Parametric Thermal Analysis of Erosion In Bends Pipes with Different Bend Angle using CFD Analysis

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Abstract :- In the present study, erosion wear of a 90° degree with 2.5 bend ratio pipe, 90° degree with 1.5 bend ratio, 0° degree with 1.5 bend ratio, 45° degree with 1.5 bend ratio, 60° degree with 1.5 bend ratio, 30° degree with 1.5 bend ratio pipe bend has been investigated using the Computational fluid dynamics code FLUENT. Solid particles were tracked to evaluate the erosion rate along with k-ε turbulent model for continuous/fluid phase flow field. Ash - solid are injected from the inlet surface at velocity ranging from 8 ms-1 at two different concentrations. By considering the interaction between solid-liquid, effect of velocity, particle size and concentration were studied. Erosion wear was increased exponential with velocity, particles size and concentrations. Predicted results with CFD have revealed well in agreement with experimental results. it is cleared that results on 90° degree with 2.5 bend ratio pipe has low erosion DPM rate compared to all different bend angle and its results is better than all bend angle pipe with all parameters . so we can suggest this modified geometry of bend pipe with 2.5 bend ratio 90 degree because it has less DPM erosion rate and reduce the leak problem bend pipe surface.

Keywords: Computational Fluid Dynamics (CFD), Erosion wear, Discrete Phase Model (DPM), Pipe bend, Turbulence Models, Transportation of Slurry, Discretization Techniques, Erosion Test Rigs(ETR).

I. INTRODUCTION

Many engineering industries and plants like thermal power plant, cement plant are comprise of erosion wear due to transportation solid-liquid mixture and solid-gas through pipe-line system. In thermal power plants large amount of ash (fly and bottom) is generated from coal used as a fuel for generating electricity. This collected ash in hoppers is transported through components like pipe-bend, plugged tees, tubes, valves, elbows and centrifugal slurry pump etc. to ash pond in the form of slurry (water and ash) having very large amount of abrasive and quartz in it Modi et al. (2000). Hence the pipe-line system suffers from erosion wear damage due these abrasive's impact angle and velocity. Many authors have been found erosion wear in pipeline system of production, transportation of petroleum products Edward et al. (2001), oil and gas production (Bozzini et al. (2003), Chen et al. (2004), Shah et al. (2007), Zhang et al. (2007), Okita et al. (2012)), production of oil Gnanuvela et al. (2009), erosion wear in boilers, space craft, pipe line, turbines and coal processing system Mazumder et al. (2012). Erosion wear takes place more severe in curved surface than straight section (Shah et al. (2007), Stack et al. (2011)). An example from one of the above stated components is pipe-bend or elbow which is connected in the pipe line system. The main function of the bend is to give the horizontal, vertical and inclined turn to the transporting fluid/mixture inside it. Many researchers have proposed many experimental and theoretical erosion models and expressions to evaluate the magnitude and location of solid-liquid erosion wear of the system. In the present study erosion wear is investigated in the pipe-bend using the CFD.

1.1 EROSION WEAR

Erosion wear is a phenomenon in which material removed from the target surface by impacting solid particles at high velocity. The erosion generally occurs in channels, pipe-bends, valves, fitting components etc. These solid particles are directed by pumps and compressors in hydraulic and pneumatic system respectively industrial utilities, thermal power plants etc. Erosion is cause of failure of the parts, unpredictable damages; shorten the life of concerned parts or system. Hence the erosion leads to extra expenditure for the eroded parts. Examples: Transportation of slurry in pipe-line system at thermal power plants.

1.2 WEAR

Wear is defined as the removal of material between the sliding surfaces due to interlocking or roughness on the surfaces. Wear tends to loss of the durability and reliability of the subjected parts. So the proper investigation and care must be taken to control it in the emerging technology.

1.2 TYPES OF WEAR

The various types of wear are exist nature due to relative motion between the sliding surface, matters, bodies and in the mixture of physical matters solid, liquid and gas.

Types of wear are given below.

a) Abrasive Wear :- In abrasive wear a hard material is moved over the material, an interlocking is formed between these causing a plowing action formed. Due to plowing action the material from soft material surface is plastically deformed or removed away and a groove is formed on the eroded material surface as shown in figure 1.1. Example of abrasive wear is: shovels on the earth moving machinery.

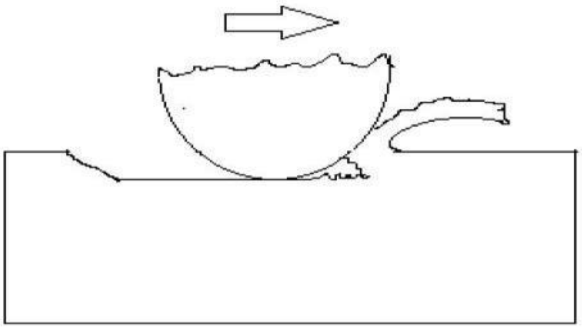

Figure 1.1: Abrasive Wear

b) Adhesive Wear

In this type of wear the contacting interfaces have enough adhesive/bonding strength to resist the relative motion between these. A dislocation or a crack is initiated at the mating zone under the tensile and shearing action due to this bonding strength.

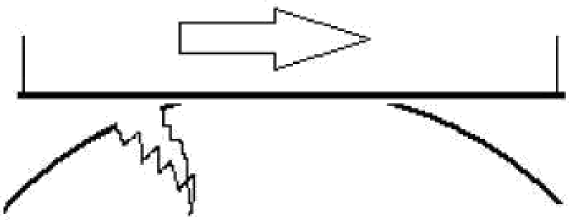

Figure 1.2: Adhesive Wear

c) Corrosive Wear

In corrosive liquid and gas flow products are formed on the surface between sliding surfaces due to chemical and electrochemical reactions. A bulk wear phenomenon is formed at the surface if the products sticks strongly on the wall/surface and treats as a bulk material. Some time products may not treat like bulk solids but products leads to wear due to reactions between solids and corrosive fluid.

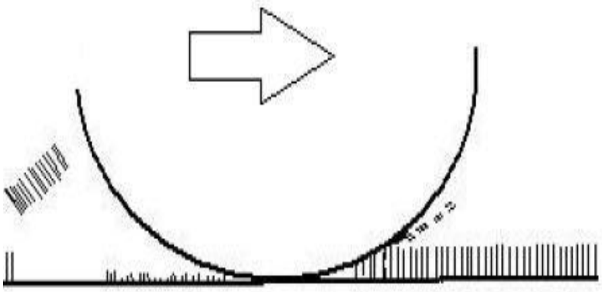

Figure 1.3: Corrosive Wear

II. LITERAURE REVIEW

In the literature review the study on erosion wear by many authors have been discussed. This chapter has been made after the complete study of their research papers to describe their investigation, findings, output, and results for the erosion wear. The numerical and experimental methodology was used by the researchers to evaluate of erosion wear due to transportation of the solid particulates through hydraulic and pneumatic system.

Graham et al. (2009) investigated slurry erosion in the pipe bend and cross-cylinder extended in pipe by experimental and numerical approaches. the surface condition for the slurry flow regions was checked with coordinate measuring machine and 3D laser scanner and compared CFD results with experimental data and paint modeling. They observed maximum erosion rate at the exit of the elbow-pipe wall, at top surface of cylinder and at vicinity (around the cylinder) of the complex domain. At the top surface of the pipe the results were deviating from the experimental results. The predicted results by Finnie and Grant erosion models were found agreement with the experimental results.[10]

Gnanuvela et al. (2011) investigated slurry erosion rate over a 90o flat plate using Jet impingement tester. They predicted the erosion ratio with experimental setup and three models in numerical approach at velocities 5m/s and 10 m/s. A good agreement between Huang erosion model and experimental results was found than Combined Finnie and Bitter erosion model. The erosion ratio was found due to deformation mechanism at impact angle from 80o to 30o and then deviated type erosion ratio was observed with cutting mechanism up-to impact angle (≤30o).[11]

Stack et al. (2011) studied the erosion-corrosion phenomenon using CFD-code over the Fe pipe-bend at different mass flow rate of solid particles and at different volume fraction. They observed that with increasing the solid concentration in the slurry the bend section was greatly influenced by the erosion wear than the straight section (pipe) but at the same time erosion dissolution (corrosion) was decreased at the particular region or erosion enhance corrosion.[12]

Zhang et al. (2011) numerically investigated the maximum erosion damage and location in the elbow and also studied the effect of slurry velocity, bend orientation and angle of the elbow. The discrete element method was used in the simulation process to track and identify the interaction between the wall and solid particles. They observed low porosity, high drag force, and high relative velocity (due to friction between particles) at the high concentrated zone. The maximum erosion was found at 25o of the elbow and different magnitude of erosion wear was also obtained at different slurry velocities (6m/s, 9m/s, 18m/s and 36 m/s).

The impact force was observed linear up to slurry velocity 9m/s and faster as well as non-linear beyond 9m/s up-to 36m/s. they also observed the gravitational force reduces the bouncing tendency of the particles. The erosion wear was found near the outer wall of the elbow.[13]

Mazumder et al. (2012) studied the effect of liquid and gas velocities on magnitude and location of maximum erosion in U- bend. They obtained that the maximum erosion location away from inlet of bend in gas-solid flow while at near for the liquid-solid flow with small particles and low velocity. Same location was found with 100 m particles at high velocities for both the flow (liquid and gas)-solid. Also results revealed that maximum erosion at same location with all size of particles for solid- liquid flow and only with larger particles in gas-solid flow.[14]

Njobuenwu et al. (2012) evaluated the erosion wear on cross duct 90o bend of four different sizes. The primary and secondary erosion was predicted in the simulation and compared with the five different erosion models, experimental data and found good agreement with the erosion models. The maximum and primary erosion was predicted on the concave wall near the entrance of bend then on the convex wall. The observed erosion wear was dependent on the momentum, velocity of the particles and number of particles tracked at the point of collision on the wall. A weak secondary erosion depth was also found at the concave wall near the exit of bend after collision of particles from the convex wall. In contrast all the physics of the erosion magnitude and location in the bend were the function of the restitution coefficients of the particles.[15]

Okita at al. (2012) studied the effects of air-water fluid viscosities and particles size on the erosion rate of flat plate by positioning at different angles. They observed the erosion ratio was decreased by increasing the viscosity of fluid in a mixture of sand- water contained particles size 20µm and 150 µm. the erosion ratio was decreased significantly with small size particles at high viscosity. But same erosion ration was found with 300µm particles at all viscosities. They found high axial velocity near the centerline and laminar type flow at exit of nozzle with viscosity of fluid 100cP and 120µm sand particles. While low velocity and turbulent type flow were found in 1Cp at same zones. The velocity was found low due to high pressure at stagnation point and increasing radially outward from centerline which tends to erosion. In air-solid, the erosion ratio was predicted at different impact angles, at two different shape and size (150 µm, 300 µm) of sand particles. High erosion ratio was found with 150 µm particles at all velocities and small impacting angles. The comparison was made between Oka, E/ECR equations and experimental data. The obtained results for erosion wear were steeper in air-solid flow than solid- liquid flow.[16]

WU et al. (2013) evaluated the erosion in oil pipe lines of different sections with 0.5% sand contamination. The less erosion rate was observed at inner side of straight pipe near the bend due to secondary flow and high erosion was found at the extrados of the bend. The erosion rate was also increasing with impact angle of the sand particles. The results revealed that erosion ratio was decreased at 30o bend instead of 45o and 90o bend, by decreasing camber angle. In long radius bend low secondary flow was examined and low erosion was observed. Also erosion was found with expansion of pipe sections, in which recirculation is decreased and leads to less erosion.[17]

Hadziahmetovic et al. (2014) predicted the erosion due to pneumatic conveying in elbow with CFD. After grid independent and particles independent test the results were revealed for the erosion depth and velocity at different planes in the elbow. The obtained results with Stochastic rebound model were more accurate than deterministic rebound models. The maximum erosion was found at 46o along the elbow curvature.[18]

III. MULTIPHASE MODELING FOR EROSION RATE

3.1 SOFTWARE INFORMATION:- Computational fluid dynamics (CFD) is an important tool which is used to solve the problems associated with fluid flow, heat flow and some reactions by simulating in computer. The CFD solve the problem by various numerical approaches and by algorithms, finally helps to optimize the solution results without any experimentation on physical models or prototype. The flow visualization characteristic of the code inside the domain make it very power-full tool in the research field and other areas. There are some governing equations are associated with the flow field and it is typically or may not possible to apply directly those equations with many variables to model. CFD divide the flow domain into number of cells and solve the governing equations for the each cell by converting PDE’s into algebraic form.

3.2 DISCRETIZATION TECHNIQUES :- In the discretization methods the governing equations are converted from partial differential and integral form to algebraic form. The various types of the dicretization methods are used in the CFD code.

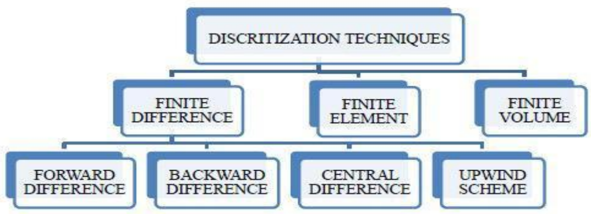

Figure 3.1: Discritization methods

IV. SOLID LIQUID EROSION WEAR USING CFD

4.1 CFD

In the present work, CFD ANSYS 19.2 multiphase euler-lagrange model is used to identify the erosion rate and to analyze the effects of velocity, particles size, and solid concentration for the erosion wear in pipe-bend. The erosion wear takes place generally in power plants due to transportation of slurry (water-bottom ash) through pipe-line system due to high velocity and impacts of solid particulates over the wall of the flow domain.

4.2 MATERIALS PROPERTIES

Properties :- The properties of the continuum media (water) and dispersed phase (bottom ash) are given the Table 4.2. The input parameters and conditions used in FLUENT for simulation the problem are described.

4.3 BOUNDARY CONDITIONS AND INPUT PARAMETERS :- The physical boundary conditions are imposed over the surfaces of flow field or domain for the simulation in fluent code. The type of the conditions are depends upon the flow field. Three boundary conditions which have been used

4.4 CFD SIMULATION AND VALIDATION

Erosion wear is material removal phenomenon due to impingement of solid particles over the surface which entrained through the carrier fluid like water. In thermal power plants bottom ash is transported in the slurry (ash-water) form with in the pipe line system which concerned with erosion wear. Various parameters are responsible for the erosion rate like impact angle, velocity, solid concentration, particle size etc. have been evaluated numerically using the erosion model in Computational fluid dynamics. At low flow velocity the of the mixture in the flow field the solid particles starts to settle down in the flow field due to low inertia, low drag and gravitational force on the particles.

V. SIMULATION RESULTS

5.1 30° DEGREE ELBOW

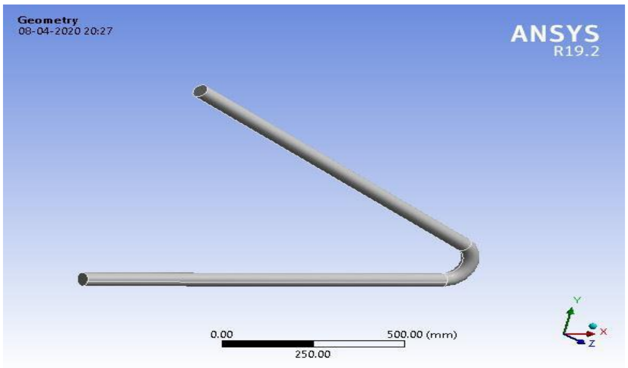

Fig. 5.1 30° Degree Elbow geometry import on ANSYS

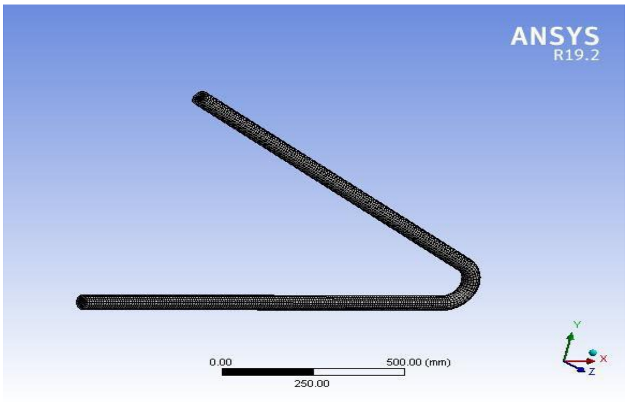

Fig. 5.2 30° Degree Elbow geometry meshing

Node: 23068

Elements: 20475

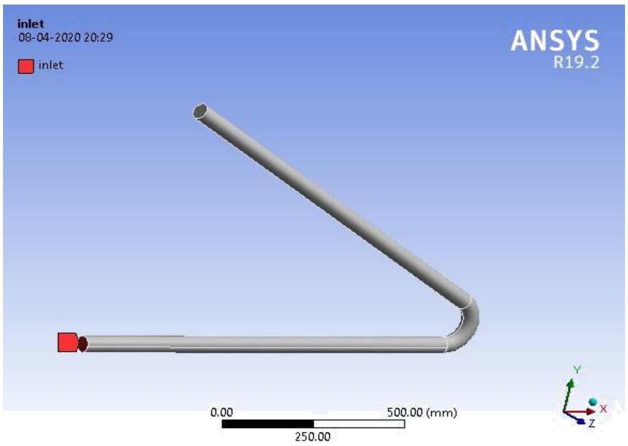

Fig. 5.3 30° Degree Elbow geometry inlet

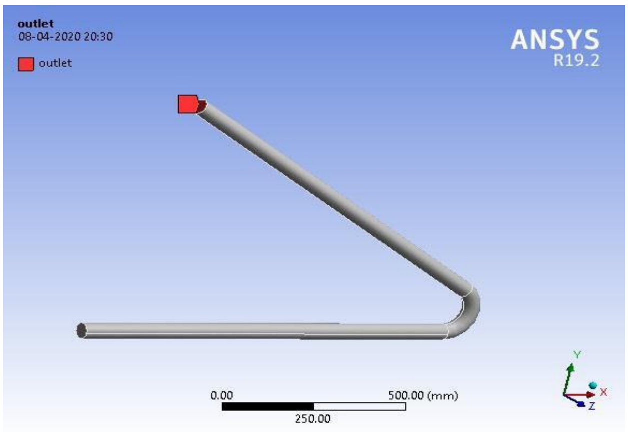

Fig. 5.4 30° Degree Elbow geometry outlet

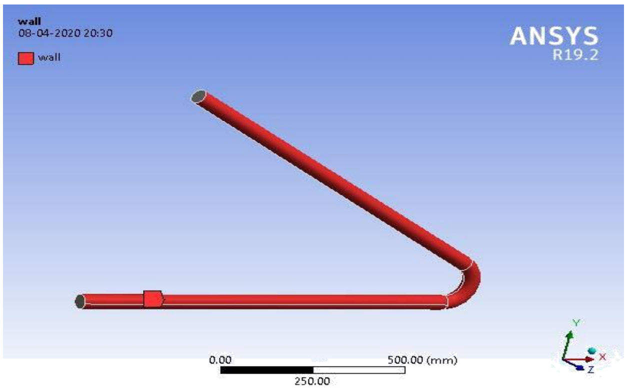

Fig. 5.5 30° Degree Elbow geometry wall

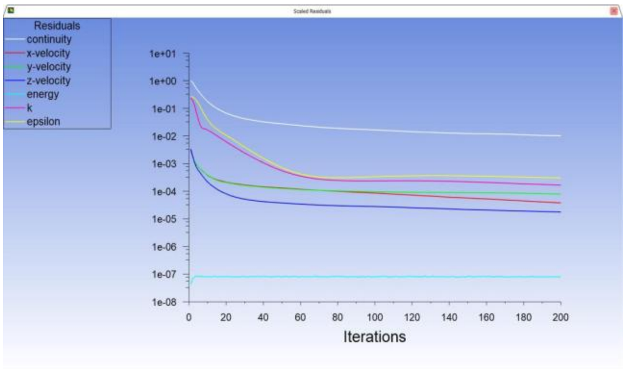

Fig. 5.6 30° Degree Elbow iterations up to 200

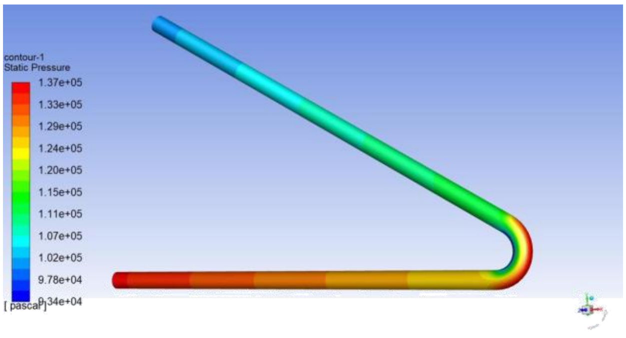

Fig. 5.7 30° Degree Elbow pressure results

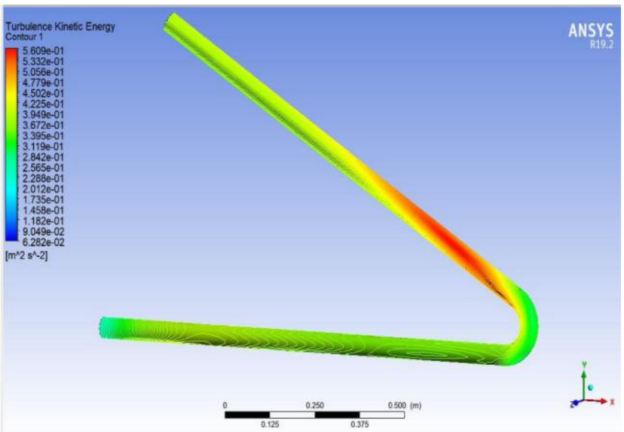

Fig. 5.8 30° Degree Elbow turbulence kinetic energy results

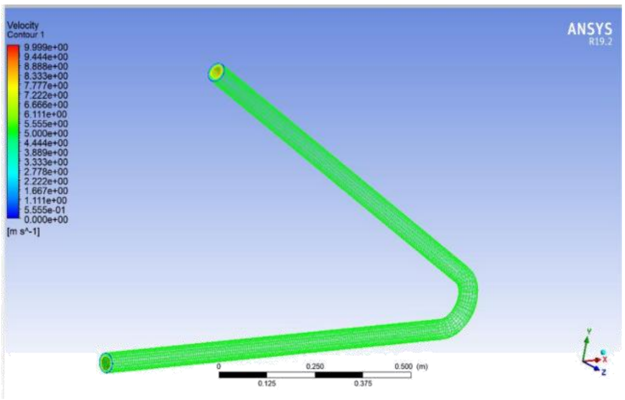

Fig. 5.9 30° Degree Elbow velocity results

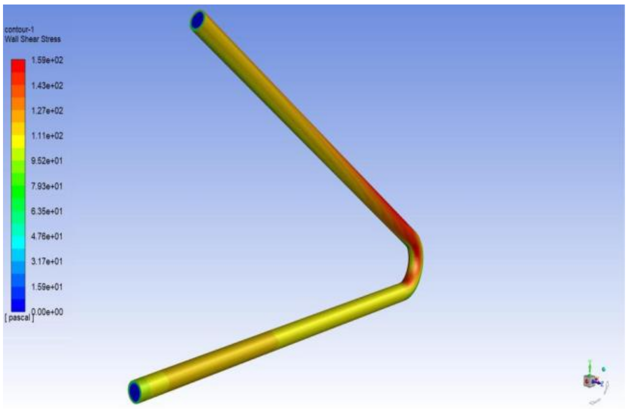

Fig. 5.10 30° Degree Elbow wall shear stress results

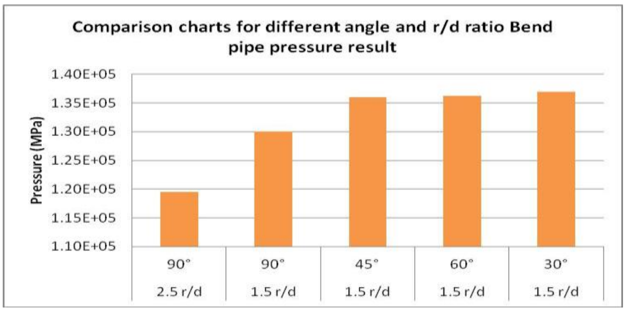

Fig. 6.1 comparison charts for different angle and r/d bend ratio pipe pressure result

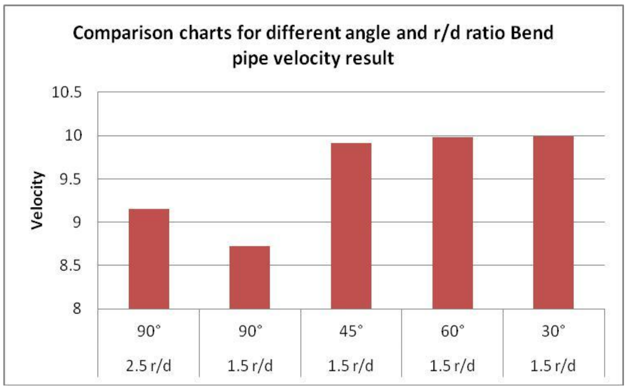

Fig. 6.2 comparison charts for different angle and r/d bend ratio pipe velocity result

Here cleared seen above table bend pipe with different bend angle Pressure Turbulence kinetic energy velocity wall shear DPM erosion rate and velocity streamline velocity results find out.

So Find out bend pipe pressure results on 90° degree with 2.5 bend ratio pipe, 90° degree with 1.5 bend ratio, 0° degree with 1.5 bend ratio, 45° degree with 1.5 bend ratio, 60° degree with 1.5 bend ratio, 30° degree with 1.5 bend ratio resulrs are respectively $1.20E^{+05}$ Pa, $1.30E^{+05}$ Pa, $1.36E^{+05}$ Pa, $1.36E^{+05}$ Pa, and $1.37E^{+05}$Pa

So Find out bend pipe Turbulence kinetic energy results on 90° degree with 2.5 bend ratio pipe, 90° degree with 1.5 bend ratio, 0° degree with 1.5 bend ratio, 45° degree with 1.5 bend ratio, 60° degree with 1.5 bend ratio, 30° degree with 1.5 bend ratio results are respectively $2.44E^{-01}$ m^2/sec2 , $3.06E^{-01}$ m^2/sec^2, $5.50E^{-01}$ m^2/sec2 , $5.44E^{-01}$ m^2/sec2 and $8.22E^{-01}$ m^2/sec^2

So Find out bend pipe velocity results on 90° degree with 2.5 bend ratio pipe, 90° degree with 1.5 bend ratio, 0° degree with 1.5 bend ratio, 45° degree with 1.5 bend ratio, 60° degree with 1.5 bend ratio, 30° degree with 1.5 bend ratio results are respectively 9.15m/s, 8.72 m/s, 9.91 m/s, 9.98 m/s and 9.99 m/s

So Find out bend pipe wall shear results on 90° degree with 2.5 bend ratio pipe, 90° degree with 1.5 bend ratio, 0° degree with 1.5 bend ratio, 45° degree with 1.5 bend ratio, 60° degree with 1.5 bend ratio, 30° degree with 1.5 bend ratio results are respectively $1.06E^{+02}$ Pa, $1.39E^{+02}$ Pa, $1.56E^{+02}$ Pa Pa, $1.57E^{+02}$ Pa, $1.59E^{+02}$ Pa

So Find out bend pipe streamline velocity results on 90° degree with 2.5 bend ratio pipe, 90° degree with 1.5 bend ratio, 0° degree with 1.5 bend ratio, 45° degree with 1.5 bend ratio, 60° degree with 1.5 bend ratio, 30° degree with 1.5 bend ratio results are respectively 9.13 m/s , 10.3 m/s, 10.1 m/s, 10.9 m/s and 10.1 m/s

So Find out bend pipe DPM erosion rate results on 90° degree with 2.5 bend ratio pipe, 90° degree with 1.5 bend ratio, 0° degree with 1.5 bend ratio, 45° degree with 1.5 bend ratio, 60° degree with 1.5 bend ratio, 30° degree with 1.5 bend ratio results are respectively $9.57E^{-26}$ kg/m^2s, $1.31E^{-25}$ kg/m^2s, $1.26E^{-23}$ kg/m^2s, $6.11E^{-25}$ kg/m^2s and $8.07E^{-25}$ kg/m^2s

VI. CONCLUSIONS

Computation fluid dynamics code FLUENT was used analyze the slurry erosion in pipe bend for the flow bottom ash slurry. based on the results conclusions are given below:The erosion wear in the horizontal pipe bend is greatly influenced with velocity of the flowing medium. settling takes place in the pipe bend due to low inertia and gravitational effect on the solid particulate, leads to erosion at bottom side of pipe line.Erosion wear takes place sever times more in curved sections than straight once. Significant of the solid concentration is very less for the erosion wear.The erosion rate is also varies with bend angle of pipe.

FUTURE SCOPE :- The present study has been done to predict the erosion rate and effect of the solid concentration, velocity and particles size on the horizontal 90^o pipe-bend. So this work can also be continuing for the long radius bend and centrifugal slurry pump impeller – section by numerical simulation.

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