INVESTIGATION OF FLOW OF CENTRIFUGAL SLURRY PUMP HANDLING BOTTOM ASH & FLY ASH MIXTURE

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CERTIFICATE

I hereby declare that the work which is being presented in the dissertation work entitled, "**INVESTIGATION OF FLOW OF CENTRIFUGAL SLURRY PUMP HANDLING BOTTOM AND FLY ASH MIXTURE**", in partial fulfillment of the requirements for the award of degree of Master of Engineering in Mechanical Engineering with specialization in **THERMAL ENGINEERING** submitted in **Mechanical Engineering Department** of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Mr. Satish Kumar** and refers other researcher's works which are duly listed in the reference section. The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

Centrifugal pumps are used for transportation of solids and liquid over short to medium distance through the pipelines. A centrifugal pump designed to handle the liquids is normally single stage, end suction type having radial or mixed flow configuration of blades. Centrifugal pump of radial-flow type is mostly used in slurry service. A conventional centrifugal pump is designed to handle bottom fly ash mixture liquids. The modifications incorporated in the pump include enlargement of flow passages to accommodate bigger solid particles, robust impeller with smaller number of vanes, special seals and proper material of construction to ensure longer life. These have to be operated with relatively wide clearance at impeller-casing contacts to minimize choking and localized wear. These modifications increase the hydraulic losses in the pump and deteriorate the pump performance. The present study is concerned with the evaluation of the performance characteristics of a centrifugal slurry pump when handling bottom fly ash at 30% concentration of bottom fly ash slurry at different speeds1000, 1150, 1300 and 1450 rpm. From the experimental evolution it is concluded that the parameters defined for head and capacity of the conventional pumps are also applicable for the slurry pumps with water despite the constructional differences. From the bottom ash characteristics it is also observed that addition of the fly ash in the bottom ash developed head decreases with increases of the flow rate results decreases the power consumptions of the transportation of the bottom ash in pipelines.

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Notation

p	static pressure, Pa
v	velocity of fluid,ms^{-1}
$\rho \vec{g}$	Gravitational force, Newton
V_d	velocity of fluid at outlet passage ,ms^{-1}
Z	difference of the centre levels of outlet passage and inlet passage
Z_d	Height of the delivery pressure transducer from ground, m
Z_s	Height of the suction pressure transducer from ground, m
$(\frac{P_d}{\rho g})$	Experimental static pressure rise at outlet passage, m
$(\frac{P_s}{\rho g})$	Experimental static pressure rise at inlet passage
H	Total head, m
ρ	mass density of water, kg m^{-3}
g	gravitational acceleration m s^{-2} ,
Q	flow rate, m^{3}s^{-1},
P_{out}	Out put power, kW
P_{in}	Input power of pump, kW
T	Torque of pump shaft, N-m
ώ	Rotational speed of the shaft,rads^{-1}
sH	Specific head
sQ	Specific discharge
sP	Specific power
N	Impeller speed, rpm
D	Impeller diameter, mm

CHAPTER 1

INTRODUCTION

1.1 PUMP

Pump is a mechanical device to increase the pressure energy of a fluid. In most cases pump is used for raising fluids from a lower level to a higher level. This is achieved by creating a low pressure at the inlet or suction end and high pressure at the outlet or delivery end of the pump. Pump does not necessarily increase the speed of fluid passing through it, rather it increase the pressure of fluid.

1.1.1 Classification of pump

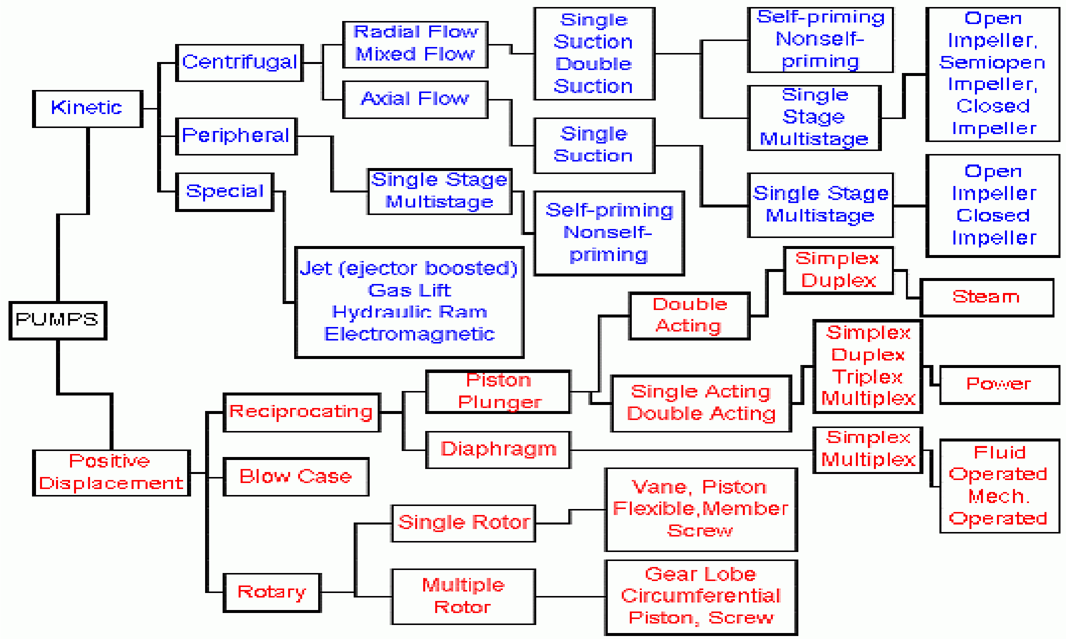

Figure 1.1

Reciprocating pump

A reciprocating pump consists primarily of a piston reciprocating inside a closed fitted cylinder, thus performing the suction and delivery strokes. The reciprocating pump is a positive acting type which means it is a displacement pump which creates lift and pressure by displacing liquid with a moving member. The cylinder is alternatively filled and emptied by forcing and drawing the liquid by mechanical motion. Suction and delivery pipes are connected to the cylinder. Each of the two pipes is provided with a non return valve. The function of a non return valve or one way valve is to ensure unidirectional flow of liquid. Reciprocating pump generally operates at low speeds.

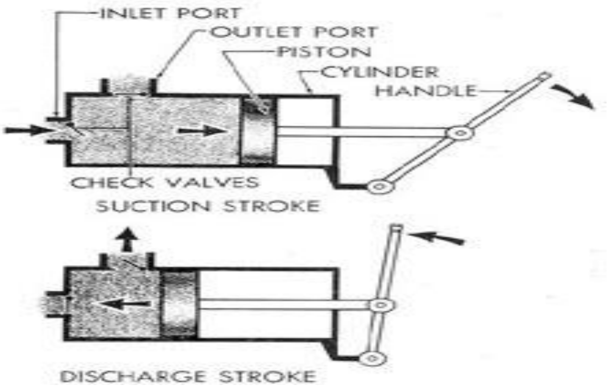

Figure 1.2 reciprocating pump

Centrifugal pump

The centrifugal pump is a device used to raise liquids from a lower level to a higher level by creating the required pressure with help of centrifugal action.In general it can be defined as a machine which increases the pressure energy of a fluid. Centrifugal pump is reversed of inward flow reaction turbine. Centrifugal pumps are typically used for large discharge through smaller heads.

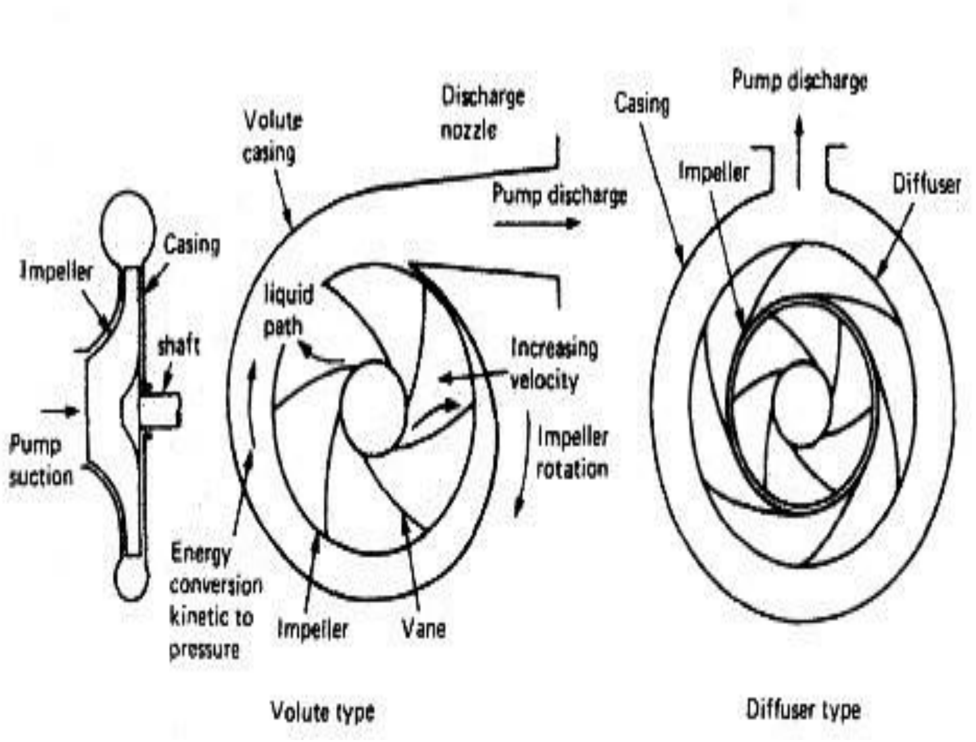

Figure 1.3 centrifugal pump

1.2 WORKING PRINCIPLE OF CENTRIFUGAL PUMP

A vessel containing liquid is rotated by some external agency, a prime mover or an electric motor, with a sufficiently high velocity, so as to enable it to rise beyond the wall of the container. More liquid is constantly supplied at the centre by some suitable means. The liquid will tend to flow out of the vessel by action of forced vortex. It is received around the periphery under pressure and supplied to the required place through delivery pipe. The rise in the pressure head at any point of the rotating liquid is proportional to the square of tangential velocity of the liquid at that point. Thus the outlet of the impeller, where radius is more, the rise in the pressure head will be more and the liquid discharged at the outlet with a high pressure head. Due to this high pressure head, liquid can be lifted to a high level.

1.2.1 Components of centrifugal slurry pump

Common components of a Centrifugal Pump are:

Moving Components

i. Impeller
ii. Shaft

Non Moving Components

i. Motor
ii. Bearings
iii. Glands
iv. Mechanical seals
v. Casing

Impeller

The rotating part of the centrifugal pump is called ‘impeller”. Impeller is the part which provides the desired pressure energy to the fluid. It changes the direction of flow of fluid in pumps. Impellers can further be classified depending upon various factors as follows:

Based on suction criterion

Single Suction

These Pumps have Fluid inlet from one side only.

Double suction

These impellers have fluid inlets from both the sides. These impellers are used for very high discharge requirements.

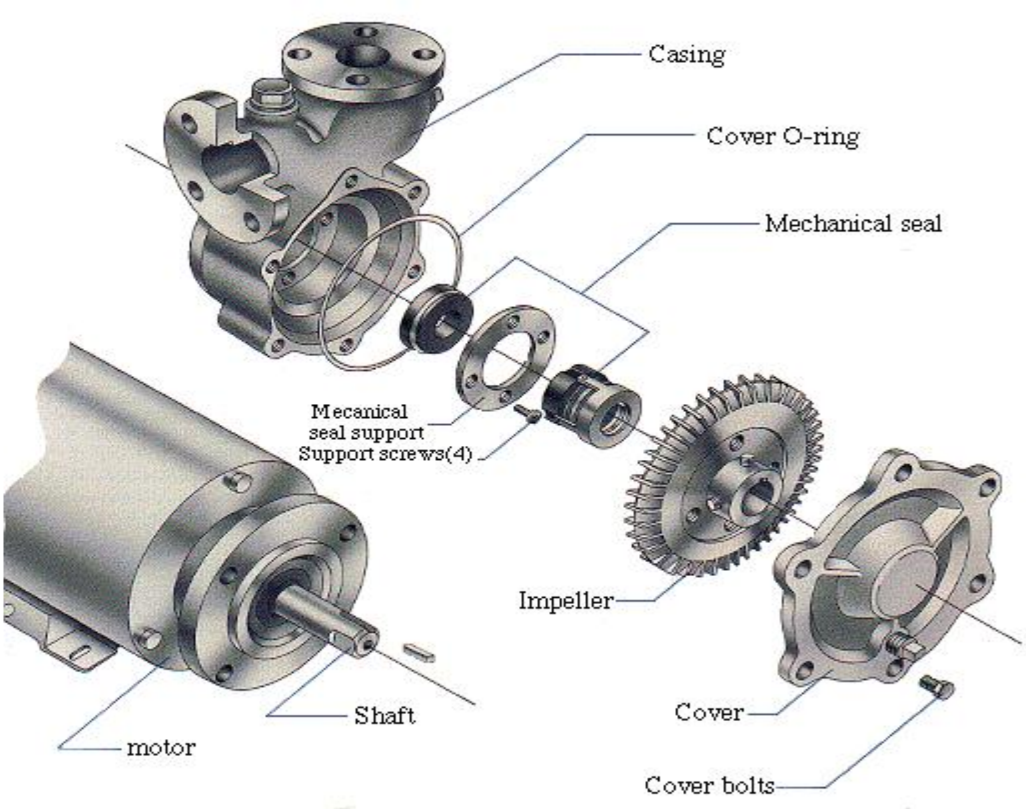

Figure 1.4 Components are briefly shown in the figure

Based on Design criterion

Closed impeller

This type of impeller has shrouds on both its sides. This type of impeller is used for fluids with high viscosity. These impellers are generally used clean liquids because tolerances airtight at the eye and the housing, and there is no room for suspended solids, crystals or sediments.

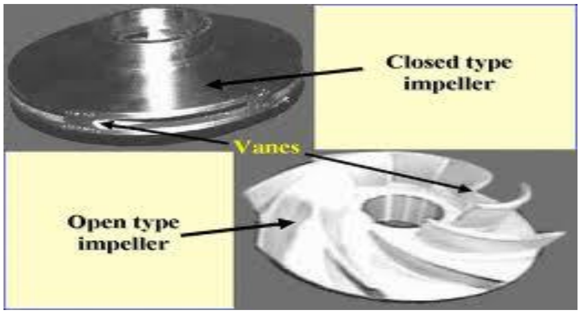

Figure 1.5 closed and open type impeller

Semi closed impeller

Semi closed type impeller is closed on one side only. They are used for comparatively low viscous fluids. The efficiency of these impellers is governed by the limited free space or tolerance between the front leading edge of the blades and the internal pump housing wall. This type of impellers is generally used at the bottom of a tank to empty it.

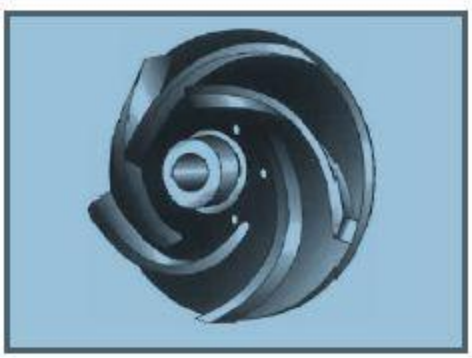

Figure 1.6 semi closed impeller

Open type impeller

Open type impeller is used for high discharge and low viscosity fluids. With its open tolerances for moving and grinding solids they are not high efficiency devices. This type of impeller doesn't provide high head discharge.

Figure 1.7 open type impeller

These types of impellers are classified according to the direction of flow of fluid at the outlet.

i. Axial flow
ii. Radial flow
iii. Mixed flow

Casing

It is an air tight passage surrounding the impeller and is designed in such way that the kinetic energy of the water discharge at the outlet of the impeller is converted into pressure energy before the water leaves the casing and enter the delivery pipe.

Type of casing

i. **Volute Casing**

A volute is a curved funnel that increases in area as it approaches the discharge port. The volute converts kinetic energy into pressure by reducing speed while increasing pressure, helping to balance the hydraulic pressure on the shaft of the pump. The name "volute" is inspired by the resemblance of this kind of casing to the scroll-like part near the top of an Ionic order column in classical architecture, called a volute. In free-vortex, angular momentum is constant. Most of the single stage pumps are built with volute casing.

ii. **Vortex casing**

If a circular chamber is introduced between the casing the casing is known as vortex casing. By introducing the circular chamber, the loss of energy due to the formation of eddies is reduced to a considerable extent. Thus the efficiency of the pump is more than the efficiency when only volute casing is provided.

iii. **Casing with guide blades**

These are those casing in which impeller the impeller is surrounded by a series of guide blades mounted on a ring which is known as diffuser. The guide vanes are designed in which a way that the water from the impeller enter the guide vanes without shock. Also the area of the guide vanes increases, thus reducing the velocity of flow through guide vanes and consequently increasing the pressure of water. The water from the guide vanes then passes through the surrounding casing which is in most cases concentric with impeller.

Seal Chamber and stuffing Box

Seal chamber and Stuffing box both refer to a chamber, either integral with or separate from the pump case housing that forms the region between the shaft and casing where sealing media are installed. When the sealing is achieved by means of a mechanical seal, the chamber is commonly referred to as a seal chamber. When the sealing is achieved by means of packing, the chamber is referred to as a Stuffing Box. Both the seal chamber and the stuffing box have the primary function of protecting the pump against leakage at the point. Where the shaft passes out through the pump pressure casing. When the pressure at the bottom of the chamber is below atmospheric, it prevents air leakage into the pump. When the pressure is above atmospheric, the chambers prevent liquid leakage out of the pump. The seal chambers and stuffing boxes are also provided with cooling or heating arrangement for proper temperature control.

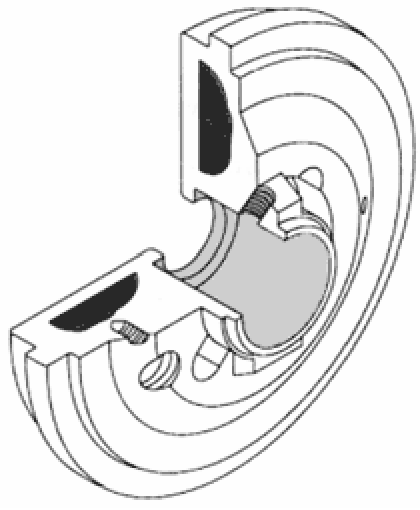

Figure 1.8 seal chamber and stuffing box

Gland

Gland is the part of pump which separates the electric motor and the pump. It provides the sealing between the motor and pump impeller. It consists of a Mechanical seal with sound ground stones, flush, quench.

Figure 1.9 gland

Throat bushing

It forms a restricted clearance between the impeller and the pump; it is used for the proper Alignment and proper adjustment of shaft.

Throttle Bushing

It forms a close clearance around the shaft at the outer end of the mechanical seal, preventing the slippage of mechanical seal and further strengthening the sealing.

Bearing housing

Bearing housing of the pump is the part which holds the bearings in the pump which supports the pump drive shaft and the impeller. The shaft rotates inside the bearings. Different types of bearings can be used depending upon the weight f the shaft and the power to be transmitted to the impeller. Bearing housing also holds lubricating oil but largely, self Lubricating bearings or the bearings with lubricant filled with seals are generally used.

Figure 1.10 Bearing housing

1.2.2 Priming of a centrifugal slurry pump

Priming of a centrifugal slurry pump is defined as the operation in which the suction pipe, casing of the pump and a portion of a delivery pipe up to the delivery valve is completely filled up from outside source with the liquid to be raised by the pump before starting the pump. Thus the air from these parts of the pump is removed and these parts are filled with the liquid to be pumped. When pump is running in air, the head generated in terms of meter of air. If the pump is primed with water, the head generated is same meter of water. But as the density of the air is very low, the head generated of air in terms of equivalent meter of water head is negligible and hence the water may not be sucked from the pump. To avoid this difficulty, priming is necessary.

1.3 CHARACTERISTICS OF CENTRIFUGAL SLURRY PUMPS

The selection of a pumping system for any system for any slurry transportation system is governed more by the 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. Centrifugal pumps are best suited for short distances and for in-plant slurry pipe line system .though the discharge pressure of centrifugal pumps is relatively low; they can also be used for moderate pressure requirements when used in series. 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. The efficiency of a centrifugal slurry pump is lower as compared to that of a conventional centrifugal pump because of robust nature of the impeller design and the relatively wide throat impeller clearances.

1.4 CHARACTERISTICS CURVES OF A CENTRIFUGAL PUMP

Characteristic curves of centrifugal pumps are defined those curves which are plotted from the results of a number of tests on the centrifugal pump. These curves are necessary to predict the behavior and performance of the pump when the pump is working under different flow rate, head and speed. The following are the important characteristics curves for pumps:

i. Main characteristic curves.
ii. Operating characteristic curves
iii. Constant efficiency or Muschel curves.

Main characteristics curves of centrifugal pump

These are obtained by fixing the speed at some arbitrary value of and plotting separately H, HP, & η against Q. The rate of flow Q is varied by means of the quantity H, HP, η are calculated. A number of different values of N are chosen and one such set of curves is drawn for each speed.

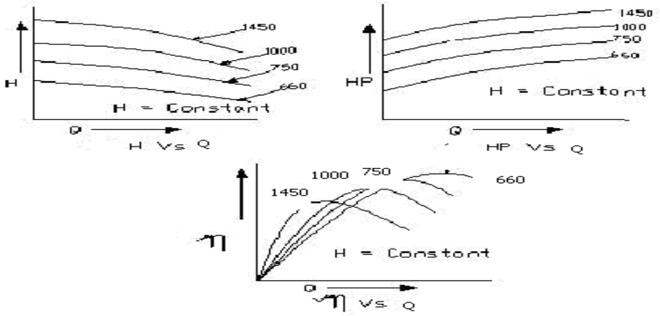

Fig 1.11 Main characteristics curves of centrifugal pump

Operating characteristics curves of centrifugal pump

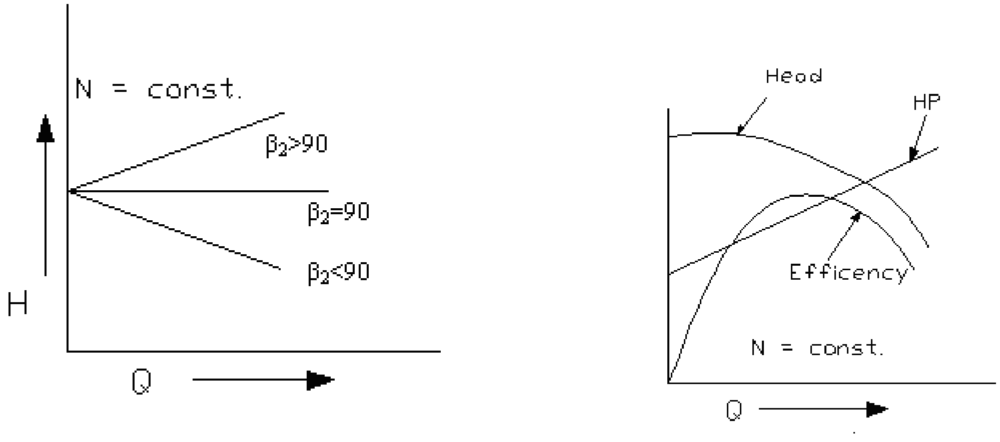

Fig 1.12 Operating characteristic curves of centrifugal pump

During operation the pump must run at a constant speed. Normally, this is the designed speed. The particular set of main characteristics which correspond to the designed speed is mostly used in operation and is therefore known as operating characteristics.

Muschal Curve or Constant Efficiency Curve

With the help of data obtained from the above curve, a series of constt. Efficiency curve can be obtained. They facilitate the job of the salesman and enable the prospective customer to see directly the range of operation with a particular efficiency,

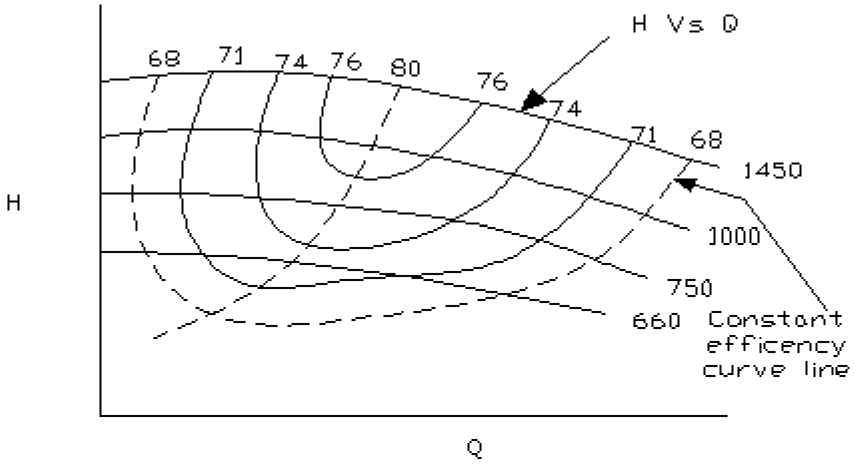

Fig 1.13 Muschal curve or constant efficency curve for centrifugal pump.

1.5 EFFICIENCIES OF A CENTRIFUGAL PUMP

In case of a centrifugal pump, the power is transmitted from the shaft of the electric motor to the shaft of the pump and then to the impeller. From the impeller, the power is given to the water. Thus power is decreasing from the shaft of the pump to the impeller and then to the water. The following are the important efficiencies of a centrifugal pump:

a. **Manometric efficiency (η_{man}):** the ratio of the manometric head to the head imparted by the impeller to the water is known as manometric efficiency.

$$\eta_{man} = \frac{Manometric\ head}{Head\ imparted\ by\ impeller\ to\ water}$$

b. **Mechanical efficiency (η_m):** the ratio of the power available at the impeller to the power at the shaft of the centrifugal pump is known as mechanical efficiency.

c. **Overall efficiency (η_o):** it is defined as the ratio of power output of the pump to the power input to the pump.

$$\eta_0 = \eta_{man} \times \eta_m$$

1.6 SLURRY

A mixture of solids and liquid, generally water. The properties may not be abrasive although this is common.

1.6.1 Coal slurry

Coal slurry consists of solid and liquid waste and is a by-product of the coal mining and preparation processes. It is a fine coal refuse and water. Mining generates enormous amounts of solid waste in the form of rocks and dirt. This refuse is used to dam the opening of a hollow between adjacent mountains. After the dam is built, the void behind it is typically filled with millions of gallons of waste slurry from a coal preparation plant. This impounded liquid waste can sometimes total billions of gallons in a single facility.

1.6.2 Types of slurry

Slurries can be divided up into settling and non settling types.

Non-settling slurry

Non-Settling slurries entail very fine **particles** which can form stable homogeneous mixtures. These slurries usually have very low wearing properties and are not normally found in milling circuits. A non-settling slurry acts in a viscous manner, but the characteristics are non-Newtonian. Particle size: less than 60-100 µm.

Non-settling slurry can be defined as a homogeneous mixture.

Homogeneous mixture

A mixture of solids and liquid in which the solids are uniformly distributed.

Settling slurry

Settling slurries are formed by coarser particles and tend to form an unstable mixture requiring particular attention to flow and power calculations. These coarser particles generally have higher wearing properties and cover the vast majority of mill pumping applications.

These types of slurries are generally referred to as being heterogeneous.

Pseudo-homogeneous mixture

A mixture in which all the particles are in suspension but where the concentration is greater towards the bottom.

Heterogeneous mixture

A mixture of solids and liquid in which the solids are not uniformly distributed and tend to be more concentrated in the bottom of the pipe or containment vessel (compare to settling slurry.

1.6.3 Basic slurry transportation system

Solids can be transported through pipelines either hydraulically or pneumatically. The difference between the two systems only in the nature of the fluid used for the motions and suspensions of the solid particles. Before the transportations of any material can be considered, it has to be first mix and proceed for further Utilization at the destination. A slurry transportation system may be different for different materials, that can be transported through pipeline, depending on the material properties and the end requirements.

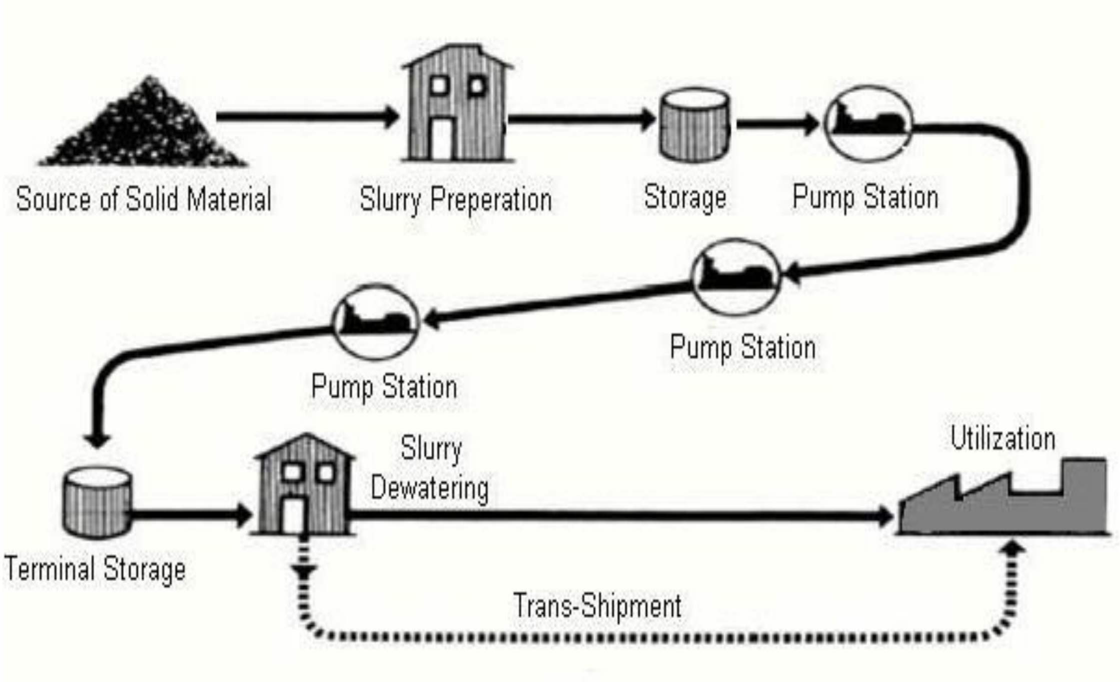

Fig 1.14.Basic slurry transportation system

1.7 FACTOR AFFECTING SLURRY PUMP PERFORMANCE

The presence of solids in the liquid affects the performance of pump. Important factor which affect the performance of the pump are :

i. Concentration of solids
ii. Density of solids
iii. Size and size distribution of particles
iv. Geometry and size of pump
v. Flow field inside the pump
vi. Rheological parameters of the slurry

1.7.1 Advantage of pipeline transportation of solids

i. Simplicity of installation as compared with the construction of a new high way or rail road.
ii. Low man-power is required for construction, operation and maintenance.
iii. There is complete possibility of automation.
iv. Elimination of traffic problem associated with trucking.
v. Large volume of data can be handled.

1.7.2 Applications:

Slurry pumps are used to move mixtures of liquid and solids in many industries with a broad spectrum of applications, for example mine drainage, dredging of settling lagoons and pumping of drilling mud.

The purpose can be:

i. To pump a medium where abrasive particles are present
ii. To transport as much solids as possible, hydraulically
iii. To pump the end product in a process
iv. To Flood control
v. To Water supply

CHAPTER 2

LITERATURE SURVEY

The basic design of centrifugal pumps meant for handling solid- liquid mixture differ in many aspects as compared to conventional pumps used for clear liquids. The performance of the centrifugal slurry pumps plays a key role in the successful operation of the hydraulic transportation system. For any application, pump is selected mostly on the basis of its performance characteristics at range of operating parameters. There are various methods available for prediction of performance such as loss analysis approach, artificial neutral network approach and various numerical methods. Various studies on slurry rheology and ash handling were carried out by many researchers in the past. Chapter reviews the previous published literatures, which lays foundation and basis for further work in this investigation. This helps to give a better understanding about the topic and also acts as a guideline for this thesis. The major focus of the following study is on the coal ash slurries and its transportation through centrifugal slurry pumps. This section deals with literature review on rheology of coal ash slurries and centrifugal slurry pump.

Roco et al. [1986] have experimentally evaluated the head-capacity characteristics of few centrifugal slurry pumps of different geometrical configurations handling Silica Sand slurries. They reported that different head losses in the pump vary differently with the solid properties and flow velocities, and hence the effect of suspended solids on individual losses has to be evaluated separately to obtain the performance of the pump in solid-liquid mixture flows.

Kazim et al. [1997] have developed a new correlation to predict the head reduction factor for centrifugal pumps handling solids. This correlation takes into account the individual effect of particle size, particle size distribution, specific gravity and concentration of solids on the centrifugal pump performance characteristics. The head reduction factor increases linearly with the increase in the concentration of the solid. The weighted mean diameter appears to be an appropriate choice to represent the particles of solids having a broad size distribution.

For slurries having a wide range of specific gravity(s) of solids, the head reduction factor was found to be proportional to (s-1)1/2. For the range of particle size (d) variation of 105–26700 micro meter, the head reduction factor was found to be proportional to ln(d/20). The deviation between the predicted and the experimental head reduction factor was within 10 per cent for slurries of all the materials tested in the present investigation and those available in the literature. The present correlation is found to be applicable to pumps having both metal and rubber-lined impellers of different dimensions. Hence, the correlation implicitly takes care in a unique manner of the effects of the geometry of the pump and the shape factor of the solid particles as well as the effects of the particle Reynolds number. Thus, the present correlation is expected to predict the performance of centrifugal slurry pumps better than the existing correlations.

Sellgern et al. [2000] have carried out experimental study of the effect of sand-clay slurries on the performance of centrifugal pumps in order to reduce frictional losses. They observed that pipeline friction losses in addition of clay in sand, thus the lowering the power consumption and increase in pumping head. Pumps water heads and efficiencies are decreased by the presence of solid particles. Experimental results are presented for a centrifugal slurry pump with an impeller. Diameter of 0.625m for three narrowly graded sands with average particle sizes of 0.64, 1.27, and 2.2mm. Reduction in head and efficiency of up to 30% were observed for sand slurries with volume concentrations of up to 30%. Head and efficiency were lowered by about one-third for sand-clay mixtures with sand to clay mass ratios between 4:1 and 6:1.

Walker et al. [2000] have conducted Experimental work on different slurry pump impeller and side-liner geometries to determine the effects of solid particle size, slurry concentration and pump speed on wear. Explanations are offered for the resultant wear patterns and empirical wear relationships are outlined for the key variables .The major wet-end components of centrifugal slurry pump, including the impeller, volute or casing liner and side-liners i.e. both inlet and frame side. Wear largely as a result of erosion. The shaft sleeve is the other major wearing part and this is worn by a quasi two-body abrasion process.

The experimental work outlined had compared the wear performance of side-liners running with three different impeller designs. The major difference in location and quantity of wear occurs between the HE (high efficiency) ‘‘wear-ring’’ style side-liner impeller and the STD (standard heavy duty) and RE (reduced eye) ‘‘expelling vane’’ style impeller and side-liner. The side-liner empirical wear relationships established for the range of tested conditions include: The wear rate for the design varies with the square of the particle size. The wear rate was constant for varying solids concentration. The wear rate was constant for varying impeller tip speed.

Gandhi et al. [2001] have evaluated centrifugal slurry pump performance characteristics experimentally. First, they evaluated the performance characteristics of pump with water, and then evaluated with solid particles at different solid concentration. During each test two efflux samples collected were further analyzed for particle size distribution to detect any attrition of solid particles. They observed that head and efficiency decrease with increase in solid concentration, particle size, and slurry viscosity, the decrease in the head being 2-10% higher than that of efficiency. At low solid concentration (less than 30% by weight), the increase in the pump input power is directly proportional to the specific gravity of slurry whereas same relationship is not applicable to at higher concentrations. This study basically confirmed that the additional head loss for slurries decrease with increase in pump size..

Usui et al. [2001] proposed a model to predict the maximum packing volume fraction for a non-spherical particle suspension. Simha’s cell model is applied for the suspension with particle Size distribution. The sphericity of fly ash particles depending on the particle diameter was measured by means of a CCD image processing instrument. An algorithm to predict the maximum packing volume fraction with non-spherical particles is proposed. The maximum packing volume fraction is used to predict the slurry viscosity under well dispersed conditions. Usui’s model developed for aggregative slurries is applied to predict the non-Newtonian viscosity of dense fly ash - water slurry. It is certified that the maximum packing volume fraction for non-spherical particles can be successfully used to predict slurry viscosity. The pressure drop in a pipe flow is predicted by using the non-Newtonian viscosity of dense fly ash-water slurry obtained by the present model. The predicted relationship between pressure drop and flow rate results in a good agreement with the experimented data obtained for a test rig with 50 mm inner diameter tube. Base on the design procedure proposed in this study, a feasibility study of fly ash hydraulic transportation system from a coal-fired power station to a controlled deposit site is carried out to give a future prospect of inexpensive fly ash transportation technology.

Brossa et al. [2001] have reported Slurry pump is governed by wear effects, which influence the pump's performance, reliability and maintenance costs. One of the highest areas of wear occurs in the impeller suction sealing area. Because of the occurring leakage flow rate and its corresponding high velocities in the nose sealing gap, it wears out much faster than most of the other wet end parts do and sets the service intervals. Moreover, increased nose wear leads to a significant increase in leakage flow rate, and a dramatic reduction in pump efficiency. In order to predict the influence of different impeller design parameters on the wear behavior of the impeller suction sealing, a simple model was developed. Therein, the velocity field in the impeller suction side and sealing gap was calculated. The local wear intensity was predicted with respect to the acting velocities and fluid materials properties. Starting with certain sealing gap geometry, it was assumed that the predicted wear intensity remains constant for a certain time step, leading to a new (worn) geometry. By repeating this procedure the evolution nose gap wear behavior with time can be predicted. Using this model the influence of different design parameters on the nose wear behavior were analyzed and discussed in the paper. A comparison of the calculated wear with actual field case data is reported.

Senapati et al. [2002] have studied the effect of solid concentration, ash content, pH, and temperature on the rheology of CWS. Highly concentrated coal-water suspensions generally show non-Newtonian character in a shear flow. The rheological properties of CWS depend significantly on the ash content, pH, and temperature of CWS. The slurries prepared in this study exhibit pseudo plastic behavior. The CWS became more viscous with increases in ash content and solid concentration.

The pH has a profound effect on the viscosity of CWS. 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. CWS 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 CWS 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.

Engin et al. [2003] conducted an experiment, using a specially designed and fabricated experimental facility .The effect of the clearance between the impeller tip and the casing and of the solid concentration, density and mean diameter on the pump performance characteristics is investigated. The results are discussed and utilized, together with data available in the literature, to establish a correlation allowing the prediction of the head reduction factor for shrouded/unshrouded impeller centrifugal pumps handling solid-liquid mixtures and studied the effects of solids in an unshrouded centrifugal pump impeller by varying the tip clearance when both handling water and solid-water mixtures. The present study introduces extensive new results, as a part of continuous investigation of tip clearance effects on a conventional centrifugal pump when handling commercial mixtures or slurries. According to the results of the present study, tip clearance loss mechanisms while pumping mixtures seem to be similar to those in single phase pumping and a steady deterioration in pump performance for varying tip clearances is observed. The head reduction factor (*RH*) appears to be almost independent of the variation in the tip clearance, and this allows us to correlate the solids effects on the pump performance. Regardless of changes in the tip clearance. However, a slight decreasing trend is observed in efficiency ratio when the tip clearance is increased.

Kumar et al. [2003] studied the effect of particle gradation on flow characteristics of ash disposal pipelines. The particle size effect on pressure drop has been analyzed through the measured solid distribution pattern in the pipeline. An integral flow model has been used for prediction of the pressure drop and solid distribution under various conditions. Experimental have been conducted in a pilot plant test loop of 150mm diameter pipe erected a thermal power plant for demonstrating the transportation of fly ash/bottom ash high concentration . The measurements of pressure drop are first made with water. Subsequent solid material is added to the water to achieve the desired solid concentration and pressure drop is measured as a function of velocity for a solid liquid mixture. It is observed that the pressure drop at any given flow velocity increased with increased in solid concentration. The rate of increase of pressure with concentration is small at low velocity but it increase rapidly at higher velocity.

Gulich et al. [2003] Developed a procedure to predict the effects of roughness and Reynolds number on the change in efficiency from a model or baseline to a prototype pump (‘‘efficiency scaling’’). The analysis of individual losses takes into account different rough nesses of impeller, diffuser/volute, impeller side disks, and casing walls in the impeller side rooms. The method also allows predicting the effect of roughness and Reynolds number on the hydraulic efficiency. He obtained flowing result the lower the hydraulic efficiency the higher is the gain from surface improvement. The higher the Reynolds number the more is to be gained from surface improvement. The hydraulic losses depend on the actual roughness geometry, near-wall turbulence and the local velocity distributions in the hydraulic passages. Toughness and turbulence are statistical phenomena; the same may be said almost of velocity distributions in impellers and diffusers.

Mehta et al. [2004] used for investigation of slurry flow in the impeller of a centrifugal slurry pump. The slurry pump is equipped with potically clear casing and Impeller. The slurry is made with sodium-iodide solution (NaI) solution and 500 micron Glass beads. The refractive indices of the sodium -iodide solution and the casing and impeller material (acrylic) are matched to facilities the measurements inside the impeller. A slight mismatch of refractive index B/W the sodium-iodide solution and glass beads facilities the measurements of particle velocities. The experiments are conducted at speeds of 1000 and 750 rpm and for different blade position. Particle volumetric concentration of 1, 2, and 3% are used. Relative velocity plots show that flow separation takes place on the suction side of the blade in the region below the blade tip for clear fluid flow conditions. At higher pump speeds and particle volumetric concentrations, a marked improvement in the slurry flow in the impeller is observed i.e. the recirculation zone decreases. This results from the centrifugal forces on the particles and its inertia at that speed. Also the slurry particles are pushed on the pressure side of the blade and slide on it which can results in friction wear.

Kaushal et al. [2005] have studied the Effect of particle size distribution on pressure drop and concentration profile in pipeline flow of highly concentrated slurry. The experiments were conducted in 54.9 mm diameter horizontal pipe on two sizes of glass beads of which mean diameter and geometric standard deviation are 440 lm & 1.2 and

125 lm & 1.15, respectively, and a mixture of the two sizes in equal fraction by mass. Flow velocity was up to 5 m/s and overall concentration up to 50% by volume for each velocity. Pressure drop and concentration profiles were measured. The profiles were obtained traversing isokinetic sampling probes in the horizontal, 45_ inclined and vertical planes including the pipe axis. Slurry samples of the mixture collected in the vertical plane were analyzed for concentration profiles of each particle batch constituting the mixture. The particle concentration profile is measured for high concentration slurry transport where the maximum overall area-average concentration is 50% by volume employing coarse particles and higher flow velocities up to 5 m/s. Narrow grading particles tend to have high frictional losses, while broad grading particles have low frictional losses at high concentrations. Concentration in the horizontal plane remains almost constant irrespective of flow velocity and overall concentration. A distinct change in the shape of concentration profiles was observed indicating the sliding bed regime for coarser particles at lower flow velocities.

Addie et al. [2005] have studied the present technologies involved in the design of centrifugal pump how these applied throughout they provide. Slurry pump design is similar to that of water pumps but important accommodation for the slurry, the passage of large spheres, thicker sections, special material and wear. Wear parts cost of slurry pumps may be as such as 50% of the total cost of operating the pump and the wear varies very significantly with the operating conditions. Wear technology and a wear modeling capability exists that can help here with both economics application of slurry pumps and understanding of which design to apply.

The studies aim at establishing the feasibility of technology of pipeline transportation of copper tailings slurry at high concentrations. The disposal system are highly uneconomical & create pollution all around the disposal area through seepage and flooding of waste slurry water. The solids concentration of these tailing slurry is as low as 15-25%. Hence the deposition rate of solids is very low at the pond and a lot of power is consumed in pumping 75-85% water only. A recent development technology i.e. thickened tailing disposal (TTD) system is gaining important worldwide & is most adaptable for the purpose. Tailing are defined as the finely ground residue or waste resulting from ore extraction and processing. It refers to high concentration solids.tailling are usually mixed with water to form a slurry.

Satoshi et al. [2006] have measured performance of a centrifugal pump when handling surfactant additives solutions experimentally. He observed that the efficiency of pump with surfactant solution was higher than with tap water and increase with increase in surfactant concentration. The total head of pump increased with increase in surfactant concentration, and shaft power decrease with decrease in the impeller rotating speed. They predict energy saving of the pumping power in the pipe line system by using surfactant additives.

Verma et al. [2006] evaluated the pressure drop across a 90°horizontal bend for fly ash slurry at high concentrations. The pressure drop across the bend has been measured at five concentrations. In this range of 50-60% (by weight)and the data has been analyzed to obtain the relative pressure drop, bend loss coefficient and permanent pressure loss measurement show that the relative pressure drop across the pipe bends increases with increase in concentration at lower velocity. However, at any given concentration relative pressure drop is independent of velocity over the range tested. The bend loss coefficient at any velocity increases with increased in concentration. The permanent pressure loss increases marginally with concentration and velocity. The contribution of distributed flow conditions downstream of the bend to the total pressure loss is much less in case of highly concentrated slurries as compared to that in water.

Pullum et al. [2007] have proposed that Centrifugal pumps performance is derated when viscous non-Newtonian fluids, such as pastes and/or coarse solids are present. Centrifugal pump tests were systematically conducted on a wide range of non-Newtonian coarse particle suspensions. Suspensions up to 38% v/v of coarse particles with mean diameters in the range of $1.1 < d50 < 3.4$ mm suspended in carrier fluids with dynamic yield stresses of $0 < \tau\gamma < 17.2$ Pa and shear thinning indices in the range $0.35 < n < 0.79$ were examined. For moderate to high viscosity suspensions typical of high concentration tailings disposal lines, the flow regime inside centrifugal pumps passages was probably laminar. The sensitivity of the method to the local shear rate was used to explain the increased viscous deration at low flow rates. Centrifugal pump tests with complex suspensions consisting of non-Newtonian fluids and coarse particles showed that the head deration was primarily a function of the coarse solids concentration. Adequate predictions of head performance could be obtained by calculating the effect of solids deration alone.

Khin et al. [2008] studied the looses of centrifugal pump with the values Q and H at various operating points. Centrifugal pumps are fluid-kinetic machines designed for power increase within a rotating impeller. In centrifugal pumps, the delivery head depends on the flow rate. This relationship, also called pump performance, is illustrated by curves. To get characteristic curve of a centrifugal pump, values of theoretical head, slip, shock losses, recirculation losses and other friction losses are calculated by varying volume flow rate. The performance analysis of centrifugal pump is also predicted in this paper. The impeller friction losses, volute friction losses and disk friction losses are considered to less the friction effect on centrifugal pump. Moreover, recirculation losses are also considered. And then, the actual performance curve of centrifugal pump is predicted obtained.

Mosa et al. [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.

Bozo et al. [2008] have carried out experimental study of the influence of ash concentration on change of flow and pressure in slurry transportation. The tests were carried-out at the semi-industrial installation at the mineral processing laboratory of the University of Belgrade. The tests were carried out for the concentration range from 34.2% to 52.6% (by mass). It is shown that as the concentration increases the significant changes in the flow occur.

The obtained 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 a decrease of both flow (per volume) and the pressure. However, this decrease is considerably small regarding the quantity of the ash and bottom ash transported during a time unit.

Wennberg et al. [2008] have studied performance of pump when handling complex slurries. Complex slurry defined as intermediate area between heterogeneous and homogeneous flowing slurries. Experiments were conducted on pump as per ANSI standard (ANSI/HI 2005) and they observed that maximum derating in efficiency and head near about 15 and 10%. Magnified shock losses, circulatory flows and blockage of slurry and possibility of vapor formation in the pump entrance region may be considered as mechanism behind unstable head curves together with the flow behavior of the slurry.

Seshadri et al [2008] have studied the Effect of Additive on Head Loss in the High Concentration Slurry Disposal of Fly Ash The rheological behaviour of five Samples of fly ash slurry having different highest particle size and particle size distribution have been determined at different concentrations with and without additive. Sodium hexametaphosphate at 0.1% concentration (by weight) has been used as additive. Using the rheological data, pressure drop has been predicted in a straight pipe line of 75 mm diameter at high concentrations. It was seen that Bingham plastic model represented the observed variation of shear stress with shear rate reasonably well. Particle size distribution and concentration of solids affected the slurry rheology, the effect being more pronounced at higher concentrations (Cw>65% by weight). The computations of pressure drop showed substantial saving in energy consumption when additive like sodium hexametaphosphate was added into the fly ash slurry at higher concentrations as it modified the rheological properties of slurry significantly.

Chandel et al. [2009] described the effect of additive on pressure drop and rheological characteristics of fly ash slurry at high concentration (above CW=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.

Chandel et al [2009] have studied Deposition characteristics of coal ash slurries at higher concentrations High concentration slurry disposal system (HCSD) for transportation of coal ash to ash ponds from coal fired thermal power plants using pipelines has emerged as an economical and environmental friendly method. Coal Ash in slurry form is deposited in the ash pond and hence the deposition characteristics at higher concentrations (Cw >60% by weight) are very important. The settled solid profile in the ash pond at high concentrations is of great interest to the ash pond designers. The present study is an attempt to establish the relationship between the settled solid profile and the physical/rheological properties of coal ash slurry at high concentrations. The settled solid profile is experimentally measured in terms of cone angle for slurries of fly ash as well as mixture of fly ash (FA) and bottom ash (BA) in the ratio of 4:1 at high concentrations. The values of cone angle if the slurries are poured on either a pervious or impervious bed have also been measured. The results obtained from the experiments show that the cone angle depends on rheological properties like yield stress and Bingham plastic viscosity which in turn depend on various properties like solid concentration, particle size distribution etc. Also, cone angle for fly ash slurry is higher than that for the mixture of FA and BA slurry at any given concentration. Further, it was also observed from the experiments that cone angle is higher for pervious bed as compared to impervious bed for both types of slurries

Naik et al. [2009] evaluated rheological characteristics of fly ash slurry at varying temperature environment with and a without additive rheological tests were conducted using advanced computerized rheometer. Fly ash slurry was prepared using ordinary tap water. Zeta potential was measured to test the stability of the colloidal fly ash particles using Malvern zeta sizer instrument. Surface tension was also measured to know the drag reducing behavior of the fly ash slurry by using surface tensiometer. Cetyltrimethyl ammonium bromide (CTAB) concentration of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% (by weight) was used as an additive with equal amount of a counter –ion (sodium Salicylate). Slurry concentration was kept at 30% by weight. He observed that fly ash slurries at 30% concentration by weight with addition of a cationic surfactant showed Newtonian and shear thinning fluid behavior. The viscosity and shear stress values decreased with increasing temperature. Decreased being more pronounced at higher temperature. It is observed from the surface tension measurements that the addition of the surfactant to the slurry suspension reduced the surface tension of the liquid indicating that there will be substantial reduction in drag friction during its transportation in the pipelines. The pressure of sizable proportion of finer fly ash particles in the colloidal suspension influenced the stability of the slurry. It was found that the zeta potential value of the fly ash slurry without any additive was -25 mV which implied that the suspension was unstable. To overcome this problem surfactant were added in to the slurry and it was found from the measured data that the zeta potential value changed from minus value to plus value and the zeta potential value for all the suspensions with addition of surfactants exceeded +30mV which confirmed that the suspensions were stable during test measurements.

Seshadri et al. [2010] have studied the pressure drop and rheological characteristics of mixture of fly ash (FA) and bottom ash (BA) slurry (4:1) at high concentrations (above Cw 50% by weight). Pressure drops have been measured at various flow velocities using a pilot plant test loop at various concentrations. Such measurements have been made for various concentrations in the range 50-70% by weight. Rheological studies are also carried out for mixture of fly ash (FA) and bottom ash (BA) slurry. The dependence of relative pressure drop on flow velocity at various concentrations has also been analyzed. Further, by using the rheological data, pressure drop has been predicted in a straight pipeline of 42 mm diameter at higher concentrations.

Experimental results obtained from a pilot plant test loop were compared with the predicted results. The comparison showed a very good agreement between these data. Specific Energy Consumption for the transportation of coal ash slurry has been calculated at fixed velocities and its dependence in solid concentration has been quantitatively analyzed. He observed that The pressure drop for any given solid concentration increases with increase in velocity and at any given flow velocity, pressure drop increases with increase in solid concentration. Relative pressure drop increases with increase in solid concentration. For a given efflux concentration, relative pressure drop decreases with increase in flow velocity. The increase in pressure drop is much higher in the low velocity range compared to high velocity region for any efflux concentration. Mixture of FA and BA (4:1) slurries can be transported at higher concentrations. The prediction model proposed by Darby and Melson [11] is suitable for the Bingham plastic fluid flow such as mixture of FA and BA (4:1) slurry at concentrations above 50% (by weight). Specific Energy Consumption decreases upto a concentration of 65% by weight and steeply

Increases beyond this value.

Naik et al. [2011] evaluated the flow characteristics of fly ash slurry at 40% concentration with and without additives. They collected six samples of fly ash from different power stations in south India. The main constituents of tested samples were fly ash, water, surfactant and counter ion. Detailed rheological properties were determined by using cylindrical coaxial rotational rheometer (Anton Parr rheometer model Physica MCR101),shear rates were varied from 100-1000s^{-1},temperature from 20-40^{0}C.They observed that all slurries exhibited shear thinning behavior in the presence of an additive and reduction in surface tension, both will manifest themselves as reduction in drag in case of transportation through pipelines. They concluded that in this way it is possible to design pipelines and pumping systems for transporting ash slurries at high concentrations

Chara et al. [2011] evaluated the flow behavior of concentrated slurry depends on particle size distribution, shape, density, and concentration. The slurry flow behavior can change from Newtonian to non-Newtonian depending on the concentration, slurry composition, and content of fine and especially colloidal particles, which evoke a complex rheological behavior of the slurry. The present article deals with experimental investigation of the flow behavior and pressure drop of dense complex slurries containing sand of different particle size distribution (five different monodispersed and polydispersed sands with mean diameters ranging from 0.20 to 1.40mm), stony dust (mean diameters of 8 lm and33 lm), or clay conveyed in water. The slurries were tested using experimental pipeline loops with inner diameters of 17.5 and 26.8mm. The slurry concentrations range from6% to 40% for sand slurries, from 26% to 48% for stony dust slurries, and from 45% to51% for stony dust-sand slurries. The study revealed the time-independent yield pseudo-plastic behavior of the concentrated fine-grained stony dust slurries and the possibility of reducing their flow resistance by adding coarse-grained material. The flow behavior of the stony dust slurries can be approximated by the

Herschel-Bulkley or the Bingham model in the laminar region and by the Wilson model in the turbulent region.

Chandel et al. [2011] observed the effect of additive on the performance of characteristics of centrifugal and progressive cavity slurry pumps with high concentration fly ash slurries. Two types of pumps differ considerably in construction as well as in operating principle compared to the conventional pumps. Mixture of sodium carbonate and henko detergent (5:1) at a concentration of 0.2 by weight has been used as an additive. For each type of pumps, the effect of additive on the performance characteristics has been experimentally evaluated at rated speed with fly ash slurries in the concentration range of 50 to 70% by weight. The head and efficiency of pump decrease with increase in solid concentration and slurry viscosity whereas pump input power increased with increased solid concentration. The addition of drag reducing additive improves the performance of centrifugal slurry psump in term of head and efficiency.

CHAPTER 3

STUDY PROPERTIES OF BOTTOM ASH AND FLY ASH

3.1 Bottom ash

Bottom ash refers to part of the non-combustible residues of combustion. In an industrial context, it usually refers to coal combustion and comprises traces of combustibles embedded in forming clinkers and sticking to hot side walls of a coal-burning furnace during its operation. The portion of the ash that escapes up the chimney or stack are, however, referred to as, fly ash. The clinkers fall by themselves into the water or sometimes by poking manually, and get cooled.

The clinker lumps get crushed to small sizes by clinker grinders mounted under water and fall down into a trough from where a water ejector takes them out to a sump. From there it is pumped out by suitable rotary pumps to dumping yard far away. In another arrangement a continuous link chain scrapes out the clinkers from under water and feeds them to clinker grinders outside the bottom ash hopper.

3.2 FLY ASH

Fly ash is a fine glass powder recovered from the gases of burning coal. Fly ash mainly collected from the chimneys of coal power plants. Fly ash include micro earth elements consist mainly of silica, alumina and iron. When mixed with lime and water the fly ash form a cementations compound with property very similar to that of Portland cement. Because of this similarity, fly ash can be used to replace a portion of cement in the concrete, providing some discrete quality advantages. The concrete is denser resulting in a tighter, smoother surface with less bleeding. Fly ash concrete offers a distinct architectural benefit with better textural consistency and sharper detail. Fly Ash is also known as Coal Ash. The fly sash contains higher levels of contaminants than the bottom ash.

3.3 PROPERTIES OF ASH:

3.3.1 Physical properties:

Fly ash consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The carbonaceous material in fly ash is composed of angular particles. The particle size distribution of most bituminous coal fly ashes is generally similar to that of silt. Although sub bituminous coal fly ashes are also silt-sized, they are generally slightly coarser than bituminous coal fly ashes. The specific gravity of fly ash usually ranges from 2.1 to 3.0, while its specific surface area (measured by the Blaine air permeability method) may range from 170 to 1000 m^2/kg.

The color of fly ash can vary from tan to gray to black, depending on the amount of unburned carbon in the ash. The lighter the color the lower the carbon content Lignite or sub bituminous fly ashes are usually light tan to buff in color, indicating relatively low amounts of carbon as well as the presence of some lime or calcium. Bituminous fly ashes are some shade of gray, with the lighter shades of gray generally indicating a higher quality of ash.

3.3.2 Chemical properties:

The chemical properties of fly ash are influenced to a great extent by those of the coal burned and the techniques used for handling and storage. There are basically four types, or ranks, of coal, each of which varies in terms of its heating value, its chemical composition, ash content, and geological origin. The four types, or ranks, of coal are anthracite, bituminous, sub bituminous, and lignite. In addition to being handled in a dry, conditioned, or wet form, fly ash is also sometimes classified according to the type of coal from which the ash was derived.

3.4 BENCH SCALE TEST

3.4.1 Specific gravity of solid

Specific gravity of solid decides the settling characteristics of the slurry. Solid’s density of different materials was determined by means of pyknometer analysis.

Specific gravity- Bottom ash-2.25, Fly Ash-1.99

3.4.2 Particle Size Distribution (PSD)

The variation in the size of the particles in the solid sample and the percentage of particles present in different pre-selected size ranges are determined to establish the particle size distribution (PSD). There are Two methods namely sieve analysis and hydrometer analysis, are employed to get the particle size distribution. For coarser particle size distribution i.e. above 75 mm, sieve analysis is used whereas hydrometer analysis is used for finer particles i.e. below 75 mm. A known weight of representative sample of solid particles is taken and washed over a B.S. 200 mesh (75 mm). Both the material retained over the sieve as well as the finer particulate material are dried in an oven. The dried coarser material is sieved through a set of standard sieves. Special care is taken to ensure that the sample is properly dried. The sample retained on each sieve is collected and the percentage retained on each sieve is calculated using the standard procedure to obtain the sieve curve.

(a)Particle size distribution (% fine by weight)

Fly ash d_{50} = 54 µm, d_{wn} = 48 µm

Particle size, µm	355	300	250	212	180	150	125	90	75	53
% finer	100	99	98.5	97	95	92	88	80	69	48

Table 3.1 Particle size distribution of fly ash

Bottom ashd_{50}= 230µm,d_{wm} = 162.139 µm

Particle size, µm	below 2000	1400	710	355	300	250	212	180	150	125	90	75

% finer	100	89.5	85.5	72.6	65.0	58.8	46.8	44.1	20.6	17.4	13.5	3

Table 3.2 Particle size distribution of bottom ash

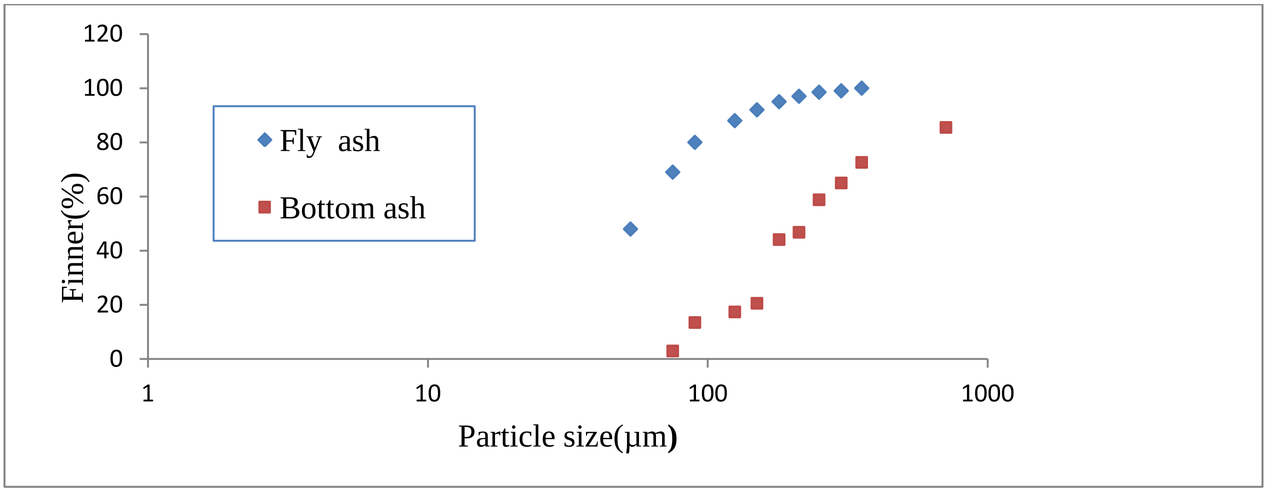

Figure 3.1 Particle size distribution of fly and bottom ash

3.4.3 Static settled concentration

Static settled concentration of bottom and fly ash can be achieved by using gravitational method. Static settled concentration is the highest limit of solid concentrations. The static settled concentration depends on a specific gravity, shape and size distribution of solids, density and viscosity, of carrier fluid etc. the mixture was kept in 1000ml. graduated jar. The slurry was thoroughly mixed and then allowed to settle. Initial level of slurry was recorded. As the solid settled in undistributed state, level of settled slurry in the jar at given interval of time were noted. Reading was noted at small interval at beginning and as the settling rate slowed down interval was increased. After some time the level of settled slurry become nearly constant. Then we plot the graph concentration v/s time to get static concentration.

(b) Settling characteristics of the suspension (Initial concentration= 20%by weight)

Time(Minute)	0	1	2	3	4	5	15	30	60	120	180	240	480
Conc. (%C_w) **Bottom ash**	20	24.97	25.28	29.80	32.20	44.35	53.90	53.90	54.49	55.70	55.70	56.98	56.98

Conc. (%C_w) **Fly ash**	20	28.12	33.16	42.37	45.25	47.39	47.39	47.39	48.54	48.54	48.54	49.01	49.01

Table 3.3 settling characteristics of the fly and bottom ash

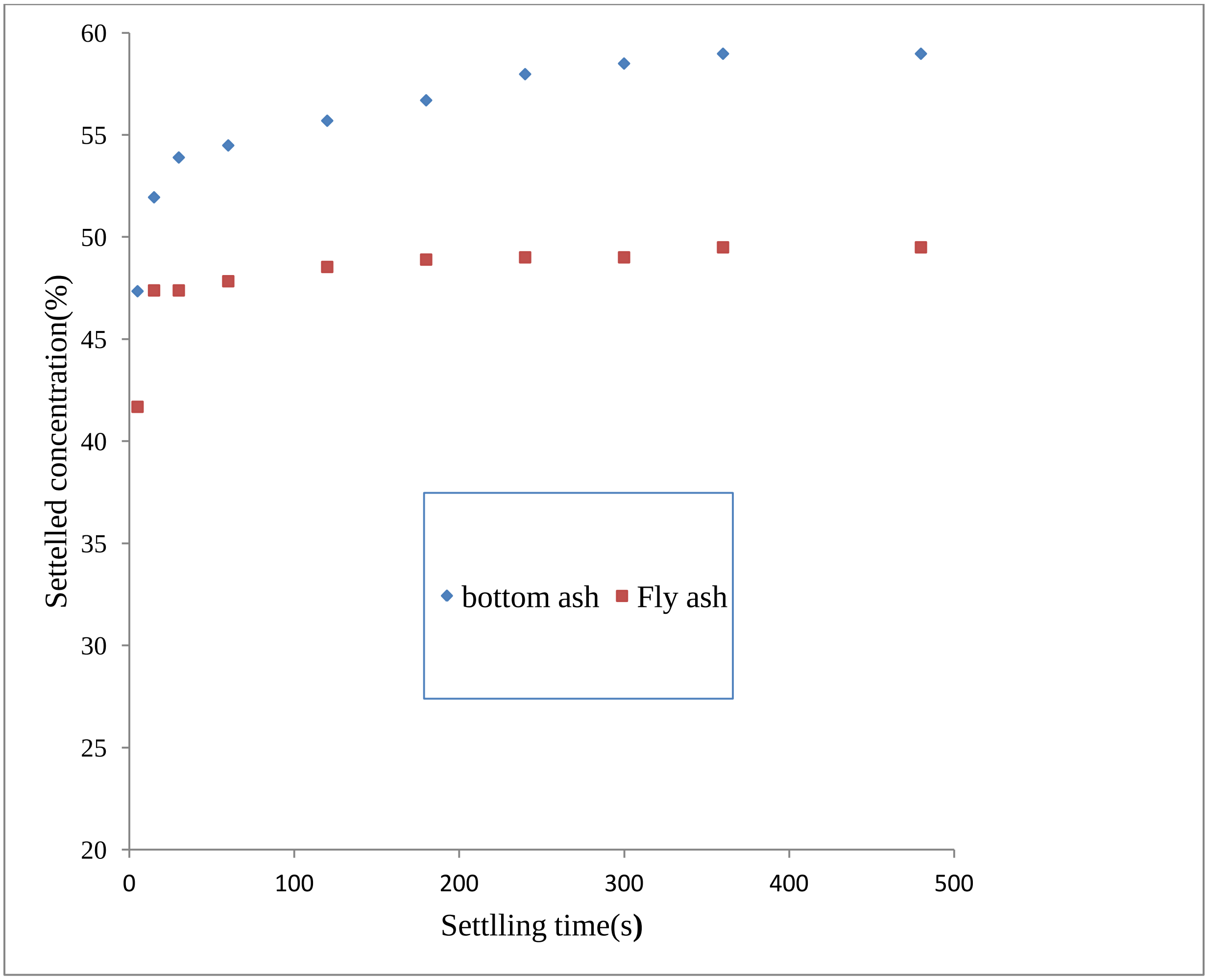

Figure 3.2 Settled concentration of fly and bottom ash

The curve 3.2 shows that settling of bottom ash is faster as compared to fly ash this could be due to higher weight of bottom ash particles as compared to fly ash. Futher for both the settling rate is fast in the beginning but slows down with time and after some time becomes constant.

3.4.4 pH values

After preparing slurry at a given concentration pH value of the slurry was determined. A pH meter was used for measurement of the pH value of the slurry. The electrode of the meter was first moistened with tap water and the lower plastic cap was removed. Then calibrated with a buffer solution of a known pH value. It is cleaned by rinsing vigorously with distilled water and then immersed in the slurry sample whose pH value was to be determined. The pH suspension was read on the digital display unit when equilibrium value was reached.

(c) pH values –

Cw, %	0	20	25	30	35	40	45	50
pH of bottom ash	7.75	7.67	7.66	7.66	7.64	7.63	7.62	7.62
pH of fly ash	7.75	7.59	7.55	7.51	7.48	7.46	7.45	7.44

Table 3.4 pH values of bottom and fly ash

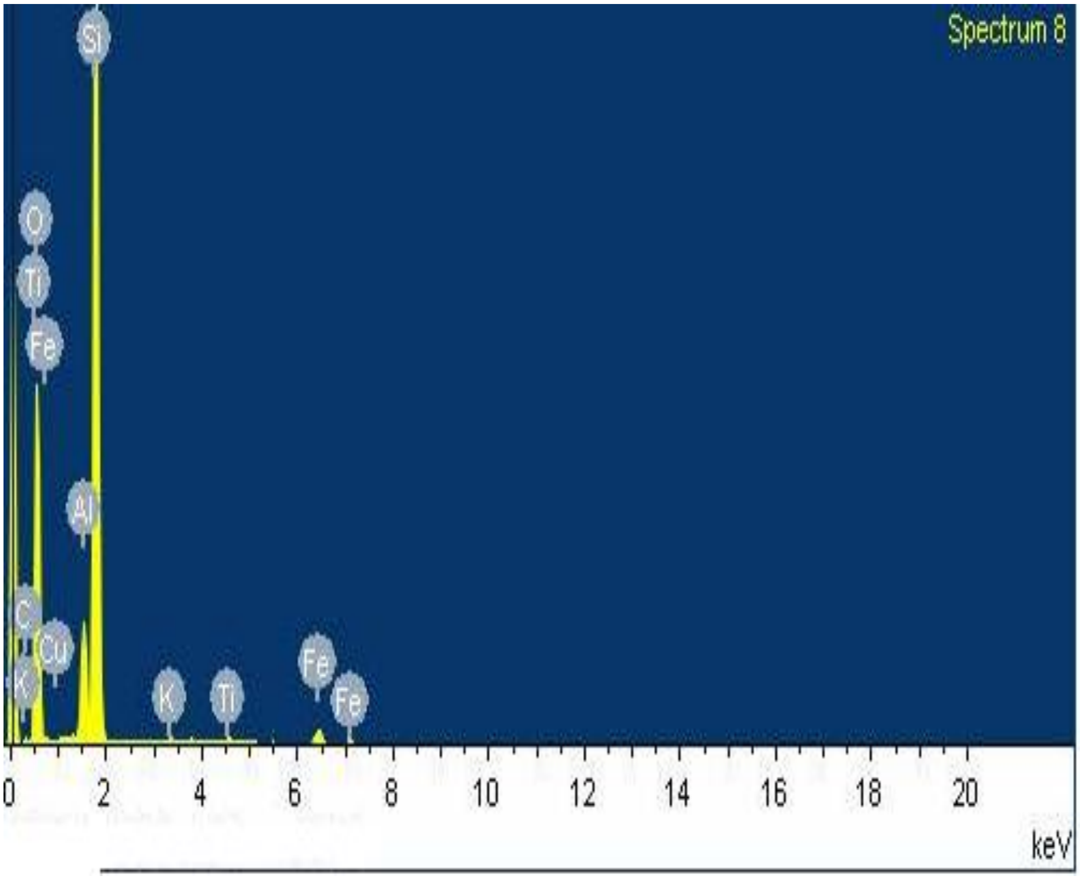

Figure 3.3 (a) Bottom ash

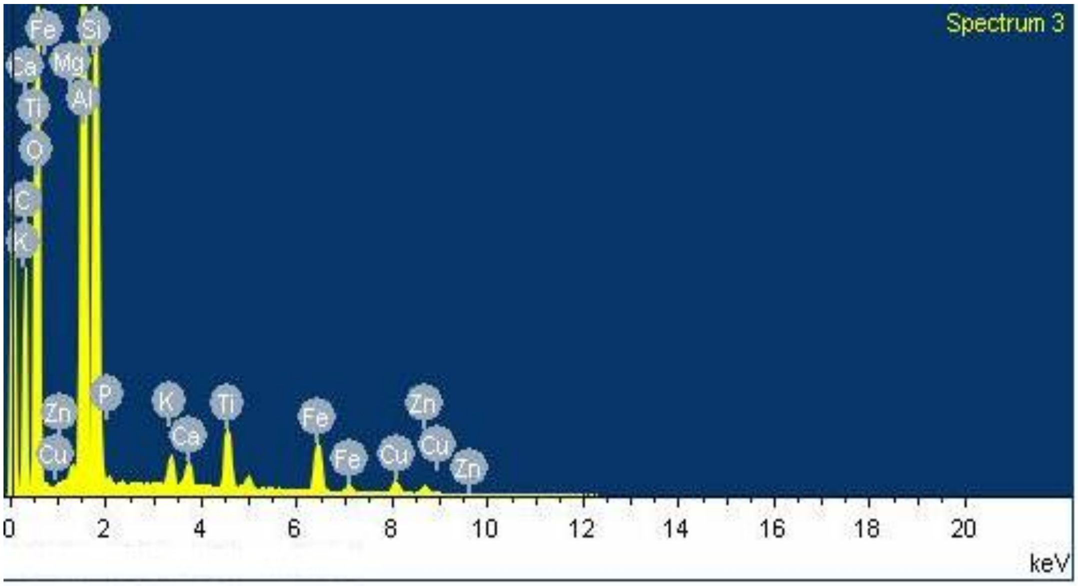

Figure 3.3(b) Fly ash

Figure 3.3(a), 3.3(b) shows EDX of fly and bottom ash

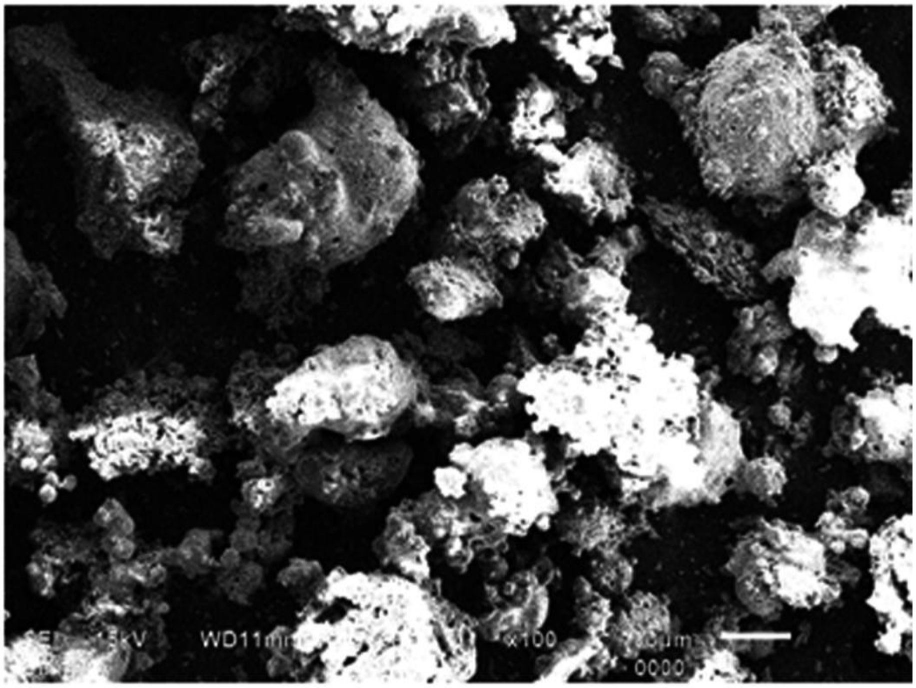

Figure 3.4(a) Fly ash

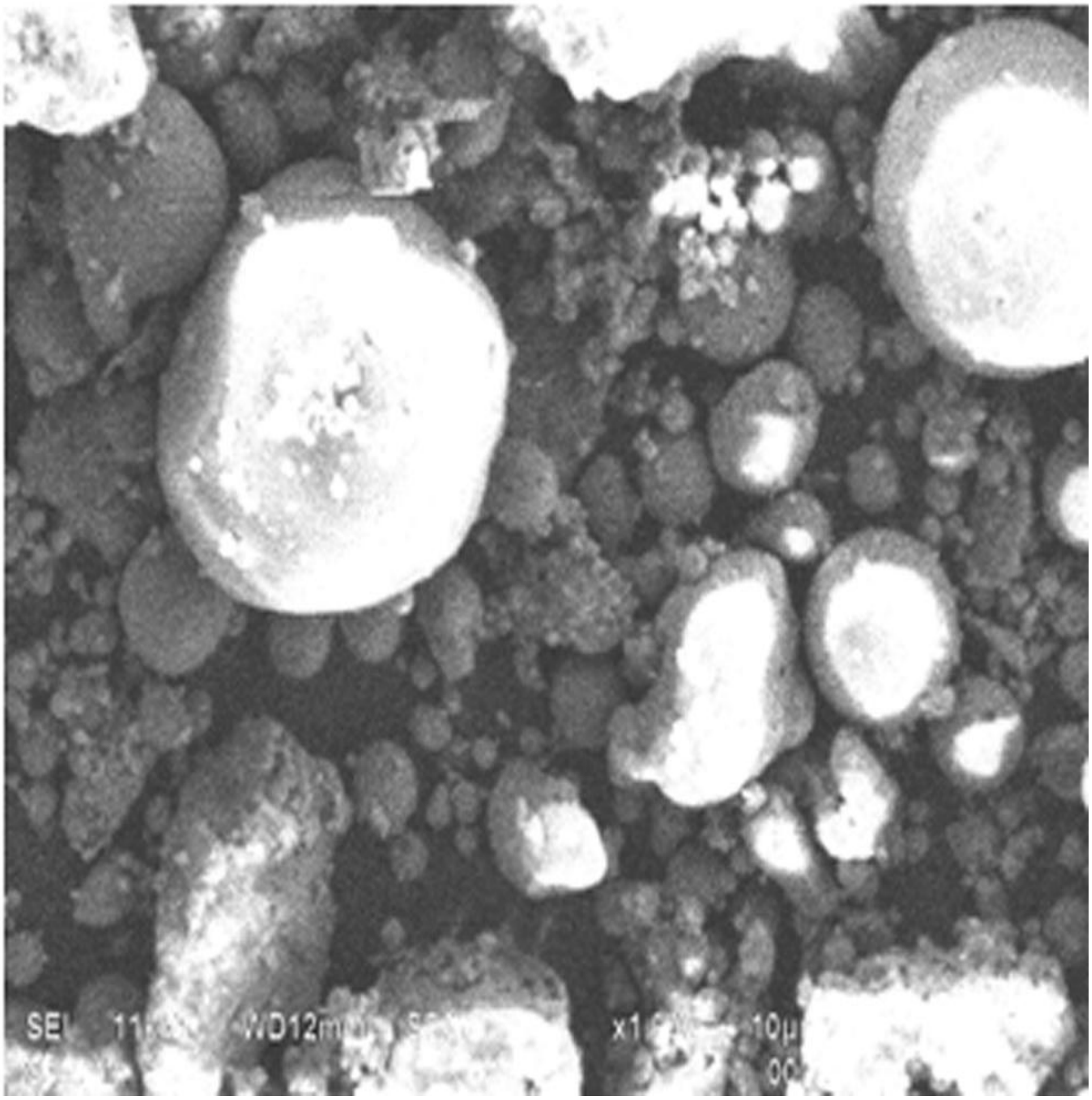

Figure 3.4(b) Bottom ash

Figure 3.4 SEM photomicrograph of ash sample with 200× Magnification

Figure 3.4 a and b reveal that fly ash and bottom ash are round in shape which reduce viscosity by providing ball bearing action.

3.5 RHEOLOGY

Rheology is the study of the flow of matter: primarily in the liquid state, but also as 'soft solids' or solids under conditions in which they respond with plastic flow rather than deforming elastically in response to an applied force. It applies to substances which have a complex molecular structure, such as mud, sludge, suspensions, polymers and other glass formers (e.g. silicates), as well as many foods and additives, bodily fluids (e.g. blood) and other biological materials.

To predict the level of input energy in transporting slurry through pumps, viscosity measurement is an important aspect. Presence of solid particles alters the viscosity of carrier fluid. Addition of solids in the carrier fluid beyond a certain proportion results in the mixture depicting Non-Newtonian behavior.

Fig. 3.5 Rheometer

The Rheometer, (Make: Anton Paar, Gurgaon) shown in figure, is an instrument to measure the viscosity of composite fluids. It comes up with different types of geometries which have to be used depending on the size of particles of the slurry. With us, Double gap geometry has been used for determination of rheological characteristics of the slurries. Slurry is subjected to shear stress with the rotation of the bob immersed in the slurry.

Before conducting tests on Rheometer, the bob and cup assembly are kept in line with the geometry, which is done using a locking device and slurry is added into cup (cylinder) up to the particular mark. In this Rheometer, the experiment is done on CSR (controlled shear rate) in which we input the particular shear rate [s^{-1}] and accordingly get the viscosity of particular concentration. The viscosity, shear stress and shear rate are recorded for each combination of shear rate and particular time intervals.

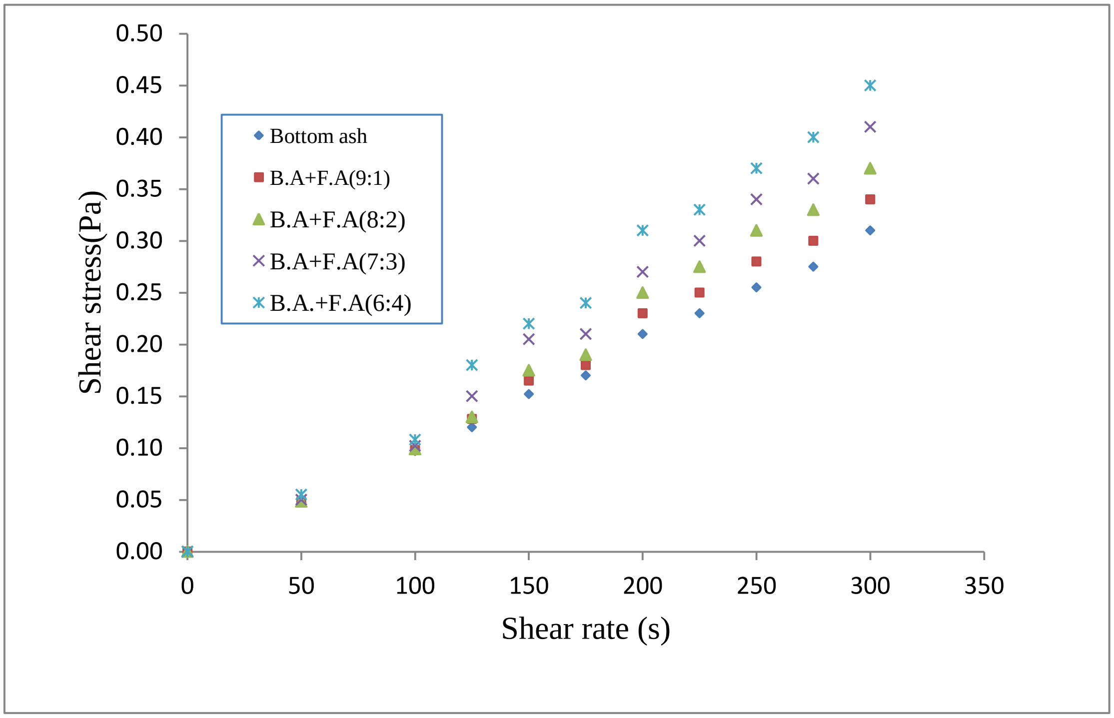

Figure 3.6 (a)

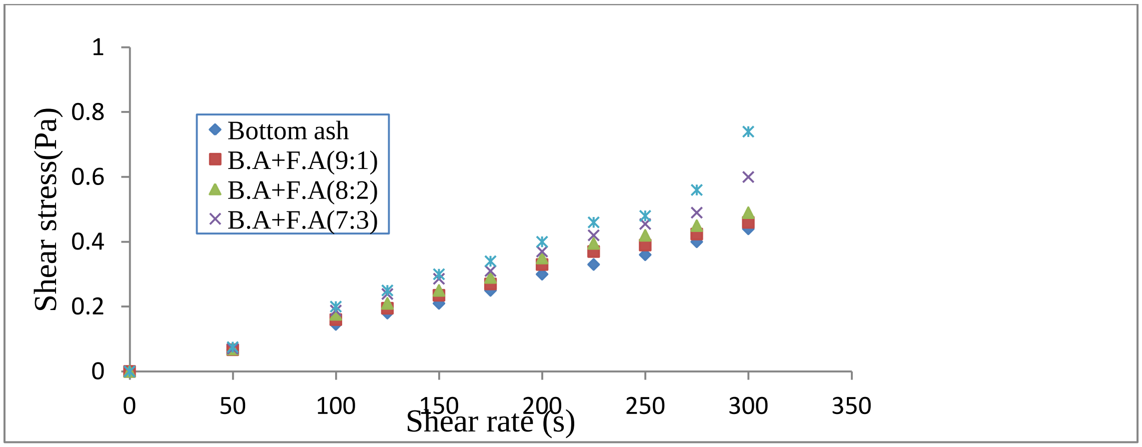

Figure 3.6 (b)

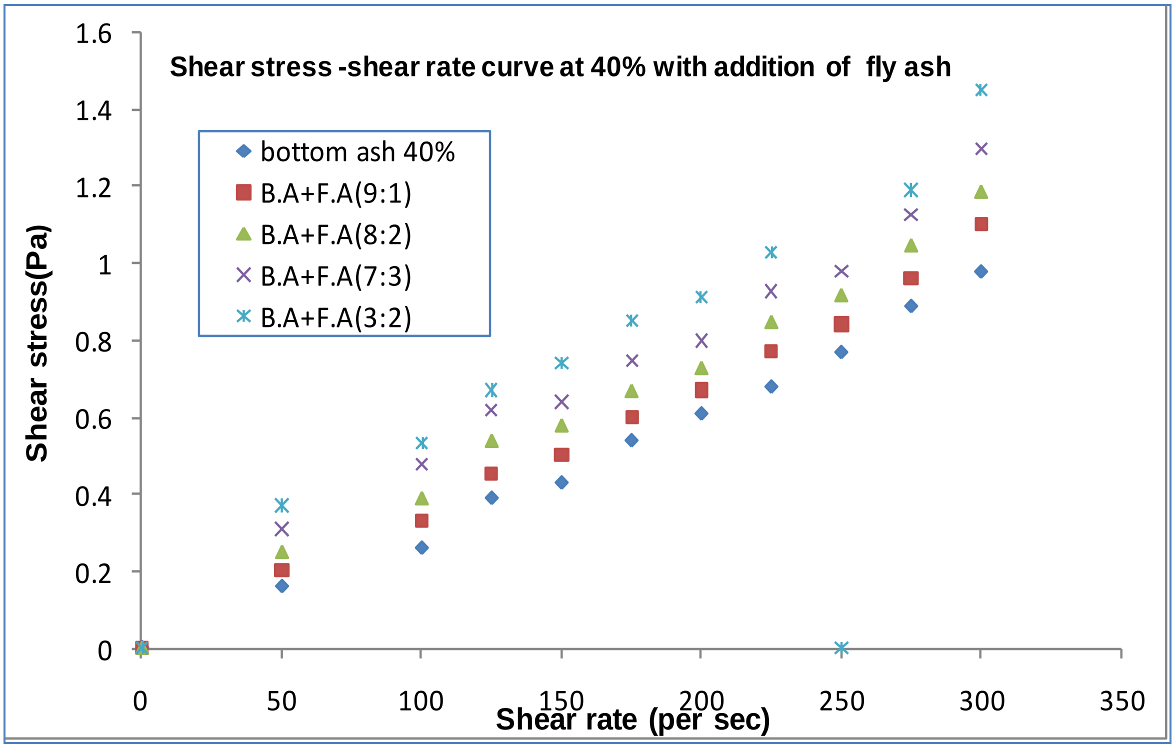

Figure 3.6 (c)

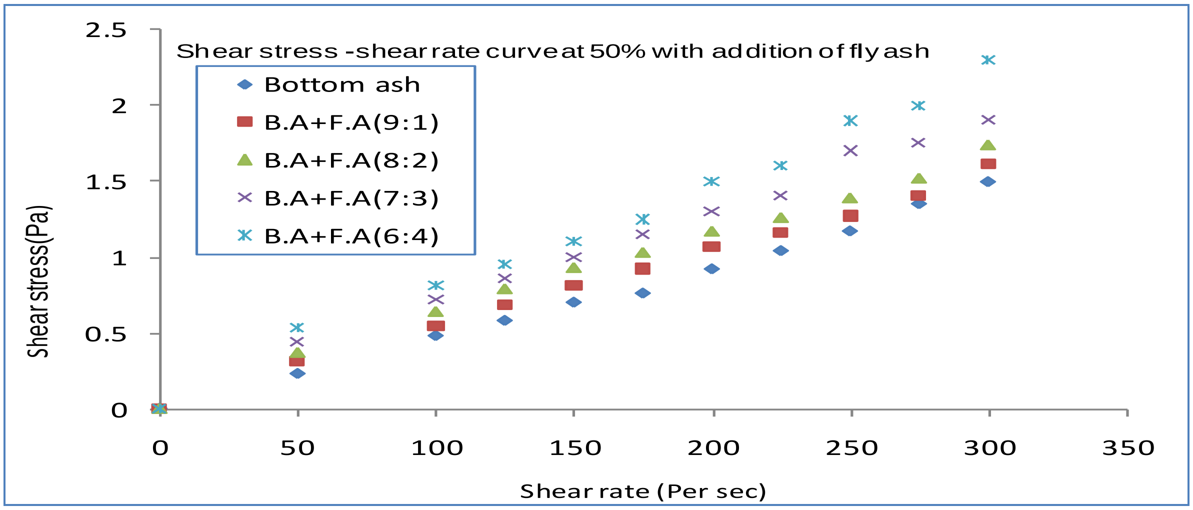

Figure 3.6 (d)

Figure 3.6- Rheogram of bottom ash and fly ash

The above graphs show that the bottom ash and fly ash mixtures show Newtonian behavior at all concentrations even when they are mixed in various proportions. The addition of fly ash in increasing proportions consistently increases the viscosity. Its can be due to the fact that fly ash particles are smaller in shape which leads to greater surface area for friction thus increasing viscosity.

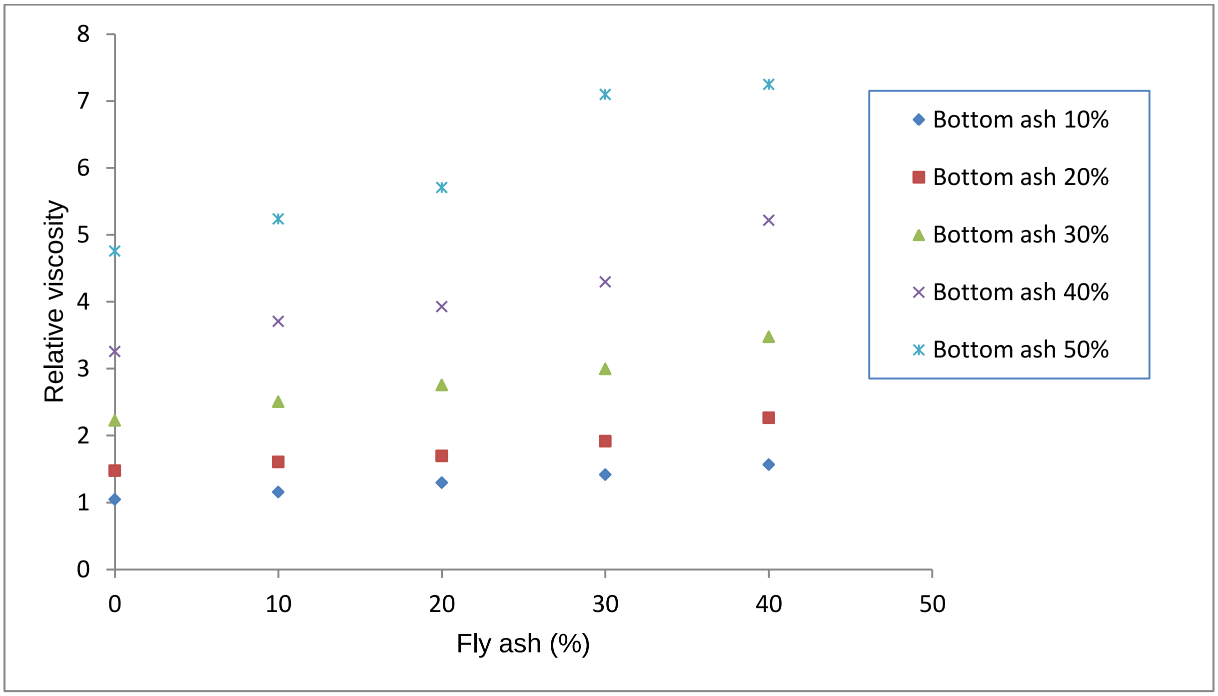

Figure 3.7 Variation of relative viscosity with addition of fly ash

The figure 3.7 shows that the relative viscosity increases with concentration of bottom ash. The curve reveals that the increase in viscosity is not linear with increase in concentration but is exponential (i.e. the rate of increase of viscosity increases with concentration).

CHAPTER 4

EXPERIMENTAL EVALUATION OF PUMP PERFORMANCE

Aim of the present work is to evaluate performance of pump handling clean water and bottom ash and fly ash mixture experimentally in the pilot plant test rig at IIT, Roorkee.

4.1 EXPERIMENTAL SET-UP

The schematic diagram of experimental set-up for performance evaluation of centrifugal slurry pump is shown in Fig.4.1. Test loop is connected by “50M WILFLY” model pump. The slurry for the tests were prepared in the hopper shaped mixing tank having a suitable stirring arrangement for keeping the slurry well mixed during experimentation. The mixing tank is made up of 4 mm thick stainless steel sheet. The height of the tank is 1.55 m and has square cross shape at top (1m x1m). The schematic layout of the pilot plant test loop is shown in the figure 4.1. It consists of a closed circuit pipe test loop of 50 mm NB pipe having a length of around 40m, along with the other necessary components.

Calibrated electromagnetic flow meter is used in test loop for continuous monitoring the flow rate. Mixing tank is placed near the measuring tank. Drain plug provided in both tank. For diverting the flow a flow deflector is provided in between mixing tank and measuring tank to divert flow during flow rate measurement.

The delivery line of pump is connected back with mixing tank for recirculation of slurry. In this experimental set up, it was modified for transportation of high concentrated slurry with shorter path. Separators are installed in suction and delivery side of centrifugal slurry pump. Purpose of separator is to prevent the entrance of sand particle of slurry in pressure transmitter. The suction and delivery pressure is measured by SMAR pressure transmitter. Pressure transmitters are attached to stand at height of 1.5 m from ground level to maintain water level till transmitter ends. For avoiding the air trap in the pipe line purging is carried out in the pressure transmitter.

Pump is driven by 7.5 kW, 373-456 V, 14.5 a variable speed induction motor (Type: 3 phase square cage, Make: M/s Bharat Bijlee Ltd, Thane, India). For the variation of motor speed, frequency modulator is used. The pump speeds was measured using digital electronic tachometer (Type: Digital photo type tachometer, Make: Systems limited). The manufacturer’s specification for centrifugal slurry pump (WILFLEY model, Make: Hindustan Dorr-Oliver Ltd. Bombay) used in present investigation are given in Table 3.1.

The selection of pipe diameter and length of test loop is based on the. fact that if we use pipe diameter more than 50 mm (l00 mm next standard available size) then slurry volume requirements for pumping would increase and if we go below this size the scale down error will increase. So we made necessary compromise between these two with 50 mm NB pipe. The design selection of different components of the pilot plant test loop is discussed in this section.

Figure 4.1 Experimental set-up

TABLE 4.1 MANUFACTURER DATA OF PUMP

IMPELLER DETAIL

Type	Closed
Material	Ni-hard
No. of vanes	5

CASING DEATIL

Type	Volute
Material	Ni-hard

OTHER DETAILS

Suction flange size (mm)	100
Non-dimensional specific speed	0.06957
Best efficiency point head (mwc)	15.1
Pump input power (kw)	4.86
Maximum efficiency (%)	46%
Minimum rated speed	1450
Delivery flange	50
Rated discharge (lps)	15.1

4.2 INSTRUMENTATION

Different type of instrument is used for the measurement of various operating parameters of pump. Main components given below.

4.2.1 Pressure measurement device

Suction and delivery pressure of the pump are measured with the help of pressure transmitters. These pressure transmitters are based on a capacitive principle that provides reliable operation and high performance. At suction side, absolute pressure transmitter is used, similarly at delivery side, gauge pressure transmitter is used.

Both pressure transmitters are calibrated by using Fluke 718 100G pressure calibrator. In calibrator, pressure is set zero according to pressure transmitter lowest reading value.

Pressure in calibrator is increased by pumping simultaneously and reading of pressure transmitter is noted down.

4.2.2 Flow measurement device

Flow rate is measured either by ABB electro-magnetic flow meter or by using the measuring tank. Measuring tank can be used to calibrate the electro-magnetic flow meter which is used for continuous monitoring of flow rate in the loops.

In second method, the flow of the slurry in the test loop is diverted to the measuring tank of 206.127 liters having height of 0.8m for a known interval of time. For a given time of interval, change in the slurry level is measured using a scale having a least count of 1mm. the least count of the stop watch is 0.01 second.

4.2.3 Speed measurement device

Speed is measured by non contact type Tachometer (manufacturing system Pvt. Ltd, New Delhi). During measurement of speed, shaft surface was cleaned for maintain minimum roughness. The least count of speed is 0.1 rpm.

4.2.4 Power measurement device

For measurement power, HIOKI 3165 clamp on power Hi Tester instrument are used. Accuracy of power analyzer is 0.001kW. Power analyzer provides additional information namely frequency, voltage, current and power factor measurement.

4.3 EXPERIMENTAL PROCEDURE

The performance of pump was determined with clear water during actual experiments so as to eliminate the possible effects of erosion of different pump components. In the test loop, all plug valves were first closed and the mixing tank, suction and delivery pressure measurement tubes were properly filled up with water and purged off all the air bubbles. The delivery plug valve was then opened and adjusted to desired flow rate. The measurements indicated by different instruments namely magnetic flow meter, power analyzer, pressure transmitter and tachometer were noted. These measurements were repeated for various delivery valves opening to cover entire operating range of pump flow rate. During every flow rate measurement proper time should be given to stabilize the indicated value in instruments. Similar procedure was followed for slurry pump at 1000rpm, 1150 rpm, 1300 rpm and 1450 rpm speeds. The speed of pump was varied by using frequency modulating device. For pump, the input power to the electric motor was also measured by power analyzer.

After evaluating the performance characteristics of the pump with water, the above procedure is repeated to evaluate the performance of the slurry pump handling bottom ash and fly ash mixture. Proper mixing of slurry can be achieved by the operation of stirrer in the mixing tank. At each solid concentration, the entire operating range feasible with the pump is covered by operating the delivery valve. During each test run, two efflux samples were collected to monitor the concentration. The collected efflux samples during each test are further analyzed to detect any attrition of solid particles. The specific gravity of the slurry is calculated from the weight and volume of the efflux samples collected. Total head developed by the pump is calculated from the suction and delivery head values obtained after applying due corrections for velocity head and potential head. The pump input power is obtained from the knowledge of the motor input power and motor efficiency.

Calculation procedure is given below.

1. Calculation of mano-metric head (H_{mano})

   $$H_{mano} = \left(\frac{\rho_a}{\rho_g} + \frac{\rho_d}{\rho_g} + z_d\right) - \left(\frac{\rho_a}{\rho_g} + \frac{\rho_s}{\rho_g} + z_s\right) \qquad (1)$$

2. Calculation of actual head (H_{total})

   $$H_{total} = H_{mano} + \frac{{V_d}^2}{2g} - \frac{{V^2}_s}{2g} \qquad (2)$$

3. Correction of head (H1450rpm) and discharge (Q1450rpm) at rated speed (1450rpm)

   $$H_{1450rpm} = H_N \times \frac{1450^2}{N^2} \qquad (3)$$

   $$Q_{1450rpm} = Q_N \times \frac{1450}{N} \qquad (4)$$

   $$P_{1450rpm} = P_N \times \frac{1450^3}{N^3} \qquad (5)$$

4. Power outlet in watts

   $$P_{out} = \rho g Q H \qquad (6)$$

5. Surry concentration C_w

   $$C_w = \frac{\rho_s}{\rho_m} \times \frac{(\rho_m - \rho_l)}{(\rho_s - \rho_l)} \qquad (7)$$

6. Efficiency of pump in percentage

$$n_{Pump} = \frac{P_{out}}{P_{in}} \times 100 \qquad (8)$$

The pump performance with solid –liquid mixtures at any rotational speed is generally estimated using head ratio, defined as ratio of head developed with slurry to the head developed with water at the same rotational speed. The head developed with water at any operating speed is estimated using affinity relationship as under

Specific head $sH = \left(\frac{gH}{N^2 D^2} \right)$ (9)

Specific discharge $sQ = \left(\frac{Q}{N \ D^3} \right)$ (10)

Specific power $sP = \left(\frac{Pin}{\left(\rho N^3 D^5 \right)} \right)$ (11)

Equations (9) to (11) are dimensionless parameters applicable to conventional centrifugal pump handling water only

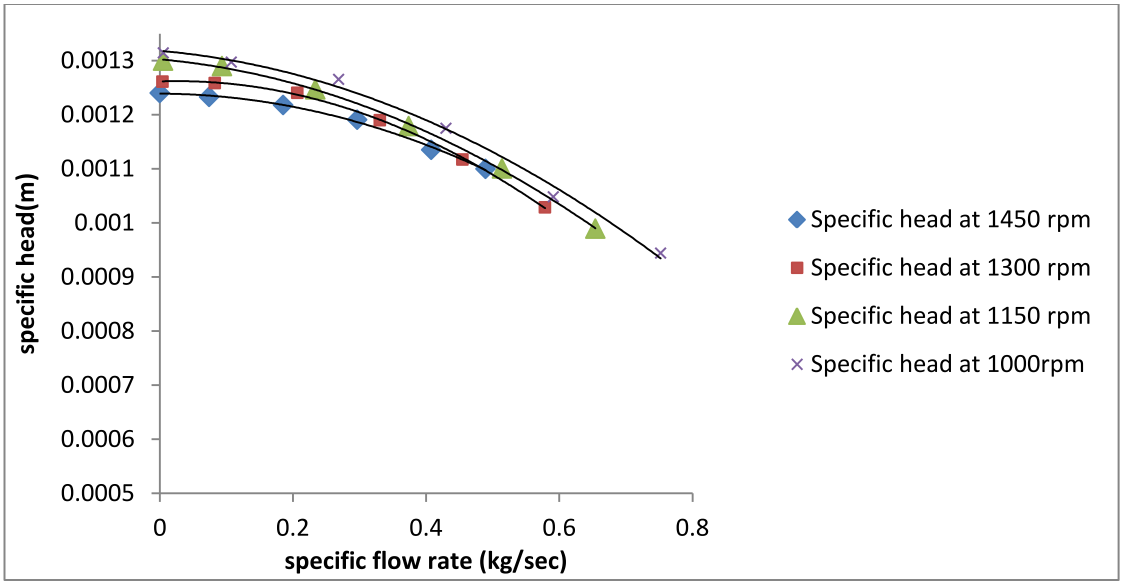

Figure-4.2 Specific head characteristics of the pump at different speed

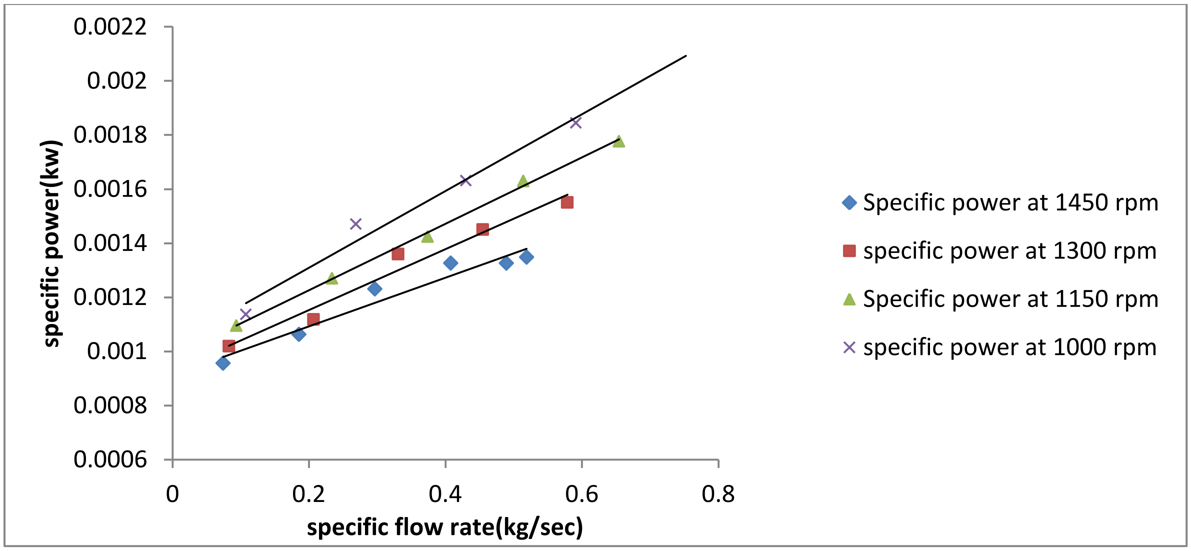

Figure-4.3 Specific power characteristics of the pump at different speed

Figures 4.2 show that the trend of the total head curve for experimental results is decreasing with the increases the mass flow rate at all the operating speed 1000,1150,1300,1450 rpm.

Figure4.3 - shows that the variation of input power of the pump with flow rate and observed that the experimental results of input power increases linearly with the flow rate at all the operating. To study the effect of speed on the performance characteristics of the centrifugal slurry pump for water, the parameters namely, specific head, specific flow rate and specific power (Eqs.9-11) are evaluated and presented in Fig. 4.2-4.3 .The figure 4.2 shows the variation of specific head with specific flow rate at all the four speed 1000,1150,1300 and 1450 rpm. It is seen that the specific head decreases with increase in the specific flow rate at all speed. It is also seen that there is no significant effect on these characteristics with pump speed. The maximum deviation in the specific head due to change in the pump speed is within 3.9% for the entire operating range. Hence, it can be concluded that the parameters defined for head and capacity of the conventional pumps are also applicable for the slurry pumps with water despite the constructional differences. Similar variation has also been reported by (Gandhi et al. 2002**)**.The variation in specific power with specific flow rate is shown in Figure 4.3 and shows that almost linear increases the specific power with the specific rate at all speed. Similar variation has also been reported by experimentally Gandhi et al. (2002**)**. However, the specific powers at any specific flow rate decreases with increase in the pump speed, the decrease being almost linear with the speed. This phenomenon can only be explained on the basis of losses taking place in the pump. The overall losses appear to reduce with increase in the speed. The magnitude of the maximum specific power decreases by nearly 17.83% for a 45% increase in the pump speed from 1000 to 1450 rpm. The above observation shows that use of the affinity relation for estimating the input power with water will result in a significant error for large change in the pump speed.

4.4 EXPERIMENTAL PERFORMANCE OF CENTRIFUGAL PUMP OF BOTTOM ASH AT 30% CONCENTRATION (by weight)

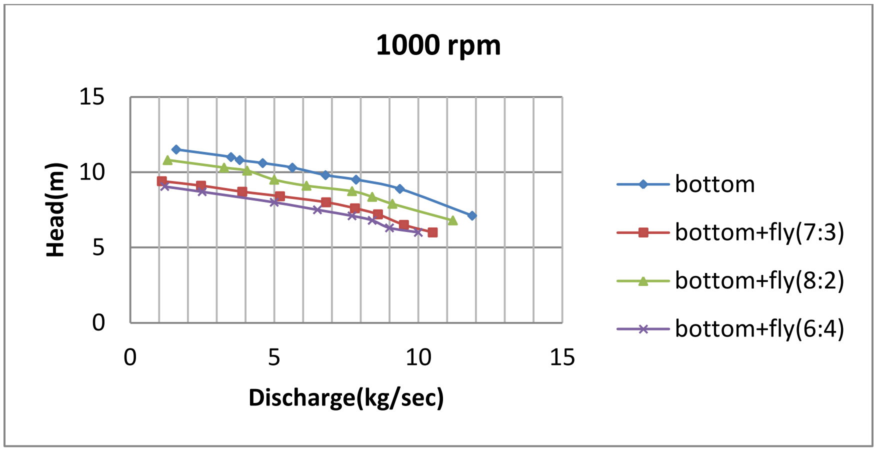

Figure 4.4 Head-discharge characteristics of centrifugal slurry pump at 1000rpm

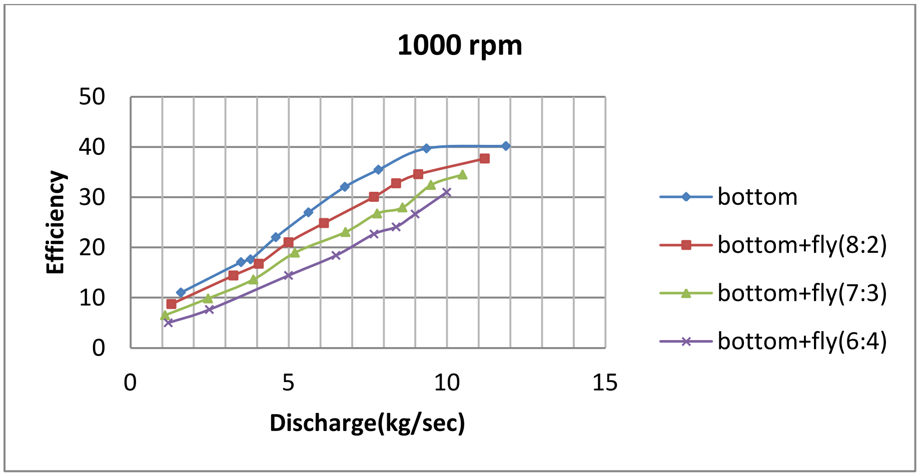

Figure 4.5 Efficiency-Discharge characteristics curve of centrifugal slurry pump at 1000rpm

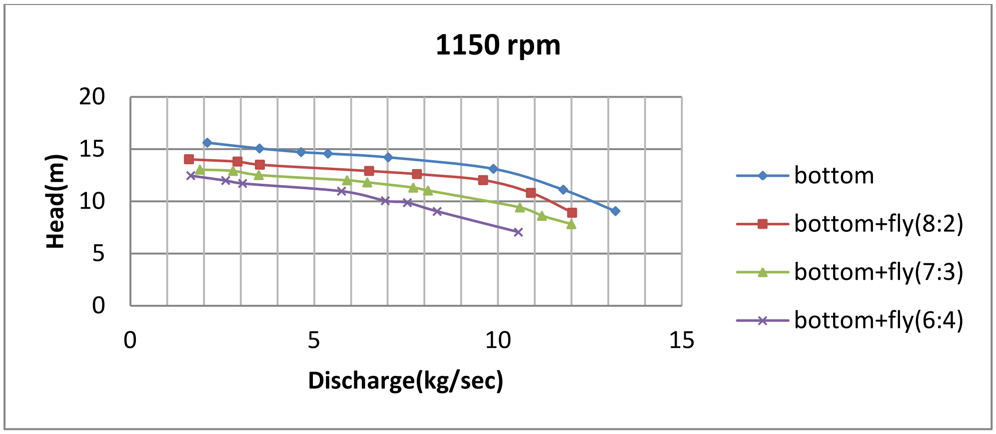

Figure 4.6 Head-Discharge characteristics curve of centrifugal slurry pump at 1150 rpm

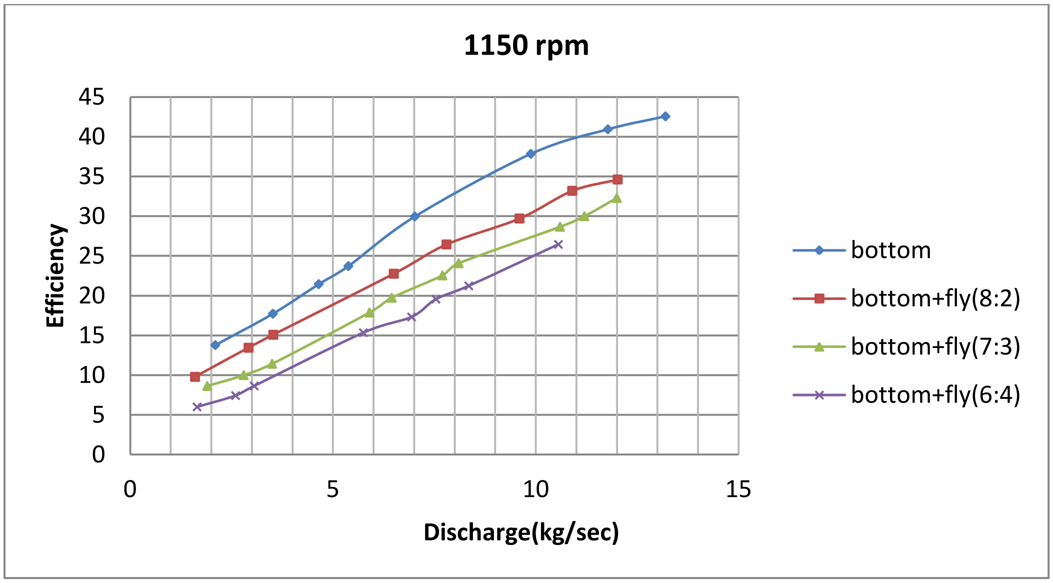

Figure 4.7 Efficiency-discharge characteristic curve of centrifugal slurry pump at 1150

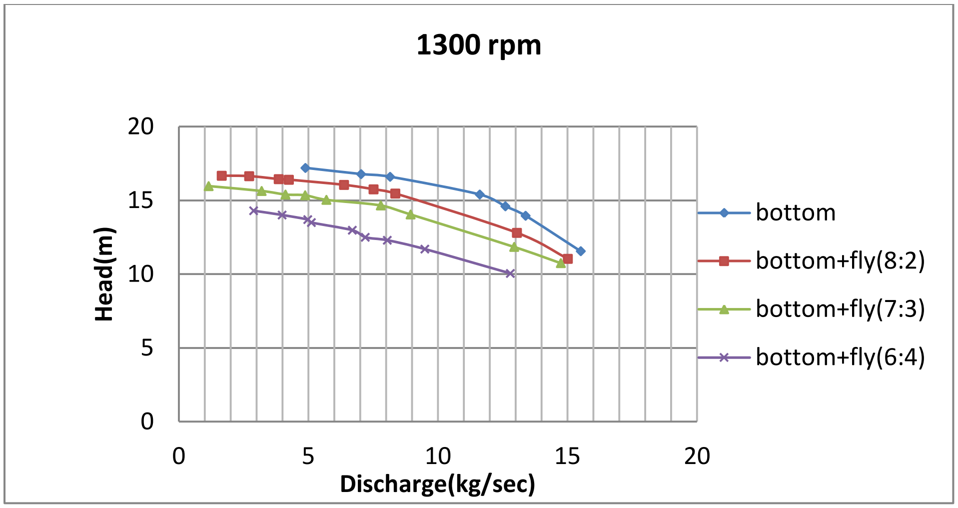

Figure 4.8 Head-Discharge characteristic curve of centrifugal slurry pump at 1300 rpm

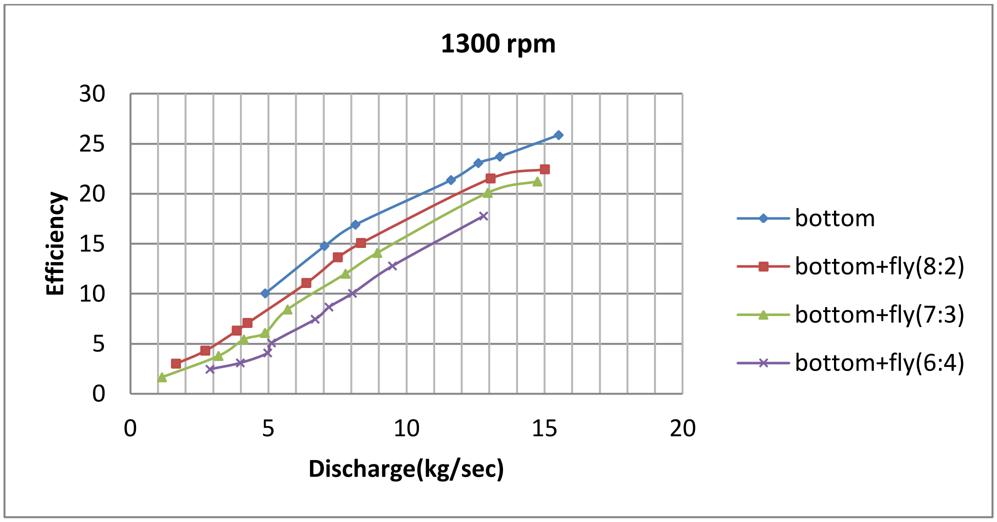

Figure 4.9 Efficiency-discharge characteristic curve of centrifugal slurry pump at 1300 rpm

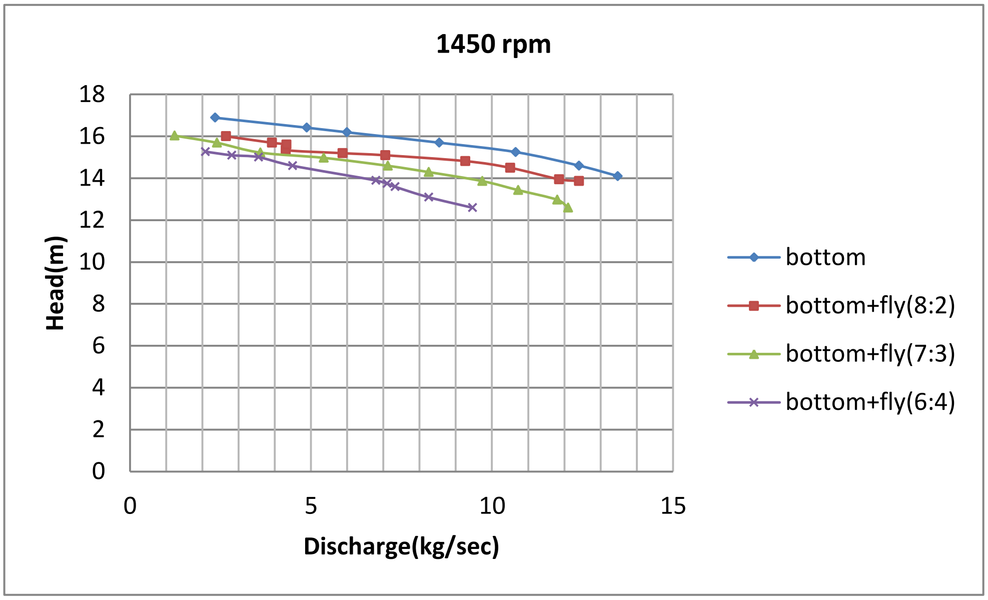

Figure 4.10 Head-discharge characteristic curve of centrifugal slurry pump at 1450 rpm

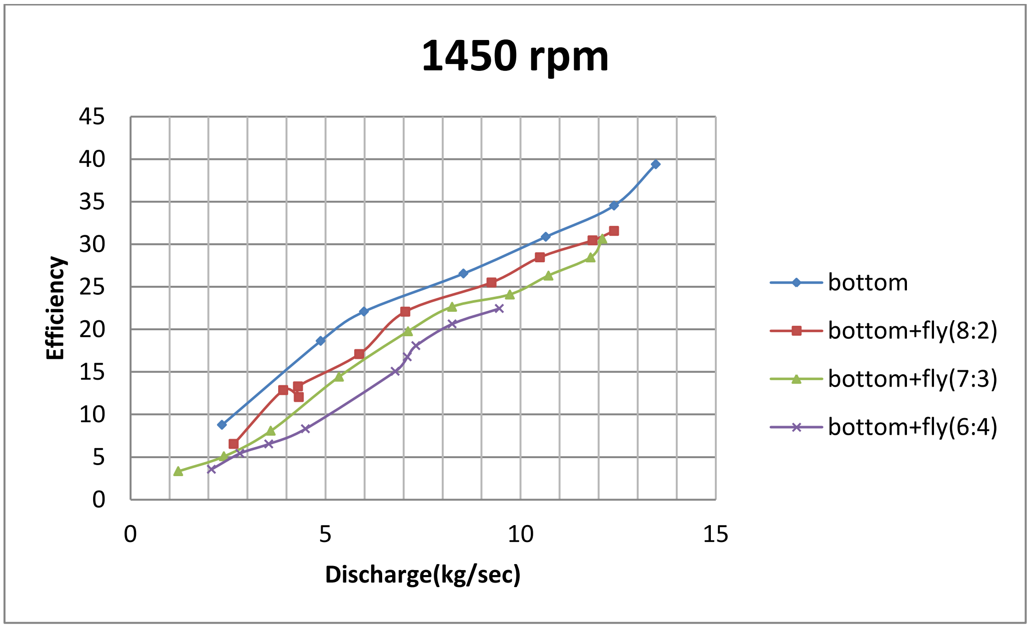

Figure 4.11 Efficiency-discharge characteristic curve of centrifugal slurry pump 1450 rpm

The performance characteristic of the centrifugal slurry pump has been predicted experimentally handling bottom and fly ash mixture slurry. The solid concentration in mixture taken 30% by weight. Head, power and efficiency characteristics of the pump are predicted by experimentally analysis at 1450rpm, 1300rpm, 1150rpm, and 1000rpm Explained graphically. The experimental results on slurry pump performance handling bottom and fly ash mixture slurry at the rated speed of 1450 rpm and at 30% concentrations are given in figure 4.10 -4.11. The parameters namely discharge rate, total head, and efficiency are calculated a constant pump speed of 1450 rpm. Figure shows that the pump head decrease steadily with increase in discharge rate and its maximum value is 16.17m at shut off conditions. The pump efficiency characteristic with bottom Ash is shown in Figure 6.11 depicts that all the data points lie on a smooth curve and the maximum efficiency of 38.26 % is measured. From the figure of the bottom ash characteristics it is also observed that addition of the fly ash in the bottom ash developed head decreases results decreases the power consumptions of the transportation of the bottom ash in pipelines.

CHAPTER 5

Conclusions:

The performance characteristics of centrifugal slurry pump are evaluated experimentally handling bottom ash and fly ash mixture. Also present work includes, study the properties of bottom and fly ash like particle size distribution, ph value, static settled concentration, specific gravity and viscosity of bottom ash and fly ash. The performance characteristics of a centrifugal slurry pump have been evaluated at four rotational speeds 1000, 1150, 1300 and 1450 rpm with solid-liquid mixtures by 30%.

Based on the present investigation of pump characteristic at different speed the following conclusion can be drawn that the specific head decreases with increase in the specific flow rate at all speed. It is also seen that there is no significant effect on these characteristics with pump speed. The maximum deviation in the specific head due to change in the pump speed is within 3.9% for the entire operating range. Hence, it can be concluded that the parameters defined for head and capacity of the conventional pumps are also applicable for the slurry pumps with water despite the constructional differences. From the bottom ash characteristics it is also observed that addition of the fly ash in the bottom ash developed head decreases with increases of the flow rate results decreases the power consumptions of the transportation of the bottom ash in pipelines.

REFERENCES

1. Roco, M.C., Marsh, M., Addie, G.R. and Maffett, J.R., "Dredge Pump Performance Prediction, *Journal of pipelines", Vol. 5, pp. 171-190.* 1986

2. K.A. Kazim, B. Maiti and P. Chand, Correlation to predict the performance characteristics of centrifugal pump handling slurries. *Journal of Proc instn Mech engrs. Vol 211, part (A)* 1997.

3. Sellgren, A., Addie, G., and Scott S., "The Effect of Sand- Clay Slurries on the Performance of Centrifugal Pump", *The Canadian Journal of Chemical Engineering* volume: 78, 2000

4. Craig I. Waker, Greg C.Bodkin," Empirical wear relationships for centrifugal slurry pumps", Journal of *Elesvier science Publishers limited, 2000*

5. Usui, Li, Suzuki," Rheology and pipeline transportation of dense fly ash-water slurry", *Journal of Koresa –Australia Rheology vol. 13, No. 1,* 2001

6. Gandhi, B. K., Singh, S. N. and Seshadri, V.," Performance characteristics of centrifugal slurry pumps", Transactions of ASME, *Journal of Fluid Engineering*, (123), 2001, 271-280

7. Senapati, Mishra, Panda." Rheological Behavior of Coal-Water Slurry", *Journal of Taylor and Francis*", 2002

8. Engin, Tahsin and Gur, Mesut, Comparative evaluation of some existing correlations to predict head degradation of centrifugal slurry pumps, Transactions of ASME, *Journal of Fluid Engineering*, (125), 2003, 149-15769

9. J.F, Gulich. Effect of Reynolds number and surface roughness on the efficiency of centrifugal pump, *Journal of ASME,* vol 125, 2003.

10. Kumar, Mishra, Singh, Seshadri.V," Effect of particle gradation on flow characteristics of ash disposal pipelines", *journal* of *Elesvier science Publishers limited",* 2003

11. M. Mehta, J.R. Cadamb, Velocity measurement of particle in the impeller of centrifugal slurry pump, 2004.

12. Kaushal, Sato, Toyota, Funatsu, Tomita," Effect of particle size distribution on pressure drop and concentration profile in pipeline flow of highly concentrated slurry", journal of *Elesvier science Publishers limited",* 2005

13. Graeme R. Addie, J. R. Kadambi," design and application, slurry pump technology", *journal of ASME Fluids Engineering* ", 2005

14. Verma, Singh, Seshadri,"Pressure drop for the flow of high concentration solid liquid mixture across 90 degree horizontal conventional circular pipe bend", *Journal of engineering and material sciences* ", 2006

15. Satoshi ogata, Asano. Kimura and keizowatanabe, Effect of surfactant additives on centrifugal pump performance, *Transaction of ASME*, Vol 128, 2006.

16. Pullum, L., Graham, L.J. and Rudman, M., Centrifugal pump performance calculations for homogeneous and complex heterogeneous suspensions, Hydro Transport 17, BHRA 17th *International Conference on the Hydraulic Transport of Solids*, 2007, 239–253.

17. Wennberg, T., Sellgren, A. and Whitlock, L., "Predicting the Performance of Centrifugal Pumps When Handling Complex Slurries", *International Conference on Transport and Sedimentation of Solid Particle*, Russia. 2008

18. Mosa, Saleh, Taha, Molla," Effect of chemical additives on flow characteristics of coal slurries ", 2008

19. Seshadri, Singh, Jain, Vema, "Effect of Additive on Head Loss in the High Concentration Slurry Disposal of Fly Ash ", *journal of IE (I)* ", 2008

20. Knezevic, Dinko, Kolonja and Bozo," The influence of ash concentration on change of flow and pressure in slurry transportation", *int. j. Mining and Mineral engineering. Vol.1.N0 1*, 2008

21. Thin, Khaing, and Maung Aye, "Design and performance analysis of centrifugal pump", *journal of* World *Academy of Science, Engineering and Technology,* 2008

22. Caridad, Asuaje, Kenyery, Termante, Aguillon,"Characterization of a centrifugal pump impeller under two-phase flow conditions", *Journal of Petroleum Science and Engineering",* 2008

23. Chandel, Seshadri, Singh," Effect of Additive on Pressure Drop and Rheological Characteristics of Fly Ash Slurry at High Concentration*", journal of* Particulate Science *and Technology* ", 2009

24. Naik, H.K, Mishra, M.K, Karanam, "Rheological Characteristics of fly ash slurry at varying temperature Environment with and without an additive ", 2009

25. Chandel, Singh, Seshadri. “Deposition characteristics of coal ash slurries at higher concentrations”, *journal of* Elesvier *science Publishers limited”,* 2009

26. Seshadri, Singh, Chandel,” Transportation of High Concentration Coal Ash Slurries through pipelines*”, journal of international archive of applied science and technology”,*2010

27. Pavel vlasak, Zdenek chara,” Effect of Particle Size Distribution and Concentration on Flow Behavior of dense slurries”, 2011

28. Chandel, Sunil, Singh, and Seshsadri,”Effect of additive on the performance characteristics of centrifugal and progressive cavity slurry pumps with high concentration fly ash slurries”, *journal of international archive of applied science and technology”, 2011*

29. Naik, Mishra, Karnanam,” Evaluation of flow characteristics fly ash slurry at 40% solid concentration with and without an additive”, 2011