EFFECT OF COAL UPGRADING ON RHEOLOGY OF COAL WATER MIXTURE

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ABSTRACT

Coal water mixture (CWM) is coal-water slurry in which particles of coal with a certain particle size distribution are suspended in water. CWM is required to have the highest possible coal concentration and a moderate viscosity in order to make handling easy. The main purpose of this study is to obtain the effect of coal upgrading on the rheology of CWM in terms of finding the most suitable dispersing additive in producing CWM with highest coal concentration. Two kinds of coal, raw and upgraded coal, from three areas in Indonesia have been used. Three kinds dispersing additives, i.e. formalin condensation product of naphthalene sulfuric acid (NSF), polystyrene sulfonic acid (PSS) and poly (meth) acrylate (PMA) were tested to produce CWM with good flow characteristics. The rheology of CWM was prepared, measured by a stress control type rheometer (Rheometric Scientific Co. Ltd., SR-5) in steady shear mode at 25ºC. The apparent viscosity of upgraded coals showed a better slurry-ability of CWM as a function of coal concentration for every dispersing additive compared to the raw coal.

Keywords : Coal upgrading, slurry, coal concentration, rheology, viscosity, additive

1. INTRODUCTION

After the increase of world's oil price, coal began to be reviewed as a substitute fuel for oil. However, complete conversion of oil fired facilities to coal fired ones would involve substantial capital expenditure. Coal water mixture (CWM) consists of a mixture of ground powder coal, water and small quantities of additive. it is a fluid with viscosity equivalent to crude or heavy oil. CWM offers potential as a replacement fuel oil in oil fired facilities with only modest retrofits of existing equipment. CWM technology also offers a lower risk technology relative to other coal conversion technologies. As a mixture of coal and water, CWM is free from major problems of solid coal such as powder dust and spontaneous combustion during storage and transportation. Unlike solid coal, moreover, CWM does not require large handling facilities (Hashimoto, 1999).

The preparation of CWM was investigated after the oil crises in 1973 and 1978 (Usui et al., 1997). Also the burning of pulverized coal, as the direct competitive technology of CWM utilization, keeps energy supply cost relatively low. Under this circumstance, it is necessary to develop preparation techniques which could produce CWM in a more economical fashion. One reasonable way to achieve this purpose is to use the low rank coal.

Normally, CWM is prepared using pulverizing bituminous coal since the surface nature of bituminous coal is hydrophobic. However, sub bituminous coal and lignite, which are commonly referred as low rank coal, constitute about 85% of the measured coal reserve in Indonesia. These low rank coals with hydrophilic surface nature could be changed to a hydrophobic by upgrading process (Usui et al., 1997).

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One of the upgrading methods, which was developed and applied, is upgraded brown coal (UBC) process. UBC process was developed as the pretreatment process of BCL (brown coal liquefaction) based on slurry dewatering process. The condition of the upgrading process at the temperature of about 140°C and the pressure of 0.35 MPa, is much milder than those of other upgrading processes. The addition of low sulfur wax residue (LSWR) of about 1% to the slurry is very important to prevent re-absorption of moisture. Beside that, the addition of heavy oil (LSWR) to the slurry can effectively adsorbing many small pores of the low rank coal to make it waterproof and to give the effect of preventing self-heating caused by moisture rebound and wetting heat. Figure1 illustrates the surface of coal before and after process. A UBC pilot plant of 5 ton/day in capacity has been built and operated since 2003 in Palimanan, Cirebon, Indonesia (Umar et al., 2005). For long distance transportation, UBC powder needs to be briquetted by using a double roll briquetting machine without the addition of binder. In the future, UBC pilot plant product is possible in the form of CWM.

The basic process of CWM production technology consists of the selection of raw material, the use of appropriate dispersing additives and stabilizer, pulverization of raw material into appropriate particle size and mixing for providing suitable rheological properties as a fluid fuel. The most simple parameter for showing the property of a slurry under the fluidable condition would be a viscosity. A technology key point for producing CWM is to satisfy these factors, which depend on how high quality of the slurry (easy to handle, easy to burn and stable during transportation and combustion) can be prepared at low cost (Hashimoto, 1999).

Different from the previous fuel handled with boiler, CWM change in apparent viscosity with a change in shearing rate (velocity gradient). As a result, the CWM is preferable to have a pseudo-plasticity, the apparent viscosity decreases with an increase in shearing rate. For effective atomization, the viscosity of CWM should be in the order of 1 Pas at shearing rate of 100^{-1} and the room temperature of 25°C. Lower viscosity of CWM is most desirable for the pumping of slurries. However, the lower viscosity of CWM causes more rapid settling of solid particle, and this settling must be avoided by the addition of a suitable additive to build up a network structure of coal particle. Thus an appropriate choice of additive is very important for the utilization of CWM (Usui et al., 1984).

The main purpose of this study is to obtain the effect of coal upgrading on the rheology of CWM. The use of dispersing additives, i.e. naphthalene sulfonic acid (NSF), poly (meth) acrylate (PMA) and polystyrene sulfonic acid (PSS) have also been studied to find the most suitable additive to reach the highest coal loaded in CWM with an appropriate viscosity.

2. EXPERIMENTAL

Three coal mine areas in the range of moisture content, Berau, Tabang and Samarangau, East Kalimantan, have been used as raw material for CWM preparation as raw and upgraded coals which were produced by UBC process. The condition of process at temperature of about 150°C and pressure of 0.35 MPa, is much milder compared to other upgrading methods (Deguchi, et al., 1999). To support this study, the proximate and ultimate analyses including calorific value have been conducted according to the ASTM standard, 1993 (American Society for Testing and Material, 1993) to obtain the characterization of the raw and upgraded coals. The analysis result is shown in Table 1.

The raw coal was ground to below 3 mm particle size and it was mixed with kerosene and low sulfur wax residue (LSWR) to prepare the slurry. The addition of low sulfur wax residue (LSWR) of about 1% was very important to prevent re-absorption of moisture. The mixing ratio of kerosene and coal was about 1.2 and the quantity of LSWR was 0.5% in the oil mixture (Umar et al., 2005). The slurry was sent to a dewatering vessel via an evaporator where the moisture content of the coal was reduced by heating. The dewatered slurry and the evaporated water were separated in a gas-liquid separator, and the separated water was utilized as the heating source of the evaporator after raising its temperature level in a steam compressor by adiabatic compression. The evaporated oil was recovered by condensation and reused as recycle oil for the next slurry dewatering. An oil recovery of more than 99% could be achieved from the material balance of the whole process.

CWM was prepared by mixing pulverized coal (passed through 200 mesh screens) with water. In order to increase the coal concentration and

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Tabel 1. Analysis results of raw and upgraded coals

Analysis	Berau		Tabang		Samarangau	
	Raw	UBC	Raw	UBC	Raw	UBC
Eq. Moisture, % adb	-	5.08	-	6.96	-	8.48
Moisture in air dried, % adb	16.13	1.52	15.35	0.98	22.33	4.65
Ash, % adb	6.36	6.81	4.42	3.93	2.15	2.61
Volatile matter, % adb	37.20	46.78	40.68	48.34	38.05	47.67
Fixed carbon, % adb	40.31	45.59	39.55	46.75	37.47	45.07
Carbon, % daf	57.01	65.19	57.55	66.58	53.59	64.43
Hydrogen, % daf	6.57	4.8	6.06	5.07	6.19	5.3
Nitrogen, % daf	1.6	1.15	0.77	0.88	0.69	0.86
Total sulfur, % daf	0.56	0.52	0.14	0.18	0.10	0.16
Oxygen, % daf	28.34	21.53	31.06	23.36	37.28	26.64
Calorific value, kcal/kg adb	5324	6805	5431	6625	5048	6310

Note:
adb: air dried basis
daf: dry ash free

improve the fluidity, the use of a suitable dispersing additive was unavoidable. Three kinds of dispersing additives, i.e. naphthalene sulfonic acid (NSF), poly (meth) acrylate (PMA) and poly styrene sulfonic acid (PSS) were used in this study. NSF, PMA and PSS have molecular weights of more than ten thousand and exhibit significant dispersing effect on the preparation of highly loaded CWM with bituminous coal (Usui et al., 1997). NSF is a condensation product of formalin and naphthalene sulfonic acid. Sodium and ammonium salts of NSF were cheap and abundant anionic additives with relatively lower molecular weight produced by San Nopco limited. The PMA, poly (meth) acrylate with molecular weight of 40,000~60,000 was produced by Nippon Shokubai Co. Ltd. and PSS, polystyrene sulfonic acid with molecular weight of 10,000~30,000 was produced by Tosoh Co. Ltd. (Saeki et al., 1999). To prevent sedimentation of coal particle in the mixture, carboxyl methyl cellulose (CMC) has been added as a stabilizer.

The amount of the additives was fixed at 0.5% CWM and coal concentration was varied to reach the highest coal loaded in CWM. The flow characteristics was prepared, measured by a stress control type rheometer (Rheometric Scientific Co. Ltd., SR-5) in steady shear mode. The measurement was conducted using a plate-plate system. The apparent viscosity measurements were performed at 25ºC. The CWM was generally prepared at apparent viscosity of 1.00 Pas at shearing rate of 100 s^{-1} as a target. The high viscosity, more than 1.00 Pa·s, will be difficult in handling during transportation and combustion.

3. RESULT AND DISCUSSION

The effect of coal concentration on the apparent viscosity of CWM at shear rate of 100 s^{-1} with different kind of dispersing additives can be seen in Figure 1.

CWM is a mixture of solid and liquid. Some factors (solid density, particle shape, volume fraction of solid, etc) and solid/liquid interface characteristics (interfacial potential, interfacial tension, surface adsorption properties of additives, etc) largely influence the rheologycal characteristics. The most simple parameter for showing the property of a slurry under fluidable condition is viscosity. When the particle concentration is very small, the fluidity of a dispersion system can be expressed by the Newtonian viscosity law. With a practical slurry, the particle concentration is high, the shear stress and shear rate are in non-linier relation. In many practical cases, the shear stress at given shear rate is measured and the viscosity obtained by applying the Newtonian viscosity law is defined as an apparent viscosity at that shear rate.

Generally, the apparent viscosity of CWM was high, more than 1 Pa.s at shear rate of 100 s^{-1} (Figure 1). The concentration of all raw coals to prepare CWM with good fluidity was low. In higher coal concentration, the apparent viscosity was very high.

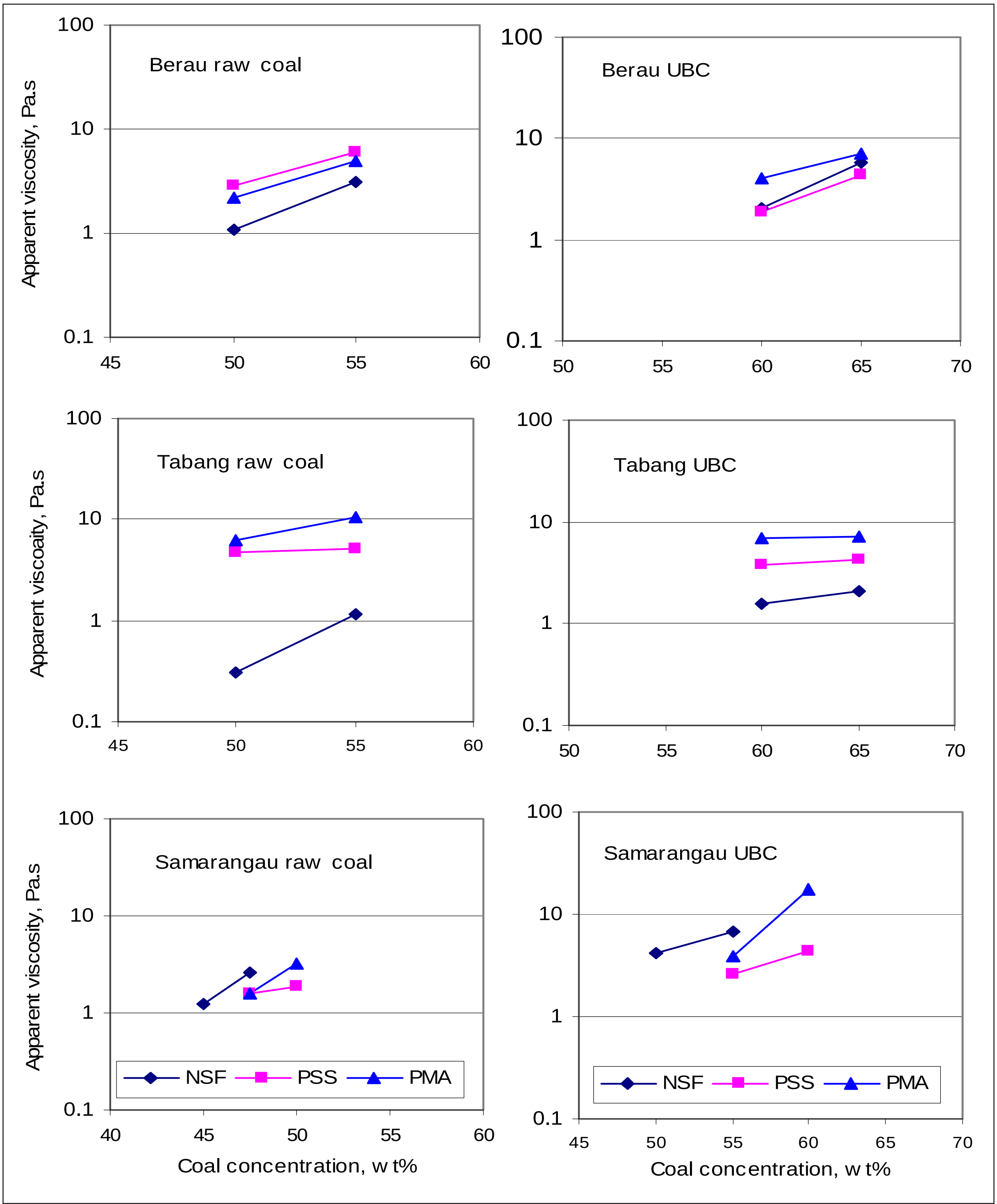

Figure 1. Effect of coal concentration on the apparent viscosity

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In case of CWM which was made using Berau raw coal, the additive of NSF showed the best rheologycal properties with lowest apparent viscosity even in high coal concentration compared to those of PSS and PMA. The lowest apparent viscosity is reached at coal concentration of 50 wt%. Different from the raw coal, the Berau UBC produced CWM with good rheological properties by using PSS as an additive at coal concentration of 60 wt%. It can be explained that upgraded coals have different surface behaviour compared to that of raw coal.

CWM using Tabang coal as raw material, either, Tabang raw coal or Tabang UBC, the lowest apparent viscosity was obtained by using NSF as additive followed by PSS and PMA at coal concentration level of 50 wt% and 60 wt% respectively.

The lower coal concentration of Samarangau either, raw or UBC in CWM preparation compared to those of the Berau and Tabang coal, might be caused by different characteristic of the Samarangau coal. The best additive for CWM production using Samarangau coal as raw material with good fluidity was PSS which produced CWM with the lowest viscosity at same level coal concentration. The coal concentration of 47.5 wt% for CWM with raw coal and 55 wt% with UBC was not good for the slurry to be used as fuel. The low concentration will give low heating value and low combustion efficiency.

4. ECONOMIC EVALUATION

To calculate the economic evaluation of CWM production, the calculation depends on complex combination of a wide variety of factors. The simple formula is:

CWM price = (coal price at mine site) + (CWM production cost) + (transportation, storage and other handling expenses)

It means that CWM is competitive in price with coal when transportation, storage and other handling expenses are less than those of coal. There are numerous cases in which CWM should be more economical in terms of price with the fact that CWM is a fluid fuel that is easy to handle, can be pumped by pipelines and free from dust problem and spontaneous combustion.

5. CONCLUSION

The apparent viscosity showed a better rheologycal properties of obtained CWM by using upgraded coals as a function of coal concentration for every dispersing additive compared to that of the raw coals. All of raw coals which were used as raw material to produce CWM showed lower coal concentration compared to upgraded coal, based on apparent viscosity value at shear rate of 100 s^{-1}.

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