Computational Investigation of Flow Velocity Variation on the Rate of Erosion Wear at the Elbow of the Slurry Pipe

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ABSTRACT

Erosion of the surfaces is one of the biggest industrial problem where the solid particles are transported. This manuscript highlights the effect of flow velocity on the solid particles erosion rate on the fluid carrying pipe. The fluid velocity is studied in the range of 2.5-20 m/s using computational fluid dynamics code ANSYS-FLUENT 2015. The sand particles and their concentration are kept constant i.e. 200 µm and 5% respectively. The computational modelling proves its importance in demonstrating the erosion rate of solid particle as well as its complex flow behaviour.

Keywords: *solid particle erosion, elbow , computational flow dynamics, discrete particle mode(DPM)*

1. INTRODUCTION

The erosion due to the solid particle is a matter of anxiety in many industries which includes the oil and gas industry, mining industry, because the deterioration of pipe material caused by erosion wear may results in failure of the pipe line and leads to economic loss and raises the issue of safety. So, for the design process as well as product sustainability, it is mandatory to analyse the rate of erosion and its pattern preciously. Various parameters which effects the rate of solid particle erosion in the pipe such as fluid properties, particle properties, material of the impinged wall and the flow path geometry. Focusing on each of the effective parameters, many studies have been done to predict erosion behaviour fordifferent operational conditions.

The solid particle erosion is a complex phenomenon to understand.Also, it is difficult to conduct experiments on the multiphase flow. However, the evolution of computational fluid dynamics (CFD) is found to be very useful in simulating such flow. The Multiphase models in CFD are generally based on Euler-Euler approach and Euler-Lagrange approach[1]. Solid Particulate (generally sand/coal particles) dispersed in the fluid strikes on the target wall and remove the inner coated material of the pipe wall. The removal of material by solid particle is labelled as erosion. A few studies utilized computational strategies to analyse the erosion behaviour at various affecting parameters [2]-[6].Habib et al.[7] studied the Erosive flow in the pipe section having sudden contraction. The influence of impact velocity, particle size and concentration were evaluated. The numerical part was performed by using commercial CFD code FLUENT with DPM to track the particles by using K-ϵ RNG turbulence modelling scheme. They examined that Erosion mainly occurs at the contraction plate. The impact of particles was significant on contraction plate and insignificant on pipe wall also the particle with higher size has the higher tendency to erode the material. Zhang et al.[8] developed a probability model to calculate the erosion caused by solid particle in a straight pipe. They investigated erosion rate using CFD code FLUENT for different particle size (50-400 μm), pipe diameter (50.5 to 203.2 mm) and flow velocity (3.048-15.240 m/s). Later the model was verified with the experimental results. They described that the penetration rate initially increases to a large extent with the particle size and then the increment is limited in extent. The influence of pipe diameter was found to be having an inverse relation with the erosion rate. Low value of penetration rate was reported on the pipe having big diameters. Their study also reports significant increase in penetration rate with velocity. Penetration rate was increased to 6.4 times at the velocity shift from 3.048 m/s to 6.096 m/s. Safaei et al.[9] studied the effect of copper particle diameter on the erosion rate in a 90° pipe bend. The size of the copper particle was varied from 10 nm to 100 μm at three different velocities of range 5-20 m/s. The most significant effect on erosion rate was observed with the change in impact velocity. For the same concentration the erosion caused by an impact velocity of 20 m/s was 7.5 times higher than that caused by 10 m/s. Shahata et al.[10] investigated the erosion rate on a carbon steel of pipe by varying both flow rates of sea water and sand concentrations (1to 11 grams per litre) and observed more erosion rate at higher concentration of sand.

Erosion wear is dependent of the number of particles striking a surface,aswell as the physical quantities associatedwith it, such as particlevelocity and their direction relative to the surface to be struck. Any minor change in the flowconditions such asviscous flow or temperature might bring large variations in the erosionrate. For example, in operations where the flow direction changesquickly such as turbine blade erosion is usually more severe than in astraight run of piping[11].

In this manuscript, the effect of the Discrete particle model(DPM) erosion rate on the elbow part of the pipe is investigated at different flow rate or flow velocity.

2. GOVERNING EQUATIONS AND EROSION MODEL

The DPM erosion rate of the water having sand particle is being studied using the numerical simulation techniques. The domain is developed in the Autodesk Fusion 360 software. The simulation is performed on the ANSYS 15.0(FLUENT) computational tool. The tetrahedral meshing is performed on the model with a high number of cells, so that the result which we get through the simulation is accurate. The k- ϵ viscous model is used for the simulation. The SIMPLEC scheme is used as a pressure velocity coupling model.

2.1 EULER-LAGRANGE APPROACH

One-way coupled Eulerian-Lagrangian model was used for the simulation. In this approachthe fluid is assumed as a continuous phase and solves it by the time averaged N-S equationandthesolution of dispersed phase obtained by tracking each particle.

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The single-phase equations for conservation of mass and momentum are:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho v) = 0, \qquad (1)$$

$$\left(\frac{\partial \rho v}{\partial t} + \nabla.(\rho v * v)\right) = \nabla.\tau \qquad (2)$$

$$\tau = \mu_{eff}[\nabla v + (\nabla v)^T] \qquad (3)$$

The turbulence is solved by using the standard k-ϵ model. The equation is in the form:

$$\nabla.(\rho v \varphi) - \nabla.\frac{\mu_{eff}}{\sigma_\varphi} = D_\varphi \qquad (4)$$

Here represents k or ϵ, $\sigma_\varphi$represents the turbulent diffusivity of $\varphi$and D_φ.

As the particle concentration is low, one-way coupling was applied in this study. Firstly, the solutionof continuous phase is obtained and after that particle trajectories are determined using lagrangianapproach by using Newtonian equation of motion:

Momentum: $$m.\frac{dv_p}{dt} = F \qquad (5)$$

Where F= Force i.e. a combined effect of drag force and the buoyancy force.

2.2 EROSION MODEL

A simplified erosion model of Finnie was implemented in this study. The implementation of theFinnie's model in CFX is as given below;

$$E = kV^n f(\gamma) \qquad (6)$$

$$f(\gamma) = \frac{1}{3}\cos^2\gamma \quad 18.5° \leq \gamma \geq 90° \qquad (7)$$

Where E= Erosion Rate, k and n are erosion parameters and for this study constant k was set to 1.0while n was set to 2.0,$f(\gamma)$ is a function that relates wear and impact angle,$\gamma$is the impact anglewith respect to normal to the surface. By implementing this model on CFX the overall erosion rate atevery point on the surface of bend is calculated by multiplying Erosion Rate (E) with the mass flowremoved by the particles that are impacting on the surface, after then adding for all the particles.This leads to a variable called as Erosion rate density having unit as Kg s-1m-2.

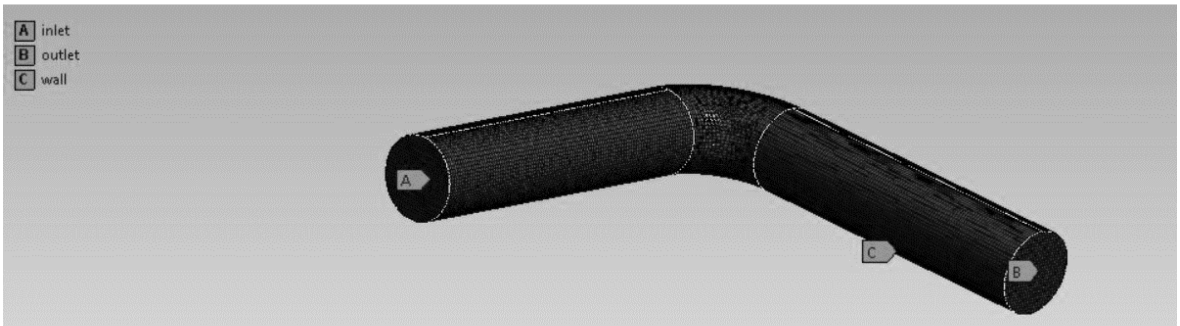

Figure 1 Physical Model of slurry pipe line

3. DOMAIN DESCRIPTION AND BOUNDARY CONDITIONS

A horizontal elbow pipe of mild steel was used in this study. The pipe has diameter D= 10 mm and lengthL= 100 mm as shown in Figure 1. The inlet is the velocity inlet whereas the outlet is considered as pressure outlet. The velocity of slurry flow is initially taken as 2.5 m/s which will be changed from 2.5 m/s to 10 m/s for further simulations. The flow is considered as fully developed flow at the inlet. The turbulent intensity at inlet is 'medium' i.e. 5%.

In this work tetrahedral type of meshing was done to discretize the domain into smaller cells. The higher grid cell increases the accuracy of the results. Table 1 shows the details of grid independency test of the meshing. it can be easily visualised from the Table 1 that after 2580273 cells, the variation in the DPM erosion rate due to meshing cells has become zero. For further simulation purpose, we consider this as our standard meshed domain.

Table 1 Grid Sensitivity Test for Meshing

S. No	Number of Cells	Change in DPM Erosion rate
1.	1012466	Yes
2.	1195872	Yes
3.	2246481	Yes
4.	2580273	No
5.	2850692	No

4. RESULTS AND DISCUSSION

The effect of flow rate on the erosion rate is studied at the elbow part of the model by keeping all other factors constant i.e. concentration of solid particle, diameter of the pipe, roughness of the pipe.

4.1 INFLUENCE OF VELOCITY

The contour of flow velocity is shown in figure 2. The flow is laminar and streamline up to the elbow point but after the elbow location , the liquid-solid particle flows on the zig zag path. The elbow portion can be considered as the transition part of the flow regimes. Also, at Elbow region, all solid particle strikes the wall of the pipe and develops the erosion of the pipe material. The momentumof solid particles is more in the transition and turbulent flow region as shown in Figure 2.

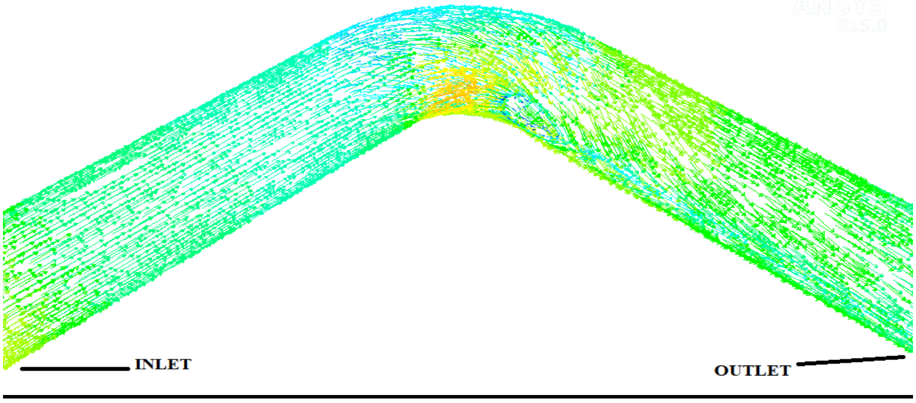

Figure 2 Velocity contour in the pipe flow

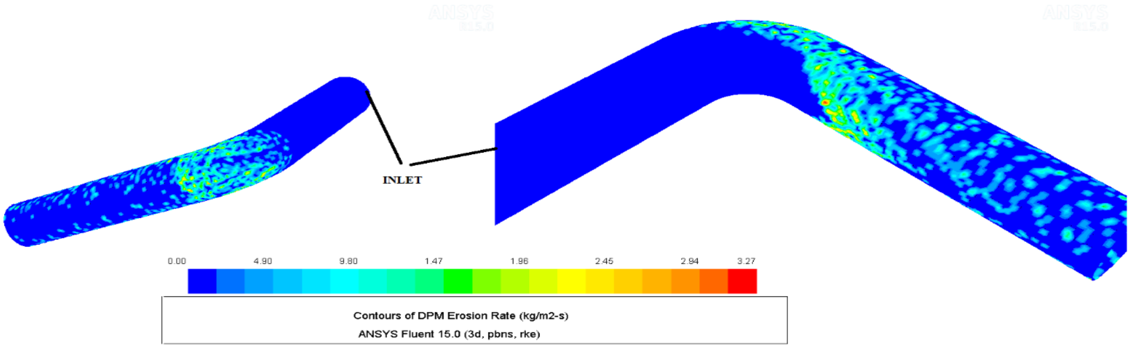

Figure 3(a) Contour of DPM Erosion Rate for 2.5 ms^{-1}

Figure 3(a) shows the contour of DPM erosion at the elbow region of the pipe. Contour shows that erosion rate is higher at the point where the solid particle collides with each other when the entered the turbulent motion. More the turbulence more will be the erosion rate. The contour profile is symmetric about the flow axis. The distribution of erosion rate is very similar in Figure 3(b) however the magnitude DPM erosion rate is 2.45 times higher for the 10ms-1 as compared to the 2.5 ms-1.

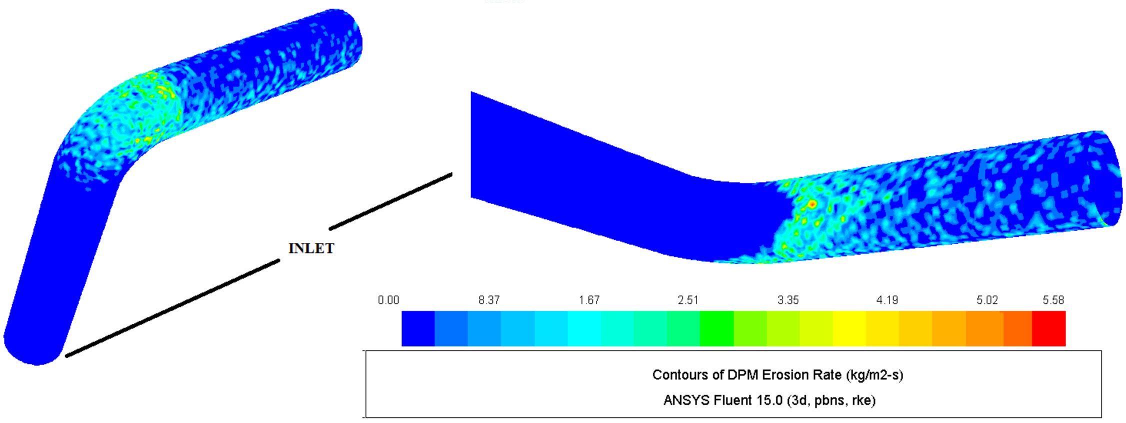

Figure 3(b) Contour of DPM Erosion rate for 10 ms^{-1}

Figure 4 demonstrate the variation of DPM Erosion rate at different flow velocity. At low velocity of 2.5 m/s erosion rate of solid particle has a very low value. The value of erosion rate density varies linearly and gets enhanced with the increase in the velocity. About 6 times increment in erosion rate is reported when the velocity gets step up from 2.5 m/s to 20 m/s. The increase in velocity increases the turbulence in the solid particles. These high momentum particles strike the elbow wall of the pipe hardly and thus causes more erosion.

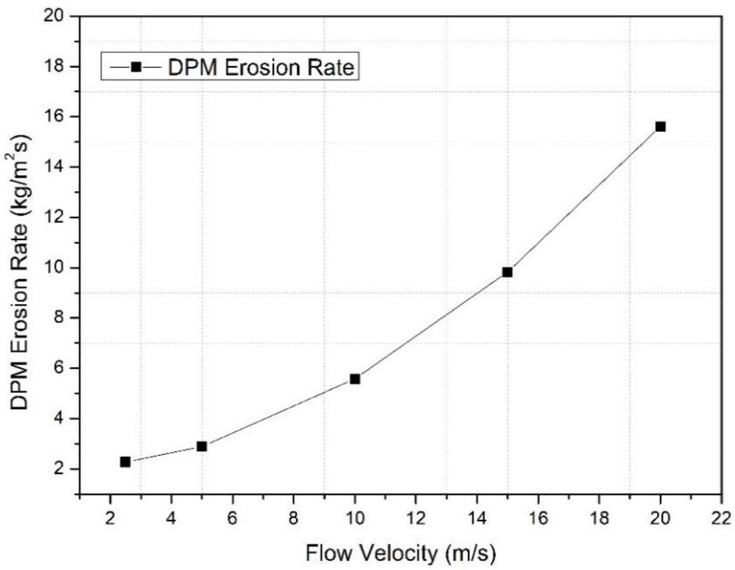

Figure 4 Variation of DPM Erosion rate and flow velocity of the solid particle in the slurry pipeline

5. CONCLUSION

With the help of CFD model, the investigation of the solid particle erosion ratein a 90° elbow bend pipe is easily be visualized and predictable. Based on the simulation results, it can be concluded that the flow velocity plays a significant role on the erosion decay in the pipeline especially at the elbow location. An increment of about 6 times in the value of erosion rate density is observed, when the velocity is shifted from 2.5 m/s to 20 m/s at 200μm particle size. Based on the main results of this analysis, it is expected that the erosion rate in other geometries can be predicted accurately with the help of Computational Tools.

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