Prediction and research on the erosion of the tubing joint in high yield gas well

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Abstract. Sand production in high-yield gas-well is a common problem in oilfield. Erosion caused by sand production often leads to pipeline failures and even endangers lives and property if serious. So, the sand production problem cannot be ignored. In this paper, computational fluid dynamics are used. I conduct numerical simulation in allusion to the process of gas flowing through pipeline with sand, with FLUENT software, and then discuss the influence on erosion caused by the flow velocity of gas, the flow rate of sand, the diameter of particles and so on. The following conclusions are drawn: with the increase of natural gas flow rate, the average erosion rate at the tubing joint increases gradually and is approximately exponential to the natural gas flow rate; with the increase of sand flow rate, the average erosion rate at the tubing joint increases gradually and is approximately linear to the sand flow rate; with the increase of sand particle size, the erosion rate at the tubing joint decreases gradually.

1. Introduction

Metal erosion is widely used in various fields of national economy, and its losses are very serious. On the one hand, metal erosion can cause great economic losses; on the other hand, corrosion can easily lead to safety problems and environmental hazards, and lead to huge consumption of natural resources.

In many industrial multiphase equipment, impact erosion is a serious problem, especially in the oil and gas industry. Due to the limited separation and filtration capacity of filtration equipment, gas-producing sand in high-yield gas wells is a common phenomenon [1-2]. Because of pedesis, sand particles move irregularly at high speed along the gas flow, eroding the wellbore, resulting in erosion of tubing in high-yield sand-bearing gas wells.

In practice, pipe flow does not consist entirely of fully developed straight lines, which is also composed of empty pipe section, elbow, valve, fittings, cross-section variation section (such as pipe shrinkage, pipe expansion) and so on. These areas are prone to erosion problems. In this paper, we study the erosion of tubing joints.

2. Three-dimensional modeling of tubing joints

2.1. Three-dimensional modeling

We consulted relevant literature and books and selected the parameters of the inner cavity size [3-4] as shown in Figure 1:
Figure 1. Internal cavity size at tubing joint (unit: mm).

The fluid inlet is the left port, extending 5m tubing in front of the coupling to eliminate the entrance effect, and adding 1m tubing after the coupling to ensure stable outflow. Under this parameter condition, Gambit software is used for three-dimensional modeling.

2.2. Mesh generation
We use Hex/Wedge type and Cooper method to mesh. The resulting grids are shown in Figure 2(a) and (b).

Figure 2(a). Grid diagram of whole pipe.

Figure 2(b). Grid diagram of tubing joint.
3. Numerical Simulation.
By consulting relevant literature and professional books and en chiridion, parameters can be obtained as shown in Table 1 [5].

| parameters               | value              |
|--------------------------|--------------------|
| Daily gas output         | 5.52×104m³/d      |
| Daily sand output        | 1.16m³             |
| Single tubing length     | 10m                |
| Tubing inner diameter    | 100mm              |
| Inner diameter of coupling| 108mm             |
| Coupling length          | 40mm               |
| Particle size of sand    | 0.38mm             |
| Sand density             | 2600kg/m³          |

3.1. Set up model
We choose the standard k-epsilon model as viscous model. Considering sand production, discrete phase model(DPM) is selected in this paper. At the same time, considering the interaction between the dispersed phase and the dispersed phase, the erosion/accretion option is chosen. In order to determine the motion properties of discrete phase, discrete random walk model is selected. Considering the influence of particle motion resistance, the spherical drag law is chosen as drag parameters.

3.2. Boundary condition
3.2.1. Inlet boundary condition. The inlet boundary condition is set to the velocity inlet. The inlet velocity is determined to be 81.4m/s according to formula (1).

\[ v = \frac{Q}{A} \]  

In the formula, Q is the gas production and A is the entrance area. The parameters at the inlet can be determined by formula (2) – (6) [6].

1. Reynolds number(Re):

\[ \text{Re} = \frac{\rho v D}{\mu} \]  

2. Turbulence length scale(L):

\[ L = 0.07D \]  

3. Turbulence intensity(I):

\[ I = \frac{u'}{u_{avg}} \simeq 0.16(\text{Re})^{-1/8} \]  

4. Turbulent Dissipation Rate(\(\varepsilon\)):

\[ \varepsilon = C_{\mu} \frac{k^{3/2}}{l} \]  

5. Turbulent kinetic energy(k):

\[ k = \frac{3}{2}(u_{avg} I)^2 \]  

In the formulas, \(\rho\) is the density of natural gas, \(\mu\) is the dynamic viscosity of natural gas, \(u_{avg}\) represents the average velocity of natural gas, \(u'\) denotes the pulsating velocity of natural gas, D denotes the hydraulic diameter of the tubing, \(C_{\mu}\) is empirical coefficient, and \(C_{\mu}=0.09\) [7].
3.2.2. Outlet boundary condition. According to the actual situation of oil pipeline, the outlet boundary condition is set as outflow.

3.2.3. Wall boundary conditions. Standard wall function is selected to correct the results. We set the wall as a reflection boundary, and the wall collision recovery equation [8] is shown in equation (7), (8).

\[
\varepsilon_T = 0.993 - 0.0307\theta + 0.000475\theta^2 - 0.0000261\theta^3
\]

\[
\varepsilon_N = 0.988 - 0.029\theta + 0.000643\theta^2 - 0.0000356\theta^3
\]

Set the impact angle function as piecewise linear, with the values shown in Table 2.

| Serial number | Angle(°) | value |
|---------------|----------|-------|
| 1             | 0        | 0     |
| 2             | 20       | 0.8   |
| 3             | 30       | 1     |
| 4             | 45       | 0.5   |
| 5             | 90       | 0.4   |

The velocity exponent function is set to constant, 2.6 [9].

4. Erosion calculation and result analysis
We change various parameters and analyze the change of erosion rate, and then study the influence of physical parameters such as production gas velocity and sand flow rate on erosion rate at tubing joint.

| gas current velocity (m/s) | gas flow rate Q(kg/s) | Sand flow rate M(kg/s) | Turbulence intensity I |
|---------------------------|-----------------------|------------------------|------------------------|
| 80                        | 0.419                 | 0.0210                 | 0.033093               |
| 75                        | 0.393                 | 0.0197                 | 0.033361               |
| 70                        | 0.367                 | 0.0184                 | 0.033650               |
| 65                        | 0.341                 | 0.0170                 | 0.033963               |
| 60                        | 0.315                 | 0.0157                 | 0.034304               |
| 55                        | 0.288                 | 0.0144                 | 0.034680               |
| 50                        | 0.262                 | 0.0131                 | 0.035095               |

4.1. Effect of natural gas flow rate on erosion rate
We change the gas flow rate and study the change of erosion rate. In order to eliminate the influence of non velocity factors, we change the sand flow rate appropriately to keep the mass fraction of sand particles in the system at 5%. According to the 4 formula, we change the turbulence intensity of the fluid, so that the parameters corresponding to different natural gas flow rate can be obtained after calculation, as shown in Table 3.

After the iterative calculation, the residual curve obtained by the iteration is shown in Figure 3 (take gas flow rate of 80m/s as an example).
Figure 3. Scaled residuals (when flow rate is 80 m/s).

By observing the residual diagram, it can be seen that the residual is basically in a stable state, so the calculation result can be considered to be correct. Because the standard wall function is used in the calculation results, the $y^+$ of the wall is checked. It can be seen that $y^+$ in most regions is between 30 and 300, so the result can be considered correct [10].

The average erosion rate of tubing joints corresponding to different gas flow rate is shown in Figure 4.

**Figure 4.** Average erosion rate of tubing joint at different velocities.

Based on the above results, it can be concluded that with the increase of gas flow rate, the erosion rate at tubing joint increases, and the average erosion rate is approximately exponential to the gas flow rate.

4.2. **Effect of sand flow rate on erosion rate**

By changing the sand flow rate, the corresponding calculation results are obtained. Taking the case of sand flow rate of 0.20kg/s as an example, the average erosion rate of tubing joint corresponding to different sand flow rates is obtained as shown in Figure 5.
Figure 5. Average erosion rate of tubing joint at different sand flow rate.

Based on the above results, it can be concluded that with the increase of sand flow rate, the erosion rate at the tubing joint increases, and the erosion rate is approximately linear with the sand flow rate.

4.3. Effect of sand particle size on erosion rate
Change the particle size and calculate the erosion rate of the tubing joint when the particle size is 0.1-0.6mm, with the sand flow rate kept at 0.02kg/s. Calculation results when the particle size is 0.3 mm are taken as an example to illustrate, and the erosion rates corresponding to different particle sizes of sand are shown in the Figure 6.

Figure 6. Erosion rate of tubing joint at different particle size (when sand flow rate is 0.20 kg/s).

It can be seen that the average erosion rate at tubing joint decreases with the increase of sand particle size. This is mainly due to the constant sand flow rate and the larger the particle size, the smaller the number of sand grains and the smaller the erosion rate.

5. Conclusions
The following conclusions can be drawn from the analysis of the numerical simulation results of the internal flow field at the tubing junction of gas wells.

(1) Many of the flow parameters of natural gas will affect the erosion rate. In the study of this paper, with the increase of natural gas flow rate, the average erosion rate at the tubing joint increases gradually and is approximately exponential to the natural gas flow rate;
(2) With the increase of sand flow rate, the average erosion rate at the tubing joint increases gradually and is approximately linear to the sand flow rate;

(3) With the increase of sand particle size, the erosion rate at the tubing joint decreases gradually.

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