

FINE PARTICLES DIRECT IMPINGEMENT CAUSING EROSION AT CHOKE VALVE

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Abstract—Fine particles that are produced together with the hydrocarbon are one of the unavoidable problems that can occur during the production period in oil and gas industry. The movement of the fine particles together with the hydrocarbon from the wellbore to the surface causing damage to the equipment and facilities. One of the effect or damages is erosion at choke valve. There are several factors that affect the erosion rate such as the velocity of the particles, size of the particles, and many others. The objectives of this project are, i) to determine whether size of the fine particles have impact in the erosion rate and ii) to study the erosion behavior related to the fine particles velocity. The analysis on the erosion rate is conducted by using Computational Fluid Dynamic, Ansys Fluent by referring to the Lagrangian Model. It is observed that the size of fine particles and flow velocity can increase the rate of erosion in the choke valve.

Keywords— Fine particles, erosion, erosion rate, choke valve

I. INTRODUCTION

The production of oil and gas involves the topside and subsea equipment. Most of the times, the oil and gas reservoirs are prone to produce sand as 70% of world's oil and gas reserve are sand formation. With all the impurities produce together with the oil and gas, it will damage the piping system and the equipment. It can cause damage like erosion, corrosion and erosion-corrosion. The component most exposed to erosion in this context is the choke valves. In extreme cases in the North Sea, critical components had been destroyed by erosion within few hours.

Choke valves is important in oil and gas industry. The function of choke valves is to control the flow of well fluids being produced. Another function of choke valves is to kill the pressure in the reservoir and to regulate the downstream pressure in the flowlines. Therefore, erosion in the choke valves will be costly to company. There are many factors that affect the erosion in the choke valves such as such as particle impact angle, particle and fluid velocity, particle properties, fluid viscosity, fluid density, wall hardness, pipe diameter and etc. However, the degree of severity of erosion on equipment is different for each parameter and it varies depending on the condition. Therefore, factors that affect erosion rate must be assessed thoroughly so that the problem can be mitigated.

II. METHODOLOGY

A. Numerical methods

a) Continuity Equation

Continuity equation is the basic equation widely used in engineering to solve problem. In term of definition, Continuity equation is the value of the flow rate is the same at every position along a tube that has a single entry and single exit for fluid flow. It is also known as the principle of the conservation of mass. This equation can provide some useful information on how fluids behave when they flow through a pipe. Related to the studies, the fluids will flow from the inlet to the outlet. Below are the equation related to Continuity equation.(Wang, Wu, & Li, 2013) Basic Continuity equation:

$$m_1 = m_2$$

(1)

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

(2)

General equation for compressible fluid:

$$\frac{\partial \rho_f}{\partial t} + \frac{\partial(\rho_f v_x)}{\partial x} + \frac{\partial(\rho_f v_y)}{\partial y} + \frac{\partial(\rho_f v_z)}{\partial z} = 0$$

(3)

Where,

ρ = density

t = time

ρ_f = fluid density

v_x, v_y, v_z = velocity vectors in x, y, z direction

b) Navier-Stokes equation

In computational fluid dynamic (CFD), Navier-Stokes equations is really important as it governs the motion of fluids. Navier-Stokes equations also represents the conservation of momentum. By solving the Navier-Stokes equation, the fluid velocity and its pressure in a given geometry can be predicted. Below are the lists of related equations:

Compressible Newtonian Fluid (Navier et al.(1845):

$$\underbrace{\rho \left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right)}_1 = \underbrace{-\nabla p}_2 + \underbrace{\nabla \cdot (\mu (\nabla \mathbf{u} + (\nabla \mathbf{u})^T)) - \frac{2}{3} \mu (\nabla \cdot \mathbf{u}) \mathbf{I}}_3 + \underbrace{\mathbf{F}}_4 \quad (4)$$

$\mathbf{u}$ = Fluid velocity
 p = Fluid pressure
 ρ = Fluid density
 μ = Fluid dynamic viscosity

1 = Inertial forces
 2 = Pressure forces
 3 = Viscous forces
 4 = External forces

c) Lagrangian Model

Lagrangian Model approach is used in this study due to its method that able to analyze a fluid flow. The fluid flow is assumed to be a large number of particles. Lagrangian model is used in this study because we want to track each of the particles that contribute to the erosion rate. In Lagrangian, particles are individually treated.

Below is the equation for the Lagrangian Model:

$$\rho_p \frac{d\mathbf{V}}{dt} = -\frac{3}{4d_p} \rho_f C_D (\mathbf{V} - \mathbf{U}) |\mathbf{V} - \mathbf{U}| - 0.5 \rho_f \frac{d(\mathbf{V} - \mathbf{U})}{dt} + (\rho_p - \rho_f) \mathbf{g} \quad (5)$$

Source (Lu, Fontaine, & Aubertin, 1993)

Where,

ρ_p = particle density
 d_p = particle diameter
 ρ_f = fluid density
 C_D = coefficient
 $\mathbf{g}$ = gravitational acceleration
 $\mathbf{V}$ = instantaneous velocity of particles
 $\mathbf{U}$ = instantaneous velocity of fluids

B. Simulation Model

a) K-ε Model

K-epsilon model is one the three type of model that is used to describe the turbulence flow. It is the most popular and being one of the top model used for CFD simulation to study the flow characteristic in turbulence flow. It is also known as two equation model to describe the turbulence representing by two transport equations. Below is the standard k-epsilon equation:

Turbulent kinetic energy,

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + P_k + P_b - \rho \epsilon - Y_M + S_k \quad (6)$$

Turbulent Dissipation,

$$\frac{\partial}{\partial t}(\rho \epsilon) + \frac{\partial}{\partial x_i}(\rho \epsilon u_i) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_j} \right] + C_{1\epsilon} \frac{\epsilon}{k} (P_k + C_{3\epsilon} P_b) - C_{2\epsilon} \rho \frac{\epsilon^2}{k} + S_\epsilon \quad (7)$$

Sources: (Launder & Spalding, 1974)

III. RESULTS AND DISCUSSION

A. Ansys Fluent Simulation

In Ansys Fluent, the simulation was run on discrete phase model which also know n as the Lagrangian Model. This model is able to track the particle inside the model to see the impact on the erosion rate. There are two objectives that need to be achieved.

From the simulation, by using the Lagrangian Model, the parameters that need to be tested will be input. The main input parameter in this simulation is the size for the particles and also the velocity of the particles. Other parameters such as the impact angle, particle shape, and choke valve material are remained constant. It is expected to obtain an increase in erosion rate when there is an increase in the particles diameter and also an increase in the erosion rate when the particles velocity increases. The result obtain also will be different based on the input parameter.

B. Effect of diameter of the fine particles on erosion rate

Diameter (μm)	Maximum Erosion rate (kg/m ² -s)
20	8.57e-10
25	8.88e-10
30	5.47e-09

Table 1 Maximum erosion rate at various diameters

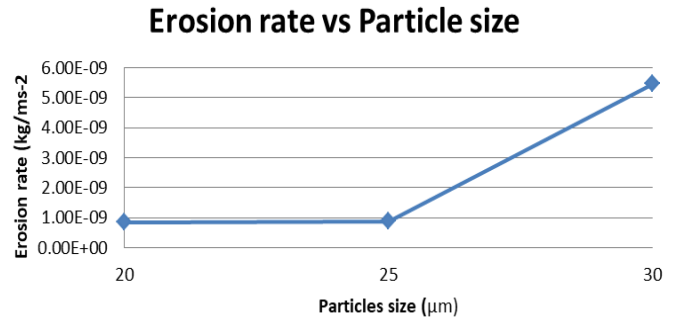


Figure 1 Erosion rate vs Particle Size

From Table 1, clearly it can be seen that the effect of the diameter on the erosion rate. Besides that, the severity of the erosion also can be seen for each diameter of particles that has been run. The relationship of the particles size and the erosion rate can be seen from Figure 1 and it can be conclude that the erosion rate increase as the particles size increases.

Diameter = 20μm

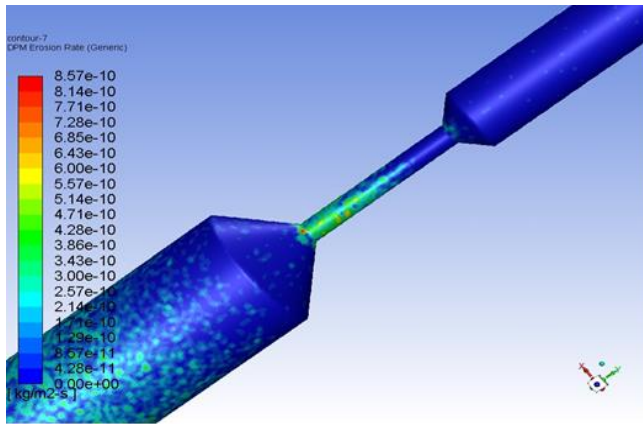


Figure 2 Erosion rate at 20µm

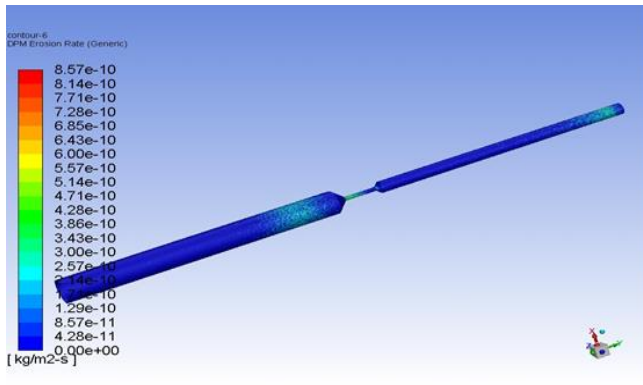


Figure 3 Erosion rate at 20µm

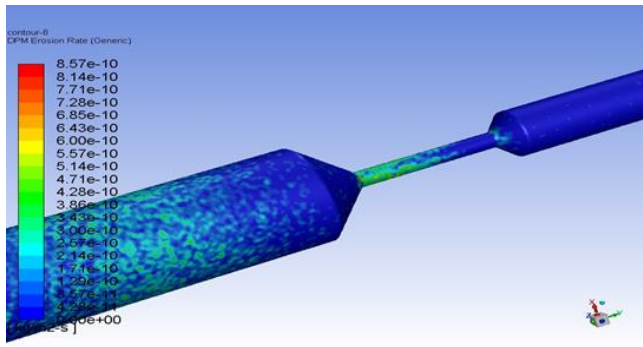


Figure 4 Erosion rate at 20µm

From Figure 3, it can be seen the erosion already occur at particles size of 20µm. It can be seen that the erosion location occur at the wall of the inlet, trim area and also the wall of the outlet of the choke valve. From Figure 2, the maximum erosion rate occur at the trim area most probably due to the smaller opening of the area and also the high pressure drop occur at that area. In general, when fluid flows from larger area to smaller surface area, the pressure will increase causing the larger size particles to impact the wall of the choke valve.

Diameter = 25µm

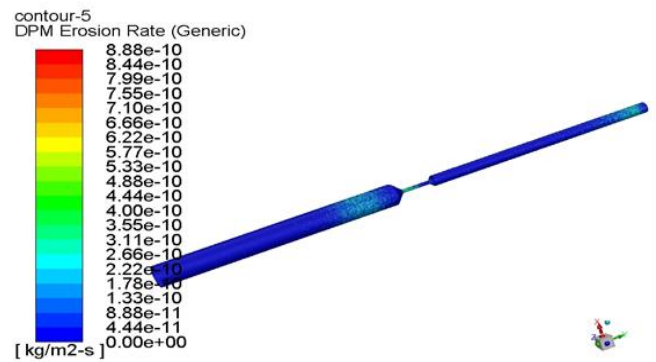


Figure 5 Erosion rate at 25µm

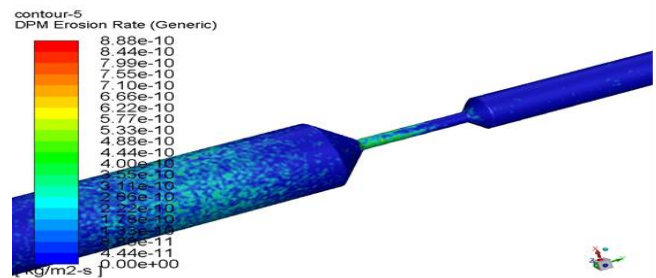


Figure 6 Erosion rate at 25µm

In Figure 5, the diameter has been increase to 25µm resulting in the increase in the erosion rate. The severity of the erosion can be seen in Figure 5 and Figure 6 where the most affected area is at the trim area of the choke valve.

Diameter = 30µm

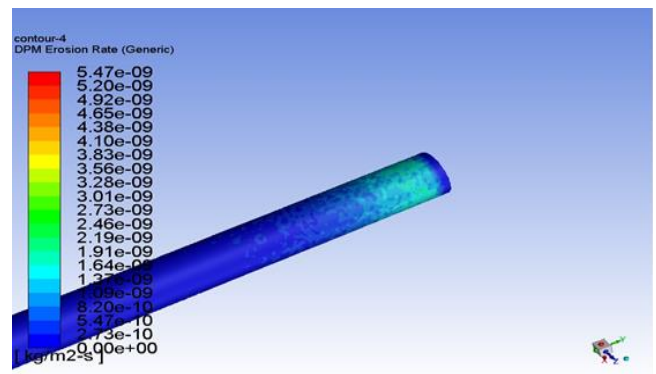


Figure 7 Erosion rate at 30µm

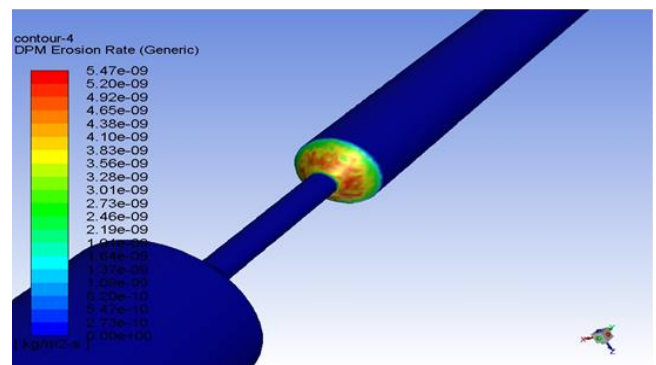


Figure 8 Erosion rate at 30µm

Last but not least, when the particles size is set to 30µm, the result showing that the erosion rate at the trim area increases whereas the maximum erosion rate occur at the trim as high as 5.47e-09 kg/ms-2 compared to 8.57e-10 kg/ms-2 for particles size

of $20\mu\text{m}$ and $8.88\text{e-}10\text{ kg/ms-2}$ for particles size of $25\mu\text{m}$. Referring to Figure 7 and 8 the trim area showing high erosion rate at that area probably due to the big particle sizes of the particles that erode the surface of the choke valve. In basic common engineering knowledge, a small particles size usually causes lower erosion rates and unlikely to cause severe damage or erode the surface because they have low kinetic energy and impact force.

C. Effect of velocity on erosion rate

Velocity (m/s)	Maximum erosion rate (kg/m ² -s)
15	1.43e-09
20	9.58e-09
25	9.69e-09

Table 2 Maximum erosion rate at various velocities

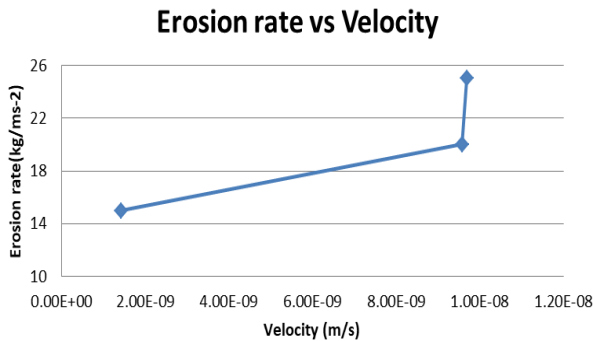


Figure 9 Erosion rate vs Velocity

The simulation is run again in Fluent by changing the velocity of the particles. From Table 2, the result showing that at high velocity, the maximum erosion rate occurs at the highest value compared to lower velocity value. Velocity is one of the crucial parameters that contribute to erosion rate. This is because, when a particle moving at high velocity, the impact force when it collide with the wall of choke valve is high and thus, will erode the surface more as compared to slower velocity of a particle. Figure 9 shows the relationship between the erosion rate and velocity. Hence, erosion rate will increase as velocity increase resulting in the lifetime of a choke valve to be reduced.

Figure 10, 12 and 14 shows the result of erosion rate at velocity 15 m/s, 20 m/s and 25 m/s. The erosion rate was small at $1.43\text{e-}09\text{ kg/ms-2}$ when the velocity is 15 m/s. Erosion rate are likely to be worst at the highest velocity. From the Figure 10 to Figure 13, the erosion rate escalated as high as $9.69\text{e-}09\text{ kg/ms-2}$ when the velocity is 25 m/s. From Figure 15, the severity of the erosion at the trim area is high. Most of the highest erosion rate occurs at the trim area due to high pressure drop that occurred. However in real situation, it depends on other parameters as well such as the impact angle, particle shape and also the material of the choke valve.

Velocity = 15 m/s

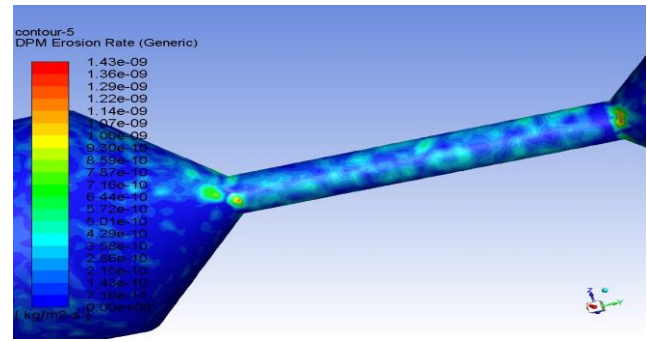


Figure 10 Erosion rate at 15m/s

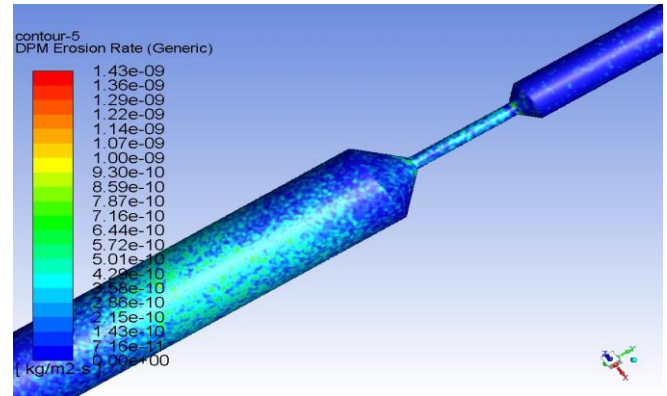


Figure 11 Erosion rate at 15m/s

Velocity = 20 m/s

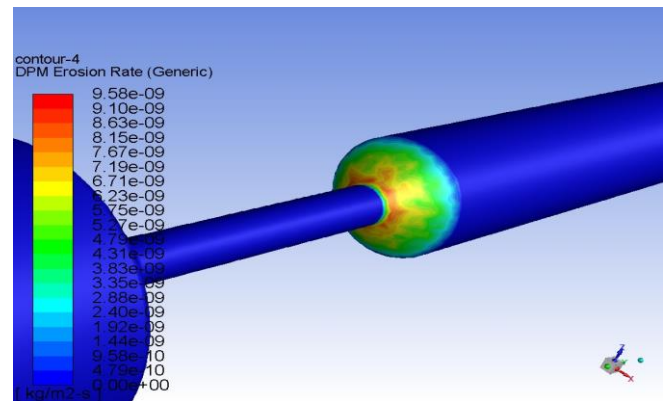


Figure 12 Erosion rate at 20 m/s

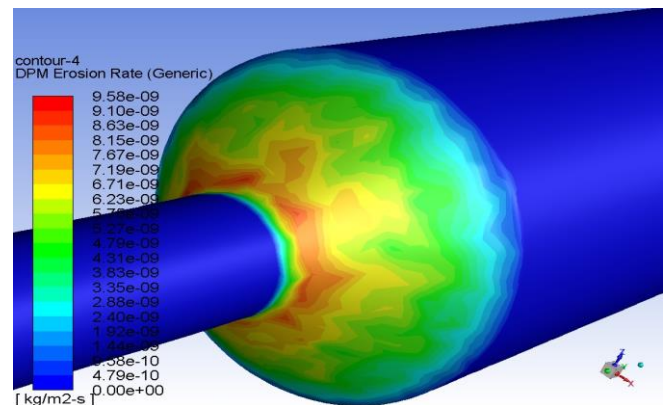


Figure 13 Erosion rate at 20m/s

Velocity = 25 m/s

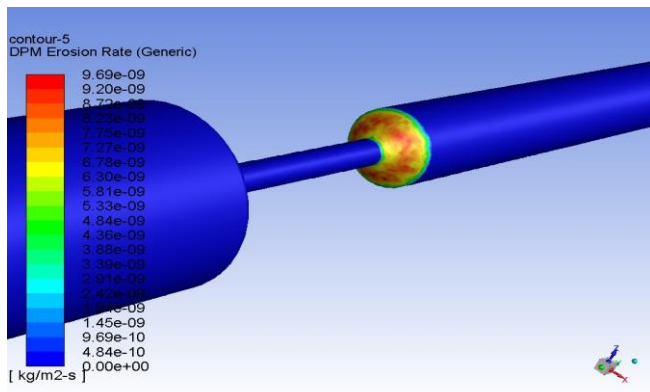


Figure 14 Erosion rate at 25 m/s

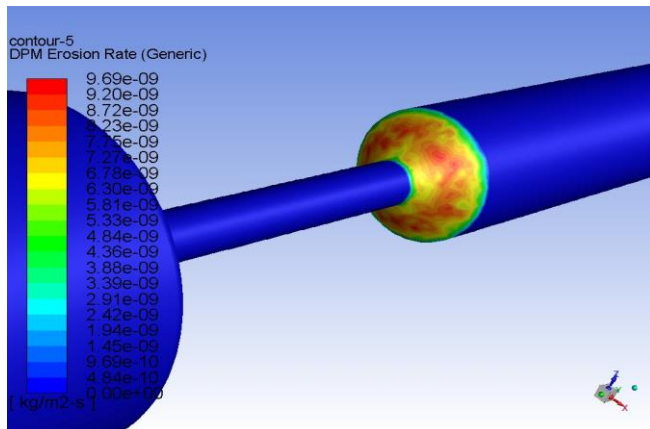


Figure 15 Erosion rate at 25 m/s

IV. CONCLUSION

As a conclusion, both parameters play a role in contributing to the erosion occur on the choke valve. Fine particles erosion in choke valve is something that is unavoidable in oil and gas industry. It is considered as a must have problem in the industry. But, mitigation action can be taken to prolong the lifetime of a choke valve.

The severity of the erosion rate depends on many parameters depending on the situation. Based on this study, it can be concluded that particles size and velocity of the particles play a significant role in erosion rate.

The objective to study the fine particles size and velocity on the erosion rate has been achieved as when both fine particles size and velocity increase, the erosion rate also increases. However, there is still a lot of improvement can be made for future project since this project only focus on the two main parameters that contributes to the erosion rate in choke valve so that we can prolong the life time of the choke valve thus reduce the cost of production for replacement of a broken equipment.

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