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CFD ANALYSIS OF EROSION RATE IN OIL AND GAS PIPELINE INDUSTRY

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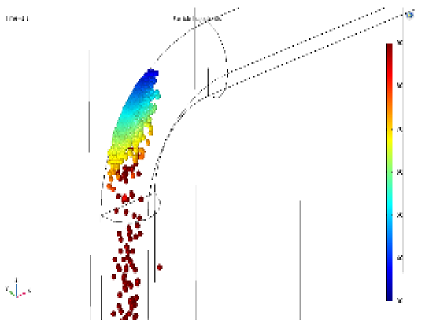
Graphic abstract



Abstract

Generally, crude oil has been transported via pipelines. But sand particles normally will be deposited on the bottom of pipeline due to the unsteady flow which it can lead to flow concern and erosion deformation of the pipe wall if not well treated. As well, this issue can cause the pipe destruction and burden the maintenance cost if not prevented in the early stage. Thus, this study was simulated to observe and predict the erosion rate at various parameter conditions with presence of solid particles in pipeline surface via COMSOL© Multiphysics 5.4 software. The model of k-ω turbulent and particle tracing were applied where several different potential impacting factors on the formation of erosion were investigated including fluids flow velocity, sand particle size, sand flow rates, pipe orientation and pipe diameter. The result simulation showed the area around the bend pipe had high predictions of erosion deformation where the maximum erosion rate of 732 mg/m^{2}s was observed for 2-inch pipe diameter and 100μm particle size. Besides, it shows the erosion rate increased as the higher mass flow rate and fluid velocity. By applying these erosion models, it could be possible to foresee the maximum point of erosion deformation along the pipelines which can reduce maintenance cost and prevent flow assurance issues.

Keywords: Sand Erosion, CFD, COMSOL© Multiphysics, Oil &gas industry

Abstrak

Secara khususnya, saluran paip digunakan dalam pemindahan minyak mentah. Namun begitu, kebiasaanya, berlaku pemendapan pasir di bahagian bawah saluran paip disebabkan oleh ketidakstabilan aliran yang boleh membawa kepada gangguan aliran dan pembentukan hakisan di permukaan paip jika tidak diselenggara dengan betul. Juga, isu ini boleh menyebabkan kerosakan pada saluran paip dan meningkatkan kos penyelenggaraan jika tidak dikawal pada peringkat awal. Oleh itu, tujuan kajian ini untuk melihat dan meramalkan kadar hakisan pada pelbagai keadaan parameter dengan kehadiran zarah pepejal di permukaan saluran paip menggunakan perisian COMSOL© Multiphysics 5.4. Model turbulen k-ω dan persamaan pengesanan zarah digunakan di mana beberapa potensi faktor berbeza yang memberi kesan terhadap pembentukan hakisan telah dikaji termasuk halaju aliran bendalir, saiz zarah pasir, kadar aliran pasir, orientasi paip dan diameter paip. Keputusan simulasi menunjukkan kawasan sekitar sesiku paip mempunyai kadar hakisan yang tinggi iaitu kira-kira 732 mg/m^{2}s bagi diameter paip berukuran 2-inci dan zarah bersaiz 100μm. Selain itu, ia menunjukkan kadar hakisan meningkat dengan peningkatan kadar aliran jisim dan halaju bendalir. Dengan menggunakan model hakisan ini, lokasi kadar hakisan maksimum dalam paip

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dapat dianggarkan bagi mengurangkan kos penyelenggaraan dan mengelakkan masalah aliran berlaku.

Kata kunci: Hakisan pasir, CFD, COMSOL© Multiphysics, industri minyak & gas

1.0 INTRODUCTION

Frequently, fluids transportation of oil and gas in the pipelines contain pollutant sand particles that are carried during fluid transportation where if it is not prevent properly will trigger problem such as flow assurance, pipe blockage, pressure drop and erosion. These problems occurred due to variation of velocities and fluid properties, surface degradation which is considered as a risk where it causes financial and environmental issues.

Due to high risk and potential to lead and contribute to sudden failures and high maintenances, the eroded position and maximum erosion rate should be foreseen and detected at the early stage. Thus, it is desirable to be able to accurately predict the erosion rate by applying predicted tool of erosion models based on some controllable parameters. There are several different ways to predict erosion damage on the system investigated. But there are very few studies of multiphase flow on the erosion of 90° pipeline. As each pipe orientation and geometry give different flow profiles and result on the various erosion patterns, thus, knowledge on the position and erosion scale that occurred is crucial to obtain efficient and economical production.

Past researchers have studied and developed numerous erosion models either via experimental, theoretical based equations or analytical model [1-11]. However, in the site industry field, it seems difficult to simulate the operating conditions on a laboratory scale as the pipe erosion is much more complex, making it difficult to predict. Therefore, to overcome this limitation, a numerical modelling based on Computational Fluid Dynamics (CFD) has drawn the interest of researchers from a wide-ranging area which it has been broadly established, investigated, and utilized to numerous functional applications. Due to advent technology, CFD study has become a crucial factor in the design of industrial goods and processes analyze flow in complex situations and geometry pipelines for transporting multiphase fluids.

Along with the progress in computing science, a very enormous level of problems can be resolved and simulated using CFD within a very reasonable time. Numerous CFD tools and complicated commercial codes have also been created to resolve the issue for investigating industrial process systems including fluid flow, heat transfer and associated phenomena. This CFD study does not simply reduce plenty of time and money, although it is more ecologically friendly in the majority cases.

Although the CFD estimate will not entirely substitute experimental analysis for gaining data for design objectives, it is considered that the computational techniques be an essential part in giving an understanding into complicated flow phenomenon. One main CFD benefit is it offers valuable local and temporal info that is frequently hard to achieve via investigational methods. Thus, several scientists are currently utilizing CFD method for erosion prediction and studies of multiphase flows in the complex geometries and interactions between fluid and particles where it can predict erosion regions accurately in various applications [12-17]. It has been studied extensively for decades as it has the benefit of forecasting erosion rate, position of the highest erosion, thus detecting potential leakage positions with temporal development of erosion.

To predict the erosion rate, there are countless parameters that affected its formation on the pipelines wall such as fluid velocity, particle size, pipe diameter and fluid properties [16-18]. Besides, CFD has been extensively applied for erosion estimate as the early 1990's. University of Tulsa, Oklahoma has been the hub for the majority of CFD based erosion estimate study for the previous two decades which given to developing abilities of CFD-based erosion estimate technique and models [19-21]. Parsi *et al*. reported the erosion model by Oka *et al*. have the greatest erosion estimate in complicated multiphase flows when the model created [18]. Also, Zhang *et al*. demonstrated comparable result using two-equation turbulence models as utilized for erosion estimate in elbows and it is fewer computationally challenging as compared to another complicated turbulence models [14] where k-ω is the best extensively utilized for study and industrial purposes in single- and multi-phase flow modelling.

Even though the CFD modeling of erosion has been done for years, there is still a need for deeper knowledge about the models and methods. By using different erosion models, and the combination of the validated particle erosion model from COMSOL© Multiphysics, erosion rate results were captured and reported.

In summary, previous studies have indicated that most studies of CFD erosion study in the pipelines have utilized the Eulerian-Lagrangian modelling method with additional emphasis on single phase flows for turbulence and another boundary factors [22]. Yet, the particle erosion mechanism in the multiphase flow is still not fully understood. Therefore, it is extremely necessary to investigate erosion loss due to sand particle effect in the multiphase fluid flows.

Due to this, this paper purpose is to simulate and determine a pipe erosion using COMSOL© Multiphysics software where the model geometry and mesh were generated. The particle trajectories are shown within the elbow section were observed where it shows the highest amounts erosion rate happens on the external radius of the bend pipe. Then, the simulated analysis of erosion rate was compared by four various erosion models. To predict erosion rate using CFD analysis, there are three key phases: flow modeling, particle tracking and determination of erosion rate on the influencing parameters; particle sizes, fluid velocities, pipe length and sand flowrate. The finding provides some understanding of wherever transporter fluid is in multiphase, and it was found to agree well when compared with result from the machine learning model and experimental data. If appropriately interpreted, this CFD modelling method will offer more comprehensive data on the local flow and particle factors that can be tough to attain empirically.

2.0 METHODOLOGY

The flow is considered as a continuous viscous flow, incompressible, and isothermal liquid, with the water as fluid and the gravitational impacts are neglected. The fluid density and viscosity are ρ=966 kgm^{-3}, and μ=3.15×10^{-4} kgm^{-1}s^{-1}, respectively [22] with averaged velocity is V_{avg}=10 ms^{-1}. The CFD solver, COMSOL© Multiphysics have been applied to mathematically find results for the governing equations for turbulent flow of sand particles in pipelines due to sand particle impact.

2.1 Model Development and Meshing

Figure 1 shows a model of 90° pipeline designed in this simulation. The fluid was fed upward through the pipe inlet that was in the bottom side on the left corner. The pipe model was designed based on the geometric complexity involved in pipeline installation at a typical oil and gas production site [18, 23]. The inside diameter for both straight cylindrical pipe is D_p=25.4 mm with L_1=182.88 mm and L_2=292.1 mm in length that connected with D_c=12.7 cm radius of curvature of a 90° elbow section. The vertical-horizontal pipe is utilized to carry fluid water and solid particles at room temperature with the highest inlet velocity of 20 ms^{-1} and at sand rate of 0.7 kgh^{-1}. The particles would be assigned a size distribution with range diameters of 100 - 460 μm. From a few previous studies, it shows the erosion deformation for case of liquid-gas-solid flow is about five times higher than the erosion for liquid-solid flow [12, 15, 18, 20, 23]. Also, they reported that the condition of gas velocity at V_g=20 ms^{-1} and liquid velocity at V_l=2 ms^{-1} was the best and optimum condition to ensure that the erosion rate can be less deformed to avoid any further distortion of pipe or pipe flow. Thus, the inlet velocity was setting at the bottom feed of the pipe inlet within the range of V_g=0-20 ms^{-1} and V_l=0-2 ms^{-1} respectively, with specified assuming no slip condition. These velocity ranges were simulated to determine its effect on the erosion deformation on the bend pipe.

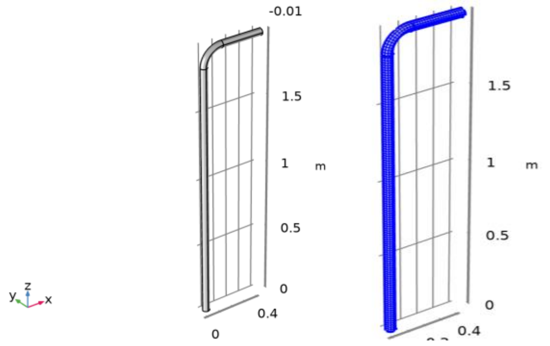
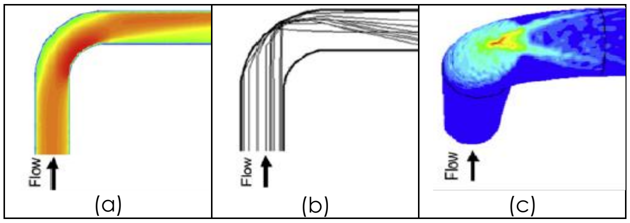


Figure 1 a) 3D pipeline flow and b) 3D meshed pipeline flow

2.2 Pipe Erosion Modeling

Commonly, CFD modelling involves three stages: flow modelling, particle tracing and erosion rate development. Every stage varies on the results achieved in the initial one, which indicates that any defective or non-physical outcomes will influence the consequence. The three stages of the CFD based erosion modelling are illustrated in Figure 2 [27].

In this simulation, COMSOL© Multiphysics software is applied to model sand particle flow and erosion development. COMSOL© programming computes the paths of distinct phase objects using a Lagrangian formulation, by resolving the governing equations of particle movement. It foresees the path of a distinct phase particle by incorporating the force balance on the particle. The COMSOL system offers various models for erosion evaluation with the Oka and E/CRC erosion model utilized as its abilities in approximating erosion rates as studied by other researchers.



(a) (b) (c)

Figure 2 The three steps of CFD based erosion modelling a) flow modelling, b) particle tracking and c) erosion calculation

Once the pipeline was developed and modelled, the data on boundary conditions, turbulence model (K), and chosen mathematical methods as shown in Equation (1) and (2) are well-defined where μ is a viscosity of fluid, u is a velocity, F_D is a drag force, m_p is a mass rate of particle and v is a velocity of fluid in the pipeline [22]. Lastly, the solver provides and inputs the flow field data for particle tracing applied to ascertain particle paths. In Eulerian field converges, the discrete phase is solved by tracking many particles. And then the CFD-based erosion modeling estimates can be done since practical relationships that can integrated to establish the erosion rate.

$$K = (\mu + \mu_T)\,(\nabla u + (\nabla u)^T) \qquad (1)$$

$$F_D = \frac{1}{\tau_p} m_p (u - v) \qquad (2)$$

In a CFD code in COMSOL© Multiphysics simulation, the erosion model was employed to predict a pipeline erosion rate as shown in Equation (3) where *E* is reference erosion rate at 90° impact angle, *V* is a particle impact velocity, V_{ref} is a reference velocity, *d* is particle diameter, d_{ref} particle reference diameter, k_2 and k_3 is diameter exponents, and *f(ɣ)* is a dimensionless function of particle impact angle [4, 22]. This model was chosen as it considers the influence of particle diameters, velocities, impact angles, and material properties in determination of erosion rate.

$$E = E_{90} . \left(\frac{V}{V_{ref}}\right)^{k_2} . \left(\frac{d}{d_{ref}}\right)^{k_3} . f(\gamma) \qquad (3)$$

3.0 RESULTS AND DISCUSSION

The result simulation on a flow observation was shown in Figure 3 where Figure 3 (a) shows a result of velocity distribution, Figure 3 (b) shows a pressure distribution and Figure 3 (c) shows a wall resolution. Figure 4 shows the particle trajectories where the disappear wall condition has been applied to obscure particles that passage along the pipe bend without tapping the walls, hence just the particles that have interacted with the pipe surfaces are shown. The particles only hit the surface at sweeping angles.

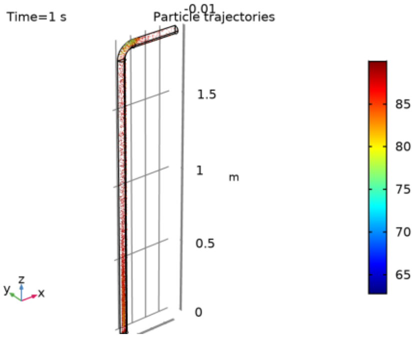


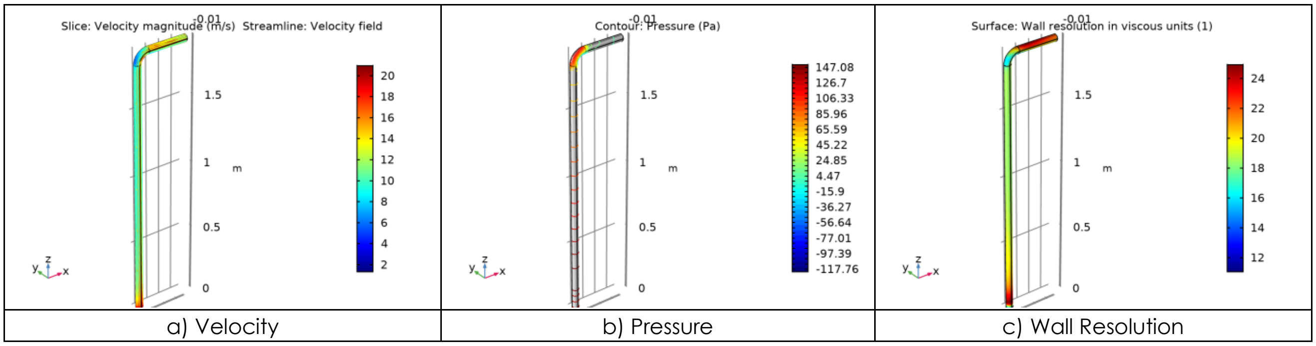
Figure 4 Simulation observation results on the particle trajectories along the pipeline

Figure 5 shows the simulation observation results on the maximum erosion rates at four erosion models. As comparison, four various erosion models; Finnie, DNV, E/CRC and Oka are applied to simulate the rate of erosive wear on the surface of the pipe elbow. The effect of fluid velocities in term of the erosion spot is tested on sand particles evaluating in a range of 10 to 460 μm. For the CFD evaluation, liquid velocities in the range of 0, 10 and 20 ms^{-1} are applied.

Figure 6 shows the selected observation results on particle trajectories and erosion rate at four sand particle sizes: 10, 100, 200 and 460 μm with V_g=10 ms^{-1}, V_l=2 ms^{-1}, m=0.2 kgs^{-1} and D_p=2 inch. From the results simulations, the maximum erosion rate was observed in the bell shape, and it is increased as the larger of particle diameter with the peak value was simulated at 120 μm. This similar result pattern also observed by Parsi *et al*. [18] where they found the maximum erosion rate was achieved at particles diameter between 100 μm and 151 μm and showed lower readings after this range of values.

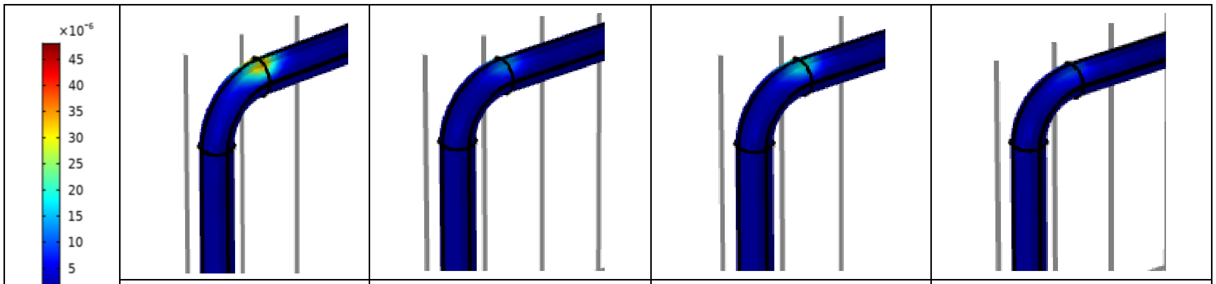
Meanwhile, Figure 6 (e)–(h) shows the particle trajectories along the pipeline near the bend pipe with the range of contour bar illustrated the maximum value of particles velocity in the fluid flow where the blue color shows the lowest value at 30 ms^{-1}, while the red color shows the highest rate at 90 ms^{-1}. It shows particle trajectories reduced with increasing of particle diameter where at the smaller particle size, the movement of particle more dispersed with higher velocity, while the probability of particles to wall impact for larger particle diameter is more affected as particles interaction and wall-particle corrosion are dominant in case of the larger particle size.

To determine the impact of particles on the erosion rate on the pipe wall, the number of particle count was calculated as shown in Figure 6 (i)–(l). This particle count will show the number of particles that will stay in the pipeline along the fluid flow process with the early assumption with the total number of particles release at the inlet is 5000 number of particles.



a) Velocity | b) Pressure | c) Wall Resolution

Figure 3 Simulation observation of flow velocity, pressure distribution effect and wall resolution along the pipeline



a) Erosion rate, Finnie | b) Erosion rate, DNV | c) Erosion rate, E/CRC | d) Erosion rate, Oka

Figure 5 Simulation observation results on the maximum erosion rates at four erosion models

As we can see from the smaller particle size in Figure 6 (i), the number of particles remaining in the pipe is around 4800 where the rest number of particles were moved out the pipe flow. But for the larger particle size, which is more than 100 µm, almost all 5000 number of particles were reminding in the pipeline that contribute to the erosion rate effect on the pipe wall.

For other parameter effect, Figures 7-10 show the simulation results on the effect of several parameter conditions on the erosion rate on the pipe wall where Figure 7 presented the effect of sand particle sizes: 10-460 μm. It shows as the larger sand particle size, the tendency and deformation of erosion on the bend pipe wall is increased where the particle size of 160 μm shown sudden increment compared to others particle size. It supported by similar finding by Ruben *et al*. 2017 where they found that the higher erosion rates took place in pipelines with smaller diameters, which can be attributed to the fact that as there exists larger particles density by unit area where the probability of particles to impact is larger.

Figure 8 presented the effect of gas velocities; 0-20 ms^{-1}, Figure 9 shown the effect of water velocities; 0-2 ms^{-1}. It shows the erosion rate of the bend increases with the increase of inlet velocity. The outer wall of the connection between the straight pipe section and the elbow is the part with large erosion loss. With the increase of inlet velocity, the erosion position moves up to the outer pipe wall of the elbow. Also, previous studies have shown that increase in the inlet velocity caused heat to be generated along with fluid-wall contact areas. Besides, higher values of crude oil flow velocity and specific gravity offered increasing wall resistance to flow and stress. As for the smaller size of particle, the erosion is more severe in gas dominated multiphase flows such as annular and mist flows than liquid dominated bubbly and slug flows [18].

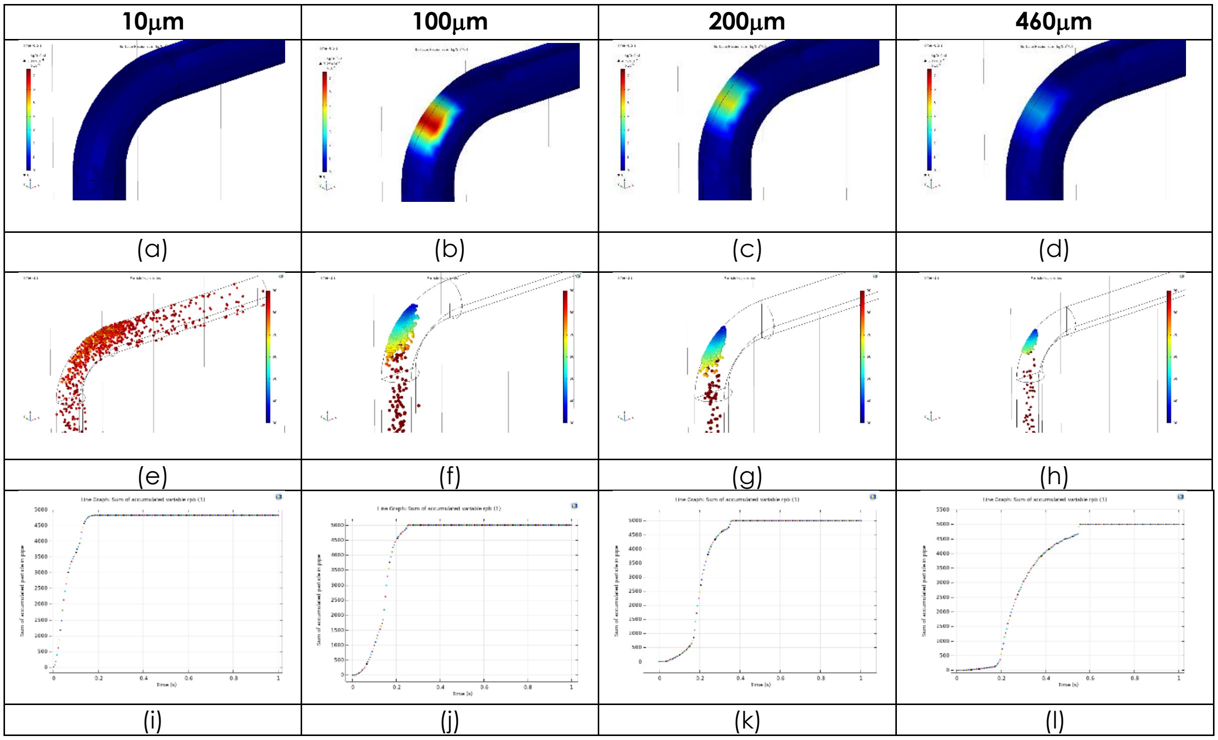


Figure 6 The observation results on particle trajectories and erosion rate at four sand particle sizes; 10, 100, 200 and 460 μm with V_g=10 ms^{-1}, V_l=2 ms^{-1}, m=0.2 kgs^{-1} and D_p=2 inch

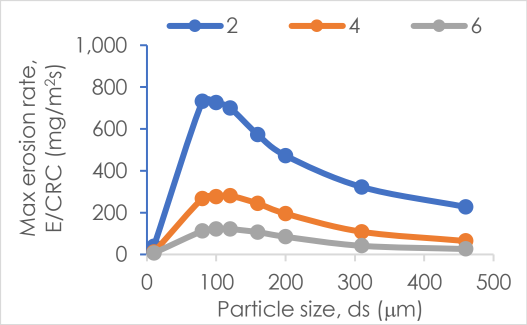


Figure 7 The effect of sand particle rate on the erosion rate at various range of sand particle sizes; 10- 460 μm with V_g=10 ms^{-1}, V_l=2 ms^{-1}, m=0.2 kgs^{-1} and D_p=2 inch

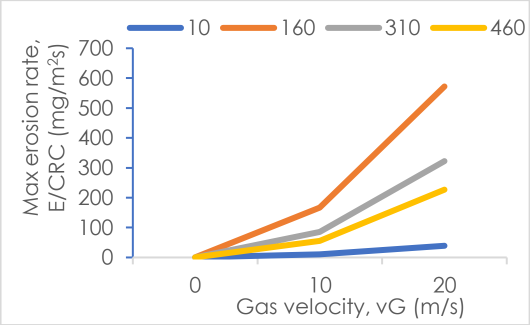


Figure 8 The effect of liquid velocity on the erosion rate at various range of sand particle sizes; 10- 460 μm with V_g=10 ms^{-1}, V_l=2 ms^{-1}, m=0.2 kgs^{-1} and D_p=2 inch

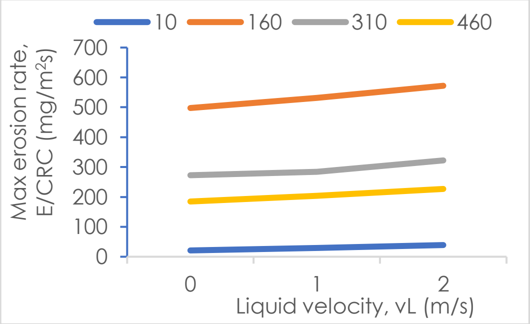


Figure 9 The effect of liquid velocity on the erosion rate at various range of sand particle sizes; 10- 460 μm with V_g=10 ms^{-1}, V_l=2 ms^{-1}, m=0.2 kgs^{-1} and D_p=2 inch

Figure 10 illustrates the effect of sand mass flow rate; 0.2 and 0.7 kgs^{-1} and pipe diameter; 2, 4, and 6 inches on the deformation of erosion rate on the pipe wall. It shows the erosion rate increased with increasing of the particle flow rate where the erosion rate decreases when the pipeline diameter is larger because of the particles density, in the transversal section area of the pipeline, decreasing the probability for the particles to impact the similar region causing smaller level of pipe damage. In addition, when the particle mass flow rate was increased, the average erosion rate increased proportionally.

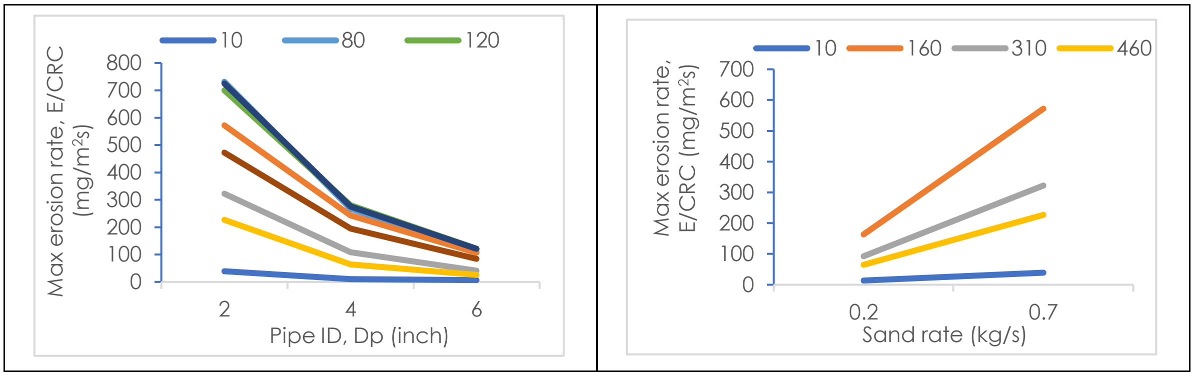


Figure 10 The effect of pipe diameter and sand rate on the erosion rate at various range of sand particle sizes; 10- 460 μm with V_g=10 ms^{-1}, V_l=2 ms^{-1}, *m*=0.2 kgs^{-1} and D_p=2 inch

4.0 CONCLUSION

A CFD simulation of a horizontal-horizontal pipe with a 90°elbow was successfully employed by using COMSOL© Multiphysics. The simulation results show the maximum erosion rate was observed at the elbow bend pipe when the higher liquid and gas velocity flow. But the erosion rate decreased in the increment of pipe diameter size due to larger surface area and less interaction between the sand particles. In case of the particle size, the bell shape increment was observed where the higher peak was at 120 μm particle size. The models have been shown to be very accurate within the range of parametric studies. Their deployment in the CFD process simulation enables process engineers to combine erosion analysis with pipe-line designs and performance evaluations. Therefore, given the pipe diameter and information about the fluid and sand particles, process engineers can evaluate the necessary fluid productions in such a way that the integrity of the pipelines are maintained.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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