International Journal of Engineering & Technology, 7 (4.39) (2018) 326-329

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper



Study of Rheological Characteristics of Coal Water Alcohol Slurry

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Abstract

A comparative analysis of coal water alcohol slurry (CWAS) has been done taking glycerol, glycol and ethanol as an additive.10 ml of alcohol additive was added to the slurry and a range of 50-64% of concentration by mass was obtained. Various parameters like shear rate, shear stress, pH, temperature, apparent viscosity, stability etc. has been examined and compared the result of coal water glycerol slurry, coal water glycol slurry and coal water ethanol slurry for a particular mono-modal sample. From each parameter study it is concluded that coal water alcohol slurry in presence of glycerol has less viscosity as well as more stability than coal water alcohol slurry in presence of glycol and ethanol. This is due to the presence of more number of OH^- radicles in the alcohol group. More OH^- radicles creates more carbon atoms which will increase the tendency to adsorb on the surface of coal.

Keywords: *Rheology; Coal water alcohol slurry (CWAS); viscosity; Bingham Model*

1. Introduction

Keeping pace with the human civilization energy use has marched from cave to palace, from forest to concrete jungles. It is inseparable to civilization. In the cave it was the protector and facilitator .In course of time human intelligence converted it to be an instrument of development. The journey of production of energy in the caves of the woods to the time of atomic age, it has experienced many a sources like woods, fossil oil, hydropower, geothermal, coal, atom etc. One gives may to another as almost all these sources are the gifts of the nature to the mankind and gifts are always limited. Fossil oil gives way to coal oil mixture. The cost benefit ratio of coal-oil mixture being uneconomical the need of coal water slurry has become a necessity. Coal has been used as an energy generating source from very early part of human civilization. The production of energy through gasification Belgiorno V. et al. [1], liquefaction Rajasekhar M. et al. [2] and carbonization Miura K. et al. [3] of solid coal is usual practice.

Mishra S.K. et al. [4] have studied that due to the hydrophobic nature of coal surface they readily agglomerates resulting the formation of clusters with reduction of the stability of coal-water dispersion. The review of inter-particle interactions shows that van der Waals forces are always present and always attractive, which leads to particle agglomeration and higher slurry viscosity. The Vander Waals forces can be dispersed by preventing particles from approaching each other, which can be accomplished by steric hindrance or by electrostatic repulsion. Gurses A. et al. [5]; Karatepe [6]; Tudor P.R. et al. [7]; Miller J.D. et al. [8]; Laskowski J.S. et al. [9]; Yong-Jie D. et al. [10] ; Casassa E.Z. et al. [11]; Celik M.S. et al [12], Sugawara et al. [13] and Huai H. et al. [14] studied that the dispersants which are used to enhance slurry viscosity adsorb to the particle surface and create steric hindrance, or electrostatic repulsion. Up to now, ample number of additives have been exposed in order to increase the stability of the coal water alcohol slurry dispersion with proper mechanism.

It has been proposed by Aktas Z. et al. [15] that high surfactant/coal ratio Triton X-405 adsorbs with the OH radicals in the form of spherical micelles. This assures on the attachment of the coal surface through short range forces. The interaction of the coal with surfactant could be enhanced due to the electrostatic force of attractions. The surface coating of the coal particle by micelles repels each other that substantially reduce the agglomeration as well as suspension viscosity.

The objective of this paper is to prepare a high concentrated CWAS (Coal water alcohol slurry) using glycerol, glycol and ethanol as an additive to increase the surface activity of the coal and to reduce the viscosity of slurry.

We have examined OH^- group present in the glycerol, glycol and ethanol and how it will affect the rheological behaviour of the coal water alcohol slurry. A comparative analysis between slurry prepared from glycerol and glycol has been done.

2. Experimental Method

2.1. Preparation of Coal

Talcher Coal Field is the source of the sample from where coal was collected. A mono-modal sample i.e. 300µm was prepared and the proximate and ultimate analysis of sample were given in the Table 1 and Table 2 respectively. Particle size distribution of coal sample was carried out by Malvern particle size analyzer and the sizes of d_{10}, d_{50}, and d_{90} of the sample are given in Table 3.

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Table 1: Proximate Analysis of the coal sample

Coal	Moisture	Ash	Volatile matter	Fixed carbon
	10.02	39.84	29.75	30.39

Table 2: Ultimate Analysis of the coal sample

Coal	Carbon	Hydrogen	Sulphur	Nitrogen	Oxygen
	77.21	5.63	3.62	1.94	11.27

Table 3: Particle size distribution of coal sample

Coal Type	Particle size, in µm		
	d_{10}	d_{50}	d_{90}
Coal	3.337	33.131	109.531

N.B.: d_{10}, d_{50}, d_{90} are the diameters percentage points 10%, 50% and 90%, respectively

Rheological measurement

HAAKE RHEO STRESS 1, a rheometer was used to explore the rheological behavior of CWAS. The total arrangement assembled of rheometer, computer, chiller, compressor and printer. The chiller was used to maintain the temperature of sample cup used in rheometer. One rotor was attached to the spindle which mainly calculated the shear stress, shear rate and viscosity. pH value of Coal Water Slurry along with additive was maintained in the range of 4.5 to 5.0. Rheological experiment indicates shear rate and shear stress. Based on the experiment data a proper model was taken up to know the nature of the slurry.

3. Result and Discussion

3.1 Result of Shear Rate on Shear Stress of the Slurry

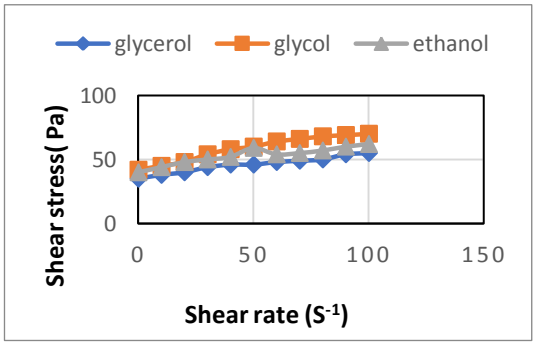

Figure 1: Graph between Shear stress and Shear rate for glycerol, glycol and ethanol

Shear rate and shear stress of three different slurries i.e. coal water glycerol slurry, coal water glycol slurry and coal water ethanol slurry are shown in the figure (1).Above graph indicates with enhancing shear rate of the slurry shear stress increases. These three graphs follow Bingham plastic flow behaviour which is non-Newtonian. The Bingham plastic model may be written as

$\tau = \tau 0 + \eta \gamma$

Where, τ= Shear Stress (Pa)

$\tau 0$ = Yield Stress (Pa)

η =Viscosity (Pas)

γ =Shear Rate(s-1)

Comparing three slurry figures shear stress of coal water glycerol slurry is less than other slurry which helps in the flow of the slurry.

3.2 Result of Shear Rate on Apparent Viscosity of the Slurry

Figure (2) explains the result of shear rate on apparent viscosity. Enhancing shear rate reduces apparent viscosity . In addition of glycerol in the slurry has less viscosity in compare to glycol and ethanol. This is because of the presence of more OH- radicals in the glycerol which will increase the inter-molecular repulsion and also breaks the coal particle closeness as a result apparent viscosity reduces Mishra S.K. et al.[16],Bogger et al [17],Covey et al [18].

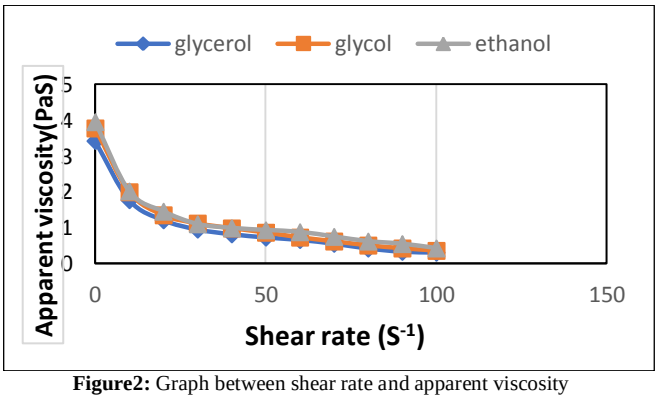

Figure2: Graph between shear rate and apparent viscosity

3.3 Result of Coal Concentration on Apparent Viscosi

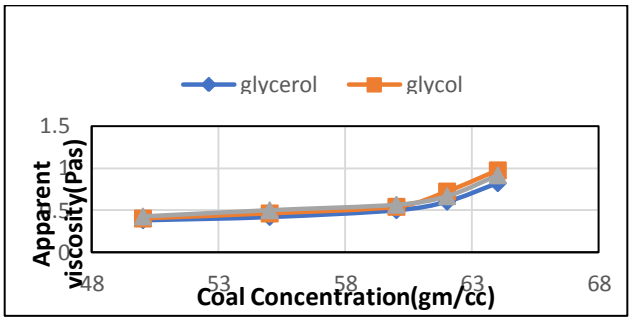

Figure 3: Graph between coal concentration and apparent viscosity

Figure (3) shows the relation between different coal concentration ranges from (50-64) by mass with the apparent viscosity. Increasing coal concentration apparent viscosity of coal water glycerol slurry is less than coal water glycol slurry and coal water ethanol slurry .This is because of the presence of the more (OH) radicles in the group. In dilute suspensions, the particles do not interact with each other much, so particle-particle interactions are not very important. But as the suspension concentration increases, the total surface area of particles increases, and the average distances between those particles decreases. The number and strength of interactions increases, and can then affect or even dominate the suspension properties. Some particle-particle interactions come about due to the material properties, such as ionization of surface species leading to surface charge.

For better efficiency as fuel, the flow behavior of coal-water slurry and its suspension viscosity is important during pipeline transport. Vander Waal forces are exerted among coal particles as a result viscosity increases. Low viscosity maintain good stability and helps the slurry to flow easily. In other way the slurry should have high viscosity at low shear rate and should have low viscosity at high shear rate. Therefore, it is important the viscosity parameter as a function of shear rate.

3.4 Result of pH on Apparent Viscosity

Figure (4) shows the relation between pH and apparent viscosity of coal water alcohol slurry taking glycerol, glycol and ethanol .Apparent viscosity of three slurries decreases with enhancing pH. As pH increases surface hydroxylation takes place which increases the negative charge density on the surface of the coal particle. With increase pH value , apparent viscosity of coal water glycerol slurry will decrease more in compare to other two.

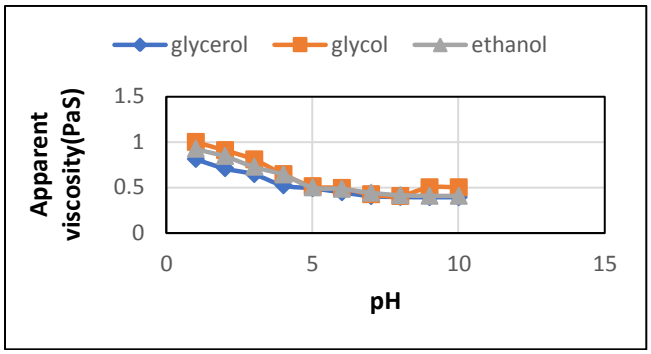

Figure 4: Graph between pH and apparent viscosity of slurry

3.5 Result of Temperature on Apparent Viscosity

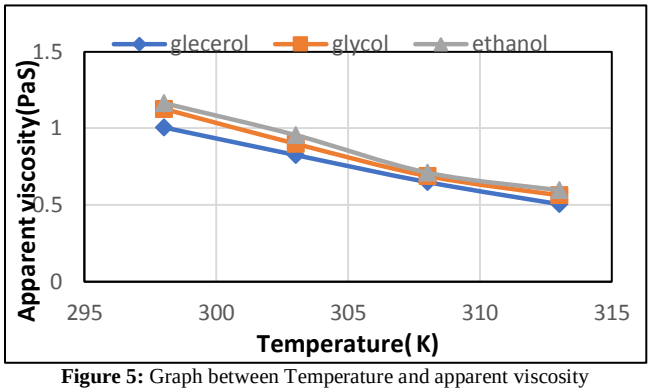

Figure 5: Graph between Temperature and apparent viscosity

The relation between temperature and apparent viscosity has given in figure (5).

From the graph it is concluded that apparent viscosity reduces exponentially with increase in temperature. Because of increase in kinetic energy inter particle attraction reduces. As the temperature increases, the time of interaction between neighboring molecules decreases because of the increased velocities of individual molecules which reduces viscosity. Arrhenius equation gives the relation between temperature and viscosity Misra et al [19].

Equation is:

$\eta = A \exp(E/RT)$

$\ln(\eta) = E/RT + \ln(A)$

Where η = viscosity (at a particular shear rate),

E = Fluid –flow activation energy,

T = Temperature (Kelvin)

A = Fitting parameter

R = Universal gas constant.

From the graph reduction in apparent viscosity of coal water glycerol slurry is more than the other two.

3.6 Result of Coal Concentration on Static Stability of the Slurry

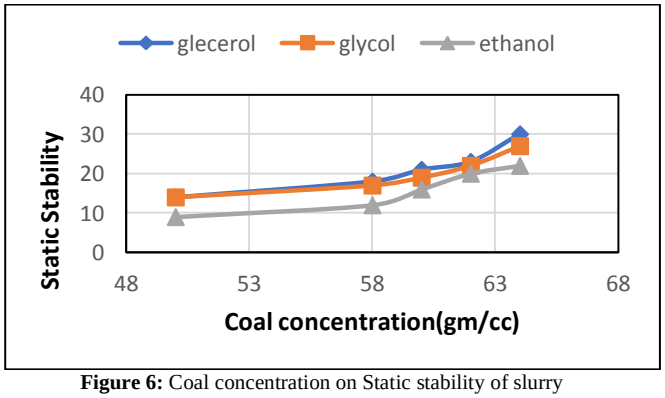

Figure 6: Coal concentration on Static stability of slurry

Figure (6) shows the effect of coal concentration on the stability of coal water ethanol slurry, coal water glycerol slurry and coal water glycol slurry .From the graph the coal water glycerol will have more stability than other two. This is because of the more OH radicals present in the slurry. More OH^- radicals present mean more is the repulsion between the coal particles. Coal water glycerol slurry will store for maximum 30 days.

3.7 Mechanism of Stabilization

Coal surface is mostly hydrophobic in nature. Hydrocarbon part of glycol and glycerol adsorbs on coal surface anchoring its hydrophilic group i.e. –OH group towards aqueous phase. As a result a barrier is created on each coal particle Das D. et al. [20] .Therefore each coal particle experience a mechanical shock. Comparing the stability of coal- water- glycol and coal- water- glycerol it has been found that coal water -glycerol slurry is more stable than coal- water- glycol. This can be explained by considering the more no of –OH group in glycol (3 OH group) in comparison to glycol (2 OH group) and more no of carbon atom in their hydrophobic part. More is the no of carbon atom in additive more will be its tendency to adsorb on coal surface. Therefore additive glycol adsorbs on coal surface more effectively. Also due to the more no of OH group in glycerol it has more tendency to be more hydrated.

4. Conclusion

I. The present study deals with the preparation and stabilization concentration coal water slurry using ethanol, glycol and glycerol as dispersant.

II. Due to the presence of OH group in three different types of dispersant the wet ability increases which increases the stability of coal water alcohol slurry.

III. The coal-water-alcohol slurry obeys Bingham plastic rheological models.

IV. We have varied different parameters like coal concentration, pH, temperature, apparent viscosity and stability .From all the parameter study it is concluded that coal water glycerol slurry is better than other two slurry. This is because of the presence of more OH- groups in glycerol.

V. All the coal- water- alcohol slurry behaves Bingham plastic rheological model.

VI. The static stability of this CWGIS exists for the maximum period of 30 days.

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