Sensitivity analysis of coiled tubing erosion wear based on FLUENT

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Abstract. Erosion wear is the main reason for the failure of coiled tubing during hydraulic jet fracturing operations. Taking Φ60.325mm×4.775mm CT90 coiled tubing as the research object. Three-dimensional finite element model of coiled tubing is established. The effects of mass flow, particle flow rate, particle diameter and other sensitive factors on the erosion characteristics of coiled tubing were analyzed by FLUENT software. The research results show that: The erosion wear rate of coiled tubing shows a nonlinear increasing trend with the increase of mass flow and particle flow rate, and the increasing trend is firstly slow and then sharply. As the particle diameter increases, the maximum erosion rate of coiled tubing changes irregularly. The particle flow rate is most sensitive to the erosion of coiled tubing. The finite element method used in this article provides a reference for the evaluation of the erosion wear of coiled tubing in hydraulic fracturing operations.

Keywords: Coiled Tubing, Erosion, FLUENT, Sensitivity.

1. Introduction
Coiled tubing because of its small footprint, low operating costs and use of a wide range of advantages, has been widely used in oil and gas field operation, solved many problems that are difficult to overcome with conventional operation technology [1-2]. In the process of hydraulic jet fracturing, coiled tubing is easily eroded by the action of high speed sand-carrying fluid, and the erosion of coiled tubing at the roller is the most serious [3]. Currently, research on the erosion of coiled tubing in the process of hydraulic jet fracturing is still very scarce, and the specific numerical analysis and theoretical model of the erosion phenomenon are not perfect. The erosion wear of coiled tubing caused by fracturing media belong to the research category of fluid mechanics. The research methods for fluid flow problems mainly include theoretical methods [4-6] and experimental methods [7-9]. Theoretical method is difficult to solve complex problems, although the experimental method can get more accurate results, but time consuming and high cost [10]. Therefore, a three-dimensional finite element model of coiled tubing with different mass flow, particle flow rate, particle diameter and other sand-carrying fluid property parameters was established. FLUENT finite element analysis software was used to quantitatively analyze the erosion rate of coiled tubing with different sand-carrying fluid properties. The influence of the above sensitivity factors on the erosion wear rate of coiled tubing was investigated.
2. Establishment of erosion wear model of coiled tubing

Based on theoretical research, the DPM model is selected as the erosion wear model of coiled tubing. The erosion rate is defined as: The reduction in the quality of coiled tubing due to erosion per unit time, the expression is shown in formula (1) [11]:

$$R_e = \sum_{p=1}^{N} \frac{m \cdot C(d) \cdot f(\alpha) \cdot v^{b(v)}}{A}$$

Where: $Re$ is the erosion rate, kg/ (m²·s); $m$ is the particle mass flow, kg/s; $C(d)$ is a function of particle diameter; $\alpha$ is the angle of particle impact wall, °; $f(\alpha)$ is the angle of attack function; $v$ is the impact rate, m/s; $b(v)$ is the velocity component function; $A$ is the area of the spiral section tubing erosion calculation unit, m².

3. Numerical simulation of erosion wear of coiled tubing

Use FLUENT software to analyze the erosion wear of coiled tubing. Taking Φ60.325mm×4.775m CT90 coiled tubing and Φ5080mm reel as the research objects, a 1/4 section of coiled tubing model is established. The meshing strategy of first overall and then local refinement is adopted, and the standard k-ε turbulence model is adopted. As shown in Figure 1, the distribution cloud diagram of erosion wear rate of fracturing fluid on coiled tubing during hydraulic jet fracturing is obtained. It can be seen from the figure that the erosion wear on the outside of the coiled tubing is more serious, while the erosion wear at the inlet and outlet is less. This phenomenon is basically consistent with the research results of Yan Biao [12].

![Fig. 1 Contour map of erosion wear rate distribution of coiled tubing](image)

4. Sensitivity analysis of sand-carrying liquid properties to the erosion wear of coiled tubing

Erosion wear often cause local defects such as pits, corrosion pits, and tube body thinning in the coiled tubing. In severe cases, it may cause the coiled tubing to break and puncture under the action of external forces. According to the analysis method of the erosion wear of coiled tubing in the second section, combined with the construction parameters of the hydraulic jet fracturing operation, the influence of three sensitive factors, namely particle mass flow, particle flow rate and particle diameter, on the erosion wear of coiled tubing was studied by using the control variable method.

4.1. Influence of mass flow on the erosion wear of coiled tubing

The particle diameter is 3mm, the particle shape factor is 0.53, and the particle flow rate is 10m/s, changing the mass flow were 0.125, 0.185, 0.245, 0.305, 0.365kg/s, the erosion distribution and wear rate under different mass flow are calculated, and the relationship curve between the maximum erosion wear rate of coiled tubing and the mass flow is shown in Figure 2. It can be seen from the figure that with the increase of particle mass flow, the erosion rate of coiled tubing continues to increase. The
critical point was 0.305kg/s, before which the erosion rate was relatively stable. After that, the erosion rate of coiled tubing increased 46.7%. The analysis shows that with the increase of mass flow, that is, the amount of sand and gravel per unit volume of fracturing fluid increases, the number of particles increases greatly under the condition that the volume of single sand and gravel remains unchanged, which leads to a sharp increase in the number of particles eroding against the inner wall of coiled tubing per unit time, thus causing more serious erosion wear on the inner wall of coiled tubing.

Fig. 2  Variation curve of coiled tubing erosion rate with mass flow

4.2. Influence of particle flow rate on the erosion wear of coiled tubing

The particle mass flow is 0.185kg/s, the particle diameter is 3mm, and the particle shape factor is 0.53. By changing the particle flow rate to 10, 15, 20, 25, 30 and 35m/s, the variation curve of erosion rate with particle flow rate is shown in Figure 3. It can be seen from the figure that with the increase of particle flow rate, the maximum erosion wear rate of coiled tubing continues to increase. When the flow rate is less than 15m/s, the kinetic energy of the solid particles is small, and the maximum erosion rate of the solid particles on the wall of the coiled tubing is small, and its value is $5.63 \times 10^{-6}$kg/(m²·s); when the particle flow rate is greater than 15m/s, the erosion rate changes significantly with the increase of the particle flow rate; when the flow rate is 35m/s, the maximum erosion rate reaches $6.66 \times 10^{-6}$kg/(m²·s), an increase of 15.47%. It is analyzed that with the increase of particle flow rate, the kinetic energy of particles increases continuously, and the stronger the cutting action is, the greater the impact and wear of solid particles on the coiled tubing is.

Fig. 3  Variation curve of coiled tubing erosion rate with particle flow rate
4.3. Influence of particle diameter on erosion wear of coiled tubing

The particle shape factor is 0.53, the particle mass flow is 0.185kg/s, and the particle flow rate is 10m/s, change the particle diameter to 1, 2, 3, 4, 5, 6mm. The change curve of coiled tubing erosion rate with particle diameter was shown in Figure 4. As can be seen from the figure, the trend of the maximum erosion wear rate of coiled tubing with the increase of particle diameter is as follows: Increase slowly-decrease sharply-increase sharply-increase slowly, erosion rate increases with increasing diameter of no variation law; When the particle diameter is 4mm, the erosion rate reaches the peak value of $6.8 \times 10^{-6}$kg/(m²·s). According to the analysis, when the particle diameter is small, the particles hit the coiled tubing wall and flow out of the pipeline by the continuous phase; With the increase of particle diameter, the loss caused by collision between particles is much greater than the loss caused by collision with the wall. After the discrete phase particles hit the wall, some particles will stay on the wall, and the phenomenon that the maximum erosion wear rate will not increase but decrease will eventually appear; When the particle diameter increases to 4mm, the maximum erosion wear rate of coiled tubing increases with the increase of the inertial force due to the influence of the particle's own inertial force; When the particle diameter is greater than 4mm, the impact kinetic energy of a single particle increases and the number of particles continues to decrease, resulting in a decrease in the maximum erosion wear rate of coiled tubing.

![Variation curve of coiled tubing erosion rate with particle diameter](image)

Fig. 4 Variation curve of coiled tubing erosion rate with particle diameter

5. Conclusion

During the hydraulic jet fracturing process, the high-speed sand-carrying liquid will cause severe erosion of the coiled tubing. Taking Φ60.325mm×4.775mm CT90 coiled tubing as the research object, the FLUENT software was used to analyze the influence of the properties of the sand-carrying liquid such as mass flow, particle flow rate and particle diameter on the erosion characteristics of coiled tubing. The following understanding was obtained:

1) The erosion wear rate of coiled tubing shows a nonlinear increasing trend with the increase of mass flow and particle flow rate, and the increasing trend is firstly slow and then sharply.

2) Since the particle diameter is related to the number of particles, particle escape and other factors, as the particle diameter increases, the maximum erosion rate of coiled tubing changes irregularly.

3) Compared with the mass flow and particle diameter, the particle flow rate is more sensitive to the erosion of coiled tubing.

References

[1] Wang Haitao, LI Xiangfang. Application situation and thinking about coiled tubing techniques in down hole operation [J]. Oil Drilling & Production Technology, 2008, 30(6): 120-124.

[2] He Huiqun. Development of coiled tubing technique and equipment [J]. China Petroleum
Machinery, 2006, 34(1): 1-6.

[3] Feng Changxing. Analysis of erosion characteristics of coiled tubing considering multi-attribute coupling [D]. Xi’an Shiyou University, 2020.

[4] Chen Guanguo, Chu Xiuping, Zhang Hongliang, et al. Problem on erosion wear [J]. Journal of Hebei Institute of Technology, 1997, 19(4): 30-35.

[5] Zhang Xiaodong, Jia Guochao, Wu Chende. Mechanism analysis of BHA erosion wear in air drilling [J]. Journal of Southwest Petroleum University (Science & Technology Edition), 2009, 31(2), 139-132.

[6] Li Shizhuo, Dong Xianglin. Erosive wear and fretting wear of materials [M]. Beijing, Machinery Industry Press, 1987.

[7] Tilly G P. Two stage mechanism of ductile erosion [J]. Wear, 1973, 23(1): 87-96.

[8] Shah S N, Jain S. Coiled tubing erosion during hydraulic fracturing slurry flow [J]. Wear, 2008, 264(3-4): 279-290.

[9] Zhou Weidong, Xia Boru, Li Luopeng, et al. An experimental study of the erosion law of drilling fluid on the drill pipe sub [J]. China Petroleum Machinery, 2011, 39(10): 1-4.

[10] Yu Li. Study on erosion of coiled roller section in hydroblasting perforation [D]. Yangtze University, 2018.

[11] Wu Han, Liu Shaohu, Liu Xuhui, et al. Study on erosion wear laws of coiled tubing affected by weldment position [J]. Journal of Safety Science and Technology, 2017, 3(2): 138-124.

[12] Yan Biao, Xia Chengyu, Chen Min, et al. Erosion wear characteristic of coiled tubing in fracturing operation[J]. China Petroleum Machinery, 2016, 44(4): 71-74.

[13] Xu Guowen. Numerical simulation research of coiled tubing hydraulic jet erosion [J]. Oil Field Equipment, 2016, 45(6): 12-15.