

The Sedimentation of Coal in Model Oils: The Effect of the Viscosity and Composition of the Oil

The results of batch settling tests with various coal powders in model oils indicated that the viscosity and the aromatic/paraffinic nature of the oil influences the sedimentation and the aggregation rate of the particles. Oxidation of paraffin oil may result in the generation of surface active agents which retards the sedimentation of certain coals.

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SCOPE

A coal-oil mixture (COM)—a dispersion of finely pulverized coal in No. 6 fuel oil—is an alternative fuel to be used as an interim measure to reduce oil imports without requiring major renovations to existing oil-fired power facilities. A question which has been raised is how significant the variability of the chemical and physical properties of the residual oil is to the sedimentation behavior of the coal-oil slurry. This variability includes differences in the content of aromatic compounds, in the content of asphaltenes and in the content of naturally occurring or deliberately added surface active agents (Dodd et al., 1952).

Ekman and Bienstock (1979) have compared the sedimentation of Pittsburgh Seam coal in several different No. 6 oils. A regression analysis was performed with the settling data and various oil characteristics. The results indicated to a level of 99% confidence that the oxygen/nitrogen ratio of the asphaltenes, the nitrogen/carbon ratio of the asphaltenes and the kinematic viscosity are correlated to the sedimentation kinetics of the slurry. The complexity of No. 6 oil required a statistical approach to the interpretation of the data. With this in mind and with the appreciation that even the meaningful characterization

of No. 6 oil is in itself a current problem, an experimental scheme was developed in this work using model oils such as hexane, toluene, kerosene and paraffin oil and their mixtures rather than No. 6 oil itself. The use of these model oils, unlike the black and opaque No. 6 oil, also permitted the rapid evaluation of the sedimentation kinetics.

The COM prepared with model oil were employed to study the effect of the viscosity and the paraffinic/aromatic composition of the oil on the settling behavior of the coal. The effect of viscosity was studied by comparing the settling rates of suspensions of four different coals having closely matched particle size distributions (including a lignite and three bituminous coals) in hexane and kerosene at 22°C and in paraffin oil at 45°C and 70°C. The slurries in paraffin oil were prepared using both a mechanical dispersator and an ultrasonic dispersator. The effect of the chemical composition (paraffinic/aromatic nature) of the oil was investigated by comparing the settling velocities of six coals having closely matched particle size distributions (including an anthracite, four bituminous samples and a lignite) in toluene, in hexane and in the three toluene/hexane mixtures at room temperature.

CONCLUSIONS AND SIGNIFICANCE

The experimental data indicated that variations of the oil viscosity affect the sedimentation rate of the coal particles not only directly, but also indirectly by changing the sizes of the aggregates of the primary particles. This added effect appears to be responsible for increasing the sedimentation rate of coal by about 50–80% for the Sewell and Pocahontas coals and by about 130% for the Illinois coal, when the viscosity of the oil was lowered from 4.3×10^{-2} kg/m-s (43 cp) to 1.6×10^{-2} kg/m-s (16 cp) (a decrease of 37%).

The above results are based on data obtained from COM prepared using an ultrasonic dispersator. These data could not be compared with results obtained from slurries which were mechanically mixed for the following reasons. First, under the conditions of mechanical mixing, a relatively large volume of air becomes entrapped in the oil. At elevated temperatures (circa 70°C), it was shown that the air caused the formation of surface active agents by the oxidation of naturally occurring substances within the paraffin oil. The presence of these surfactants reduced the settling of the Illinois COM from 1.20 cm/h at 45°C to 0.45 cm/h at 70°C. This result indicates that the SAA reduces the aggregation of the Illinois particles. This reduces the size of the "particles" and thus the settling rate is reduced. Similar

behavior has been observed with Illinois coal in model oil by the deliberate addition of dispersants, such as calcium petroleum sulfonate (Witco's Calcium Petronate 25H), bis(2-hydroxyethyl) octadecylamine (Armak's Ethomeen 18/12), and dimethyldi(hydrogenated-tallow) ammonium chloride (Armak's Arquad 2HT-75) (Adams-Viola, 1981). Secondly, mechanical agitation in certain systems appears to lead to higher velocities than ultrasonic mixing. The sedimentation rates of the Illinois coal were 1.31 and 0.37 cm/h, for the mechanically mixed and ultrasonically treated slurries, respectively. Since Illinois coal has a strong tendency to aggregate (Botsaris et al., 1979) it is assumed that the ultrasonic energy breaks apart aggregates of the primary particles.

Sedimentation data collected for suspensions for six different coals in hexane, toluene and in three different hexane/toluene mixtures showed that differences in the chemical nature of the oil produced variations in the settling rate of the coals to an extent which depended upon the nature of the coal. These variations could not be explained on the basis of differences in the kinematic viscosities of the oil alone. Therefore, it is speculated that the chemical nature of the oil affects: (1) the nature of particle/particle interactions, possibly as a result of the solvation of the coal particles by the liquid; (2) the ability of the coal particles to swell; and (3) the extraction of soluble substances from the coal matrix.

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BACKGROUND

Sedimentation is not only affected by hydrodynamic factors but can also be profoundly affected by interfacial phenomena to an extent which depends upon the degree of attraction between the particles, as well as their size distribution.

In an aggregatively stable system, i.e., a suspension in which the particles do not interact or aggregate with each other, the hindered settling velocity of a sphere greater than a few microns may be expressed according to Stokes' law:

$$V_s = \frac{d^2(\rho_P - \rho_L)}{18\eta} \quad (1)$$

More recent settling rate expressions have attempted to account for hindered settling, particle aggregation and polydisperse particle size distributions in a quantitative fashion using various numerical and computer analysis techniques (Fitch, 1979). The setting behavior of coarse suspensions (particles greater than a few microns in diameter) can be most easily discussed in terms of certain regimes which are defined by two parameters: the degree of particle/particle interactions and the solids concentration (on a volume basis). The three regimes which can be identified over certain ranges of these two parameters are (Fitch, 1978):

1. Clarification
2. Zone settling
3. Compression

It is important to emphasize that although each of the above mentioned regimes have certain distinguishing features, there are no sharp transitions from one regime to the next. This implies that although the regime of some real systems undergoing sedimentation may be easily identified, other systems which actually lie in transitional zones may not be so easily characterized.

Clarification

In the clarification regime, particles settle freely, at a rate which is dependent upon their size. The most distinguishing feature of the clarification regime is that in a batch settling test, the settled bed can be observed to build up from the bottom of the cylinder. Moreover, if the particles have a polydisperse size distribution, no distinct interface is formed in the supernatant liquid during the separation process.

Zone Settling (Subsidence)

When the solids concentration reaches a critical level in either an aggregatively stable or aggregatively unstable suspension, the particles (or the aggregates) come into contact with each other and form some sort of structure which controls the settling rate of the solids. Whether or not the structure is continuous throughout the liquid, the particles (or aggregates) will be constrained to settle at a single rate, independent of their size (Fitch, 1979). Under such conditions, the slurry enters a zone-settling regime of sedimentation and the settling behavior is often termed subsidence. [This definition of subsidence is more general than the definition used by La Mer and Healy (1963), who implied that subsidence is associated with flocculation by a polymeric additive.] Zone settling can easily be distinguished by a batch settling test, since a sharp interface which is formed between supernatant liquid and pulp, moves downward from the top of the suspension.

Compression

As the concentration is further increased, the pulp structure becomes so firm that each layer of solids is capable of transmitting mechanical support to layers of particles above. Thus, the solids develop a compressive strength and in order to compact the structure further a stress greater than the compressive yield stress of the structure must be exerted upon it. Under such conditions, the sediment of slurry is said to be in the compression or compaction regime of sedimentation.

EXPERIMENTAL

Materials

Coal samples were obtained from the following seams: Buck Mountain (anthracite); Pittsburgh No. 8, Pocahontas No. 4, Sewell No. 3, Illinois (all bituminous); and North Dakota (lignite). The coal powders were pulverized (dry) and classified to approximately 80% through 200 mesh and 65% through 325 mesh. The densities of these coals were evaluated by measuring the density of a 35 wt% coal-oil slurry. The slurries were prepared with 45°C residual oil, then degassed in a vacuum desiccator for 20 minutes. The density of the slurry was measured at 45°C with a hydrometer immediately after preparation to minimize the possibility of the development of a coal concentration gradient. The densities (in g/cm) of the coals were evaluated to be: 1.38 for the Pocahontas, 1.36 for the Sewell and 1.42 for both the Illinois and lignite. The ultimate and proximate analysis of these coals may be found elsewhere (Adams-Viola, 1981). The surface properties and namely the hydrophilic/oleophilic behavior of these coals have also been evaluated (Adams-Viola, 1981; Adams-Viola et al., 1981). The degree of hydrophobicity of these coals (in order of increasing hydrophobicity) is as follows: Buck Mountain < Pittsburgh Bituminous < Pocahontas Bituminous < Sewell Bituminous < Illinois Bituminous < North Dakota.

All of the oils were obtained from Fisher Scientific Company and were used without any special pretreatment. The viscosity of the paraffin oil was measured to be 4.3×10^{-2} kg/m-s (43 cp) at 45°C and 1.6×10^{-2} kg/m-s (16 cp) at 70°C. Its density was also measured to be 0.88 g/cm and 0.86 g/cm at 45°C and 70°C, respectively. According to the supplier, the kerosene contained at most 1.0 wt.% aromatics. Its viscosity was measured to be 1.8 cp and its density was 0.78 g/cm at 22°C.

Procedures

The "70°C paraffin oil/coal slurries" were prepared by adding the oil, which was preheated to 80°C, to the coal powder. The oil was preheated to a temperature higher than the slurry settling temperature to offset the heat losses incurred during the subsequent slurry preparation steps. The oil and the coal (35 wt.%) were subsequently mixed for two minutes using the mechanical dispersator or for four minutes when the ultrasonic dispersator was used. If the slurry was mechanically mixed, it was subsequently degassed until no bubbles were further removed (about 10–15 minutes). If the slurry was ultrasonically mixed, the oil was degassed for 10–15 minutes before the oil was preheated, but the slurry itself was not degassed. After mixing and degassing, the slurry was stored in a 70°C bath until its temperature returned to 70°C. During this time, the slurries were gently stirred by hand. Finally, the slurries were poured into 250 mL graduate cylinders and placed in a bath maintained at 70°C by immersion heaters. The procedure for the "45°C paraffin oil slurries" was the same as above, except that the oil was preheated to 52°C before the addition of the coal.

The suspensions of the coal powders in hexane and/or toluene were prepared by gently blending the coal and oil(s) for 3 minutes using a magnetic stirrer. The slurry was then transferred into a graduate cylinder which was maintained at room temperature (22°C ± 2°C). The rate of sedimentation was measured by observing the height of the supernatant/slurry interface as a function of time.

RESULTS AND DISCUSSION

Ultrasonically Mixed Coal/Paraffin Oil Suspensions

The settling velocities of the coal/paraffin oil slurries prepared with the ultrasonic mixer at 45°C and 70°C were evaluated from the sedimentation curves and are presented in Table 1 in the first two columns. As it was expected, the decrease in the kinematic viscosity, incurred by the increased slurry storage temperature, enhanced the sedimentation rate of the coal. It is also interesting to note that both 45°C and 70°C the relatively oleophilic coals, the

TABLE 1. SETTLING VELOCITIES OF ULTRASONICALLY MIXED COAL/PARAFFIN OIL SUSPENSIONS

Coal	Settling Velocities, V (10^2 cm/h)			
	V_{45}	V_{70}	V_{70}^*	$(V/V^*)_{70}$
Pocahontas	6.6	26.4	18.0	1.5
Sewell	5.4	26.4	14.6	1.8
Illinois	37.2	233.	100.4	2.3
Lignite	33.6	78.0	90.7	0.9

* V_{70}^* is the settling velocity predicted at 70°C from data obtained at 45°C by using Eq. 3.

Pocahontas and Sewell, settled five to six times slower than the Illinois bituminous and the lignite which are relatively hydrophilic, although the particle size distributions of the coal powders were closely matched. Moreover, it is unlikely that this difference is a result of the disintegration of primary coal particles of the Pocahontas and Sewell coals. The Hardgrove Grindability Indices of the lignite and the Illinois are above 50 and 60, respectively, while the values reported for coal samples obtained from the Sewell and Pocahontas Seams are between 100 and 110 (McNally, 1976). Although Dooher et al. (1977) has shown that severe ultrasonic treatment may disintegrate primary coal particles in No. 2 oil to an extent which increases as the Hardgrove Grindability of the coal decreases, the gentle ultrasonic treatment applied here has been shown not to significantly effect the primary particle size distribution of the coal (Filmyer, 1981). These results then suggest that the particle/particle interactions or particle/oil interactions, as evidenced by the settling rate, are strongly affected by the oleophilic/hydrophilic nature of the coal's surface.

Based on the settling velocity at 45°C, the settling velocity at 70°C was predicted from the following relationship which can be obtained from any of the several formulas for hindered settling:

$$V_{70}^* = V_{45} \cdot \frac{\eta_{45}}{\eta_{70}} \quad (2)$$

where

V_{70}^* = the predicted settling velocity at 70°C
 V_{70} = experimental settling velocity at 45°C
 η_{45}, η_{70} = the viscosity of the oil at 45°C and 70°C, respectively

In Eq. 2, the correction for the difference in the specific gravity of the liquid has been neglected. The predicted settling rates at 70°C, V_{70}^* , and the ratios of the observed velocity at 70°C to the predicted velocity at the same temperature, $(V/V^*)_{70}$, are also presented for the four coals in Table 1. Comparison of the predicted and observed settling velocities for the bituminous coals (Pocahontas, Sewell and Illinois) reveals that there is a discrepancy of 50–130%. This suggests that the viscosity of the oil affects the sedimentation rate directly but also affects the sedimentation rate indirectly by changing the aggregation rate of the particles. As the viscosity of the oil decreases, the rate of particle aggregation increases since the liquid film formed when two particles collide can drain more rapidly (Hiemenz, 1977). This enhanced aggregation rate shifts the size distribution of the "partiles" to larger sizes, which thereby further increases the settling velocity. This dual effect of the viscosity on the settling behavior of nonaqueous suspension has also been observed in carbon black/paraffin oil systems (Van der Minne, 1946).

Although it is possible that an increase in temperature can in itself increase the aggregation rate of the particles, it is not considered likely that this factor itself is directly responsible for the observed phenomena. Experiments were also performed with the Pocahontas and Sewell coals in kerosene and n-hexane at room temperature (22°C) and the results which are presented in Table 2, were consistent with those obtained with the paraffin oil. This is reasonable because the particles are too coarse for Brownian motion to be responsible for the particle/particle collisions which influence the rate of aggregation. Moreover, since there were no surface active agents added to these suspensions, the potential

TABLE 2. SETTLING VELOCITIES OF MECHANICALLY MIXED COAL/PARAFFIN OIL SUSPENSIONS

Coal	V_K	V_H	V_H^* ^a	(V_K/V_H^*)
Pocahontas	2.5	30.6	13.2	2.3
Sewell	3.0	34.2	15.9	2.2

^a V_H^* is the settling velocity in hexane predicted from settling data of a corresponding slurry in kerosene and a scale factor, based on the relative viscosities of the two fluids.

energy barrier is most likely negligible, so that the effect of temperature is again nil.

Unlike the bituminous coals, the values of $(V/V^*)_{70}$ for the lignite was slightly less than one. The discrepancy between V_{70}^* and V_{70} may either be a result of experimental error or may be due to the extraction of trace amounts of surface active materials from the lignite. An explanation of why lignite behaves differently in this respect from the other bituminous coals is not available at this time.

Mechanically Mixed Coal/Paraffin Oil Suspensions

The settling velocities of 45°C and 70°C coal/paraffin oil slurries prepared by dispersing the coal using the mechanical mixer are presented in Table 3. As before, the predicted velocity at 70°C estimated from Eq. 1 and from the ratio of the observed velocity at 70°C to the predicted velocity at 70°C is also given in Table 3, from which the following remarks can be made. The experimental settling velocities and the ratio of the experimental velocity to the predicted velocity of the mechanically mixed slurries agreed well with the corresponding slurries which were prepared with the oleophilic Pocahontas and Sewell coals and which were ultrasonically dispersed. However, two discrepancies appeared in the sedimentation behavior of the hydrophilic coals: (1) the settling velocity of the Illinois coal at 45°C increased by a factor of four when the slurry was prepared by mechanical mixing rather than by ultrasonic mixing; and (2) the settling velocities of the mechanically dispersed Illinois slurries were less at 70°C than at 45°C.

The first discrepancy suggests that the mechanical mixer does not effectively disperse the Illinois coal while the ultrasonic mixer effectively destroys aggregates of Illinois particles, which are formed at least in part as a result of its relatively hydrophilic nature. The Sewell and Pocahontas coal particles which are much more hydrophobic (Botsaris et al., Aug. 1979; Adams-Viola, 1980) do not aggregate extensively. Thus, it was observed that these coals could be equivalently dispersed by either the ultrasonic or mechanical mixer. Although attrition of relatively large coal particles (250 micron) by ultrasonic energy has been reported in the literature (Dooher et al., 1977), these results above cannot conclusively support or reject the conclusion that an ultrasonic dispersator can disintegrate both primary particles as well as aggregates of primary particles.

Since the second "discrepancy" was quite unexpected, the settling test at 70°C was performed four times, and the 45°C slurry was prepared two times. The values in Table 3 represent averages of all of the data. The standard deviations were determined to be 18 and 13 cm/h for the 45°C and 70°C slurries, respectively. Based on all of the available information, it was hypothesized that naturally occurring resin-like materials in the paraffin oil were being oxidized when the coal was mechanically dispersed into the hot

TABLE 3. SETTLING VELOCITIES OF MECHANICALLY-MIXED COAL/PARAFFIN OIL SUSPENSIONS

Settling Velocities, V (10^2 cm/h)				
Coal	V_{45}	V_{70}	V_{70}^*	$(V/V^*)_{70}$
Pocahontas	7.2	24.6	19.4	1.3
Sewell	7.2	24.6	19.4	1.3
Illinois	120.	45.0	32.4	0.14
Lignite	33.6	87.0	90.7	0.96

* V_{70}^* is the settling velocity predicted at 70°C from data obtained at 45°C by using Eq. 3.

(80°C) oil. Unlike the ultrasonic mixer, the mechanical dispersator aerates the slurry quite effectively. It was further hypothesized that these oxidized resin-like materials are surface active and are therefore capable of modifying the surface properties of the coal. In this way, the nature of the particle/particle and particle/solvent interactions which controls the aggregation kinetics of the dispersion are altered. The formation of the surface active agents in paraffin oil by the oxidation of naturally occurring resin-like materials at elevated temperature has also been previously identified during an investigation of the aggregation of carbon black in paraffin oil (Van der Minne, 1946).

The above hypothesis was tested by agitating the paraffin oil alone for two minutes at 80°C with the mechanical dispersator. The oil was cooled to 45°C and 10 wt.% water was added. The mixture was again agitated for two minutes and then poured into a graduated cylinder. The emulsion produced was milky in color and the phases did not begin to separate until at least 15 minutes after preparation. A control emulsion was prepared in which extensive oxidation of the oil was avoided by maintaining the temperature of the oil below 45°C. In the control emulsion, 10 wt.% water was mixed with 45°C paraffin oil for 2 minutes with the mechanical dispersator. This time the mixture immediately separated into two layers as soon as the agitation was stopped, although the oil phase remained somewhat hazy for some time afterwards. The stability of the emulsion prepared by the oxidized paraffin oil and the absence of stability in the emulsion prepared from the unoxidized paraffin oil strongly suggests the presence of a surface active substances in the former dispersion. Thus, the unexpected decrease in settling rate observed for the hydrophilic COM when the temperature of the slurry was increased to 70°C can be explained by the modification of the surface of the coal by surfactant generated at elevated temperatures (about 70°C) as a result of the oxidation of naturally occurring components in the paraffin oil. This result has very important implications to the behavior of coal-oil mixtures prepared with No. 6 oil, since No. 6 oil most likely also contains similar components which may be oxidized to form surface active substances.

The Effect of the Aromatic/Paraffinic Composition of the Oil

Sedimentation profiles (interface height versus time) were obtained for slurries containing 35 wt.% of each coal in pure hexane, pure toluene and three hexane/toluene mixtures. The velocity of the interfaces, evaluated from the sedimentation profiles for each coal are shown as a function of the hexane content of the oil in Figure 1. In most cases, the supernatant/slurry interface which traveled down the column was very distinct. However, in two slurries—Sewell in toluene and Pocahontas in a 75/25 toluene/hexane mixture—the supernatant was very black, although eventually as the upper layers gradually became less concentrated, the settled solids collecting at bottom of the cylinder could be observed. The upper boundary layer of these settled beds appeared to rise as additional solids accumulated. This type of sedimentation behavior is known as particulate clarification and is quite different from the zone settling regime sedimentation behavior which was observed in the other slurries. In those slurries which appeared to display particulate clarification, the "interface velocity" plotted in Figure 1 is considered to be zero.

The possibility of the dissolution of certain components from the coal and the swelling of the cross-linked matrix caused by the penetration of solvent molecules into the pores must not be overlooked. Dissolution was evidenced especially in the dispersions in toluene by the amber colored supernatants. Moreover, the swelling would undoubtedly reduce the sedimentation rate. It is also reasonable that toluene would most effectively permeate the bituminous coal matrices since they have the highest degree of aromaticity.

In all cases, the sensitivity of the settling rate to composition of the oil cannot be explained by differences in the kinematic viscosity alone. Moreover, the aromatic/paraffinic composition of the oil influences the sedimentation kinetics of the particles to an extent which depends upon the nature of the coal.

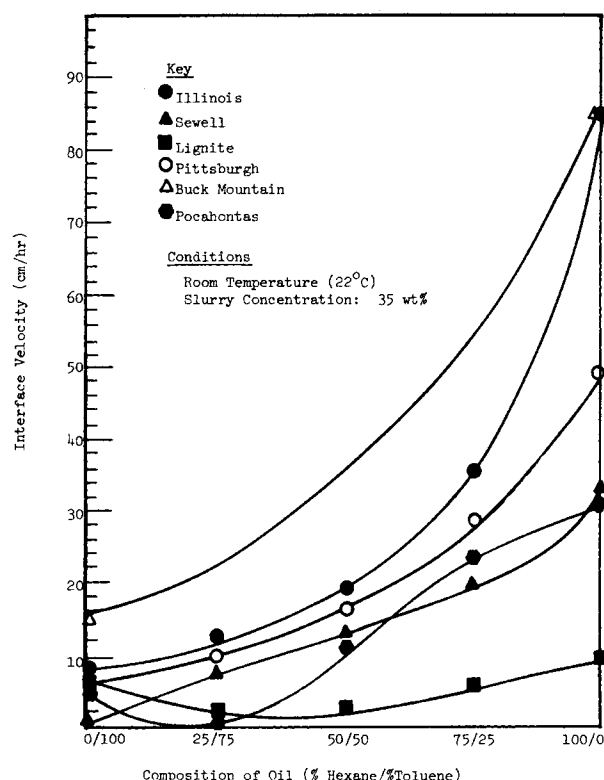


Figure 1. Interface velocities for various coal/oil suspensions.

In order to establish whether the aromatic/paraffinic composition of the oil influenced the sedimentation of the coal, an attempt was made to separate both the direct and indirect effects of the viscosity from the chemical effect of the solvent. For a given coal, the relationship between viscosity and settling rate was assumed to be a modified form of Stoke's law (Eq. 1):

$$V = C(\rho_C - \rho_L)/\eta^x \quad (3)$$

where c and x are empirical constants. The purpose of the exponent, x , in this equation is to account also for the indirect effect of viscosity on the sedimentation (as a result of its direct effect on aggregation rate) by modifying the viscosity term which appears in the equations for hindered settling which are based on hydrodynamic considerations alone. The coefficients, c and x , were determined for each coal from the sedimentation data of that coal in the paraffinic oils including paraffin oil at 45°C and 70°C, and in kerosene and hexane at room temperature. The values of x and c and the correlation coefficient are given in Table 4 for the Pocahontas, Sewell, Illinois and lignite coals.

The analysis of the constants for the Illinois were based on the sedimentation data obtained for the 45°C, mechanically-mixed slurry only. Using Eq. 4 and empirical constants obtained above, the settling velocity of each coal toluene suspension, V_T was predicted. These values are shown in Table 5. Comparison of the predicted to the observed values of the settling velocity of each coal in toluene (Table 5) shows that V_T does not equal V_T for any coal. The discrepancy must be attributed to chemical interactions in-

TABLE 4. EMPIRICAL CONSTANTS FOR VELOCITY/VISCOSITY RELATIONSHIP (Eq. 2)

Coal	c	x	Correlation Coefficient
Pocahontas	10.6	1.16	0.997
Sewell	12.4	1.17	0.998
Illinois*	26.6	1.28	0.999
Lignite	3.9	0.98	0.997

* Based on sedimentation of mechanically-mixed paraffin oil slurry at 45°C only.

TABLE 5. COMPARISON OF THE PREDICTED AND OBSERVED
SETTLING RATES OF THE COAL/TOLUENE SLURRIES

Coal	V_T (cm/h)	V_T^* ^a (cm/h)	(V/V^*)
Pocahontas	5.0	10.5	0.5
Sewell	N.D. ^b	11.9	—
Illinois	9.0	30.4	0.3
Lignite	6.5	3.7	1.8

^a V_T^* is the settling velocity predicted for settling in toluene using sedimentation data in hexane and a scale factor, based on the relative viscosities of the two fluids.

^b Not Determined. Settling occurring in the particulate clarification regime. No supernatant/slurry interface formed, instead the settled bed could be observed to grow upward from the bottom of the cylinder.

duced by the chemical properties of the oil with the coal. For the bituminous coals, the observed value of V_T^* exceeds V_T . It is speculated that this is a result of the tendency of the aromatic molecules to solvate the bituminous coal particles which contain polynuclear aromatic groups and to thereby provide a barrier to their aggregation. As in the paraffin oil suspension, at 45°C or at 70°C, the lignite did not show the same trend as the bituminous coals since V_T is greater than V_T^* .

CONCLUSIONS

1. The kinematic viscosity of the oil effects the sedimentation kinetics of coal-oil slurries, not only in the usual hydrodynamic manner (i.e., according to the hindered Stokes' equation) but also by effecting the aggregation kinetics of the particles.

2. Agitation of paraffin oil at elevated temperatures (about 70°C) may cause the formation of surface active substances as a result of the oxidation of naturally occurring resin-like materials in the paraffin oil. These surface active compounds were assumed to be responsible for the dramatic reduction in the settling velocity of an Illinois coal in a mechanically mixed slurry when the oil preheat temperature was raised from 52°C to 80°C.

3. The degree of influence of the physical/chemical properties (aromatic/paraffinic composition and kinematic viscosity) of the oil depends upon the hydrophilic/hydrophobic properties of the coal.

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NOTATION

c	= empirical constant in Eq. 2
d	= diameter of sphere, cm
g	= gravitational constant, cm/S
k	= Boltzmann's constant, J·K ⁻¹
T	= absolute temperature, K
V	= observed settling velocity, cm·h ⁻¹

V_H	= observed settling velocity in hexane, cm·h ⁻¹
V_K	= observed settling velocity in kerosene, cm·h ⁻¹
V_T	= observed settling velocity in toluene, cm·h ⁻¹
V_{45}	= observed settling velocity at 45°C, cm·h ⁻¹
V_{70}	= observed settling velocity at 70°C, cm·h ⁻¹
V^*	= predicted settling velocity, cm·h ⁻¹
(V/V^*) ₇₀	= ratio of observed settling velocity to predicted settling velocity at 70°C
x	= empirical constant in Eq. 2

Greek Letters

ϵ	= volume fraction of liquid
η_{45}	= dynamic viscosity at 45°C, kg m ⁻¹ ·s ⁻¹
η_{75}	= dynamic viscosity at 70°C, kg m ⁻¹ ·s ⁻¹
ρ_C	= density of the coal, g·cm ⁻³
ρ_L	= density of the liquid, g·cm ⁻³
ρ_P	= density of the particle, g·cm ⁻³
$\theta(\epsilon)$	= empirical factor to account for hindered settling in Eq. 2

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