

# **STUDY OF PERFORMANCE OF ASH DISPOSAL SYSTEM**

Thesis Submitted in the partial fulfilment of requirement for the award of the

Degree of

**MASTER OF ENGINEERING**

**IN**

**(CAD/CAM & ROBOTICS)**

Submitted by

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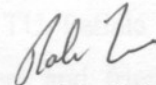
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## CERTIFICATE

This is to certify that the work which is being presented in this thesis report entitled "Study of Performance of Ash Disposal System Using CFD" in partial fulfillment of requirement for the award of the master degree in CAD/CAM & Robotics submitted in the mechanical engineering department, Thapar University, Patiala, is an authentic record of the initial work carried out by me under the guidance of **Dr. S.K.MOHAPATRA Professor & H.O.D. ,MED** and **Mr. SATISH KUMAR Assistant Professor, MED Thapar University Patiala**

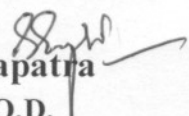
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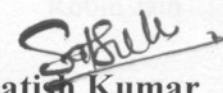
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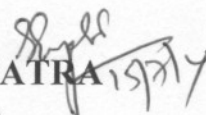
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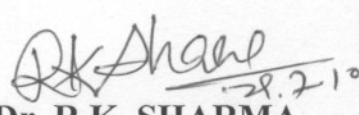
This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

  
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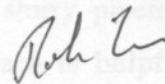
  
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## ACKNOWLEDGEMENT

I am highly grateful to the authorities of Thapar University, Patiala for providing this opportunity to carry out the thesis work.

I would like to express a deep sense of gratitude and thank profusely to my thesis guide **Dr. S.K.MOHAPATRA, Professor & H.O.D., MED** and **Mr.SATISH KUMAR, Assistant Professor, MED Thapar University Patiala** for his sincere & invaluable guidance, suggestions and attitude which inspired me to submit thesis report in the present form.

I am also thankful to other faculty members of Mechanical Department, TU, Patiala for their intellectual support. My special thanks are due to my family members and friends who constantly encouraged me to complete this study.



Robin Jain

## **ABSTRACT**

Centrifugal slurry pumps are the most commonly used pump used for ash disposal system. The present work is based on study of properties of ash contents present in slurry at different concentration of water. In the present investigation, the performance of centrifugal slurry pump would be studied at different concentration of water present in slurry. The amount of water content in the mixture of coal-ash and water will be varied to see the effect on the performance of ash disposal system in centrifugal pump. Simulation of the flow will be done with the help of CFD software and verification will be done with experimental work.

# CHAPTER 1

## INTRODUCTION

A thermal power station is a power plant in which the prime mover is steam driven. A huge quantity of ash is produced in central stations, sometimes being as much as 10 to 20% of the total quantity of coal burnt in a day, Hundreds of tons of ash may have to be handled every day in large power stations and mechanical devices become indispensable.

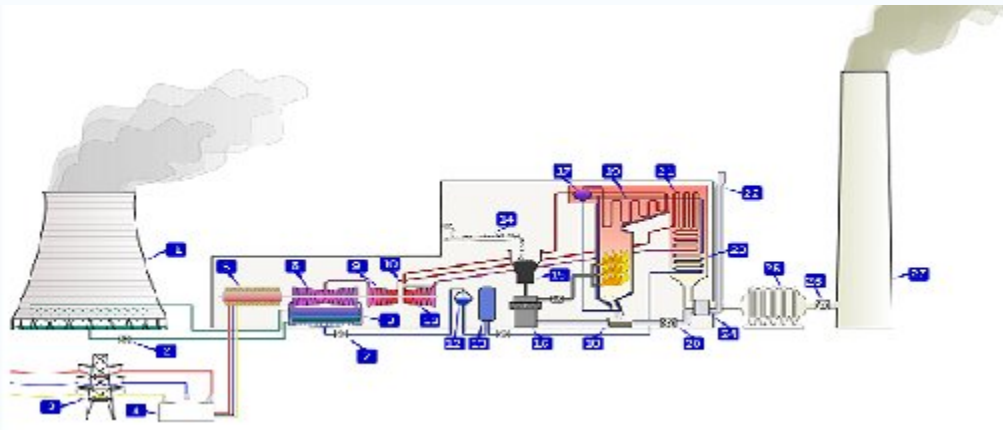


Fig.1.1 Typical diagram of a Coal-Fired Thermal Power Station

1. [Cooling tower](#)

2. [Cooling water pump](#)

3. [Three-phase transmission line](#)

10. [Steam control valve](#)

11. [High pressure steam turbine](#)

12. [Deaerator](#)

19. [Super heater](#)

20. [Forced draught \(draft\) fan](#)

21. [Reheater](#)

[4. Step-up transformer](#)

[5. Electrical generator](#)

[6. Low pressure steam turbine](#)

[7. Boiler feed water pump](#)

[8. Surface condenser](#)

[9. Intermediate pressure steam turbine](#)

[13. Feed water heater](#)

[14. Coal conveyor](#)

[15. Coal hopper](#)

[16. Coal pulverizer](#)

[17. Boiler steam drum](#)

[18. Bottom ash hopper](#)

[22. Combustion air intake](#)

[23. Economizer](#)

[24. Air preheater](#)

[25. Precipitator](#)

[26. Induced draught fan](#)

[27. Flue gas stack](#)

## 1.1 ASH DISPOSAL SYSTEM

All the available coals have some percentage of ash. When the coal is burnt in a boiler furnace, about 10 to 20% of quantity of coal used results in ash. In the modern large steam power plants where huge amounts of coal are used, the amount of ash may be go up to many thousands tonnes of ash per year. Theoretically whole of the ash from the furnace should get deposited in the ash hoppers, but actually from 5 to 40% of it leaves with the outgoing gases. Ash handling comprises the following operations:

1. Removing the ash from the furnace ash hoppers.
2. Conveying this ash to a fill or storage by means of conveyors.
3. Disposal of the stored ash.

To handle huge amounts of ash per day, mechanical means are employed. The advantage of mechanical handling over manual handling has been already enumerated under the topic of coal handling. The ash handling and disposal system can work continuously or intermittently. The following are some of the places where the ash can disposed off:

- Where seaborne coal is used, barges may take the ash to sea for disposal into a watery grave.
- Disused queries within reasonable distance of the power station may be used for dumping the ash into evacuated land.
- Building contractors may use it to fill the low lying areas.
- Wasteland sites may be reserved for the disposal of the ash.
- Deep ponds may be constructed and the ash can be dumped into these ponds and when they are completely filled, they may be covered with soil and seeded with grass.

Ash handling is major and difficult problem due to the following difficulties encountered in its handling and disposal:

1. Ash is dusty and so irritating and annoying in handling.
2. It is hot when it comes out of the boiler furnace.
3. It is abrasive and wears out the containers.
4. Poisonous gases are produced.
5. Corrosive acids are produced in water.
6. It forms clinkers by fusing together in lumps.

The following points should be kept in view while handling and disposing ash:

- Locate the ash plant on the leeward side of the power station to avoid blowing in and drawing into the buildings of the dry ash.
- If the ash is cold and cannot be disintegrated, it may be better to crush it before passing it further or otherwise it might choke the sluiceway.
- In case of pulverised fuel firing, 60 to 80% of ash is in the form of dust and fly ash; the plant should be designed accordingly.

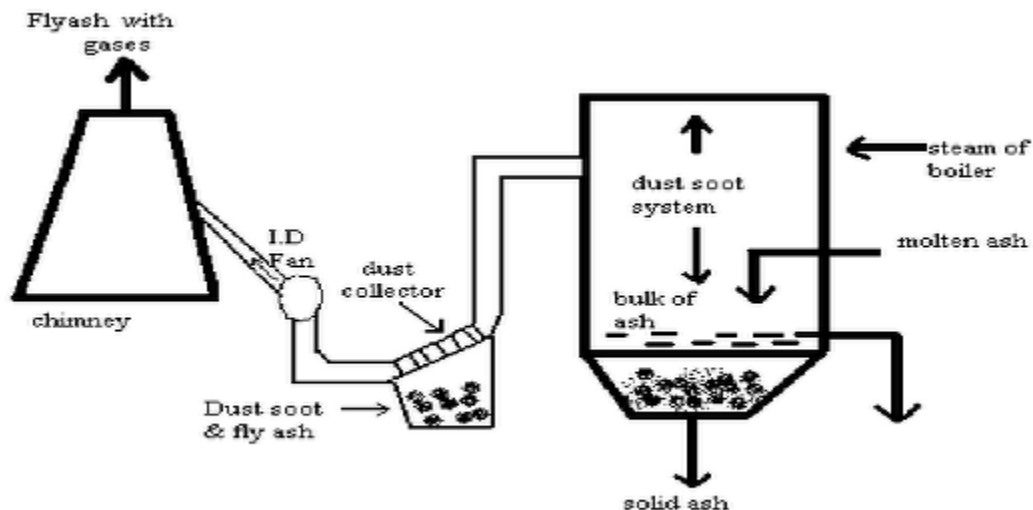


Fig.1.2 General Outline of Generation of Ash

The modern ash handling systems are mainly classified into four groups:

### **Mechanical Handling System**

This system is generally employed for low capacity power plants using coal as fuel. The hot ash released from the boiler furnaces is made to fall over the belt conveyor after cooling it through water seal. This cooled ash is transported to an ash bunker through the belt conveyor. From ash bunker the ash is removed to the dumping site through trucks.

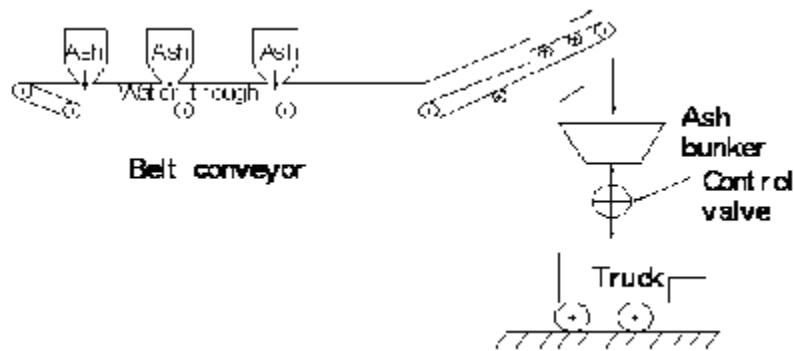


Fig1.3 Mechanical Handling System

### **Hydraulic System.**

In this system ash is carried with the flow of water with high velocity through a channel and finally dumped in the sump. This system is subdivided as follows.

- (a) Low pressure system.
- (b) High Pressure system.

**(a) Low Pressure System.** In this system a trough or drain is provided below the boilers and water the is made to flow through the trough. The ash directly falls into the troughs and is carried by water to sumps. In the sump the ash and water are made to pass through a screen so that water is separated from ash; this water is pumped back to the trough for reuse and ash is removed to the dumping yard. The ash carrying capacity of this system is 50 tones/hour and distance covered is 500 meters.

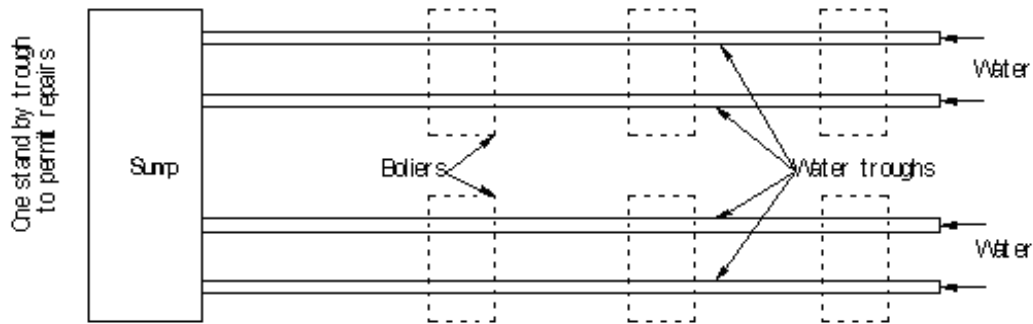


Fig. 1.4 Low Pressure Handling System

**(b) High Pressure System.** The hoppers below the boilers are fitted with water nozzles at the top and on the sides. The top nozzles quench the ash while the side one provides the driving force for the ash. The cooled ash is carried to the sump through the trough. The water is again separated from ash and recalculated.

The ash carrying capacity of this system is as large as 120 tones per hour and the distance covered is as large as 100 meters.

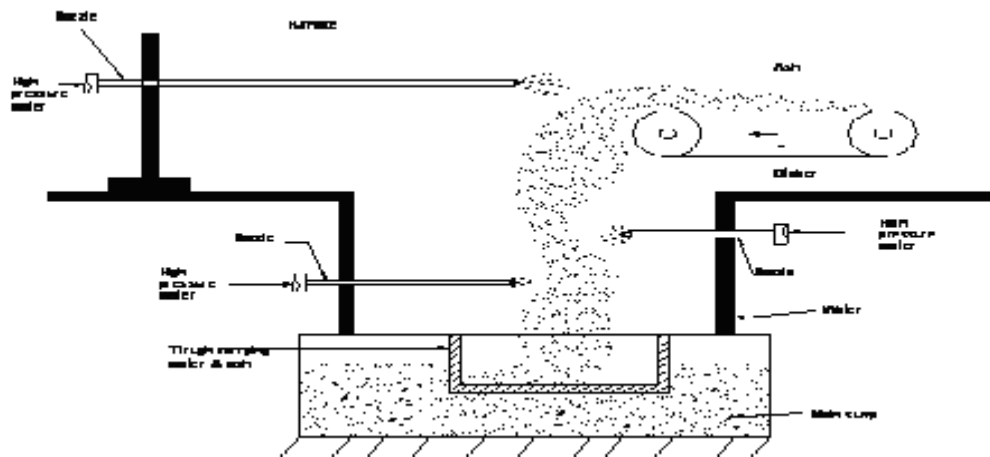


Fig. 1.5 High Pressure Handling System

#### Advantages of Hydraulic System:

- The system is clean and healthy.
- It can also be used to handle stream of molten ash.
- Working parts do not come into contact with the ash.

- It is dustless and totally closed.
- It can discharge the ash at a considerable distance (1000 m) from the power plant.
- The unhealthy aspects of ordinary ash basement work is eliminated
- Its ash carrying capacity is considerably large, hence suitable for large thermal power plants.

### **Pneumatic System**

This system can handle abrasive ash as well as fine dusty materials such as fly ash and soot. It is preferable for the boiler plants from which ash and soot must be transported some far off distance for final disposal. The exhauster provided at the discharge end creates a high velocity stream which picks up ash and dust from all discharge points and then these are carried in the conveyor pipe to the point of delivery. Large ash particles are generally crushed to small sizes through mobile crushing units which are fed from the furnace ash hopper and discharge into the conveyor pipe which terminates into a separator at the delivery end.

The separator working on the cyclone principle removes dust and ash which pass out into the ash hopper at the bottom while clean air is discharged from the top. The exhauster may be mechanical or it may use steam jet or water jet for its operation. When a mechanical exhauster is used it is usually essential to use a filter or washer to ensure that the requirements are less. Steam exhauster may be used in small and medium size stations. Where large quantities of water are easily and cheaply available water exhauster is preferred. The ash carrying capacity of this system varies from 25 to 15 tones per hour.

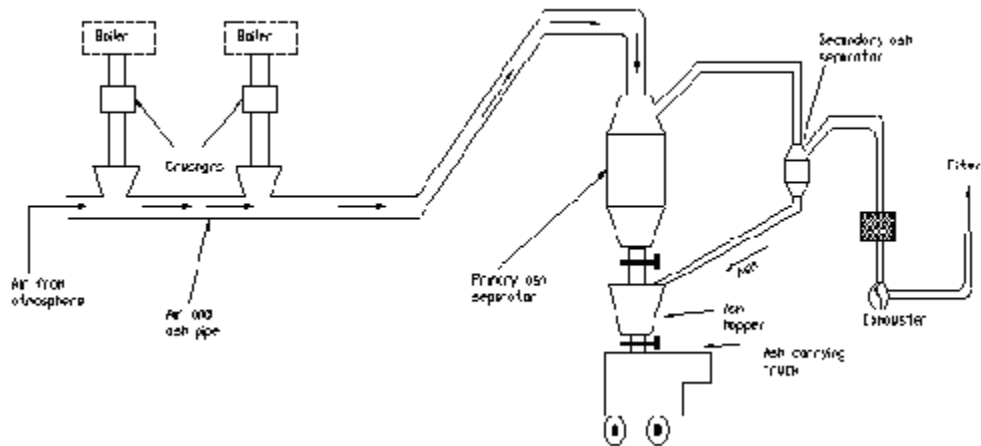


Fig. 1.6 Pneumatic System

**Advantages:**

- No spillage and rehandling.
- High flexibility.
- There is no change of ash freezing or sticking in the storage bin and material can be discharged freely by gravity.
- The dustless operation is possible as the materials are handled totally in an enclosed conduit.
- The cost of plant per ton of ash discharged is less comparison to other system.

**Disadvantages:**

- There is a large amount of wear in the pipe work necessitating high maintenance charges.
- More noisy than other systems.

**Steam Jet System**

In this case steam at sufficiently high velocity is passed through a pipe and dry solid materials of considerable size are carried along with it. In a high pressure steam jet system a jet of high pressure steam is passed in the direction of ash travel through a conveying pipe in which the ash from the boiler ash hopper is fed. The ash is deposited in

the ash hopper. The system can remove economically the ash through a horizontal distance of 200 m and through a vertical distance of 30 m.

## 1.2 PRINCIPAL REQUIREMENTS OF A GOOD ASH HANDLING PLANT

1. The plant should be able to operate with minimum personal attention and should be able to handle large clinkers as well as dust and soot.
2. Precautions should be taken against abrasiveness of ash.
3. It should be able to handle both wet and dry ash and operate with little noise and keep the dust menace to minimum.
4. Disposal of ash from the plant site should be speedy.
5. The plant should have adequate capacity to deal with the ultimate station capacity.

## 1.3 ASH DISPOSAL USING CENTRIFUGAL PUMP

The selection of a pumping system for any slurry transportation system is governed more by the practical considerations rather than purely on economical considerations of maximum efficiency. However, discharge pressure and the abrasivity are the two key factors for the selection of a pump.

### **Working Principle of Centrifugal Pump**

The centrifugal pump works on the principle of forced vortex flow, which means that when a certain mass of liquid is rotated by an external flow, the rise in pressure head of the rotating liquid takes place. The rise in pressure head at any point of the rotating liquid is proportional to the square of tangential velocity of the liquid at that point. Thus at the outlet of the impeller where the radius is more, the rise in pressure head will be

more and the liquid will be discharged at the outlet with high pressure head. Due to high-pressure head, the liquid can be lifted to a high level. Figure 1.9 shows flow of fluid in a centrifugal pump.

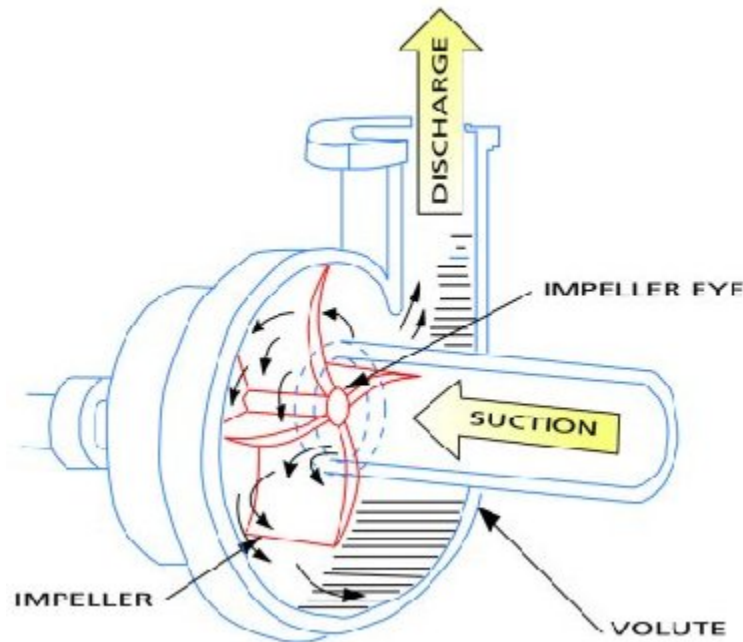


Fig. 1.9 Flow of Fluid in a Centrifugal Pump

### **Advantages of using Centrifugal Pumps for Transportation of Slurry**

- 1) Simplicity of design
- 2) Easier installation
- 3) Low maintenance
- 4) Lower weight
- 5) Handles suspensions and slurry easily

Centrifugal pumps are best suited for short distances and for in-plant slurry pipe line systems. Though the discharge pressure of centrifugal pumps is relatively low, they can also be used for moderate pressure requirements when used in series. The centrifugal pumps are used for over 97% of all short distance slurry pipelines. The design of a centrifugal pump for slurry handling system needs special consideration to ensure that the flow passage are such as to offer no restriction to the passage of solids. The abrasivity of solids cause wears in the pumps. A vertical split casing design is necessary to provide ready access to the wearing parts for replacement

For a given duty, centrifugal pumps are usually cheaper, occupy less space and have lower maintenance costs than positive displacement types, and can handle much larger solids.

Centrifugal pumps are used in a variety of applications, such as, water supply and irrigation, power generating utilities, flood control, sewage handling and treatment, process industries, transporting liquid-solid mixtures. The list can go on and on. Because of their wide spectrum of application, centrifugal pump are manufactured in a variety of shapes and with a variety of performance characteristics.

## 1.4 SURVEY OF ROPAR THERMAL POWER PLANT

### Visit Report

Ash sample both fly and bottom ash were taken from (GGSTP) Guru Gobind Singh Thermal Power Plant, Ropar

Impeller-Ni-hard –IS4771 TYPE-B,785 mm dia of shaft -125,width- 200mm,weight-400Kg.

Ash water ratio (1:13)

	Speed (rpm)	Flow rate(m <sup>3</sup> /hr)	Lift(Kg/cm <sup>2</sup> )	Power (kW)	Pipe length (Km)	Dia.(inch )
<b>Stage1(Two pump)</b>	520 960	650	4	110 Three phase LT 415 VA	2.5	12
<b>Stage2(Two pump)</b>	550 1440	650	4.5	110 Three phase LT 415 VA	4	12
<b>Stage3(Three pump)</b>	580 1440	850	6	190 Three phase HT 6.6KVA	5.25	14

## 1.5 MOTIVATION OF THE WORK

Power generation in India is primarily coal based in the present scenario. The coal used in our thermal power plants produce a large amount of ash, which is around 100 million tons per year, at present. Out of this, around 80 million tons will be fly ash and the remainder will be bed ash. It is expected that at the best 30% of the total ash produced will be utilized which will still leave the remaining 70% for safe disposal. The visit of the ash handling unit of the Guru Gobind Singh Thermal power plant Ropar, Punjab has motivated us to undertake the project work currently, both the type of ash are being mixed together and transported hydraulically from thermal power plant to ash ponds through pipelines at the solid concentration of around 10-20% by weight. The operation of ash disposal pipelines is highly uneconomical due to requirement of large quantity of water and increase in power consumption for pumping 80-90% of clear water. The other problems associated in the pipeline are excessive wear due to high transportation velocity of the ash water mixture which reduces their working life.

## CHAPTER 2

### LITERATURE REVIEW

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**Ahmad et al<sup>1</sup> [1994]** have measured the pressure drop across a 90° bend in a horizontal plane using two multi-sized particulate slurries namely iron ore slurries and zinc tailings. The pressure measurements are made just across the bend. From their studies, they have concluded that the presence of the particles reduces the additional pressure drop across the bends, an effect which they have attributed to the suppression of turbulence and secondary flow in bends.

**Gupta et al<sup>2</sup> [1994]** carried extensive measurements for pressure drop and concentration distribution in a 55mm ID 90° horizontal bend having a radius ratio of 5.5 measured pressured

drop which confirms the findings of Ahmad . The additional pressure drop increases with solid concentration but is always less than that for clear water flows.

**Kozhevnik N.N<sup>3</sup> [1996]** evaluate the Optimization of hydraulic transport of ash and clinker of thermal power stations. Pneumatic removal of ash opens the possibility of its loading into chambers of a sluice feeder for hydraulic transport with high economic indices to a distance up to 20 km by means of a water pump.

**Ni et al<sup>4</sup>. [1996]** experimentally evaluated the effect of high delivered volumetric concentration ( $c_{vd}$ ) on characteristics of slurry. They performed extensive experiments by using three sorts of narrowly graded sands tested in the laboratory of DN150 mm pump loop of the Delft University of technology, for the observation of pump and pipeline characteristics. They conclude that high solid concentration has a strong influence on the pump head, efficiency and power consumption and this influence behaves differently with different sand size. The pump efficiency in coarse sand slurry service may drop almost 60% compared to that of water service, when  $c_{vd} = 42\%$ . Within the measured range of concentrations in each passages may experience similar stratification process occurred in pipelines. The mechanical friction regime in the impeller passages could be similar to that in pipelines. Therefore the delivered volumetric concentration and the size affect the head loss in the same way both in pumps and pipelines.

**Panda et al<sup>5</sup> [1996]** have established the pressure loss in horizontal pipes for transportation of fly ash up to 60% concentration (by weight) by correlating it with the rheological behavior of the slurry. They have also reported that the pressure loss could be estimated reasonably well using pressure loss models developed for Newtonian fluids in the range of 20-25% concentration by weight.

**Gahlot et al<sup>6</sup> [1998]** investigated the performance of two 50 mm centrifugal slurry pumps made of two different materials namely Ni-hard (metal) and rubber-lined having closed and open impellers respectively with coal and zinc tailings slurries at 1450 rpm in the concentration range of 0-57% by weight. They observed that the head and the efficiency of the pump decrease with

increase in solid concentration, particle size and specific gravity of solids where as they are fairly independent on the pump flow rate. They observed higher reduction in the head compared to the efficiency and have shown linear decrease in the head and the efficiency ratios with increase in solid concentration up to 50% by weight. For higher solid concentrations, relatively larger drop in both the head and efficiency were observed.

**Mishra et al<sup>7</sup> [1998]** have measured the pressure drop across there 90° bends in horizontal plane namely 90° mild steel commercially available pipe bend (100mm NB diameter having a radius ratio of 4) and two diverging converging bends having an area ratio of 1.5 and 2.0 up to middle plane with inner curvature same as commercial bend using zinc tailing slurry. They observed higher pressure drop for diverging-converging bends compared to the conventional bends, but the extent of increase of pressure droop for bend with area ratio 2.0 over the conventional bend was only marginal.

**Turian et al<sup>8</sup> [1998]** have investigated flow of non-Newtonian fluids through various fittings such as bends, fittings, valves etc. using laterite and gypsum slurries. For fully developed laminar flow, they found that resistance coefficient decreases with increasing Reynolds number for bends with different angles of turn and finally reaches an asymptotic value for fully developed turbulent flow. They have attributed the phenomenon to the dominance of inertial forces over other forces. This phenomenon was observed for all concentration tested.

**Bunn T et al<sup>9</sup> [1999]** have conducted experiments on fly ash slurries in the concentration range of 65% <math>C\_w</math><math>74\%</math> in a 120 mm diameter pipe loop having a length of 125m. A positive displacement pump was used for pumping the slurry. Rise in pressure loss is accompanied by a change in the flow properties of slurry which changes from a liquid like mixture to one that tends to form sliding paste at the concentration of around 69% +-1% by weight.

**Mishra S.K et al<sup>10</sup> [2001]** investigates the rheological behavior of coal-water slurry using a HAAKE RV30 viscometer. The coal water slurry became more viscous with increases in ash content and solid concentration. The pH has a profound effect on the viscosity of coal

water slurry. The apparent viscosity is high in acidic medium, being the highest around pH 6 for all three types of coal and the lowest around pH 8. coal water slurry shows non-Newtonian behavior at low pH. The variation in apparent viscosity seems to be in proportion to the value of the flow consistency index  $k$ . The change in apparent viscosity with the temperature of coal water slurry could be described by a simple Arrhenius-type equation. However, the values of apparent activation energy were found to be relatively independent of the rate of shear and solid concentration.

**Usui H et al<sup>11</sup> [2001]** have carried out experimental studies on rheology and pipeline transportation of dense fly ash water slurry. Simha's model is used to predict the maximum packing volume fraction for non-spherical suspension and successfully used to predict the slurry viscosity under completely dispersed conditions. The model results in the estimation of inter particle bonding force between primary particles in a cluster and the power consumption and flow rate relationship in hydraulic slurry pipeline transportations system is predicted. A possible way to reduce the total cost of slurry pipeline system by means of periodical addition of stabilizer is proposed.

**Ghanta et al<sup>12</sup> [2002]** using two different solids namely coal and copper ore. These solids have different surface characteristics. They observed that coarse size coal-in-water slurries exhibit lower viscosities compared to fine size coal-in-water slurries, whereas copper ore behaves in a reverse way due to its opposite surface characteristics. The results have also shown that PSD has market influence on viscosity of suspension. The studies reveal that mixing fines particles with coarse slurry could reduce the viscosity of the suspension. For coal water system 60:40 weight proportion gave maximum reduction and for copper ore-water system 40:60 gave maximum reduction.

**Kaushal D.R et al<sup>13</sup> [2002]** have modified the Wasp model by modifying the particle diffusivity of the slurry flow based on the solid concentration in the range of 10 to 40% (by weight) for calculating the pressure drop for homogeneous and suspended portions. The pressure drop thus predicted agreed reasonably well with the experimental data for straight pipe and 2-D channel for zinc tailing slurries.

**Korving et al<sup>14</sup> [2002]** An experimental study done by on pipeline flow of fine sand slurry at various densities up to 1800 kg/m<sup>3</sup> has shown that the fine sand slurries above 1700 kg/m<sup>3</sup> density behave quite differently at high concentrations than for slurries at lower densities. For lower density slurries the bed formation was observed at about 1.5 m/s velocity even at higher concentration whereas no bed formation was observed even at the lowest velocities tested ( $<.5\text{m/s}^2$ ) for higher densities.

**Lei L et al<sup>15</sup> [2002]** studies the pipeline transportation of dense fly ash –water slurry. Rheological characteristics and sedimentation stability of the slurry with the addition of four kinds of stabilizing additives were measured. Using usui thixotropy model the relationship between flow rate and pressure drop has been estimated for the transportation of slurry. A feasibility study of new transport system was also performed.

**Slatter et al<sup>16</sup> [2002]** studies the turbulent flow phenomena of non-Newtonian slurries in pipes and found that the rheology derived from laminar pipe flow is most useful for the prediction of the pipe flow head loss in laminar and turbulent flow.

**Thomas<sup>17</sup> [2002]** performed a critical analysis of the extensive experimental data on the relative viscosity of the suspensions of uniform spherical particles. The scattering of the data was reduced from  $\pm 75\%$  to  $\pm 13\%$  up to a solid volume fraction of 0.50 by extrapolation techniques. The coefficients in the power series relating relative viscosity and solid volume fraction were determined using least squares procedure and a new expression for viscosity containing six terms was proposed.

**Vlasak et al<sup>18</sup> [2002]** in his paper has highlighted the use of peptizing agent to decrease the viscosity and yield stress depressing the strong non-Newtonian behaviour of the slurry due to presence of colloidal particles. The tests were performed on Kaolin water suspensions for laminar and turbulent regimes using an experimental test loop of 17.5 mm inner diameter and rotational rheometer.

**Heywood N<sup>19</sup> [2003]** has described three alternative methods to reduce pipe friction for highly viscous, often non-Newtonian slurries. In addition to frequent economic advantages to be

had by employing one of these methods, other benefits also accrue. These include lower wear rates and therefore maintenance costs for pumps, and reduced instances of pipe blockages. These methods also increase the flexibility of existing pipeline systems when there is a requirement to increase slurry concentrations, and therefore slurry viscosities. Each of these three methods is considered whenever an existing pipeline needs upgrading, or a new pipeline system is to be designed.

**Kumar .A et al<sup>20</sup> [2006]** have carried out the measurements for concentration profiles in mid-horizontal and mid-vertical planes at 6D, 25D and 50D downstream of a conventional 90° horizontal circular pipe bend using equi-sized silica sand slurries in a 50 mm NB re-circulating pilot plant test loop having total length of 30m. The concentration profile just downstream of the bend is more uniform in the mid vertical plane as compared to the mid horizontal plane because the effect of bend is more pronounced at the latter. For the flow to be fully developed (free from the effect of the bend to its downstream side), the re-adjustment length required for the slurry flow through the bend is of the order of 50 diameter from the bend exit as the concentration profile at 50D and thereafter showed no sign of effect of the bend.

**Rudman M et al<sup>21</sup> [2006]** performed extensive experiments to explore the behavior of non-Newtonian fluids at transition to turbulence or in a weak turbulent pipe flow situation and compared the behavior with the behavior of Newtonian fluids. Operating in the transitional regime may be advantageous for suspension transport with the intermittency of such flows being useful in re-suspending solids that have settled but still operating at lower pressure gradient than fully developed turbulent flow.

**Knezevic D et al<sup>22</sup> [2008]** presents the influence of ash concentration on change of flow and pressure in slurry transportation. The results indicate that the transport should be accomplished with ash and bottom ash concentration below 50% but above 40% of solids. In this concentration range there is decrease of both flow (per volume) and pressure. However this decrease is considerably small regarding quantity of fly and bottom ash transported during the time limit.

**Mosa .E.S et al<sup>23</sup> [2008]** examined the effect of chemical additives or reagents on rheological characteristics of coal water slurry (CWS). Apparent viscosity and flow properties of coal water slurry are sensitive to the use of chemical additives (dispersants and stabilizers). Among studied dispersing agents, sulphonic acid recorded the best performance in modification and reducing CWS viscosity. The best dosage of all tested dispersants was found to be as 0.75 % by wt of solids. With regard to studied stabilizers, Na- CMC recorded better performance than xanthan gum. The best dosage of investigated stabilizers was found to be as 0.1 % by wt. from total solids.

**Senapati et al<sup>24</sup> [2008]** studied the modeling of viscosity for power plant ash slurry at higher concentrations and effect of solid volume fraction, particle size and hydrodynamic forces in a non-Newtonian laminar flow regime. A model incorporating maximum solids fraction ( $\Phi_m$ ), power law index ( $n$ ), median particle size ( $d_{50}$ ), co-efficient of uniformity ( $C_U$ ), shear rate ( $\gamma$ ) has been developed to predict the viscosity.

**Branganca S.R et al<sup>25</sup> [2009]** finds that the coal ash transportation as high solids content (68% by weight) pastes are technically feasible. Viscosity results showed significant variations depending on the chemical composition, particle size distribution, concentration of fine particles and medium ph. Best paste fluidity was found when water content ranged from 30% to 35% by weight. The wetted ashes did not show any pozzalanic behaviour; particle interaction in the pastes is probably due to electrostatic forces. The viscosity of the pulps tends to be high when they are motionless, but it diminishes under stirring (thixotropic behaviour) and becomes stable after a short period.

**Chandel S et al<sup>26</sup> [2009]** described the effect of additive on pressure drop and rheological characteristics of fly ash slurry at high concentration (above  $C_w=60$  by weight). There is reduction in pressure drop when additive like soap solution is added to the fly ash slurry at higher concentrations. Slurries of fly ash at these concentrations show a Bingham fluid behavior. The Bingham viscosity and yield shear stress values increase with increase in concentration, the increase being more pronounced at higher concentrations. The addition of soap solution as additive to the fly ash slurries reduces the rheological parameters and result in

substantial decrease in energy parameters.

**Chen L et al<sup>27</sup> [2009]** adopted the Eulerian multiphase approach with kinetic theory of granular flow was applied to predict flow behaviors of coal-water slurries in horizontal pipelines. The numerical investigations have displayed some important slurry flow characteristics, such as constituent particles concentration and velocity distribution as well as pressure gradients. The model captures the main features of solid-liquid flow of super dense coal-water slurries in horizontal pipelines over a wide range of operating conditions. The total and constituent particle volume concentration profiles along the vertical diameter are affected not only by gravitational force but also by strong particle-particle interactions between fine and coarse particles. The axial velocity profiles along vertical diameter are affected not only by the total volume concentration distribution but also by the local volume ratio of fine to coarse particles. The axial velocity distribution along the vertical diameter usually shows great discrepancies from that along the horizontal diameter. Coal-water slurries filled with binary solid phase are distributed more uniformly and exhibit higher fluidity than slurries with single solid phase.

**Naik H.K et al<sup>28</sup> [2009]** observed the effect of drag reducing additives on the rheological properties of fly ash water suspensions at varying temperature environment. The distinctive reduction of surface tension on colloidal disperse characteristics of the resulting slurry was observed in the presence of surfactants. Zeta potential measurements also confirmed that the additive has the capability to keep the fly ash particles water borne during its transportation in pipelines. All the treated slurries exhibited the shear thinning or / and Newtonian flow properties with zero yield stress.

**Steward N.R et al<sup>29</sup> [2009]** tested the pipe flow behavior of fly ash and water mixtures in a closed loop pipe system at solids concentrations ranging from 51% to 74% by mass, in three different pipe sizes, 40, 50 and 65 nominal bore. The resulting flow behavior has been presented on pipe flow curves, and the laminar flow data have been used to rheologically characterize the material as viscoplastic, using the Herschel-Bulkley rheological model. Anomalous transitional flow behavior is reported in that the results appear to fit the Newtonian laminar to turbulent transition model as opposed to the more widely accepted Slatter transition model.

**Mishra et al<sup>30</sup> [1998]** have measured the pressure drop across there 90° bends in horizontal plane namely 90° mild steel commercially available pipe bend (100mm NB diameter having a radius ratio of 4) and two diverging converging bends having an area ratio of 1.5 and 2.0 up to middle plane with inner curvature same as commercial bend using zinc tailing slurry. They observed higher pressure drop for diverging-converging bends compared to the conventional bends, but the extent of increase of pressure droop for bend with area ratio 2.0 over the conventional bend was only marginal.

## **CHAPTER 3**

### **RHEOLOGICAL BEHAVIOR OF ASH SLURRY**

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The rheological characteristics for fly ash and bottom as slurries for different samples having different particle size distributions have been determined. The pilot plant loop tests particularly at high concentrations are tedious, time consuming and complex in nature. Therefore the slurry pipeline designers have been adopting the prediction methodology for slurry pipeline design based on some rheological model of the slurry. The present study shows that in high concentration fly ash slurry disposal (HCSD) system, analytical models could be used for pressure droop prediction when once rheological parameters are known accurately and suitable rheological model is identified.

### **3.1 DEPENDENCE ON SLURRY RHEOLOGY IN THE DESIGN OF SLURRY TRANSPORTATION SYSTEM**

One of the most important input data needed for the design of the slurry transportation system is the rheological behavior of the slurry at various concentrations and flow conditions. If the rheological data is available, it may be used to find the flow rate-pressure drop relationship. Rheological parameters also help in determining the power requirement in agitating the slurry in the agitation tank. It also helps in determining the wear rate and life of the pipeline. Knowledge of suspension rheology is also important to ensure a stable/energy efficient pipeline transportation system. The rheological characteristics of a slurry depends on several parameters such as shape, size and size distribution of particles, solids concentration, carrier fluid properties etc. By suitably manipulating the particle size distribution, if other parameters are same, it is possible to obtain a stabilized slurry suspension. The particle size is also important from the dewatering view point. If the solids' are coarse then the cost of dewatering is less but the flow becomes more heterogeneous whereas if the particles are fine then the flow is homogenous but the slurry becomes non-Newtonian and the cost of dewatering also increases. Thus in a slurry transportation system, a compromise has to be made between the particle size and the cost of dewatering.

The rheological behavior of the slurry is also required to predict the head requirement for pumping the slurry. The presence of solid particles in the slurry affects the performance characteristics of the pump. In addition, surfaces of the impeller and the walls of the casing wear more rapidly due to solid particles. Shaft sealing also becomes a significant problem in slurry pumps.

The characterization of rheological behavior of slurry is complicated due to the fact that a large number of factors influence it. Also the behavior of the slurries is generally non-Newtonian at the concentrations that are commercially used. Non-Newtonian slurries make the principles of fluid mechanics more complex since the

resistance to flow ‘viscosity’ now must be defined through a physical model reflecting process conditions. It is essential that a good understanding of the methods of characterizing rheological properties and extrapolating these characteristics to commercial slurries be obtained.

## **3.2 EXPERIMENTAL APPARATUS AND MEASUREMENTS**

Various tests required to determine the Rheological parameters of the slurries can be classified as those required on ash slurry.

### **3.2.1 Tests on Solids**

The test performed on solids is briefly discussed below:

#### **1. Specific Gravity of Solids**

Specific gravity of solid is an important property as it decides the settling characteristics of the slurry. Solid’s density of different materials was determined by means of pyknometer analysis.

Calculate the specific gravity of solids as given below

$$\text{Specific Gravity of solids} = (W_{bs} - W_b) / (W_{bw} - W_{bsw} + (W_{bs} - W_b))$$

Where  $W_{bs}$  = wt of beaker + solid

$W_{bsw}$  = wt of filled beaker with slurry & water

$W_{bw}$  = wt of beaker with fully filled water

$W_b$  = wt of pyknometer in gms



Fig 3.1 Pycnometer on Weighing Machine

## 2. **Determination of Particle Size Distribution**

As the particles in all the solid samples were finer than 75 microns, the particle size distribution of solids was determined by the standard hydrometer analysis. 50gms. Of solid was taken and mixed in 1000 ml of distilled water in a graduated jar. 5 ml of a dispersing agent (sodium meta Hexaphosphate) solution of 2% concentration was added and the mixture is thoroughly mixed. The hydrometer was gently placed in the mixture and its readings were taken repeatedly at small intervals of time. Temperature of the mixture was also recorded simultaneously. Then the hydrometer was taken out and cleaned in distilled water. The hydrometer was placed in the mixture after various time intervals and its readings were taken till the change in the two successive readings was very small. Temperature of the mixture was also recorded.

Data from sieve analysis and hydrometer analysis of different materials were plotted between percentages finer vs. particle diameter. Annexure 1 gives the particle size distribution for fly ash and Fig. 3.2 depicts the particle size distribution for fly ash graphically. The top particle size is below 1400 microns for fly ash .35.4% particles of fly ash are finer than 75 microns Weighted mean diameter of particles and median diameter have also been tabulated .The weighted mean diameter and median diameter of fly ash are 41 and 82 mm .

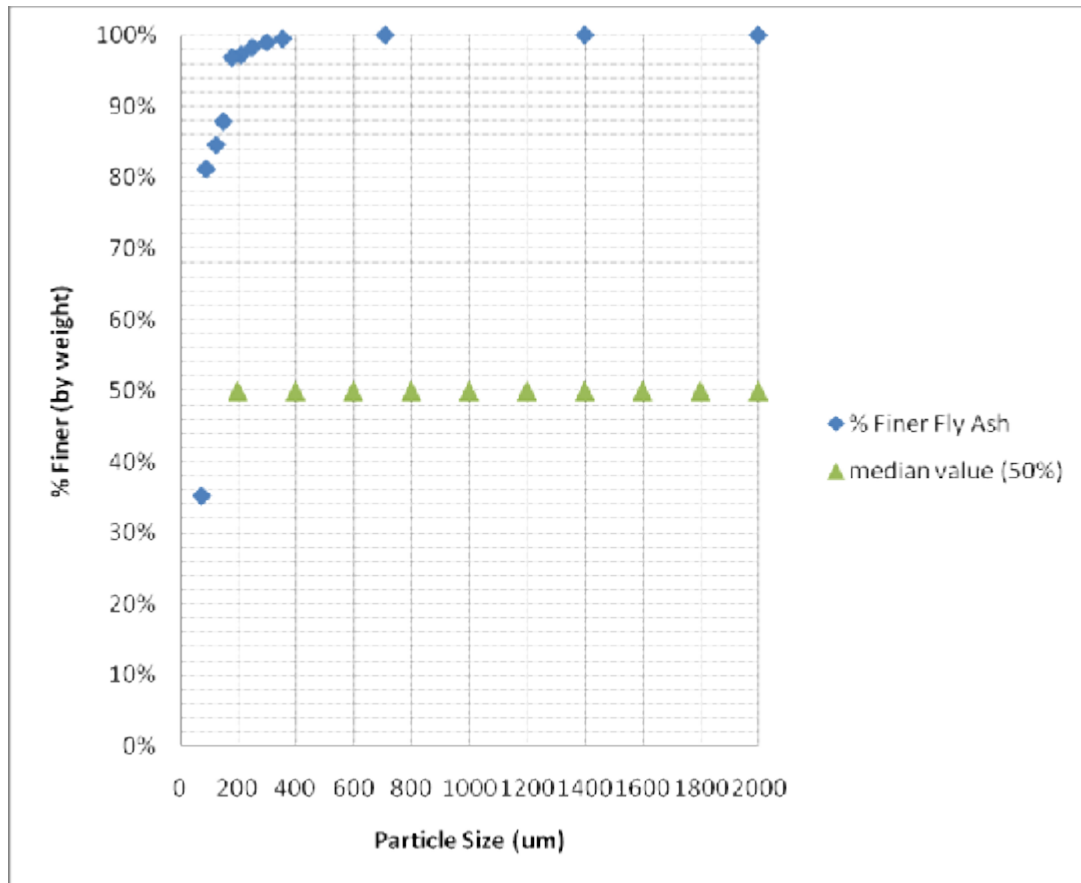


Fig. 3.2 Particle Size Distribution Curve of Fly Ash

### 3. Settling Characteristics of Solids

To determine the settling characteristic of solids approximately 300 gms. Of solids were taken and a mixture of an initial concentration of approximately 40% by weight was prepared. The mixture was kept in a 1000 ml. graduated jar. The slurry was thoroughly mixed and then allowed to settle. Initial level of slurry was recorded. As the solid settled in an undisturbed state, level of settled slurry in the jar at given intervals of time were noted. Readings were taken at small intervals at the beginning and as the settling rate slowed down, the interval was increased. After some time the level of settled slurry becomes nearly constant.

Settling characteristics and the maximum static settled concentration of the fly ash are given in Annexure 4. It indicates that fly ash slurry is slow settling slurry and the initial rate of settling is somewhat dependent on the particle size distribution. The value of final static settled concentration does not change appreciably when the particle size distribution is changed. It is observed that the top particle size distribution have strong influence on the settling characteristics of the solids. Rate of settling slows down with increase in the fineness of particles and decrease in top particle size.

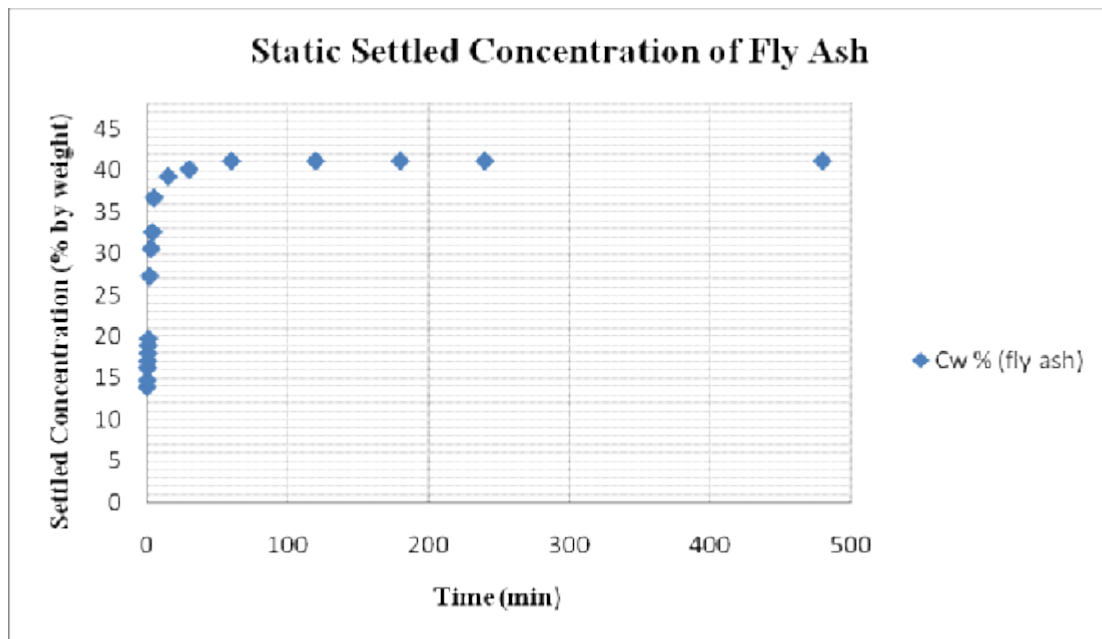


Fig. 3.3 Static Settled Concentration of Fly Ash

### 3.2.2 Rheological Measurements

The rheolabQC is a rotational rheometer which works according to the Searle principle. It consists of a high precision encoder and a highly dynamic EC motor, which is also used in the MCR rheometer series.

We can select between controlled shear rates (CR) and controlled shear stress (shear stress) test settings. These options together with the wide speed and torque ranges and very short motor responses time.

Fig. (3.6) shows a typical curve between the shear stress and shear rate for ash slurry. A straight line to the experimental points passed through the origin indicating that the slurry behavior is Newtonian at the given concentration. The rheological parameters of ash slurries have been tabulated in Annexure 7.

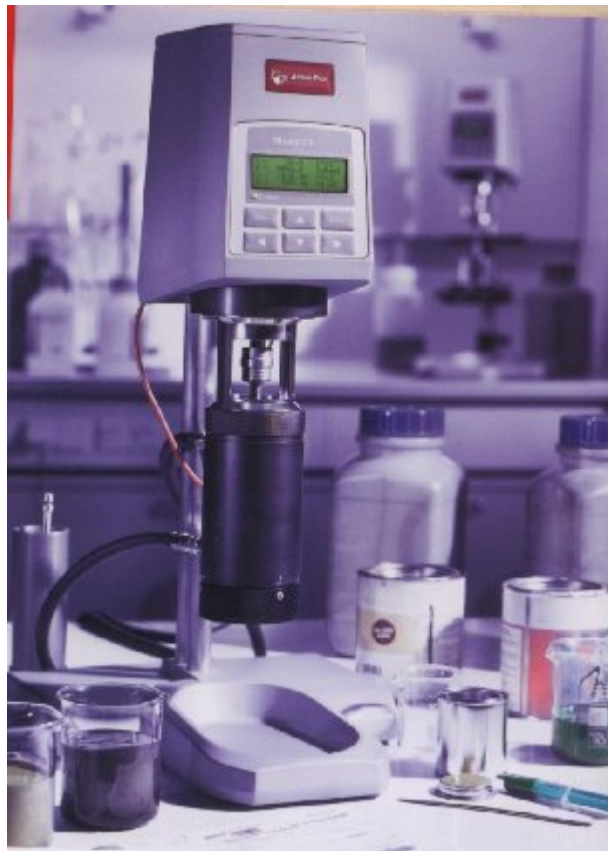


Fig.3.4 Anton Paar Temperature Control Rheogoniometer

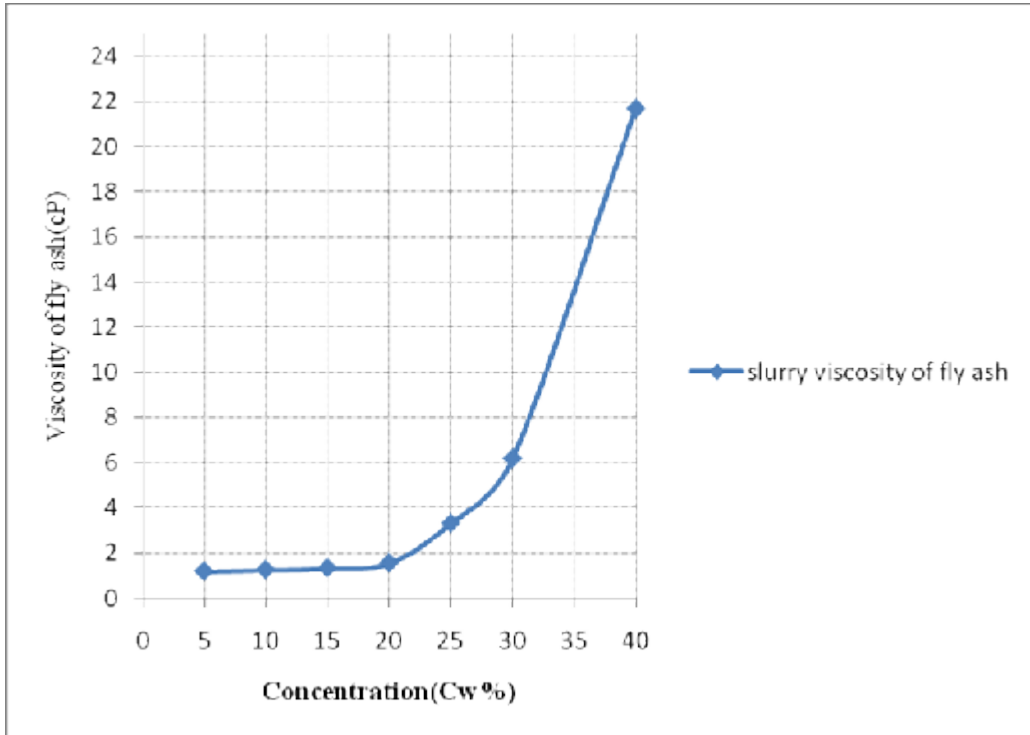


Fig.3.5 Slurry Viscosity of Fly Ash at Various Concentrations

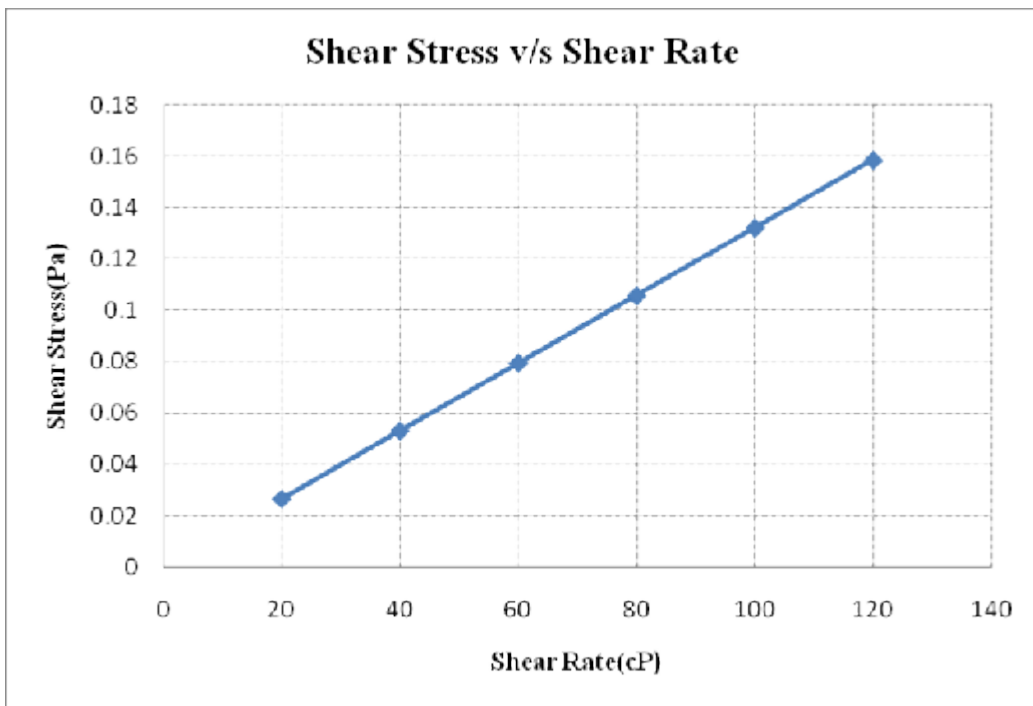


Fig. 3.6 Shear Stress v/s Shear Rate

### 3.2.3 Determination of PH of the Slurry

After preparing slurry samples of a given concentration, PH value of the slurry was determined. First the electrode was moistened with tap water and the lower plastic cap was removed. The lower end was then immersed in water to make it useable with the solution. The electrode was then calibrated by rinsing it in a buffer solution whose PH value was known. The electrode was then removed from buffer solution, rinsed vigorously with distilled water. The electrode was then shook off and immersed in the slurry sample whose PH value was to be determined. The PH of the suspension was read on the digital display unit when full equilibrium was reached.

Fig 3.8 shows the ph of the fly ash used with different concentrations of the ash suspension. The ph of the suspension ranged from 7.4 to 7.7 which indicate that ash slurries are non-reactive at all concentrations. It was found that paste formulations of fly ash are very stable without any acidic nature.

Fig.3.9 shows that coal ash that is fly ash behavior as a function of time. The ph was measured within intervals of 15 minutes during a 4 hour time period. A very small variation in ph with time was observed. This analysis also showed that there is no occurrence of chemical reactions that could alter ph significantly.



Fig 3.7 Digital PH Meter

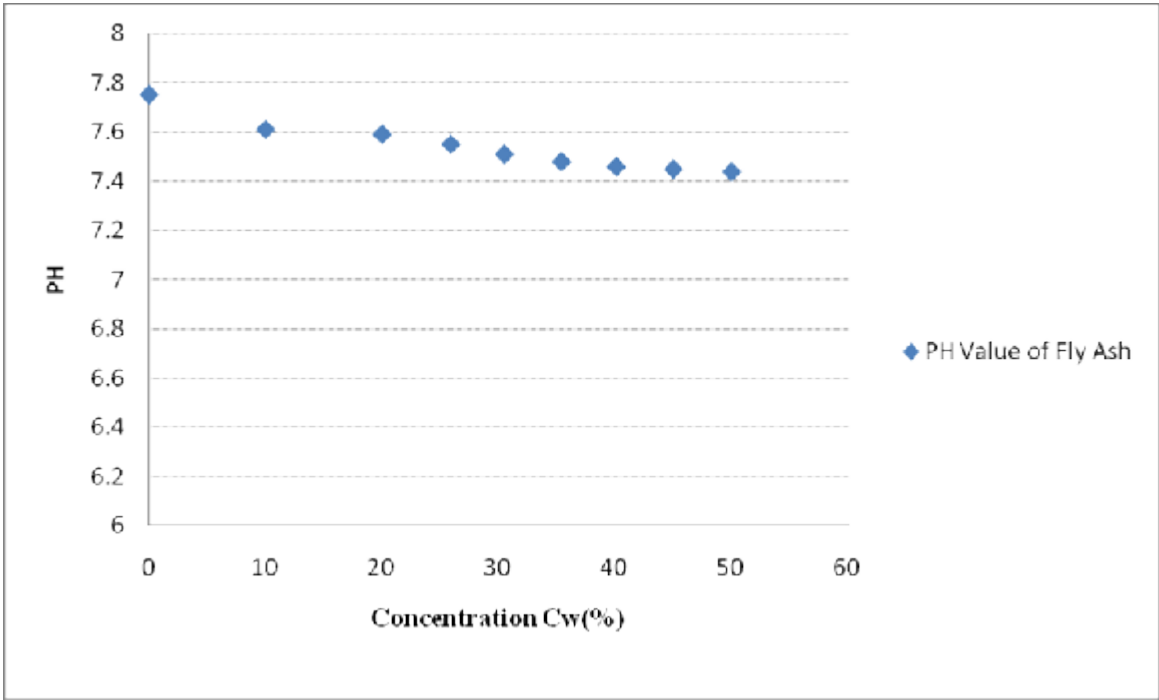


Fig. 3.8 PH Value of Fly Ash at various concentrations

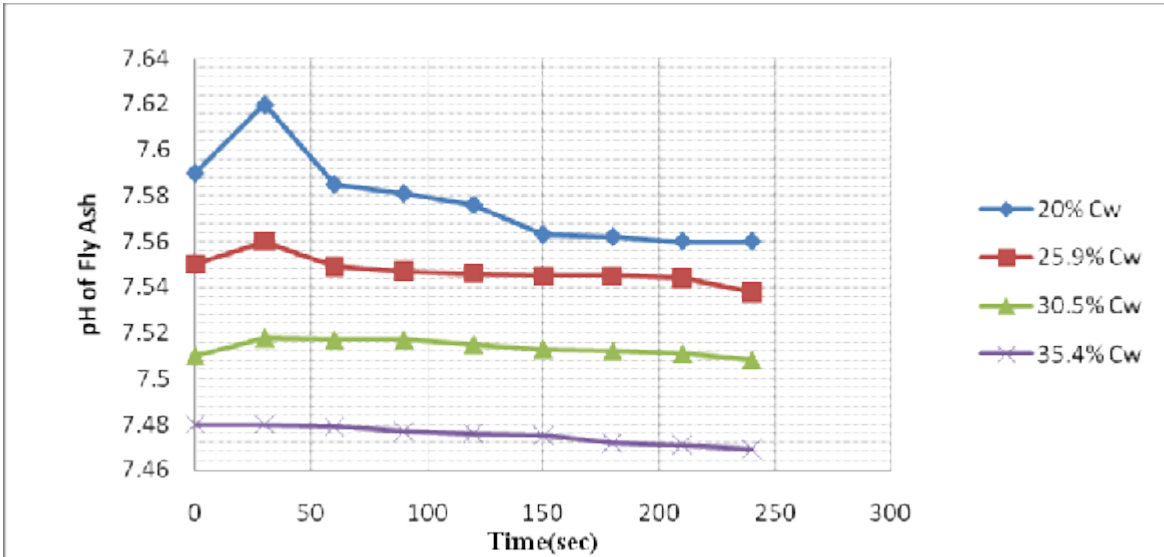


Fig.3.9 PH Value of Fly Ash at Various Time Intervals

### MODELING OF ASH DISPOSAL SYSTEM

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The design of Ash Disposal System is dependent on large number of parameters broadly classified into two subheads namely design of centrifugal pumps and hydraulic design of slurry pipeline. The focus of the present study is on modeling of centrifugal pump and slurry pipelines with horizontal straight pipelines and bends incorporating simulation at different flow rates and concentration of fly ash slurry.

1. Modeling of Centrifugal Pump
2. Modeling of Slurry Pipeline

Computational fluid dynamics (CFD – the use of computers to solve fluid flow problems numerically) is increasingly being used to investigate the variety of multiphase fluid flow problems in closed conduits. One advantage of the CFD-based approach is that three-dimensional solid – liquid two-phase flow problems under a wide range of flow conditions and solid concentration, and their characteristics, may be evaluated rapidly, which is almost impossible experimentally. However, the use of such a methodology for evaluating flow characteristics in slurry pipelines is limited.

#### 4.1 MODELING OF CENTRIFUGAL PUMP

Computational fluid dynamics (CFD) is being increasingly applied in the design of the centrifugal pumps. 3-D numerical computational fluid dynamics tool can be used for simulation of the flow field characteristics inside the turbo machinery. Numerical simulation makes it possible to visualize the flow condition inside a centrifugal pump, and provides the valuable hydraulic design information of the centrifugal pumps. Present work is aimed to analyze the pressure and velocity distribution inside the pump passage and evaluate the pump performance using the Fluent, a computational fluid dynamics simulation tool. A numerical model of an impeller and casing has been generated and the complex internal pressure and velocity distribution are investigated by using the fluent computational code. Pressure and velocity

distribution inside impeller of the centrifugal pump has direct influence due to change of stream wise location.

## MODELING OF THE PUMP

The Schematic diagram of pilot plant of slurry pump is shown in fig.4.6. The Centrifugal Pump is connected to the disposal pipeline having straight horizontal and bends at 90°. Centrifugal pump are modeled and meshing is generated in gambit 2.4. The mesh generation used here is of tetrahedral elements with fluid impeller, casing and inlet passage having cells is shown in table below. The assembly consisted of the casing, impeller and suction discs (frame 37 and follower plate). The pump under study is the part of a test loop used to study the slurries transportation physics at different speeds and concentrations. To get an initial solution T-Grid scheme was used to mesh the model. An interval count of 6 was taken to generate a coarse mesh.

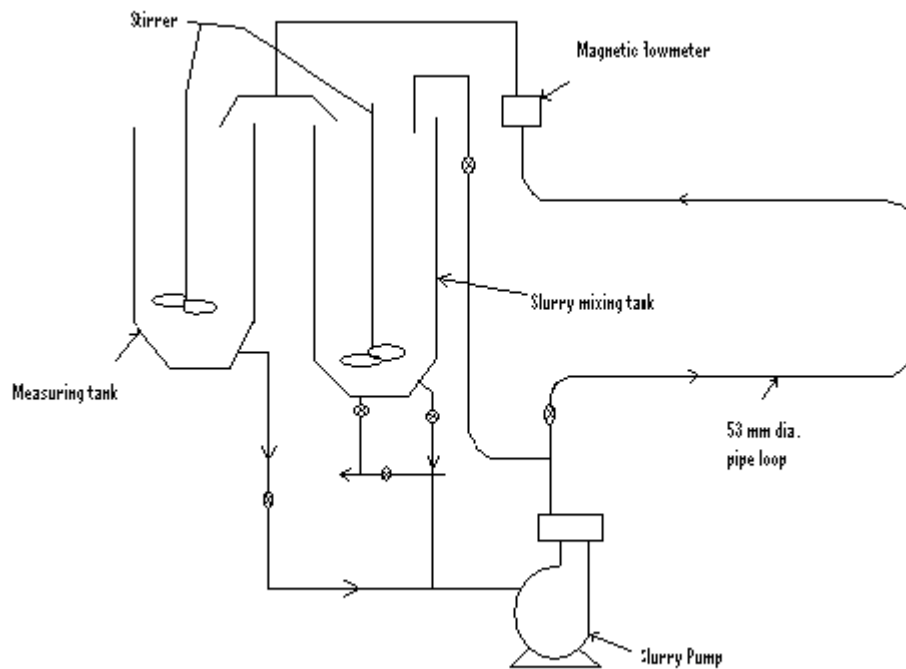


Fig.4.6 Schematic Diagram of Slurry Pump Pilot Plant

## MESH GENERATION

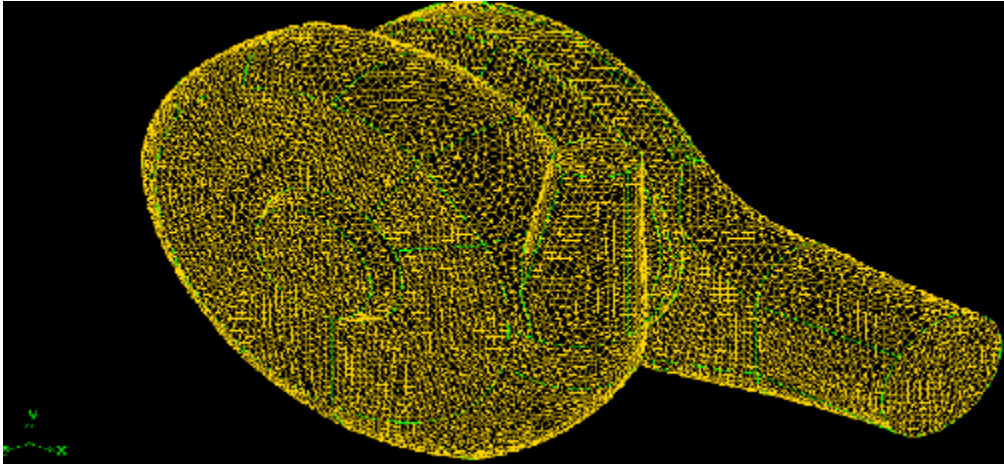


Figure 4.7 Mesh (tetrahedral elements with interval count 5)

Volume	No of elements
Fluid in impeller	91736
Inlet passage(2 highly skewed elements)	247462
Casing	334676

Table 4.1 Showing Meshing Elements of Components of Pump

### 4.2.1 MODELING OF SLURRY PIPELINE

Bends are an integral part of any slurry pipeline system because they provide flexibility in routings. However, they cause additional pressure losses due to secondary flows, and are prone to excessive wear.

Following are the geometrical dimensions of the pipe bend:

Pipe Diameter = 53 mm

Internal Radius of Pipe Diameter = 26.5 mm

Radius of Curvature of Bend = 148.4 mm

Radius ratio  $R/r = 5.6$

Length of Pipe Bend = 1000 mm

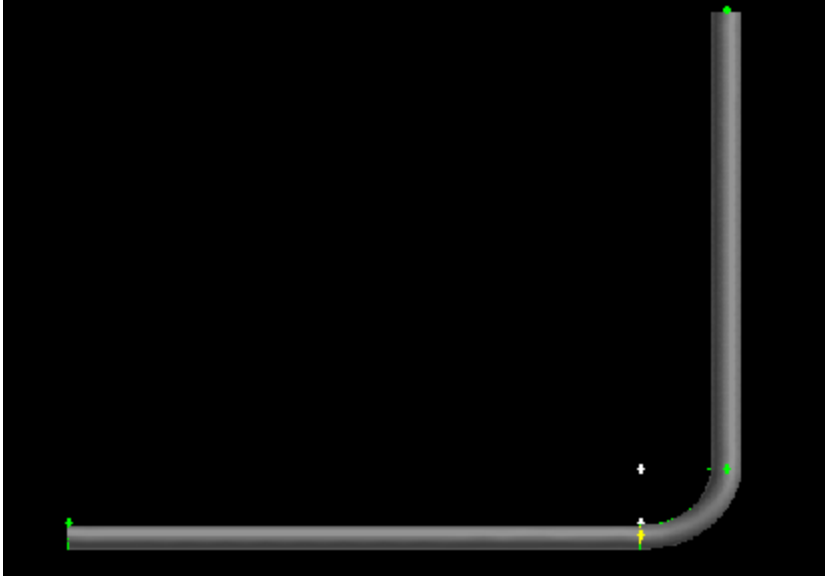


Fig.4.8 Modeling of the pipe bend in gambit 2.4

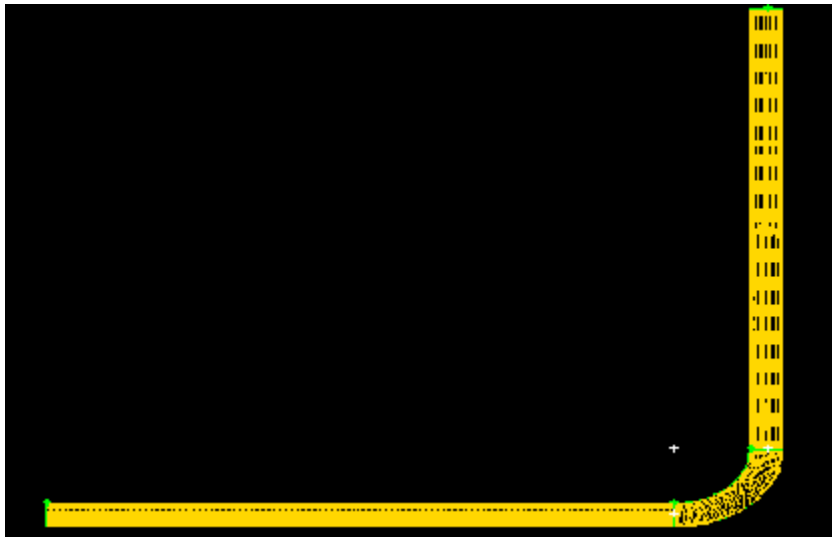


Fig.4.9 Meshing of the pipe bend (a hexagonal shape and a Cooper-type element)

The computational grid for a pipe bend of total length approximately 1000 mm and 53 mm diameter, similar to the experimental slurry pipeline, consists of 49500 cells (Figs 4.9). This number was generated by applying the same cross-sectional meshes of pipe as obtained from the optimum cross-sectional meshes of the pipe for

the single-phase flow case. The grid was generated using Gambit 2.4, which is compatible with Fluent 6.2. A boundary layer that contained four cells with a distance of the cell adjacent to the wall at 5% of the diameter of the pipe and a growth factor of 1.2 was employed on the wall to improve the performance of the wall function. To obtain better convergence and accuracy for a long pipe, a hexagonal shape and a Cooper-type element have been employed. The Cooper-type element is a volume-meshing type.

After meshing of the model of pump assembly commercial CFD code fluent is used for simulation of the pipe bend. The boundary conditions of inlet velocity and viscosity of mixture of slurry are given at inlet of pipe .The performance results are obtained at different velocity inlet ranging from 1.5 to 3 m/s<sup>2</sup>.

#### **4.3 MATHEMATICAL FORMULATION FOR CALCULATION OF PRESSURE LOSS IN SLURRY PIPELINE**

Design of slurry pipeline system involves the estimation of head loss and thus, the power requirement under various operating conditions. Several correlations for the prediction of Fanning friction factor are available in literature, which are mostly of empirical nature. These correlations have been developed based on rheological parameters and experimental data on multi-sized homogeneous slurries. Fortunately, the flow of fly ash slurries in pipeline at high concentrations is of non-settling type, homogeneous and normally in laminar regime. Hence, the prediction of friction factor and subsequently the pressure drop becomes rather straight forward.

For laminar flow, the Fanning friction factor expression can be obtained analytically. However for transition as well as for turbulent flow the evaluation of friction factor is based on some empirical approach.

The Fanning friction factor equation for Bingham Plastic model for laminar flow regime can be obtained theoretically. It relates the Hedstrom number ( $H_e$ ), the Bingham Reynolds number ( $R_{cb}$ ) and friction factor as.

$$\frac{1}{Re_b} = \frac{f}{16} - \frac{Hr}{6R_{3eb}} + \frac{H_{4r}}{3f3 R_{8eb}} \quad (4.4)$$

$$\text{Where } H_e = \frac{Dz\tau YH\rho m}{\eta z\rho} \quad (4.5)$$

$$\text{And } Re_b = \frac{DV\rho m}{\eta\rho} \quad (4.6)$$

It is also possible to express the friction factor in terms of modified Reynolds number,  $Re_{mod}$  as

$$f = \frac{16}{Re_{mod}} \quad (4.7)$$

$$\text{Where } Re_{mod} = \frac{6R_{2eb}}{6Re_b + H_e} \quad (4.8)$$

Though the exact formula for Fanning friction factor is expressed by equation (4.4), the friction factor can also be obtained approximately from the equation (4.7).

For transition from laminar to turbulent flow Hanks and Pratt proposed the following critical Reynolds number criteria. It occurs at a critical value of ' $Re_b$ ' given by

$$(Re_b) = \frac{He}{8xc \left(1 - \frac{4}{3}xc + \frac{1}{3}x^2c\right)} \quad (4.9)$$

Where  $X_c$  is evaluated from the relation

$$\frac{xc}{(1-xc)^3} = \frac{He}{16800} \quad (4.10)$$

In the regime of turbulent flow, for the expression for ' $f_\tau$ ' the analysis is based on some empirical formulae developed by Darby and Melson. This expression is used for evaluating the Fanning friction factor in the present study.

$$f_\tau = 10^C R_{eb}^{-.193} \quad (4.11)$$

Where

$$C = -1.378(1 + 0.146 \exp(-2.9 \times 10^{-5} R_{eb})) \quad (4.12)$$

To arrive at a single expression for friction factor valid for all flow regimes, a modified friction was evolved as

$$f = [f_L^m + f_\tau^m]^{1/m} \quad (4.13)$$

Where

$$M = 1.7 + 40000/R_{eb} \quad (4.14)$$

The pressure drop per unit length of pipe is calculated from well-known Darcy-Weisbach Equation using the value of Fanning friction factor obtained in steps above. If the flow is in turbulent regime, the correction for the pipe-wall roughness is applied.

$$\frac{\Delta p}{L} = 4f \frac{\rho m}{\rho_w \left( \frac{V^2}{2gD} \right)} \quad (4.15)$$

The pressure drop is presented in terms of meter of water column (mWc) per 100 m length of the pipe as a function of flow velocity.

## CHAPTER 5

### STUDY OF ASH DISPOSAL SYSTEM PERFORMANCE USING CFD

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In the present study, experimental data for bend pressure drop were collected from a pilot plant test loop with a pipe diameter of 53 mm. The experiments were performed at various volumetric concentrations (5%, 10%, 20%, and 30%) of 41  $\mu\text{m}$  fly ash and for each concentration the flow velocity was varied from 1.98 to 4.8 m/s. It was observed that pressure drop along the pipe bend increases with flow velocity. Bends are an integral part of any slurry pipeline system because they provide flexibility in routings. However, they cause additional pressure losses due to secondary flows, and are prone to excessive wear.

The pressure loss in a bend depends significantly on the concentration of solid particles, the pipe diameter, the mean flow velocity, the radius of curvature of the bend, the bend angle, the specific gravity and particle size distribution (PSD of the solid, and the geometrical configuration of the bend). For solid – liquid flow, the secondary flow generated influences not only the pressure loss but also the distribution of solids leading.

#### 5.1 SIMULATION

After meshing of the model of pump assembly commercial CFD code fluent is used for simulation of the pipe bend. The boundary conditions of inlet velocity and viscosity of mixture

of slurry are given at inlet of pipe .The performance results are obtained at different velocity inlet ranging from 1.5 to 3 m/s.

Inlet Velocity =1.5 to 3 m/s

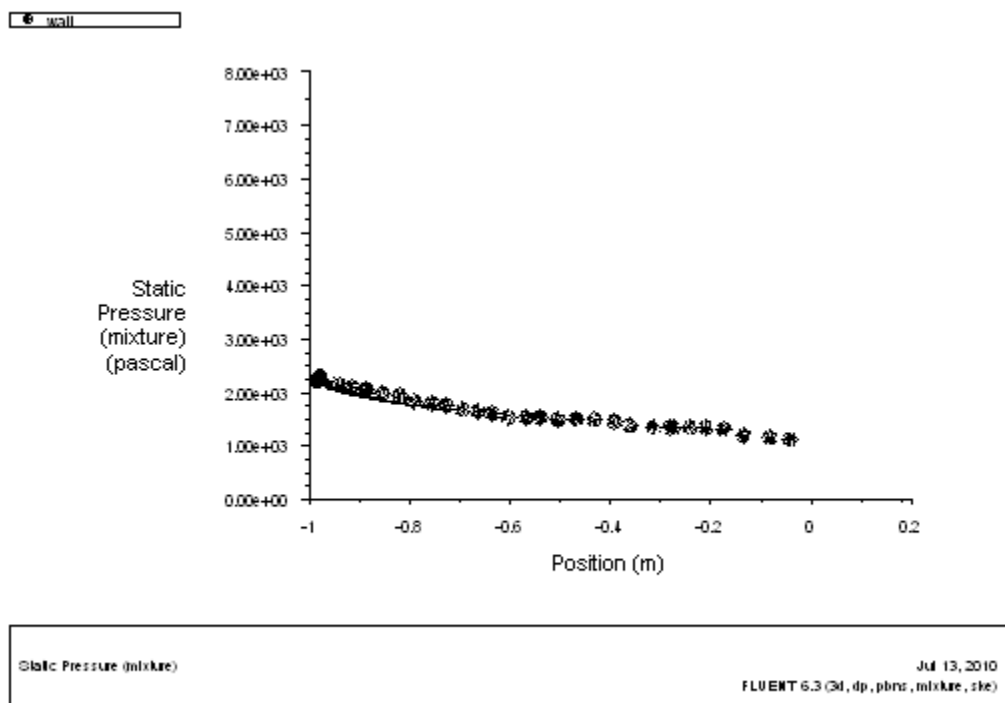
Viscosity of Fly Ash =  $1.2 \times 10^{-4}$  kg m/s

Density of Fly Ash =  $1984 \text{ kg/m}^3$

Diameter of Fly Ash Particle =.000041 microns

Turbulence intensity = 5%

Hydraulic Diameter = .1



Variation of Pressure at mean velocity of 1.98m/s with  $C_w$  5%

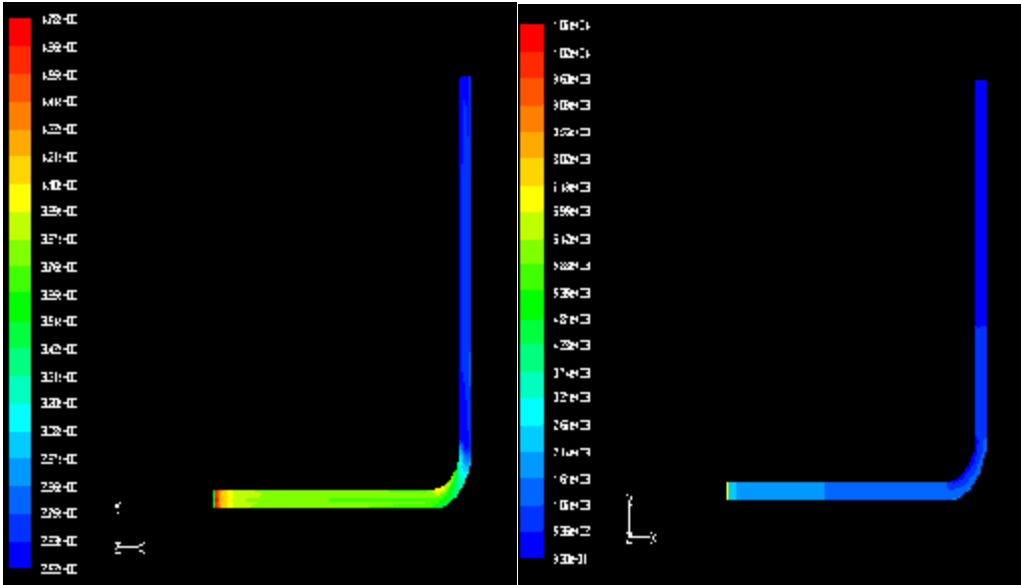


Fig representing (a). Velocity contours (b) Pressure Contours of 1.98m/s with  $C_w$  5%

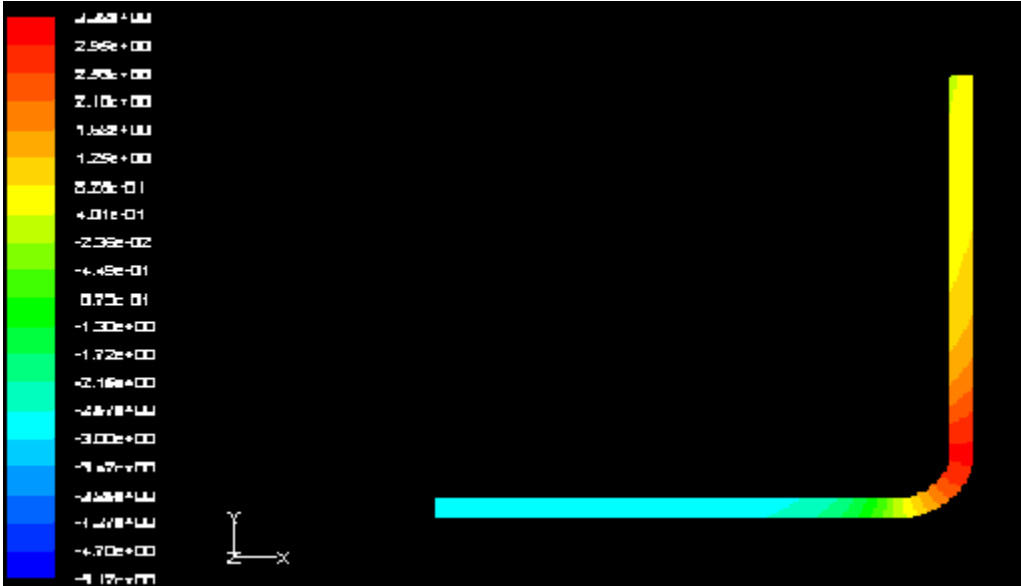
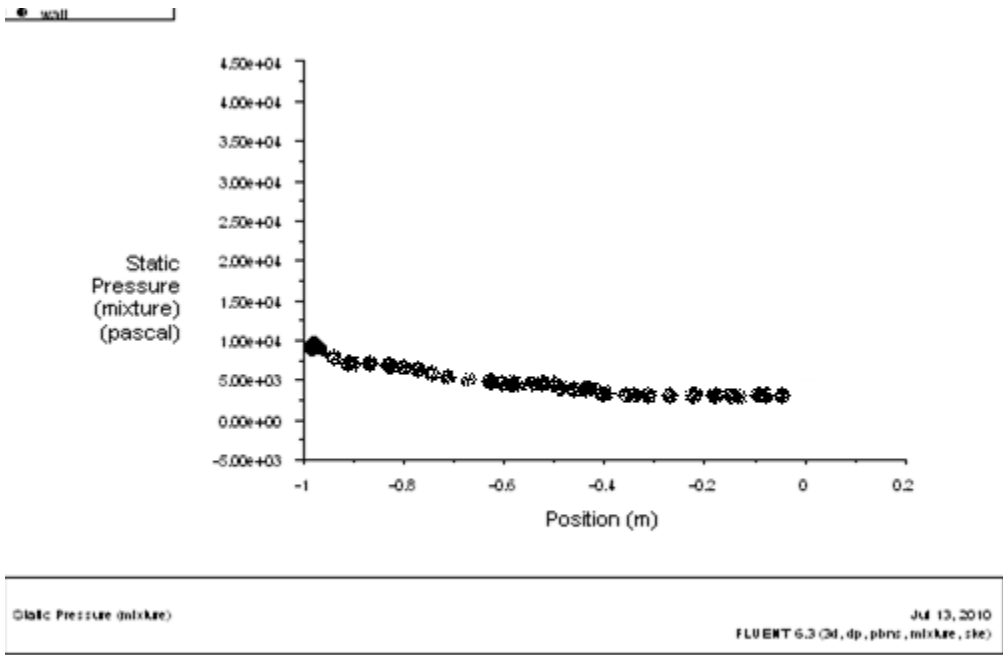


Fig. Variation of Radial Velocity to Mean Flow Velocity of 1.98m/s with  $C_w$  5%



Variation of Pressure at mean velocity of 4.8m/s with  $C_w$  30%

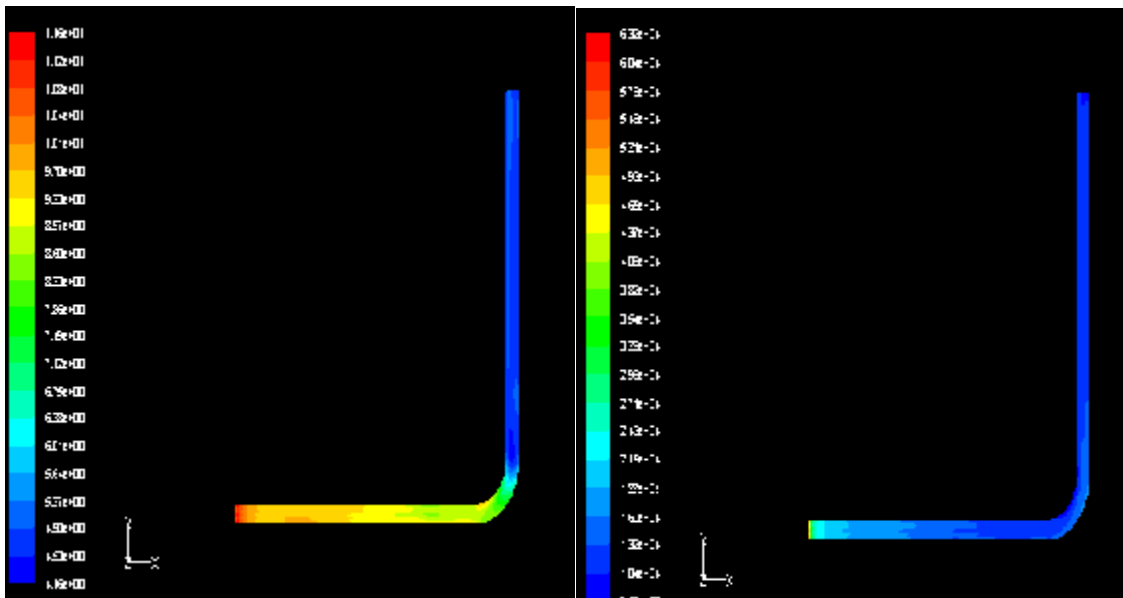


Fig representing (a). Velocity contours (b) Pressure Contours of 4.8m/s with  $C_w$  30%

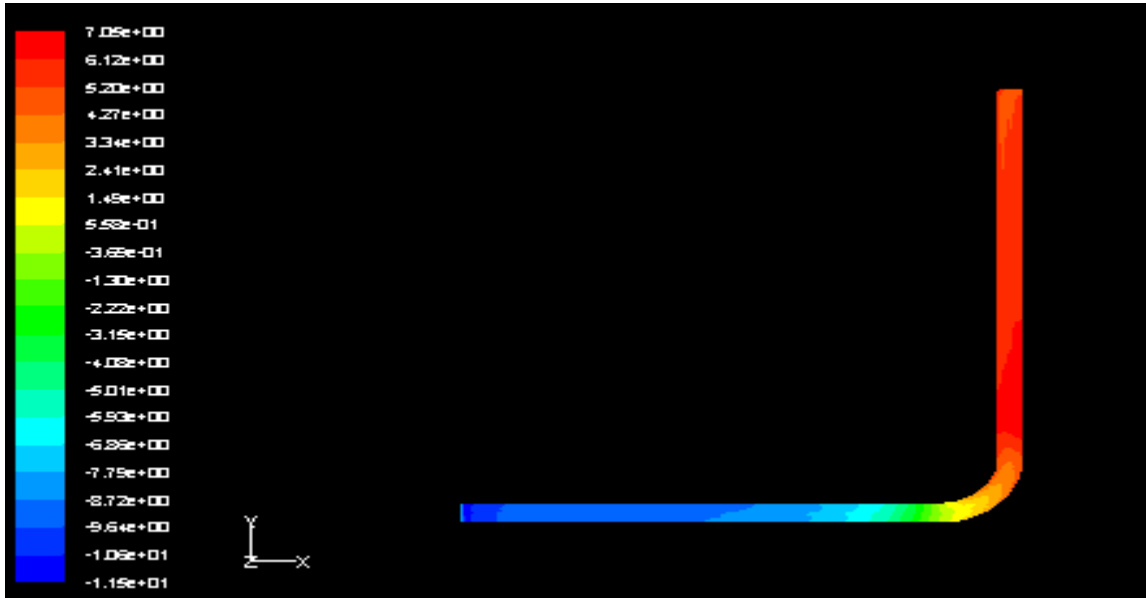


Fig. Variation of Radial Velocity to Mean Flow Velocity of 4.8m/s with  $C_w$  30%

The pressure loss data after CFD simulation is compared with the predicted values of the pressure loss data obtained from Darcy Weisbach equation.

**Graph comparing the pressure loss data obtained from Darcy Weisbach equation with the pressure loss data after CFD simulation at different concentrations and mean flow velocity.**

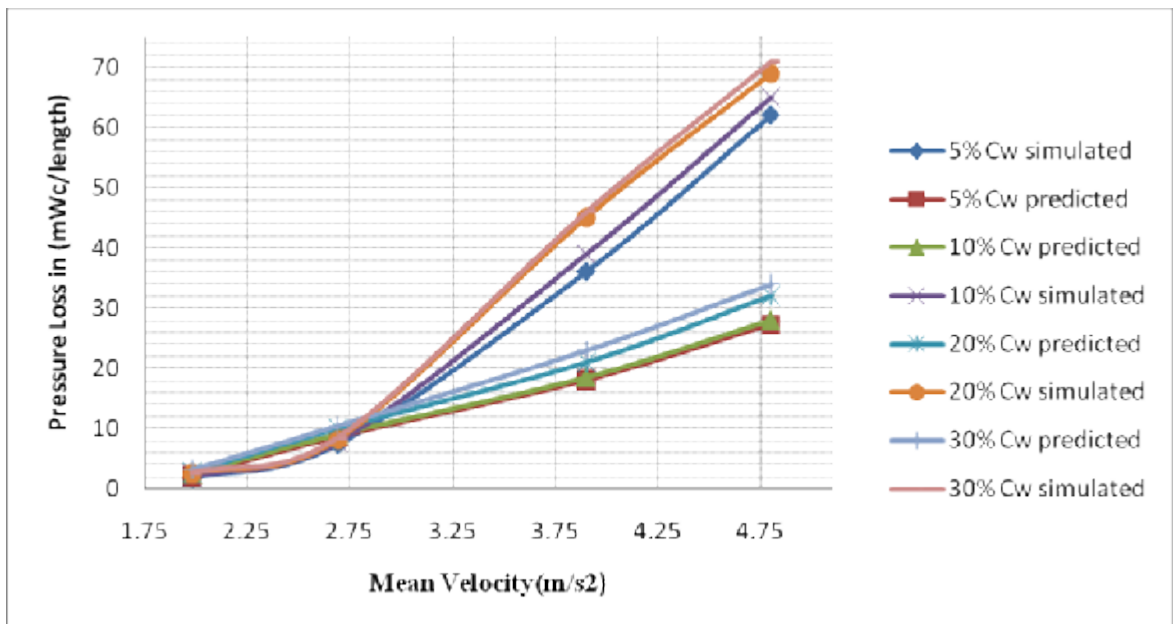


Fig. Comparison of simulated and predicted values of pressure drop at selected velocities

with different concentrations

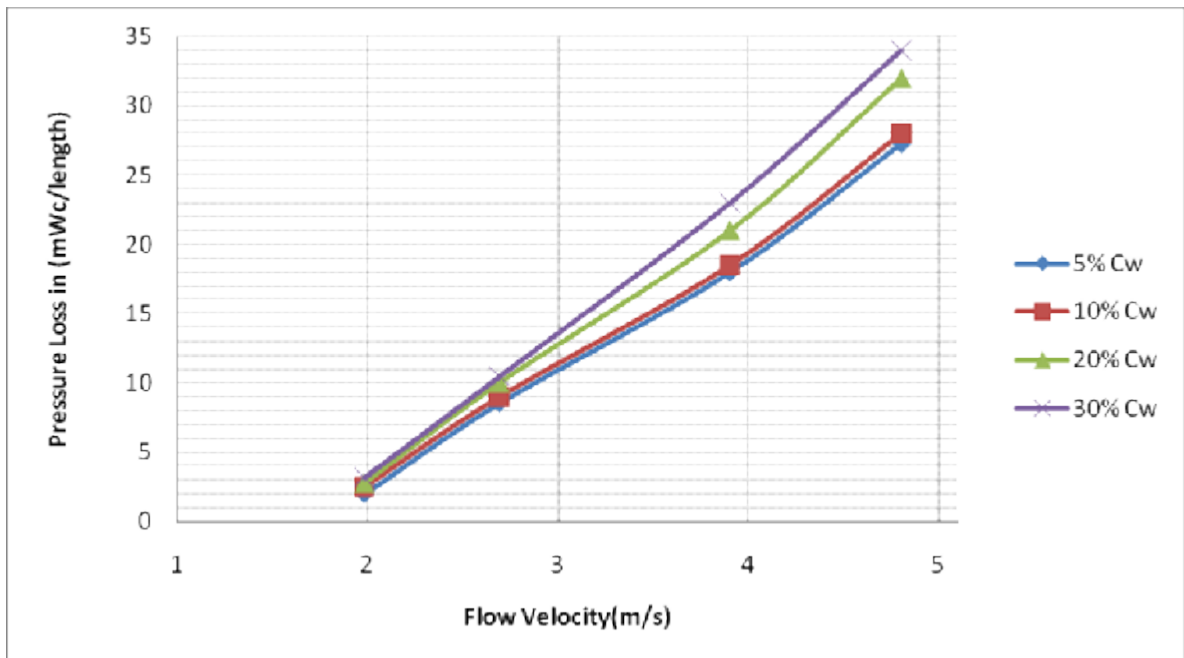
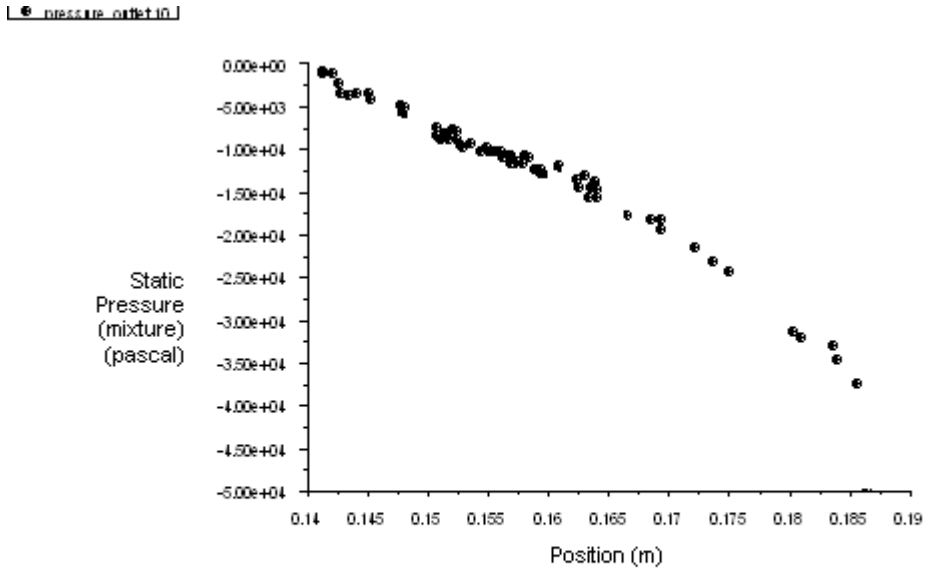
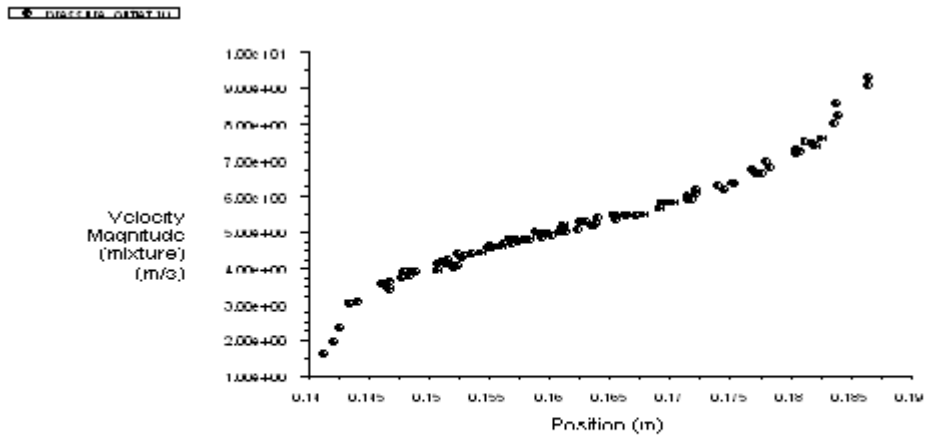


Fig Predicted Pressure Drop at selected velocities for different solid concentrations

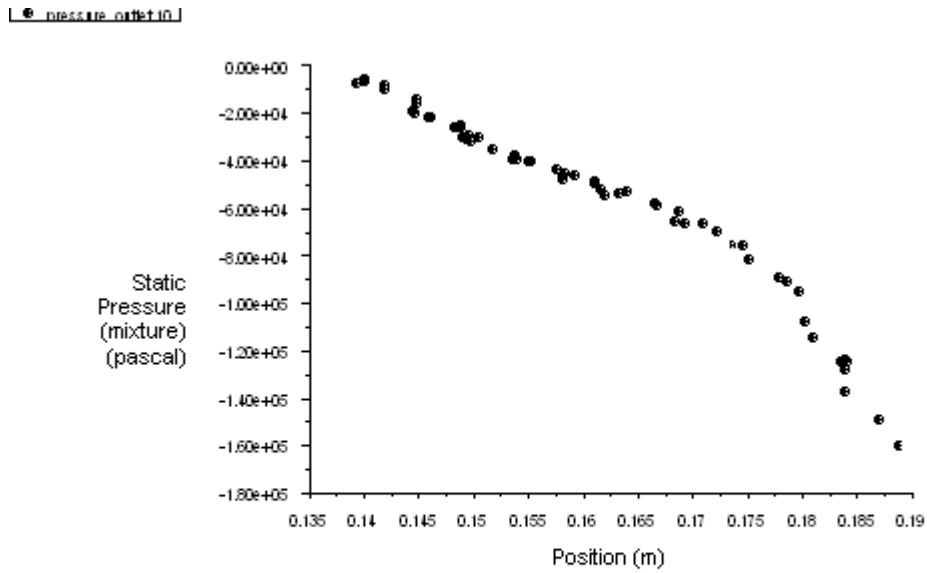
## 5.2 PRESSURE LOSS OBTAINED FROM SLURRY PUMP AT DIFFERENT CONCENTRATIONS AND FLOW RATE



Variation of Pressure at mean velocity of 2.5m/s with  $C_w$  30%



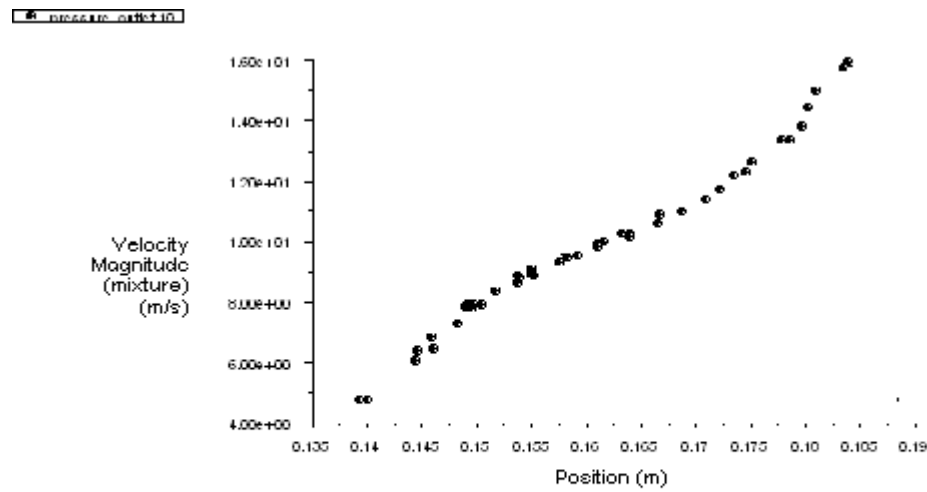
Variation of Velocity profile at mean velocity of 2.5m/s with  $C_w$  30%



Static Pressure (mixture)

Jul 13, 2010  
 FLUENT 6.3 (3d, dp, pbrn, mixture, sbe)

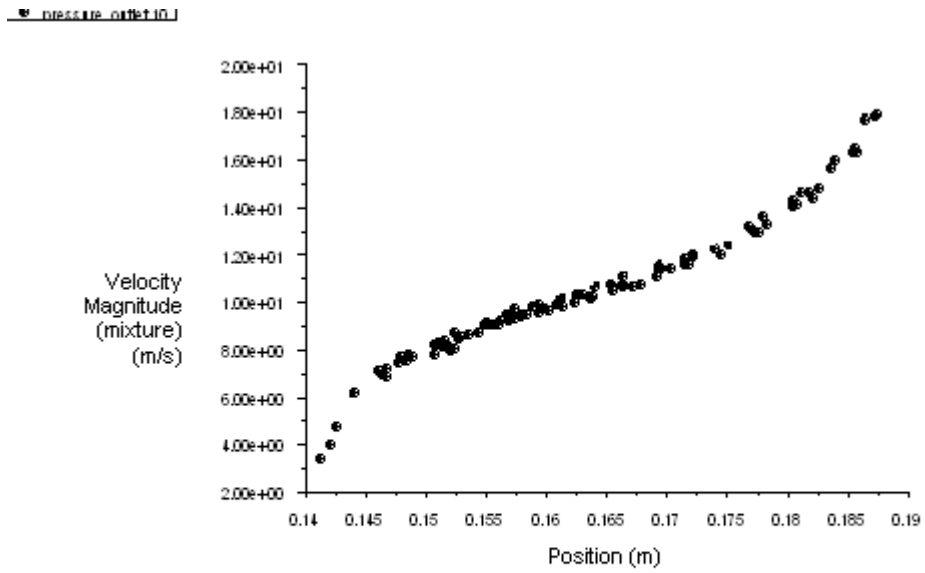
Variation of Pressure at mean velocity of 4.8m/s with  $C_w$  20%



Velocity Magnitude (mixture)

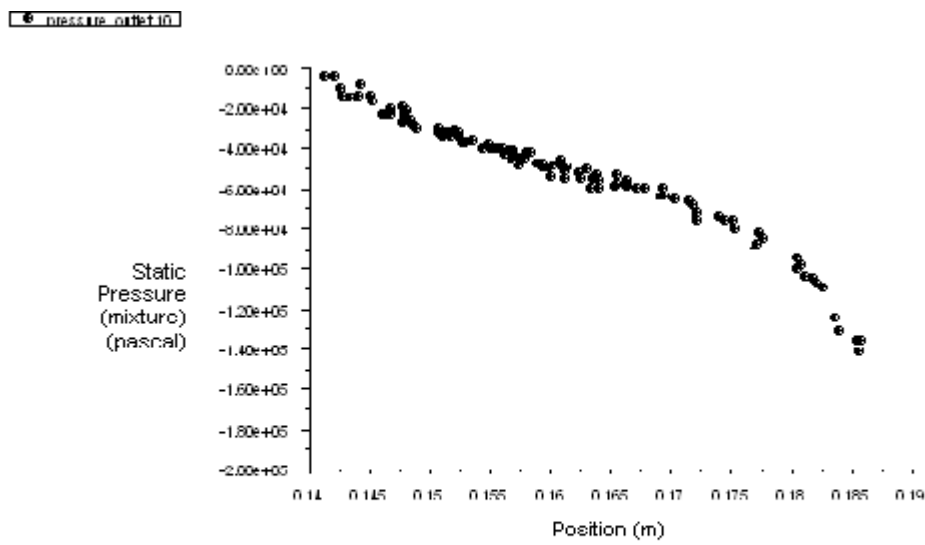
Jul 13, 2010  
 FLUENT 6.3 (3d, dp, pbrn, mixture, sbe)

Variation of velocity at mean velocity of 4.8m/s with  $C_w$  20%



Velocity Magnitude (mixture) Jul 13, 2010  
FLUENT 6.3 (3d, dp, pbns, mixture, she)

Variation of Velocity profile at mean velocity of 4.8m/s with  $C_w$  30%



Static Pressure (mixture) Jul 13, 2010  
FLUENT 6.3 (3d, dp, pbns, mixture, she)

Variation of Pressure at mean velocity of 4.8m/s with  $C_w$  30%



## CHAPTER VI

### CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

#### **7.1** MAJOR CONCLUSIONS

The Present study has been aimed at getting more insight into the effect of particle size of distribution and top particle size on the rheological behaviour of the slurries and also the effect of presence of solids on the performance of centrifugal slurry pumps. The following major conclusions can be drawn from the present investigations.

The commercial slurries of solid materials are generally Newtonian at relatively lower concentrations but at high concentrations non-Newtonian behaviour is exhibited. The size and size distribution of particles have significant influence on the rheological behaviour of the slurries. Any correlation which does not take into account the effect of size and size distribution of particles in addition to solids concentration will not be very successful. Maximum packing concentration of solid, used by many investigators, is a useful parameter to account for the effect of size distributions well. But the difficulty, in the determination of the maximum packing concentration accurately for solids having wide particle size distribution limits the use of this parameter for the determination of the rheological properties of commercial slurries. Maximum static settled concentration of solids is a very useful parameter that can be experimentally determined easily and it has been found to be suitable for use in the correlations for predicting the rheological parameters of slurries of different materials tested. Maximum static settled concentration of solids account for various parameters like size and size distribution of particles, particle shape and solid's specific gravity. It also reflects the crowding of particles in the carrier liquid. Correlations based on reduced volumetric concentration, for the predictions of rheological parameters of fine particulate slurries following Bingham model, have been found to give satisfactory results.

In the absence of suitable correlations for the predication of rheological properties of multisized particulate slurries, the viscometric tests are inevitable. For slurries containing larger sized/heavy particles in a low viscosity carrier liquid, the measurement of shear stress-shear rate relationship is a difficult task. Scalping or removal of large sized particles from the original sample is one of the solutions to this problem. Rheometric tests when performed at solids concentrations of the original sample but with the fine particulate slurries (after the removal of larger sized particles from the original sample) will lead to an overestimation of the rheological parameters. A criterion has been determined to obtain the

equivalent concentration of the scalped sample slurry (fine particulate slurry) which would give approximately the same rheological parameters as those of the original slurry. The criterion is based on the ratio of surface area of solids per unit volume of slurry of the original and scalped samples at any given solids concentration and the reduced volumetric concentration of the original sample. The criterion has been applied to determine the equivalent concentration of the 3 various scalped sample slurries for different top particle size samples of coal and zinc tailings. The rheological parameters of different samples of coal and zinc tailings obtained from the rheometric test results of the scalped sample slurry at the equivalent concentration, derived from the proposed criterion, are within  $\pm 20\%$  error over a wide range of parameters.

Venturimeter has been found suitable for the measurement of flow of slurries also. The venturimeter coefficient is slightly higher than that given for water only. The effect of specific gravity of mixture must be properly considered.

The presence of solids in the slurry has a great effect on the performance of centrifugal slurry pumps. The heads developed and the efficiency of the pump decrease while the input power increases with the increase in solids concentration. NPSH, in meters of slurry column, required for centrifugal pumps handling slurries is lower than that required with water. Hence, if NPSH required for the slurry pump is specified in meters of slurry column having the same magnitude as that determined for the pump with water only, then the estimate would be conservative. The head ratio is found to decrease with flow rate at high discharges and at higher concentration of solids. At low concentrations, it is fairly independent of flow rate. Head ratio decreases linearly with solids concentration. The head and efficiency ratios of any given pump appear to be weakly dependent on the magnitude of rheological parameters of the coal slurry over the range tested. The efficiency ratio decreases slightly due to increase in the input power. In the case of slurries of heavier solids where the rheological effects are relatively small, deterioration in the pump performance is more pronounced in the rubber lined pump as compared to the metal closed impeller pump. However, as the slurry becomes homogeneous and more viscous, the reduction in the pump performance is more pronounced in closed impeller pumps. The present results have shown that the assumption of equivalence between head and efficiency ratio is reasonably accurate.

Materials properties such as specific gravity, size and size distribution and concentration of solids have significant influence on the pump performance with slurries. For solids having wide particle size distribution, the weighted mean particle diameter is a better choice as the representative particle size as compared to the average or median diameter of particles. The proposed correlation for the head reduction factor for the centrifugal slurry pumps, accounts for the specific gravity of solids, size and size distribution of particles and the concentration of solids. Satisfactory prediction have been obtained for

pump performance with the present correlation, for a wide range of specific gravity of solids, size distribution of particles and solids concentrations.

## **7.2 SUGGESTION FOR FUTURE WORK**

The pipeline transportation can be used for a wide number of solids including minerals, ores, coal, tailing etc. The proposed correlations for the rheological parameters of fine particulate slurries need to be tested with other materials also to determine their generality and the range of applicability.

Again the proposed criterion for the determination of the equivalent concentration of scalped sample slurry has been obtained from the results on two materials namely coal and zinc tailing. The criterion has given satisfactory results for these two materials. But it is required to be verified with solids of other materials also.

The effect of rheological parameters of slurry on the performance of slurry pump needs more careful investigation. Record of measurements must be done at still shorter time intervals of a time in the beginning of the tests. Effects of pump size and the geometry of pumps can be further investigated, performance of slurry pumps can also be investigated with solid materials of almost similar particle size distribution but of various density of solids so as to confirm the dependence of specific gravity of solids on the head ratio or head reduction factor.

It is needless to stress the fact that the present state of knowledge in this highly complicated field is at best incomplete. Basic studies for identifying the effects of numerous parameters affecting slurry pumping and transportation need to be made.



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## ANNEXURE-I

SIZE RANGE(IN MICRONS)below	% Finer Fly Ash	Dmean Fly Ash	Dwmi Fly ash
2000	100.00%		
1400	100.00%		
710	100.00%		
355	99.48%		
300	98.96%	41	82.5
250	98.24%		
212	97.24%		
180	96.84%		
150	87.84%		
125	84.52%		
90	81.12%		
75	35.12%		

<b>wt of pycnometer (Wb) in gm</b>	13.370gm
<b>wt of solid</b>	30 gm
<b>wt of beaker + solid (wbs)</b>	43.370 gm
<b>wt of filled beaker with slurry &amp; water</b>	89.815 gm
<b>wt of beaker with fully filled water</b>	74.540 gm

<b>Specific gravity</b>	<b>Density of Liquid kg/m<sup>3</sup></b>	<b>Density of FLY Ash (kg/m3)</b>
1.98766797	998.2	1984.090167

<b>Weight in gms</b>	<b>Weight of water (gms)</b>	<b>Concen. (%)</b>	<b>PH Value of Fly Ash</b>
0	100	0	7.75
10	100	10	7.61
25	100	20	7.59
35	100	25.9	7.55
44	100	30.5	7.51
55	100	35.4	7.48
67	100	40.1	7.46
82	100	45	7.45
100	100	50	7.44

time (sec)	20% Cw	25.9% Cw	30.5% Cw	35.4% Cw
0	7.66	7.66	7.64	7.63
30	7.658	7.656	7.639	7.629
60	7.657	7.656	7.637	7.628
90	7.656	7.655	7.637	7.627
120	7.656	7.653	7.636	7.627
150	7.655	7.652	7.635	7.626
180	7.653	7.652	7.634	7.623
210	7.651	7.65	7.633	7.621

240

7.651

7.649

7.633

7.62

Table 6 PH Value of Fly ash at various time intervals

Concentration	Water Viscosity	Slurry Viscosity of Fly Ash	Relative Viscosity
[Cw %]	[cP]	[cP]	
0	0.995		1
5	0.995	1.19	1.20
10	0.995	1.26	1.27
15	0.995	1.33	1.34
20	0.995	1.56	1.57
25	0.995	3.32	3.34
30	0.995	6.18	6.21
40	0.995	21.69	21.80

Table 7 Rheological properties of Fly Ash

Cw	velocity	Predicted Pressure Drop	Simulated Pressure Drop	
5	4.8	27.27	62	
5	3.9	18	36	
5	2.69	8.56	7.3	
5	1.98	2	1.785	
10	4.8	28	65	
10	3.9	18.5	39	
10	2.69	9	7.8	
10	1.98	2.5	2.1	
20	4.8	32	69	
20	3.9	21	45	
20	2.69	10	8.1	
20	1.98	2.75	2.5	
30	4.8	34	71	
30	3.9	23	46	
30	2.69	10.5	8.5	
30	1.98	3.2	2.7	

Table 8 Comparison of simulated and predicted values of pressure drop at selected velocities with different concentrations