CFD Simulation and Experimental Results Validation of Slurry Erosion Wear using Slurry Pot Test Rig

Satish R More[1,2,*], Dhananjay V Bhatt[3], Jyoti V Menghani[3] and Rahul K Jagtap[4]

[1]Faculty of Mechanical Engineering, Velagapudi Ramakrishna Siddhartha Engineering College, Vijayawada, Andhra Pradesh520007, India
[2]Faculty of Mechanical Engineering, Nutan Maharashtra Institute of Engineering and Technology, Talegaon-Pune, Maharashtra 410507, India
[3]Faculty of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat 395007, India
[4]School of Mechanical Engineering, Dr. Vishwanath Karad MIT World Peace University, Kothrud, Pune, Maharashtra 411038, India

([*]Corresponding author's e-mail: moresatish11@yahoo.co.in)

Abstract

Erosion wear is a severe issue in different industrial applications results in economic costs and operational failure. In most of the industry pipelines are used to handle the slurry during industrial process, the slurry handling pipeline is failure due to erosion wear. The slurry pot test rig is developed and fabricated for investigating the erosion wear rate of different material and solid particles used in the slurry pipeline with various working conditions. The various influencing parameters such as solid particle flow velocity, impact angle, solid particle size, and concentration are responsible for the rate of material loss and erosion wear mechanisms. The present study is based on experimental work and its validation of results of slurry erosion wear for slurry handling pipeline using slurry pot test rig and CFD simulation. For experimentation, mild steel is used as pipeline material and coal bottom ash is used as solid particles for simulating slurry handling pipeline use in a thermal power plant. The experimentation is performed on the slurry pot test rig. The computational fluid dynamics (CFD) tool is used to predict and simulate the experimental results of the slurry pot test rig. The simulation results compared with experimental results and check the percentage of errors with both the results. The simulation results show a similar kind of trend for erosion wear behavior of mild steel as per the experimental results. Simulation results show the average error up to ± 21% variation with the experimental result. The simulation results give the position of erosion wear over the sample surface.

Keywords: Slurry pot, Slurry erosion, Prediction, Validation, CFD simulation

Introduction

The thermal power plant, oil refinery, chemical industry, the hydraulic power plant has used the various size of pipelines for the transfer of liquid from one place to another place.According to applications of these industries some solid particles are available or mixed with flowing liquid. Due to the repetitive impact of solid particles present in flowing liquid as a result in a continuously removed pipeline material from the inner side of the pipeline. Such types of removal of material called as slurry erosion wear or solid particle erosion wear. The slurry erosion wear is the most common problem for such process industries. From last decade, slurry erosion problem in the thermal power plant has drawn major attention amongst researchers, because coal ash (fly/bottom) particles lead to savvier damage on many components of coal ash transport or disposed systems such as pipelines, pumps (casing/Impeller), flow control valve and elbows. This damage can start leakages or sudden failure of the component and can result in loss of production time and expensive repairs. Therefore, prediction of erosion wear rate and location identification is an essential task for avoiding failure and damage of components. There are a number of parameters responsible to erosion wear out of that solid particle size, concentration, impact velocity and impact angle play a significant role for material removal in slurry erosion wear. The variety of equations developed by various researchers either empirical or purely theoretical based reported in

papers. All such equations are valid for specific working conditions not suitable for general all type of application use. Simulation of slurry erosion wear is a difficult task because of variations, and complicated particulate-Liquid multiphase flow between flowing liquid and suspended solid particles [1,2].

However, for simulation of such type of multiphase flow is possible using computational fluid dynamics (CFD). In CFD solution of the multiphase model is done by using Lagrange and Euler approach. The coal ash particles available in water strikes on the inner surface of the slurry pipeline and remove the material form inner sidewall or surface. The few researchers have used CFD methodology toperformed studies and analyses the erosion rate and behavior at different working conditions and affecting parameters.

Mansouri *et al*. [3] used experimental and CFD methodology for finding the erosion equation and prediction of erosion wear.They developed the correlation by measuring the depth from normal impingement Air as well as liquid jet test. The velocity of solid particles measured using Utilizing a particle image velocimetry (PIV) technique. The local erosion wear depth was measured for better understanding of erosion patter. A 3D surface profile meter was used for depth measurement. The effect of the impingement angle and gas velocity on the slurry erosion profile was investigated. The developed equation results are good in agreement with prediction and measured profile observed. Frawley *et al*. [4] used CFD and DOE method to analyses the solid particle erosion in elbows. The CFD was used to simulate the erosion wear in elbows and DOE used to perform the analysis of erosion wear factors. Form result of the combined work of CFD and DOE was the most efficient and effective way to study and analyzed the erosion wear in pipeline elbows. The results are good in agreement with experimental results. Wong *et al*. [5] studied the experimental and computational modeling of slurry erosion wear in pipeline annular cavity. CFD simulation technique was used for computation study. They performed work on-air and sand slurry flowing through the aluminum pipe annual cavity with multilayer paint erosion and parent material loss investigated. They found that the higher erosion observed at the leading edge of the forward-facing step. Shahata*et al*. [6] investigated the erosion wear rate of the pipeline (carbon steel) by changing sand concentration and laminar and turbulent flow of sea-water. They found for both flow erosion wear increases by increasing sand concentration. Habib *et al*. [7] performed the erosion prediction for the pipeline with sudden contraction. They used CFD code for performing the study. Lagrangian particle tracking was used for tracking the sand particles. They found that at contraction plate maximum erosion wear observed. The size of solid particles increases the rate of erosion wear. Kannojiya*et al*. [8] studied and investigated erosion wear of straight pipeline made by mild steel at various operating parameters particle size, velocity and concentration. ANSYS-CFX with Euler-Lagrange approach used for computational simulation. They conclude that erosion wear was strongly responsible due to particle size, velocity and concentration. Similarly, some other researchers Grewal *et al*. [9], Kim *et al*. [10], Ma *et al*. [11], Mansouri *et al*. [12] are performed computational simulation study under the different input parameters and techniques for investigating the erosion wear due to solid particles. Azimianand Bart [13] studied experimental analysis and CFD simulation of erosion wear using a slurry tank test rig. The simulation was done to find the erosion wear for 2 different materials namely stainless steel and ST-50 with sand as solid particles. For simulation and experimentation, they vary velocity, concentration and plate material. They found simulation results are in good agreement with experimental results. Some of the researchers are work on SS316 L and SS 410 for improving their mechanical properties for various applications [14-16]

From the literature survey, the study of simulation effect with respect to variation in solid particle impact angles is an untouched part form simulation of slurry erosion wear. In this paper, authors are tried to simulate the slurry erosion wear occurs in slurry handling pipeline use in a thermal power plant. The coal ash is used to simulate exact working conditions. Simulation and experimentation study is based on a change in impact angle (7.5° to 90°). This will be helpful for investigating the position of erosion wear in slurry handling pipeline.

Material and method

Experimental setup and methodology

The present investigation experimental work is done using slurry pot test rig. The slurry pot test rig is one of the accurate test setup to finding the erosion rate in accelerated manner. Slurry pot test rig widely used for study the slurry erosion wear for various industrial application. It has the provision to change the various operating parameters according to requirement. Generally, slurry pot test rig is used to simulate the slurry erosion wear for slurry handling pipeline. **Figure 1** shows the experimental setup of

slurry pot test rig. The details of slurry pot test rig are considered same as per **Figure 1** available in More *et al*. [17]. Furthermore, details of experimental methodology and sample preparation similar as mention in More *et al*. [18]. The erosion wear rate is evaluated according to the relationship was proposed by Bree *et al*. [20] on the basis of average weight loss of 2 test samples as mentioned in More *et al*. [18].

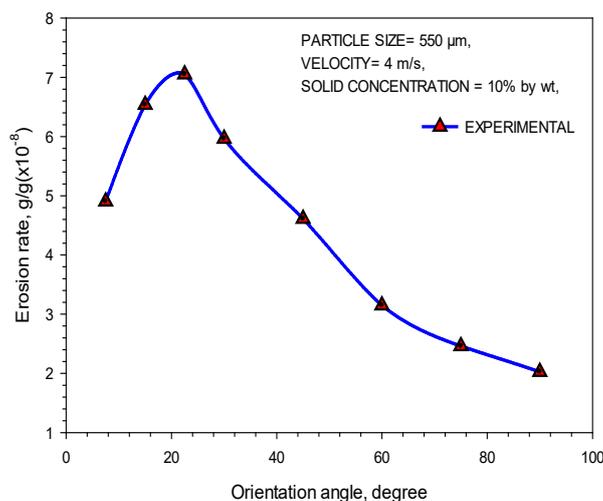**Figure 1** Photographic view of slurry pot test rig.

Figure2 Variation of erosion rate with orientation angle for [MS] surfaces (d = 550 μm, Cw = 10 %, V = 4 m/s).

Material used

The mild steel pipelines are used to handled and transport the coal ash slurry in a thermal power plant. For the present experimental work, mild steel is used as a target or sample material similar to pipeline and coal bottom ash particles are used as solid particles. The coal bottom as particles simulates exact working conditions as available in a thermal power plant. As per the requirements, the preparation of slurry is done using a mixture of water and coal bottom ash. Elemental composition of mild steel and physical properties of coal bottom ash as similar to **Tables 1** and **2**, respectively discussed in More *et al*. [18].

Experimental parameters

The coal ash solid particles of the size of 550 μm are used for preparing slurry by using a mixture of coal bottom ash and water. The selection of particle size is base on ash collection from the thermal power plant. The particle size and weight analysis result of coal ash collected from the slurry pipeline discussed in More *et al*. [19] are useful for selection of solid particles size. The experiments were performed at 10 % by weight solid particles concentration of the coal bottom ash in the slurry. Four m/s solid particle impact velocity is used for study erosion rate at various impact angles in the range of 7.5° - 90°.

Experimental results

Figure 2 shows the slurry erosion wear rate and behavior at various impact angles in a slurry of coal bottom ash and water mixture. Mild steel erosion rate calculated using correlation developed by Bree *et al*. [20]. Experimental results show that initially wear rate increases with an increase in impact angle from 7.5° to 22.5°. The maximum wear rate is observed and occurs at 22.5° impact angle. Then wear rate continuously decreases with increasing impact angle from 22.5° to 90°. Similar kind of variations in rate and behavior of erosion wear with different impact angles observed by Desale*et al*. [21].

Simulation work

Geometric data

The experimental set-up model was built using the CAD software CREO. The assembly features in the software were made use to fix the relative position of the components. The major components in the assembly are shown below.
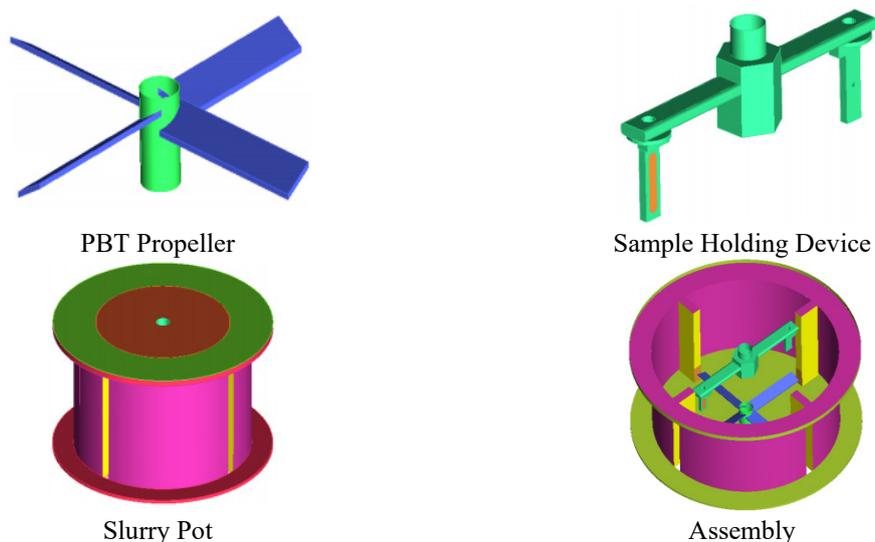

PBT Propeller   Sample Holding Device

Slurry Pot   Assembly

Figure 3 CAD modelling of slurry pot tester with detailing.

The CAD data were exported into ANSYS CFX V15.0 using the neutral file format called as IGES. In the 1st phase of the present work, the necessary fluid volume from the CAD model needs to be extracted.

Mesh generation

The computational volume was discretized on ANSYS ICEM software. The domain discretization into the finite volume is known as meshing. The present work used tetrahedral elements for domain discretization. Robust Octree algorithm that was available in ANSYS ICEM was utilized for generating the mesh. The total number of mesh elements was 456,932. In the images in this section, the mesh distribution had been shown along with a cross-sectional view of mesh in the computational domain. As discussed earlier, the regions near the rotating surfaces such as stirrer and the specimen were assigned to a separate Material Body to identify them in ANSYS CFX.
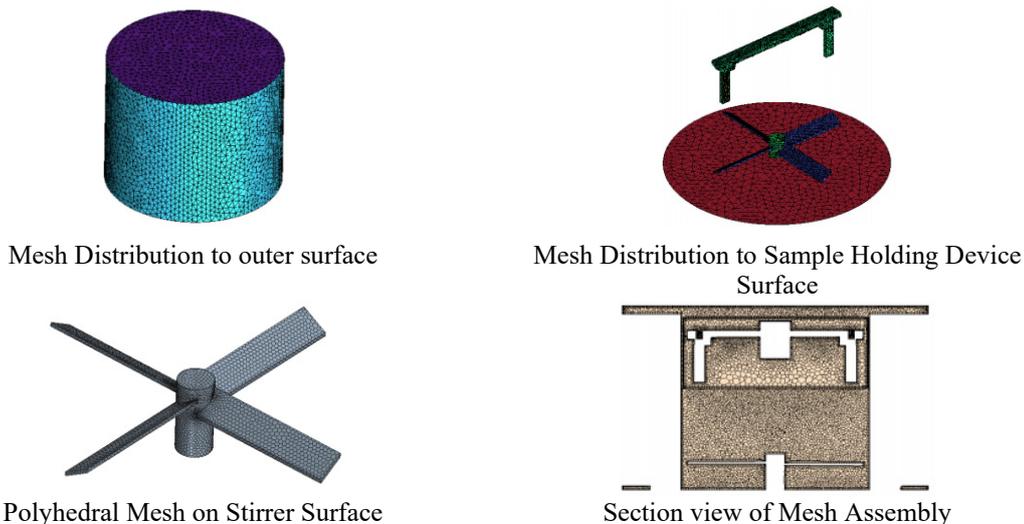
Mesh Distribution to outer surface

Mesh Distribution to Sample Holding Device
Surface

Polyhedral Mesh on Stirrer Surface

Section view of Mesh Assembly

Figure 4 Mesh distribution on components of erosion set-up.

Z Direction

Y Direction

Figure 5 Cross-sectional view of the mesh distribution in the computational domain.

Simulation setting and boundary conditions

The present work was assumed to be a steady-state. The problem considered didn't have flow inlets and flow outlets. The quantity of slurry inside the chamber remains the same as it is closed from everywhere. So, inlet and outlet type boundary conditions were selected for modeling the problem. There was no heat transfer across the solid walls. So, the walls were modeled using the No-Slip, Stationary and Adiabatic Wall boundary conditions.

Both the stirrer and the Specimen holder rotate at a constant speed. This would result in the adjacent fluid also to have rotational motion. These kinds of problems were modeled using Multiple Reference Frame approach. To use this modeling approach, the rotating volumes need to be identified. So, 2 rotating zones, near the stirrer and the specimen, were modeled using the rotational speed of 200 rpm while the remaining volume was modeled as stationary [8,12].
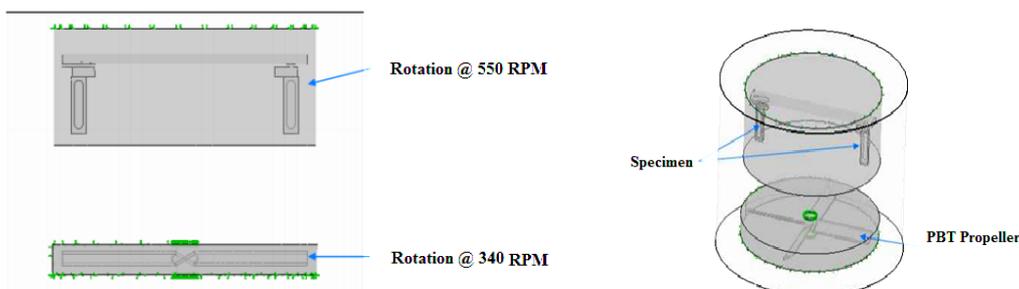

Figure 6 Description of rotational domain oferosionmodel.

The material erosion for this research work was modelled using Finnie model in ANSYS CFX. This model is available in the commercial CFD code ANSYS CFX. The Finnie's model of erosive wear mostly used because of its simplicity and it is relates the rate of wear to the kinetic energy angle of impact of solid particles on the surface.

$$E = kV_p^n f(\gamma)$$

Where, E – Dimensionless mass erosion

K – Particle impact rate

V_p^n – Particle impact velocity

$f(\gamma)$ – Dimensionless function of the impact angle

$$f\gamma = \frac{1}{3}\cos^2\gamma \qquad \text{If } \tan\gamma > \frac{1}{3}$$

$$f\gamma = \sin(2\gamma) - 3\sin^2\gamma \qquad \text{If } \tan\gamma > \frac{1}{3}$$

In the Finnie [22] model, the constant, n was taken as 2 for modelling the material erosion. The solver settings related to material erosion are provided in the following image.

Higher-Order numerical discretization schemes were employed to improve the solution accuracy. Multi-Grid solution cycles were imposed for the governing equations to accelerate the solution. Solution convergence was defined based on the reduction of governing equation residuals over the iterations.

Simulation results

During the simulation work, some assumptions are considered because of software limitations. Assumptions are mostly related to physical, chemical and material properties of solid particles (coal bottom ash) use in a thermal power plant. It is very difficult to use such solid particles. Also, some impurities and other solid particles are available in actual practice. With considering some assumption for simulation work **Figure 7** the contour plots of a specimen of the given condition at various impact angles. These contour plots are useful to represent the intensity and position of slurry erosion wear over the sample surface. Finally, after simulation software displayed the overall erosion wear rate. Form **Figure 7** contour plots of samples at 22.5° impact angle shows less blue color on both the samples as compared to another impact angles this is because maximum wear rate is observed at 22.5° impact angle.
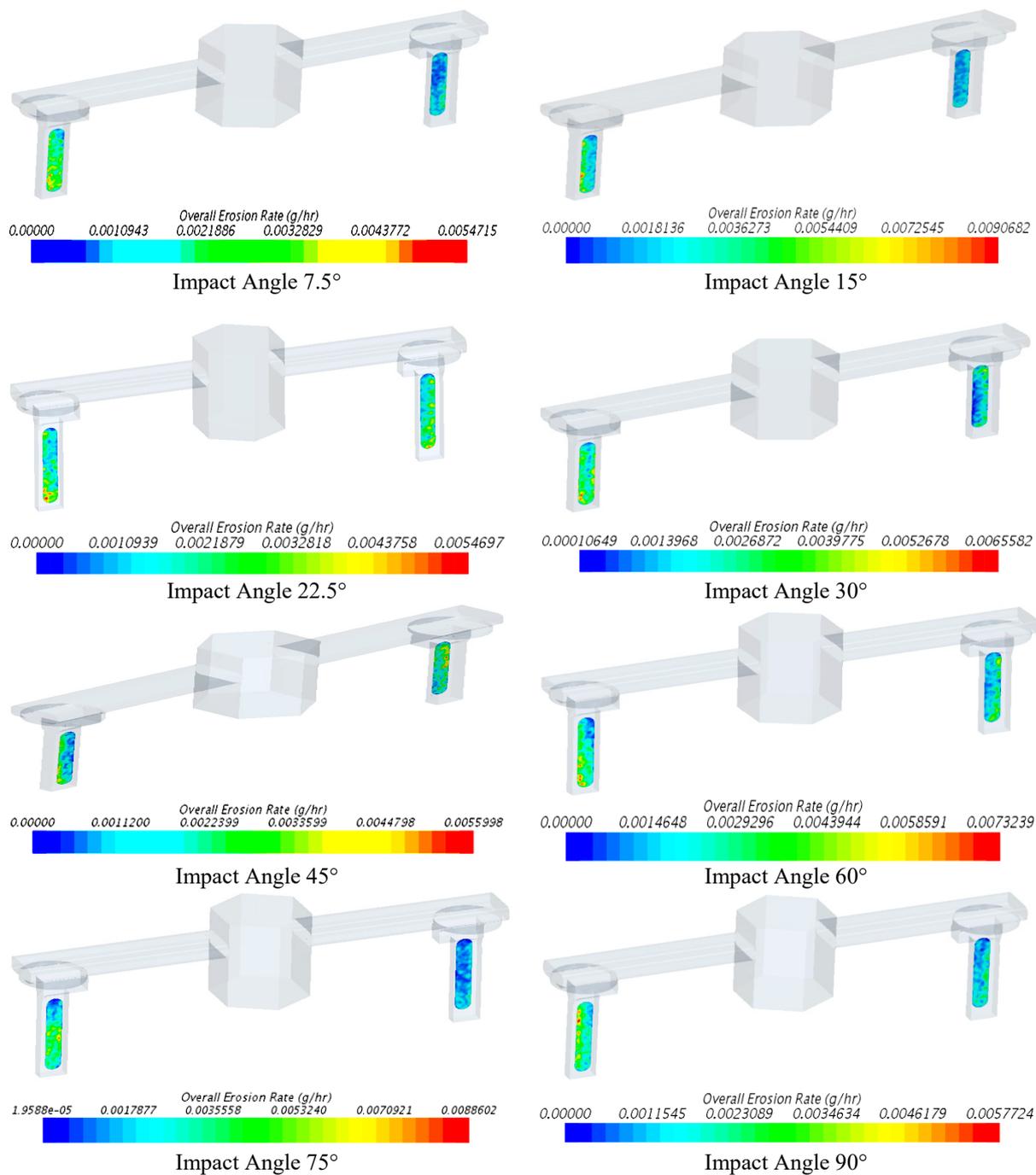
Figure 7 Contour plots of specimen of given condition at various impact angle.

Results and discussion

Table1 shows the experimental and simulation results for the rate of slurry erosion wear under thermal power plant slurry handling pipeline conditions. The rate of erosion wear calculated for 8 different impact angles. Errors percentage between the experimental and simulation results represented in the 4th column in **Table 1**. From the **Table 1** the average error is obtained in between ±21%. This variation of errors in erosion wear rate occurs due to limitations of the software. During the simulation work, some assumptions need to consider. Mostly assumptions are considered for solid particles, because it is very difficult to give input to software as per exact available solid particle (coal bottom as). **Figure**

8shows the slurry erosion wear behavior for both the studies. The behavior is the same for experimentation as well as simulation results. Only the differences in exact erosion wear value that is due to assumptions. The simulation results also show similar kind of curve nature, the maximum erosion wear rate at 22.5° impact angle.

Table 1 Experimental and simulation results of mild steel erosion wear behaviour.

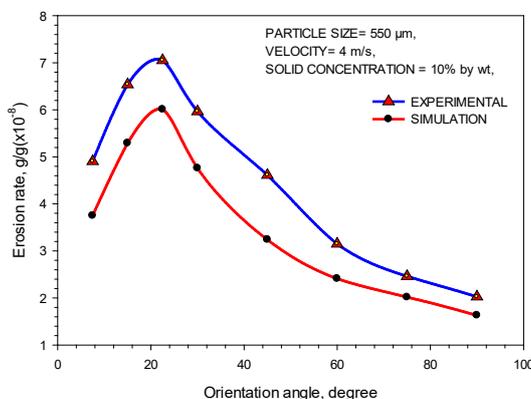| Impact Angle	Experimental Results	Simulation Results	Error (%)
7.5	4.9048	3.7500	23.54
15	6.5372	5.2900	19.08
22.5	7.0515	6.0100	14.77
30	5.9645	4.7600	20.19
45	4.6130	3.2400	29.76
60	3.1478	2.4100	23.44
75	2.4604	2.0170	18.02
90	2.0270	1.6300	19.59

Figure 8 Erosion wear behaviour of mild steel at actual experimental and software conditions.

Conclusions

The simulation results show a similar trend of erosion wear behavior of mild steel as per the experimental results. It shows the variation with the experimental result this variation appears due to the limitations of software related to input parameters, material properties and boundary condition given to the model. The simulation results give position and intensity of erosion wear over the sample surface also it gives the overall value of average erosion wear rate for the experimental duration. The experimental results give the exact value of erosion wear rate but it does not show the position of maximum wear over the sample surface. Therefore, the experimental results are used for finding the erosion wear rate i.e. value of the sample and simulation results are used for finding the position of maximum erosion wear over the target sample.

References

[1]   V Javaheri, D Porter and VT Kuokkala. Slurry erosion of steel -review of tests, mechanisms and materials. *Wear* 2018; **408-409**, 248-73.
[2]   S R More, D V Bhatt and J V Menghani. Recent research status on erosion wear - an overview. *Mater. Today Proc*. 2017; **4**,257-66.
[3]   A Mansouri, H Arabnejad, SA Shirazi and BS McLaury. A combined CFD/experimental methodology for erosion prediction. *Wear* 2015; **332-333**, 1090-7.
[4]   P Frawley, J Corish, A Niven and M Geron. Combination of CFD and DOE to analyse solid particle erosion in elbows. *Int. J. Comput. Fluid Dyn*. 2009; **23**, 411-26.
[5]   C Y Wong, C Solnordal, A Swallow and J Wu.Experimental and computational modeling of solid particle erosion in a pipe annular cavity. *Wear* 2013; **303**, 109-29.

[6] AI Shahata, MT Youssef, KM Saqr and M Shehadeh. CFD investigation of slurry seawater flow effect in steel elbows. *Int. J. Eng. Tech. Res.* 2014; **3**, 364-70.

[7] MA Habib, R Ben-Mansour, HM Badr and ME Kabir. Erosion and penetration rates of a pipe protruded in a sudden contraction. *Comput. Fluids* 2008; **37**, 146-60.

[8] V Kannojiya, S Kumar, M Kanwar and SK Mohapatra. Simulation of erosion wear in slurry pipe line using CFD. *Appl. Mech. Mater.* 2016; **852**, 459-65.

[9] HS Grewal, A Agrawal and H Singh. Experimental and computational modelling of solid particle erosion in a pipe annular cavity. *Tribol. Lett*. 2013; **51**, 1-7.

[10] JH Kim, HG Joo and KY Lee. Simulation of solid particle erosion in WC-Ni coated wall using CFD. *J. Mater. Proc. Technol*. 2015; **224**, 240-5.

[11] L Ma, C Huang, Y Xie, J Jiang, KY Tufa, R Hui and ZS Liu. Modelingof erodent particle trajectories in slurry flow. *Wear* 2015; **334-335**, 49-55.

[12] A Mansouri, H Arabnejad, S Karimi, SAShirazi and BS McLaury. Improved CFD modeling and validation of erosion damage due to fine sand particles. *Wear* 2015; **338-339**, 339-50.

[13] M Azimian and H J Bart. CFD simulation and experimental analysis of erosion in a slurry tank test rig. *Eur. Phys. J. Conf*. 2013; **45**, 01009.

[14] DD Deshmukh and VD Kalyankar. Deposition characteristics of multitrack overlay by plasma transferred arc welding on SS316L with Co-Cr based alloy - influence of process parameters. *High Temp. Mater. Process*. 2019; **38**, 248-63.

[15] HV Naik, DD Deshmukh and VD Kalyankar. *Study of heat treatment effect on microstructure of PTA weld deposited surface of SS 316L steel*. *In*: M Shunmugam and M Kanthababu (Eds.). Advances in additive manufacturing and joining.Lecture notes on multidisciplinary industrial engineering. Springer, Singapore, 2020.

[16] VD Kalyankar and DD Deshmukh. Failure investigations of failed valve plug SS410 steel due to cracking. *IOP Conf. Ser.: Mater. Sci. Eng.* 2017; **282**, 012007.

[17] SR More, DV Bhatt and JV Menghani. Study of the parametric performance of solid particle erosion wear under the slurry pot test rig. *Tribol. Ind*. 2017; **39**, 471-81.

[18] SR More, SP Ingole, DV Bhatt and JV Menghani. *The study of slurry erosion wear behaviour of coal bottom ash slurry handling pipeline*. *In:* TMS 2019 148th annual meeting & exhibition supplemental proceedings. The minerals, metals & materials series. Springer, Cham, Switzerland, 2019, p. 697-710.

[19] SR More, DV Bhatt and JV Menghani. Failure analysis of coal bottom ash slurry pipeline in thermal power plant. *Eng. Fail. Anal*. 2018; **90**, 489-96.

[20] D Bree, WF Rosenbrand and AWJD Gee. On the erosion resistance in water-sand mixtures of steels for application in slurry pipelines. *In*: Proceedings of 8[th]Hydrotransport of Solids in Pipes, BHRA Fluid Engineering, Johannesburg, South Africa. 1982.

[21] GR Desale, BK Gandhi and SC Jain. Particle size effects on the slurry erosion of aluminium alloy (AA 6063). *Wear* 2009; **266**, 1066-71.

[22] I Finnie. Erosion of surfaces by solid particles. *Wear* 1960; **3**, 87-103.