STUDY OF PERFORMANCE CHARACTERISTICS OF CENTRIFUGAL SLURRY PUMP HANDLING BOTTOM ASH

Thesis submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering

In

CAD/CAM & Robotics

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DECLARATION

I hereby declare that the work which is being presented in the dissertation work entitled, **"EXPERIMENTAL STUDY OF PERFORMANCE CHARACTERISTICS OF CENTRIFUGAL SLURRY PUMP"**, in partial fulfillment of the requirements for the award of degree of Master of Engineering in Mechanical Engineering with specialization in **CAD/CAM & ROBOTICS** submitted in Mechanical Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. S.K Mohapatra and Mr. Satish Kumar** 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.

Date: - 15 July'2010
Place: - Patiala

(JAIINDER PREET SINGH)

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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 radial-flow type is the most common in slurry service. A conventional centrifugal pump is designed to handle clear 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. 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 slurry pump, and provides the valuable hydraulic design information of the centrifugal slurry pumps. The present study is concerned with the evaluation of the performance characteristics of a centrifugal slurry pump when handling clear water and numerical simulation with different concentration of bottom ash slurry at different speeds. The pump characteristics of centrifugal slurry pumps are influenced by various particle parameters such as concentration and flow velocity of slurries. 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 commercial computational code.

CONTENTS

List of figures and tables

NOMENCLATURE

SYMBOLS

D	Diameter, m
Q	Mass flow rate, m^3/sec
H	Head, m
BHP	Brake horse power, hp
N	Speed, RPM
P	Density of liquid, kg/m^3
$\vec{v}$	Velocity vector
r	Stress tensor
g	Acceleration due to gravity, m^2/sec
h_0	Enthalpy
μ_t	eddy viscosity
$\vec{F}$	Force vector, N
$\dot{m}$	Flow rate
E	Total energy, J
k	kinetic energy per unit mass, J/kg
U	Free stream velocity, m/s
ε	Turbulence dissipation rate, m^2/sec
σ_k and σ_ε	Turbulent Prandtl numbers for k and ε, respectively

Suffix:

i	x coordinate
j	y coordinate
z	z coordinate
1	inner diameter
2	outer diameter

CHAPTER 1
INTRODUCTION

1.1PUMP

A pump is a device used to move fluids, such as liquids, slurries, and gases. Pumps are found in such services as steam power plants, water supply plants, sewage, drainage or irrigation, oil refineries, chemical plant, sand steel mills.

1.1.1 Classification of Pump

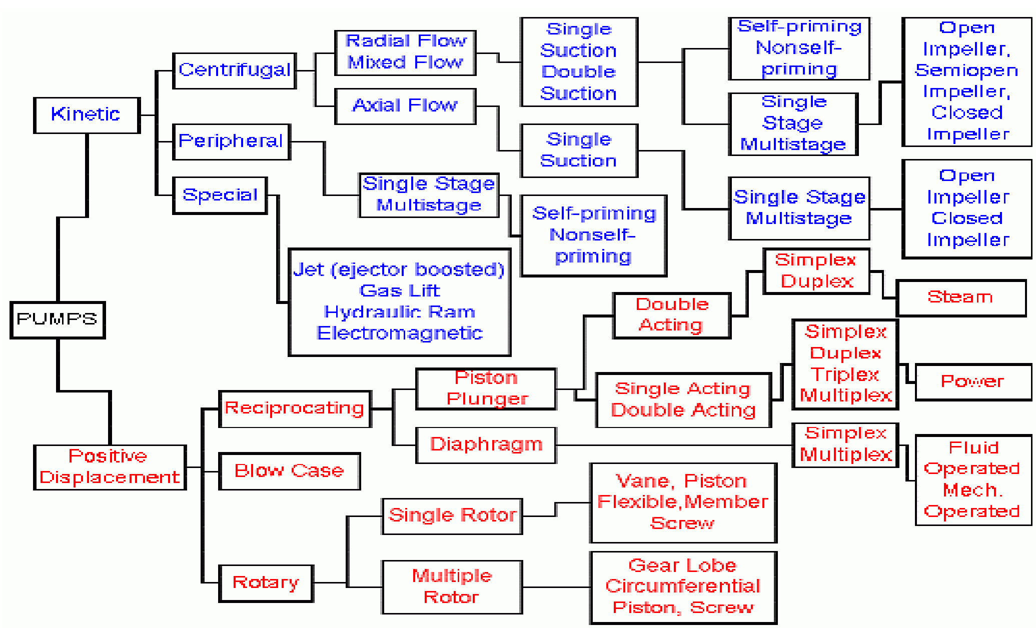

Figure 1.1 Classification of pump

- **Reciprocating Pumps**

In reciprocating pumps the mechanical energy is converted into hydraulic energy by sucking the liquid into a cylinder in which a piston is reciprocating (moving backwards and forwards) which exerts the thrust on the liquid and increases its hydraulic energy(pressure energy), the pump is known as reciprocating pump. Reciprocating pumps are used where a precise amount of liquid is required to be delivered, also where the delivery pressure required is higher than that can be achieved with other types.

- **Centrifugal Pump**

The hydraulic machines, which convert the mechanical energy into hydraulic energy, are called pumps. The hydraulic energy is in the form of pressure energy. The mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid; the hydraulic machines are called centrifugal pumps. The flow in a centrifugal pump is in radial outward direction. Figure 1.2 shows the 3 dimensional model of a centrifugal pump.

Figure 1.2: Centrifugal pump

1.2 WORKING PRINCIPLE OF CENTRIFUGAL PUMP

A centrifugal pump works by the conversion of the rotational kinetic energy, typically from an electric motor or turbine, to an increased static fluid pressure. The rotation of the pump impeller imparts kinetic energy to the fluid as it is drawn in from the impeller eye (centre) and is forced outward through the impeller vanes to the periphery. As the fluid exits the impeller, the fluid kinetic energy (velocity) is then converted to (static) pressure due to the change in area the fluid experiences in the volute section. Typically the volute shape of the pump casing (increasing in volume), or the diffuser vanes (which serve to slow the fluid, converting to kinetic energy in to flow work) are responsible for the energy

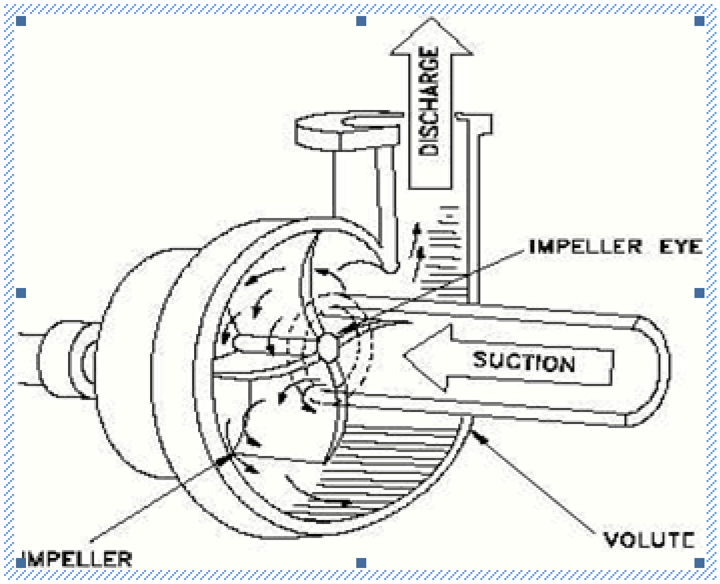

Figure 1.3 working principle of Centrifugal pump

conversion. The energy conversion results in an increased pressure on the downstream side of the pump, causing flow. Centrifugal pumps are used in a variety of applications, such as, water supply and irrigation, power-generating utilities, flood control, sewage handling and treatment, food industries, chemical and petrochemical industries, domestic appliances, mining and ore processing, transporting liquid-solid mixtures, environmental control, spaceships, airplanes, and motor vehicles. Since they are used in a wide spectrum of application, the centrifugal pumps are manufactured in different shapes to meet the application requirements.

1.2.1 Components of a centrifugal slurry pump

A centrifugal pump has two main components:

- A rotating component comprised of an impeller and a shaft
- A stationary component comprised of a casing, casing cover, and bearings.

The general components, both stationary and rotary, are depicted in Figure 1.4. The main components are discussed in brief below.

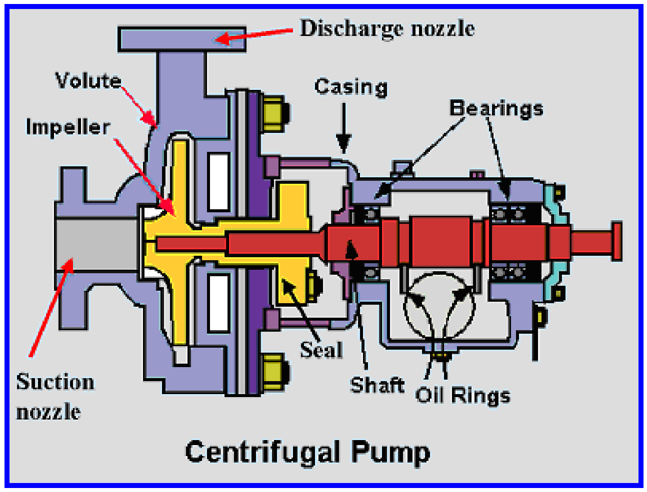

Figure 1.4 General components of a centrifugal pump

- **Impeller**

The impeller is the main rotating part that provides the centrifugal acceleration to the fluid. They are often classified in many ways.

- Based on the direction of flow

  (a) Radial flow (b) Axial flow (c) Mixed flow

- Based on the suction type

  (a) Single-suction: Liquid inlet on one side.

  (b) Double-suction: Liquid inlet to the impeller symmetrically from both sides.

- Based on mechanical construction

  (a) Closed: Shrouds or sidewall enclosing the vanes.

  (b) Open: No shrouds or wall to enclose the vanes.

  (c) Semi-open or vortex type.

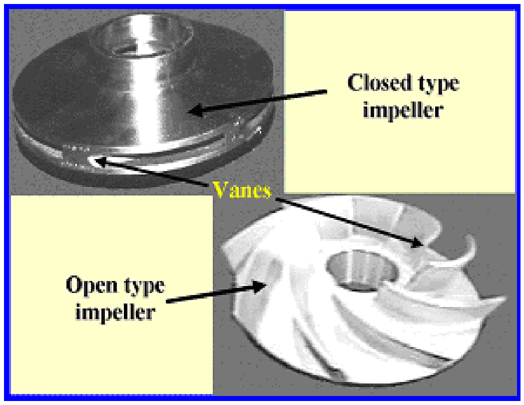

Figure 1.5 Closed and Open type Impeller

Closed impeller: The closed impellers are designed with the blades between two support shrouds or plates. These impellers are generally used clean liquids because tolerances are tight at the eye and the housing, and there is no room for suspended solids, crystals or sediment, Figure 1.5 shows a closed impeller.

Open impellers: The open impellers are used pumps to perform a chopping, grinding action on the liquid. The totally open impeller imparts motion to a large volume flow, without creating greater head or pressure. With its open tolerances for moving and grinding solids, they are not high efficiency devices

Semi-open impeller: A semi-open impeller has open blades, but with a support plate or shroud on one side. These types of impeller are generally used for liquids with a small percentage of solid particles from the bottom of a tank or river, or crystals mixed with the liquid. 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.

- **<u>Casing</u>**

Casing of a pump is an airtight passage surrounding the impeller and is designed in such a way that the kinetic energy of the water discharged at outlet of the impeller is converted into the pressure energy before the water leaves the casing and enters the delivery pipe.

Pump casing should be designed as to minimize the loss of kinetic head and efficiency of the pumps largely depends on the type of casing

a) Volute casing: A casing operates on the principle of increasing the pressure energy in a free-vortex or spiral flow. In free-vortex, angular momentum is constant so, $mvr = constant$ and $r \propto 1/v$. Volute casing cross-section of the moving stream gradually increases from torque towards the discharging pipe. This increase in area results in a gradually decrease in velocity (kinetic energy) with corresponding increases in pressure. Most of the single stage pumps are built with volute casing.

b) Volute with vortex chamber: Vortex or whirl pool chamber: Annular space is provided between the volute and impeller. This arrangement minimize the formation of eddies and gives an improved performance of the pump.

c) Diffusion Pump: Impeller surrounded by a guide wheel consisting of a number of stationary vanes or diffuser providing outlets with cross-section gradually enlarging towards the periphery. Water emerging from impeller flow past the guide vanes and as the section across flow increases, velocity falls and pressure is build up. Angle of guide vanes at the entrance should coincide with the direction of absolute velocity of water at impeller outlet. This arrangement is employed in all multistage pumps.

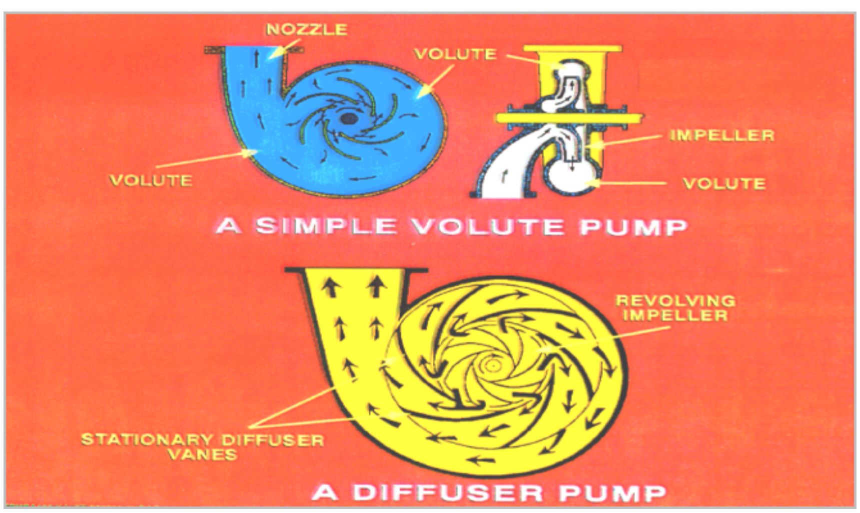

Figure 1.6 Simple volute and diffuser pump

- **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 1.7 below depicts an externally mounted seal chamber and its parts.

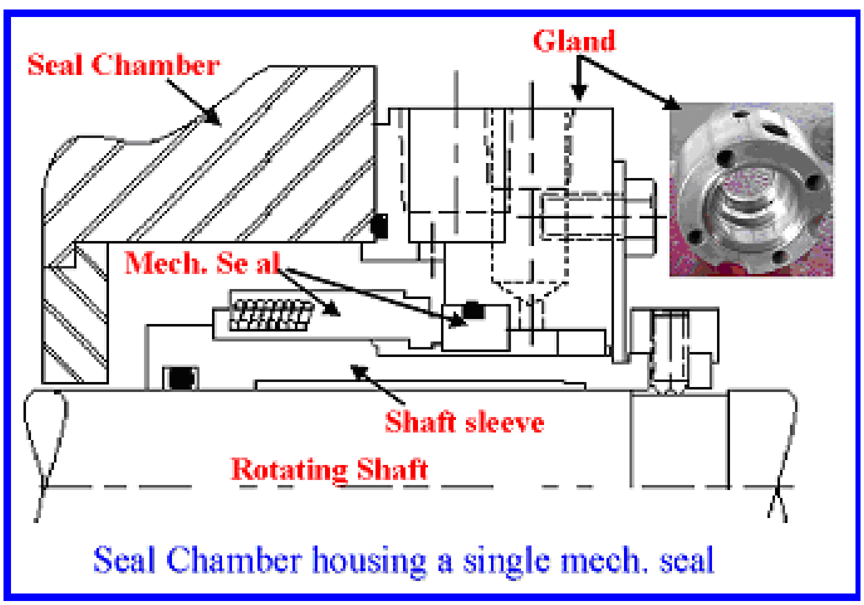

Figure 1.7 Parts of a simple Seal Chamber

a) **Gland:** Glands gives the packing or the mechanical seal the desired fit on the shaft sleeve. It can be easily adjusted in axial direction. The gland comprises of the seal flush, quench, cooling, drain, and vent connection ports.

b) **Throat Bushing:** The bottom or inside end of the chamber is provided with a stationary device called throat bushing that forms a restrictive close clearance around the sleeve (or shaft) between the seal and the impeller.

c) **Throttle bushing** forms a restrictive close clearance around the sleeve (or shaft) at the outboard end of a mechanical seal gland.

d) **Internal circulating** device located in the seal chamber to circulate seal chamber fluid through a cooler or barrier/buffer fluid reservoir. Usually it is referred to as a pumping ring.

- **Bearing housing**

The bearing housing encloses the bearings mounted on the shaft. The bearings keep the shaft or rotor in correct alignment with the stationary parts under the action of radial and transverse loads. The bearing house also includes an oil reservoir for lubrication, constant level oiler, jacket for cooling by circulating cooling water.

1.3 SLURRY

Slurry is a mixture of solids and liquids. The most commonly used liquid is water. Its physical characteristics of the slurry are dependent on many factors such as size and distribution of solid particles, level of turbulence, temperature, and absolute (or dynamic) viscosity of the carrier fluid. Single-phase liquids are allowed to flow at slow speeds from a laminar flow to a turbulent flow but in slurry flows, the flow must overcome a deposition critical velocity or a viscous transition critical velocity. If the speed of flow is not sufficiently high, the particles will not be maintained in suspension.

1.3.1 Types Slurry Flows

Based on the solid fluid interaction slurry flows are divided into two different types:

Homogeneous flows or non-settling slurries

In homogeneous flows solids are uniformly distributed throughout the liquid carrier. For example copper concentrate slurry after undergoing a process of grinding and thickening, drilling mud, sewage sludge, and fine limestone behave as homogeneous flows. Figure 1.8

shows the distribution of solid particles in homogeneous flows.

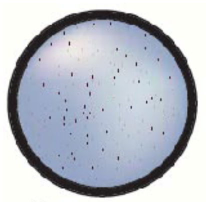

Figure 1.8 Homogeneous slurry flow

Figure 1.9 Heterogeneous slurry flow

Heterogeneous flows or settling slurries

In heterogeneous flows, solids are not uniformly mixed in the horizontal plane. Heavier particles tend to settle down and lighter particles tend to float. Sliding bed may form in the pipe, with the heavier particles at the bottom and the lighter ones in suspension. Heterogeneous slurries are encountered in many places mining, phosphate rock mining, and dredging applications. Heterogeneous flows require a minimum carrier velocity. Figure 1.9 shows the distribution of solid particles in heterogeneous flows.

1.3.2 Operating parameters of slurries

- **Apparent viscosity:** It is defined as the property of the fluid resistance offered to the flow.
- **Critical carrying velocity:** It is defined as the mean velocity of the specific slurry in a particular conduit, above which the solids phase remains in suspension, and below which solid-liquid Separation occurs.
- **Effective particle diameter:** Effective particle diameter is the single or average particle size used to represent the behavior of a mixture of various sizes of particles in slurry. This designation is used to calculate system requirements and pump performance.
- **Concentration of solids by volume:** The actual volume of the solid material in a given volume of slurry, divided by the given volume of slurry, multiplied by 100.
- **Concentration of solids by weight:** The weight of dry solids in a given volume of slurry, divided by the total weight of the slurry, multiplied by 100.
- **Settling slurry:** slurry in which the solids will move to the bottom of the containing vessel or conduit at a discernible rate, but which will remain in suspension if the slurry is

agitated constantly.

- **Settling velocity:** It is the rate at which the solids in slurry will move to the bottom of stationary container.
- **Square root law:** This law is used to calculate t he approximate increase in critical carrying velocity for given slurry when pipe size is increased. It states:

Where:

V = Critical carrying velocity in larger pipe

Vs = Critical carrying velocity in smaller pipe

V_L = Diameter of larger pipe

Vs = Diameter of smaller pipe

- **Yield value (Stress):** It is the value of stress at which slurries will start to deform and under this value there will be no relative motion between adjacent particles in the slurry.

1.4 TRANSPORTATION OF SLURRY

Over the last few decades there has been a phenomenal growth in the demand of raw materials. This rise in demand has led to drastic changes the existing techniques of mining, food processing, power generation and other sectors where transportation of suspended solids play a major role. Due to this change, there has been an increase in requirements in slurry transportation. A typical slurry transport system is shown in the figure 1.10. Pump plays a vital role in transportation of slurry; different types of pumps are available for slurry transportation, but centrifugal pumps are most widely used in slurry transportation applications due to the following reasons:-

- Higher flow rates can be obtained.
- Pulse free flow can be obtained.
- Higher initial and maintenance cost of positive displacement pumps.
- Solid particle of any size can be transported.

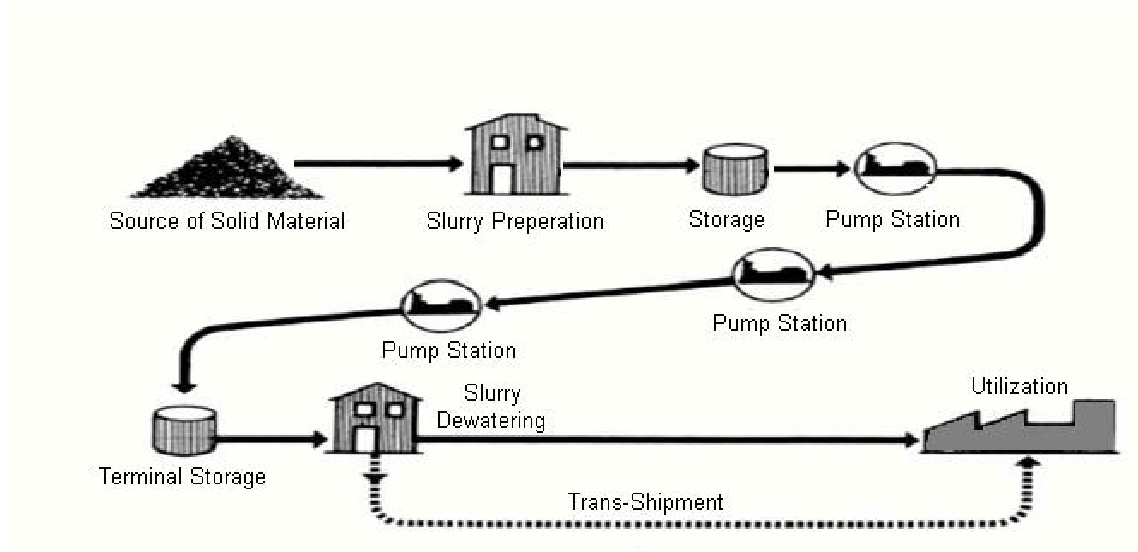

Figure 1.10 Transportation of slurry

1.4.1 Pumps used for transportation of slurries

The choice of pumps or pumping systems for slurry transport will depend not only on the flow, head required, suction conditions, type of installation and location, as for any other pump application, but also on the slurry flow regime and properties. Rot dynamic pumps, of which the centrifugal or radial-flow type is the most common in slurry service, are usually considered for the higher flow, lower head duties, whereas conversely, positive-displacement reciprocating types tend to be used for the lower flow, high pressure applications, e.g. long-distance pipelines. However, relatively high pressures may also be achieved with centrifugal pumps, depending on casing pressure limitations, by arranging them in series. 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. Figure 1.11 gives a pictorial idea of pump application depending upon discharge and particle size required.

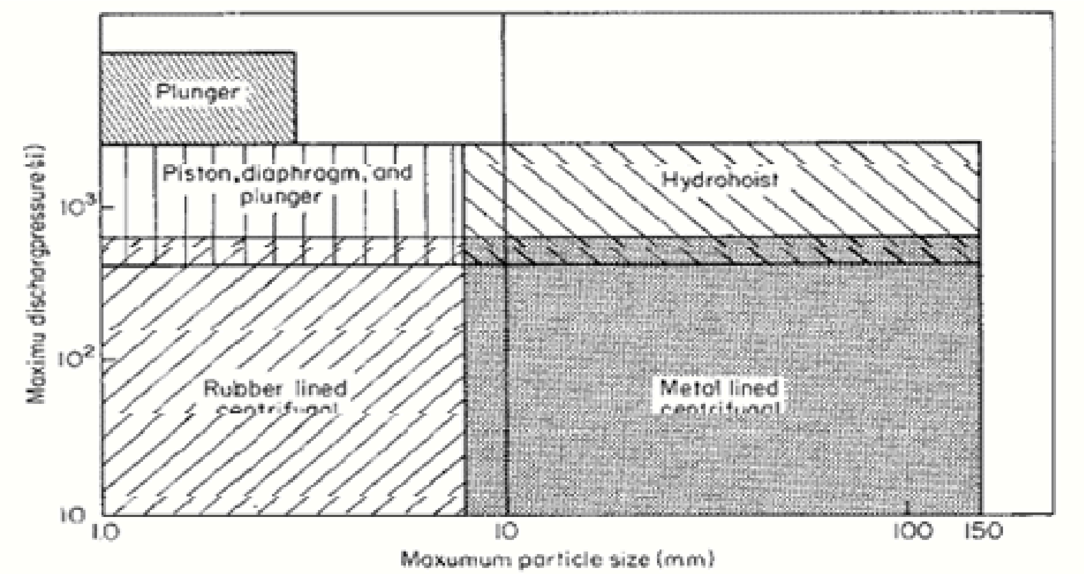

Figure 1.11 Pumps used for transportation of slurries

1.5 MOTIVATION OF THE PRESENT WORK

Pumping system is widely used in the transportation of coal, iron ore, mineral concentration, and sewage sludge. In many of these applications, Transported slurries are complex multi-species mixtures containing solid with different densities and particle size. Several studies were dedicated to the effect of particle size in single species slurries on pipeline flow. In this we use the slurries having different particle size, density, viscosity, flow rate etc and measure the performance characteristics of the centrifugal pump.

The objective of the work is to investigate the performance of the centrifugal slurry pump handling clear water experimentally in the pilot plant test rig at IIT Roorkee at different speed and calculate the physical properties of bottom ash like Particle size distribution, Static settle concentration, PH value, Specific gravity and viscosity. Also numerical simulation of pump performance handling bottom ash is evaluate with different concentrations i.e 2%, 5%, 10% and 20% (by weight) at 1450 rpm.

CHAPTER 2

LITERATURE REVIEW

Walker et al. [1]**(1993)** have investigated the effect of impeller geometry on the performance of centrifugal slurry pump with sand slurries of two sizes. They found that except for the vane shape, other vane parameters do not have any significant effect on either the head or the efficiency.

T. Cader, M.C Roco [2]**(1994)**:- Used LDV technique to investigate the particle two phase flows in centrifugal slurry pump. The measurements are done with dilute suspension of 0.8 mm glass beads and have quasi uniform size distribution at the impeller casing flow interface. The velocity and concentration results can be used to determine pump head and flow rate. The study of velocity triangles for both phases shows the effect of pump flow rate and inlet recirculation on pump head at the impeller outlet as well as the effect of particle slip on pump energy efficiency.

Leigh C Fairbank [3]**(1995)**:- Have studied the effect of suspended material upon the head capacity characteristics. The main purpose was to obtain the charactertics of centrifugal pump while pumping in suspension material on various size and concentration. The suspended material was include two grade of sands and one grade of oil well drilling mud and found the results that the head developed by the suspension is less than that by water and the power input to the centrifugal pump varies directly with the apparent specific gravity of the suspension being pumped. The fall velocity of the suspended material is the most material properties in predicting the effect of material on the pump performance.

K.A Kazim. B Maiti [4]**(1997)**:- As a centrifugal pump is used for the transportation of slurries through pipe lines so we have to study the effect of solid particles on the pump performance. This study take into account the individual effect of particle size, particle size distribution, specific gravity and concentration of the solid of pump characterstics according to this study the head reduction factor increase linearly with the increase in the concentration of the solid ,for slurry having wide range of specific gravity of solid the head reduction factor is found to be proportional to (s-1)$^{0.5}$ where s is the specific gravity of the solid ,for the range of the particle size (d_{wn}) the variation of 105 to 26700um,the head reduction factor is found to be proportional to ln(d_{wm}/20) where "d_{wn}" is weight mean diameter.

Miner, S. M. [5](1997) has calculated numerically the flow field and pressure field within the rotor of an axial flow pump. Velocity and pressure profiles were developed on both sides of the impeller. It is observed that the value of tangential velocity increases from the centre line to the outer radius. The axial velocity profile shifts towards the outer radius because of the presence of nose on the hub. The use of coarse and fine mesh does not show significant difference in the values, thus even coarser mesh can be used.

Dr. F.Ni W.J Vlasblom [6](1999):- Three sorts of narrowly graded sands were tested in the delft university with DN 150 mm pump loop with delivering volumetric concentration up to 44%. The main focus is on observation of pump & pump pipeline characteristics. According to the results the pump efficiency in the coarse sand and slurry may drop almost 60% as compared to water. For the coarse sand, the pump efficiency drops must faster than pump head when $C_{vd} > 15$ %. As a result power requirements increases non- Linearly with the slurry relative density.

Sellgren et al. [7](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 the addition of clay in sand reduces the pipeline friction losses, thus lowering the power consumption and increase in pumping head.

Ni et al. [8](2000) have evaluated slurry pump performance of three types of narrow graded sands with volumetric concentration up to 44% experimentally. They observed that high solid concentration has strong influence on pump head, efficiency and power consumption and this influence behaves differently with different sand size. The pump efficiency in the coarse sand slurry service may drop almost 60%, compared to that to that of water service. The head ratio and efficiency ratio drops faster at solid volumetric concentration of about 35 %. However, the pump efficiency drops much faster than pump head when volumetric concentration is less than 15%. Thus, power requirement increases nonlinearly with slurry relative density. At exit, two layers with different solid concentrations are observed in each passage of a pump impeller due to impeller rotation.

Gandhi B. K. et al [9](2001) have observed that performance of pumps decreases for increase in solid concentration, particle size and specific gravity. The head and efficiency of the pump decrease with increase in solid concentration, particle size, and slurry viscosity, the decrease in the head being 2–10 percent higher than that of the efficiency. The presence of finer particles (less then 18micron) in coarser slurries substantially attenuates the loss of performance of the pump in terms of head and efficiency. At low solid concentrations less than 30 percent by weight, the increase in the pump input power is directly proportional to the specific gravity of slurry whereas the same relationship is not applicable at higher concentrations. The study on the pumps has confirmed that the additional head loss for slurries decrease with increase in the pump size.

Gandhi B. K. et al [10](2001) had studied the erosion wear at various location inside the volute casing of centrifugal pump for the flow of solid liquid mixture the measurement show that the wear increase along volute periphery with increase in the amount of solid suspension in the mixture .it is also observed that the wear is smaller when the pump operate near the best efficiency point flow rate compare to that at lower flow rate. Based on the investigation he concluded that the relative wear along the casing is the function of the erosion wear of the casing material and the variation of impact angle on the casing.

Engin Tahsin et al [11](2003) have evaluated some existing correlations to predict head degradation of centrifugal slurry pumps. A new correlation has been developed in order to predict head reductions of centrifugal pumps when handling slurries. The proposed correlation takes into account the individual effects of particle. The proposed correlation is therefore recommended for the prediction of performance factors of ‘‘small-sized’’ slurry pumps having impeller diameters lower than 850 mm. size, particle size distribution, specific gravity and concentration of solids, and impeller exit diameter on the pump performance.

J.F.gulich.et al [12](2003). A procedure has been developed 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 to predict the effect of roughness and Reynolds number on the hydraulic efficiency. And he concluded 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.

Weidong Zhou.et al [13](2003). Used of computational fluid dynamics and the complex internal flows in water pump impellers can be well predicted, thus facilitating the design of pumps. he describes the three-dimensional simulation of internal flowing three different types of centrifugal pumps (one pump has four straight blades and the other two have six twisted. and concluded that The commercially available three-dimensional Nervier-Stokes code called CFX, which has a standard *k*¡″ two-equation turbulence model, was chosen to simulate the internal flow of various types of centrifugal pumps—M1, M2, and M3. The predicted results of the head-flow curves are presented over the entire flow range. It was found that the predicted results for pumps M2 and M3 were better than those for pump M1, which suggests that the efficiency of pumps M2 and M3 will also be higher than that of pump M1. Thus, future work will be focused on improving the design of pump M1. This study also shows the flow feature in the off-design condition. It was found that when the flow rate decreased below a certain value of the design flow rate, backflow occurred near the pressure surface of the pump impeller. That might occur because when the flow rate through the impeller decreases, the impeller passage correspondingly "narrows" itself so that continuity theory can be satisfied.

Jaikrishnan R. Kadambi.et.al [14](2004) Investigate the Particle Velocities in a Slurry Pump Using (PIV) and concluded that The particle image velocimetry technique was successfully utilized to investigate the velocities and kinetic energy fluctuations of slurry particles at the tongue region of an optically-clear centrifugal pump. The tongue region separates the flow into two streams where the location of the stagnation point on the tongue was not significantly affected by either the pump speed or the solid concentration in the ranges tested. In the impeller passage region, the highest velocities are generated on the suction side of the blade and in the blade trailing edge region as the blade sweeps through. However, these particle velocities are slower than the circumferential velocity of the blade tip ~8.96 m/s for 725 rpm pump speed and 12.36 m/s for 1000 rpm pump speed!. The tangential velocity component and the radial velocity component are significant in this region. In contrast, the particles that are moving through the discharge region are much slower and are nearly tangential ~horizontal!. The up-coming blade does not appear to substantially affect the flow velocity.

M. Mehta et al. [15](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 up of slodium-iodide solution (NaI) solution and 500 micron glass beads. The refractive indices of the NaI 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 NaI 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 1,2,3% 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.

Frank. Kenyery [16](2005) in this study Three-dimensional computational fluid dynamics simulations were carried out on an impeller of known geometry from which values of slio factor were calculated for both single and two phase flow. These results include curves of the slip factor as a function of the specific capacity and the gas void fraction. Additionally, Results for the slip factoring the case of single phase flow are given for various centrifugal impellers in order to illustrate the influence of the flow rate on this parameter. Finally, based on the numerical results, a methodology for prediction of the pump head is presented. Excellent agreement with experimental results has been found.

Xu, C. et al. [17](2005) have calculated the detailed flow structures in the volute and the compressor performance was calculated for different tongues. It was observed that the flow in the volute sections has a single vortex structure, as opposed to two counter-rotating vortices. The round tongue creates significant blockage near the tongue. This blockage forces secondary flow center away from the tongue area. It was shown that the round tongue produces better performance than the sharp tongue. The flow simulation was observed to better understand the volute flow mechanisms and provide design guidance in volute design to meet performance goals.

Theodar W. von Backstrim [18](2006) The simple analytical method drives the slip velocity in terms of a single relative eddy (SRE) centered on the rotor axis instead of the usual multiple (one per blade passage) eddies. It proposes blade solidity (blade length divided by spacing at rotor exit) as prime variable determining slip. Comparisons with the analytical solution of Busemann and with tried and trusted methods and measured data shows that SRE method is a feasible replacement for the well known Wiesner Prediction method: It is not a mere curve fit, But is based on a fluid dynamic model; it is inherently sensitive to impeller inner-to-outer radius ratio and does not need a separate calculation to find a critical radius ration; and it contains a constant, F_0 that may be adjusted for specific constructed families of impellers to improve the accuracy of prediction. Since many of the others factors that contribute to slip are also dependent on solidity. It is recommended that radial turbo machinery investigators and designers investigate the use of solidity to correlate slip factor.

Satoshi ogata.et al [19](2006) Performance of a centrifugal pump when handling surfactant solutions was measured experimentally. It was clarified that the pump efficiency with surfactant solutions was higher than that with tap water and increased with an increase in surfactant concentration. The value of maximum flow rate also increased. The total pump head increased with an increase in concentration, and the shaft power decreased with a decrease in the impeller rotating speed. There was an optimal temperature, which maximizes the efficiency. By combining the data for the piping section and for the pump efficiency, it is concluded that the total pump head of surfactant solution increased and the shaft power of surfactant solution decreased, comparing to those of tap water. The pump efficiency with surfactant solutions is increased in comparison to that with tap water. Additionally, the maximum flow rate of the pump also increased with the use of surfactant solutions. The pump efficiency of surfactant solutions increased with an increase in surfactant concentration. The surfactant temperature affected the pump performance, and it was clarified that there was an optimum temperature,

Pullum et al. [20](2007) have calculated the performance reduction of the centrifugal slurry pump by using Hydraulic Institute method for handling 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. They found that the reduction in the head is the function of coarse solid concentration.

Addie et al. [21](2007) have developed ANSI/HI standard of centrifugal slurry pump. They studied the effect of slurry on pump performance; net positive suction head required and wear by using the ANSI/HI standard.

Min-Guan, Y. et al. [22](2007) have observed the phenomena of two-phase flow with salt crystallizing in the chemical pump, the 3-D turbulent flow in the impeller of chemical pump was simulated at the condition of rinsing. The internal flow between the impellers of chemical pump was investigated. Based on the Reynolds-averaging N-S equations and the standard k-ε two equations turbulent model, the simulations of turbulent flow between the impellers were performed using the flow computing software Fluent under different operating conditions. Based on the analysis of the calculated results of velocity and pressure profiles in the chemical pump and experimentally observed phenomenon of flow impact, secondary flow, and recirculation, some design improvements were proposed, which give suggestions on the optimal design and internal two-phase flow study of the chemical pump

Wennberg et al. [23]**(2008)** have studied the performance of centrifugal pump when handling complex slurries. Complex slurry refers to the intermediate area between homogenous and heterogeneous flowing slurries. Various experiments were conducted on pump as per ANSI standard (ANSI/ HI 2005) and they observed that maximum derating in head and efficiency of about 10 and 15 % respectively provide a stable head curve. Magnified shock losses, circulatory flows and blockage of slurry and possibility of vapour formation in the pump entrance region may be considered as mechanisms behind unstable head curves together with the flow behavior of the slurry.

Many investigators [4, 5, 6, 7, 8, 9, 10, and 11] have carried out experimental investigation on different aspects of centrifugal slurry pump like evaluation of pump performance and wear behavior of pump by handling different type of slurries. They explain procedure to evaluate slurry properties and performance.

Kalekudithi ekambara et al [24]**(2009)** the behavior of horizontal solid_ liquids (slurry) pipeline flow was predicted using a transient three dimension hydrodynamic model based on the kinetic theory of granular flow. computational fluid dynamics simulation result obtained using a commercial CFD software package .the simulation were carried out to investigate the effect of in solid volume concentration (8 to 45%),practical size (90 to 500um) mixture velocity (1.5 to 5.5m/s) and pipe diameter 50 to 500mm. and concluded that the CFD model describe here is capable of predicting particle concentration profile for fine particle slurry .it also concluded that when particle are coarse and concentrated profile are primary depends upon the in situ solid volume fraction.

CHAPTER 3

EXPERIMENTAL PERFORMANCE OF CENTRIFUGAL SLURRY PUMP

In short distance, in plant, slurry transportation systems where the head requirements are normally low, centrifugal pumps are best suited for pumping slurries. Centrifugal pumps are basically designed for handling water and their performance if affected by the presence of solid particles in the slurry. The performance of the pump will improve of deteriorate depending upon whether the slurry behaves as Newtonian fluid or Bingham fluid. Thus for designing a slurry pump, extensive data is required for accurate estimation of the deviation in the pump performance due to the presence of solids. Tests are required to be performance on pump handling slurries of solids different distance and concentrations for determination of pump performance.

3.1 EXPERIMENTAL SET UP

The pump under study was the part of a test loop used to study the slurries transportation physics at different speeds and concentrations. The purpose of the test loop was to conduct the slurry transportation under controlled conditions so that the effect of different parameters on slurry transport can be studied. The test loop consists of a closed circuit pipe test loop of 50 mm NB pipe having a length of 40m along with other necessary components. The main components of a pilot plant are shown in figure 3.1

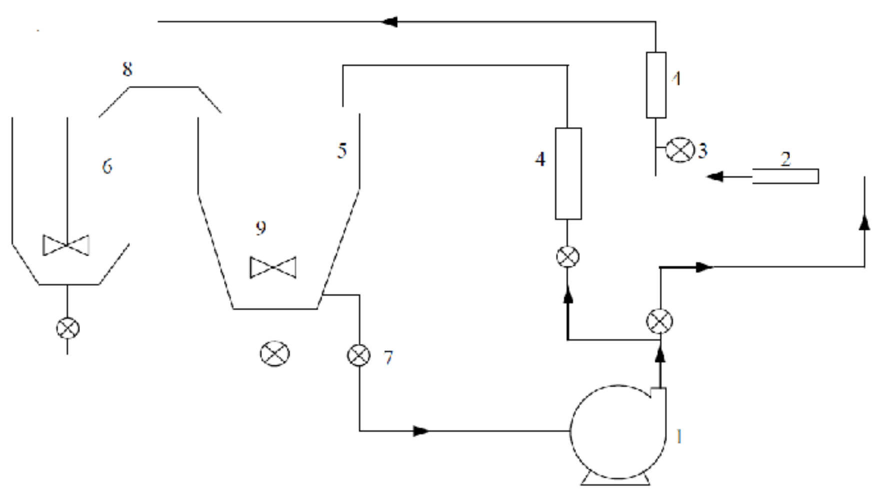

Figure 3.1 Schematic diagram of test loop

1. Centrifugal slurry pump
2. Observation chamber
3. Flow meters
4. Density meter
5. Slurry preparation tank
6. Measuring tank
7. Bypass line
8. Flow diverter
9. Stirrer

Figure 3.2 Existing Experimental Setup

As per the previous experimental setup shown in figure 3.2, we had two tanks one was measuring tank and another was mixing tank just to prepare the slurry i.e bottom ash and water with particular concentration. In this setup the water was collected into the mixing tank up to the particular mark with the help of pipe. After collection of water in the mixing tank, water was pumped into "50M WILFLY" pump having 100 mm diameter pipe of suction inlet and was coming out at particular pressure from the outlet having 50 mm diameter pipe and was then goes to the mixing chamber to make a closed loop circuit as shown in figure. The flow meter was used to calculate the mass flow rate. The flow meter was attached to the outlet pipe so that during the working of the pilot pump, direct reading was displaced on the flow meter. The main function of the flow diverter was to divert the flow of water from mixing tank to the measuring tank with the help of lever mechanism. The separators were attached to the inlet and the outlet ports just to separate the mixing slurry and the water to get the pressure. The separators are made up of acrylic sheet and the cock is attached with it and the outlet pipe is attached to the pressure transducer to get the inlet and the outlet pressure. Three phase induction motor was used to run the "50M WILFLY" pump and the variable frequency drive was used to vary the speed of the pump. In this setup the height of the outlet pipe from the pump was 1265 mm.

- **<u>Modified Experimental Setup</u>**

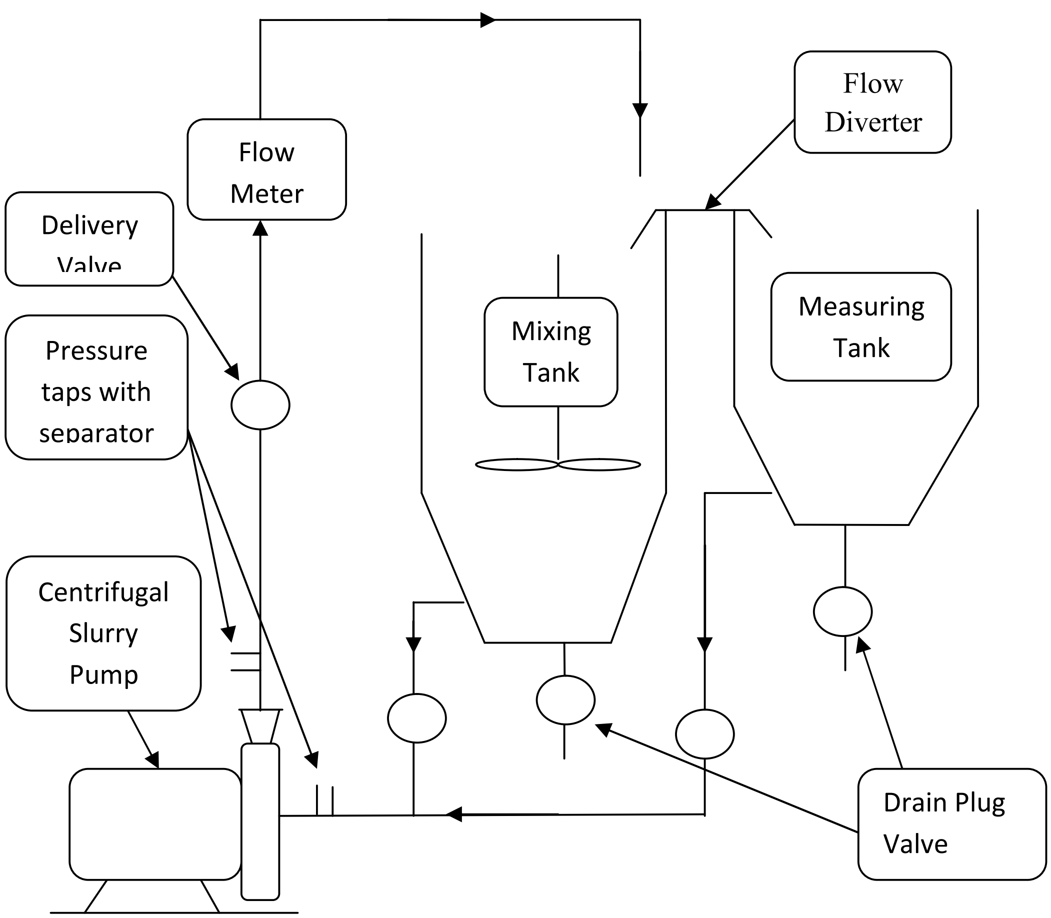

Figure 3.3 Schematic diagram of test loop

The schematic diagram of experimental set-up for performance evaluation of centrifugal slurry pump is shown in Fig.3.3 and its photographic view is shown in Fig. 3.4. 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 3 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 fig. 3.3. 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.

Figure 3.4 Modified Experimental Setup

Measuring tank is provided near the mixing tank for slurry collection over known intervals of time for magnetic flow meter calibration. Flow deflector is provided in-between mixing and measuring tank. For continues monitoring of flow rate, pre-calibrated electromagnetic flow meter (type: Magmaster, Make: ABB Limited, Faridabad, India) is installed in vertical pipe section of test loop as shown in Fig.3.4. The return line of pump delivery is connected back into mixing tank for recirculation of slurry. Both tanks have provided drain plug at bottom side for tank for cleaning purpose.

Separators are installed in suction and delivery side of centrifugal slurry pump. Purpose of separator is avoided to enter 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 1.4 m from ground level to maintain water level till transmitter ends.

Table 3.1 Manufacturer's data of the pump of test rig.

Sr.No.	Specification	50M WILFLY pump
A) Impeller Details		
1.	Type	Closed
2.	Material	Ni-hard
3.	No. of vanes	5
B) Casing details		
1.	Type	Volute
2.	Material	Ni-hard
C) Suction flange size (mm)		100
D) Delivery flange size (mm)		50
E) Non-dimensional Specific speed		0.06957
F) Minimum Rated speed (rpm)		1450
G) Minimum Rated head (mwc)		14
H) Minimum Rated discharge (lps)		8.333
I) Maximum efficiency		50%

Pump is driven by 7.5 kW, 373-456 V, 14.5 Amp 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 were 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.

3.1.1 Additional Components in the Setup

- **Add the ABB Magnetic Flow Meter at Bypass Line and increase the length of line.**
- **Two stands for pressure transmitter**

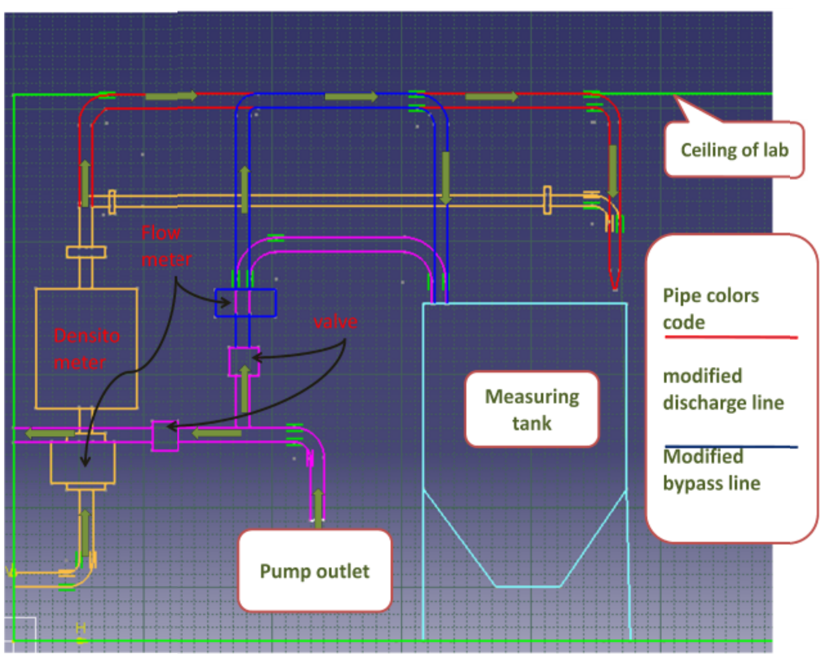

Figure 3.5 Comparison of Previous and Modified Setup

➢ **<u>Add the ABB Magnetic Flow Meter at Bypass Line and increase the length of line</u>**

In the modified setup, ABB Magnetic flow meter is installed at Bypass Line and the height of the outlet pipe from the pump is 2330 mm as compare to the previous height 1256mm.

➢ **<u>Two stands for Pressure Transmitter</u>**

In the Previous experimental setup, there was no stand for the pressure transmitter but in the Modified setup, two stands are fabricated at the height of 1.4m and two pressure transducers are attached to it.

3.2 INSTRUMENTATION

3.2.1 Closed circuit pipe test loop: This is a closed circuit pipe test loop of 50mrn NB pipe having a length of around 40m. The slurry often circulates through the pipe loop returns back to mixing tank either directly or through the measuring tank.

Figure 3.6 Centrifugal slurry pump of the test loop

3.2.2 Mixing or slurry preparation tank: The slurry for tests is prepared in the hopper shaped mixing tank called slurry preparation tank. A stirrer, being fabricated by welding plates on 50 mm pipe which will be rotate around 50 rpm by a 3 phase induction motor 50 rpm) using 1:30 reduction gear, for keeping the slurry always in a well mixed state during experimentation.

The dimensions of slurry preparation tank are as follows

Capacity	:	$0.76m^3$
Total height of tank	:	1.6m
Trapezoidal section	:	l.0m
Square section	:	0.6m
Upper surface area	:	1.0mxl.O m
Lower surface area	:	0.4m x 0.4m
Material	:	SS 202 sheet
Thickness	:	3mm

3.2.3 Measuring tank: The slurry is drawn from the mixing tank by the pump and returned after circulation through the test loop to mixing tank either directly or through the measuring tank. The rate of flow is ascertained by measuring the rise in the level of the slurry in measuring tank collected over a known interval of time.

The capacity of measuring tank has been chosen so that maximum flow rate can be measured with reasonable time duration. Let the maximum flow rate is 10 lps and time for collection is 20 seconds, then the capacity of measuring tank would be 200L

The detailed of measuring tank are as follows:

Capacity	:	$0.242\ m^3$
Total height of tank	:	1045m
Trapezoidal section	:	0.85m
Square section	:	0.6m
Upper surface area	:	0.85 m x 0.85m
Lower surface area	:	0.23 m x 0.23m
Material Thickness	:	SS 202 sheet 3mm

3.2.4 Water flush by pump: Clear water from flush tank is pumped when the slurry pipe line gets blocked with settled slurries. For this purpose one 2 HP centrifugal water pump has been selected and procured.

3.2.5 VFD (Variable Frequency Drive): Operating speed plays predominant role in the performance of slurry pumps. When duty point changes or the original specification is found to be inappropriate then one has to change the operating speed of the slurry pump. There are alternatives by which we can change the speed of slurry pump to meet variable duty points.

One is by trimming the impeller, but unlike water and chemical pumps, it is difficult to trim the hard metal slurry pump impeller. Other option is, belt drives where speed adjustments are done by altering the pulley sizes. However it often more economical then VFD but here still accurate control lacks. The introduction of variable speed drives, on slurry pump duties has offset many of the problems of incorrect selection, duty change or variable head. Particularly when pumping slurries, a small change in slurry concentration or flow rate can lead to a large change in head which presents no problems to a pump with a variable speed drive.

The parameters that should be considered while selecting pump for any slurry application are; the head and discharge requirements, type of slurry to be handled, maximum solid concentrations and initial and operating costs.

A Centrifugal Slurry pump of following specifications has been selected:

(i)	Rated Head	:	14 m of water column
(ii)	Rated Capacity	:	15 lps
(iii)	Rated pump Efficiency	:	50 %
(iv)	Type of Slurry	:	Abrasive
(v)	Maximum Particle Size to be handled	:	2 nun
(vi)	Maximum solid concentration to be	:	Up to 60 % (by weight)
(vii)	Suction Flange Size	:	100 nun
(viii)	Materials of Construction	:	Hard metal with good erosion resistance like Ni-hard, High Chrome etc.

Pump wear is also compensated with accurate speed control, which is a further advantage of VFD. Hence with VFD, process performance is maintained and pump life can be extended with overall process cost savings. A motor of 10 HP is chosen to direct coupled to pump

3.2.6 Electro-magnetic Flow Meter: For continuous monitoring of flow rate pre-calibrated electro-magnetic flow meter is installed as shown in the figure 3.7

Figure 3.7 Magnetic flow meter

. The specifications of electro-magnetic flow meter are as follows:

1.	Pipe diameter	: 50 mm NB
2.	Range of discharge rate	: minimum 0-15 lps
3.	Accuracy	: ± 0.5%
4.	Application	: abrasive slurry flow measurement
5.	Maximum operating pressure	: 5 bar
6.	Maximum liquid temperature	: 60· C
7.	Max. Specific gravity of fluid	: 2.2
8.	Display	: 3 1/2 digit digital display for discharge and velocity

3.2.7 Density monitoring instrument: The concentration of the slurry' flowing through pipe loop is monitored by using a Nucleonic density meter installed in the vertical section of the pipe loop near the discharge end as shown in the figure. Alternatively, a density sampler is also provided to collect the slurry samples. In this method the specific gravity of the sample is determined and then average efflux concentration is evaluated g the standard correlation between the slurry specific gravity and solid concentration.

Figure 3.8 Density Monitoring Instrument

The specification details for nucleonic density meter are as follows;

Detector	:	Scintillation counter, stainless steel
Nominal pipe diameter	:	50 mm
Power supply	:	230/115 V AC
		18 to 32 V DC
Operation temperature	:	0 to + 50°C
Display	:	LCD-display

3.2.8 Pressure Transmitter: The separators for each pressure taps is provided in the loop to allow only water in the pressure measuring devices to measure the variation across the loop, for this, three sets of pressure transducers are provided. One pressure gauge transmitter at pump outlet, one vacuum gauge transmitter at pump inlet and one pressure differential in the pipe loop.

The suction and delivery pressures of the pump were measured by providing pressure transmitters with separation chambers at upstream and downstream of the suction and delivery flanges respectively. At suction side, the LD301 is a smart pressure transmitter for absolute pressure measurements and at delivery side; LD290 is a smart pressure transmitter for gauge measurement. These pressure transmitters are based on a capacitive principle that provides reliable operation and high performance.

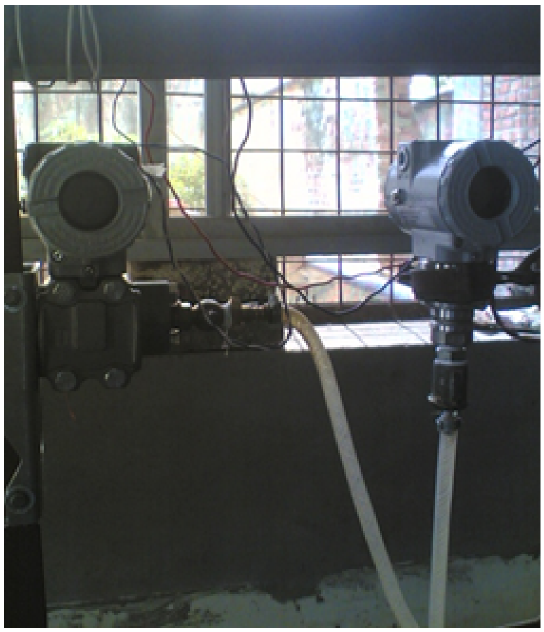

Figure 3.9 Pressure Transducer for suction and delivery gauge

The specifications of gauges are as follows

Type: Gauge

Calibrated range: 0-250 kPa

Type: Vacuum

Calibrated range: 0-100 kPa

Type: Differential

Calibrated range: +20 to -20 kPa

Technical Specifications:

1. Basic Accuracy	:	+/- 0.075%
2. Process temperature limit	:	-10 to 70°C
3. Output signal	:	4-20 rnA with digital display
4. Power supply	:	12V/24V
5. Integral digital display	:	LCD
6. Humidity	:	95% condensing
7. Sensor Housing	:	Stainless steel
8. Process Connection	:	12.5 nun NPT/stainless steel

3.2.9 Speed Measurement Device:

Non contacting type Tachometer (Manufacturer: System pvt. Ltd, New Delhi) is used for measurement of speed and its accuracy is 0.1 rpm.

Figure 3.10 Tachometer

Figure 3.11 Power Analyzer

3.2.10 Power Measurement Device:

For measurement power, HIOKI 3165 clamp on power Hi Tester instrument are used. Accuracy of power analyzer is 0.001kW.

3.3 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 800rpm, 1000 rpm, 1200 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.

The details of the instruments and methodology adopted for the measurements are described as follows:

(a) **Pressure measurement:** The suction and delivery pressures of the pump were measured by providing pressure taps with separation chambers. The separation chambers were provided to have an interface separation for slurry and manometric fluid / pressure gauge material, water being the intermediate fluid. The separator outlet was connected to one limb of U-tube mercury manometer for suction pressure and to a Bourdon tube type pressure gauge for discharge pressure measurements. The U-tube manometer had least count of 1 mm of mercury column for suction pressure measurement. A 250 mm dial size Bourdon tube type calibrated pressure gauge was used for delivery pressure measurement of the pump.

(b) **Flow measurement**: Flow can be measure either by using measuring tank or by electro magnetic flow meter / ultra-sonic flow meter. In the measuring tank method, the flow of slurry in the test loop is diverted to the measuring tank of 0.242 m3 having a height of 1.45 meters for a known interval of time. The rise in the level of slurry in the tank for a given time interval was measured using a scale of a least count of 1 mm. The least count of stop watch used for the time interval was 0.01 second. The measuring tank was also used for flow meter calibration. Due to non delivery of electro-magnetic flow meter ordered from ABB, Delhi created an obstacle in the way of experimental work. Thus a clamp on type ultra sonic flow meter is used for continuous monitoring of the flow rate of the test loop.

The mal functioning of ultra sonic flow meter after water runs increased my work and labour exponentially and measured the rate of flow of pump by measuring tank method.

(c) **Speed measurement:** The speed is measured by a non contact type tachometer. It measures the rotational speed of pump with the help of a light reflector tape pasted at accessible portion of the pump-motor shaft and gives digital display of the speed of the pump. The resolution of tachometer was 1 rpm.

(d) **Density measurement:** Due to delay in completing the necessary formalities for the purchase of Nucleonic type density meter ordered from Berthold Technology (P) Ltd. Germany could not arrive before conducting the experiments. Thus the density of slurry is measured by density sampler method. In this method, two efflux samples were collected in measuring jar. The volume of mixture indicated by jar was noted and then the mixture is weighted by a weighing machine (Digital Weighing Machine-TH 5DDDA). Finally the density of mixture comes by the relation;

Density = Mass of the mixture I volume of the mixture.

(e) **Measurement of input power to the pump:** In order to calculate the efficiency of pump under examination, we were in need of input power to the pump. To achieve the objective, a power analyzer has been installed between output of VFD and input to the pump motor, and the KVA rating of motor and power factor were noted. The input power to the pump is simply calculated as,

Pump input power = (efficiency of motor) x (motor input power)

3.4 RANGE OF PARAMETERS STUDIED

Experiments have been carried out on centrifugal slurry pump to investigate the pump performance with clear water only. The head developed, power and efficiency of the pump for clear water have been measured at various mass flow rates to estimate the head-capacity, power-capacity and efficiency-capacity characteristics. These characteristics for 50M WILFLY Pump have been evaluated at four speeds namely 800 rpm, 1000 rpm, 1200 rpm and 1450 rpm with clear water. Experiments were conducted with clear water at different mass flow rate and at different rpm's to evaluate the performance characteristics of the pump.

3.5 PERFORMANCE CHARACTERISTICS OF SLURRY PUMP

The performance characteristics of centrifugal slurry pump have been evaluated experimentally for handling clear water. The experimental observations on pump with clear water at the rated speed 1450 rpm are presented graphically in Figures 3.12-3.15.

Figure 3.12 shows that the pump input power for water increases steadily with increase in discharge rate and its maximum value is 3.93682 KW at 10.753 lps discharge. The pump efficiency characteristic with water, shown in Figure 3.15, depicts that all the data points lie on a smooth curve and the maximum efficiency of 31.175 % is measured. Figure 3.13 shows that the maximum value of specific head is 3.99 (m). Figure 3.14 shows that maximum value of actual head developed by pump is 16.50 (m) at 1450 rpm and at 0 lps of specific discharge. It shows that with increase in discharge actual head is decreased.

The pump input power was obtained from the knowledge of the motor input power and motor efficiency and its detail formulation are given bellow.

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

$$H_{mano} = \left(\frac{p_a}{\rho g} + \frac{P_2}{\rho g} + z_2\right) - \left(\frac{p_a}{\rho g} + \frac{P_1}{\rho g} + z_1\right) \quad (3.1)$$

where, P_a= Atmospheric pressure in Pascal

ρ= Density of fluid in kg/m^3

g=Gravitational acceleration in m/s^2

P_2= Delivery pressure in Pascal

P_1= Suction pressure in Pascal

Z_1= Suction datum head in mwc.

Z_2= Delivery datum head in mwc.

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

$$H_{total} = H_{mano} + \frac{V_2^2}{2g} - \frac{V_1^2}{2g} \quad (3.2)$$

where, V_2= Delivery pipe velocity in m/s

V_1= Suction pipe velocity in m/s

3. Correction of head ($H_{1450rpm}$) and discharge ($Q_{1450rpm}$) at rated speed (1450 rpm)

$$H_{1450rpm} = H_N \times \frac{1450^2}{N^2} \quad (3.3)$$

$$Q_{1450rpm} = Q_N \times \frac{1450}{N} \quad (3.4)$$

$$P_{1450rpm} = P_N \times \frac{1450^3}{N^3} \quad (3.5)$$

4. Power outlet in watts

$$P_{out} = \rho g Q H \quad (3.6)$$

5. Efficiency of pump in percentage

$$\eta_{pump} = \frac{P_{out}}{P_{in}} \times 100 \quad (3.7)$$

6. Measurement of slurry concentration C_w

$$C_w = \frac{\rho_s(\rho_m - \rho_l)}{\rho_m(\rho_s - \rho_l)} \quad (3.8)$$

- **Experimental Results of Performance of centrifugal slurry pump with water only at 1450 rpm, 1250 rpm, 1000 rpm and 800 rpm are shown in table 3.2 (Annexure 1), table 3.3 (Annexure 2), table 3.4 (Annexure 3) and table 3.5 (Annexure 4) respectively.**

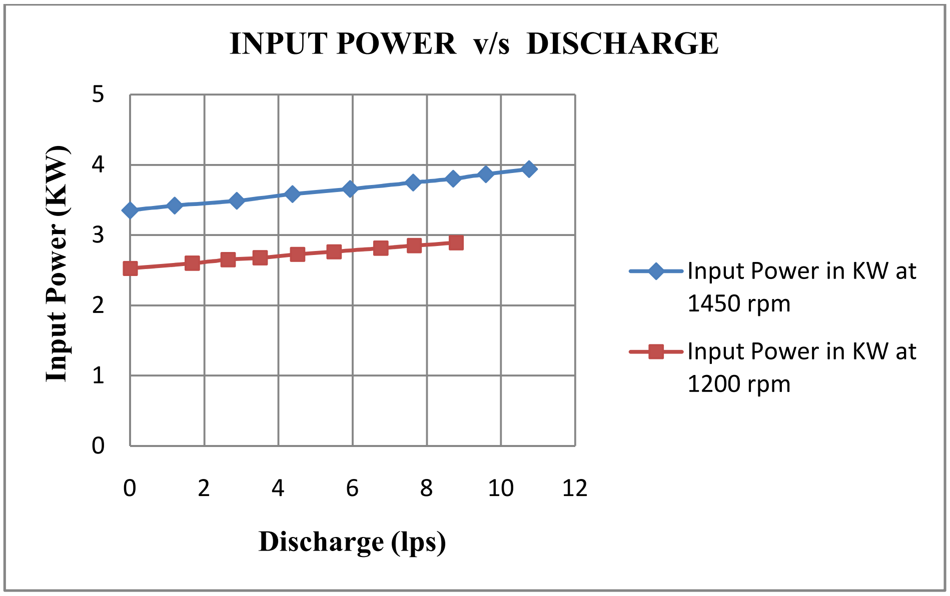

Figure 3.12 Input power-Discharge characteristics of centrifugal slurry pump

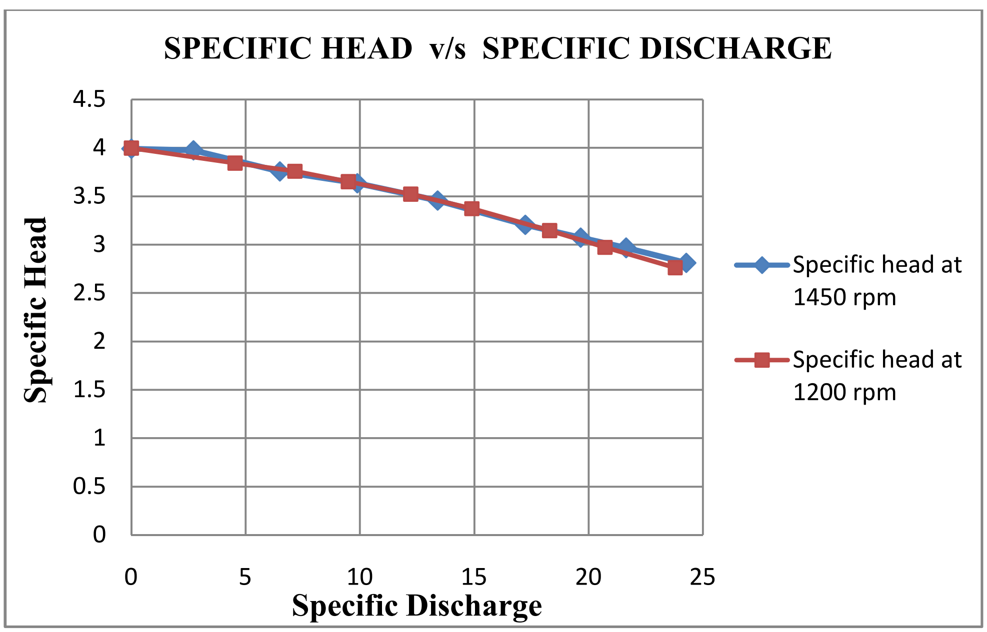

Figure 3.13 Specific head-Discharge characteristics of centrifugal slurry pump

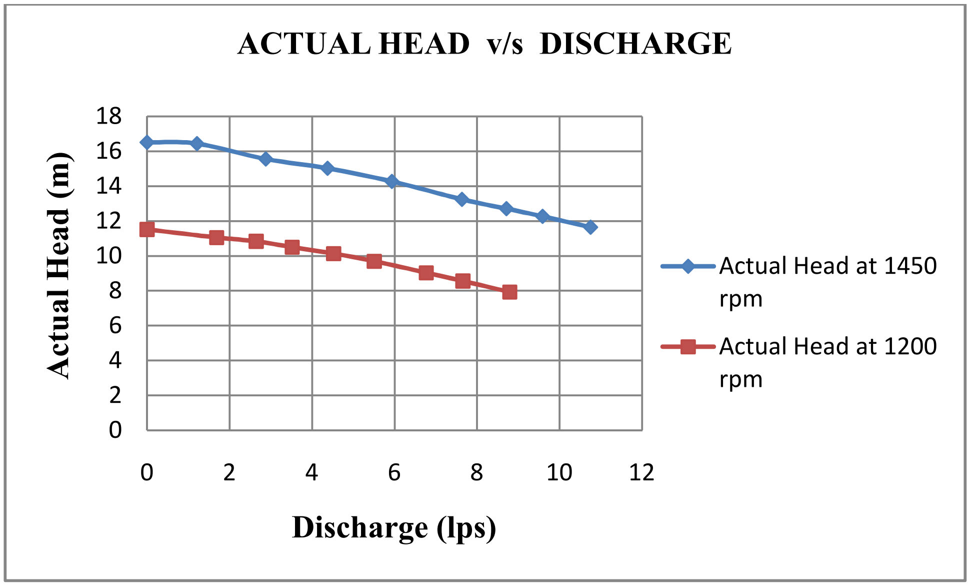

Figure 3.14 Actual Head-Discharge characteristics of centrifugal slurry pump

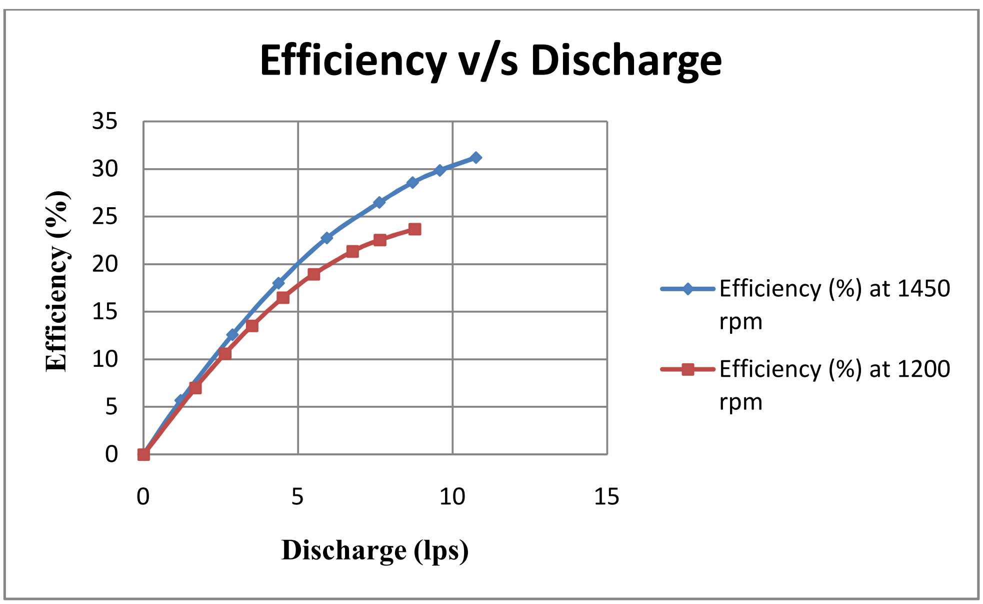

Figure 3.15 Efficiency-Discharge characteristics of centrifugal slurry pump

CHAPTER 4

STUDY OF PROPERTIES OF BOTTOM ASH

Bottom ash refers to the non-combustible constituents of coal with 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 is, 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.

4.1 BOTTOM ASH

Bottom ash and fly ash are quite different physically, mineralogical, and chemically. Bottom ash is a coarse, granular, incombustible by-product that is collected from the bottom of furnaces that burn coal for the generation of steam, the production of electric power, or both. Bottom ash is coarser than fly ash, with grain sizes spanning from fine sand to fine gravel. The type of by-product produced depends on the type of furnace used to burn the coal.

Figure 4.1 Bottom ash

4.2 PROPERTIES OF BOTTOM ASH

4.2.1 Physical properties

Bottom ash has angular particles with a very porous surface texture. Bottom ash particles range in size from a fine gravel to a fine sand with very low percentages of silt-clay sized particles. Bottom ash is predominantly sand-sized, usually with 90 to 100 percent passing below 2000 micron sieve size, 90 to 80 percent passing a below 1400 micron sieve size, 30-20 percent passing below 75 micron sieve size. Boiler slags have a smooth surface texture, but if gases are trapped in the slag as it is tapped from the furnace, the quenched slag will become somewhat vesicular or porous.

4.2.2 Chemical properties

Bottom ash and boiler slag are composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulfates, and other compounds. The composition of the bottom ash or boiler slag particles is controlled primarily by the source of the coal and not by the type of furnace.

4.3 BENCH SCALE TESTS

Standard methods are used in the laboratory to determine the physical properties of solids, carrier fluid and slurry. A brief description of these tests is presented here:

4.3.1 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). Two methods namely sieve analysis and hydrometer analysis, are employed to get this 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. The particle size distribution of the fine particles collected (<75 mm) is then determined using the standard hydrometer analysis. The experimental result of Bottom Ash is shown in **table 4.1 in (Annexure 5)**

$$\text{Weight mean diameter (dwm)} = \sum_{i=1}^{n} (Wi * Di)/(Wi)$$

$d_{50} = 230\ \mu$ $\quad d_{wm} = 162.139\ \mu$

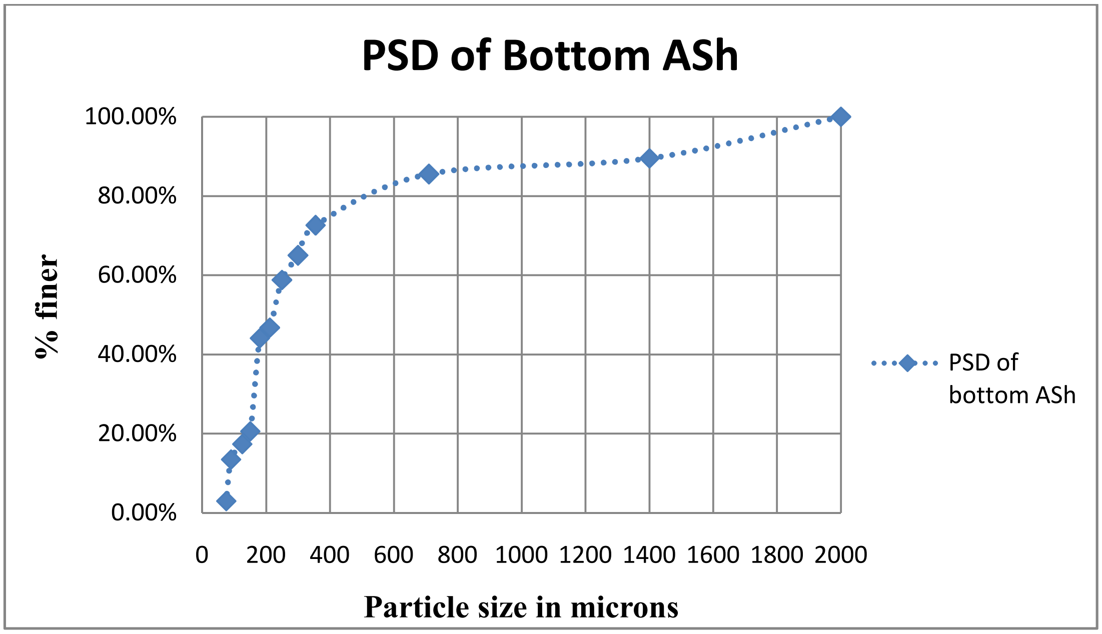

Figure 4.2 Variation of particle size with % finer.

4.3.2 Specific Gravity of Bottom Ash

In the present study, the specific gravity of solid particles (bottom Ash) is determined using Standard Pyknometer Method. In this method first take 50 ml Pyknometer and clean it thoroughly, keep it in the oven in order to remove moisture from pyknometer. After 2 hours, take out the pyknometer from an oven and allow it to cool down, and then take the weight of pyknometer (Wb). After weight put some solids (over dried) about 30 grams in it and weight it again and note down this weight (Wbs). After this slowly pour water (distilled) in the pyknometer so that no air is entrapped in it and shake it well, and keep on pouring the water. Shake it well each time till all the solid get wet. Fill 3/4th of bottle with water and put the thumb on the mouth of the bottle and shake it well for 5 minutes. Keep it for at least 2 Hours, so that air bubbles get out from the bottle. Then fill the bottle of water and cork it. Clean it with cloth/tissue paper and weight it. Note down the weight (Wbsw). Now remove the solids from the bottle and clean it, Thoroughly, Dry it and fill it with distilled water. Note down the weight (Wbw). Calculate the specific gravity of solids as given below.

Specific Gravity of solids= (Wbs-Wb)/(Wbw-Wbsw+(Wbs-Wb))

Where Wb = Weight of beaker

Wbs = Weight of beaker and solid

Wbw = Wight of beaker and water

Wbsw = weight of beaker, solid and water

Table 4.2 Specific Gravity of Bottom Ash

S.No.	Weight of beaker (Wb) gm	Weight of beaker+solid (Wbs)gm	Wbsw (gm)	Wbw(gm)	Specific Gravity
1	32.4105	62.4118	167.26	150.2206	2.314575795
2	32.7065	62.8265	163.436	146.7342	2.244712406
3	33.4172	63.4178	161.9163	145.2747	2.245721985

Density of solid= Specific gravity * Density of Liquid

Specific gravity	Density of Liquid kg/m^3	Density of Bottom Ash (kg/m3)
2.252711808	998.2	2248.656926

Figure: - 4.3 Pyknometer **Figure: - 4.4 Oven**

4.3.3 Static Settled Concentration

The static settled concentration is a very important parameter as it decides the highest limit of solid concentration, which can be achieved by gravitational settling. The static settled concentration depends on a large number of parameters like specific gravity, shape and size distribution of solids, density and viscosity, of carrier fluid etc. It is well accepted that the optimum concentration for solids transportation is around 5 to 10% lower than the static settled value.

In the present study, the static settled concentration has been determined by preparing a slurry sample of intermediate concentration i.e. 10% (by weight) and allowing it to settle in a graduated measuring jar till the level of the solids become constant. This value of solid concentration in the settled portion of slurry is the static settled concentration. The slurry level at regular intervals of time was also recorded during the process of settling of the slurry to determine the setting rate of the slurry.

In this test take 160 gram of solid (Bottom ash) in jar and put 1400 gram water in jar to make the 10% concentration by weight. Then leave the jar for 2 hour. After 2 hours block the jar opening by one hand and vigorously mix the mixture and keep jar upright. Note the reading level of sand (bottom ash) w. r. t time (sec) in each 10 second. Note the reading till you get steady static state. Calculate the static settled concentration, for the volume and specific gravity of same. Then plot concentration v/s time to get static concentration. The experimental results of Static Settled Concentration of bottom ash is shown in **Table 4.3 in (Annexure 6)**

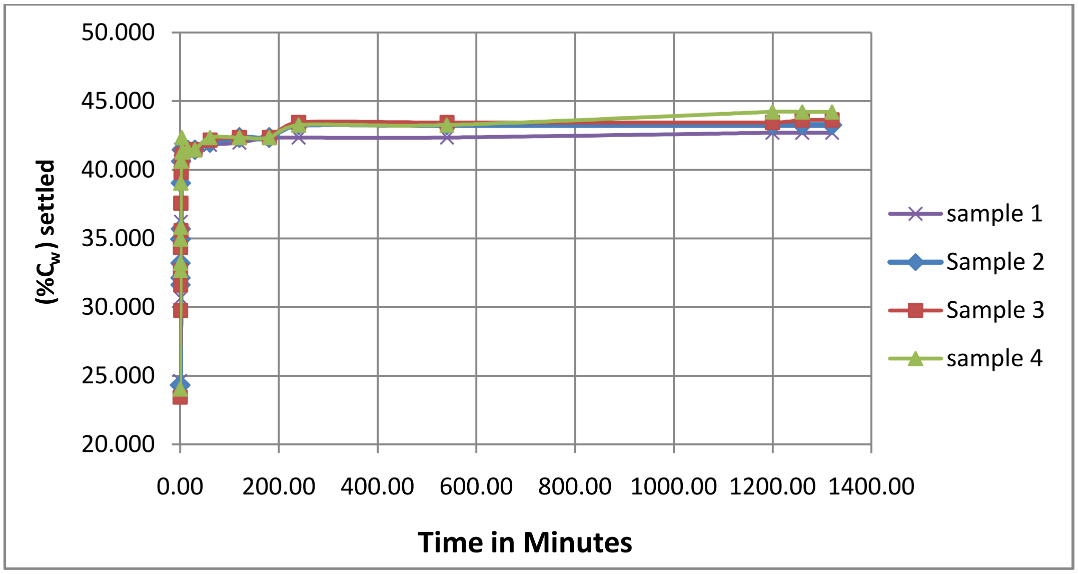

Figure 4.5 :- Static Settling Characteristics of Bottom Ash

Figure :-4.6 Beakers used for Static Settled Conc. of Bottom Ash

4.3.4 P^H VALUE

A pH meter was used for measurement of the pH value of the slurry of any given solid concentration. The electrode of the meter was first moistened with tap water and 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. The experimental results of ph value of bottom ash are shown in **table 4.4 in (Annexure 7) and table 4.5 in (Annexure 8).**

In this test first prepare 7 PH or 4 PH solution dissolve 1 buffer tablet in 100 ml of distilled water. Insert the probe PH meter in the solution and wait for 5 minutes till readings get stabilized. If reading is not equivalent to the PH of solution, then change the control and make the readings equivalent to the PH value of solution. Remove the probe and dip into the distilled water beaker and then dip into the solution or slurry of which PH value is to be determined. Wait for 5 minutes till the reading is stabilized.

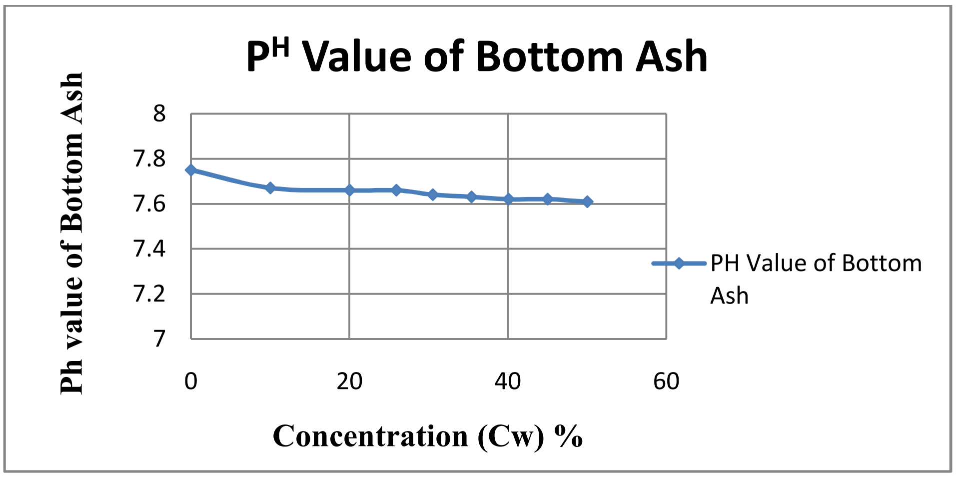

Figure 4.7: - Ph value of bottom ash at different concentration.

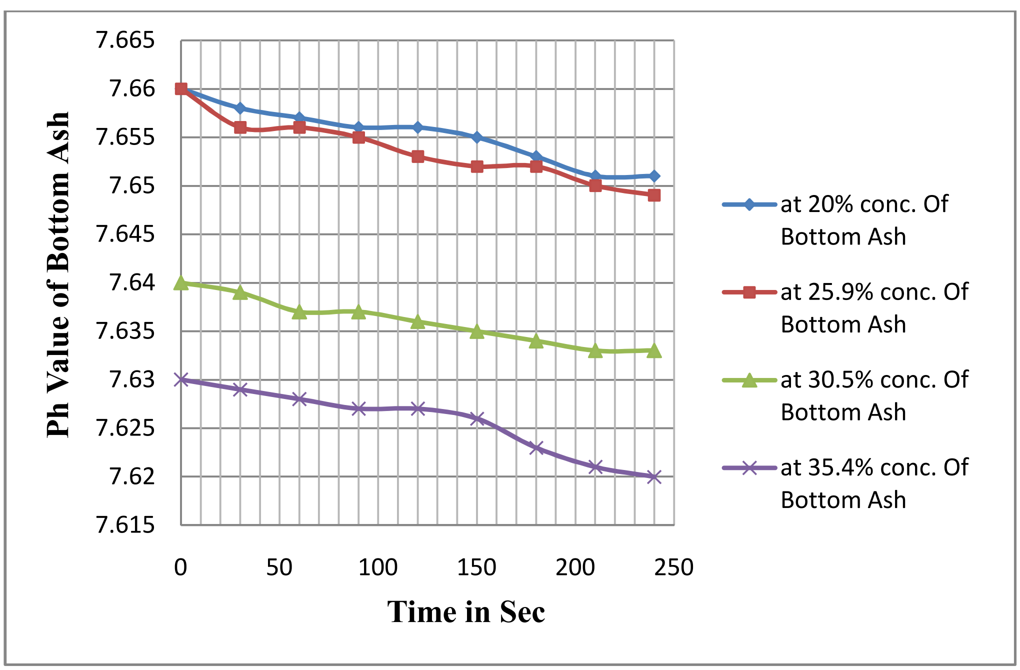

Figure 4.8:- Ph value of bottom ash v/s Time interval.

4.3.5 Rheological Behavior of Solid-Liquid Mixture

In the estimation of energy required for transporting solid particles through pipelines, viscosity of the slurry plays a vital role. 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. Therefore the variation of shear stress with shear-rate has been measured for a wide range of concentrations varying from 20 to 40% (by weight) for bottom ash and water slurries to establish the rheology of the mixtures.

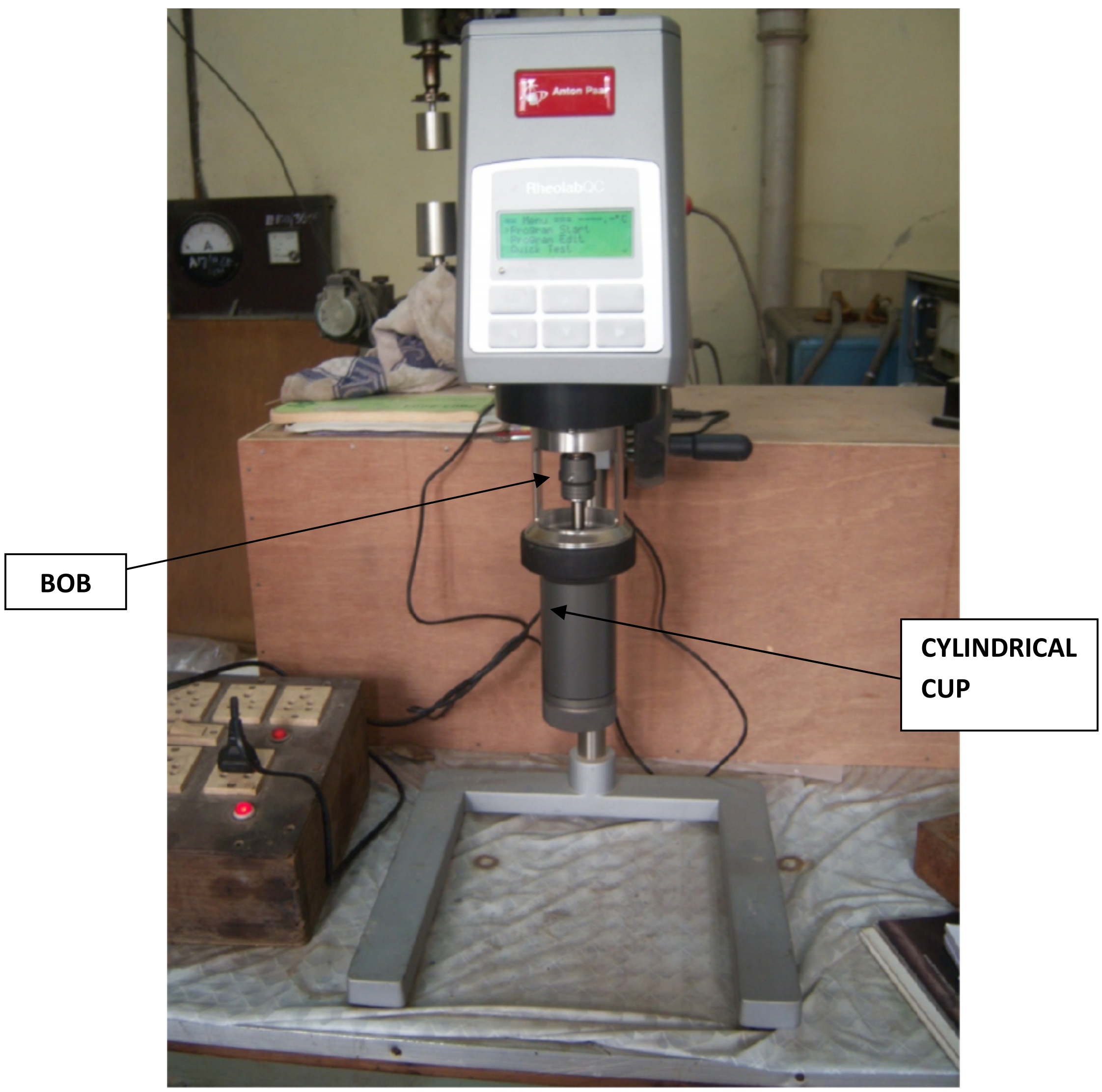

Figure 4.9: Setup of Rheometer

The Rheometer, (Make: Anton Paar, Gurgoan) shown in figure 4.9 has been used for determination of rheological characteristics of the slurries. A particular cylindrical geometry is used for particular type of fluid depending upon nature of fluid. Slurry undergoes shearing action as the rotation of the bob takes place. Before conducting tests on rheometer, the bob and cup assembly 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 CSR (Controlled shear rate) and CSS (Controlled shear stress) basis. Most of the experiments are 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. The experimental results of viscosity of bottom ash are shown in **table 4.6 in (Annexure 9)**

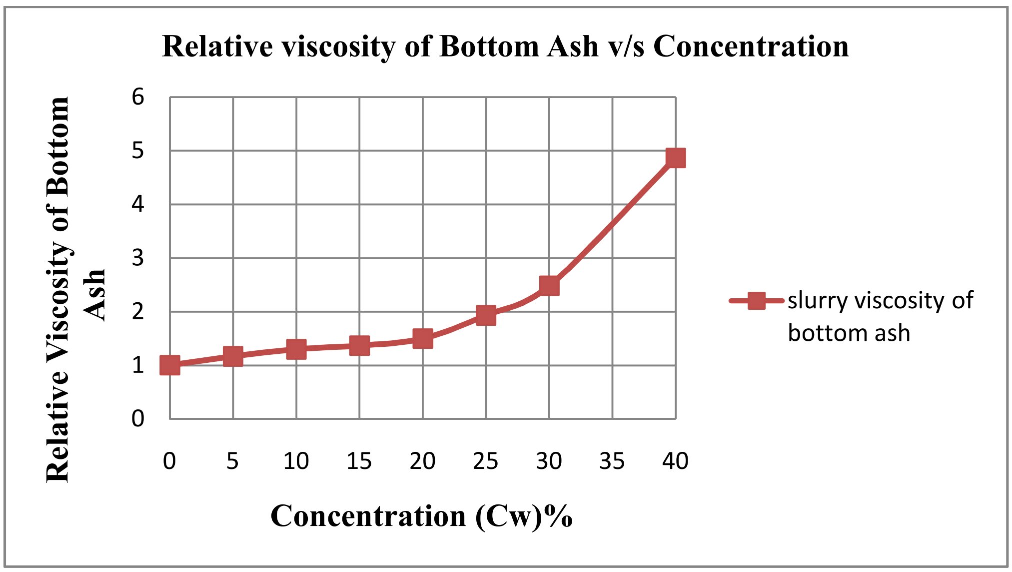

Figure 4.10:- Variation of viscosity of bottom ash with concentrations

CHAPTER 5
COMPUTATIONAL FLUID DYNAMICS

5.1 INTRODUCTION

In the recent years, Computational Fluid Dynamics (CFD) has been increasingly used for a wide variety of engineering applications. In the beginning, the use of these techniques was customary only in the areas of aerospace and nuclear technology. Subsequently, the use has spread to a variety of products, physical situations, and manufacturing processes. Some examples of interesting applications of computational modeling are cooling of electronics systems, rotating and reciprocating machinery, furnaces and combustion chambers. The basis of computational fluid dynamics is the reduction of continuum deferential equation describing the dynamics of the fluid (Navier stokes, Mass & energy conservation equation) into a system of algebraic equation of finite number of “grid” points, and the solving of the equation at these limited number of points only. Computational Fluid Dynamics (CFD) provides a qualitative or quantitative prediction of fluid flows by means of

· Mathematical modeling (partial differential equations)

· Numerical methods (discretization and solution techniques)

· Software tools (solvers, pre- and post processing utilities)

Fluid flows and related phenomena can be described by partial differential (or integro differential) equations, which cannot be solved analytically except in few special cases. To obtain an approximate solution numerically, we have to use a discretization method which approximates the differential equations by a system of algebraic equations, which can then be solved on a computer. The approximations are applied to small domains in space and/or time so the numerical solution provides results at discrete locations in space and time. Much as the accuracy of experimental data depends on the quality of the tools used, the accuracy of numerical solutions is dependent on the quality of discretization used. CFD is finding its way into process, chemical, civil, and environmental engineering. Optimization in these areas can produce large savings in equipment and energy costs and in reduction of environmental pollution.

5.2 CFD PROCEDURE

In order to obtain better design in CFD, following procedure (Figure 5.1) is applied so that fluid flow can easily be modeled in the centrifugal pump impeller.

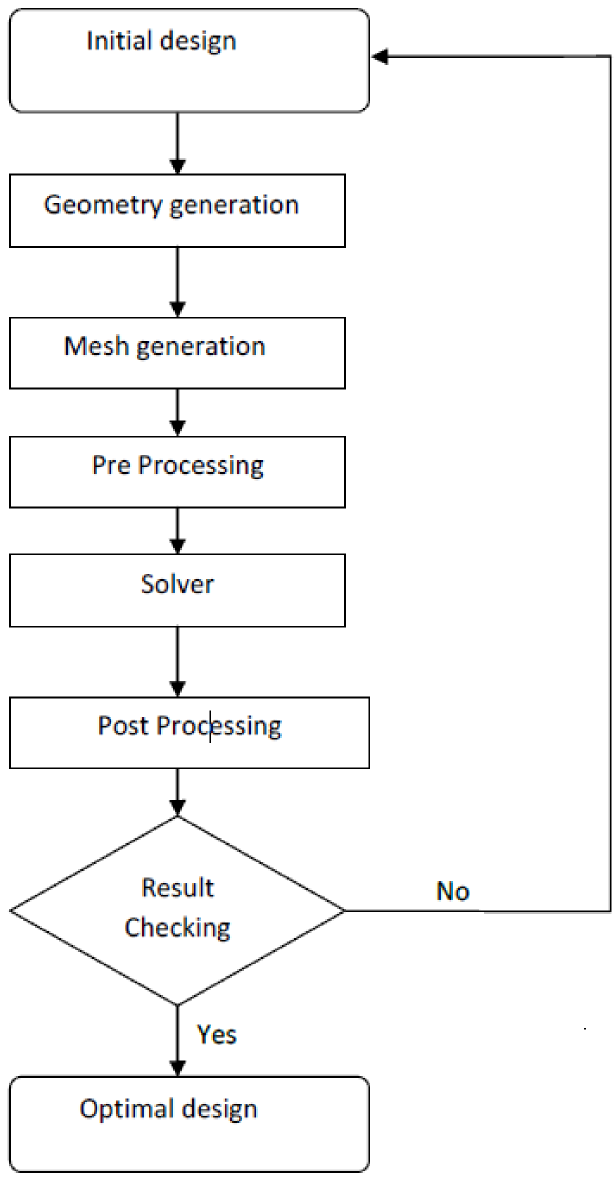

Figure 5.1 Flow chart of CFD procedure

All CFD codes contain three main elements:

1. A **pre-processor**, which is used to input the problem geometry, generates the grid; define the flow parameter and the boundary conditions to the code.
2. A **flow solver**, which is used to solve the governing equations of the flow subject to the conditions provided. There are four different methods used as a flow solver:
   i. **Finite difference method**: Finite difference method utilizes the Taylor series expansion to write the derivatives of a variable as the differences between values of the variable at various points in space or time.
   ii. **Finite element method**: In the finite element method, the fluid domain under consideration is divided into finite number of sub-domains, known as elements. A simple function is assumed for the variation of each variable inside each element. The summation of variation of the variable in each element is used to describe the whole flow field.
   iii. **Finite volume method**: The finite volume method is currently the most popular method in CFD. The main reason is that it can resolve some of the difficulties that the other two methods have. Generally, the finite volume method is a special case of finite element.
3. A **post-processor**, which is used to massage the data and show the results in graphical and easy to read format.

5.2.1 Governing equations of CFD

The physical aspects of any fluid flow are governed by the following three fundamental principles:

a) Conservation of mass

b) Conservation of momentum (Newton's second law)

c) Conservation of energy (first law of thermodynamics)

These fundamental principles can be expressed in terms of mathematical equations which in their most general form are usually partial differential equations. CFD is the art of replacing the governing partial differential equations of fluid flow with numbers and advancing these numbers in space and / or time domain to obtain a final description of complete flow field of interest. With the development of high-speed digital computers, CFD has become a powerful tool to predict flow characteristics in varied problem, in an economical way.

5.3 BOUNDARY CONDITIONS

Boundary conditions are the set of conditions specified for the behavior of the solution to a set of differential equations at the boundary of its domain. Boundary conditions are important in determining the mathematical solutions to many physical problems. These conditions specify the flow and thermal variables on the boundaries of a physical model. They are, therefore, a critical component of simulation and it is important that they are specified appropriately. The boundary conditions are defined on cell faces and they do not have a finite thickness and they provide a means of introducing a step change in flow properties.

5.3.1 Types of boundary conditions

The following boundary conditions at the walls are used with the equations of motion

• No slip conditions

At fluid wall interface, there must be no slip\

$$Vfluid = Vwall \quad (1)$$

• Temperature field

The principle different types of boundary conditions are as follows:

• Dirichlet boundary condition (first type)

• Neumann boundary condition (second type)

• Robbins boundary condition (third type)

5.4 MODELING OF THE PUMP COMPONENTS

To study the numerical analysis on the pump, the dimension data of the pump was required to generate a model in the software. For taking the dimensions of components reverse engineering techniques were used. The test loop was shut and all the valves were closed to prevent any leakage of water or slurry. The pump was first disconnected from the pipes of the test loop and the water in the pump assembly was drained. The pump assembly was disassembled and all the parts were separated. The assembly consisted of the casing; impeller and suction discs (frame 37 and follower plate).

5.4.1 Computational Modeling

- **Problem specification and Geometry preparation**

The first step in computational modelling is to understand specification of the problem including geometry, flow conditions, and methodology of simulation. The geometry is obtained from measurement of existing "50M WILFLEY" centrifugal slurry pump flow passage. The geometry of impeller, volute casing and inlet passage are modelled by using pre-processor Gambit 2.3.16.

Geometry is modelled by following steps

- First create the vertices of impeller blade profile, casing and inlet passage.
- Connect the vertices by cubic spline curve and create the edges of blade and casing.
- Connect the edges and create the faces.
- For three dimensional modelling stitch the faces together and create the volume of impeller blade, impeller flow passage, inlet flow passage and casing flow region.

  Figure 5.1 shows cross sectional view of actual centrifugal slurry pump.

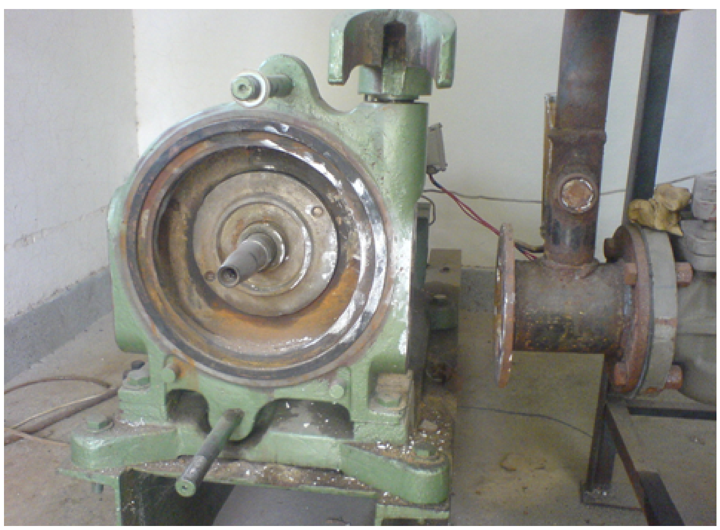

Figure 5.1 Disassembled view of centrifugal slurry pump

Three-dimensional computational model of volute casing, impeller, flow passage are shown in Figure 5.2, 5.3, 5.4.

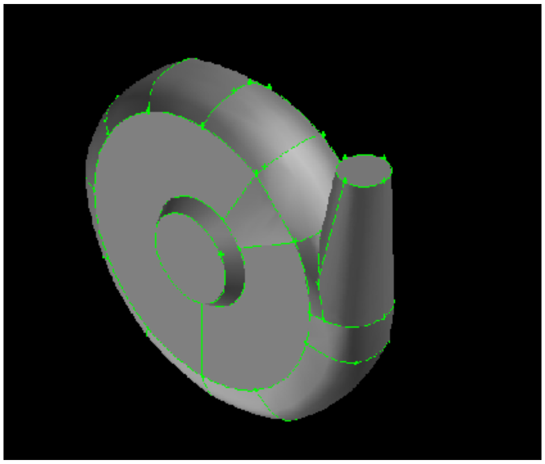

Figure 5.2:- Casing domain

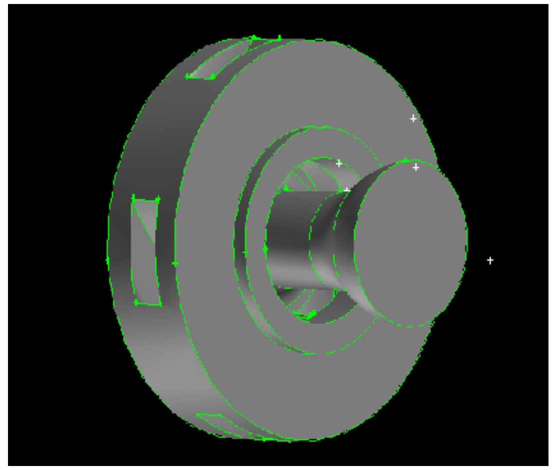

Figure 5.3:- Impeller domain

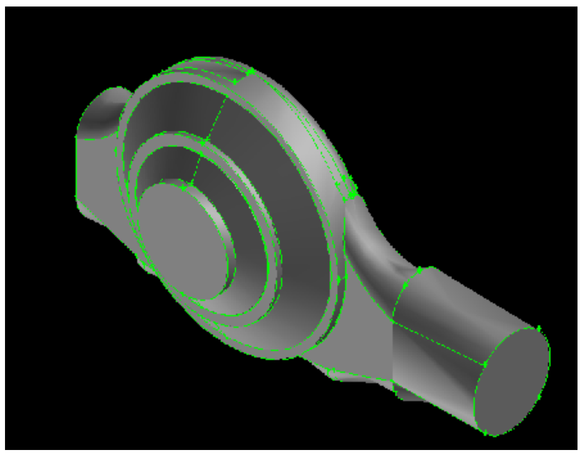

Figure 5.4:- Flow passage domain

5.4.2 Mesh Generation

The first step after modeling the pump components is importing the model in pre-processor and descretize it into smaller elements. The model is descretized so that the affect of external or internal forces acting on a body can be captured at any point on the body. This process of discretization is called meshing. In the present work, coarse tetrahedral mesh with interval size 6 is used in pump domain.

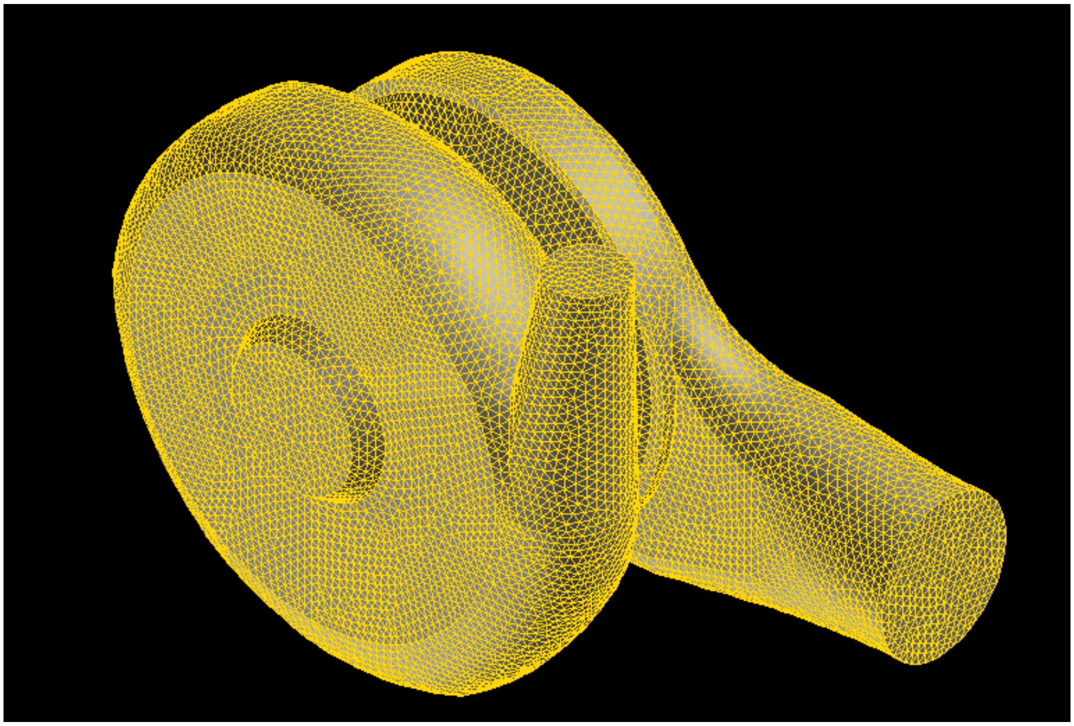

Figure 5.5 Coarse mesh (tetrahedral elements with interval count 6)

Volume	No of Elements
Fluid in impeller	30760
Inlet passage (4 highly skewed elements)	116026
Casing	110149

CHAPTER 6

NUMERICAL EVALUATION OF PUMP PERFORMANCE HANDLING BOTTOM ASH

6.1 BOUNDARY CONDITIONS

The pump inlet was defined as mass flow rate boundary condition and pressure outlet was given at the pump outlet. The pressure outlet condition is appropriate when the flow exits at atmospheric pressure and back pressure is created in the flow and is best suited for pumps. The outer surfaces such as walls of casing and inlet passage were given wall boundary conditions.

Following boundary types are considered for numerical simulation.

- Mass flow inlet: It is the inlet face at suction pipe entry.
- Wall: It is applied to Inlet passage faces, rotating faces of impeller and fixed faces of volute casing.
- Pressure outlet: It is applied on outlet face at delivery pipe entry.
- Fluid zone: It is applied suction pipe, impeller passages, volute casing, inlet passage and delivery pipe.
- Solid zone: It is applied to impeller solid part.

6.2 SOLUTION TECHNIQUE

The multiple reference frame (MRF) model is used to simultaneously simulate flow through rotating impeller and stationary volute casing. The impeller is modeled in a rotating reference frame and suction pipe, inlet passage and casing are kept as stationary reference frame. The mixing multiphase model is used to simulate slurry transportation through pump and it uses a single fluid approach.

MRF is a steady-state approximation in which individual cell zones move at different rotational/translational speeds. This approach is appropriate when the flow at the boundary between these zones is nearly uniform (“mixed out"). While the multiple reference frame approach is clearly an approximation, it can provide a reasonable model of the time-averaged flow for many applications. For example, the MRF model can be used for a turbo machinery application in which rotor-stator interaction is relatively weak. In mixing tanks, since the impeller-baffle interactions are relatively weak, large-scale transient effects are not present and the MRF model can be used. In general, any problems where transients due to rotor-stator interaction are small are candidates for the MRF model. Another potential use of the MRF model is to compute a flow field that can be used as an initial condition for a transient sliding mesh calculation. This eliminates the need for a startup calculation.

Following techniques are used for simulation of centrifugal slurry pump handling 2%,5%, 10%, and 20% concentrated (by weight) bottom ash slurry.

- The most appropriate numerical scheme for the flow equations is segregated implicit solver.
- The standard k-ε model is used for turbulence modeling with standard wall function. The standard k- ε model is a semi-empirical model based on model transport equations for the turbulence kinetic energy (k) and its dissipation rate (ε).
- The mixture multiphase model is selected for slurry transportation and its phases are selected as phase-1 is water and phase 2 is bottom ash slurry at any specific volume fraction.
- The mixture moment equation is solved using first-order-upwind-scheme.

Under relaxation factor are chosen as 0.3 for pressure, 0.7 for momentum equation, 0.8 for turbulent kinetic energy and 0.8 for turbulent dissipation rate. These values are selected for fast convergence of solution and better results. Residual tolerance 0.001 is used for convergence of velocity and turbulence parameters.

6.3 POST PROCESSING OF CFD RESULT

The numerically simulated flow field of centrifugal slurry pump was analyzed to investigate the performance characteristics of centrifugal slurry pump at 2%, 5% and 10% and 20% concentration at 1400 rpm. In this the velocity and pressure contours are developed and gives the information about the maximum velocity and pressure region developed on the impeller. The study of flow field is divided into following two parameters behavior across different pump sections are velocity vectors and static pressure contours.

- **Velocity vectors**: - Velocity vectors may be help to identify directional motion of fluid particles in impeller domain. It can be seen internal circulation and separation zones in impeller vane channels. The velocity vectors at different flow rates and at different concentrations are shown in Figure 6.1- 6.6. As the flow entering the impeller eye, it is diverted into the blade-to-blade passage. Due to the unsteady effect developed at upstream, the flow entering the passage is no longer tangential to the leading edge of impeller blade. Separation of flow can be observed at all passages leading edge. The following observations are made

1. The flow field inside the pump is visualized at two different flow rates 10.735 lps, 4.375 lps at 2% concentration and 10.753 lps, 4.54 lps at 5% concentration.
2. It is shown that the velocity is high at the tailing edge of the impeller vane as compare to the leading egde of vane as shown in figure 6.5 and 6.6

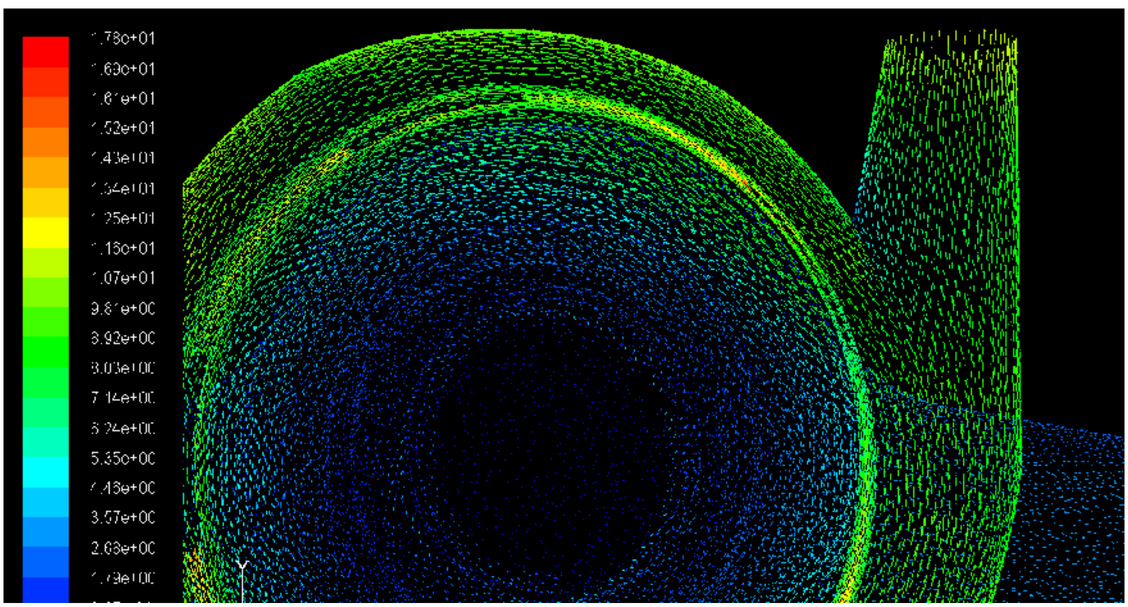

Figure 6.1 Velocity vectors near casing for 2% concentration. (Q=10.753, N= 1450rpm)

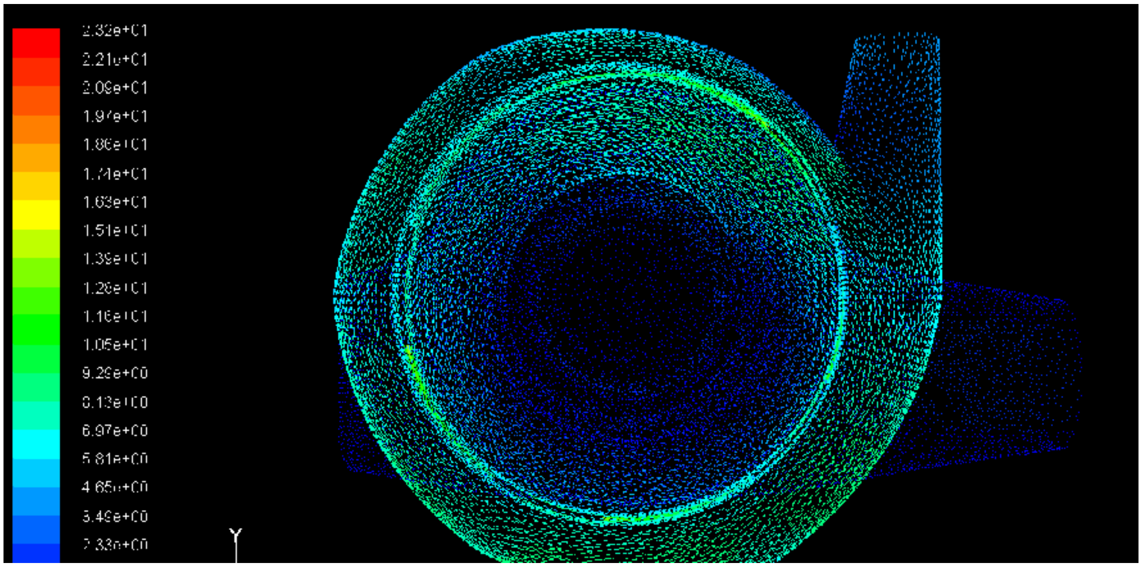

Figure 6.2 Velocity vectors near casing for 2% concentration. (Q=4.375, N= 1450rpm)

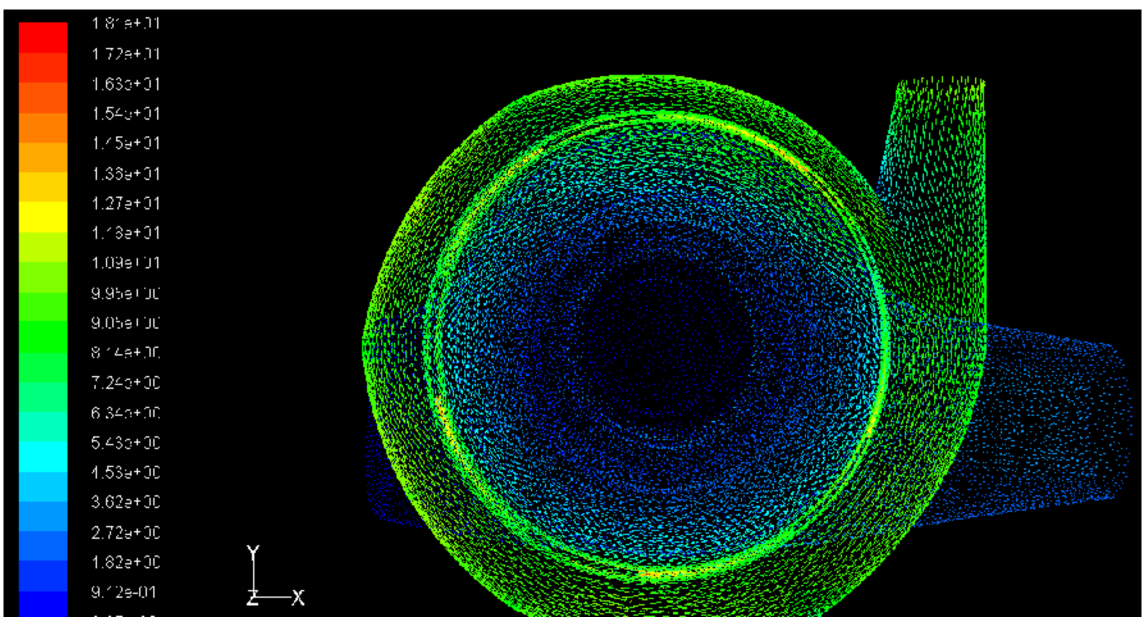

Figure 6.3 Velocity vectors near casing for 5% concentration. (Q=10.753, N= 1450rpm)

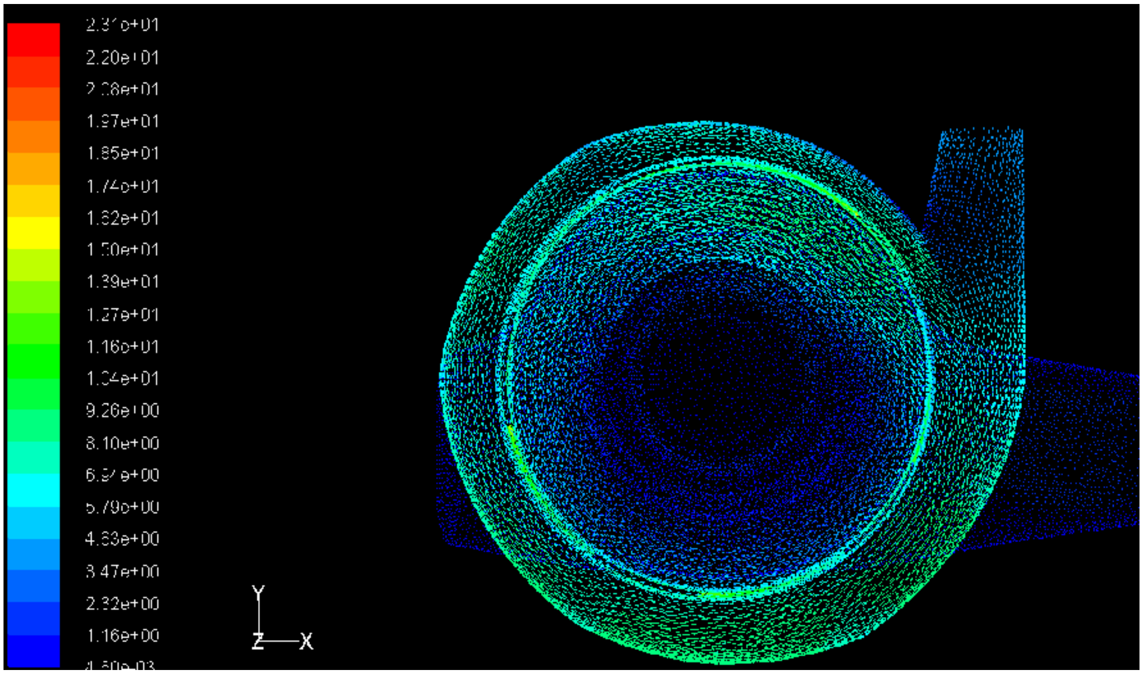

Figure 6.4 Velocity vectors near casing for 5% concentration. (Q=4.54, N= 1450rpm)

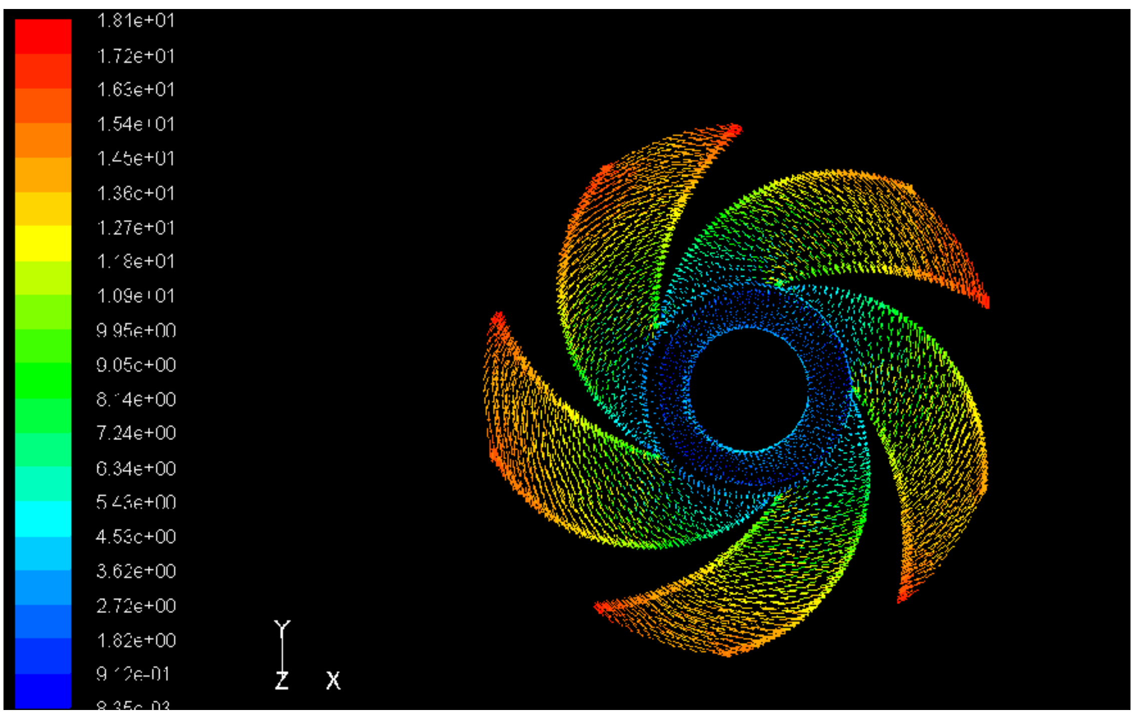

Figure 6.5 Velocity vectors near impeller for 5% concentration (Q=10.753, N= 1450 rpm)

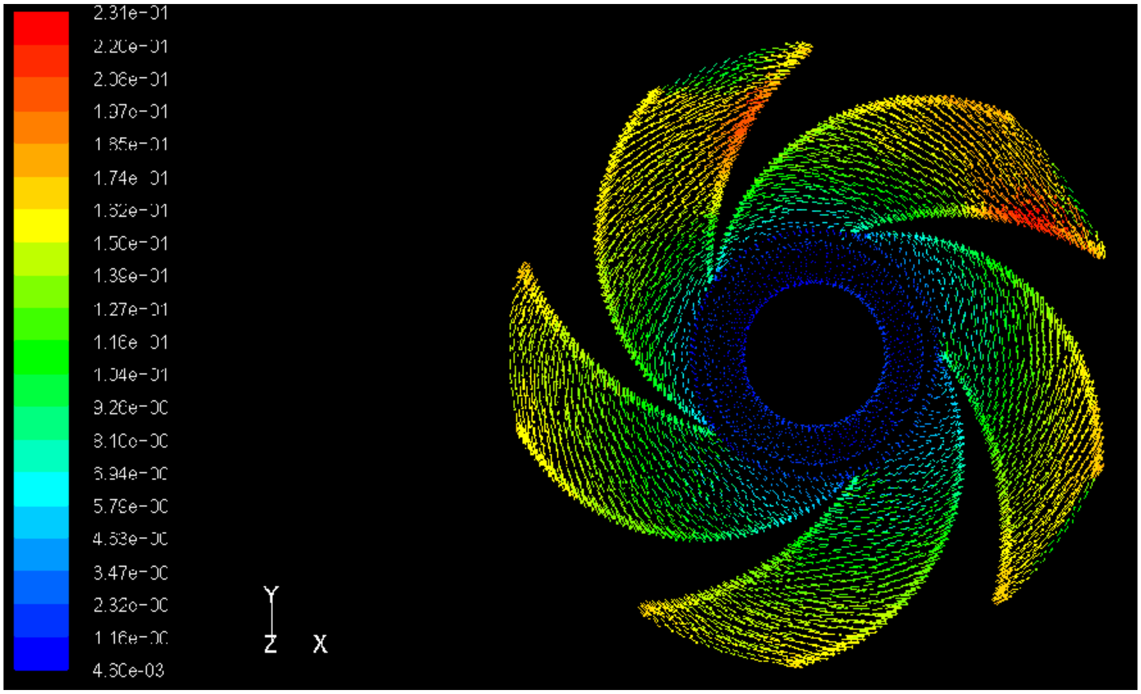

Figure 6.6 Velocity vectors near impeller for 5% concentration (Q=4.54, N= 1450 rpm)

- **Static pressure contours**

Static pressure distribution inside the impeller channels has been observed and is shown in Figure 6.7- 6.10. The result shows that the pressure increases from inlet to outlet. It has a minimum value at inlet and increases at the tip of the vane.

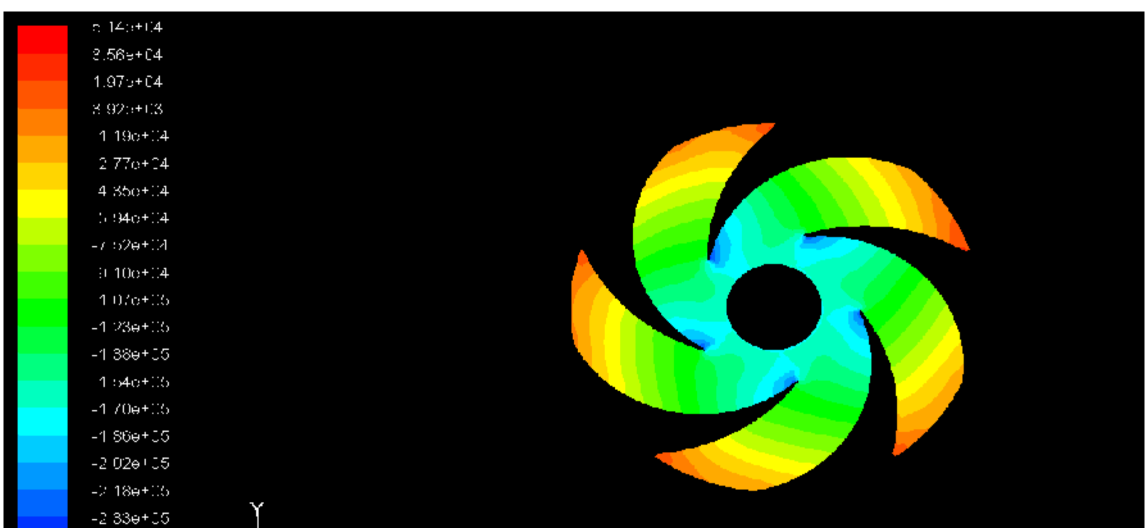

Figure 6.7 Static pressure contour of impeller at 2% concentration (Q =10.754 lps and N=1450rpm)

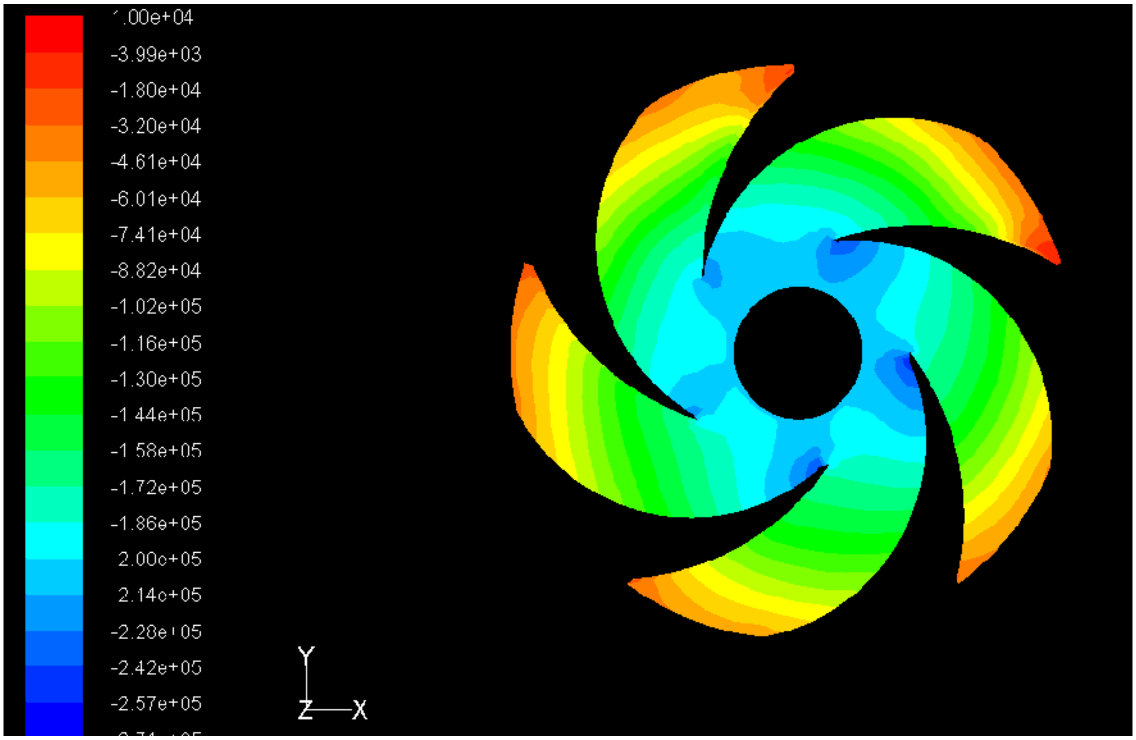

Figure 6.8 Static pressure contour of impeller at 2% concentration (Q =4.375 lps and N=1450rpm)

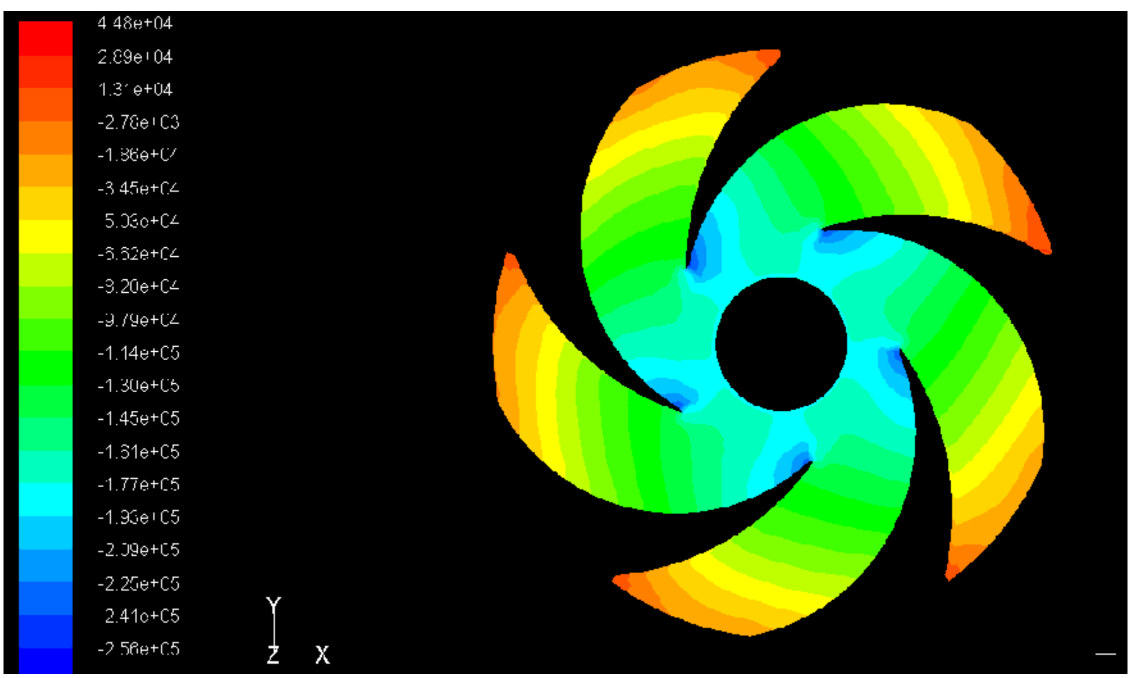

Figure 6.9 Static pressure contour of impeller at 5% concentration (Q =10.753 lps and N=1450rpm)

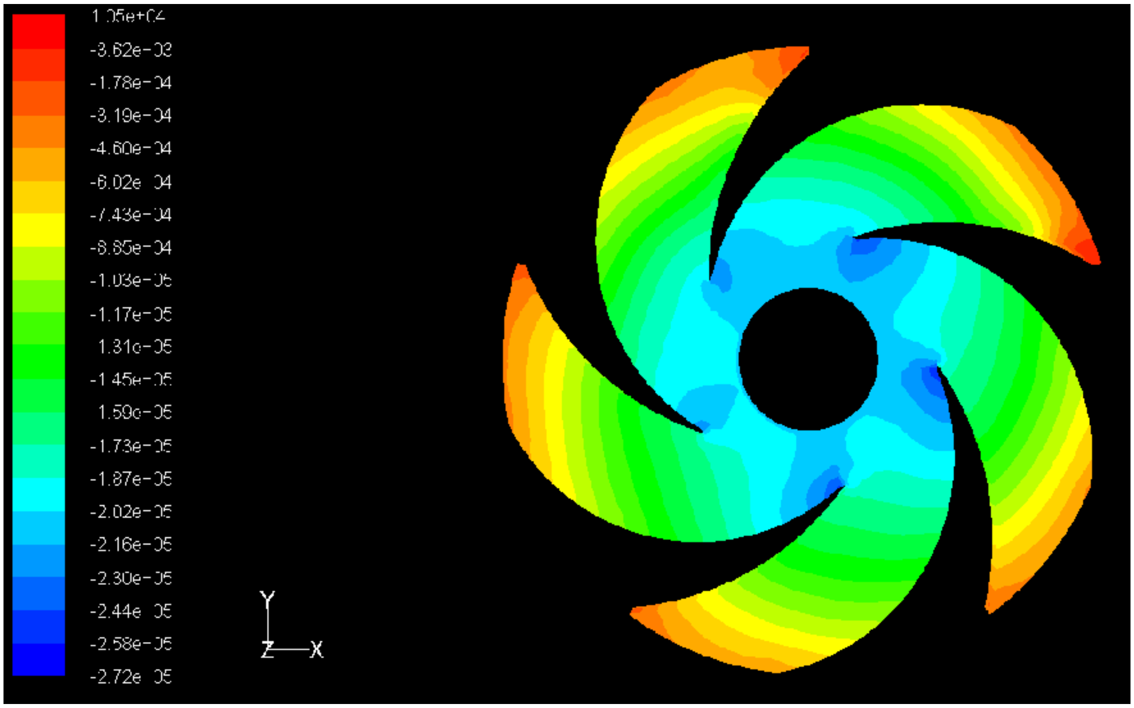

Figure 6.10 Static pressure contour of impeller at 5% concentration (Q =4.54 lps and N=1450rpm)

6.4 PERFORMANCE CHARACTERISTICS OF PUMP

The performance characteristic of the centrifugal slurry pump has been predicted numerically handling bottom ash slurry. The solid concentration in mixture varied in between 2%,5%, 10%, and 20 % by weight. Head, power and efficiency characteristics of the pump are predicted by CFD analysis at 1450rpm and explained graphically in Figures 6.11-6.12. The Numerical results on slurry pump performance handling bottom ash slurry at the rated speed of 1450 rpm and at different concentrations are given in Table 6.1. The parameters namely discharge rate, total head, input power and efficiency are tabulated for a constant pump speed of 1450 rpm.

Figure 6.13 shows that the pump input power increases steadily with increase in discharge rate and its maximum value is 5.17 KW at 11.71 lps discharge. The pump efficiency characteristic with Bottom Ash is shown in Figure 6.12, depicts that all the data points lie on a smooth curve and the maximum efficiency of 44.26 % is measured. Figure 6.11 shows that maximum value of actual head developed by pump is 20.37 (m) at 1450 rpm and at 4.375 lps of discharge. It shows that with increase in discharge, head is decreased.

Table 6.1 Performance of pump with 2,5,10 and 20% concentration of bottom ash slurry at 1450 rpm

Sr. No	Concentration (C_w) %	Discharge (Q) l/s	Head (m)	Input power (kw)	Efficiency %
1	2	11.59	15.54	4.5	37.9
2	2	10.753	16.36	4.3	41.35
3	2	8.71	18.82	4.1	44.26
4	2	4.375	20.37	3.76	27.45
5	5	11.63	14.7	4.847	34.9
6	5	10.01	16.4	4.483	40.7
7	5	8.5	17.84	4.23	41.5
8	5	4.54	19.52	3.945	35.5
9	10	11.63	12.79	5.04	30.6
10	10	10.29	14.35	4.762	35.8
11	10	8.41	16.71	4.5	32.5
12	10	4.63	18.91	4.2	19.6
13	20	11.71	11.52	5.17	20.6
14	20	10.27	13.01	4.86	27.2
15	20	8.9	15.19	4.7	24.7
16	20	4.28	17.86	4.3	10.5

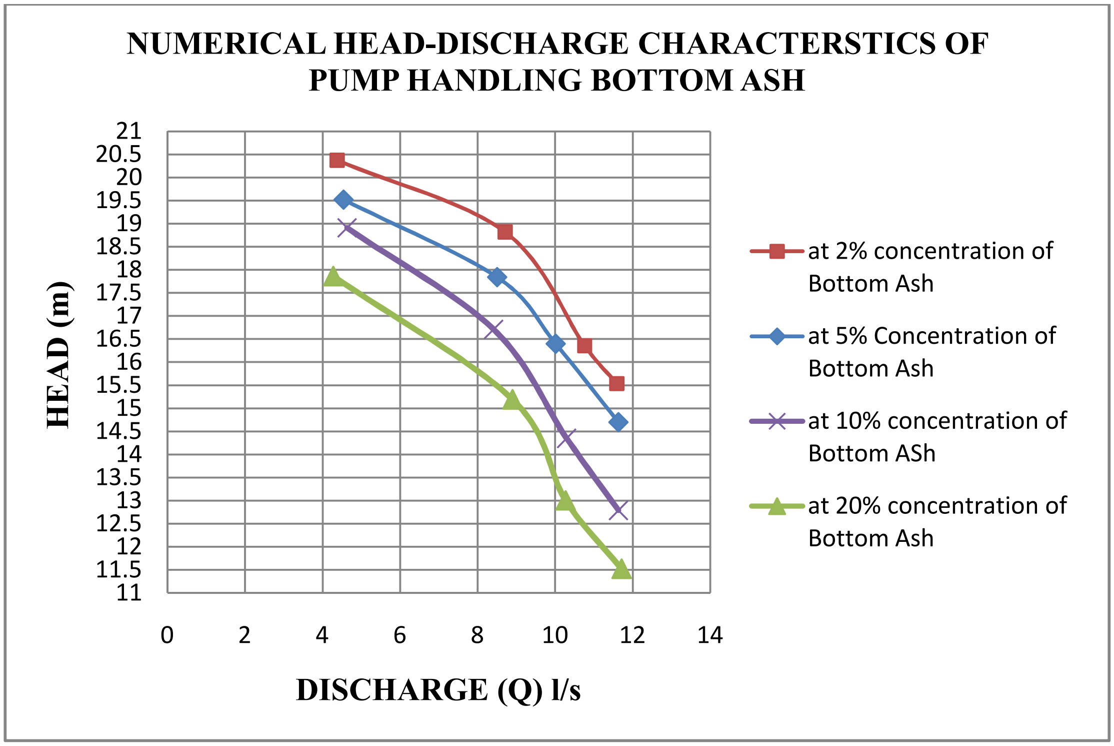

Figure 6.11 Numerical Head-Discharge characteristics of pump handling slurry at 1450 rpm

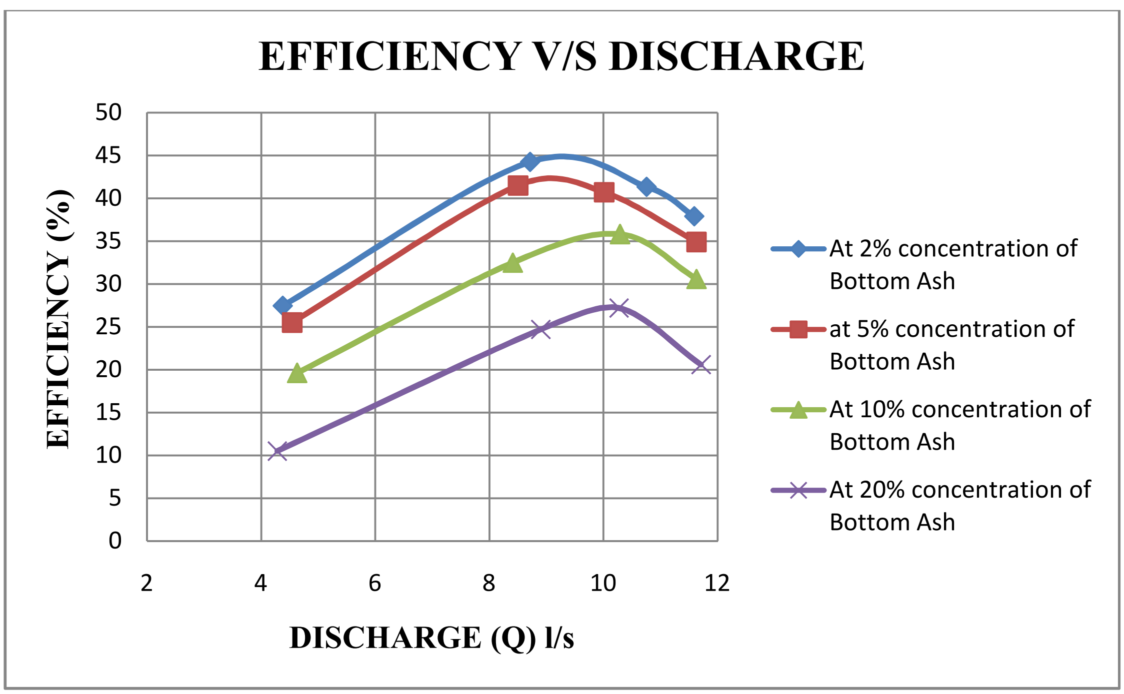

Figure 6.12 Variation of Efficiency v/s Discharge characteristics of pump handling slurry at 1450 rpm.

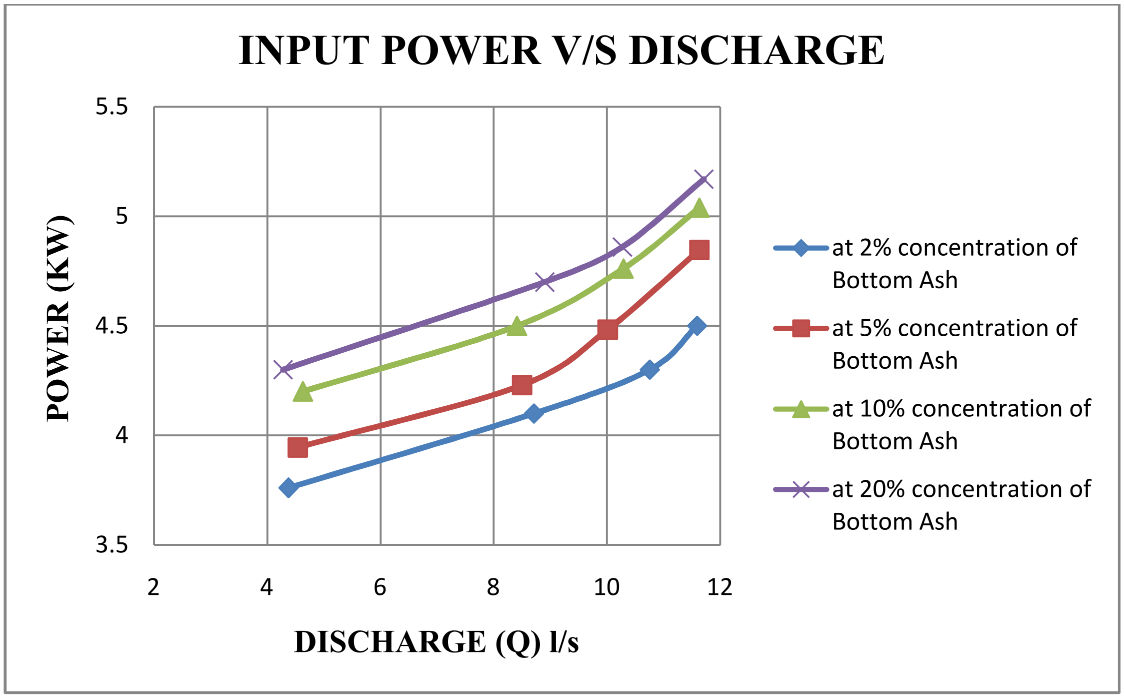

Figure 6.13 Variation of Input Power v/s Discharge characteristics of pump handling slurry at 1450 rpm.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

Conclusion

The performance characteristics of centrifugal slurry pump are evaluated experimentally handling clear water. Also present work includes, study the properties of bottom ash like particle size distribution, ph value, static settled concentration, specific gravity and viscosity of bottom ash. It also includes the numerical simulation of flow through pump handling 2%, 5%, 10% and 20 % (by weight) concentrated bottom ash slurry. The simulation results are obtained at the operating speed 1450rpm with different mass flow rates. The complex pump internal flow field was investigated by using numerical methods .The complex internal flow of the centrifugal pump simulation has permitted to study the internal flow pattern and pressure distribution of the pump operating at 1450 rpm.

Based on the present investigation the following conclusions can be obtained

- It is observed that, head and efficiency of centrifugal slurry pump decreases with increase in solid concentration (by weight).
- In Numerical simulation, Pressure contours shows that the pressure increases from inlet to outlet. It has a minimum value at inlet and increases at the tip of the vane.
- Velocity Vectors shows the velocity is high at the tailing edge of the impeller vane as compare to the leading edge of vane

Future Scope

- Experimental investigations of centrifugal slurry pump performance handling higher concentrated bottom ash slurry (up to 50% by weight).
- To analyze the hydraulic losses and erosion wear of pump and pipeline in pilot plant.
- Some additive can be added in bottom ash slurry to improve performance characteristics of pump.

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APPENDIX

Annexure 1

Table 3.2:- Experimental results of Performance of centrifugal slurry pump with water only at 1450 rpm.

Sr. No	Discharge (Q) in lps	Speed in rpm	Input Power in kW	Actual head at Observed speed in m of H_20	Discharge (Q) at 1450 rpm in lps	Rated head at rated speed in 1450 rpm	Rated power in kW	efficiency in (%)	Specific discharge	Specific head at 1450 rpm
1	10.7	1449	3.93	11.63	10.76	11.65	3.94	31.17	24.25	2.81
2	9.59	1449	3.86	12.26	9.59	12.28	3.87	29.85	21.63	2.96
3	8.71	1449	3.80	12.71	8.71	12.73	3.81	28.56	19.65	3.07
4	7.63	1448	3.74	13.29	7.64	13.27	3.76	26.46	17.23	3.20
5	5.93	1448	3.62	14.27	5.94	14.31	3.66	22.74	13.39	3.45
6	4.37	1448	3.58	15.01	4.38	15.05	3.59	17.98	9.87	3.63
7	2.87	1449	3.48	15.54	2.87	15.56	3.49	12.56	6.48	3.75
8	1.20	1449	3.41	16.43	1.20	16.45	3.42	5.67	2.71	3.97
9	0	1449	3.35	16.50	0	16.53	3.35	0		

Annexure 2

Table 3.3:- Experimental Results of performance of centrifugal slurry pump with water only at 1200 rpm.

Sr. No	Discharge (Q) in lps	Speed in rpm	Input Power in kW	Actual head at Observed speed in m of H2o	Discharge (Q) at 1200 rpm in lps	Rated head at rated speed in 1200 rpm	Rated power in kW	efficency in %	Specific discharge	Specific head at 1200 rpm
1	8.78	1208	2.88	7.93	8.72	7.83	2.83	23.67	23.77	2.76
2	7.65	1208	2.84	8.54	7.60	8.43	2.79	22.54	20.71	2.97
3	6.76	1208	2.81	9.04	6.71	8.92	2.75	21.31	18.29	3.14
4	5.50	1208	2.76	9.70	5.46	9.57	2.71	18.94	14.89	3.37
5	4.52	1209	2.72	10.14	4.48	9.99	2.66	16.48	12.22	3.52
6	3.51	1209	2.67	10.50	3.48	10.35	2.61	13.52	9.49	3.64
7	2.64	1209	2.64	10.82	2.62	10.66	2.59	10.60	7.15	3.75
8	1.67	1209	2.59	11.06	1.66	10.89	2.54	7.00	4.53	3.84
9	0	1209	2.52	11.51	0	11.34	2.47	0	0	3.99

Annexure 3

Table 3.4:- Experimental Results of performance of centrifugal slurry pump with water only at 1000 rpm.

Sr. No	Discharge (Q) in lps	Speed in rpm	Actual head at Observed speed in m of H_20	Discharge (Q) at 1000 rpm in lps	Rated head at rated speed in 1000 rpm	Specific discharge	Specific head at 1000 rpm
1	7.05	996.5	5.41	7.07	5.44	23.13	2.76
2	6.13	996.8	5.81	6.15	5.85	20.12	2.97
3	5.55	996.9	6.13	5.56	6.16	18.20	3.13
4	4.77	997	6.48	4.79	6.52	15.66	3.31
5	3.57	997.3	6.92	3.58	6.95	11.71	3.53
6	2.66	996.9	7.23	2.67	7.27	8.73	3.69
7	1.65	997.9	7.46	1.66	7.49	5.43	3.80
8	0.95	997	7.53	0.95	7.58	3.11	3.84
9	0	997.1	7.61	0	7.66	0	3.88

Annexure 4

Table 3.5:- Experimental results of performance of centrifugal slurry pump with water only at 800 rpm.

Sr. No	Discharge (Q) in lps	Speed in rpm	Actual head at Observed speed in m of H_20	Discharge (Q) at 1000 rpm in lps	Rated head at rated speed in 1000 rpm	Specific discharge	Specific head at 1000 rpm
1	5.38	791	3.48	5.44	3.56	22.25	2.82
2	4.74	790.5	3.77	4.79	3.86	19.61	3.06
3	3.99	790.9	3.97	4.04	4.06	16.51	3.22
4	3.78	790.7	4.03	3.82	4.13	15.64	3.27
5	2.72	791.1	4.33	2.75	4.43	11.25	3.51
6	2.26	791	4.50	2.28	4.60	9.34	3.65
7	1.53	790.8	4.65	1.55	4.76	6.34	3.78
8	0.88	791	4.73	0.89	4.84	3.66	3.84
9	0	791	4.81	0	4.92	0	3.90

Annexure 5

Table 4.1 Experimental Results of Particle Size Distribution of Bottom Ash

S. No	Size in (u)	Size in microns	Sample 1	Sample 2	Sample 3	Sample 4	Average (Wi)	% total	Di	Wi*Di	Dwm
1	below 2000	Above 1400	26	25	28	26	26.25	10.50	600	15750	162.13
2	1400	710-1400	10	10	9	11	10	4.00	690	6900	
3	710	355-710	33	30	35	31	32.25	12.90	355	11448.75	
4	355	300-355	19	20	17	20	19	7.60	55	1045	
5	300	250-300	16	14	16	16	15.5	6.20	50	775	
6	50	212-250	30	30	29	31	30	12.00	38	1140	
7	212	180-212	5	8	6	8	6.75	2.70	32	216	
8	180	150-180	60	56	59	60	58.75	23.50	30	1762.5	
9	150	125-150	8	9	8	7	8	3.20	25	200	
10	125	90-125	9	11	9	10	9.75	3.90	35	341.25	
11	90	75-90	24	30	26	25	26.25	10.50	15	393.75	
12	75	below75	6	4	5	3	4.5	1.80	75	562.5	
		Total	**246**	**247**	**247**	**248**			**600**	**40534.75**	
		Lost	4	3	3	2	3	1.20	690		

Annexure 6

Table 4.3:- Static settled Concentration of Bottom Ash

S. No	Time (min)	($\%C_w$) settled			
		Sample 1	Sample 2	Sample 3	Sample 4
1	0.166666667	24.622	24.323	23.466	24.030
2	0.333333333	30.662	31.632	29.749	32.665
3	0.5	32.665	32.140	31.632	32.665
4	0.666666667	33.768	33.207	32.665	33.207
5	0.833333333	34.348	34.948	34.348	34.948
6	1	36.213	35.696	35.569	35.824
7	1.166666667	40.627	39.041	37.574	39.041
8	2 Min	41.470	40.627	39.818	40.627
9	3 Min	41.470	41.470	40.627	42.348
10	4 Min	41.470	41.470	41.129	41.298
11	5 Min	41.470	41.470	41.129	41.298
12	15 min	41.470	41.470	41.470	41.470
13	30 min	41.470	41.470	41.470	41.470
14	60 min	41.816	41.992	42.169	42.348
15	120 min	41.992	42.348	42.348	42.348
16	180 min	42.348	42.348	42.348	42.348
17	240 min	42.348	43.264	43.452	43.264
18	540 min	42.348	43.264	43.452	43.264
	Maximum static settled conc. ($\%C_w$)	42.709	43.264	43.641	44.220

Annexure 7

Table 4.4: - Ph value of Bottom Ash at different Concentration

Sr. No	Weight of bottom ash (gms)	Weight of water (gms)	Concentration. (%)	PH Value
1	0	100	0	7.75
2	25	100	20	7.67
3	35	100	25.9	7.66
4	44	100	30.5	7.66
5	55	100	35.4	7.64
6	67	100	40.1	7.63
7	82	100	45	7.62
8	100	100	50	7.62

Annexure 8

Table 4.5:- Ph value of Bottom Ash at different Concentration and Time interval

Sr. No	Time in sec	20% (Cw)	25.9% (Cw)	30.5% (Cw)	35.4 % (Cw)
1	0	7.66	7.66	7.64	7.63
2	30	7.658	7.656	7.639	7.629
3	60	7.657	7.656	7.637	7.628
4	90	7.656	7.655	7.637	7.627
5	120	7.656	7.653	7.636	7.627
6	150	7.655	7.652	7.635	7.626
7	180	7.653	7.652	7.634	7.623
8	210	7.651	7.65	7.633	7.621

Annexure 9

Table 4.6:- Viscosity of Bottom Ash

Sr. No	Temperature	Concentration	Water viscosity	Slurry viscosity of bottom ash	Relative viscosityof Bottom Ash
	[°C]	[Cw %]	[cP]	[cP]	
1	20	0	0.995		1
2	20	5	0.995	1.16	1.17
3	20	10	0.995	1.29	1.30
4	20	15	0.995	1.36	1.37
5	20	20	0.995	1.49	1.50
6	20	25	0.995	1.92	1.93
7	20	30	0.995	2.47	2.48
8	20	40	0.995	4.84	4.86