Mechatronics and Automation Technology
J. Xu (Ed.)

doi:10.3233/ATDE221187

CFD Erosion Wear Simulation in Three Elbows by Bottom-Ash Solution

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Abstracts. The authors evaluations using CFD analysis to calculate the rate of pipe bend erosion utilised in fluid-circulating technological installations along with solid particles on small size in the nature of bottom ash are described in this work. The examined pipe bends have various degrees of curvature and the same wall thickness and diameter and is made with stainless steel. The regions of erosion and the values of the erosion rate are the main goals of this CFD study. The pipe bend extrados is where erosion mostly happens. The type of pipe bend that is used affects the variations that have been seen, as the maximum amount of erosion wear rate rises with bend curvature. In order to compare the findings of the experimental programme and the CFD, the future studies will proceed by developing multiples test rig for the erosion wear check.

Keywords. CFD, elbows, erosion.

1. Introduction

[1] Erosion is a complicated process that is impacted by several elements present in the operating settings, and it has long been recognised as a potential cause of issues in the production of fluids (oils and gas) systems. There are several potential pathways that might result in severe erosion damage.

- Erosion corrosion;
- Cavitation;
- Particulate erosion;
- Liquid droplet erosion.

[2] The components in production systems where the direction of the flow abruptly changes, flow with high velocities resulting from flow rates with high volumetry are present, or flows with high velocities resulting from flow constraints are also present, are the important susceptible sections of the system.

Erosion wear is a kind of surface deterioration created by solid particles hitting with a surface quickly. Particles gather speed from the carrier liquid in slurry disposal systems, and their impacts on the inner surface of the walls of the elbow create the erosion. At tees and elbows, as well as bend portions, such pipelines suffer severe erosion wear [3-5].

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[6] Particle erosion is the removal of material or degradation of the target material integrity brought on by solid particle impact on the surface of the material. When developing production systems of fluids, erosion must be given a minimal tolerance. It can be realized by establishing a minimum erosion wear rate, from which the system's target surface service remaining life and maintenance costs must be calculated.

The following factors are important to be considered while finding the particulates erosion wear.

- The Density and viscosity of the fluid
- The flow rate of the bottom ash and mass
- The particles average shape, size, and its hardness
- The injected fluid velocity; Using a velocity exponent, the target material erosion wear depends on the fluid velocity n: Wear = f (velocity)n.

[7] have perform a work on how to reduce the erosion wear in a pipe wall by creating a vortex flow with a powder of anthracite transport in power plant by using computational fluid dynamic (CFD) and found that although the erosion wear phenomenon is mostly dependent on the fluid velocity the flow direction changes and the ratio between the radius of the bend section and the diameter of the pipe wall. By removing a spiral volume in the wall of the horizontal pipe just before the upward or downward of the bend it results a vortex flow in the wall which permit a more even erosion distribution in the wall of the bend. Thus, the loss of material due to the erosion in the bend were reduced by 28,8%.

[8] did research on the erosion phenomenon in elbows by using CFD simulation and try to reduce the erosion and solid materials impact angle by placing a twisted tape at different upstream positions of the bend part of the elbow and was investigated numerically. The results of the simulation were compared with some experimental data then he found that the motion imparted by the twisted tape to the motion of the particles reduce the penetration of the particles in the bend and farther the tape is inserted upstream of the bend, the lower the erosion occurred then the tape were more eroded.

[9] The primary consideration in design calculations need to be the flow velocity. A limit for the pipeline's flow rate, V_e [feet/sec], represent the velocity above the erosion wear can happen.

$$V_e = \frac{C}{\sqrt{\rho}} \tag{1}$$

Where: ρ represent the fluid mixture and C is an empirical constant.

- If the value of C is up to 250 is used for intermittent service
- C = 150 to 200 is for solid-free fluids and when corrosion is not anticipated.
- C= 125 is for intermittent services while C = 100 is for continuous service

According to [6] the formula to estimate the erosion wear is the following expression:

$$E_{L,y} = \frac{K * F(\alpha) * U_p^n}{\rho_t * A_t} * G * C_1 * GF * m_p * C_{unit} \tag{2}$$

Where G - particle diameter correction function, C_{unit} - factor of conversion (m/s to mm/year), GF - geometry correction factor, $E_{L,y}$ is the loss of surface thickness per annum [mm/year], n - velocity exponent (n = 2.6 for ductile steels), K - material erosion constant [(m/s)$^{-n}$], U_p - particle impact velocity [m/s], ρ_t - density of wall target material [kg/m^3], α- impact angle of the particle, $F(\alpha)$ is the ductility of the target material as written as follow (impact angles of 20°… 50°), A_t - area exposed to erosion [m^2], C_1 -

model/geometry factor, G - particle diameter correction function, C_1 - model/geometry factor [-]

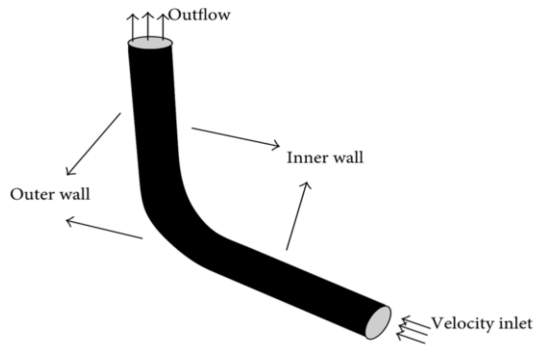
$$F(\alpha) = 0.6 * [\sin(\alpha) + 7.2 * (\sin(\alpha) - \sin^2(\alpha))]^{0.6} * (1 - e^{-20\alpha}) \tag{3}$$

2. CFD Analysis

[10] In the field of fluid mechanics known as computational fluid dynamics (CFD), issues involving fluid flows are solved and analysed using numerical methods and data structures.[6] For a given fluid domain, a CFD study translates into solving the Reynolds averaged Navier-Stokes equations.

2.1. Geometric Description

Three different bend pipes have been designed in order to evaluate the erosion impact on the bend pipe with the same diameter and different curvature.



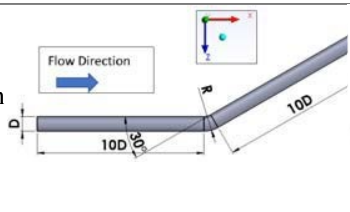
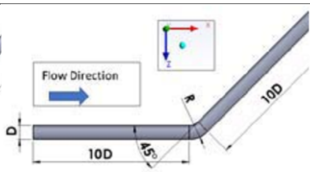
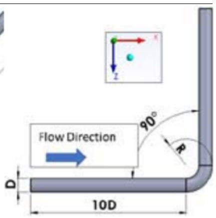
Bend Type	30°	45°	90°
Drawing			

Figure 1. Design of the different elbows

Table 1 displays the 3 bend variants together with the precise measurements. A 10D long straight segment is used to introduce fluid flow, which is then continued through a 30°, 45° or 90° bend section.

Table 1. Pipe Dimensions

Diameter D	100mm	100mm	100mm
Tickness e	10mm	10mm	10mm
Bend radius	150mm	150mm	150mm

The mesh details of the 30°, 45°, and 90° bends with the diameter De = 100 mm are shown in figure 2. Table 2 provides information on the mesh's cells and nodes for each bend arrangement.

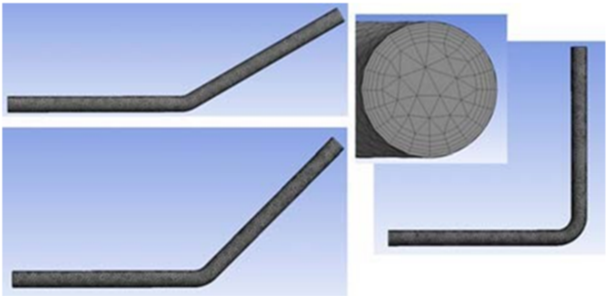


Figure 2. Meshing

Table 2. Meshing information number of elements and nodes

Bend type	Nodes	Elements
30°	174719	510435
45°	172946	509524
90°	173011	509318

Table 2 displays the 3 bend meshing details as shown by the figure 2.

2.2. Parameters of the Flow

The issue is solved by simulating the steady flow of water through the three various elbows designs on the XZ plane which horizontal while accounting for gravity effects on the Y axis at g = -9.8 m/s2. Water has a viscosity of 0.001003 $kg{\cdot}m^{-1}{\cdot}s^{-1}$ and a density of 998.2 kg/m^3 at the stated temperature of 20ºC. The injected particle Bottom ash has a density of 2220 kg/m^3. Three different velocities 2m/s, 3m/s, 4m/s and 5m/s have been used in the Z direction at the inlet.

The turbulence is modelled using a typical k-ε a two-equation model of turbulence based on the transport equations for turbulence's kinetic energy (k) and dissipation rate (ε). The model is only applicable to completely turbulent flows. Turbulent flows that are wall-bounded are modelled using scalable wall functions.[11] The viscosity-affected region, which includes the viscous sublayer, may now be solved with a grid all the way to the wall thanks to a modification to the turbulence model.

2.3. Boundary Conditions

- Inlet: Four different velocities 2m/s, 3m/s, 4m/s and 5m/s have been considered
- Wall treatment: Standard wall function
- Equation of solver: Navier-stokes
- Flow turbulence model: Standard k-ε
- Outlet pressure: Ambient

2.4. Discrete Phase Parameters

[11]The discrete phase is modelled via the Euler-Lagrange method. The Navier-Stokes equations are used to solve the liquid phase, which is a continuum one, while tracking a

huge number of injected particles is used to solve the discrete phase. The fluid phase and the discrete phase are capable of exchanging mass, energy, and momentum.
Bottom ash is considered as dispersed phase, and have a density of ρ=2220 kg/m^3, particles flow rate of 0.01 kg/s with the size of 250 µm and 300 µm. The spherical law was used for the erodent particles.

3. Results and Discussion

The materials loss in the three elbows at four different velocities and two size of particles injected are present the following table 3. Results are obtained in the order of 10^{-8} with unit Kg/ m^{2}s.

Table 3. Erosion wear value in each elbow after calculation

Type	**30°**				**45°**				**90°**			
velocities	2	3	4	5	2	3	4	5	2	3	4	5
250µm	8.304	10.66	19.31	23.20	12.71	23.33	36.43	38.45	5.639	18.34	26.88	43.97
300µm	10.89	14.81	23.36	26.67	14.30	22.08	39.32	52.07	5.478	23.57	27.92	52.66

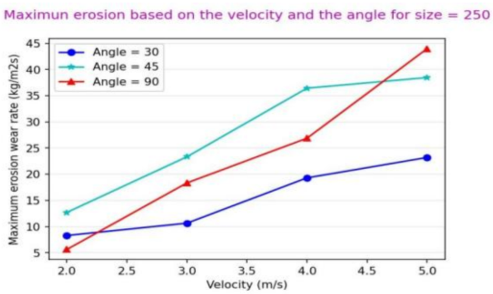


Figure 3. Plots of Maximum erosion wear rate at different velocities for 250 µm particles

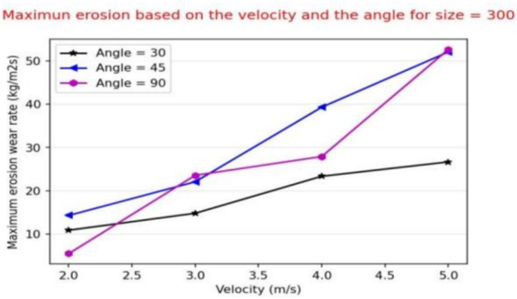


Figure 4. Plots of Maximum erosion wear rate at different velocities for 300 µm particles

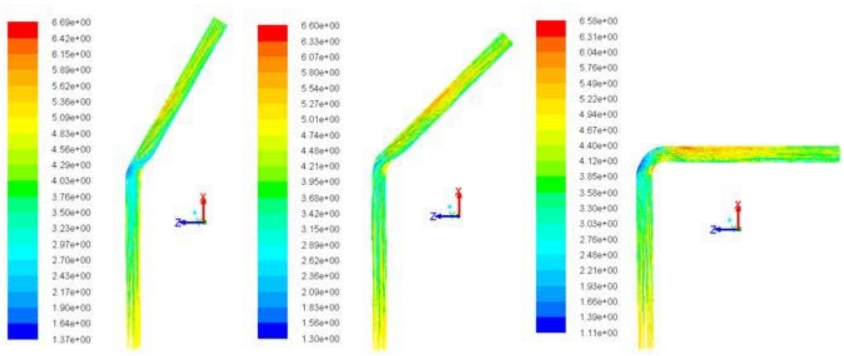


Figure 5. Particles trajectory based upon velocity

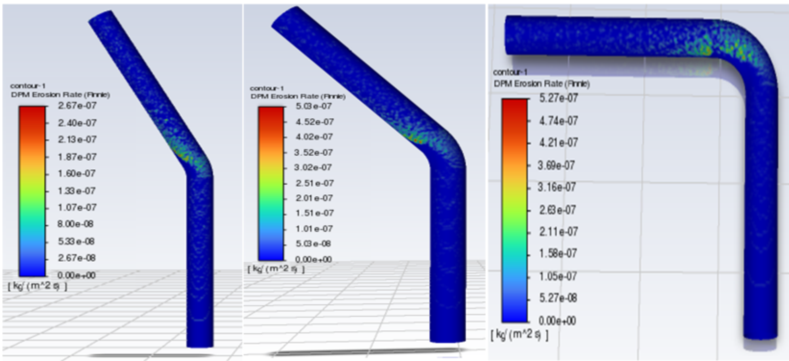


Figure 6. Erosion wear rate for 5m/s inlet velocity and 300 µm

The simulation and experimental findings show good agreement with [12] work on 90-degree elbows transporting 350 µm diameter sand and water particles in table 4.

Table 4. Experimental data of Bourgoyne on erosion wear rate

Geometry	r/D	U (m/s)	Sand flow rate (kg/s)	ER (kg/m^{2}s)	ER (mm/year)
Seamless elbow	1.5	9.45	1.44	3.42 x 10^{-9}	0.014 mm/year
Cast elbow	3.25	14.6	1.72	2.41 x 10^{-8}	0.1 mm/year
Cast elbow	3	11.5	6	3.49 x 10^{-9}	0.014 mm/year

He has worked on the erosion caused by sand particles entrained in flow streams that leads to diverter system failure. To evaluate and compare the severity of erosion for various geometries, an experimental diverter system with varied fittings was constructed. Results from simulations and experiments differ because of the diameter, the type of erodent material used here is bottom ash instead of sand and the velocities of the particles.

In figure 3 and figure 4 we can observe that the impact of the velocity is as the velocity increase the erosion rate also increase in each of the pipe no matter the size of the particles.

The figure 5 illustrate the particles trajectory based on the velocity and the regions of the impact of the particles with the bend sections are blue.

Following an analysis of the data in table 3 and table 4, the following conclusion may be made: figure 6 visual description of 90° bends obtaining maximum erosion rates; To make 90° bends

- Due to the centripetal force of action, as the velocity rises, the position of the highest erosion shifts toward the convex side of the curve.
- Sand particles are swirling after impacting the pipe bend wall. The particles reaching the bend intrados accelerate, with the types of bend with a 30° bend having the biggest predicted velocity increases;
- The erosion wear rate is observed to be increasing as the velocity increase and also depends on the injected particles size.
- It has been observed also that as the elbow angle is small the erosion wear doesn't occur as for the 90° elbows.
- The impact of the shape factor of the particle and the kind of particle, material will be examined using CFD analysis as the following procedures.

Based on the authors' study of the literature, experimental data for elbow erosion caused by sand particles in a liquid flow are extremely few. In order to obtain the experimental data for comparison with the findings of the CFD simulation, the study will proceed with the design and construction of several test rig.

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