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Erosion of Metal Wire Mesh Screens under Varying Flow Velocity, Sand Concentration, and Impact Angle

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ABSTRACT: This study investigates the erosion behavior of metal mesh sand-control screens under representative operating conditions and develops an empirical model for predicting erosion rate and screen service life. Single-layer metal mesh screens were tested using a Multifunctional Spin Hydrodynamics (MSH) rotating apparatus under systematically varied liquid velocity, sand concentration, and particle impact angle. The influence of each operating parameter on erosion was quantified using a one-factor-at-a-time experimental design, while the underlying wear mechanisms were characterized by scanning electron microscopy (SEM) and optical microscopy. The results show that liquid velocity is the dominant factor controlling erosion, producing the largest variation in erosion rate over the investigated range. The erosion rate increases monotonically with liquid velocity (0.5, 2.0 m/s), sand concentration (0.3%, 0.8%), and impact angle (15°, 45°). Erosion is highly localized and is governed primarily by pitting, cutting, and plowing mechanisms, with blocked regions exhibiting the most severe material degradation. An empirical erosion model is developed and validated against the experimental data, achieving an average prediction error of 13.3%.

KEYWORDS: Metal mesh screen; erosion behavior; influencing factors; erosion mechanisms; mathematical modeling

1 Introduction

Sand production from weakly consolidated sandstone reservoirs threatens well integrity, production stability, and the reliability of downhole and surface equipment. Formation particles entrained by produced fluids may cause deposition, plugging, and erosive wear. Mechanical sand-control systems, particularly stand-alone and metal-mesh screens, are widely used because they provide direct particle retention with relatively simple completion structures. Nevertheless, screen performance can deteriorate through plugging, corrosion, structural deformation, and erosion. Erosion is especially critical because localized material removal can enlarge filtration openings, reduce sand-retention capability, and cause premature screen failure [1–3].

At the material scale, solid-particle erosion results from repeated momentum and energy transfer from entrained particles to the target surface. For ductile metallic materials, material removal may involve impact indentation, localized plastic deformation, microcutting, and plowing, with the dominant mechanism depending on particle characteristics, carrier-fluid properties, impact velocity, and impact angle. Wang et al. [4] reported a non-monotonic angle dependence for 316 L stainless steel under liquid-solid jet conditions. More directly, Kanesan et al. [5] investigated Grade 316 stainless-steel wire mesh and found

that erosive wear increased with particle size and carrier-gas velocity; within the tested range of 30° – 90° , the maximum wear occurred at 45° , accompanied by deeper plowing and pitting.

Liquid velocity, sand concentration, particle-size distribution, and impact angle are among the principal operating variables governing screen erosion [6–9]. Increasing velocity generally increases particle momentum and collision frequency, although reported velocity-erosion relationships vary from approximately linear to exponential or power-law forms, depending on screen architecture, carrier fluid, and the definition of velocity [10,11]. Nominal carrier-fluid velocity may differ substantially from particle-impact velocity and local aperture velocity because of slip, fluid drag, and flow contraction through the mesh [12]. Particle-size and concentration effects are also range-dependent. Kanesan et al. [5] observed increasing wear with particle size under air-blast conditions, whereas Deng et al. [6] reported that erosion of a monolayer metal mesh in sand-laden crude oil initially increased and then decreased with increasing median particle size or sand concentration. Such differences indicate that concentration effects observed over a low-solids range should not be extrapolated to higher concentrations, where particle–particle collisions, shielding, rheological changes, and bridging may alter the effective impact energy.

The screen geometry further couples particle retention, flow redistribution, and localized erosion. Partial blockage reduces the effective open area and redirects flow through the remaining apertures, potentially generating high local velocities and erosion hot spots. Experiments comparing blocked and non-blocked metal screens showed that blockage can intensify local wear through increased aperture velocity [9], while numerical studies have demonstrated that screen geometry and carrier-fluid conditions can lead to strongly nonuniform flow and erosion distributions at the screen scale [13–15]. In addition, non-uniform sand retention and sequential bridging can develop strong local flows and erosion hot spots on the screen [16]. These findings indicate that blockage-prone conditions should be interpreted in terms of localized flow redistribution rather than a spatially uniform increase in erosion.

Screen erosion has been investigated using sand-blasting rigs, liquid-solid jet systems, rotating apparatuses, pressure-driven circulation loops, radial-flow devices, and CFD-based models. These approaches reproduce different aspects of field operation. Air-blast tests provide controlled particle size, velocity, and angle, whereas oil-circulation and slurry-flow systems better represent viscous carrier-fluid conditions. Radial-flow experiments can reproduce localized inflow and hot-spot damage, while CFD and discrete-particle methods resolve aperture-scale flow and erosion distributions that are difficult to measure experimentally [12–15]. Previous studies have also proposed erosion-rate or service-life models using laboratory fitting, numerical simulation, and field comparison [17]. Orthogonal design and analysis of variance have been used to rank multiple factors for slotted-screen erosion [18]. Nevertheless, differences in screen architecture, flow orientation, blockage state, particle-size distribution, and failure criteria limit direct quantitative comparison among published results.

Accordingly, controlled comparisons of liquid velocity, low sand concentration, and impact angle under a common reference condition remain insufficient for single-layer plain-weave metal wire mesh exposed to viscous, blockage-prone oil–sand flow. The present study therefore employed a Multifunctional Spin Hydrodynamics rotating apparatus and a one-factor-at-a-time design to quantify the individual effects of these parameters on mass loss and area-normalized erosion rate. Optical and scanning electron microscopy were used to characterize localized damage mechanisms, and an empirical erosion-rate correlation was calibrated for the investigated conditions.

2 Experimental Design and Results Analysis

2.1 Experimental Apparatus and Materials

2.1.1 Experimental Apparatus

To precisely control the influence of experimental concentration and erosion angle on the screen erosion samples, the experiment used a MSH rotating erosion instrument with different angles. This device can accurately control the erosion angle of abrasive particles and particle content. It was used to conduct indoor screen erosion damage experiments to replace the on-site screen erosion damage process, and the configured oil-sand ratio is used to determine the concentration of sand-carrying fluid for experimental circulation. Currently, the erosion tests conducted at home and abroad are mainly solid-liquid erosion experiments, with a few being gas-liquid erosion experiments, studying the short-term erosion laws of screens under the influence of flow rate, sand concentration, erosion angle, etc., and using a relatively short laboratory erosion time to study the screen erosion laws under long-term operation of oil wells. At the same time, the phenomenon of sand blockage during the experiment is considered to discover the erosion damage process and mechanism of metal mesh screens.

Erosion experiments were performed using a MSH rotational erosion apparatus (Fig. 1), which allows precise control over the impact angle of abrasive particles, sand concentration, and erosion velocity. The apparatus is composed primarily of an agitator, a slurry storage tank, a screen specimen holder, a base frame, and a vertically adjustable rotating wheel. The screen specimen holder was employed to secure each test screen, ensuring that the specimens remained fully submerged in the sand-laden fluid within the storage tank throughout the experimental procedure (Fig. 2). During the tests, the masses of the screen specimens were determined using an electronic balance with a resolution of 0.0001 g (Fig. 3). Furthermore, the surface morphologies of the screens following erosion were characterized using scanning electron microscopy (SEM) and optical microscopy, providing detailed insight into the erosion patterns and mechanisms.

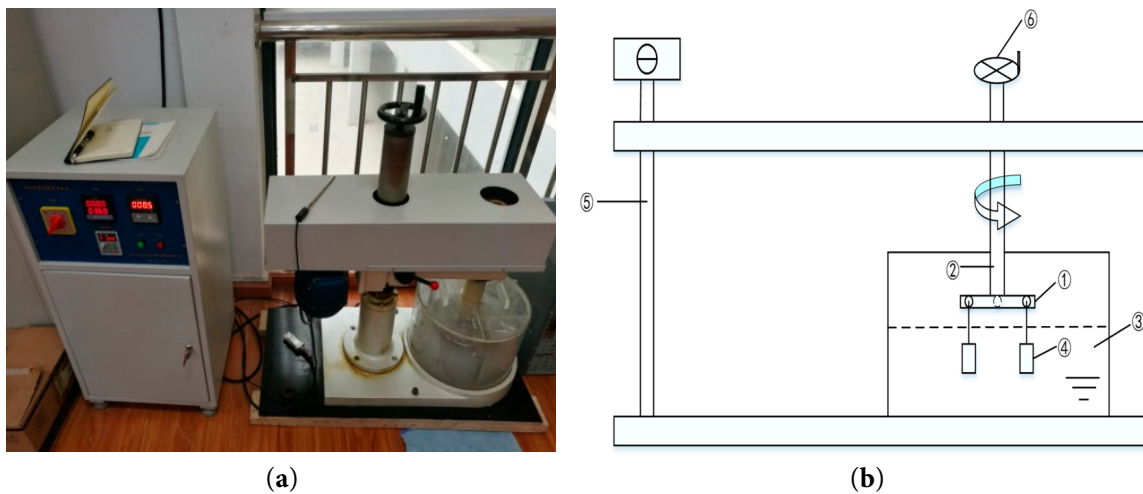


Figure 1: Screen erosion test device diagram (a,b). (a) Photograph of the experimental system; (b) schematic configuration: ① the agitator, ② the slurry storage tank, ③ the screen-specimen holder, ④ the base frame, ⑤ the vertically adjustable rotating wheel.

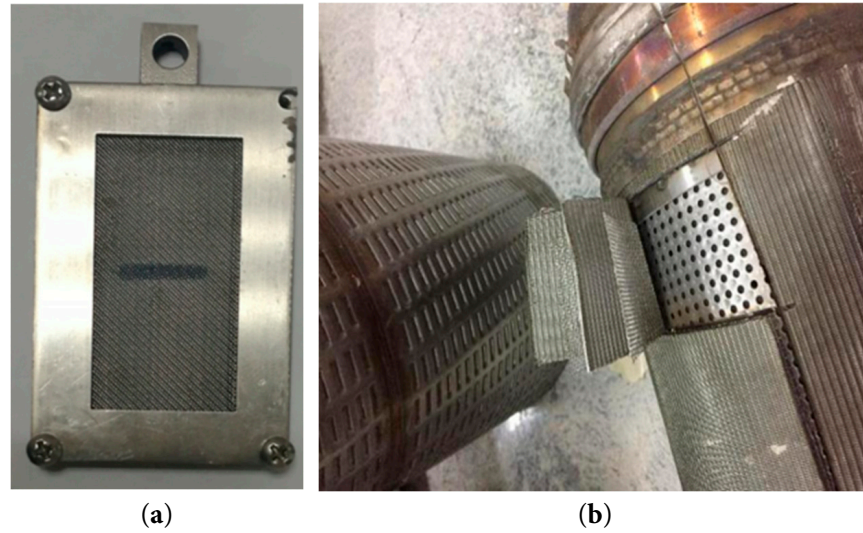


Figure 2: Screen mesh and screen tube used in the experiment (a,b). (a) Single-layer plain-weave metal wire mesh specimen mounted in the holder; (b) commercial metal-mesh sand-control screen pipe from which the test specimens were prepared.

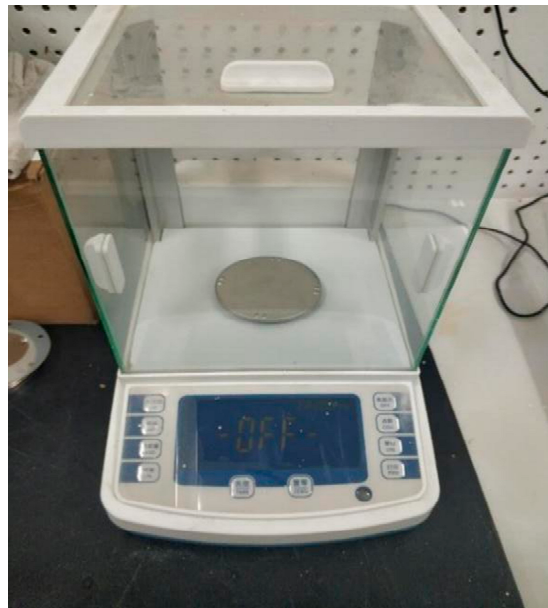


Figure 3: Electronic balance.

2.1.2 Experimental Materials

A high-quality metal wire mesh screen pipe was selected for the experiments. The sand control medium consisted of two layers of metal plain weave mesh, two layers of metal square-hole mesh, and a supporting mesh. As the square-hole mesh does not contribute to sand retention, the experimental configuration was simplified to a single layer of metal plain weave mesh. The nominal sand-retention rating of the plain-weave metal mesh was 250 μm . Inappropriate sand particle interception precision and gravel particle size will lead to serious blockage of the screen [19,20]. According to the one-third bridging criterion [9,21], particles with a characteristic diameter exceeding approximately one-third of the nominal sand-retention rating

may promote particle bridging and progressive blockage of the screen openings. Accordingly, for a screen with a nominal sand-retention rating of 250 μm , the corresponding threshold particle size is approximately 83 μm . Because the industrial sand used in the present study had a median particle diameter of 300 μm , the experiments were conducted under blockage-prone conditions rather than nominally non-blocking conditions. Particle accumulation, bridging, and progressive local blockage were therefore regarded as integral components of the erosion process investigated in this study. The carrier fluid was crude oil with a density of 860–870 $\text{kg}\cdot\text{m}^{-3}$ and a dynamic viscosity of 46 $\text{mPa}\cdot\text{s}$. Industrial sand was used as the abrasive medium, comprising 65 wt.% of the 60-mesh fraction and 35 wt.% of the 80–120-mesh fraction.

2.2 Experimental Objectives

The objectives of this study were to: (1) quantify the individual effects of liquid velocity, sand concentration, and impact angle on the erosion rate of metal wire mesh screens; (2) characterize the associated erosion mechanisms through microscopic and macroscopic surface observations; and (3) develop an empirical model for estimating the erosion rate within the investigated parameter ranges and supporting preliminary service-life assessment. Interaction effects among the three operating parameters were outside the scope of the present experimental design.

2.3 Experimental Program and Procedures

2.3.1 Experimental Program

A one-factor-at-a-time experimental design was employed to evaluate the individual effects of liquid velocity, sand concentration, and impact angle on the erosion behavior of metal wire mesh screens. The abrasive medium was prepared by blending 60-mesh and 80–120-mesh industrial sand at a mass ratio of 65:35. The quantities of the two particle-size fractions used to prepare the nominal sand concentrations of 0.3%, 0.5%, and 0.8% are listed in Table 1, and the cumulative particle-size distribution of the abrasive medium is presented in Fig. 4.

Table 1: Specific ratio of experimental sand and gravel concentration.

Mesh Number of Industrial Sand		60 Mesh	80~120 Mesh	Sum (g)
Concentration Ratio of Sand and Gravel		0.65	0.35	
Specific proportion of sand-gravel concentration	concentration of 0.3%	16.965	9.135	26.1
	concentration of 0.5%	15.29	24.36	43.5
	concentration of 0.8%	45.24	24.36	69.6

The parameter levels were selected by considering the stable operating range of the MSH apparatus and the test conditions reported in previous experimental studies on metal wire mesh erosion. Liquid velocities of 0.5, 1.0, 1.5, and 2.0 m/s were selected to provide four progressively increasing hydrodynamic conditions while maintaining stable circulation of the oil-sand slurry. Sand concentrations of 0.3%, 0.5%, and 0.8% were selected to characterize the erosion response within a relatively low solids-loading range and to facilitate comparison with previous metal-screen erosion experiments conducted at the same concentration levels. Impact angles of 15°, 30°, and 45° were selected at uniform 15° intervals to provide a systematic comparison of angle-dependent erosion within the investigated range. Because impact angles greater than 45° were not examined, the selected angular levels were not intended to identify the global critical angle associated with maximum erosion.

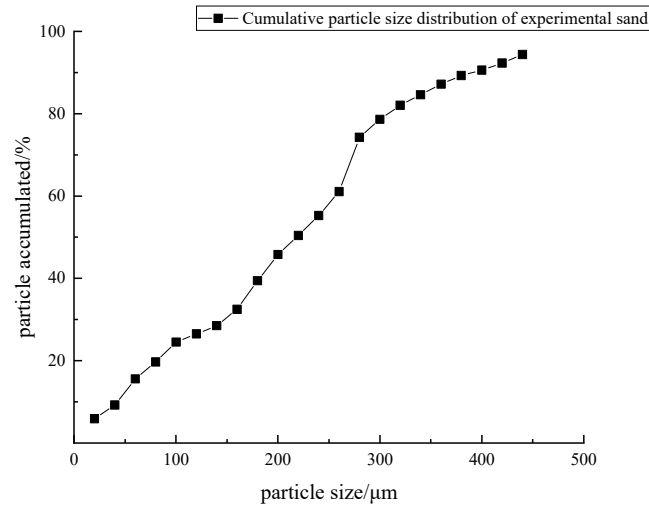


Figure 4: Sand and gravel particle size ratio.

Within this one-factor-at-a-time framework, three experimental series were established. In the liquid-velocity series, the impact angle and sand concentration were maintained at 45° and 0.5%, respectively, while the liquid velocity was varied among 0.5, 1.0, 1.5, and 2.0 m/s. In the sand-concentration series, the liquid velocity and impact angle were fixed at 0.5 m/s and 45° , respectively, while the sand concentration was varied among 0.3%, 0.5%, and 0.8%. In the impact-angle series, the liquid velocity and sand concentration were maintained at 0.5 m/s and 0.5%, respectively, while the impact angle was varied among 15° , 30° , and 45° . The condition defined by a liquid velocity of 0.5 m/s, a sand concentration of 0.5%, and an impact angle of 45° served as the common reference condition for all three experimental series. Because this reference condition was shared among the three series, the experimental matrix comprised eight unique test conditions. The selected design enabled the individual effect of each parameter to be evaluated while the remaining parameters were held constant; however, it did not permit interaction effects among liquid velocity, sand concentration, and impact angle to be quantified. The complete experimental matrix is summarized in Table 2.

Table 2: Erosion test scheme of sand control screen.

Exp. No.	Parameter	Particle Size	Liquid Velocity (m/s)	Angle/(°)	Concentration/(%)	Initial Mass (g)
1	Impact velocity	65% 60 mesh + 35% 80~120 mesh	0.5	45	0.5%	3.98
2			1	45	0.5%	3.96
3			1.5	45	0.5%	4.11
4			2.0	45	0.5%	4.09
5	Solid concentration		0.5	45	0.3%	3.95
1			0.5	45	0.5%	3.98
6			0.5	45	0.8%	4.15
7	Impact angle		0.5	15	0.5%	4.01
8			0.5	30	0.5%	4.05
1			0.5	45	0.5%	3.98

The erosion duration was 24 h for each experimental condition. One specimen was tested under each condition. Before and after erosion testing, the specimen was cleaned and dried according to the procedure described above and was subsequently weighed five to six times using an electronic balance with a resolution of 0.0001 g. The arithmetic mean of the repeated balance readings was taken as the specimen mass, and the difference between the mean pre-test and post-test masses was defined as the erosion-induced mass loss. The repeated readings were used to reduce random balance-reading variability and should not be interpreted as independent replicate erosion tests. Since the original mass of the metal mesh screen varies, the mass loss in the experiment cannot fully indicate the severity of erosion and wear on the screen. Therefore, this study introduced the erosion rate to evaluate the severity of erosion and wear on the screen, which represents the mass loss rate of the metal screen.

The area-normalized erosion rate of the metal wire mesh specimen was calculated from the measured mass loss as follows:

$$Q = \frac{(m_0 - m_t) \times 10^{-3}}{At} = \frac{\Delta m \times 10^{-3}}{At} \quad (1)$$

where Q is the erosion rate ($\text{kg} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$); m_0 and m_t are the masses of the specimen before and after the erosion test, respectively (g); $\Delta m = m_0 - m_t$ is the measured mass loss (g); A is the effective flow-through area of the metal mesh specimen (m^2); and t is the erosion duration (s). The factor 10^{-3} converts the measured mass loss from grams to kilograms, thereby ensuring dimensional consistency.

2.3.2 Experimental Procedure

The experiment used a MSH rotating tester, and the erosion screen sample was a single-layer metal mesh screen. During the experiment,

- (1) Sample preparation: Test specimens with dimensions of 30×38 mm were cut from the sand control screen using a cutting machine. For each experimental condition, three specimens were prepared;
- (2) Sample pretreatment: The specimens were rinsed with clean water to remove surface contaminants. After drying, repeated measurements were conducted using an electronic balance, and the averaged value was taken as the initial mass;
- (3) Experimental setup adjustment: The specimens were mounted in the sample holder and fixed onto the base pipe at erosion angles of 15° , 30° , and 45° , respectively. Consistency of experimental conditions was ensured;
- (4) Preparation of sand-laden fluid: Oil-sand slurries with the designated concentrations were prepared according to the experimental scheme. The slurries were poured into the storage tank, ensuring that the specimens were completely submerged throughout the experiment.
- (5) Experimental operation: The rotational speed and test duration were set as specified. The apparatus was operated continuously, and the specimens were retrieved at 24 h intervals;
- (6) Post-treatment of specimens: The retrieved specimens were immersed in petroleum ether for 1 h to remove residual oil. After being wiped with anhydrous ethanol and dried, the specimens were weighed, and the data were recorded;
- (7) Surface morphology observation: After testing, the specimens were examined using scanning electron microscopy (SEM) and optical microscopy to analyze changes in surface morphology.

2.4 Results and Discussion

2.4.1 Effects of Operating Parameters on Erosion Rate

Effect of Liquid Velocity on Erosion Rate

Liquid velocity was identified as the factor influencing the erosion of the screens. Both the erosion rate and mass loss were observed to increase significantly with increasing liquid velocity (Table 3, Fig. 5). Specifically, as the liquid velocity increased from 0.5 m/s to 2.0 m/s, the erosion rate increased from $0.46 \times 10^{-7} \text{ kg}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ to $1.82 \times 10^{-7} \text{ kg}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, corresponding to an increase of 295.7%.

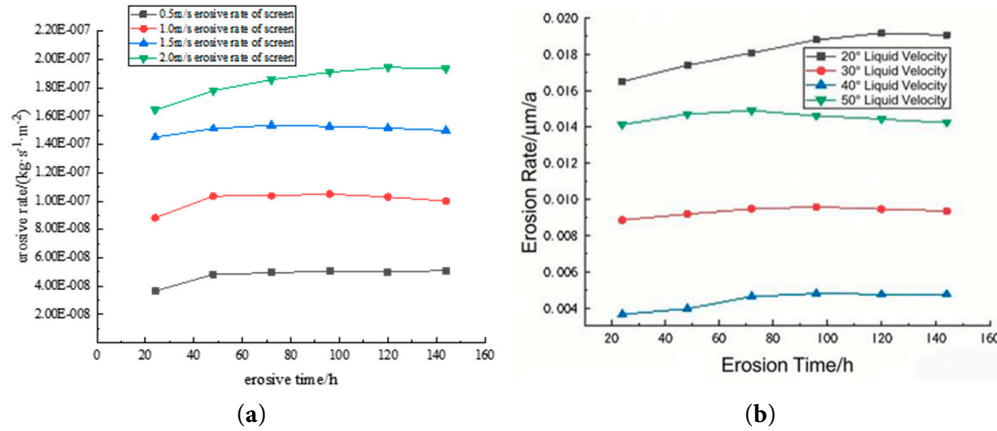


Figure 5: Mass loss and erosion rate of metal wire mesh screen (a,b). (a) Area-normalized erosion rate at different liquid velocities; (b) equivalent thickness-loss erosion rate under the corresponding test conditions.

Table 3: Experimental results of metal mesh cloth screen mesh.

Experiment	Liquid Velocity ($\text{m}\cdot\text{s}^{-1}$)	Angle ($^{\circ}$)	Concentration	Mass Loss (g)	Erosion Rate ($\times 10^{-7} \text{ kg}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$)
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
1	0.5	45	0.5%	0.0045	0.46
6	0.5	45	0.8%	0.0059	0.60
7	0.5	15	0.5%	0.0023	0.26
8	0.5	30	0.5%	0.0042	0.42
1	0.5	45	0.5%	0.0045	0.46

As shown in Fig. 5a, cumulative mass loss increased monotonically with erosion time at all investigated liquid velocities, whereas the interval-averaged erosion rate increased during the early-to-intermediate stage and subsequently decreased at later times (Fig. 5b). Initially, particle impacts occurred on relatively smooth wire surfaces, resulting in a comparatively low erosion rate. As surface irregularities, pits, and grooves developed, repeated particle impacts became more effective, increasing the interval-averaged erosion rate.

At the later stage, particle accumulation and partial blockage may have produced two competing effects. The reduction in effective open area could redirect the slurry through the remaining apertures and increase local aperture velocity, thereby intensifying erosion near residual flow passages and deposit

boundaries. Conversely, deposited particles and temporary sand bridges could partially shield covered wire surfaces from direct impact and reduce the effective exposed area. The decrease in specimen-averaged erosion rate therefore suggests that the shielding effect became increasingly important, although localized erosion could remain severe adjacent to blocked regions. Because local velocity, pressure distribution, and particle coverage were not measured *in situ*, this mechanism should be regarded as an interpretation consistent with the time-resolved mass measurements, post-test morphology, and previous blockage-related studies, rather than as direct evidence of the local flow field.

The rotating apparatus did not permit *in-situ* measurement of the pressure drop, slurry flow rate, or sand breakthrough during testing. Accordingly, the present experiments were not used to determine a quantitative screen-failure threshold. Post-test mass loss and surface morphology were instead used to evaluate the relative severity, spatial localization, and dominant mechanisms of erosion damage.

Fig. 6 shows the experimental conditions with liquid velocities of 1 m/s, 1.5 m/s, 2 m/s, an erosion angle of 45°, and a concentration of 0.5%. Scanning electron microscope image of the metal mesh screen. It could be seen from the image that under the above experimental conditions, there were obvious erosion damage phenomena on the surface of the screen, accompanied by the accumulation of sand particles in the mesh. Moreover, with the increase of liquid velocity and other conditions remaining unchanged, the erosion damage on the screen surface intensified, and the accumulated gravel increased. Most of the erosion damage areas of the screen were in the blocked areas of the screen, and in Fig. 6c, the screen exhibited relatively severe erosion and wear. This indicated that during the sand control process, the screen was gradually blocked over the experimental duration. When the screen mesh was blocked, the particle size of gravel that can pass through the mesh became smaller and smaller, and the flow velocity increased at the same time. However, during the entire experiment, the entire metal mesh screen did not suffer overall erosion, but local damage points occurred. These damage points may be one or multiple at the same time. Except for the local damage areas, the rest of the screen exhibited basically no obvious changes or only slight damage.

Effect of Impact Angle on Erosion Rate

Within the erosion angle range of 15°–45°, the erosion rate of the metal wire mesh screen was found to increase monotonically with increasing angle, reaching a maximum at 45° (Fig. 7). The erosion rates measured at erosion angles of 15°, 30°, and 45° were $0.26 \times 10^{-7} \text{ kg}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, $0.42 \times 10^{-7} \text{ kg}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ and $0.46 \times 10^{-7} \text{ kg}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, respectively. Compared with that at 15°, the erosion rate at 45° was increased by 76.9%. This behavior could be attributed to more effective particle–screen interaction at higher erosion angles, which facilitated greater kinetic energy transfer to the screen surface and intensified erosion wear. SEM observations further indicated that, at an erosion angle of 45°, the screen surface was subjected not only to pitting and cutting wear but also to slight plowing, resulting in the most severe erosion damage.

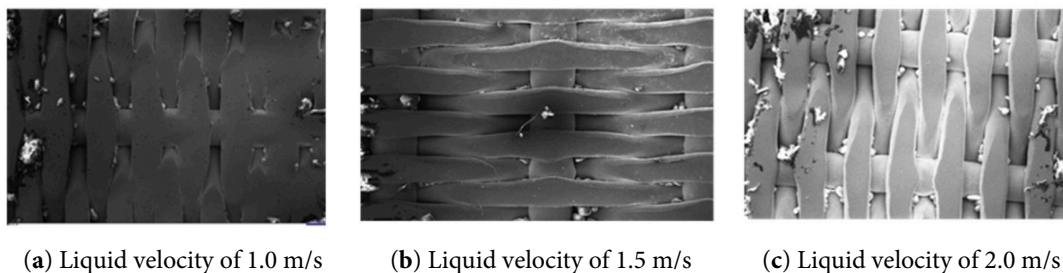


Figure 6: Electron micrograph of screen mesh (a–c).

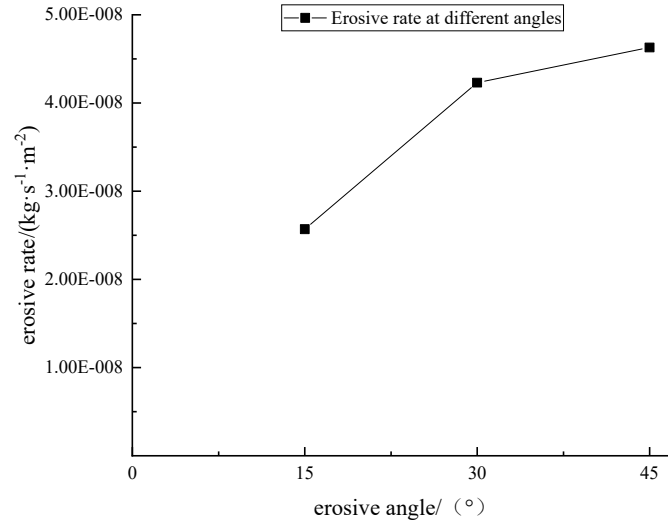


Figure 7: Erosion rate diagrams at different angles.

Effect of Sand Concentration on Erosion Rate

Within the low concentration range investigated in the experiments (0.3%–0.8%), the erosion rate was observed to increase with increasing particle concentration (Fig. 8). As the sand concentration increased from 0.3% to 0.8%, the erosion rate increased from $0.23 \times 10^{-7} \text{ kg} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$ to $0.60 \times 10^{-7} \text{ kg} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$, corresponding to an increase of 160.9%. At low sand concentrations, an increase in particle content led to a higher probability of particle–screen collisions, thereby intensifying erosion wear. When the concentration exceeds a critical threshold, particle–particle collisions become more frequent, and a portion of the kinetic energy is dissipated through inter-particle rebound, which can result in a gradual reduction of the screen erosion rate. However, within the concentration range employed in the present experiments, no such phenomenon was observed.

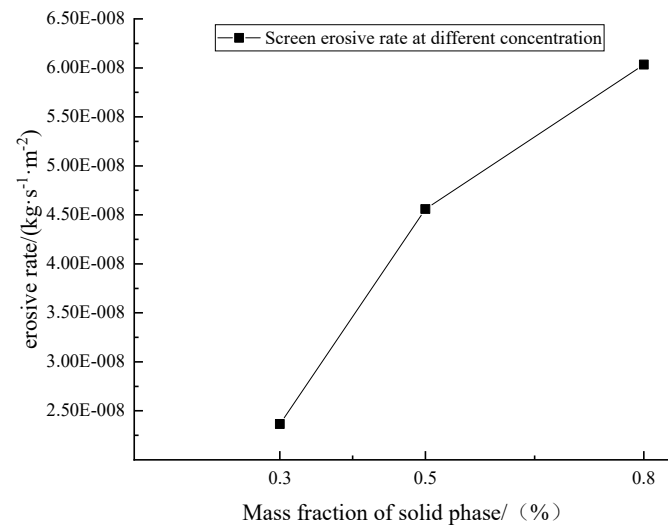


Figure 8: The erosion rate of metal mesh at different concentration.

Comparative Assessment within the Investigated Parameter Ranges

To provide a descriptive comparison of the three independently varied parameters, the relative change in erosion rate was calculated as $(E_{\max} - E_{\min})/E_{\min} \times 100\%$ for each experimental series. Over their respective investigated ranges, increasing liquid velocity from 0.5 to 2.0 m/s produced a relative increase of 295.7% in erosion rate, increasing sand concentration from 0.3% to 0.8% produced an increase of 160.9%, and increasing impact angle from 15° to 45° produced an increase of 76.9%. Therefore, within the investigated parameter ranges and based on the relative change in erosion rate, liquid velocity can be regarded as the dominant factor among the three parameters examined independently.

This comparison is descriptive and range-dependent. It should not be interpreted as a statistical significance ranking or as evidence that liquid velocity is universally the dominant parameter. The three parameters were examined over different physical ranges, and the one-factor-at-a-time design did not quantify experimental variance, parameter interactions, or standardized sensitivity coefficients. A factorial design with independent replicate tests and an analysis of variance would be required to establish statistical significance and interaction effects.

2.4.2 Analysis of Erosion Mechanisms

Macroscopic Morphological Analysis

Comparisons of screen specimens subjected to different experimental durations and sand concentrations (Figs. 9 and 10) demonstrated clear trends. With increasing experimental duration and particle concentration, the surfaces of the screens exhibited more pronounced polishing. At the same time, the mesh openings experienced intensified clogging, and the severity of erosion wear progressively escalated. Observations under optical microscopy (Figs. 11 and 12) revealed that the eroded regions of the screens could be delineated into three distinct zones: a central erosion zone, an edge erosion zone, and an uneroded zone. Within the central erosion zone, substantial surface polishing and deformation of the screen wires were discerned. This was accompanied by a noticeable reduction in wire height. The edge erosion zone displayed comparatively minor polishing and deformation. In contrast, the uneroded zone remained largely unaltered, with no significant variation detected in the diameters of warp and weft wires. These findings indicated that the erosion of metal mesh screens predominantly manifested in a localized manner. The clogged regions constituted the principal loci of erosion damage.

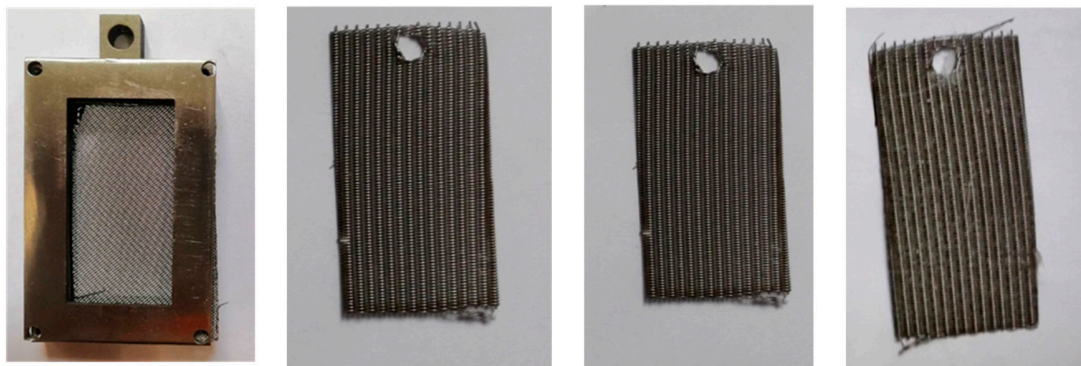


Figure 9: Screen mesh sample of metal mesh screen with solid mass fraction of 0.3% and liquid velocity 2 m/s.



Figure 10: Screen mesh sample of metal mesh screen with solid mass fraction of 0.5% and liquid velocity 2 m/s.

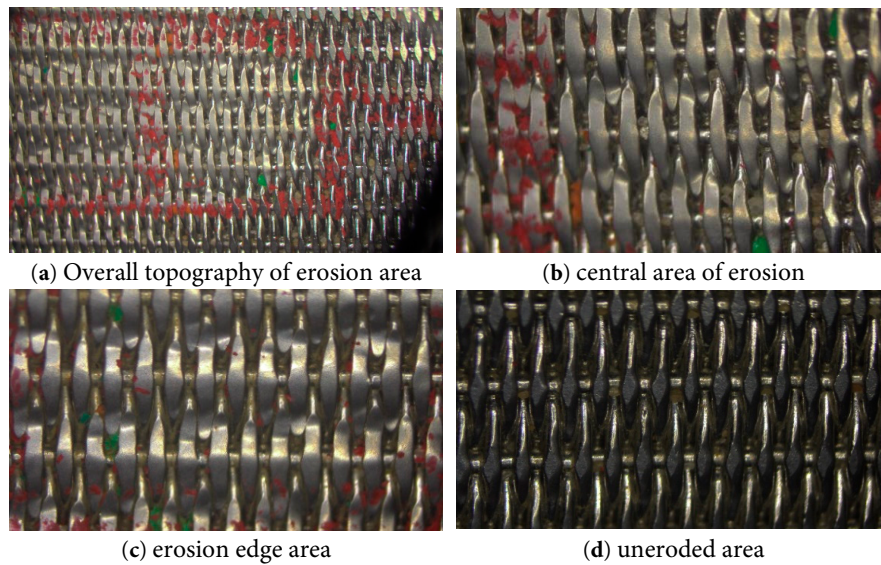


Figure 11: Erosion area of screen mesh (a–d).

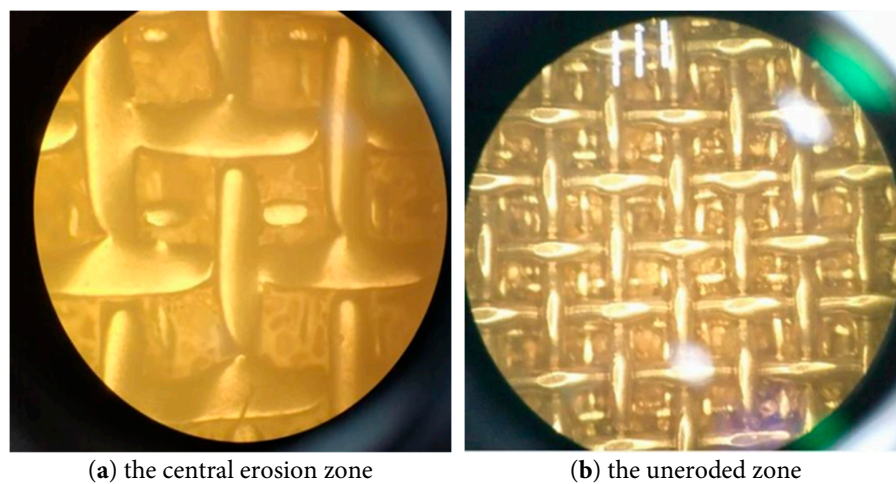


Figure 12: Optical observation results (a,b).

Microscopic Morphological Analysis

Fig. 13 shows the overall erosion morphology of the metal mesh screen under scanning electron microscopy after the erosion test. After erosion, the warp and weft wires of the metal mesh screen were deformed to varying degrees. After the erosion test, the mesh holes of the screen sample were filled with sand gravel clogging occurs, and the screen in the clogged area suffered significant erosion and wear. From the overall erosion view in the electron microscope images, it could be seen that the erosion of the metal screen was not uniform across the entire screen; instead, local areas of the screen experienced varying degrees of erosion and wear, with the main erosion areas located where gravel clogs the screen holes.

Fig. 14 shows the electron microscope images of the screen mesh magnified 5000 times at liquid velocities of 0.5 m/s, 1 m/s, 1.5 m/s and 2.0 m/s. It could be clearly observed that at low liquid velocities, the metal mesh exhibited slight cutting wear and slight pitting. At 1.5 m/s, there were relatively obvious pitting and cutting wear on the surface of the screen mesh, and at 2.0 m/s, there was also obvious plowing on the surface of the screen mesh. This indicated that the erosion wear of the screen mesh under different liquid velocities exhibited varying degrees of pitting, plowing and cutting wear, and as the liquid velocity increased, the erosion wear on the screen mesh increased.

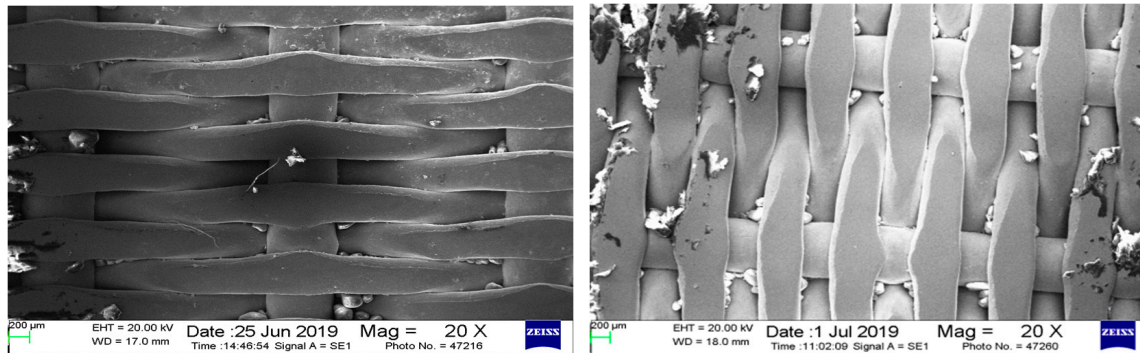
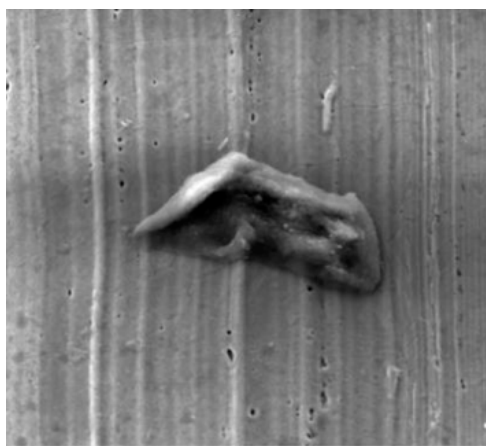
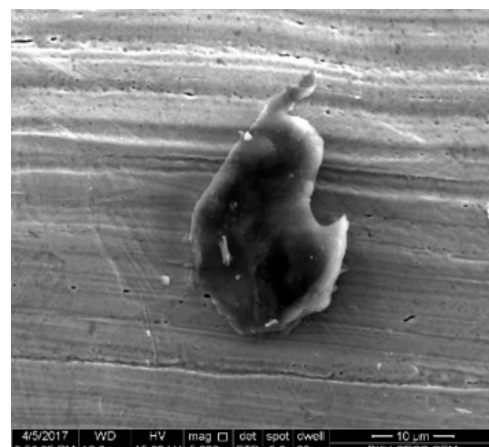


Figure 13: Electron microscope scan of screen after experiment.

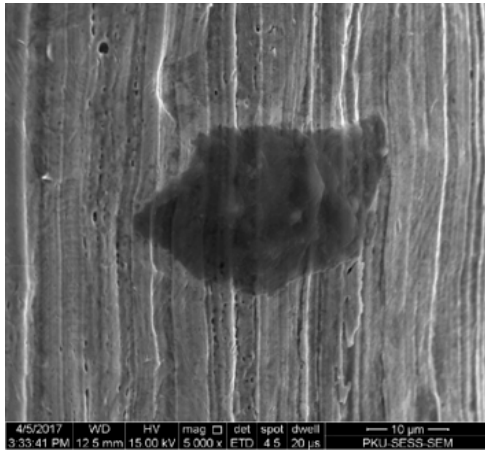


(a) Electron microscope picture at 0.5 m/s

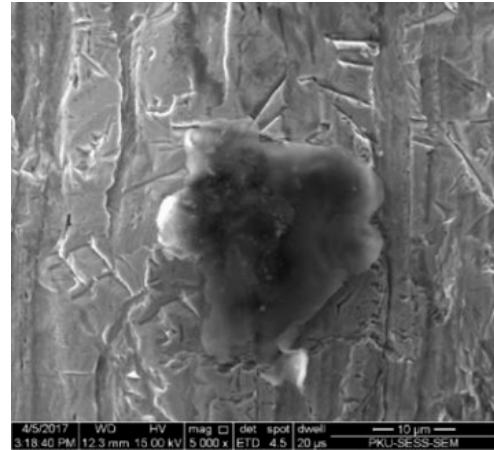


(b) Electron microscope picture at 1.0 m/s

Figure 14: Cont.



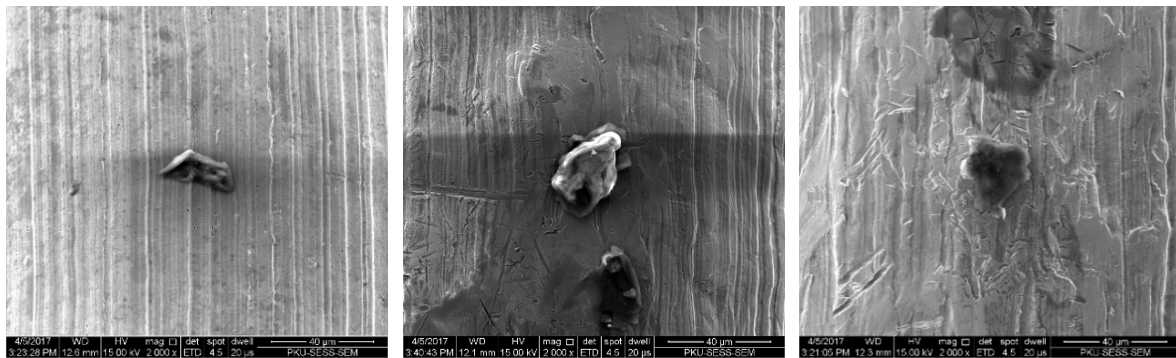
(c) Electron microscope picture at 1.5 m/s



(d) Electron microscope picture at 2.0 m/s

Figure 14: Electron microscope pictures of screen at different liquid velocities (a–d).

The effect of erosion angle on surface wear was relatively limited compared with velocity, so we compared the electron microscope images of the metal screen surface with erosion angles of 15° , 30° and 45° magnified 2000 times. It can be seen from Fig. 15 that the erosion wear of the metal screen is related to the erosion angle; different angles resulted in different erosion wear on the screen. When the screen was in the MSH rotating instrument, the erosion angle changed with the rotation of the experimental screen hanging piece. When the erosion angle was 45° , the erosion wear on the screen increased, and it is mainly subject to pitting and cutting wear.

**Figure 15:** The electron microscope picture at different angles.

When the particle concentration was 0.3%, 0.5%, and 0.8%, the electron microscope images of the metal mesh screen magnified 1000 times were shown in Fig. 16. It could be seen that the weft wires of the screen exhibited pitting and cutting wear, and as the concentration increased, the wear on the screen surface increased.

The metal screen after the erosion experiment was scanned by electron microscopy, and the entire experimental screen was observed optically. The pictures of the screen after observation were shown in Fig. 11. A comparison between the eroded area and the non-eroded area of the metal screen revealed that the screen after the experiment could be divided into the erosion center area, the erosion edge area, and the non-eroded area. It was found through the optical microscope that different “polishing” and “deformation” phenomena occurred in different areas of the metal screen. The erosion center area exhibited an obvious “polishing” phenomenon, and the screen wires in the center area were significantly deformed. The erosion

edge area exhibited a slight “polishing” phenomenon, and the deformation and wear of the screen wires were smaller than those in the erosion center area. The surface of the non-eroded area of the screen was basically not “polished” and the screen wires were basically not deformed.

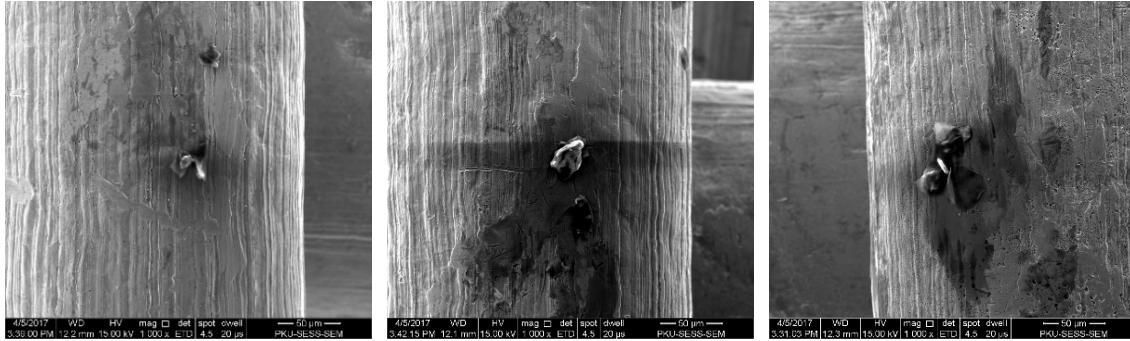


Figure 16: The electron microscope picture at different concentration.

Separate optical observations were conducted on the eroded area and the uneroded area, and the results were shown in Fig. 12. Comparison in the surface of the screen wires in the central erosion area showed obvious “polishing” and deformation phenomena, while the non-erosion area of the screen did not show significant changes. The central erosion area exhibited significant cutting, and the height of the warp wires was reduced. Measurements of the warp and weft wires showed that there was no significant change in their diameters.

As shown in the scanning electron microscope results in Figs. 14–16, the main erosion mechanisms of the metal mesh screen included pitting, cutting wear, and plowing: at low liquid velocities of 0.5 m/s and 1.0 m/s, the screen mainly exhibited pitting, and slight cutting wear occurred at 1.0 m/s; at high liquid velocities of 1.5 m/s and 2.0 m/s, pitting and cutting wear intensified significantly, and obvious plowing appeared at 2.0 m/s; under the conditions of an erosion angle of 45° and high concentration, the phenomena of cutting wear and pitting were more prominent. The differences in these erosion mechanisms were essentially caused by changes in particle kinetic energy, collision modes, and frequencies under different experimental conditions.

3 Establishment and Validation of the Erosion Mathematical Model

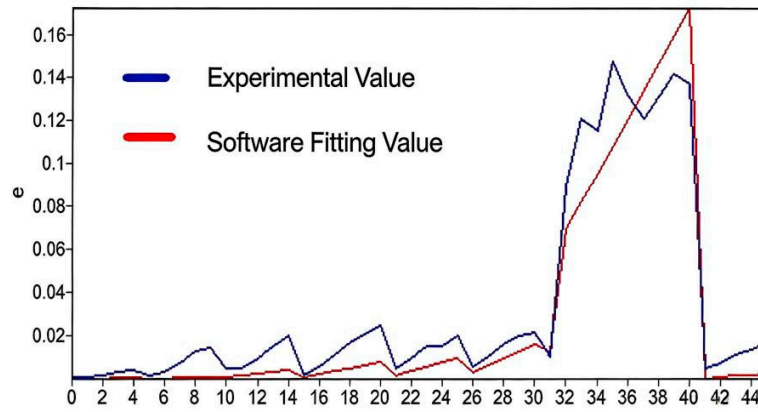
3.1 Model Development

Based on the experimental dataset, an erosion rate prediction model was established using the 1stOpt15PRO mathematical fitting software. Flow velocity v , erosion angle α , particle concentration C , and particle diameter D were incorporated as the principal governing parameters. The convergence criterion was specified as 1.00×10^{-10} , and the maximum number of iterations was set to 10,000. Model calibration was performed through a hybrid optimization strategy combining the Levenberg–Marquardt algorithm with a general global optimization method. As a result, a mathematical expression describing the erosion rate of the metal wire mesh screen was derived as follows:

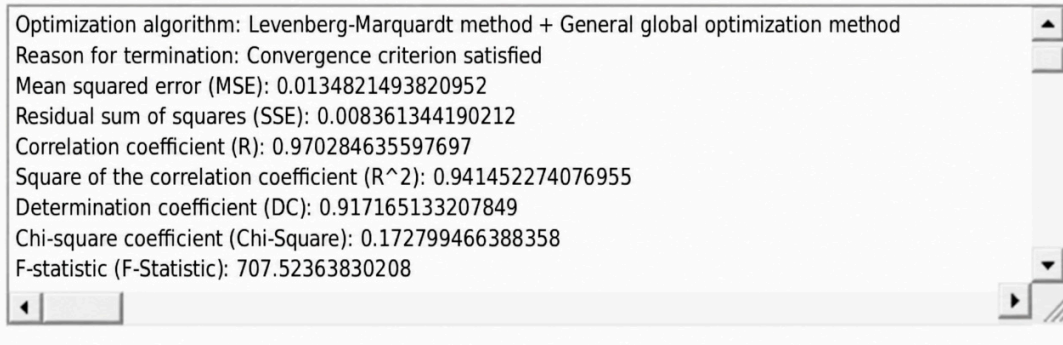
$$Q = \frac{a \times v^b \times \sin^c \alpha \times C^d}{D^e} \quad (2)$$

where Q is the predicted erosion rate expressed in $\text{kg}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$; a is the fitted coefficient; v , α , C , and D denote flow velocity, erosion angle, particle concentration, and particle diameter, respectively; and b , c , d , and e are the fitted exponents.

The fitting outcomes of the proposed model (Fig. 17) indicated that a coefficient of determination R^2 of 0.941 was obtained, accompanied by a mean squared error of 0.0135 and a residual sum of squares of 0.0084. These statistical metrics collectively confirmed that a strong consistency was achieved between the model predictions and the experimental observations.



(a) Model iteration curve and actual data coincidence degree curve



(b) Accuracy evaluation of model iteration

Figure 17: Accuracy check of prediction model of metal wire mesh screen erosion rate (a, b).

The final obtained erosion rate formula of the metal mesh is as shown in Eq. (3):

$$Q = \frac{0.29 \times 10^{-8} \cdot V^{1.02} \cdot \sin^2 \alpha \cdot c^{0.768}}{D^{-0.05}} \quad (3)$$

In Eq. (3), Q is expressed in $\text{kg}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, provided that the input variables are entered using the units specified above.

3.2 Model Validation

Experimental values obtained under varying liquid velocities, particle concentrations, and erosion angles were compared with predictions from the developed mathematical model (Fig. 18).

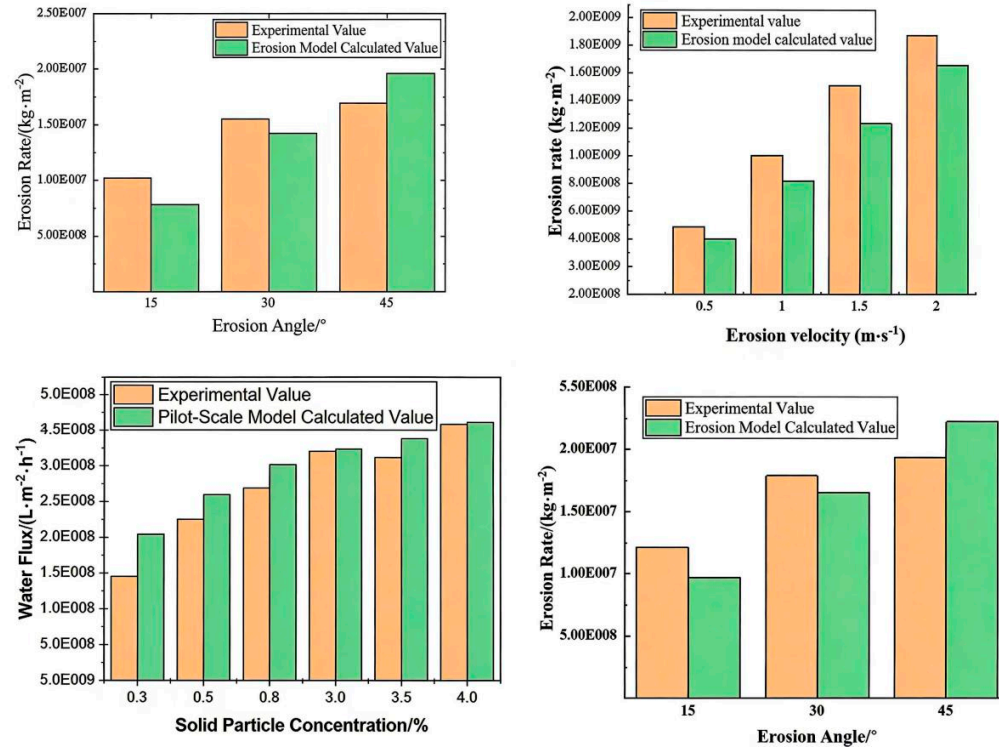


Figure 18: Comparison of experimental and model predicted values.

The comparison showed that, for all tested conditions, the differences between the model predictions and experimental measurements remained within 20%, with an average error of 13.3%. These results demonstrated that the established erosion model provided satisfactory accuracy and reliability. Therefore, the model can provide a practical basis for preliminary service-life assessment of metal mesh screens when an appropriate erosion-failure criterion is specified.

4 Conclusions

Eight unique experimental conditions were examined using a one-factor-at-a-time design to evaluate the individual effects of liquid velocity, sand concentration, and impact angle on the erosion behavior of single-layer metal wire mesh screens. Surface morphology observations obtained by scanning electron microscopy and optical microscopy were used to characterize the erosion mechanisms, and the experimental data were used to develop an empirical erosion-rate model. The principal findings are summarized as follows:

- (1) Within the investigated parameter ranges, the erosion rate increased independently with increasing liquid velocity from 0.5 to 2.0 m/s, sand concentration from 0.3% to 0.8%, and impact angle from 15° to 45° . Among the three parameters examined separately, liquid velocity produced the largest variation in erosion rate. The maximum measured erosion rate occurred at an impact angle of 45° under the corresponding reference conditions.
- (2) Erosion damage was spatially nonuniform and concentrated mainly near partially blocked apertures, wire intersections, and particle-deposit boundaries. Localized pitting was predominant at lower liquid velocities, whereas cutting grooves and plowing became more pronounced as velocity increased. Particle accumulation may have redirected the slurry through residual openings and promoted local

erosion, while deposited particles could partially shield the covered wire surfaces. These observations suggest that blockage and erosion were closely coupled under the investigated conditions.

- (3) The model predictions showed reasonable agreement with the experimental measurements over the investigated parameter ranges, with an average prediction error of 13.3% and deviations below 20% for all tested conditions. These results indicate that the proposed model can provide preliminary estimates of the erosion rate of metal wire mesh screens within the ranges of liquid velocity, sand concentration, and erosion angle examined in this study. Its application to service-life assessment should, however, be regarded as preliminary because such an assessment additionally requires a clearly defined erosion-failure criterion and further validation under broader operating conditions.
- (4) The findings of this study provided a theoretical basis for the structural optimization of metal mesh screens. They also supported the adjustment of field sand-control operation parameters, such as controlling liquid velocity and optimizing particle concentration. These insights carried significant engineering implications. In particular, they contributed to enhancing the reliability of sand-control operations in oilfields.

The present study was based on a one-factor-at-a-time experimental design and covered a limited range of operating parameters. Consequently, the interaction effects among liquid velocity, sand concentration, and erosion angle were not quantified, and the applicability of the proposed model should not be extrapolated beyond the investigated parameter ranges without additional validation. Future work should incorporate factorial or multivariable experimental designs, a larger number of independent replicate tests, broader operating conditions, and external validation data to evaluate parameter interactions and improve the robustness and general applicability of the model.

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