NUMERICAL SIMULATION ON THE SLURRY FLOW THROUGH STRAIGHT PIPE FOR THE EVALUATION OF PRESSURE DROP

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Abstract— The thermal power plants where mostly used with Slurry transportation. This system has proved its efficient working and advantages such as less noisy, no air pollution. But still now optimization is required for better performance. In the present work rheological properties of various bottom and fly ash mixtures are studied to evaluate the factors affecting the flow behaviour of slurry. Bottom and fly ash for the present investigation was collected from the Guru Gobind Singh thermal power plant, Ropar. Particle size distribution, pH , settling characteristics of bottom and fly ash are investigated. Rheometer is used for the shear rate and shear stress variation for the different ratios of bottom and fly ash. Numerical simulation is performed on the slurry flow through straight pipe and 900 horizontal bend for the evaluation of pressure drop per unit length. designing of Straight pipe and 900 horizontal bend is performed in Gambit version 2.2 It is found that pressure drop increases with increasing flow velocity and higher concentrations (by weight) of bottom and fly ash combinations.

Keywords—Slurry; Fly Ash; Rheological Studies on Bottom and Fly Ash Mixture; Numerical evaluation of pipeline.

I. INTRODUCTION

Transportation of some materials through slurry transportation system proved a much better means of material transport. One of the best examples is the transport of bottom ash through slurry pipelines in thermal power plants. There are various advantages of slurry transport system such as very less pollution less and less noise. Therefore, due to its well response and good characteristics, detailed study is needed to improve its functioning for better performance.

1.1 Slurry

A slurry is a thin sloppy mud or cement or, in extended use, any fluid mixture of a pulverized solid with a liquid (usually water), often used as a convenient way of handling solids in bulk. Slurries behave in some ways like thick fluids, flowing under gravity and being capable of being pumped. The physical characteristics of slurry are dependent on many factors such as particle size and distribution, solid concentration in the liquid phase, turbulence level, temperature, conduit size, and viscosity of the carrier. Slurry is a mixture of a solid particles and fluid held in suspensionWater is the most commonly used fluid. Theoretically, for laminar to a turbulent flow a single-phase liquid of low absolute (or dynamic) viscosity can be allowed to flow at slow speeds. However, slurry which is two-phase mixture must overcome a deposition critical velocity or a viscous transition critical velocity. The speed of slurry flow is sufficiently high to maintain the particles in suspension. The mixture resists the flow in highly viscous mixtures because of excessively low shear rate in the pipeline.

1.1.1 Types of Slurry Flows

There are two types of slurry flows:

i. Homogeneous flow
ii. Heterogeneous flow

1.2 Thermal Power Plant Ash

Ash coming out after the combustion of pulverized coal in thermal power plants is divided into two main categories: Fly ash and Bottom ash.

1.2.1 Fly As

Fly ash is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases .In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO), both being endemic ingredients in many coal-bearing rock strata.
Two classes of fly ash are defined as: Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the

fly ash are largely influenced by the chemical content of the coal burned.

Class F Fly Ash. The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 20% lime (CaO).

Class C Fly Ash

Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulphate (SO4) contents are generally higher in Class C fly ashes.

1.2.2 Bottom Ash

Main components of bottom ash are Nickel, Chromium, arsenic Lead and Sulphur. Bottom ash from the pulverized power plants consists of granular particles with a minor input of melted glassy fragments, while the bottom ash from the fluidized bed combustor consists entirely of granular particles. The sulphur and carbon contents of pulverized bottom ashes range from 0.03 to 2.32 weight % and 0.19 to 6.62 weight %, respectively. For the fluidized bed combustor, the sulphur and carbon contents were 5.27 wt % and 10.72 weight %. The concentrations of As, Cr, Hg, Ni, and Pb in bottom ash are related to sulphur content of coal and are higher for bottom ashes from high sulphur feed coals.

1.3 Ash Handling System

The ash handling system handles the ash by bottom ash handling system, coarse ash handling system, fly ash handling system, ash disposal system up to the ash disposal area and water recovery system from ash pond and Bottom ash overflow. Description is as follows:

1.3.1 Bottom Ash Handling System

Bottom ash resulting from the combustion of coal in the boiler shall fall into the over ground, refractory lined, water impounded, maintained level, double V-Section type/ W type steel- fabricated bottom ash hopper having a hold up volume to store bottom ash and economizer ash of maximum allowable condition with the rate specified. The slurry formed shall be transported to slurry sump through pipes

1.3.2 Coarse Ash (Economizer Ash) handling System

Ash generated in Economizer hoppers shall be evacu ated continuously through flushing boxes. Continuous generated Economizer slurry shall be fed by gravity into respective bottom ash hopper pipes with necessary slope.

1.3.3 Air Pre Heater ash handling system

Ash generated from air pre heater hoppers shall be evacuated once in a shift by vacuum conveying system connected with the Electrostatic separator hopper vacuum conveying system.

1.3.4 Dry Fly Ash Handling System

Fly ash is considered to be collected in electrostatic separator hoppers. Fly ash from electrostatic separator hoppers extracted by vacuum pumps transported to intermediate surge hopper cum bag filter for further dry Conveying to fly ash silo. Under each surge hopper ash vessels shall be connected with Oil free screw compressor for conveying the fly ash from Intermediate Surge Hopper to silo. Total fly ash generated from each unit will be conveyed through streams operating simultaneously and in parallel.

1.3.5 Ash Slurry Disposal System

Bottom Ash slurry, Fly ash slurry and the Coarse Ash slurry shall be pumped from the common ash slurry sump up to the dyke area which is located at a distance from Slurry pump house.

1.4 Different Types of Losses in Pipelines

When fluid flows through a pipe, it is subjected to hydraulic resistances which are of two types (i) Viscous frictional resistance (ii) Local resistance. Viscous frictional resistance associated with the fluid flow is called major loss of energy, where as local resistances are called losses of energy. Local resistances are essentially due to change of velocity either in magnitude or direction, in which the portion of energy possessed by the flowing fluid gets dissipated as heat energy. Losses due to change in cross section, bends, valves and frictions of all types are categorized as minor losses. In short pipes ,minor losses sometimes be more than the frictional losses. Losses due to the local disturbances of the flow in the conduits such as changes in cross-section, projecting gaskets, elbows, valvesand similar items are called minor losses. So, minor losses can be defined as the losses that occur in pipelines due to bends, joints, valves, etc. In case of a very long pipe, these losses are usually insignificant in comparison to the fluid friction in the length considered.

i. Losses due to sudden contraction
ii. Losses due to gradual contraction
iii. Losses due to gradual expansion
iv. Losses due to sudden expansion
v. Losses due to bends
vi. Entrance losses
vii. Exit losses

II. RHEOLOGICAL STUDIES ON BOTTOM AND FLY ASH MIXTURES

2.1 Rheology

Rheology characteristics of slurry depend up on various factors such as particle size distribution, pH, settling characteristics, specific gravity etc. Change in these characteristics of slurry shows a significant change in the viscosity of the slurry. Therefore, analysis of mentioned factors is to be done for given sample. In present study particle size distribution, pH, settling characteristics, specific gravity are found for the bottom and fly ash samples.

2.1.1 Particle Size Distribution

The particle size distribution of a material can be important in understanding its physical and chemical properties. The way particle size distribution is usually defined by the method by which it is determined. The most easily understood method of determination is sieve analysis, where particles are separated on sieves of different sizes. Thus, the particle size distribution is defined in terms of discrete size ranges: e.g. "% of sample between 45 µm and 53 µm", when sieves of these sizes are used. The particle size distribution is usually determined over a list of size ranges that covers nearly all the sizes present in the sample. Some methods of determination allow much narrower size ranges to be defined than can be obtained by use of sieves, and are applicable to particle sizes outside the range available in sieves. However, the idea of the notional "sieve", that "retains" particles above a certain size, and "passes" particles belowhat size, is universally used in presenting particle size distribution data of all kinds.

2.1.2 Settling Characteristics

Settling is the process by which particulates settle to the bottom of a liquid and form a sediment. Particles that experience a force, either due to gravity or due to centrifugal motion will tend to move in a uniform manner in the direction exerted by that force. For gravity settling, the particles will tend to fall to the bottom of the vessel, forming a slurry at the vessel base. For settling particles, there are two main forces enacting upon any particle.

2.1.3 pH Value

pH tells the nature if the sample is basic or acidic. In the present study pH value of ash samples are measured with the help of pH meter. A pH meter is an electronic instrument used for measuring the (acidity or alkalinity) of a liquid though special probes. A typical pH meter consists of a special measuring probe (a glass electrode) connected to an electronic meter that measures and displays the pH reading.

III. RHEOMETER

Variation of shear rate and shear stress of ash slurry is found out by ANTAN PAAR rheometer (shown in Fig2.1). Various mixtures of bottom and fly ash with different solid concentrations are tested on the rheometer. The slurry is placed within the annulus of one cylinder inside another. One of the cylinders is rotated at a set speed. This determines the shear rate inside the annulus.

Fig 2.1 Rheometer (Antan Paar)

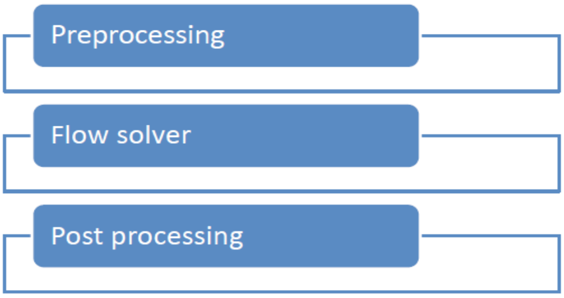
The slurry tends to drag the other cylinder round, and the force it exerts on that cylinder (torque) is measured, which can be converted to a shear stress. In the present study the shear stress value and viscosity measured at the shear rate range from 0-300 s-1 at the constant temperature condition 26 °C with wide range of concentrations varying from 20 to 50% (by weight) for ash and water slurries. Stress versus shear rate graphs are plotted with bottom ash and fly ash with different ratios.

IV. NUMERICAL EVALUATION OF PIPELINE

Computational fluid dynamics usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. CFD simulations are used to model model fluid flows over a wide range of physical scales. The fundamental of the CFD simulation is the conservation of equations. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions.

4.1 Methodology

There are three main steps to solve a computational fluid dynamics problem.



4.1.1 Preprocessing

First step in preprocessing is the definition of the geometry of the region of interest. Definition of geometry is followed by grid generation. Grid generation is the sub division of domain in the number of smaller sub domains e.g grid, cells, control volumes. After this appropriate boundry conditions are defined. Boundary condition involves the specification of the fluid behaviour and properties at the boundaries of the problem.

4.1.2 Flow Processor

In Flow solver the simulation is started and the equations are solved iteratively as a steady-state transient. There are mainly three methods for this solver.
(i) Finite volume method
(ii) Finite element method
(iii) Finite difference method

4.1.3 Post processor

Finally a postprocessor is used for the analysis and visualization of the resulting solution It displays the domain geometry and grid. Vectors, contours plots are used to visualize the results.

4.2 Modeling of Straight Pipe

For the study of numerical evaluation of pipeline, a straight pipe is modeled to study per unit length pressure drop. Modeling of straight pipe is done in Gambit software version 2.2. Three dimensional model of straight pipe is shown in Fig 4.1.

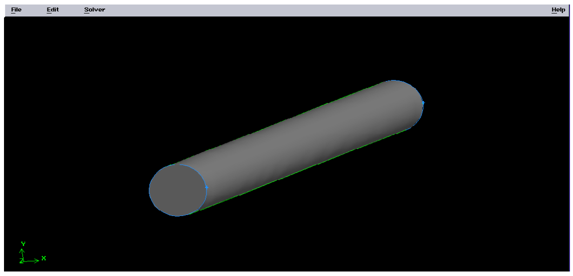


Fig. 4.1: Model of straight 1 metre pipe

4.3 Assumptions for Simulation

Basic assumptions on which the simulation is done are as follows
1. Steady state condition
2. Incompressible fluid flow
3. Constant fluid properties

4.4 Simulation Results of Straight Pipe

Fig 4.3(a)-(d) shows the pressure variation in straight pipe at different bottom and fly ash mixture with different flow velocities from 1.5 to 3.

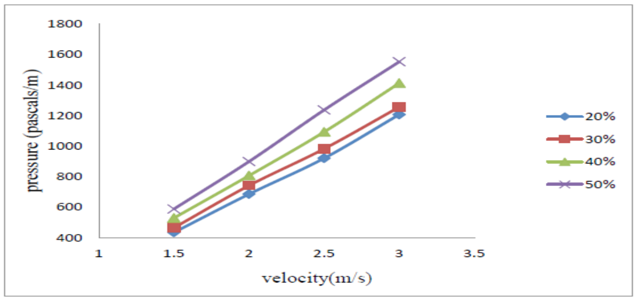


Fig 4.3(a): Pressure variation in straight pipe with 6:4 (B.A:F.A)

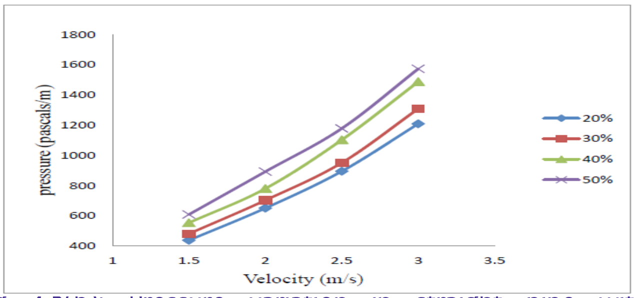


Fig 4.3(b): Pressure variation in straight pipe with 8:2(B.A:F.A)

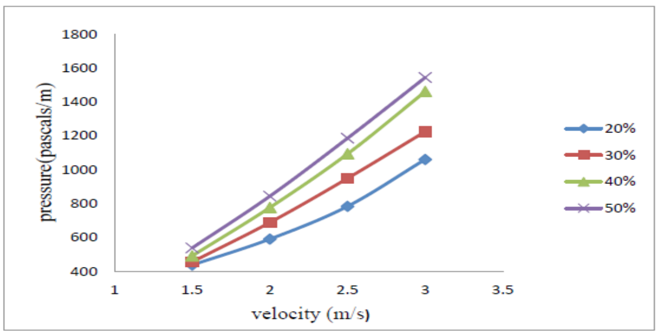


Fig 4.3 (c): Pressure variation of B.A with 4% additive (sodium bicarbonate) for straight pipe

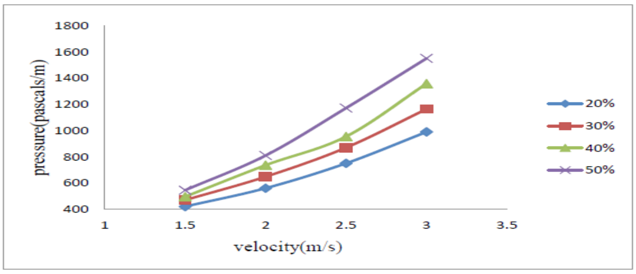


Fig 4.3(d): Pressure variation of B.A with 6 % additive (sodium bicarbonate) for straight pipe

Fig 4.3(a)-(d) shows that pressure loss at less concentrations is less as compared to pressure loss at high concentrations. Pressure drop increases as the concentration of solids increases and also increases with the increase of flow velocity. From the mentioned figures it can be also concluded that pressure drop at low concentrations with Bottom ash and additive mixture shows less pressure drop as compared with bottom and fly ash mixtures.

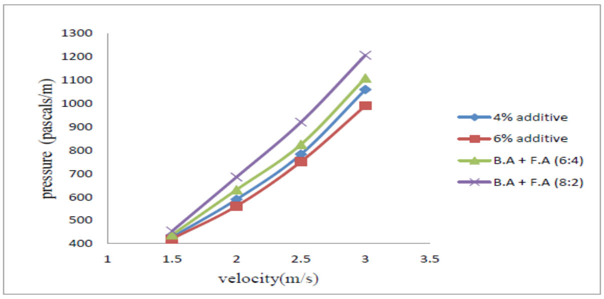


Fig 4.4 (a): Pressure variation of B.A + F.A ratios and bottom ash with additive (sodium bicarbonate) at 20% concentration (by weight)

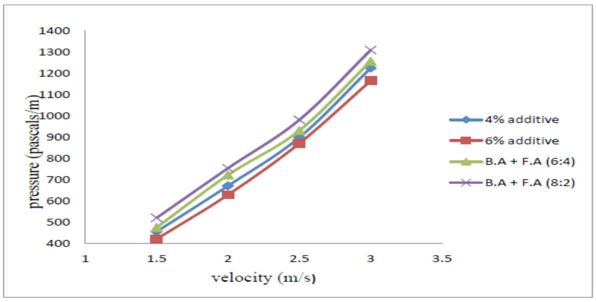


Fig 4.4 (b): Pressure variation of B.A + F.A ratios and bottom ash with additive (sodium bicarbonate) at 30% concentration (by weight)

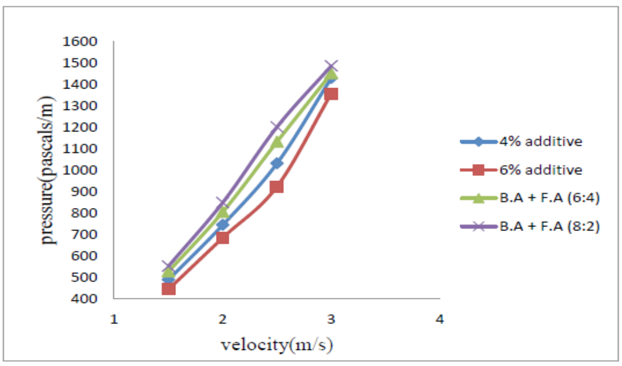


Fig 4.4 (c): Pressure variation of B.A + F.A ratios and bottom ash with additive (sodium bicarbonate) at 40% concentration (by weight)

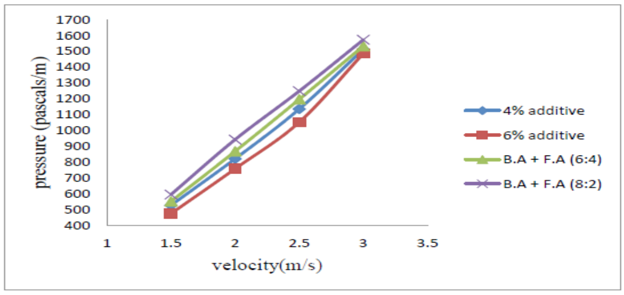


Fig 4.4 (d) Pressure variation of B.A + F.A ratios and bottom ash with additive (sodium bicarbonate) at 50% concentration (by weight)

Fig 4.4(a) - (d) shows that pressure drop variation is dependent also on weight percentage (%) of additive and ratio of B.A + F.A ratios. Mentioned figures clearly shows that at each concentration, bottom ash with 6% additive has least relative pressure increase and B.A + F.A (8:2) exhibits more pressure drop than other ash mixtures.

4.5 900 Horizontal Bend Modeling

Model Of 900 Horizontal Bend Is Created In The Gambit Version 2.2. Fig 4.5(A) Shows The Three Dimensional Model Of Pipe Bend.

4.5(A): Three Dimensional Model Of 900 Horizontal Bend

4.5.1 Grid Independency Test Fig

Meshing Of 900 Horizontal Bend With Three Different Element Sizes Is Done In Gambit Version 2.2.Table 4.3 Shows The Parameters Of Meshing With Different Sizes.

Table 4.3 Mesh Comparison for 900 Horizontal Bend

Element type	Element size	Elements	Skewness	Aspect Ratio
Mixed mesh	4	252642	0.74	2.95
Mixed mesh	5	197212	0.74	3.07
Mixed mesh	6	11586	0.74	2.98

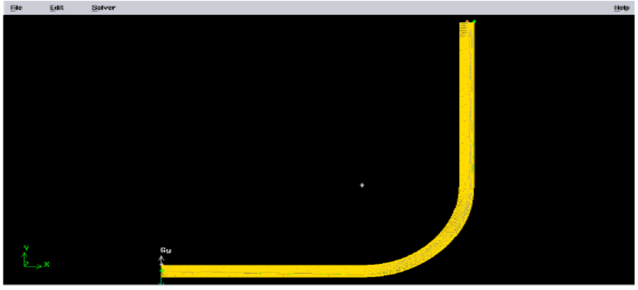


Fig 4.5(B): Meshed 900 Horizontal Bend

Mesh Size Of 4 And Mixed Element Type Meshing Is Considered For Further Simulation. Fig 4.5(B) Shows The Meshed 900 Horizontal Bend.

4.6 Simulation Results of 900 Horizontal Bend

Fig 4.6 (A)-(D) Shows The Variation Of Pressure For Different Ratios Of Bottom And Fly Ash With Different Flow Velocities And At Different Concentrations.

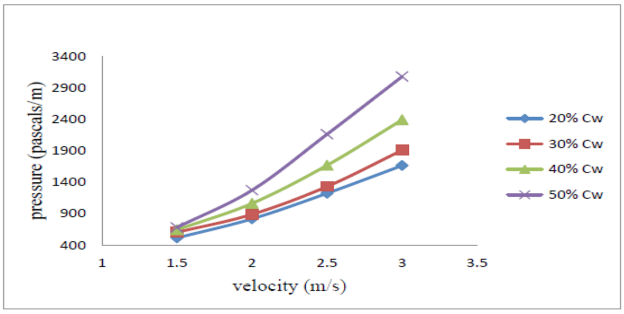


Fig 4.6 (A) : Pressure Variation In 900 Horizontal Bend With B.A+F.A (6:4)

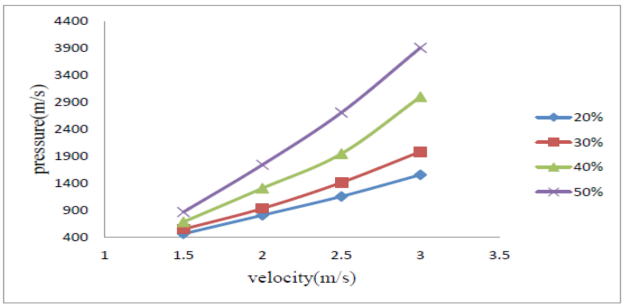


Fig 4.6 (B) : Pressure Variation In 900 Horizontal Bend With B.A+F.A (8:2)

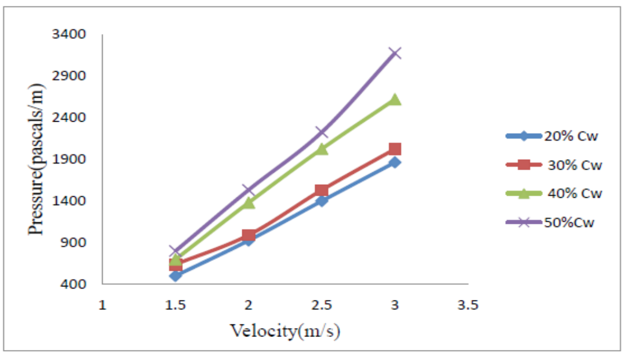


Fig 4.6 (C): Pressure Variation In 900 Horizontal Bend With 4% Additive (Sodium Bicarbonate) Of Bottom Ash.

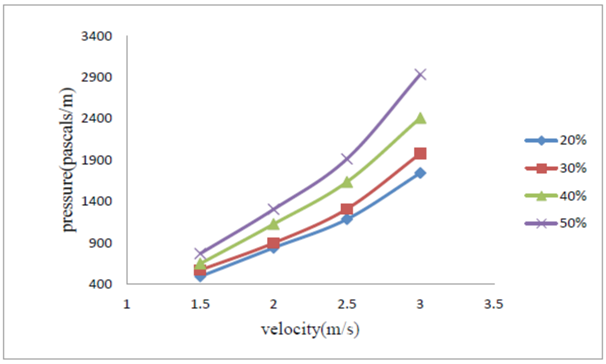


Fig 4.6(D): Pressure Variation In 900 Horizontal Bend With 6% Additive (Sodium Bicarbonate) In Bottom Ash.

Fig 4.6(A)-(D) Shows That Pressure Drop In 900 Horizontal Bend Increases With Increasing Concentration And Flow Velocity. It Can Be Observed That Pressure Loss Difference At High Velocities Is Considerably More Than Pressure Loss Difference At Low Velocities.

CONCLUSION

Pressure distribution along the straight pipe and 900 horizontal bend is evaluated at various mixture with ratio 8:2,6:4 and additive(sodium bicarbonate)at concentrations (20%, 30%,40% and 50%) and flow velocity range of 1.5 - 3 m/s. The result is validated from the analytical formula (Darcy Weisbach Equation) for the pressure drop of water in straight pipe. Rheological properties of bottom and fly ash ratios are investigated using Rheometer. Physical characteristics of ash such as Particle size distribution, pH specific gravity and settling behaviour has also been studied. The simulation results are obtained with different mass flow velocity conditions and different concentrations. Based on the present investigation the following conclusions can be obtained. Pressure drop per unit length across the straight pipe and horizontal bend increases as the flow velocity increases. Pressure drop per unit length across the straight pipe and horizontal bend at high concentrations is significantly higher than pressure drop at low concentrations and low flow velocity. Pressure drop per unit length in case of bottom ash with 6% additive is found relatively lower than other bottom and fly ash mixtures. Pressure drop across horizontal pipe bend is significantly higher than straight pipe. FLUENT results give the good agreement with analytical results for pressure drop in straight pipe for water and different slurry concentrations of bottom and fly ash ratios.

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