

# Investigation on the Rheological characteristics and Flow behaviour of Bottom ash-water slurry with additive

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**Abstract.** Present study is focused in the investigation of flow characteristics of bottom ash water slurry at high solid concentrations. The solid suspension of bottom ash is varied within the range of 10-60% (by weight). The rheology of solid suspension is carried out by rheometer. Experimentation is also extended to investigate the effect of detergent based additive in the flow behaviour of high concentrated bottom ash water slurry (i.e. 60%). The dosage of additive is varied in range of 1-4%. It is noticed from experimentation that bottom ash water suspension shows Newtonian flow behaviour at solid concentration range up to 30%. Whereas, slurry exhibits Non-Newtonian flow characteristics above solid suspension of 40%. It is also seen that the viscosity of slurry increase with solid concentration. Addition of sodium triphosphate leads to appreciable decrease in the slurry viscosity as dosage of additive is increased. The optimum addition of additive is found as 3% (by weight).

## 1. Introduction

In India the power is mainly generated from coal based power plants. The use of coal in thermal power station leads to generation of large amount of solid waste in terms of fly and bottom ash[1–3]. The deposition of huge quantity of fly and bottom ash from coal based power stations leads to a serious problem. Now a days, the fly ash is used in many cement industries, road embankments, production of high volume composites etc. But the utilization of the bottom ash is still very low. The bottom ash is only used in land filling[3,4]. However the production of coal ash after combustion of coal is leveled off. The bottom and fly ash is generally conveyed to dyke area located at far distance from power station[5]. This leads to consumption of huge power to run slurry pumps, so there is a need to develop cost efficient slurry disposal system.

The two phase flow of solids and liquids generally exhibits very complex flow characteristics. The interaction of solid particles leads to the formation of internal structure that results in complex behaviour. Verma et al. [6] studied the effect of particle size range on flow characteristics of coal ash suspension. They reported that fly ash exhibits Non-Newtonian flow at concentration above 40% (by weight). Bbren ganca et al. [7] reported that apparent viscosity of coal ash suspension depends on solid concentration, potential of hydrogen, range of solid particle size and properties of carrying liquid. Chandel et al. [8] analyze the rheological behaviour of fly ash water suspension with use of additive. They found that with the use of sodium hexametaphosphate the apparent viscosity of slurry decreased. Pani et al. [9] studied rheological characteristics of fly ash collected from Jinal power, Rajgarh. They performed rheology of 50-60% concentrated fly ash water slurry. They reported that by



addition of sodium silicate leads to appreciable decrease in slurry viscosity. Singh et al. [10] studied the rheology of fine coal water slurry. They performed rheology on high concentrated slurry ranging from 30-60% (by weight). They reported that use of sulfonic acid improve flow behaviour of coal water suspension.

From the literature available it is revealed that limited work is reported on study of flow characteristics of bottom ash water slurry at higher solid concentration. There is a need to develop a method to reduce the transportation cost for slurry disposal at high concentration. Also, the design of slurry conveying system is function of numerous parameters like density of solid and liquid particles, flow rate, flow behaviour etc. The complete knowledge of rheological behaviour helps to design and operate the slurry disposal system an optimum conditions. In present study, the attempt has been made to investigate the floe behaviour of bottom ash water slurry at higher concentrations ranging from 10-60% (by weight). The effect of additive is also investigated, sodium triphosphate is taken as an additive. The dosage of additive is varied in the range of 1-4% (by weight).

## 2. Materials and Methods

The Bottom ash sample used in characterization is procured from the dyke area of DeenbandhuChhotu Ram Thermal Power Station, Yamuna Nagar, Haryana, India. The physical and chemical characteristics of bottom ash sample are determined with several laboratory scale tests. The particle size distribution of collected coal sample is obtained by particle size analyzer. The bulk density and specific gravity of ash sample is determined by using pycnometer. The coefficient of permeability and water holding capacity is determined by constant head permeameter and Keen box method respectively. The static settling of aqueous ash suspension is determined by gravitational settling method at various time intervals. The morphological and chemical properties of bottom ash suspension are carried out by using SEM-EDS machine. The phases of various minerals present in bottom ash sample are determined by X-ray spectroscopy. The rheological behaviour of bottom ash-water suspension is studied by using standard Rheolab Q-C Rheometer. The detailed experimentation is carried out by preparing bottom ash-water slurries for 10-60% (by weight) solid concentration. The desired amount of bottom ash was mixed in water to prepare 50 ml slurry for every experiment. The slurry samples are stirred continuously with help of stirrer so that settling of solid particles can be avoided. The slurry is poured into cup and bob assembly up to specific mark. The shear rates during rheological experiments are varied in the range of 25-600 s<sup>-1</sup> at a constant room temperature of 25 °C.

**Table 1.** Physical properties of Bottom ash

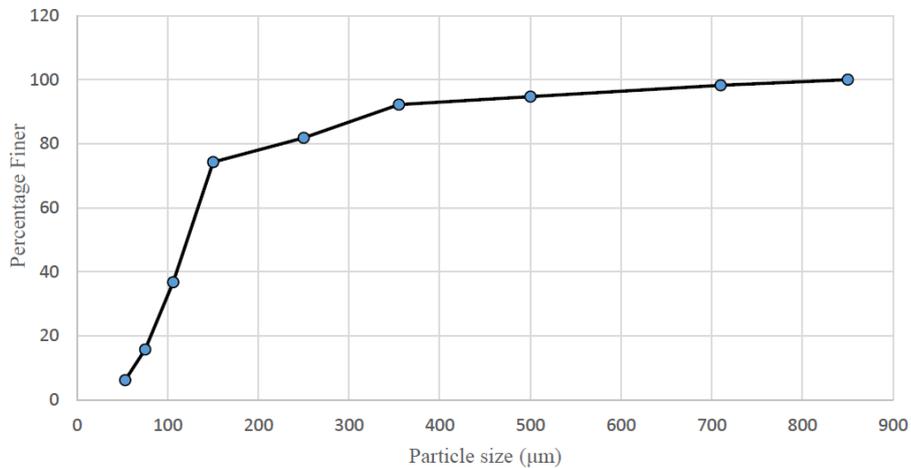
Solid Concentration	10%	20%	30%	40%	50%	60%
pH value	7.6	7.5	7.4	7.4	7.3	7.2
Static settled concentration	48.43	50.43	53.23	56.05	57.92	60.56
Specific Gravity	Bulk density(gram/cm <sup>3</sup> )		Porosity (%)		Water Holding Capacity (%)	
2.16	1.34		30.8		35.62	

## 3. Result and Discussions

### 3.1 Physical and chemical characterization

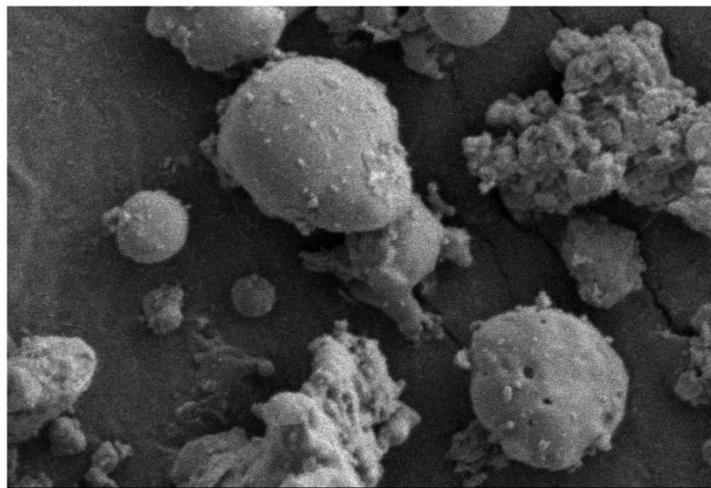
The physical and chemical properties of collected bottom ash sample are listed in the Table 1. Figure 1 depicts the particle size range of the bottom ash sample. From the results it is seen that all the bottom ash particles are finer than 850µm. However, 94.74 and 15.8% particles are finer than 500 and 75µm respectively. The specific gravity and bulk density of the bottom ash sample is calculated as 2.16 and 1.34 gram/cm<sup>3</sup> respectively. Static settled concentration of the bottom ash sample is determined for the

solid concentration range of 30-60%. In transportation of slurry through pipelines the static settled concentration plays very important role. As the static settled concentration approaches to its maximum



**Figure 1.** Particle size distribution of bottom ash sample

value the specific energy consumption for conveying of slurry suspension increases. The slurry of desired concentration is prepared in glass cylinder and allowed to settle down. The reading is taken at desired intervals of time till the settling of bottom ash particle is ceased. It is observed that after 12 hours the settling of sold particles is negligible. The maximum static settled concentration of bottom ash particles at solid concentration of 30, 40, 50 and 60% is observed as 53.23, 56.05, 57.92 and 60.56% respectively. The water holding capacity and porosity of procured bottom ash sample is observed as 35.62 and 30.8% respectively.

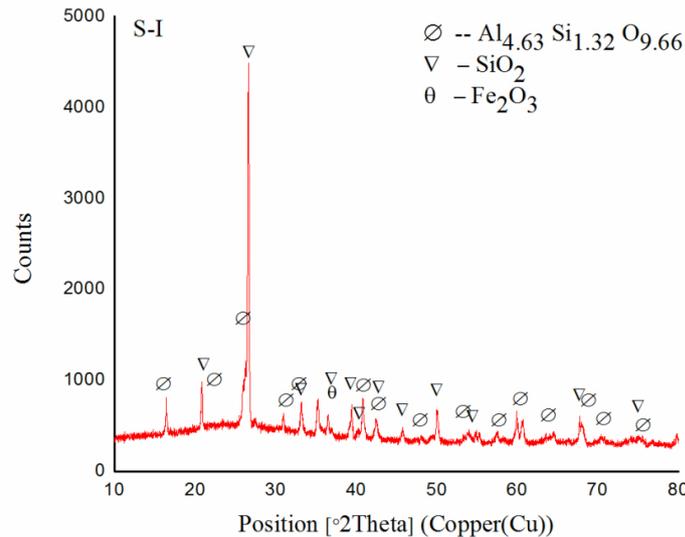


**Figure 2.** SEM micrograph of bottom ash

### 3.2 Mineral and Morphological characterization

The SEM micrograph of bottom ash sample at the magnification of 2500 is shown in Figure 2. From the SEM image it is seen that bottom ash particles are dark grey in color this shows the presence of unburnt carbon. Also the bottom ash particles have smooth and regular in shape having spherical morphology. These spherical bottom ash particles are known as cenospheres. Some coarser particles are also agglomerate with cenosphere. The chemical composition of the bottom ash sample is studied with the help of EDS spectrum. From the results it is noticed that the alumina and silica oxide is

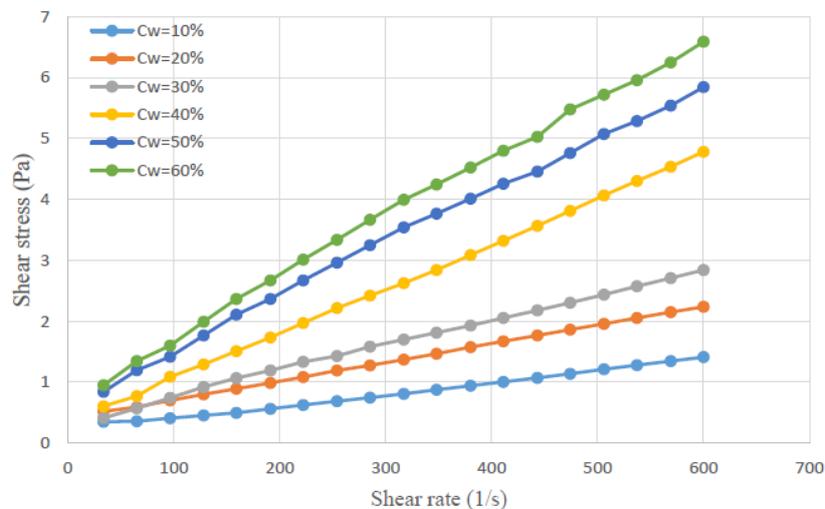
present in more percentage as compared to magnesium, titanium, iron, potassium and zinc. The presence of silica oxide, aluminum oxide, calcium oxide and iron oxide is 50.34, 33.65, 3.43 and 1.43% respectively. The loss in ignition of coal ash is determined as 1.65%. Figure 3 depicts the XRD spectrum of bottom ash sample. From the results it is identified that quartz and mullite are found as major crystalline phases. However, hematite is found in minor proportion. Chemical composition of quartz, hematite and mullite are  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{Al}_{(4+2x)}\text{Si}_{(2-2x)}\text{O}_{(10-x)}$  here the value of x varies in range of 0.16-0.57. The highest peak of quartz and mullite is observed close to  $26.64^\circ$  and  $26.21^\circ$ .



**Figure 3.** XRD spectrum of bottom ash sample

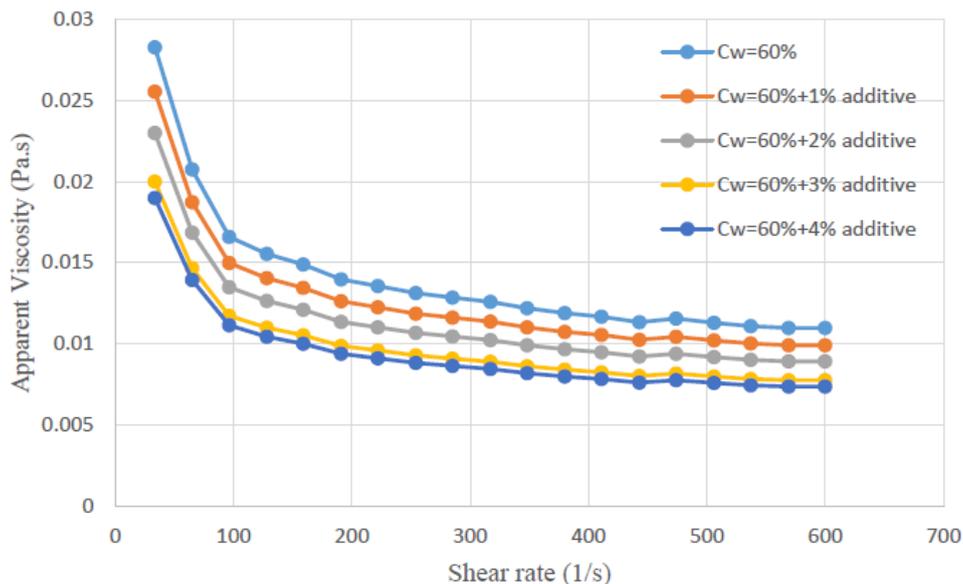
### 3.3 Rheological characteristics of bottom ash slurry

The rheological characteristics of bottom ash-water slurry are studied for 10-60% (by weight) solid concentration. Figure 4 depicts variation of shear stress with shear strain rate at different solid concentrations. From the results it is seen that the shear rate shows linear variation with shear stress. The slurry exhibits Newtonian behaviour for solid suspension upto solid concentration of 30%.



**Figure 4.** Rheogram of bottom ash water suspension at various solid concentrations

At the higher solid concentrations (i.e. above 40%) the slurry shows Non-Newtonian behaviour. At solid concentration above 40% slurry shows Bingham flow behaviour. The yield stress for Bingham flow increases with solid suspension. The viscosity slurry suspension increases with solid concentration. This increase in the slurry viscosity is observed due to increase in the number of solid particles per unit volume of the slurry. As the number of bottom ash particles in the slurry suspension is increased the slurry becomes thicker this leads to more resistance in the flow of slurry suspension. Thus more shear strain rate is required to start shearing process. Due to this reason high yield stress is observed at higher solid concentration for Bingham flow characteristics.



**Figure 5.** Effect of additive on rheology of bottom ash water suspension at 60% solid concentration

### 3.4 Effect of additive on rheological characteristics of bottom ash water slurry

The extensive experimentation is carried out to study the flow behaviour of bottom ash water slurry by using additive. The effect of additive is studied at higher solid concentration i.e. 60% (by weight). In present study the sodium triphosphate is used as an additive. Sodium triphosphate exhibits detergent like properties and is highly soluble in water. The addition of sodium triphosphate is varied from 1-4% (by weight). The addition of small amount of additive results in appreciable decrease in the apparent viscosity of slurry. Whereas, the flow behaviour of bottom ash-water slurry suspension at 60% concentration (i.e. Bingham flow) remain unchanged. Figure 5 shows the variation in apparent viscosity of solid slurry suspension at solid concentration of 60%. As the amount of additive increased from 1-4% the drastic decrease in apparent viscosity is noticed. It is also observed that percentage decrease in apparent viscosity is less as the percentage addition of additive is increased from 3-4%. The optimum addition of additive is observed as 3% (by weight).

## 4. Conclusions

Present investigation is undertaken to investigate the rheological behaviour of bottom ash water slurry suspension. The experimentation is carried out for solid suspension range of 10-60%. The following detailed and precise outcomes are found from present study.

- Bottom ash water slurry exhibits Newtonian flow characteristics below solid concentration of 30%. The flow behaviour is changed to Non-Newtonian (i.e. Bingham flow) at higher concentration i.e. above 60%.
- The static settled concentration of bottom ash slurry is increased as solid suspension in slurry is increased.
- The addition of sodium triphosphate leads to appreciable decrease in slurry viscosity. The optimum dosage of additive is observed as 3%.
- The use of additive results in effective transportation of slurry at high concentrations that results in effective slurry conveying system.

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