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Effect of addition of bottom ash on the rheological properties of fly ash slurry at varying temperature

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Abstract. Presently, fly ash is transporting through slurry pipeline in the thermal power plant. Aim of the present investigation is to examine the rheological behaviour of finer particle (fly ash) slurry suspension with and without addition of coarser particles (bottom ash). Mixture of fly and bottom ash is taken with proportion of 9:1, 8:2 and 7:3 (by weight). The temperature of slurry suspension is varying from 25 to 40ºC at solid concentration 30 % (by weight). Rheological tests are conducted with the variation of shear rate from 100 to 300 sec⁻¹ for all slurry samples. Addition of coarse particles of bottom ash in finer particles of fly ash slurry, leads to improve the rheological characteristics of slurry suspension. The addition of bottom ash can result substantial saving in energy consumption with reduction in relative viscosity.

Keywords. Bottom ash, Fly ash, Rheology, Relative viscosity, Temperature of slurry

1. Introduction

In India, about 60% electricity generated by coal based thermal power plants. Coal use as a fuel in thermal power plants and its combustion produced large quantity of ash. The finer particles of ash discharge with flue gases and collected from Electrostatic Precipitators (ESP) is known as fly ash, while bottom ash consists of coarser particles generally collected from the bottom boiler furnace. Only in India, about 70 million tons of bottom ash and almost twice of its, fly ash is producing in various thermal power plants [1]. Generally, pneumatic mode of transportation is using for transporting of fly ash whereas bottom ash is transporting through hydraulic mode from generation unit to ash pond with the help of pipelines. Rheology of slurry suspension plays very important role to design slurry transportation system, which depends on particle size distribution (PSD), particle shape, solid concentration and chemical composition of the solid materials.

Many researchers [2-10] have examined rheological properties of ash slurry suspensions. However no any universal correlation is available to predict rheological characteristics of the slurry suspension. Researcher studied rheological properties of fly ash slurry by using (Henko detergent and sodium-hexa-met phosphate detergent with ratio of 1:5) as additives [11]. They found that rheological characteristics of the ash slurry improved with additives. Author reported similar observations by using fly ash slurry with drag reducing polymers [1]. In current analysis, an attempt has been made to study rheological behaviour of fly ash (fine particulate) slurry without and with addition of bottom ash (coarser particulate). Respective mixture of fly and bottom ash is used with proportion of 9:1, 8:2 and 7:3 (by weight).
Slurry is taken with solid concentration of 30% (by weight) at varying temperature environment. Temperature of slurry suspension varied from 25°C to 40°C for all shear rate condition. Based on measured data, investigate the possibility for transportation of bottom ash slurry in pipeline.

2. Physio-chemical properties of fly and bottom ash

Samples of ash are procured from Rajiv Gandhi thermal power plant, Hisar, Haryana, India. Fly ash is taken from ESP and bottom ash from the bottom of combustion chamber. SEM analysis of fly and bottom ash samples are illustrated in Figure 1 and 2. The bottom ash particles are coarser, irregular and having rough surface texture as compared to regular shaped fine particles of fly ash. In case of bottom ash sample, about 62.50 % particles are coarser than 150 μm, only 7.40% particles are finer than 53 μm. The biggest particle size for fly ash is observed as 355μm and have 62.80 % particles are finer than 75 μm. Static settled concentration of slurry suspension is measured by taking initial solid concentration of fly and bottom ash as 30% (by weight). The value of static settled concentration for bottom and fly ash is found as 59.68 and 52.15 % (by weight) respectively. The pH value of slurry suspension is determined by using digital pH meter. The pH value varies from 7.75 to 7.40 having solid concentration range from 10 to 50% (by weight), which indicate its non-reactive nature.

![Figure 1: SEM of bottom ash sample](image1.png)  ![Figure 2: SEM of fly ash sample](image2.png)

3. Rheological Measurement

Rheological characteristics of ash slurry suspension are determined by using standard rheometer (Rheolab Q-C, Anton Paar Company Ltd, Germany), working on the Searle principle. Rheological parameters of slurry suspension are evaluated by determining shear stress at specific value of shear rate. For rheological tests, 100 ml ash slurry is arranged by proper mixing of essential quantity of water with ash. Single pan balance of electronic type with (least count=0.1 mg), is used to measure the weighed of slurry suspension. A glass rod is used for proper mixing of slurry suspension. Prior from laboratory testing, the rotating bob and cup assembly is fixed with the help of locking device. The slurry suspension is poured into cup (cylinder) till the specified mark. Rheological tests are commenced by changing the shear rate value (100 to 300 s⁻¹) for all concentrations with temperature range of 25 to 40°C. The experimental study is conducted with slurries of fly ash, bottom ash and their mixture. Few distinct slurry suspensions are also prepared for every dried sample, by using water at solid concentrations of 30% (by weight). Same experiments are also repeated for mixture of slurries. Rheological value has been measured at any shear rate condition is repeated, to ensure the precision of measured data.
4. Results and Discussion

Relative viscosity of fly ash suspension is determined for concentration range 10 to 50\% (by weight) at constant temperature 25\(^{\circ}\)C. For each fly ash sample, the shear stress - shear rate data is also observed at above mentioned range of concentration. The behaviour of slurry suspension can be specified as:

\[ \tau = \tau_y + \eta \frac{d\gamma}{dt} \]  

(1)

In equation (1), \( \tau \) = Shear stress, \( \tau_y \) = Yield stress and \( \eta \) = Coefficient’s of rigidity. Ratio of Newtonian dynamic viscosity (for slurry) to water viscosity under condition matching the same parameters is called relative viscosity. To assess viscosity of all slurries, a straight line equation is applied for every data set.

The shear stress -shear rate of fly ash with dissimilar solid concentrations are presented in Figure 3. From Figure 3 it is noticed that values of shear stress are rises linearly with shear strain rate up to solid concentration 30\% (by weight) for fly ash slurry suspensions. However, Newtonian flow characteristics are shown by stress-strain rate relationship up to concentration of 30\% (by weight), beyond that fly ash slurry shows non Newtonian flow characteristics. Result also indicated that slurry viscosity of both the suspension is a function of solid concentration. In Non-Newtonian flow characteristics of fly ash slurry suspension, value of yield stress is also a function of solid concentration. Similar observations are also drawn by [1, 8, 12 and13] with fly ash slurry.

![Figure 3: Shear stress-shear rate curve of fly ash](image)

4.1. Rheological behaviour of fly ash slurry with addition of bottom ash

Rheological behaviour of fly ash slurry suspension with additive material (bottom ash) has been studied at 30\% concentration (by weight). Data measured at temperature environment of 25\(^{\circ}\)C is presented in Figure 4. It is realized that shear stress of fly ash decreases with addition of bottom ash in its slurry at fixed shear rate. Hence relative viscosity also gets reduced with addition of bottom ash in fly ash slurry. Maximum decrease in shear stress value for the fly ash slurry is observed as 1.05 to 0.963, 0.824 and 0.784 Pascal, with mixture of fly and bottom ash having ratio of 9:1, 8:2, and 7:3 at solid concentration 30 \% (by weight) respectively. The decrease in
relative viscosity of slurry is observed as 1.75, 4.26, and 1.36% respectively. Maximum reduction in shear stress and relative viscosity is observed with the mixture ratio of 8:2 as compared to 9:1 and 7:3. This reduction in relative viscosity helps to lower down the pressure drop and energy consumption for flow of slurry suspension in the pipeline. Researchers [8, 13 and 14] studied the rheological behaviour of fly ash slurry with different additives.

![Figure 4: Rheological behaviour of fly ash without and with addition of bottom ash](image)

4.2. Effect of temperature on the rheology of fly ash

Rheology of slurry suspension is evaluated with the variation of temperature from 25ºC to 40ºC for all shear rate condition. Temperature of slurry suspension increases in the step of 5ºC at concentration of 30 % (by weight). The relative viscosity of slurry suspension with variation of temperature is shown in Figure 5. The relative viscosity of all slurry suspensions decreases with increase in temperature. Relative viscosity of slurry suspension found minimum value at 41ºC for all tested data. When more solid particles exist in the slurry suspension, high initial shear stress is mandatory for starts the shearing process. With increase in temperature, the amount of solid particles as well as surface area per unit volume of slurry suspension decreases and hence shear stress gets reduced.

When slurry suspension temperature increases from 25ºC to 30ºC, relative viscosity decreases 2.74, 2.54, 2.85 and 2.65% with fly ash, mixture of fly and bottom ash with ratio 9:1, 8:2, and 7:3 respectively. Similarly relative viscosity reduces 4.84, 4.52, 4.68 and 4.75% with increase in the slurry temperature from 30ºC to 35ºC. With increase in temperature from 35ºC to 40ºC, relative viscosity decreases in the percentage of 1.51, 1.63%, 2.05% and 1.80%. With rise in slurry temperature, increased kinetic energy of slurry particles promotes to reduce intermolecular forces between adjacent layers which further results decrease in relative viscosity of slurry suspension. This is also due to superior dissolving activity of the surfactant at higher temperature. Optimum modification temperature is noticed as 35 ºC. Marginal relative viscosity reduction is observed with increasing the temperature from 35 ºC to 40 ºC for all test shear rate condition. Authors [1, 15 and 16] also studied the rheology of coal-water slurry, limestone-water slurry and fly ash slurry with variation of temperature and found similar observation.
5. Conclusions

Rheological behaviour of fly ash slurry is investigated without and with addition of bottom ash at variation of temperature. Following results are drawn from the present study:

- The fly ash particles are finer, regular and having smooth surface texture as compared to irregular shaped coarser particles of bottom ash.
- Addition of coarser particles of bottom ash in fine particulate fly ash slurry, improves the rheological behaviour of slurry suspension.
- Relative viscosity reduced with increasing temperature of fly ash slurry without and with addition of bottom ash.
- Maximum reduction in shear stress and relative viscosity is observed for the mixture (fly ash and bottom ash) with ratio of 8:2.
- The optimum modification temperature of fly ash slurry is noticed as 35 ºC.

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