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ORIGINAL CONTRIBUTION

# The Effect of Additives on the Behavior of Coal-Oil-Water Slurries

Tapas Kumar Manna and Somak Jyoti Sahu*

*Department of Chemical Engineering, Haldia Institute of Technology, Haldia, W.B., India*

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**ABSTRACT**

Presence of trapped water in coal-oil-water (COW) slurry droplets increases the stability of slurry, enhances the combustion process to a certain extent due to the micro explosion caused by rapid evaporation of water at high temperature in furnace and decreases the total cost of fuel. To establish the technology of COW slurry system and for industrial application of these slurries, through knowledge of settling and rheological behavior, atomization and combustion characteristics is required. The effect of additive - guar gum on the settling and rheological behavior of COW slurry is studied and observed to be effective upto 0.5% concentration by weight.

**Key words:** additive, COW, rheological behavior, slurries

## 1. INTRODUCTION

The principal driving force behind the development of coal slurries, namely, the coal-oil mixture (COM) and coal-water slurry (CWS) has been searched for a replacement of liquid fuel [1], as the oil sources are rapidly depleting in the world and also, due to the uncertainties of the supply of oil.

However, commercial application of these slurries has always some problems, like the tendency of coal particles to settle out of suspension, causing difficulties in storing, pumping and injection. Also, the combustion of these slurries has been reported to be incomplete, due to agglomeration of slurry droplets during burning inside furnace. It has been observed that presence of water in coal-oil-water (COW) slurry increases the, stability of slurry and decreases the total cost of fuel [2]. Also, it enhances the combustion process to a certain extent, because of the splattering of slurry droplets inside the furnace, which arises due to the micro explosion caused by rapid evaporation of trapped water inside the droplets. However, presence of water in the slurry decreases the calorific value and increases the viscosity of slurry, the effect of which is less using high ash coals, liquid phase along with oil in slurry fuel, thus saving the cost for complete de-watering of coal using thermal energy. In view of the above facts, the COW slurry may have the prospect of substituting liquid fuel, coal, COM and CWS [3].

To establish the technology of COW slurry system and for industrial application of these slurries, through knowledge of settling and rheological behavior [4], atomization and combustion characteristics is required. The present work is an attempt to study the effect of additives on the settling and rheological behavior of COW slurry [5, 6, and 7].

## 2. EXPERIMENTAL

In this work the additive, namely, gaur gum are selected to study their effect on the settling and rheological behavior of COW slurry, as the increase in stability and drag reduction is very important for proper utilization of these slurries. Slurries are prepared using 30% by weight of coal, particle size 58.5 μm from Dabour collieries (ash content 22%), 10% water and the rest high speed diesel oil and additives.

*Corresponding Address: somaksahu@gmail.com

## Stability study of slurry

The stability of COW slurry in storage is the ability of the coal particles to remain suspended uniformly throughout the slurry under stagnant condition. The experiments on the settling of COW slurries in static condition have been conducted in five graduated glass cylinders of 250 ml capacity, each. Five coal slurries were prepared with five additives concentration (0, 0.1, 0.2, 0.5, and 1.0) but fixed coal, oil and water concentration. These five slurries were poured into five cylinders up to a height of0.22 m. The height of the slurry head i.e., the line of separation between the black slurry and the clear liquid is measured time to time for two hours period and settling time vs. height of the slurry head charts were prepared for two additives.

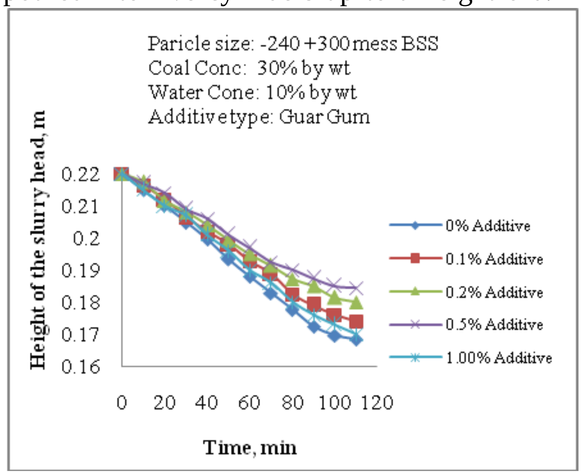


Figure 1: Variation of height of slurry head with time for different gaur gum concentration of coal – oil water slurry

For each sample, the height of the slurry head with time is plotted. During the constant rate period, the terminal settling velocity is calculated for each sample by dividing height of the slurry head by plotting time against additives concentration as shown in figure 1.

## Rheological behavior study of slurry

The set up for the study of the rheological behavior of COW slurry is shown in figure 2(a) &2 (b). It consists of a storage tank, straight upstream test section, bypass line and the downstream section. A progressive cavity pump, pumps the slurry through the pipeline of diameter 0.01905 m. The test section consists of a horizontal upstream straight pipeline of 2.845m length and four fittings, namely union joint, $90^0$ bend, return bend and the commercially available fully open gate valve with the spindle pointing vertically upwards, each of the parts being fitted with suitable entrance and exit length [8, 9 and 10].

Figure 2 (a): Actual setup of the experiment

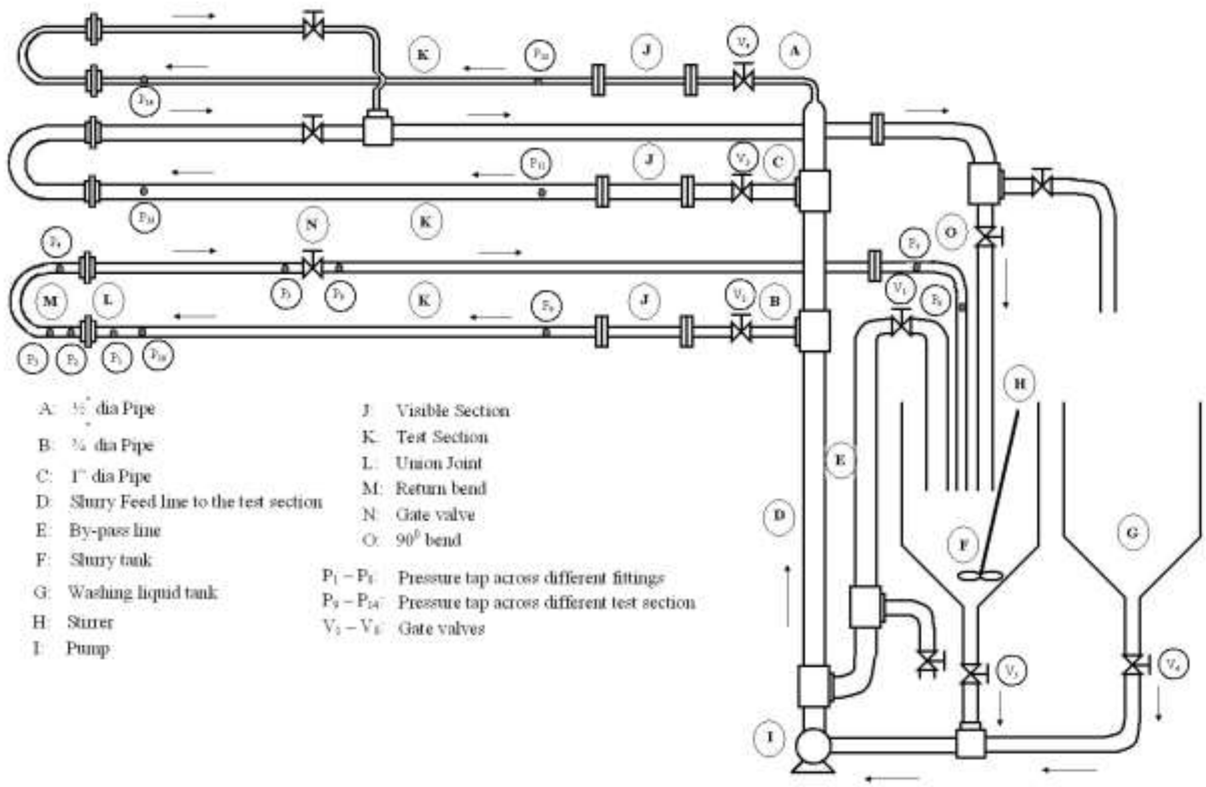


Figure 2 (b): Schematic diagram of experimental set-up for studding the rheological behavior of coal – oil-water – additive slurry

Each part of the test section is provided with digital pressure transducer to measure the pressure across the test section. The volumetric flow rate is measured by a 1000 ml graduated glass cylinder and a stop watch.

The test slurry is prepared and circulated through the bypass line initially and then the valve $V_2$ is opened slowly, so that the slurry can flow slowly through the horizontal straight test section and four fittings. Under steady state condition the pressure drop and the corresponding volumetric flow rate are noted. The slurry- flow rate through the test section is varied by regulating the bypass valve $V_1$. In this way, for the straight test section and four pipe fittings, the pressure drop-volumetric flow rate data are generated for particular slurry. The data collected cover both the laminar and the turbulent zone.

Rheological behavior of a time independent non Newtonian fluid can be studied using Metzner and Reed generalized correlation [11], which is applicable to laminar flow through straight pipe and can be written as

$$\tau_w = \frac{D\Delta P}{4L} = k' \left(\frac{8V}{D}\right)^n \qquad (1)$$

Where, $\tau_w$ is the shear stress at the wall in N/m$^2$, $\Delta$P is the pressure drop (N/m$^2$) across the straight pipe of length L (m) and diameter D (m). V is the average velocity in m/s. $k^/$ is called the generalized fluid consistency index (N s$^n$/ m$^2$) and n' is called the generalized flow behavior index. For each slurry, the $\tau_w$ and (8V/D) values are calculated for different V and plotted on a log-log graph paper.

One sample plot for the slurry is shown in figure 3. From the slope and the intercept the n' and k' are calculated. For slurries with guar gum these values are shown in table l.

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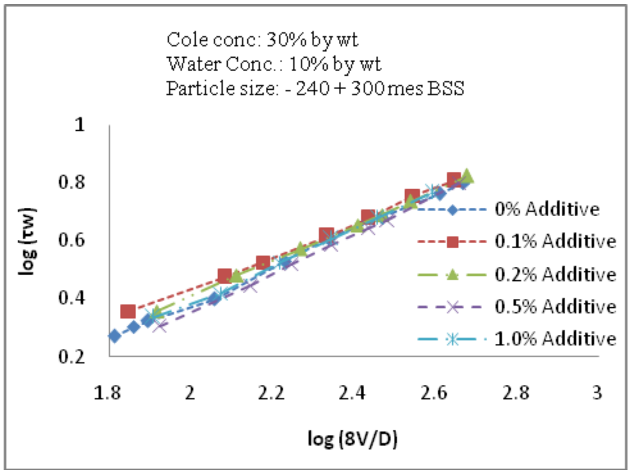


Figure 3: - Variation of log ($\tau_w$) with log (8V/D) for coal oil water slurry with additives

Table l: The values of n' and k' for slurries with guar gum as additive

| % Guar gum | n' | k' |
|---|---|---|
| 0.0 | 0.616 | 0.143 |
| 0.1 | 0.571 | 0.201 |
| 0.2 | 0 606 | 0.156 |
| 0.5 | 0.658 | 0.110 |
| 1.0 | 0.641 | 0.126 |

K factor method [12] is used to study the effect of pipe fittings, where the friction losses across pipe fittings is represented in terms of number velocity heads lost as given in equation 2.

$$\Delta H = \frac{\Delta P_b}{\rho_m g} = K.\frac{V^2}{2g} \qquad (2)$$

Where K is loss coefficient, V is the average flow velocity in m/s; 'g' is the acceleration due to gravity in m/s$^2$, $\Delta P_b$ is the pressure drop across fittings in N/m$^2$ and $\rho_m$ is the density of slurry (kg/m$^3$), which is given in equation 3.

$$\rho_m = C_c\,\rho_c + C_w\,\rho_w + C_o\,\rho_o + C_a\,\rho_a \qquad (3)$$

Where $C_c, C_w, C_o$ *and* $C_a$ are the concentrations of coal, water and oil and additives respectively in weight fraction and $\rho_c, \rho_w$ $\rho_o$and $\rho_a$ are the respective densities in kg/m$^3$.

The fanning friction factor 'f' for non Newtonian fluid can be expressed in the form of equation 4, which is in the form similar to the conventional relationship for Newtonian fluids in laminar zone.

The fanning friction factor 'f' [13 and 14] is expressed s

$$f = \frac{16}{N_{Re^*}} \qquad (4)$$

Where $N_{Re}$ *generalized Reynolds number is is given in the equation 5.

$$N_{Re}* = \frac{D^{n'}V^{2-n'}\rho_m}{k'8^{n'-1}} \qquad (5)$$

$k'$and $n'$are constants for each slurry and are independent of V. At each V for particular slurry, K is calculated for all fittings by equation 5. In this way, for all fittings and all slurry the K and $N_{Re*}$ values are calculated and plotted as K vs. $N_{Re*}$ plot. One such plot is shown in figure 4.

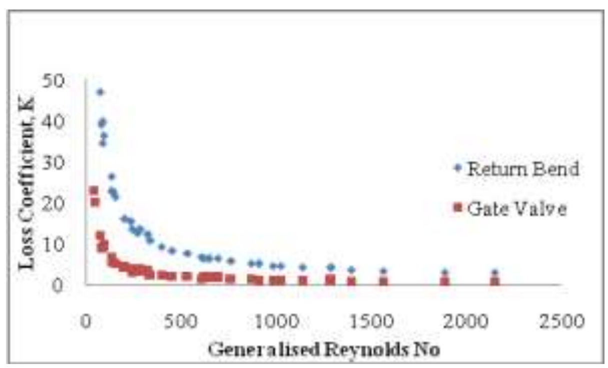


Figure 4: Plot of Loss coefficient (K) vs. Generalized Reynolds No. ($N_{RE*}$)

## 3. RESULTS AND DISCUSSIONS

### Stability of slurry

From the figure 1, it has been observed that for the additive, the terminal settling velocity decreases up to a concentration of 0.5% by weight, i.e, they can stabilize the slurry with high efficiency up to a concentration of 0.5% by weight beyond which the settling tendency tends to increase. This is probably due to the fact that upto a concentration of 0.5% by weight, water along with additive helps in the formation of better loose flocculated network, which gives better stability. Beyond that, the stability decreases due to the breaking of the loose flocculated network by forming more compact coagula by coagulation process, where the interaction between the additive, water and particle is strong.

**Rheological behavior of slurry**

From table l, the slurry behavior is observed to be pseudo-plastic in nature and the pseudo-plasticity varies with change in additive concentration for the additive. It is observed that only, Guar Gum can be used as drag reducing agent. It is also observed that initially the $k^/$ value, which indicates the viscous nature of slurry, increases probably due to the increase in stability[15, 16].

Beyond 0.1% additive concentration and upto a concentration of 0.5%, the drag reducing effect of additive predominates by reducing the friction between the slurry layer, thus decreasing the k' value and subsequently, the viscous nature. Beyond0.5% additive concentration, the additive viscosity contribution predominates, which gives the increasing tendency of $k^/$ values again.

From the calculations for fittings, it is observed that K values for a particular fitting are practically unaffected by the nature of additives and also the concentration of additives. The values are only dependent on the average velocity, or in other words on $N_{Re*}$. With increase in $N_{Re*}$, the K values decrease in the laminar zone and ultimately reaches to a constant value in the turbulent zone. Also, in the laminar zone, the decrease in K value with increase of $N_{Re*}$ is sharp up to $N_{Re*}$ = 500 and then slows up to $N_{Re*}$ = 2100. Beyond $N_{Re*}$ = 2100, i.e., in the turbulent zone, the K values are also calculated for four fittings. These are 1.80 for return bend, 0.95 for $90^0$ bend, and 0.50 for gate valve 0.31 for union joint. The values are found to be higher than that reported in the literature for Newtonian and also, for pure non Newtonian fluids. For each fittings the functional relationship between K and $N_{Re*}$ is developed by linear regression analysis as given below.

i) Correlation for return bend

$$K = 1284.5[N_{Re*}]^{-0.82}$$

ii) Correlation for $90^0$ bend

$$K = 415.02[N_{Re*}]^{-0.76}$$

iii) Correlation for fully open gate valve

$$K = 327.50[N_{Re*}]^{-0.81}$$

iv) Correlation for union joint

$$K = 100.6[N_{Re*}]^{-0.76}$$

The above equations are in good agreement with the experimental results.

## 4. CONCLUSION

The additive, i.e., guar gum can stabilize the slurry upto a concentration of 0.5% by weight. Guar gum can be used as drag reducing agent. The slurry is pseudo plastic in nature and the pseudo plasticity changes with additive concentration. K factors are independent of additive concentration and the nature of additive. It only depends on the type of fittings and the generalized Reynolds number in the laminar zone. Empirical correlations have been developed for each fitting relating K factor and the generalized Reynolds number which are in good agreement with the experimental values.

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