30 rpm (cP)	Static stability		
		Storage time (hr)	Sediment height (mm)	% settled
-100+170 mesh	62	1.0	14	29.2
		1.5	19	39.6
		2.5	33	68.8
		3.0	35	72.9
		4.0	40	83.3
		t_{∞}	48	
-170+200 mesh	112	1.0	2	4.3
		1.5	2	4.3
		2.0	3	6.4
		2.5	3	6.4
		3.0	4	8.5
		4.0	6	12.8
		4.5	7	14.9
		5.0	8	17.0
		t_{∞}	47	
-200 mesh ^b	134	1.0	4	11.4
		1.5	5	14.3
		2.0	7	20.0
		2.5	8	22.9
		3.0	9	25.7
		4.0	14	40.0
		4.5	16	45.7
		5.0	17	48.6
		t_{∞}	35	

^aSlurry composition: SRC(A), 60 wt %; Dispersant A-23, 0.5 wt %; Stabilizer CW-23, 0.15 wt %. Temperature = 78°F and pH = 7.9.

^bOn complete sedimentation the slurry separated into three distinct layers: a fine particle suspension at the top, clear water in the middle and hard-packed solid at the bottom.

Table 4

Effects of Solid Concentration and Particle Size
Distribution on the Settling Rate of SRC-Water Slurry^a

SRC concentration (wt %)	Particle size	Static stability		
		Storage time (hr)	Sediment height (mm)	% settled
65	100% -170 mesh	17	3	6
		24	5	10
		48	13	26
		72	28	56
		t_{∞}	50	
65	-150 +170 mesh	17	27	55.1
		24	40	81.6
		t_{∞}	49	
70	100% -170 mesh	8	1	2.0
		24	3	5.9
		48	6	11.8
		72	12	23.5
		96	26	51.0
		t_{∞}	51	

^aDispersant A-23, 0.5 wt %; Stabilizer CW-23, 0.25 wt %. Temperature = 78°F and pH = 8.4 - 8.6.

Table 5

Effect of Dispersant A-23 Concentration on the Viscosity of
65 wt % SRC-Water Slurry with 0.25 wt % Stabilizer CW-23^a

A-23 concentra- tion (wt %)	Shear rate (sec ⁻¹)	Viscosity (cP) after shear time of 120 sec
0.1	234	539
0.3	468	154
0.5	468	147

^aTemperature 77-78°F.

Table 6

Effect of Dispersant A-23 Concentration on the Static
Stability of 65 wt % SRC-Water Slurry with
0.25 wt % Stabilizer CW-23^a

A-23 concentration (wt.%)	Static stability		
	Storage time (hr)	Sediment height (mm)	% settled
0.1	24	8	16
	28	10	20
	48	19	38
	72	30	60
	t_{∞}	50	
0.5	17	3	6
	24	5	10
	48	13	26
	72	28	56
	t_{∞}	50	

^aTemperature = 78°F.

Table 7

Effect of Stabilizer CW-23 Concentration on the
Viscosity and Stability of SRC-Water Slurry^a

CW-23 concentration (wt %)	Brookfield viscosity at 30 rpm	pH	Static stability		
			Storage time (hr)	Sediment height (mm)	% settled
0	202	7.2	2.0	8	16
			4.0	14	28
			4.5	16	32
			5.5	20	40
			6.5	24	48
			∞	50	
0.08	163	7.9	3.0	8	19.0
			3.5	9	21.4
			4.5	12	28.6
			5.5	15	35.7
			7.0	19	45.2
			7.5	20	47.6
			∞	42	
0.15	114	--	2.0	5	11.6
			3.0	6	14.0
			4.0	9	20.9
			4.5	11	25.6
			5.0	12	27.9
			∞	43	
0.25	78	--	2.0	4	8.9
			2.5	4	8.9
			3.0	5	11.1
			3.5	6	13.3
			4.5	7	15.6
			5.0	8	17.8
			∞	45	
0.30	122	7.9	2.5	3	6.5
			3.0	4	8.7
			4.0	6	13.0
			5.5	8	17.4
			6.0	8	17.4
			∞	46	

^aSlurry composition: SRC(B), 60 wt %; Dispersant: A-23, 0.5 wt %; temperature = 78°F.

Table 8

Effect of Stabilizer CW-23 Concentration
on the Static Stability of 65 wt % SRC(A) Water-Slurry
with 0.5 wt % Dispersant A-23^a

CW-23 concentra- tion (wt %)	Static stability		
	Storage time (hr)	Sediment height (mm)	% settled
0	17	8	16
	24	14	28
	48	24	48
	72	31	62
	∞	50	
0.10	24	10	19.6
	48	21	41.1
	72	30	58.8
	∞	51	
0.25	17	3	6
	24	5	10
	48	13	26
	72	28	56
	∞	50	
0.40	16	2	4.1
	24	4	8.2
	48	10	20.2
	72	22	44.9
	∞	49	

^a pH = 8.1 - 8.4 and temperature = 78°F.

Table 9

Effect of Stabilizer CW-23 Concentration on the
Viscosity of 65 wt % SRC(A) Water-Slurry with
0.5 wt % Dispersant A-23^a

CW-23 concentra- tion (wt %)	Shear rate (sec ⁻¹)	Viscosity (cP) at shear time (sec)			
		30	60	90	120
0.0	180	1,151	1,094	1,027	980
0.10	294	486	458	433	417
0.25	468	210	179	160	147
0.40	468	277	241	213	194
	936	238	215	198	187

^aTemperature = 78°F.

Table 10

Effect of Sonication on the Viscosity of SRC Water-Slurries

Solid concentration (wt %)	Total sonication time (sec)	Shear rate (sec ⁻¹)	Viscosity (cP) at shear time			
			30	60	90	120
55	0	468	282	172	160	129
		1,404	124	120	116	113
	20	468	138	116	100	91
		1,404	97	94	92	90
	120	468	83	74	69	63
		1,404	65	63	62	61
62	40	468	190	160	144	133
		1,404	126	121	118	114
	90	468	172	144	128	116
		1,404	98	92	89	87
	180	468	100	91	82	75
		1,404	79	77	75	74
70	Partial sonication	180	894	818	780	751
		270	831	786	748	723
	High sonication (~180 sec)	180	514	485	447	428
		540	476	447	425	409

^aDispersant A-23, 0.5 wt %; Stabilizer CW-23, 0.25 wt %.

Table 11

Temperature Effect on SRC Water-Slurry

Temperature (°F)	Shear rate (sec ⁻¹)	Viscosity (cP) at shear time (sec)			
		30	60	90	120
78	468	201	179	160	147
	936	180	165	154	144
	1,404	169	160	154	149
99	468	249	171	157	144
	936	193	173	158	148

^aComposition: SRC(A), 65 wt %; A-23, 0.5 wt %, CW-23, 0.25 wt %; particle size, 100% minus 170 mesh.

FIGURE 1
VARIATION OF VISCOSITY AS A FUNCTION OF SRC SOLID CONCENTRATION
SHEAR RATE: 500 SEC⁻¹
SHEAR TIME: 120 SEC.

FIGURE 2
SLURRY VISCOSITY AS A FUNCTION OF SHEAR TIME
SHEAR RATE: 500 SEC-1

FIGURE 3
SLURRY VISCOSITY AS A FUNCTION OF SHEAR RATE

FIGURE 4
EFFECT OF PARTICLE SIZE ON THE VISCOSITY OF SRC-WATER SLURRY
SLURRY COMPOSITION: SRC(A), 60WT.%; A-23, 0.5WT.%; CW-23, 0.15WT.%

FIGURE 5
PARTICLE SIZE DISTRIBUTION EFFECT
SRC(A), 60 WT.%; A-23, 0.5 WT.%; CW-23, 0.15 WT.%

FIGURE 6
EFFECTS OF SOLID CONCENTRATION AND PARTICLE SIZE DISTRIBUTION
ON THE SETTLING RATE OF SRC - WATER SLURRY

FIGURE 7
EFFECT OF DISPERSANT CONCENTRATION
ON THE VISCOSITY OF 65 WT.% SRC - WATER SLURRY
WITH 0.25 WT.% STABILIZER CW-23

FIGURE 8
EFFECT OF STABILIZER CW-23 CONCENTRATION
ON THE STATIC STABILITY OF SRC - WATER SLURRY

FIGURE 9
EFFECT OF STABILIZER CW-23 CONCENTRATION
ON THE VISCOSITY OF 60 WT.% SRC(B)-WATER SLURRY
WITH 0.5 WT.% DISPERSANT A-23

FIGURE 10
EFFECT OF STABILIZER CW-23 CONCENTRATION
ON THE STABILITY OF SRC - WATER SLURRY

FIGURE 11
EFFECT OF STABILIZER CW-23 CONCENTRATION
ON THE VISCOSITY OF 65 WT.% SRC(A) - WATER SLURRY
WITH 0.5 WT.% DISPERSANT A-23

FIGURE 12
EFFECT OF SONICATION ON THE
VISCOSITY OF SRC - WATER SLURRY
DISPERSANT A-23, 0.5 WT.%
STABILIZER CW-23, 0.25 WT.%

Appendix

Size Distribution of SRC Samples

Sample	Wt % retained on mesh size (Tyler sieve series)				Used for preparing data in	
	100	150	170	200	Table no.	Figure no.
<u>SRC (A)</u>						
-100 +170 mesh	0		100		3	4,5
-170 +200 mesh			0	100	3	4,5
-200 mesh				0	3	4,5
-170 mesh			0		2,4,5,8, 9,10,11	1,2,3,6,7, 10,11,12
-150 +170 mesh		0	100		4	6
<u>SRC (B)</u>						
-200 mesh				20	7	8,9