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"A REVIEW ON FINITE ELEMENT ANALYSIS METHOD FOR FINDING SHEAR RATES OF SLURRY IN BEND PIPES"

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ABSTRACT

Material loss due to erosion wear is a serious problem associated with flow of solid-liquid mixtures. Slurry erosion limits the useful life of equipment and is therefore a critical parameter for design, selection and operation of the hydraulic transportation system. Engineering interest is to estimate the service life of equipment / components subjected to slurry erosion and to investigate the possibilities of enhancement of their life. To being with the research work, it is essential for a researcher to get acquainted with previous investigation carried out in the relevant domain. Hence, present overview is intended to put forward the various type of geometries used for computational experimental work by various researchers. Also explore the effect of tribological parameters on erosion wear mainly slurry erosion like target material, erodent material, impact angle, impact velocity, particle size and solid concentration. Finally, some inference drowns from an overview and concludes future research scope that will be helpful to a new researcher in the field of slurry erosion wear.

Keyword: *Slurry, Shear Rate , Erosion Wear, Separated By Semicolons*

I. INTRODUCTION

Wear is related to interactions between two or more than two surfaces and specifically the removal and deformation of material on a surface. It is purely mechanical process. It may occur due to corrosion, abrasion or erosion. Corrosive wear is caused by due to the chemical reactions, abrasive wear caused by a hard rough surface slides across a softer surface and erosion wear is due to the impact of solid particle on the surface of an object. Erosion wear mainly classified in three type's solid particle erosion, liquid erosion and cavitations erosion. The solid particle erosion again classified in two type's gas solid and slurry erosion. In gas solid erosion the solid particle is suspended with gas and in slurry erosion solid particle is suspended with liquid. Slurry erosion has gained importance in the second half of 20th century as many slurry transportation systems came into existence during that period.

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 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.

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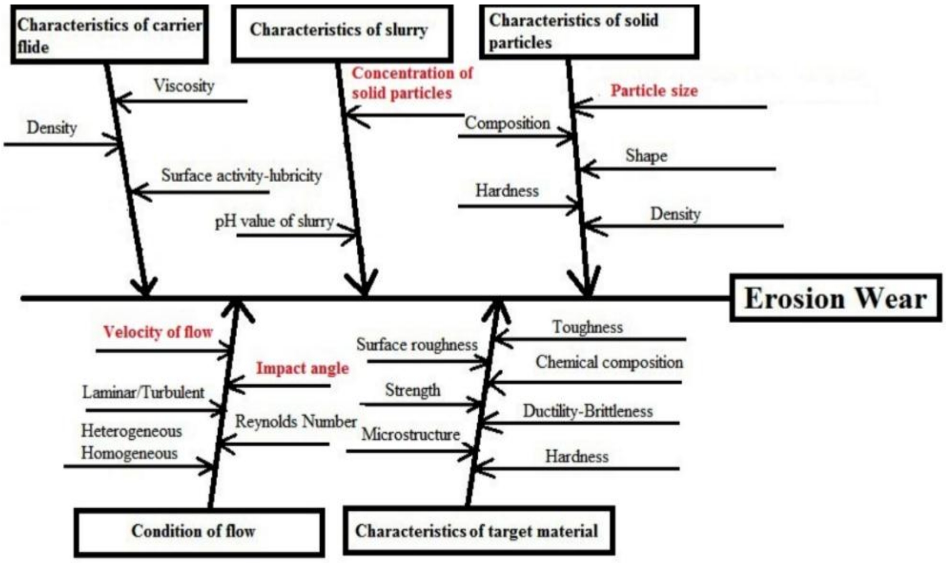

Fig. 1 Cause and effect diagram for slurry erosion wear

II. LITERATURE REVIEW

In the literature review the study on erosion wear by many authors have been discussed. This paper 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.

Modi et al. (2000) performed the jet impingement test on the 304 stainless steel specimen with coal and bottom ash slurry to evaluate the erosion wear. The high erosion wear was found with bottom ash slurry due to presence of the carbon, un-burnt coal and α particles in the bottom ash. They observed that the coal particles breakdown into small particles due to collision with wall and may not have enough energy to deform the target wall surface, hence less erosion rate was found with coal slurry. Also the results revealed that the high weight loss in the initial stage and became stable in the final stage along the travel distance of both the slurries.[1]

Zhang et al. (2000) performed simulation for the solid-liquid two phase flow to evaluate the erosion-corrosion in the pipe in CFD. The k-ε turbulent model and Lagrangian-model were used with the boundary conditions velocity inlet and outlet over the domain. The glass material of particles size 8μm was used as erodent material. The results obtained for the erosion rate, corrosion were found good agreement with experimental results of Nesic & Postlehwaite.[2]

Edward et al. (2001) numerically studied the solid particle erosion in Standard elbows, long radius elbows and plugged tees. They found more momentum transfer in long radius elbow instead of standard elbow. Due to the momentum the particles does not strike to the wall. The large amount of particles followed the fluid streamline or remain suspended in the fluid through the long curvature (don't strikes early to the wall). The gradual redirection of the flow leads to less erosion than instantly flow redirection. They observed the particles lose the velocity near the stagnant zone due to fluid cushion effect due this particles don't strikes the wall and low erosion wear was observed in plugged tees. Also they found low erosion depth in long radius elbow instead of standard elbow and plugged tees.[3]

Bozzini et al. (2003) studied erosion phenomenon of pipe bend in CFD code Fluent by using four phases (oil, sea water, hydrocarbon mixture and sand particles). The Discrete Phase Model was used to track solid particles of diameter 300 µm. They observed the solid particles have less transporting capacity at low velocity and settle-down pipe-bend where the erosion wear was examined at the same time they increased the gas volume flow rate in the mixture to improve the erosion rate. The total mass flow rate of particles was affecting the fluid flow behaviour not the erosion rate. The high velocity of mixture had generated high drag force and inertia force on solid particles which push the solid particles toward outer radius of bend where the high erosion rate was examined.[4]

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Wood et al. (2003) performed CFD simulation to evaluate the erosion induced by sand water in steel pipe-bend of pilot and laboratory scaled. The particle tracking and turbulence models were employed in the simulation process. The almost constant velocity as well as small impact angle was observed in straight pipe but fluctuated velocity profile and high impact angle were obtained in the bend cross-section. Due to this high velocity and impact angle the high erosion rate was found in the bend zone than the straight pipe. The experimental and numerical results had found good agreement.[5]

Chen et al. (2004) studied erosion wear on 1 inch elbow and plugged tee of aluminum in CFD code CFX code by considering air and sand particles (150μm in diameter). Grid independent test and particle independent test had been carried out for both the geometries. In lagrangian model, two wall collision approaches (Stochastic rebound and Forder rebound) were used to evaluate the erosion rate at different velocities (15.24m/s, 30.38m/s, 45.72m/s). The results obtained with Forder rebound model had 15% more erosion rate in elbow and large number of re-circulations leads to local erosion rate in tee domain. But stochastic rebound model's results have made a good agreement with experimental results. Finally, the average erosion wear location was found by graphical approach for the elbow and tee.[6]

Habbib et al. (2004) numerically investigated the erosion rate at different contraction ratio of carbon steel straight pipe. The simulation was carried out at different velocities, different particles sizes for the contraction ratio of the upward and down ward of pipe. The high erosion rate was found at contracted zone with different particles size at constant velocity for the upstream and downstream pipe. Also thrice erosion rate was examined with double size particles in up and downstream at different velocity at the same zone.[7]

Wood et al. (2004) studied slurry erosion rates in horizontal pipe-bend using CFD code-Fluent V5.4. The results were predicted at midway of the straight pipe and 45o along the bend. The particle velocity and supply of particles were varying along with the peripheral angles. The erosion rates, sand volume, impact angle, impact velocity, were predicted for the straight pipe and bend. Negative impact angle or reverse flow were found at 90o and 270o plane angles of pipe-bend. Due to the particles loading and impact velocity of the particles, somewhat erosion wear was examined at these angles and resulting the damaging of material at the particular zone.[8]

Gnanavelu et al. (2009) predicted wear rate of material due to erosion by jet impingement tester method in CFD code FLUENT. With particle tracking scheme the simulations results were validated with experimental data at different impingement angles in two cases (90o and 105o, 135o). At jet impingement angle of 90o with velocity 7m/s three different erosion scars were predicted on target wall. The particles were impacting near the centerline at stagnation point with low velocity due to high pressure. Away from the centre the particles velocity was high where the high erosion was examined. At impingement angle of 105o at 5m/s asymmetry erosion profile was found and also the unequal number of particles were impacting at each side of stagnation point. But at 135o angle, the particles were impacting at a single side of stagnation point. They observed difficulties to maintain the distance between nozzle and test surface, particles-particles collisions and the size and distribution of particles at different angles except normal angle of test specimen.[9]

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

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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 100μm 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]

Masouri et al.[2014] predicted erosion rate with two methodologies i.e. air –sand and water-sand using CFD code. Particles tracking approach was used to evaluate the erosion rate at different angles and different velocities for both the cases. The parallel flow path of particles in air and equal normal impingement and impact angles were found in air-solid erosion mechanism. But deviated-type flow path of particles and unequal angles were found in solid-liquid erosion. In air- solid flow, erosion depth (U-shape profile) was proportional to impact frequency of air, velocity and incident angle of impacting particles. In solid-liquid flow, near the target wall and at center of injection low velocity (due to static pressure) was observed which leads to a stagnation point where erosion depth decreases. Away from centre of injection along radius, the velocity was increasing which leads to high erosion depth and formed a W- shape erosion profile on wall.[19]

Pereira et al. (2014) studied for the erosion due to particles in elbow using Euler- lagrange approach in CFD-UNSKYFL3D code. Similar flow behaviour and different magnitudes of erosion were obtained in all the four erosion

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models. The results obtained with Oka and Zhang erosion models were good agreement the experimental results. They observed a noisier type penetration ratio with less number of particles and an effective penetration ratio was formed with 50,000 particles only in Oka erosion model. The erosion penetration was influenced by surface roughness and friction factor.[20]

Safaei et al. (2014) investigated the erosion wear on 90o bend with micro and nano meter copper particles using discrete phase erosion model. The effect of the velocities and six different particles size were examined at different solid concentrations. The maximum erosion rate obtained with micro size particles was many times more than nano size particles at high velocity. Also the effect of high concentration was examined and high erosion rate was found with increasing the solid concentration. The graphical representation was made for the threshold impact velocity and threshold particles size. threshold velocity means below which negligible erosion rate was found.[21]

Zeng et al. (2014) studied the erosion-corrosion on carbon steel elbow using CFD codes Gambit/Fluent. The mesh interval size was 0.004 m and turbulent flow model was employed. The simulations were carried out using Single phase, DPM, Euler models for pure erosion rate, pure corrosion rate, erosion–enhanced corrosion rate and corrosion–enhanced erosion rate. Due to gravitational effect, the sand concentration was found high at inner side of upstream straight pipe and also high erosion magnitude was observed at the same zone. Erosion magnitude and sand concentration were shifting from inner to outer wall along the elbow curve. The erosion rate was increasing along the outer radius (at azimuth angles 130 o, 180 o and 230o) and decreasing along the inner radius (at azimuth angles 0o, 50o and 310o) of elbow. At downstream pipe-section the erosion magnitude at outer wall was found contrary to upstream pipe..[22]

Chen et al. (2015) predicted the erosion of liquid-solid flow in three different bend angles with CFD-DEM. In simulation the maximum erosion was found near the exit of the all bends and minimum erosion rate was found in smaller bend angles. The predicted results agreed the experimental results.[23]

M.G Droubi et. al [2016] The prediction of erosion damage due to sand presence during hydrocarbon production is a major threat to the integrity of the production facilities. Sand production from oil and gas reservoirs can cause a significant damage to different pipeline components, and as a consequence, may lead to unwanted maintenance costs and potential environmental damage. In this work, a computational fluid dynamics (CFD) model was developed to investigate how altering flow conditions, pipe geometry and solid particle variables might affect the sand erosion rates at pipe bends. The model was first validated against particle tracks and erosion profiles presented by a published research with reasonable agreement. Erosion rate was found to decrease as the pipe diameter was increased with significant reductions observed when the pipe diameter was increased by the smallest degree (i.e. from 4" to 6"). Increasing the bend radii of 1.5D, 3D and 5D also resulted in a gradual decrease in maximum erosion rate observed in each test case respectively. However, it was observed that the surface area damaged by erosion increased as the bend radius was increased. It was found also that increasing particle size results in significantly larger erosion rates with different erosion scarring associated with each particle size. Moreover, no direct correlation was observed between increasing the carrier fluid density and the erosion rate. . However, much larger magnitudes of erosion were observed when gas (low density) was the carrier fluid when compared to oil and water individually. The final tests conducted were carried out when the distance between two bends in series was increased from 2.5D to 5D and then to 7.5D. Interestingly, erosion was found to increase as the distance between the bends was increased. [24]

Satish R Morea et. al [2017] Material loss due to erosion wear is a serious problem associated with flow of solid-liquid mixtures. Slurry erosion limits the useful life of equipment and is therefore a critical parameter for design, selection and operation of the hydraulic transportation system. Engineering interest is to estimate the service life of equipment / components subjected to slurry erosion and to investigate the possibilities of enhancement of their life. To being with the research work, it is essential for a researcher to get acquainted with previous investigation carried out in the relevant domain. Hence, present overview is intended to put forward the various type of test rig used for the experimental work by various researchers. Also explore the effect of tribological parameters on erosion wear mainly slurry erosion like target material, erodent material, impact angle, impact velocity, particle size and solid concentration. Finally, some inference drowns from an overview and concludes future research scope that will be helpful to a new researcher in the field of slurry erosion wear.[25]

Duarte et al. [2017] The results revealed that good agreement with experimental data by considering the wall roughness rather than a smooth wall in the simulation. have numerically and experimentally investigated the low

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erosion on twisted pipe bend than untwisted. Less erosion was found in elbow due to the swirling of particles in the 4-spiral designed pipe than the 8-spiral designed pipe bend and untwisted pipe bend.[26]

V. Singh et al [2018] In the present study, erosion wear of a 90o 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. Spherical shaped sand particles of size 183 μm and 277 μm of density 2631 kg/m3 are injected from the inlet surface at velocity ranging from 0.5 to 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. The magnitude and location of maximum erosion wear were more severe in bend rather than the straight pipe.[27]

Chukwugozie Jekwu Ejeh, et. al [2020] The flow dynamics in pipes is a very complex system because it is largely affected by flow conditions. The transport of crude oil in pipelines within unconsolidated petroleum reservoirs is associated with presence of solid particles. These particles are often transported as dispersed phases during crude oil production and are therefore detrimental to the pipe surface integrity. This could lead to the occurrences of crevice corrosion due to pipe erosion. In relation to the above discussion, this paper is aimed at analyzing crude oil dynamics during flow through pipeline and identifying erosion hotspot for different pipe elbow curvatures. Reynolds Averaging Navier–Stokes (RANS) and Particle Tracing Modeling (PTM) approach were used. The focus is to simulate fluid dynamics and particle tracing, respectively. Post-processed results revealed that the fluid velocity magnitude was relatively high at the region with minimum curvature radius. The maximum static pressure and turbulence dissipation rate were experienced in areas with low-velocity magnitude. Also, the rate of erosive wear was relatively high at the elbow and the hotspot varied with pipe curvature. The particle flow rate, mass, and size were varied and it was found that erosion rate increased with an increase in particle properties. [28]

III. CONCLUSION

Computation fluid dynamics code FLUENT was used to 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 will be greatly influenced with velocity of the flowing medium.
- ✓ Particulate, leads to erosion at bottom side of pipe line.
- ✓ Erosion wear takes place sever times more in curved sections than straight once.
- ✓ The erosion rate will be also varies with bend angle of pipe.

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