

Application of Poly(vinyl alcohol) with an Alkyl End Group Containing Anionic Groups to Coal–Water Slurry as a Dispersant

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SYNOPSIS

Anionic groups were introduced with copolymerization of corresponding vinyl monomers with vinyl acetate into poly(vinyl alcohol) (PVA) with an alkylthio end group. The polymers were investigated as a dispersant for coal–water slurry (CWM). Anionic groups such as sodium sulfonate and sodium carboxylate enhance remarkably the ability of PVA with an alkylthio end group to disperse coal. Sodium polyacrylic acid with an alkyl end group also showed a good ability of dispersing coal. The order of the ability of dispersing coal in these polymeric dispersants along with sodium naphthalene sulfonate formaldehyde condensate (NSF) varied by the kind of coal used. In cases of the polymeric dispersants, the fluidity of coal in terms of dependence of viscosity on shear rate also varied, from dilatancy to thixotropy, in accordance with coal used. Impurities in coal as well as surface properties of coal particles might play important roles in the properties of CWM. © 1995 John Wiley & Sons, Inc.

INTRODUCTION

Many studies have been carried out on coal–water slurry (CWM) which has been regarded as a promising fuel instead of petroleum oil. To achieve the demands that coal content in CWM should be attained as high as possible and the amount of dispersant utilized to prepare CWM should be as low as possible, many articles have been published.^{1–7} Sodium naphthalene sulfonate formaldehyde condensate (NSF) has been known as one of the most useful dispersants with respect to the points as well as having a preferable thixotropic fluidity. Polymeric dispersant such as sodium sulfonated polystyrene^{4,8} and polypropyleneoxide-*b*-polyethylene oxide³ were also reported as useful dispersants for CWM.

The authors have studied synthesis and surface-chemical properties of poly(vinyl alcohol) (PVA) with an alkylthio end group.^{9–11} PVAs copolymerized with a small amount of ionic monomers have been

also investigated.^{12–15} By using the two techniques, several kinds of surface-active PVAs can be synthesized. In this work the abilities of polymers related with these PVA as dispersants for CWM will be reported.

EXPERIMENTAL

As sodium naphthalene sulfonate formaldehyde condensate (NSF), Mighty FD-2 (NSF-1, Kao Co.) was mainly used. Other NSFs used were Mighty 150 (NSF-2) and Mighty FDR-1 (NSF-3). Ordinary PVAs (PVA 203: degree of polymerization (DP) 300, degree of hydrolysis (DH) 88%; PVA 403: DP 300, DH 80%; PVA 117: DP 1700, DH 99%; Kuraray CO.) were used after extraction of sodium acetate with methanol in a Soxhlet apparatus.

PVAs with an alkylthio end group were synthesized by polymerizing vinyl acetate (VAc) in the presence of a regulated amount of corresponding alkyl mercaptan, followed by the usual alkaline methanolysis.¹⁶ Sodium-sulfonate-containing PVA with an alkylthio end group (n -C_{*n*}H_{2*n*+1}S-PVA/SAPS) was synthesized by copolymerizing 2-methyl-2-(ac-

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Table I Properties of Coal

Coal	Water ^a (%)	Analysis (%)						
		C	H	N	S	O	Ash	O/C
Taiheiyo I	6.2	63.67	5.08	1.13	0.60	14.32	15.20	22
Taiheiyo II	5.4	66.66	5.48	1.06	0.25	14.35	12.20	22
Taiheiyo III	5.7	67.28	5.54	1.09	0.19	15.40	10.50	23
Deashed coal	6.0	76.31	5.31	1.54	0.43	16.41	2.10	22

^a At 75% RH, 20°C.

ryolamino)-1-propanesulfonic acid (APS) with VAc¹³ in the presence of a regulated amount of an alkyl mercaptan, followed by the usual alkaline methanolysis. Cationically modified PVA with a dodecylthio end group was synthesized by the same method using trimethyl[3-(methacryloylamino)propyl]ammonium chloride (QAPM) instead of APS.^{14,15} Itaconic acid (IA) as well as maleic anhydride was copolymerized with VAc in the presence of a regulated amount of an alkyl mercaptan, followed by the usual methanolysis catalyzed by sodium hydroxide. The copolymers synthesized were sodium-itaconate-containing PVA with an alkyl end group [n -C_nH_{2n+1}S-P(VA/SIA)] and sodium-maleate-containing PVA with an alkyl end group [n -C_nH_{2n+1}S-P(VA/SM)], respectively. In the anionic groups in both copolymers, there exist one sodium carboxylate and one lactone ring formed between a carboxylate group and an adjacent hydroxyl group.¹⁷ Sodium polyacrylate with an alkyl end group (n -C_nH_{2n+1}S-P AA-Na) was synthesized by polymerizing acrylic acid (AA) in methanol in the presence

of an alkyl mercaptan, followed by neutralization with sodium hydroxide.

Coal were purchased from Taiheiyo Coal Co., which treats domestic coal. Three kinds of coals were used, Taiheiyo coal I, II, and III. Analytical data of these coals are listed in Table I. A deashed coal (DC) was used, whose composition is also listed in Table I. Coals were pulverized with ball-mills after drying in a drier at 90°C for 2 h, followed by sifting. Distributions of particle size of used coals are shown in Figure 1.

CWM were prepared by stirring a mixture of prescribed amount of water containing a dispersant and pulverized coal at 8500 rpm for 3–5 min. Fluidity after preparation was judged on CWM just after preparation as good, fair, poor, and bad. Viscosities of CWM were measured at 25°C with a BL-type, a EH-type and a Haake RV-12 viscometers. Coal content in slurry was based on dried coal.

IA-copolymerized PVA and QAPM-copolymerized PVA used in thixotropy affording experiments were obtained as described elsewhere.^{14,15} Carboxymethylcellulose (CMC, Cellogen 3H, Daiichi Kogyo Seiyaku Co., Ltd.), xanthan gum (Kelzan, Sansho Co., Ltd.), and sodium bentonite (Kunigel V-1, Kunimine Ind. Co., Ltd.) were used as received. Aluminum sulfate was of reagent grade.

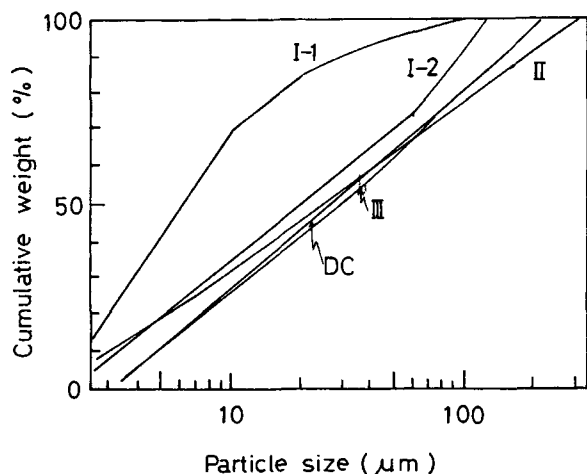


Figure 1 Particle size distribution of used coals.

RESULTS AND DISCUSSIONS

Table II lists the viscosities as well as the fluidity after preparation of CWM using ordinary PVAs and PVAs with an alkylthio end group as a dispersant, where the data using a typical dispersant NSF (NSF-1) are also shown as a reference. Stirring speeds 6–60 rpm on BL-type viscometer and 10–100 rpm on EH-type viscometer correspond to shear rate of 3–30 s⁻¹ and 10–100 s⁻¹, respectively.

In the case of NSF, the well-known thixotropic fluidity, that is, decrease in viscosity with increase

Table II Viscosities of CWM Using PVA with Various Nonionic PVA as a Dispersant^a

Dispersant	DP		Fluidity After Preparation	Viscosity (mPa s)							
	DP (%)	DH (%)		BL-Type Viscometer (rpm)				EH-Type Viscometer (rpm)			
				6	12	30	60	10	20	50	100
NSF-1	—	—	Good	3800	2490	1900	1780	580	539	510	481
PVA 203	300	88	Fair	7440	4570	3100	> 2000	—	—	—	—
PVA 403	300	80	Fair	3600	2800	1960	1560	—	—	—	—
<i>n</i> -C ₈ H ₁₇ S-PVA	90	88	Good	—	—	—	—	2140	1410	979	856
<i>n</i> -C ₁₂ H ₂₅ S-PVA	120	88	Fair	7700	4950	2940	> 2000	2560	2050	1730	> 1000
<i>n</i> -C ₁₂ H ₂₅ S-PVA	120	99	Fair	8620	5550	3460	> 2000	—	—	—	—
<i>n</i> -C ₁₈ H ₃₇ S-PVA	160	87	Fair	7000	4480	2660	1880	—	—	—	—

^a Coal: Taiheiyo I-1, 60 wt %/slurry; dispersant: 1 wt %/coal.

in shear rate, was observed and fluidity of CWM after preparation was good enough. Ordinary PVA with degree of hydrolysis 80% showed almost the equal viscosity and fluidity at varying shear rate as NSF, but fluidity after preparation of CWM was worse. Ordinary PVA with degree of hydrolysis 88% and PVAs with an alkylthio end group showed less dispersing ability compared with NSF. Among PVAs with an alkylthio end group, PVA with an octylthio group was the best dispersant. This tendency is not coincident with the result that the surface tension of the aqueous solution of PVA with a dodecylthio end group revealed minimum.¹⁰ Accordingly it is

clear that other factors also influence the ability of dispersing coal.

Table III lists the effect of ionic groups introduced with copolymerization in PVA with a dodecylthio end group on the ability of dispersing coal, where coal with larger particle size (I-2) was used instead of coal (I-1) in Table II. Anionic groups such as sodium sulfonate and sodium carboxylate showed remarkable improvement in the dispersing ability of PVA, that is, lower viscosities than NSF system and good fluidity after preparation of CWM. On the contrary, cationic groups in QAPM yielded poor result. In the cases of PVA without an alkylthio end

Table III Effect of Ionic Groups Copolymerized in PVA Used as a Dispersant on Viscosities of CWM^a

Dispersant	Comonomer			Fluidity After Preparation	Viscosity (mPa s)				
	Comonomer (Mol %)	DP (%)	DH (%)		BL-Type Viscometer (rpm)				
					6	12	30	60	
NSF-1	—	—	—	Good	—	780	740	704	
<i>n</i> -C ₁₂ H ₂₅ S-PVA	None	0	120	88	Fair	—	1480	1260	1040
<i>n</i> -C ₁₂ H ₂₅ S-PVA	SAPS	3	110	91	Good	Low	Low	232	236
<i>n</i> -C ₁₂ H ₂₅ S-PVA	QAPM	3	130	89	Bad	6500	4500	2200	1520
<i>n</i> -C ₁₂ H ₂₅ S-PVA	SIA	3	260	88	Good	Low	Low	260	276
HOCH ₂ CH ₂ S-PVA	SAPS	3	80	87	Good	—	—	480	460
<i>n</i> -C ₁₂ H ₂₅ S-PVAc	APS	3	110	0	Good	—	750	616	556

^a Coal: Taiheiyo I-2, 60 wt %/slurry; dispersant: 1 wt %/coal.

group and PVAc with a dodecylthio end group, sodium sulfonate groups brought good result (the latter PVAc was soluble in water).

In the case of sodium sulfonate and sodium carboxylate in PVA with a dodecylthio end group, dilatant fluidity within the shear rate range in Table III appeared, which was the opposite phenomenon compared with that of NSF and nonionic PVA. Further discussion about the point will be made later.

Since anionic groups in PVA showed the remarkable effect of improving the dispersing ability, further experiments were carried out. Table IV lists the results, where results concerning storage stability after 3 days were added. Used coal (coal II) was different from those used before.

In the case of sodium-sulfonate-containing PVA, an octadecylthio end group was more effective to decrease the viscosity compared with a dodecylthio end group, but both PVA showed high viscosities after storage for 3 days. In the case of sodium-maleate-containing PVA with an octadecylthio end group, better effect to decrease the viscosity was observed, although the amount of 1 mol % modification was too small to exhibit the effect. Storage stability after 3 days was not good to result in the occurrence of precipitation. In the case of sodium salt of polyacrylic acid with an alkylthio end group, where vinyl alcohol portion does not exist any more, revealed excellent effect to decrease the viscosity. An octadecylthio end group was also more effective in this case compared with a dodecylthio end group. In both polymers, the storage stability was not good to result in the occurrence of precipitation. With decrease in the amount of dispersant from 0.5 to 0.3 %/coal, anionic group-containing PVAs with an octadecyl-

thio end group could not disperse the coal (II) satisfactorily, whereas sodium salt of polyacrylic acid with an alkylthio end group as well as NSF showed good dispersing ability. This tendency is different from the following one.

Table V lists the ability of the anionic polymers to disperse Taiheiyu coal III. In this case the ability of dispersing coal was in the order $n\text{-C}_{18}\text{H}_{37}\text{S-P(VA/SAPS)} \geq n\text{-C}_{18}\text{H}_{37}\text{S-P(VA/SM)}$ (MAN = 3 mol %) $> n\text{-C}_{18}\text{H}_{37}\text{S-PAA-Na} > \text{NSF-1}$, while in the case of coal II (Table IV), the order was $n\text{-C}_{18}\text{H}_{37}\text{S-PAA-Na} > \text{NSF-1} > n\text{-C}_{18}\text{H}_{37}\text{S-P(VA/SM)}$ (MAN = 3 mol %) $> n\text{-C}_{18}\text{H}_{37}\text{S-P(VA/SAPS)}$. In other words, dispersants having a large amount of anionic groups are effective in coal II, while those having a small amount of anionic groups are effective in coal III. As listed in Table I, there are not so large differences in composition, oxygen-carbon ratio, water content, and ash content between both coals. To clarify the reason why the difference comes about, detailed studies on the surface of coal particles as well as on impurities in coals such as inorganic substances in ash will be needed.

As mentioned previously, the fluidity of CWM using anionic PVAs with an alkylthio end group as dispersants was dilatant at lower shear rate range whereas that using NSF was thixotropic. By using a Haake viscometer that covers broader shear rate range, relationship between shear stress and shear rate up to 400 s^{-1} at several runs (increasing and decreasing shear rate) were obtained. Figure 2 shows the relationship between the apparent viscosity of CWM and shear rate using NSF and sodium-sulfonate-containing PVA with a dodecylthio end group. In the case of NSF, a remarkable thixotropy

Table IV Effect of Ionic-Polymer Dispersants on the Properties of CWM^a

Dispersant	Comonomer (Mol %)	Dispersant 0.5 Wt %/Coal			Dispersant 0.3 Wt %/Coal		
		Fluidity After Preparation	Viscosity ^b (mPa s)	Stability After 3 Days	Fluidity After Preparation	Viscosity ^b (mPa s)	Stability After 3 Days
NSF-1	—	—	—	—	Good-Fair	1460	High vis.
$n\text{-C}_{12}\text{H}_{26}\text{S-P(VA/SAPS)}$	3	Good	1760	High vis.	—	—	—
$n\text{-C}_{18}\text{H}_{37}\text{S-P(VA/SAPS)}$	3	Good	1020	High vis.	Bad	—	—
$n\text{-C}_{18}\text{H}_{37}\text{S-P(VA/SM)}$	1	Poor	7800	High vis.	Bad	—	—
$n\text{-C}_{18}\text{H}_{37}\text{S-P(VA/SM)}$	3	Good	460	Pptd.	Bad	—	—
$n\text{-C}_{18}\text{H}_{37}\text{S-P(VA/SM)}$	10	Good	600	Pptd.	Fair-Poor	7210	High vis.
$n\text{-C}_{12}\text{H}_{26}\text{S-PAA-Na}$	—	—	—	—	Good-Fair	660	Pptd.
$n\text{-C}_{18}\text{H}_{37}\text{S-PAA-Na}$	—	Good	400	Pptd.	Good	300	Pptd.

^a Coal: Taiheiyu II, 65%/slurry; Ionic polymer: DP about 100; PVA copolymer: DH about 98%.

^b Measured with a BL-type viscometer on the samples just after preparation.

Table V Comparison of the Effect of Polymeric Dispersants Containing Various Anionic Groups on the Properties of CWM Composed of Taiheiyu Coal III^a

Dispersant	Dispersant 0.5 Wt %/Coal				Dispersant 0.3 Wt %/Coal		
	Comonomer (Mol %)	Fluidity After Preparation	Viscosity ^b (mPa s)	Stability After 3 Days	Fluidity After Preparation	Viscosity ^b (mPa s)	Stability After 3 Days
NSF-1	—	Bad	—	—	Bad	—	—
<i>n</i> -C ₁₈ H ₃₇ S-P(VA/SAPS)	3	Fair	490	Pptd.	Fair-Poor	590	Pptd.
<i>n</i> -C ₁₈ H ₃₇ S-P(VA/SM)	1	Fair-Poor	550	High vis.	Poor-Bad	8300	High vis.
<i>n</i> -C ₁₈ H ₃₇ S-P(VA/SM)	3	Good-Fair	400	Pptd.	Poor	1230	High vis.
<i>n</i> -C ₁₈ H ₃₇ S-P(VA/SM)	10	Fair-Poor	540	Pptd.	Fair-Poor	590	Pptd.
<i>n</i> -C ₁₈ H ₃₇ S-PAA-Na	—	Fair-Poor	650	Pptd.	Bad	—	—

^a Coal: Taiheiyu III, 67%/slurry. Polymeric dispersant: DP about 100; PVA copolymer: DH about 98%.

^b Measured with a BL-type viscometer on the samples just after preparation.

at the first run going was observed, followed by almost Newtonian fluidity at the first coming and succeeding runs. In the case of sodium-sulfonate-containing PVA with a dodecylthio end group, a dilatent fluidity took place at the first run going at shear rate lower than 120 s⁻¹ and a weak thixotropy appeared at higher shear rate, followed by weak dilatency at the first coming and succeeding runs.

As is well known, the thixotropic fluidity arises

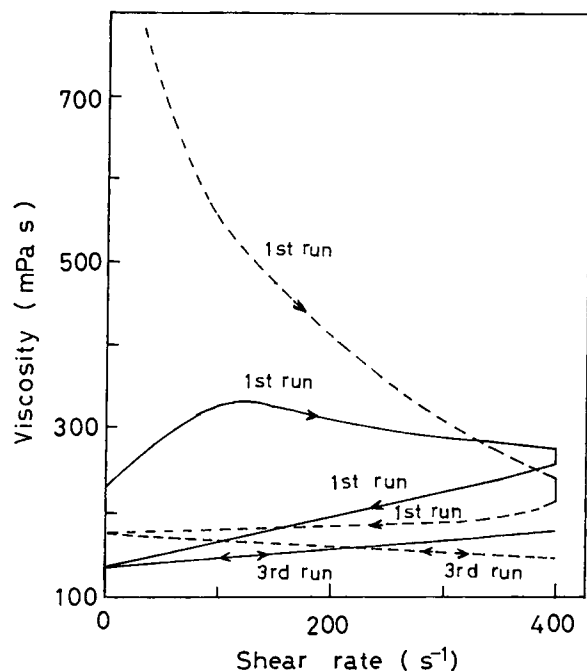


Figure 2 Relationship between viscosity and shear rate. Coal: II, 60%/slurry. Dispersant: 1%/coal. (—) *n*-C₁₂H₂₅S-P(VA/SAPS), SAPS 3 mol %, DP 100, DH 91%. (---) NSF-1.

from formation of weak structures between particles and breakdown of the structures under shear stress. On the other hand, dilatent fluidity seems to be not clear in CWM. Kaji et al.⁵ and Keller and Keller, Jr.¹⁸ reported that CWM using NSF or nonionic dispersant gave dilatent fluidity, while Tsai⁷ reported that there was no dilatent fluidity in CWM using NSF as a dispersant and that CWM using a large amount of nonionic dispersant gave dilatency. In this study the occurrence of dilatency might be related with the surface of coal particles as well as impurities in coals such as inorganic substances in ash.

To afford thixotropy to CWM, water-soluble polymers such as cellulose derivatives and natural carbohydrates have been reported to be useful.^{19,20} In this study PVAs were tested along with other water-soluble polymers and inorganic materials. To make the effect of additives clearer, CWM used as a control was chosen to be low viscosity, the storage stability of which was bad to yield precipitation. Table VI lists the effect of the additives on the fluidity and the storage stability of CWM.

In the control where Taiheiyu coal III and sodium-sulfonate-containing PVA with an octadecylthio group were used, slight thixotropy was observed. The phenomenon is different from the case of Taiheiyu coal II, described previously (Fig. 2). By adding ordinary PVA (PVA 117), weak thixotropy was afforded, that is, viscosity at 5 s⁻¹ shear rate in the first going increased from 1400 to 5000 mPa s, and increase of viscosity at 100 s⁻¹ shear rate in the fourth coming was small (from 560 to 660 mPa s). Cationic-group-containing PVA showed somewhat better ability to afford the property compared with ordinary PVA, especially in storage stability after

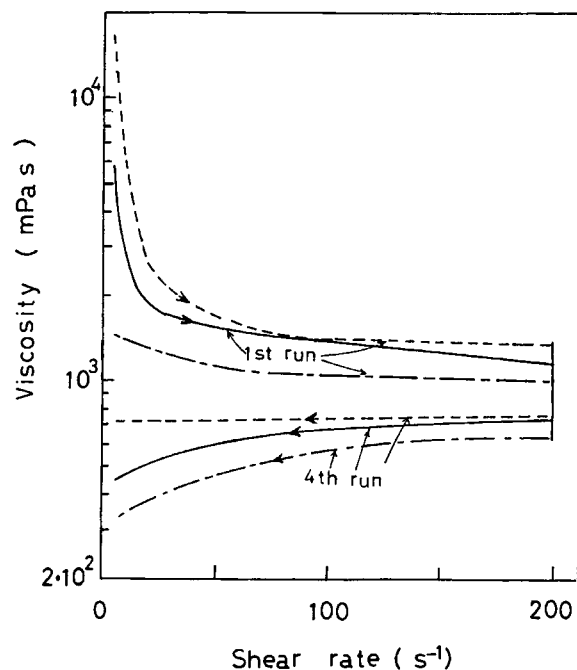


Figure 3 Effect of additives on the relationship between viscosity and shear rate. Coal: III, 67%/slurry. Dispersant: *n*-C₁₈H₃₇S-P(VA/SAPS), SAPS 3 mol %, 0.5%/coal, DP 100, DH 99%. Additives: (---) none, (—) PVA 117, (— · — · —) Al₂(SO₄)₃.

30 days, while anionic-group-containing PVA showed less ability. Ionic interaction between added PVA and the additives may be the reason of the afforded thixotropy. In the cases of other water-soluble polymers, the same amount of added polymers (0.03 %/coal) caused strong thixotropy and increase in viscosity at higher shear rate. CMC afforded better storage stability after 30 days, and with decrease in the added amount to one-third, the ability became almost the same as those of ordinary and cationic-group-containing PVAs. Aluminum sulfate exhibited the best ability to afford thixotropy and storage stability. Figure 3 shows the relationship between viscosity and shear rate in the repeated increase-decrease runs in shear rate in the cases of the control, ordinary PVA-added and aluminum-sulfate-added CWM. All additives in Table VI, however, could not be utilized as a thixotropy-affording material since there was no fluidity after storage for 30 days.

Table VII lists the effect of pH in CWM on fluidity and viscosity. The coal used in Table VII (coal II) can be dispersed without dispersant up to 55% concentration. In alkaline region (pH 10.4), the viscosity of CWM without dispersant showed a marked decrease, which may suggest the existence of ionizable groups on the surface of coal particles. Po-

Table VI Effect of Additives on Viscosity and Storage Stability of CWM^a

Additives (Wt %/Coal)	Viscosity ^b (mPa s)		After 15 Days Softness of CWM	After 30 Days		Viscosity of Remixed CWM After 30 Days (mPa s)
	1st Run Going at 5 s ⁻¹	4th Run Coming at 10 ² s ⁻¹		Clear Portion ^c (ml)	Softness of CWM	
None	—	1400	Hard	10	Hard	3650
PVA 117	0.03	5000	Soft	2-3	Hard at bottom	NM ^g
P(VA/IA) ^d	0.03	1800	Hard	10	Hard	NM
P(VA/QAPM) ^e	0.03	6000	Soft	2-3	Soft-Hard	NM
CMC	0.01	5500	Soft	—	—	—
CMC	0.03	VH ^f	Soft	2-3	Soft	NM
Xanthan gum	0.03	12000	—	—	—	—
Na-bentonite	0.03	2300	Soft-Hard	2-3	Soft-Hard	NM
Al ₂ (SO ₄) ₃	0.03	17500	Soft	2-3	Soft	NM

^a Coal: Taiheiyo III, 67%/slurry. Dispersant: *n*-C₁₈H₃₇S-P(VA/SAPS), SAPS 3 mol %, 0.5%/coal, DP 100, DH 99%. Additives: Added before preparation of CWM.

^b With Haake viscometer.

^c Total volume 100 ml.

^d IA 2 mol %, DP 1700, DH 99%.

^e QAPM 2 mol %, DP 1700, DH 99%.

^f Too high to be measured.

^g Could not be re-mixed.

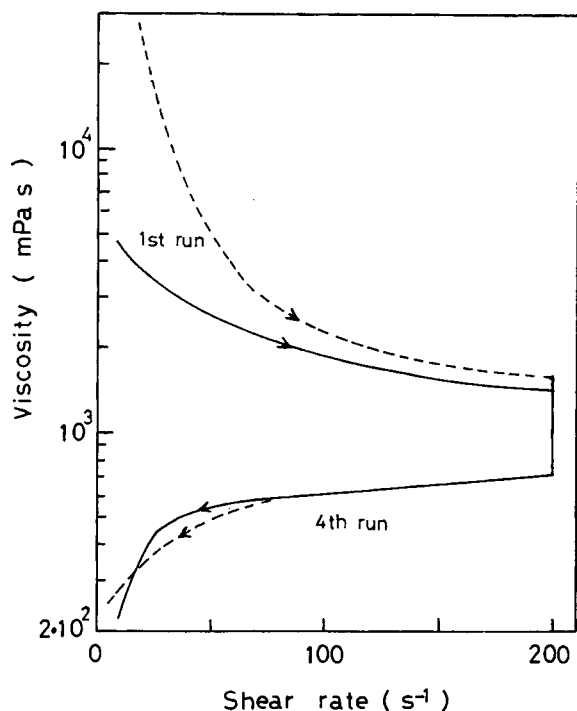


Figure 4 Relationship between viscosity and shear rate of CWM using deashed coal. Coal: DC, 65%/slurry. Dispersant: 0.5%/coal. (—) $n\text{-C}_{18}\text{H}_{37}\text{S-P(VA/SM)}$, SM 3 mol %, DP about 100. (---) NSF-1.

lyacrylic acid sodium salt with an octadecylthio end group exhibited good ability to disperse the coal at pH higher than 7. However, it did not show good dispersibility at pH 7.3, while sodium-sulfonate-

containing PVA with a dodecylthio end group showed less ability to disperse the coal, as mentioned before. In the later case, with increase in pH from 7.6 to 9.1, viscosity of CWM increased. At pH 7.2 the latter polymer could not disperse the coal. If there are inorganic impurities in coal that are ionized at higher pH region, dispersant may be influenced by the ions, unless the amount of ionic groups in dispersant are much more than ionized impurities. In the case of sodium-sulfonate-containing PVA with an alkylthio end group, there exist only 3 mol % sodium sulfonate groups. The amount might be too small to surpass the influence of ions. Nakai et al.²¹ reported that inorganic materials play an important role in dispersing coal at high pH region, and that after removing the inorganic material, stable slurry cannot be obtained.

Several methods to lower ash content in coal have been reported to decrease ash in boiler.²²⁻²⁴ The authors obtained a deashed coal (DC), although detailed information of which was not disclosed. As listed in Table I, ash content of DC is low to be 2.1% and O/C ratio is almost the same as other coals used. Table VIII lists the results of preparation and viscosity of CWM using DC in the presence of various dispersants. In this case, anionic-group-containing PVA with an octadecylthio end group exhibited the best dispersing ability, sodium salt of polyacrylic acid with an octadecylthio end group did worse, and NSF-1 had the worst dispersing ability. Two other NSF (NSF-2, NSF-3) also exhibited the worst ability. Figure 4 shows the relationship between viscosity

Table VII Effect of pH of CWM on Viscosity

Coal ^a (Wt %/Slurry)	Dispersant (Wt %/Coal)	Additives	pH of CWM	Fluidity After Preparation	Viscosity ^b (mPa s)
55	None	HCl	7.4	Good-Fair	730
55	None	None	7.9	Good-Fair	710
55	None	NaOH	10.4	Good	200
65	$n\text{-C}_{18}\text{H}_{37}\text{S-PAA-Na}$, ^c 0.3	HCl	7.3	Good	3680
65	$n\text{-C}_{18}\text{H}_{37}\text{S-PAA-Na}$, ^c 0.3	None	7.7	Good	300
65	$n\text{-C}_{18}\text{H}_{37}\text{S-PAA-Na}$, ^e 0.3	NaOH	9.0	Good	350
65	$n\text{-C}_{12}\text{H}_{25}\text{S-P(VA/SAPS)}$, ^d 0.5		7.2	Bad	—
65	$n\text{-C}_{12}\text{H}_{25}\text{S-P(VA/SAPS)}$, ^d 0.5	None	7.6	Good	1760
65	$n\text{-C}_{12}\text{H}_{25}\text{S-P(VA/SAPS)}$, ^d 0.5	NaOH	7.9	Good	2070
65	$n\text{-C}_{12}\text{H}_{25}\text{S-P(VA/SAPS)}$, ^d 0.5	NaOH	9.1	Good	4690

^a Taiheiyo coal II.

^b With a BL-type viscometer measured at 12 rpm after stirring at 6, 12, 30, 60, 30, 12, 6 rpm for 1 min each.

^c DP about 100.

^d SAPS 3 mol %, DP 100, DH 99%.

Table VIII Properties of CWM Using Deashed Coal in the Presence of Various Dispersants

Coal (Wt %/Slurry)	Dispersant	Fluidity After Preparation	Viscosity (mPa s)	
			BL-Type ^a	Haake ^b at 10 ² s ⁻¹
69	NSF-1	Very bad	—	—
	<i>n</i> -C ₁₈ H ₃₇ S-P(VA/SAPS) ^c	Fair-Poor	660	2070
	<i>n</i> -C ₁₈ H ₃₇ S-P(VA/SM) ^d	Fair-Poor	630	1930
	<i>n</i> -C ₁₈ H ₃₇ S-PAA-Na ^e	Poor-Bad	640	1580
67	NSF-1	Bad	—	—
	NSF-2	Bad	—	—
	NSF-3	Bad	—	—
	<i>n</i> -C ₁₈ H ₃₇ S-P(VA/SM) ^d	Good-Fair	480	1810
65	NSF-1	Poor-Bad	460	580
	<i>n</i> -C ₁₈ H ₃₇ S-P(VA/SM) ^d	Good	260	600

^a Measured at 12 rpm after stirring at 6, 12, 30, 60, 30, 12, 6 rpm for 1 min each.

^b Measured in 4th run coming.

^c SAPS 3 mol %, DP about 100, DH 99%.

^d SM 3 mol %, DP about 100.

^e DP about 100.

and shear rate of CWM obtained in the lowest coal content in Table VIII. As is clear from Table VIII and Figure 4, all CWM obtained in Table VIII had dilatent fluidity except the first run going on Haake viscometer. Although a deashing process was performed to the coal, it still contains a small amount of ash. The remaining ash might influence the fluidity of the CWM.

CONCLUSION

There are three main points requested for CWM to be used for fuel instead of petroleum oil. First, increase coal content in CWM as high as possible. Second, decrease the amount of expensive dispersant as low as possible. Third is a preferable fluidity of CWM. The former two points are closely related with the nature of dispersant. As indicated in this work, the ability of dispersant depends on kind of coal used, so that detailed analysis of coal such as quantitative analysis of impurities in coal and surface chemical properties of pulverized coal particles will be needed to determine the kind of dispersant. As for the third point, further study should be carried out to find out the preferable thickener that can afford high viscosities at 0 s⁻¹ shear rate and low viscosities at higher shear rate (i.e., thixotropy). In this case, a weak structure at 0 s⁻¹ shear rate should not proceed in storage duration to a strong structure that

cannot be destroyed at higher shear rate. Further study will be necessary in this regard.

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