

Rheological Behaviour of Coal Water Slurries with and Without Additive

Ayush Singh¹, Amir Hussain Idrisi², Ankit Kulshrestha³Assistant Professor, Department of Mechanical Engineering, Amity University, Lucknow, U.P., India¹Assistant Professor, Department of Mechanical Engineering, S.R.M.S. C.E.T., Bareilly, U.P., India^{2,3}

ABSTRACT: Coal Water Slurries (CWS) are concentrated suspensions of coal particles in water and are used as fluid fuels. The rheological properties of Coal Water Slurries depend on a number of factors such as the type of coal, the solid content and its size distribution, the temperature, the pH and the presence of electrolytes and chemical additives. In the present study rheological behavior of Indian coal water slurry (CWS) was investigated using an Anton Parr RheolabQC rheometer. The objective of the current work was to determine the effect of concentration and additive on the rheological behaviour of coal water slurries. It is observed that the coal water slurry exhibits shear thinning/thickening effects at low concentrations while at 50% Cw and above the slurry prepared from both coal samples consistently shows shear thinning behaviour. The increase of viscosity is found to be exponential with concentration. The viscosity is significantly affected by surfactant Triton X-100 which is observed to lower the viscosity at all selected dosages (i.e:0.5%-2.4% by weight of slurry). The optimal dosage is 1.5% of additive by weight of slurry. The maximum reduction in viscosity is about half at 1.5% additive dosage at 50% Cw of slurry. From work on surfactant loading it can be concluded that it might be possible to produce pumpable coal slurries at concentrations of 50% and above by adding suitable dispersant/additive at optimal dosage.

KEYWORDS: Coal-Water slurries, Apparent Viscosity, Rheology, Rheometer, Additive.

I. INTRODUCTION

Factors such as the continued rise in oil prices, the difficulties associated with a stable supply of crude oil, increased fuel consumption, and the limited oil reserves in recent years have increased interest in and research related to the use of coal, which is relatively cheaper, plentiful, and widely distributed across the globe. Coal slurry fuel can be divided into CWS (coal-water slurry), COS (coal-oil slurry), COWS (Coal-oil-water slurry), CMS (coal methanol slurry), and CMWS (coal-methanol-water slurry) depending on the type of liquid mixed with the solid coal. Among these different types, CWS fuel is considered by some to have the greatest economic feasibility as a fuel source and the greatest potential for commercialization.

As a result research on coal-water slurries CWS was commenced. The suspension contains 50%–75% coal. The coal content varies depending on particular requirements. CWS would produce less SO_x, CO and NO_x on combustion than a coal-oil mixture COM. The emission of CO and NO_x are much lower for a CWS than COM because of the slightly lower combustion flame temperature (Botsaris et al., 1989; Panda et al., 1989). Special storage and transportation are not required, therefore, loading and unloading costs are considerably reduced.

One of the most important requirements to be met while preparing a coal water slurry is that coal concentration should be made as high as possible, but the viscosity is to be kept at a minimum level for ease of handling during preparation, storage, transfer through pipelines, and subsequent atomization. But the viscosity of coal water slurry (CWS) increases with solid concentration in the slurry and the stability of the suspension becomes poor if the viscosity is reduced (Henderson et al., 1983; Kim et al., 1983; Papachristodoulou and Trass, 1987). Another difficulty encountered in the preparation of HCCWS (Highly Concentrated Coal water Slurries) is the diversity of coals in their physical and chemical properties, which largely depends on the place where it is mined. A universal correlation for all coal samples is quite difficult. The flow behavior of CWS depends on many factors, such as (i) physico-chemical properties of coal, (ii) volume fraction of the suspension, (iii) particle size range and its distribution, (iv) temperature of the suspension, (v)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 10, October 2016

pH, and (vi) presence of electrolytes and additives (Schack et al., 1957; Papachristodoulou and Trass, 1987). Hence design of the operations encountered in preparation, transport, and utilization of HCCWS requires prior knowledge of its rheological behavior for the effective application and economic viability of these processes.

Viscosity measurements show that surfactant addition to the suspension affected the rheology. This is presumed to be related to the adsorption of the reagent on the coal surface, which is dependent both on the nature of the surface and the reagent type and its concentration (Chapman et al., 1986)

Surfactants used as dispersants are classified into ionic and non-ionic surfactants. Ionic types of matter stick to coal particles; the hydrophilic group of the dispersant is ionized in water and electrically charges the particles, thereby causing electrostatic repulsion between the particles, increasing their dispersibility. With non-ionic substances, the high-molecular absorbent layer formed on the surface of the coal particle causes steric repulsion, thereby promoting dispersion.

Various investigators have studied the effect of surface active agents on the rheology and stability of coal ash and coal water slurries. (Aktas Z et al., 2000) noted the effect of addition of surface active agent on the viscosity of a high concentration slurry of a low-rank British coal in water. They found that the viscosities of the slurries with low ash content were significantly reduced by the surfactant addition (Triton X-405 *p*-tert-octylphenoxy-polyethoxyethanol) which also altered the rheological characters of these slurries from non-Newtonian towards Newtonian fluids. However, they noted that the sample containing very fine particles with a high ash content 24.5%. It showed non-newtonian behaviour even in the presence of reagent. (Mosa .E.S et al., 2008) examined the effect of chemical additives or reagents on rheological characteristics of coal water slurry (CWS). Among studied dispersing agents, sulphonic acid recorded the best performance in modification and reducing CWS viscosity. The best dosage of all tested dispersants was found to be as 0.75 % by wt of solids. With regard to studied stabilizers, Na- CMC recorded better performance than xanthan gum. The best dosage of investigated stabilizers was found to be as 0.1 % by wt. from total solids (Dincer H et al., 2009) studied the effect of chemicals on stability and viscosity of coal water slurries. In their experiments, anionic type of chemicals—polyisoprene sulphonic acid soda (Dynaflow-K), a derivative of carboxylic acid (AC 1320) and naphthalenesulfonate–formaldehyde condensate (NSF)—were used as dispersing agents and the stabiliser was the sodium salt of carboxymethyl cellulose (CMC-Na). They found that polymeric anionic dispersing agents such as Dynaflow have much greater effect on the viscosity and the stability of coal water slurry. (Das et al., 2009) their work involved the preparation of a highly concentrated coal-water slurry employing three different low-rank coals of Indian origin having variable ash content. The formulation, rheology, and stabilization of the slurry were investigated using saponin extracted from the seeds and pericarps (mods) of the *Acacia concinna* plant as a dispersant. The saponins extracted from both the seeds and pericarps of the plant are found to stabilize the slurry. They claim that the plant-based additive saponin from *A. concinna* (both pericarps and seeds) can be suitably substituted for a synthetic additive, such as SDS (Sodium Dodecyl Sulphate). A few pilot experiments with other commercially available additives, such as CMC and SDDBS, also yielded the same results. The present work describes the effect of the solids concentration and surfactant Triton X-100 on the rheology of high ash Indian coal slurry.

II. MATERIALS AND EXPERIMENTAL PROCEDURES

A. EXPERIMENTAL MATERIALS

Pulverized coal: Pulverized Coal samples were collected from Guru Nanak Dev Thermal Power Plant Bathinda, Punjab (sample A) and Panipath Thermal Power Plant, Haryana (sample B). They were stored in moisture proof air tight gunny bags. Sieve analysis was done for the particle size distribution the results of which are given in fig 1. For coal A almost all the particles are finer than 750 μm while about 28% of the particles are finer than 53 μm . For coal B almost all the particles are finer than 270 μm while about 18% particles are finer than 53 μm . Hence coal B is overall finer as compared to Coal A.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 10, October 2016

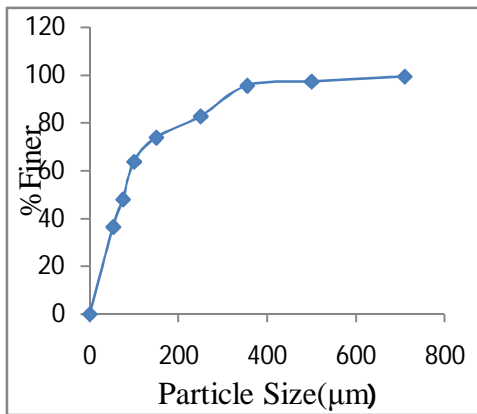


Figure 1(a) Particle Size Distribution For Coal A

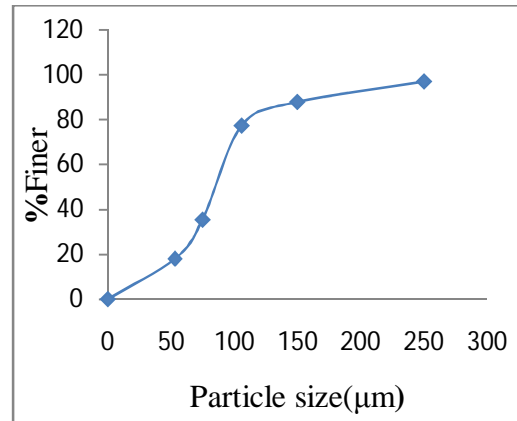


Figure 1(b) Particle Size Distribution For Coal B

Figure 1 Particle size distribution

Energy-dispersive X-ray spectroscopy (EDS or EDX) reveals the elemental composition of both coal samples (tables 1 & 2). These Elements are present in compound form as:CaCO₃,SiO₂,Al₂O₃,SiO₂,GaP,FeS₂,KCl and the remaining such as Ti(Titanium),Cu(Copper),Fe(iron) and Zn(zinc) are present in elemental form.

Table 1: Elemental Composition of Coal A

Element	C	O	Al	Si	S	K	Ca	Ti	Fe	Cu	Zn
Weight%	52.19	34.58	3.71	4.79	0.64	0.25	0.34	0.92	0.75	0.87	0.96
Atomic%	62.88	31.28	1.99	2.47	0.29	0.09	0.12	0.28	0.19	0.20	0.21

Table 2: Elemental Composition of Coal B

Element	C	O	Al	Si	P	S	K	Ca	Ti	Fe	Cu	Zn
Weight%	39.85	34.83	8.09	11.67	0.31	0.37	0.84	0.89	0.99	0.43	1.03	0.70
Atomic%	52.41	34.39	4.73	6.56	0.16	0.18	0.34	0.35	0.33	0.12	0.26	0.17

The S.E.M. (scanning electron microscope) image of both coal samples is shown in fig 2.

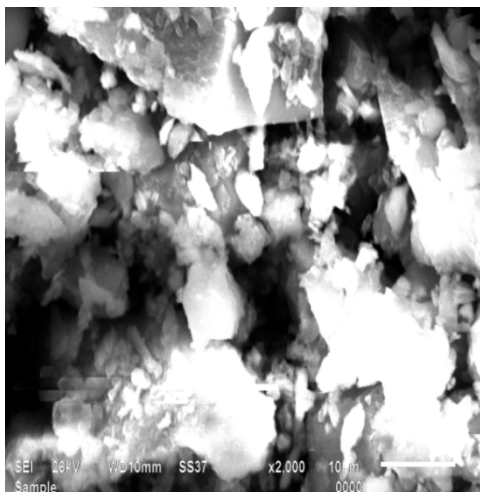


Figure 2a: SEM image of coal A

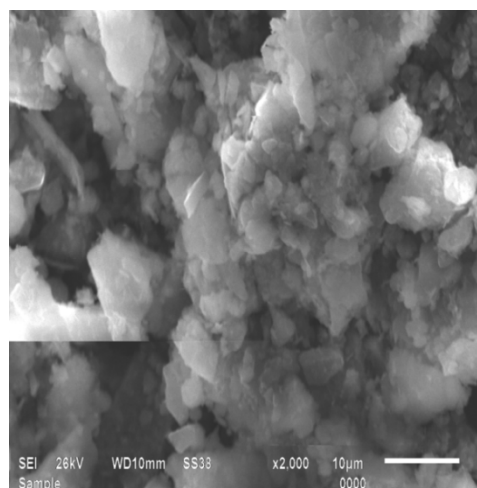


Figure 2b: SEM image for coal B

Figure 2 SEM image for coal

Water: Distilled water (pH 7) was used for preparing coal water slurries at all concentrations.

Drag Reducing Reagent: The non-ionic surfactant TRITON X-100 purchased from Loba Chemie Pvt.Ltd,Mumbai is used to analyze the effect of surfactants on the rheology of coal slurries. Its chemical name is iso-octyl phenoxy polyethanol. pH(5% aqueous solution) is between 6-8. It is a commonly used as detergent in laboratories. Fig.2 shows the chemical structure of TRITON X-100.

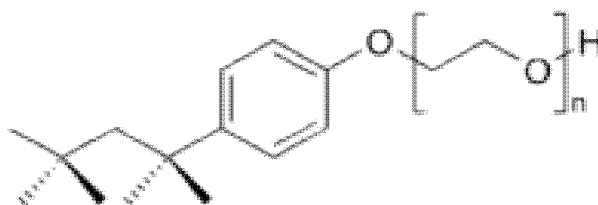


Figure 3: Triton X-100

B. SAMPLE PREPARATION AND PARAMETRIC VARIATIONS

For rheumatic tests, 50mL of the suspension is prepared by mixing the required quantity of coal with distilled water to obtain the desired concentration (C_w).An electronic balance with a resolution of 10^{-4} gm is used for weighing the materials accurately. The suspension was mixed gently by a glass rod, taking care to avoid attrition of the particles. For examining the effect of solids concentration the coal samples are sieved in two particle size range of 53-75 μm and 75-106 μm and the concentration C_w is varied between 10%-50%.However while studying the effect of additive(triton X-100) only sample A(unseived) at two concentrations (C_w) of 40% and 50% is used. All the measurements are taken at a room temperature of 26⁰ Celcius.The range of shear rates for all rheological measurements is from 0-500/s.The additive dosage selected based on literature review is between 0.5%-2.4% by weight of slurry.

C. EXPERIMENTAL METHOD

The RheolabQC (Make:AntonParr,Gurgaon) is used for carrying out all rheological measurements. It is a rotational rheometer which works according to the Searle principle. It consists of a high precision encoder and a highly dynamic EC motor, which is also used in the MCR rheometer series. We can select between controlled shear rates (CR) and controlled shear stress (shear stress) test settings. It has wide speed and torque ranges and very short motor responses time. The measuring system DG42-SN22909 was used for lower concentrations (less than 40% C_w). This geometry consists of a fixed cylinder (bob) and a rotating cylinder (cup). The slurry placed between the annular space between

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 10, October 2016

the two cylinders and a torque applied on the rotating cylinder (cup). At higher concentration the measuring system used was ST22-4V-40-SN23352.

III. RESULTS AND DISCUSSIONS

A. EFFECT OF SOLIDS CONCENTRATION ON VISCOSITY OF COAL-WATER SLURRY

To examine the effect of solids concentration on viscosity (it is the averaged value when shear rate is varied from 0-500/s for each concentration). The results are shown in graphs fig. 4 and 5 and tables 3 and 4. It can be seen that the apparent viscosity of coal water slurries is a strong function of concentration of solids for both particle size distributions and both coal samples. The viscosity first increases on an average about 2-4 times at lower concentrations (upto 30%) for every 10% rise in solids concentration by weight while it increases several folds (upto 8-9 times) for each 10% rise in concentrations at higher concentration of slurry (i.e above 30%) for both particle sizes and samples. Hence we can say that the averaged apparent viscosity increases exponentially with concentration for both samples. This could be attributed to increase in interparticle frictional resistance with concentration.

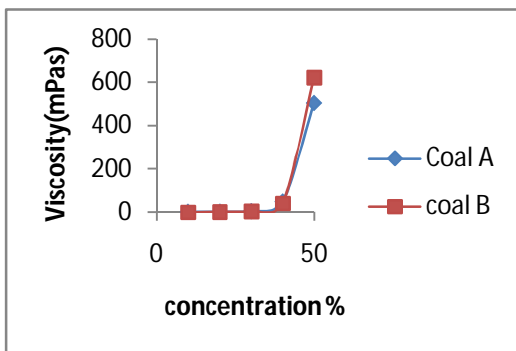


Figure 4: Viscosity Vs Concentration (53-75µm)

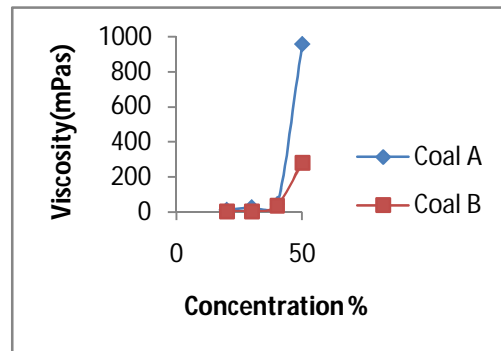


Figure 5: Viscosity Vs Concentration (75-106µm)

Table 3: Concentration vs. Viscosity for coal A and B (53-75µm)

Concentration Cw%	Viscosity coal B(mPas)	Viscosity coal A(mPas)
10	1.21	1.47
20	3	3.37
30	5.19	5.59
40	42.2	50
50	624	506

Table 4: Concentration vs. Viscosity for coal A and B (75-106µm)

Concentration Cw%	Viscosity Coal A(mPas)	Viscosity Coal B(mPas)
20	10	3.71
30	24	4.75
40	42.66	35.56
50	957	281

B. EFFECT OF TRITON X-100 ON THE RHEOLOGY OF COAL WATER SLURRIES

The two curves (figs. 6 and 7) clearly show that triton X-100 has profoundly affected the rheology of coal water slurry obtained by coal A (unseived). The following points can be made.

- (1).The slurry shows lower viscosity for all tested dosages of additives as compared to without additive.
- (2).The Additive is more effective at 50% C_w than at 40% C_w where at 1.6% dosage the averaged viscosity is reduced by more than half.
- (3).At 40% C_w of coal slurry the additive more vigorously reduces viscosity at low shear rates (less than 100/s).This is highly desirable effect as it shows that it is easier to make the slurry flow from rest.
- (4).The increase in additive dosage does not guarantee a consistent decrease in viscosity. The optimal dosage is near 1.5 % by wt. of slurry.

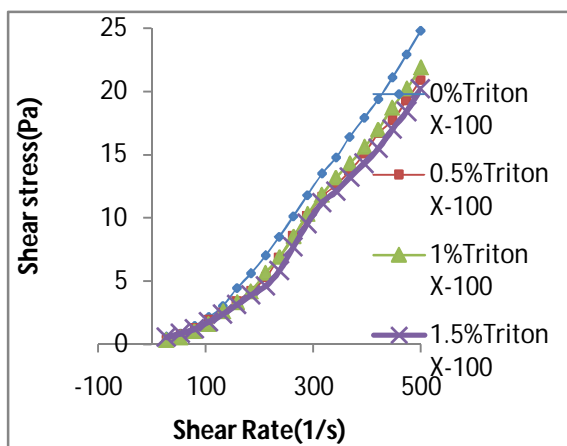


Figure 6: Coal A (40% C_w) with Additive

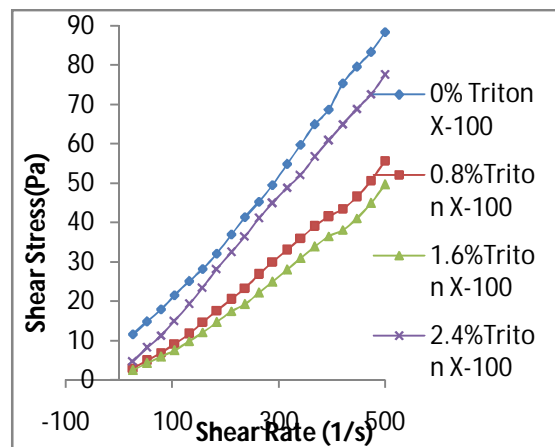


Figure 7: Coal A (50% C_w) with Additive

IV. CONCLUSION

From the present work it is evident that the rheological properties of coal water slurries are dependent on concentration and the presence of additive. Both samples show an exponential increase in viscosity with concentration showing shear thickening/thinning behaviour at lower concentrations and shear thinning/pseudoplastic behaviour at higher concentrations (i.e. 50% C_w and above). The effect of additive (Triton X-100) on the rheology is profound, the additive lowers the yield stress and in the limiting case has reduced the averaged apparent viscosity by half at optimal dosage of around 1.5% concentration by weight of slurry at 50% C_w . From the work on additive it can be concluded that additives might be used to tame the rheological behaviour of slurries in a way suited for storage and transportation.

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