Experimental study on erosion resistance evaluation of single-layer metal mesh screen

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Abstract
In order to predict the erosion life and erosion failure time of the metal mesh, based on the rotating erosion experiments under different working conditions, the erosion mass loss of the metal mesh under different factors was measured by the weight loss method and the erosion mathematical prediction model was put forward. The erosion wear mechanism of the single-layer metal mesh was explored by using electron microscope scanner and optical microscope. The results show that the erosion rate increases exponentially with the increase of liquid velocity (0.5, 1.0, 1.5, 2.0 m/s). When the solid mass fraction (0.3%, 0.5%, 0.8%) and erosion Angle is 15°–45°, the erosion rate is proportional to the solid mass fraction and erosion Angle. After erosion, the mesh samples suffered different degree of pitting corrosion, ploughing and cutting wear, and the mesh wear was local wear. Compared with the experimental value, the error of the erosion mathematical model is less than 20%, which has a certain reliability, and has an important reference significance for guiding the production control of sand oil Wells.

Keywords
Metal mesh screen, single wire, erosion rate, life prediction

Introduction
Screen pipe is an important downhole tool for sand prevention completion. Screen pipe failure is an important factor leading to sand prevention failure. Among them, erosion wear is one of the main reasons leading to sand prevention failure of screen pipe. The failure of sand prevention screen is mainly caused by the erosion wear caused by particles passing through the screen and the increase of erosion wear caused by particles blocking the screen to form a high flow rate erosion area. It can be effectively reduce sand production and production accidents in oil wells by taking correct sand prevention measures.

The research on sand prevention screen mainly focuses on the analysis of erosion mechanism and the prediction of erosion life. Finnie proposed microcutting erosion theory, which can explain the erosion problem of materials and the erosion wear mechanism of plastic materials under low impact angle clearly. Bitter put forward the deformation wear theory. By analyzing the mass loss, impact angle, impact velocity, and other related factors, Finnie model was further improved, which can fully explain the erosion of metal materials at different angles of attack. Since then, Levy and Chik carried out dynamic research on the etching process and put forward the forging extrusion theory, which has been approved by some scholars at present. Evans et al. put forward the elastoplastic indentation fracture theory, which can well explain the erosion problem of low temperature plastic materials. In the same year, Hutching found that the material was locally adiabatic after being impacted by solid particles by annular particle erosion experiments, which eventually led to mass loss at this position. Tilly put forward the theory of secondary erosion, which introduces the critical value of erosion damage, and well explains the erosion problem of broken particles on materials after particle impact crushing.

Head and Harr found that the influencing factors of erosion are velocity, shape, hardness, erosion resistance, etc. through erosion experiments on metals. Liu et al. carried out experimental research on sand-
control slotted screen pipes, and established a prediction model for erosion life of slotted screen pipes considering crude oil flow rate, sand particle diameter, sand particle concentration, and erosion angle. Liu et al.15 used self-developed experimental devices to simulate the erosion effects of different sand-containing particle sizes, different flow rates, different erosion angles, and different sand-containing concentrations on screen pipes. Deng et al.16 and Wang et al.17 carried out numerical simulation on the oil slotted screen, discussed the influence law of flow rate and sand concentration on the erosion of slotted screen, and proposed an erosion prediction model based on flow rate, solid mass fraction, and particle size. Wang et al.17 used finite element analysis software CFX to simulate the erosion of the outer protection pipe of the spiral composite screen pipe, and analyzed the erosion effects of inlet flow rate, sand particle diameter, and sand particle content on the outer protection pipe. Follansbee et al.18 proposed a cumulative damage model through experiments combined with Coffin-Manson model. Verspui et al.19 proposed that velocity distribution is an important parameter of erosion through CFD simulation, and established a simple erosion model in the erosion process of brittle materials. A new erosion model is obtained by studying vertically incident metals in the laboratory. Zhang et al.20 obtained the life prediction model through the velocity distribution of CFD at different angles. Procyk et al.21 aimed at the specific screen configuration of multiple subsea gas wells under high flow rate conditions.

According to the analysis of screen pipe life, Cameron and Jones22 established an erosion model based on fluid type, flow rate, solid load and particle size distribution combined various erosion test results of predecessors, and predicted the erosion life of sand prevention screen pipe. Gillespie et al.23 studied the erosion failure of wire-wound screen and metal mesh screen under open hole completion conditions, conducted several groups of erosion experiments under different velocities and sand concentration, and proposed a screen service life model for given oil and gas well production conditions under open hole completion conditions. Kumar et al.24 studied the cavitation resistance and sand prevention effect of different types of screen pipes through laboratory tests. The corrosion life of screen pipes is: glass bead filled screen pipe > metal mesh screen pipe > wire wound screen pipe.

A large number of production practices and experiments show that the main factors affecting screen erosion include particle velocity, particle size, solid mass fraction, and erosion angle. Most of the existing sand prevention technologies and tools are difficult to meet the requirements of sand prevention operations in oil wells with serious sand production and fine sand in the middle and late stages. In addition, there is little research on metal mesh screen at home and abroad. In this paper, on the basis of the conditions and influencing factors put forward by the erosion theory at home and abroad, a single variable experiment is carried out on each influencing factor, and a screen life prediction model based on flow rate, solid mass fraction and erosion angle is established by actual production situation of the oil field.

**Erosion test device**

The metal mesh screen is used as the experimental research material, and the sand retaining accuracy is 250 μm. A screen pattern of 38 × 30 × 0.28 mm was cut from a screen sheet of 100 × 50 × 0.28 mm to remove any impurities on the surface and clean it. The density of the crude oil used is 860–870 kg/m³ and the viscosity is 46 mPa s.

The equipment used in the experiment is MSH rotary erosion equipment, as shown in Figure 1. Before the experiment starts, weigh the mass of the metal screen used in the experiment. The gravel is made of industrial quartz sand. The particle size distribution of the gravel measured by laser particle size analyzer is shown in Figure 2. The sand distribution for experiment is shown in Table 1. The gravel density is 1550 kg/m³.
Materials and method

In order to evaluate the impact of different liquid velocities, solid mass fractions and impact angles on the erosion wear of metal mesh, an MSH rotary erosion equipment as shown in Figure 1 is adopted. Using a clamp to clamp the screen sample on the equipment base pipe, it can simulate the downhole screen erosion condition with the rotary of test bed. By directly setting four different gradient particle velocities on the equipment, the erosion effect of different velocities in actual production can be obtained. The equipment base tube provides four impact angles of 15°, 30°, 45°. The erosion time of each group is 24 h, and a total of 5–6 groups are measured, and the mass loss of the screen is recorded every 24 h. In the first group of experiments, liquid velocities of 1.5, 1, 1.5, 2.0 m/s, constant solid mass fraction of 0.5% and constant angle of 30° were selected to carry out screen erosion wear laws at different velocities. In the second group of experiments, different solid mass fractions of 0.3%, 0.5%, 0.8%, constant liquid velocity of 0.5 m/s and constant impact angle of 30° were selected to mainly explore the erosion wear law of metal screen under different solid mass fractions. In the third group of experiments, angles of 15°, 30°, 45°, constant flow rate of 0.5 m/s and constant solid mass fraction of 0.5% were selected to impact the metal mesh. The specific experimental plan is shown in Table 2.

After 24 h of experiment, clean the screen surface sand, the experimental screen sample placed in petroleum ether soaked for half an hour, and then use anhydrous ethanol to wipe the residual petroleum ether on the screen surface, and then use the oven to dry the screen surface. When the screen surface is completely clean, the electronic balance is used to weigh screen sample several times, and the average value of the experimental screen mass is obtained. The accuracy of the electronic balance used in the experiment was 0.0001.

In the experiment, the erosion rate is used as the standard to measure the erosion damage of metal mesh screen. As shown in formula 1, it represents the mass loss rate of the metal mesh per unit time.

### Table 1. Proportion of experimental sand.

| Industrial sand mesh number | 60 mesh | 80–120 mesh | Sum (g) |
|----------------------------|---------|-------------|--------|
| The ratio of the proportion | 0.65    | 0.35        |        |
| Specific weight            |         |             |        |
| Solid concentration 0.3%   | 16.965  | 9.135       | 26.1   |
| Solid concentration 0.5%   | 15.29   | 24.36       | 43.5   |
| Solid concentration 0.8%   | 45.24   | 24.36       | 69.6   |

### Table 2. Experimental application parameters table.

| Experiment | Parameter | particle size | Velocity (m/s) | Angle (°) | Concentration (%) | Initial mass (g) |
|------------|-----------|---------------|----------------|-----------|-------------------|------------------|
| 1          | Impact    | 65% 250 μm+   | 0.5            | 30        | 0.5               | 3.98             |
| 2          | velocity  | 35% 125–180 μm| 1              | 30        | 0.5               | 3.96             |
| 3          |           |               | 1.5            | 30        | 0.5               | 4.11             |
| 4          |           |               | 2.0            | 30        | 0.5               | 4.09             |
| 5          | Solid     |               | 0.5            | 45        | 0.3               | 3.95             |
| 6          | concentration |         | 0.5           | 45        | 0.5               | 3.96             |
| 7          |           |               | 0.5            | 45        | 0.8               | 4.15             |
| 8          | Impact angle |           | 0.5            | 15        | 0.5               | 4.01             |
| 9          |           |               | 0.5            | 30        | 0.5               | 4.05             |
| 10         |           |               | 0.5            | 45        | 0.5               | 3.91             |

Figure 2. Cumulative particle size distribution of experimental sand.
Where: $Q$ is the erosion rate of metal mesh screen ($\text{kg s}^{-1} \text{m}^{-2}$); $m_l$ is screen mass loss (g); $t$ is the experimental erosion time (s); $A$ is the flow area ($\text{m}^2$) of the metal screen.

**Analysis of experimental results**

The main purpose is to obtain the erosion rate of the metal mesh screen, so as to explore the erosion law and analyze the erosion mechanism under different factors of the metal mesh screen. Table 3 shows the results of experimental data under different experimental conditions including the experimental mass loss and erosion rate measured by the weight loss method.

**Table 3. Proportion of experimental sand.**

| Experiment | Velocity (m/s) | Angle (°) | Concentration (%) | Mass loss (g) | Erosive wear ($\times 10^{-7}$) (g/g) |
|------------|----------------|-----------|-------------------|---------------|--------------------------------------|
| 1          | 0.5            | 45        | 0.5               | 0.0045        | 0.46                                 |
| 2          | 1              | 45        | 0.5               | 0.0086        | 0.88                                 |
| 3          | 1.5            | 45        | 0.5               | 0.0130        | 1.32                                 |
| 4          | 2.0            | 45        | 0.5               | 0.0179        | 1.82                                 |
| 5          | 0.5            | 45        | 0.3               | 0.0023        | 0.23                                 |
| 6          | 0.5            | 45        | 0.5               | 0.0045        | 0.45                                 |
| 7          | 0.5            | 45        | 0.8               | 0.0059        | 0.60                                 |
| 8          | 0.5            | 15        | 0.5               | 0.0023        | 0.26                                 |
| 9          | 0.5            | 30        | 0.5               | 0.0042        | 0.42                                 |
| 10         | 0.5            | 45        | 0.5               | 0.0045        | 0.46                                 |

![Figure 3. Erosive rate of screen at different liquid velocities.](image)

**Liquid velocity**

As can be seen from Table 3, liquid velocity is the most important factor affecting the erosion wear of metal mesh screen. Erosion rate and mass loss increase with the increase of liquid velocity. As can be seen from Figure 3, when erosion first occurs, the mass loss of the screen is small. As the experiment continues, the mass loss of the screen increases first and then decreases. This is because at the beginning of the experiment, the screen erosion is mainly caused by the cutting wear caused by particles passing through the mesh and the impact of particles on the screen. As the experiment progresses, the screen is gradually blocked, resulting in a decrease in the through-flow area of the screen and an increase in the local velocity. The screen erosion is caused by particle cutting wear and local through-flow hot spots at the same time. When the particles completely block the screen, the particles with large particle size cannot pass through the screen and form sand bridges on the surface of the screen. The formation of sand bridges protects the screen and reduces the mass loss and erosion rate.

**Erosion angle**

As can be seen from Table 3 and Figure 4, when the impact angle of the metal mesh screen is 15° to 45°, the erosion rate increases with the increase of the impact angle and reaches the maximum at 45°. This shows that at 45°, more kinetic energy of particles is transferred to the metal mesh, and the erosion wear of the metal mesh increases.

**Solid phase mass fraction**

It can be seen from Figure 5 that under low solid mass fraction, when the liquid velocity and erosion angle of the single-layer metal mesh screen are constant, the erosion rate of the metal mesh screen increases with the increase of solid mass fraction. This is because at low concentration, with the increase of sand content, the collision chance between sand and particles increases, which increases the erosion wear of particles. However, with the increase of solid mass fraction exceeding the critical value, the screen erosion rate begins to decrease. This is because the increase of particles causes a part of
kinetic energy to be applied to the collision rebound between particles, resulting in the reduction of erosion wear on the screen.

**Life prediction**

In order to better analyze the downhole working life of the screen, formula fitting is carried out according to the data measured in the laboratory, and a screen life prediction model based on flow rate, solid phase mass fraction, and erosion angle is established.

The mathematical model fitting software 1stOpt15PRO was used for formula fitting. The relevant factors were Angle $\alpha$, liquid velocity $V$, concentration $C$, and particle diameter $D$. $1.00 \times 10^{-10}$ was set as the judgment index of formula convergence, and the maximum number of iterations was 10,000, the number of repeats was 400, the number of control iterations was 300, and the number of convergence judgment iterations was 150. The basic formula is Equation 2.

$$Q = \frac{6.3 \times 10^{-5} \cdot c^b \times \sin^2 \alpha \times C_0}{D^c}$$

Where $Q$ is the screen erosion rate ($\text{kg s}^{-1} \text{m}^{-2}$); $c$: mass fraction of solid phase; $d$: diameter of sand grains (mm); $v$: liquid velocity (m/s); $\alpha$: Erosion angle.

Comparing the experimental value of screen erosion rate with the simulated value, as shown in Figure 6, the error range is within 20%. The accuracy and feasibility of the formula are verified. Therefore, in the actual production of the oilfield, 8% of the erosion mass loss is taken as the standard of the screen erosion damage. When the erosion mass loss is greater than 8% of the original mass of the screen, it indicates that the screen has been eroded.

**Analysis of erosion mechanism**

Figure 7 is a screen sample diagram with solid phase mass fraction of 0.3% and liquid velocity of 2 m/s. Figure 8 is a screen sample diagram with solid phase mass fraction of 0.5 m/s and liquid velocity of 2 m/s. (Figures 7 and 8 are diagrams of screen samples that have not been tested, and screen samples that have been tested for 24, 72, and 168 h from left to right.) As can be clearly seen from Figure 7, the mass fraction of solid phase is 0.3%. When the experiment is carried out for 24 and 72 h, the screen has no obvious change. When the experiment is carried out for 168 h, the screen is obviously blocked and the screen surface is seriously damaged.
eroded. For Figure 8, the mass fraction of solid phase increases to 0.5%. When the experiment is carried out for 24 h, the screen surface has polishing phenomenon and slight blockage. When the experiment is carried out for 72 h, the screen blockage is more obvious than that for 24 h. When the experiment is carried out for 168 h, the screen sample surface has multiple blockages and receives more serious erosion wear.

Comparing Figure 7 with Figure 8, we can see that when the liquid velocity and experimental angle are unchanged, the increase of solid mass fraction will aggravate the mesh blockage of the screen and aggravate the erosion wear on the screen surface, and the mesh blockage of the screen is serious and the erosion wear on the screen surface intensifies.

Figure 9 shows the average flow rate of the experimental sample when the solid mass fraction is 0.3% and 0.5%. As the experiment progresses, the screen sample gradually becomes blocked. As the mass fraction of solid phase increases, the blockage of screen samples intensifies (as shown in Figures 7 and 8). Figure 9 show that as that screen blockage intensifies, the flow rate of the screen sample gradually increase, and the more serious the screen blockage, the greater the flow rate of the screen. This is because with the blockage of the screen, the local through-flow area of the screen decreases, resulting in an increase in the local through-flow velocity of the screen. At the same time, the local flow velocity of the screen increases, and the erosion wear of the screen intensifies.
Figure 10. Electron microscopy of screen at different concentration of solid phase: (a) electron microscopy at 0.3% and (a) electron microscopy at 0.8%.

Figure 11. Electron microscopy of screen at different liquid velocities: (a) liquid velocity 0.5 m/s and (b) liquid velocity 2.0 m/s.

Figure 12. Erosion area of screen mesh: (a) overall topography of erosion area, (b) central area of erosion, (c) erosion edge area, and (d) uneroded area.

Figure 10 is an electron microscope picture of the experimental metal mesh screen respectively. Ploughing, pitting, and cutting can be observed from the figure. As shown in Figure 10(a) and (b) are electron microscope screen diagrams magnified 100 times and 200 times by 0.3% and 0.8% of the solid mass fraction of the screen respectively. It can be observed in the diagram that the screen of Figure 10(a) is pitted to different degrees. When the solid mass fraction increases, the screen of Figure 10(b) is not only pitted, but also subjected to different degrees of cutting wear.

Figure 11(a) and (b) are electron microscopic picture of that screen at liquid velocities of 0.5 and 2.0 m/s. It can be clearly observed that at low liquid velocity, the metal mesh has ploughing and slight pitting corrosion, and at high liquid velocity, the metal mesh can observe greater ploughing pitting corrosion and cutting wear. This shows that the erosion wear of the metal screen intensifies with the increase of the liquid velocity.

After the experiment, the metal screen was scanned by electron microscope, and the whole experimental screen pendants were also observed by optical observation. The screen screen picture after observation is shown in Figure 12. In the figure, the erosion area and the non-erosion area of the metal screen are compared and observed. Through the optical observation of the screen mesh, the experimental screen mesh can be divided into the erosion center area, the erosion edge area and the non-erosion area. Through the optical microscope, it was found that different “polishing” and “deformation” phenomena occurred in different areas of the metal screen. Erosion center area is evident in the “polished” phenomenon, the center area of the screen have obvious deformation, erosion border area had minor “polished” phenomenon, screen wire by deformation wear than erosion center area is lesser, screen mesh surface erosion area basic not subjected to the “polished” basic not subjected to deformation and wire mesh.
Conclusions

The erosion wear law of metal mesh screen under the influence of different liquid velocity, erosion angle and solid phase mass fraction is studied by MSH rotary experimental equipment. Combined with the actual production conditions in oil fields, a screen life prediction model based on liquid velocity, solid phase mass fraction and erosion angle is proposed. The main conclusions are as follows:

(1) The erosion rate of single-layer metal mesh screen increases with the increase of liquid velocity, and with the increase of erosion time, the erosion rate of metal mesh screen increases first and then gradually begins to slow down.

(2) The screen erosion rate increases with the increase of erosion angle and reaches the maximum at 45°.

(3) Under the condition of low solid mass fraction, the erosion rate of single-layer screen increases with the increase of solid mass fraction.

(4) Based on liquid velocity, solid mass fraction and erosion angle, a new screen life prediction model is established. After comparing the experimental value with the predicted value, the error is within 20%.

(5) Electron microscope images of the screen show that the erosion wear of the metal mesh mainly includes ploughing, pitting and cutting wear, and the erosion wear of the screen intensifies with the increase of solid mass fraction and liquid velocity.

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