STUDIES ON THE FLOW OF HIGH CONCENTRATION COAL ASH SLURRY THROUGH PIPELINES

by

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Dedicated

to

My Dear Parents, Wife, Daughter

and

Teachers

CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON THE FLOW OF HIGH CONCENTRATION COAL ASH SLURRY THROUGH PIPELINES"** being submitted by **Mr. Sunil Chandel** to the Indian Institute of Technology Delhi, New Delhi, India for the award of the degree of **Doctor of Philosophy** is a record of bonafide work done by him under our guidance and supervision. It is also further certified that the work done by him has reached a standard fulfilling the requirement of the regulations relating to the degree.

The research reported and results presented in this thesis have not been submitted in part or full to any other Institute or University for the award of any degree or diploma.

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(Sunil Chandel)

ABSTRACT

Thermal power plants generate more than half of the world's electric power by burning millions of tonnes of coal and simultaneously produce large quantity of coal ash. Slurry pipelines are commonly used across the world for the transportation of coal ash (fly ash and bottom ash) from the plant to the ash ponds in thermal power plants. Most of the pipelines operating today in Indian thermal power plants transport ash at low or medium solid concentrations over short as well as medium distances. These systems are very energy intensive and also lead to excessive wear of pipeline and wastage of water. Further, the present enhanced consciousness towards the imbalance in the eco-system and related stringent government policies are forcing the thermal power plants to adopt environment friendly transportation systems. Thus, high concentration slurry disposal (HCSD) system has emerged as preferred option to transport coal ash in thermal power plants as it is economical and environment friendly. Literature review has shown that the present knowledge about hydraulic design of slurry transportation system (mainly pipeline and pumps) is far from being fully understood particularly at high solid concentrations. Literature has also revealed that efforts have been made to develop such systems in other countries but very little effort has been done in India. The ash produced in India usually has higher specific gravity as Indian coal has much higher content of non-combustible matter. Further, these also differ widely in their chemical/mechanical properties depending on the coal field. Therefore in order to optimize the hydraulic design procedure for transporting fly ash (FA) and the mixture of fly ash and bottom ash (BA) at higher concentrations, it is essential to carry out basic studies using bench scale tests and pilot plant loop to develop the required technology and develop correlations for scaling-up the pilot plant loop data to

the prototype pipeline. Looking into the recent trends for the design of slurry pipelines, the entire emphasis of the present work is towards the coal ash slurry pipelines and pumps operating in higher range of solid concentration i.e. $C_w > 50\%$ by weight. Fly ash and mixture of FA and BA in the ratio of 4:1 have been chosen as the materials due to their relevance in the Indian context.

The knowledge of slurry rheology is very vital in the dense phase slurry conveying system. The rheological behavior of the slurry depends on a large number of parameters like solid concentration, particle size distribution, particle shape etc. Therefore in the first part of the work, suspensions of fly ash and mixture of FA and BA (4:1) for different solid concentrations in the range of 50 to 70% (by weight) were prepared to study the effect of solid concentration on the rheological parameters. The study for both types of slurries shows that for a solid concentration of 50% by weight and above the behavior of slurries is non-Newtonian and that the experimental data fits a simple Bingham plastic model. It also shows that the rheological parameters namely Bingham viscosity and yield stress increase monotonically with the solid concentration and have higher values for fly ash slurries compared to mixture of fly ash and bottom ash (4:1) slurries. These rheological parameters can be used to predict the pressure drop in pipelines based on adoption of some suitable rheological model of the slurry. Further, the direct method for slurry viscosity reduction by using soap solution (Sodium Carbonate and Henko detergent (5:1)) at 0.2% concentration of total mixture weight as the additive has been studied. It is found that the slurry rheological parameters get modified and the values of Bingham viscosity and yield stress for both types of the slurry reduce considerably.

In order to carry out in-depth study on pressure drop characteristics for fly ash and mixture of FA and BA (4:1) slurry flow through straight pipeline, basic data for pressure drop has been generated in a 40 mm NB pipe loop as a function of velocity in the solid concentration range of 50-70% (by weight). The measurements show that the pressure drop increases with increase in solid concentration for both types of slurry. The dependence of relative pressure drop on flow velocity and efflux concentration has also been established. The effect of additive on pressure drop characteristics for fly ash as well as mixture of FA and BA (4:1) slurry has also been determined experimentally. The analysis of data shows that at any selected velocity there is a substantial reduction in the pressure drop with the average reduction being around 30% for fly ash slurry and 18% for mixture of fly ash and bottom ash (4:1) slurry. From the pressure drop characteristics, specific energy consumption (SEC) has been calculated for both types of slurry and it is found that the specific energy consumption decreases upto a concentration of 65% (by weight) and steeply increases beyond this value. Further, the pressure drop data for non-Newtonian coal ash slurries at high concentrations has been compared with the computed values based on the analytical model that uses rheological data as input. The deviation in the results are within the reasonable limits (± 15%). Hence, the analytical approach can be adopted by the slurry pipeline designers for designing of slurry pipelines instead of resorting to the extensive and time consuming pilot loop studies.

Slurry pumps are extensively used in the hydraulic transportation of solids through pipes in the form of slurry over short/medium distances. Today a wide range of slurry pumps are available and they are generally classified into two main categories namely positive displacement and centrifugal type. These pumps differ considerably in design and construction and hence the performance of these pumps changes depending upon the flow behavior of the slurry. Review of literature has revealed that studies on pump characteristics with high concentrated Indian coal ash slurries are few and there exists a need for comprehensive study for both types of slurry pumps to gain further insight. The experimental studies carried out are aimed at generating extensive data and provide some insight into the existing gaps in the knowledge on the performance of centrifugal and progressive cavity screw pumps handling highly concentrated slurries.

The performance of a 50 mm centrifugal pump has been evaluated experimentally at rated speed (1450 rpm) with water and solid-liquid mixtures at higher concentration (60-70% by weight) with fly ash and mixture of FA and BA (4:1). It is found that at rated speed, the head developed and the efficiency of the pump reduce with increase in solid concentration and the performance is strongly dependent on solid concentration. The power input to the pump increases linearly with solid concentration. The head and efficiency ratio of centrifugal pump at rated flow rate decreases with increase in concentration. Further, to establish the effect of soap solution as an additive on performance characteristics of centrifugal slurry pump at high concentration has also been investigated. The results show that additive improves the performance of centrifugal slurry pump in terms of head and efficiency.

The performance of a progressive cavity screw pump has also been evaluated experimentally at rated speed (125 rpm) with water and solid-liquid mixtures in the higher concentration range (50-70% by weight) with fly ash slurries. It is found that the head and efficiency of screw pump increases with increase in solid concentration and slurry viscosity whereas pump input power decreases with flow rate at a given solid concentration. The head and efficiency ratio for screw pump increases with increase in concentration at designed flow rate. Further, it is found that the performance of screw pump deteriorates for slurry with soap solution as an additive.

In the final phase of the study, wear studies have been performed in the Coriolis wear test rig using Indian coal ash slurries. A Coriolis wear test rig on the lines proposed by Pagalthivarthi et al. [114] was suitably modified and fabricated to undertake a comprehensive study for two materials. Systematic experiments conducted on brass and mild steel specimen with slurries of fly ash and mixtures of FA and BA in the ratio 4:1 and 3:2 show that wear has a strong dependence on rotational speed, particle size and solid concentration. The erosion wear increases with increase in rotational speed, particle size and solid concentration.

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