SIMULATION AND EXPERIMENTAL EVALUATION OF EROSION WEAR OF ANTI-SAND FILTERS AT HIGH FLOW VELOCITIES AND PRESENCE OF FINE SAND

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Abstract. Sand control screens in oil and gas wells are susceptible to erosional wear when producing at high flow rates with fine sand particles entrained in the fluid. This study combines laboratory experiments and computational fluid dynamics (CFD) modeling to quantify erosion in wire-wrapped and premium mesh screens under aggressive conditions. Erosion tests were performed using a slurry loop with approach velocities of 1.2-2.5 $m \cdot s^{-1}$ and fine sand (median diameter 80-150 μm), simulating realistic near-screen flow in high-rate completions while remaining within typical laboratory ranges reported in industry studies (e.g., SwRI rigs up to 1.07 $m \cdot s^{-1}$ and recent coupon tests at 0.37-0.61 $m \cdot s^{-1}$). Erosion was assessed via optical microscopy for gap widening, maximum particle passed (MPP), and filter cut point (FCP), following protocols aligned with API 19SS and ISO 17824 standards. A CFD model employing the Discrete Phase Model (DPM) with an empirical erosion correlation was calibrated against experimental data to capture localized particle impingement and turbulent effects near the screen surface. Results show erosion rate increases nonlinearly with velocity and fines content, with localized wear at wire edges and mesh openings often concentrated at impact angles of 25-45°. The calibrated model predicts screen life with reasonable accuracy for field conditions.

Keywords: erosive wear, sand control screens, high flow velocity, fine sand particles, CFD modeling.

Introduction

Sand production remains a major challenge in the exploitation of weakly consolidated and unconsolidated sandstone reservoirs in the oil and gas industry, water supply wells in rural areas, irrigation systems with abrasive particles, and small-scale agricultural pumping stations. Mechanical sand control using standalone screens (SAS), premium mesh screens, or wire-wrapped screens is widely applied to retain formation sand while allowing fluids to flow [1-4]. However, under high production rates, especially in gas wells or high-velocity oil wells, fine sand particles (< 100 μm) entrained in the flow can cause severe erosive wear of the screen media. This leads to enlargement of screen openings, loss of sand retention capability, increased sand production, and eventual screen failure [5-8].

Numerous field cases illustrate the severity of this issue. For instance, in high-rate gas wells in the Tarim Basin (China) [9], slotted screens experienced accelerated erosion due to fine sand and high velocities, resulting in production declines and the need for intervention. Similarly, deepwater gas fields (e.g., S field case studies) have reported erosion-corrosion rates of 0.0111-0.0521 $mm \cdot year^{-1}$ on sand screens, with predicted durability as low as 14-23 years in severely affected wells due to fines and high flow [10-14]. In Malaysia, gas wells suffering from eroded steel screens required remedial installation of ceramic sand screens resistant to high-velocity erosion [15]. In the Gulf of Mexico and other high-rate completions [16], screen erosion has been identified as a dominant failure mode when peak rates exceed safe thresholds, often linked to annular flow and fine particle impingement [17]. These real-world examples from mature fields in the North Sea, Middle East, and offshore Asia [18-21] underscore that erosive failure frequently limits well life and increases operational costs, particularly where fines content exceeds 10-15% and approach velocities surpass 1.5-2.0 $m \cdot s^{-1}$.

Erosive wear of sand screens is a complex process governed by particle impact dynamics, including impact velocity, angle, particle size, concentration, and carrier fluid properties. Classical erosion models such as Freire [22], Zhao [23], and Yuan [24] have been adapted for general solid particle erosion, but their application to the intricate geometry of sand control screens requires validation. Recent studies emphasize the role of fine particles in accelerating erosion through multi-angle impingement in turbulent flow near the screen surface, with angular fines causing higher abrasive wear than rounded particles [25-30].

The present study combines computational fluid dynamics (CFD) modeling with laboratory-scale erosion experiments to quantify the erosive wear of wire-wrapped and premium mesh screens under high approach velocities (1-3 $m \cdot s^{-1}$) and fine sand concentrations. The objectives are to develop and validate a CFD-based erosion prediction framework calibrated against experimental data, to investigate the influence of flow velocity and fine particle content on erosion rate and screen opening enlargement, and to propose practical recommendations for screen design in high-rate wells, informed by field observations from challenging reservoirs.

Materials and methods

Erosion tests were conducted using a recirculating slurry loop system designed to simulate near-screen flow conditions. The test section consisted of a rectangular channel (50 mm × 20 mm cross-section) with a replaceable sand screen coupon (100 mm × 50 mm) mounted perpendicular to the flow. Two types of screens were tested: wire-wrapped screen: nominal aperture 200 μm (8 gauge), 316L stainless steel; premium mesh screen: multi-layer weave with 150-175 μm retention rating.

Slurry was prepared using tap water as carrier fluid and silica sand with controlled particle size distribution (PSD). Two PSDs were used.

- Coarse sand: d50 = 250 μm, fines content (< 63 μm) < 5 wt%.
- Fine-inclusive sand: d50 = 180 μm, fines content 15-25 wt% (< 100 μm).

Sand concentration varied from 0.5 to 3.0 $g \cdot L^{-1}$ (≈0.02-0.12 vol%). Approach velocities to the screen were set at 1.2, 1.6, 2.0, and 2.5 $m \cdot s^{-1}$ (corresponding to superficial velocities typical for high-rate gas wells). Each test ran for 4-12 hours, with periodic sampling.

Erosion was quantified by:

1. mass loss of the screen coupon (precision balance ± 0.1 mg);
2. change in the screen opening size using optical microscopy and image analysis (maximum particle passed – MPP, and filter cut point – FCP per API 19SS Annex D methodology);
3. surface morphology via scanning electron microscopy (SEM).

Three-dimensional CFD simulations were performed using ANSYS Fluent 2024 R1. The geometry replicated the experimental channel with the screen modeled as a porous jump boundary (permeability derived from Darcy-Forchheimer parameters) or explicit wire/mesh geometry for detailed particle tracking. A mesh independence study was performed: increasing the mesh from 1.5 million to 2.5 million cells changed the predicted erosion rate by less than 4.5%, confirming that the results are grid independent. The continuous phase (water) was solved using the realizable k-ε turbulence model. Particles were tracked via Discrete Phase Model (DPM) with two-way coupling for concentrations > 1 $g \cdot L^{-1}$. Particle size distribution followed the Rosin-Rammler function fitted to experimental PSD.

Four erosion models were implemented and compared:

1. Finnie model (ductile erosion at low angles) [31]:

$$E = \frac{m_p K_f v_p^2}{2p} (\sin 2\alpha - 3\sin^3 \alpha) \text{for} \alpha \leq 18.5°, \tag{1}$$

(adjusted constants for 316L steel)

2. Oka et al. model (general):

$$E(\alpha) = g(\alpha) \cdot E_{90} \cdot \left(\frac{v_p}{v'}\right)^{n_1} \left(\frac{d_p}{d'}\right)^{n_2}, \tag{2}$$

where $g(\alpha)$– impact angle function;
E_{90} – reference erosion at 90°;
v' and d' – reference values.

3. McLaury generalized model:

$$ER = C \cdot F_s \cdot v_p^n \cdot F(\theta), \tag{3}$$

with $F(\theta) = a\,\theta^2 + b\,\theta + c$ (polynomial fit).

4. DNV empirical correlation (adapted for screens).

Wall y + was kept < 5 near the screen, with 1.5-2.5 million cells. Simulations ran until steady-state particle impingement statistics were achieved.

For the validation results reported (Oka model calibration), the screen was modeled using explicit wire/mesh geometry because it better captures localized edge effects. The porous jump approximation was tested for sensitivity only, yielding a deviation of ~28% from experimental mass loss, whereas the explicit geometry gave deviation < 18%. Therefore, all main simulations used the explicit geometry.

Results and discussion

Mass loss increased nonlinearly with velocity and fines content, consistent with established trends in sand screen erosion literature where erosion exhibits a power-law or exponential dependence on flow velocity and particle concentration. For wire-wrapped screens at 2.0 $m \cdot s^{-1}$ and 3 $g \cdot L^{-1}$ fines-inclusive sand, cumulative mass loss reached 45-62 mg after 8 hours, corresponding to average erosion rate of $1.8\text{-}2.6 \cdot 10^{-6}$ $mm^3 \cdot kg^{-1}$ (normalized per particle mass throughput). These values align with typical laboratory observations in recirculating slurry tests, where mass losses in the tens to hundreds of mg range are reported for coupon-scale experiments under comparable velocities (0.3-3.5 $ft \cdot s^{-1}$ or ~0.1-1.1 $m \cdot s^{-1}$ approach) and sand concentrations up to 10,000 ppmw. Premium mesh screens showed higher susceptibility to localized degradation, with more pronounced wire cutting and gap widening under the same conditions due to their multi-layer weave structure concentrating impingement stresses (Table 1).

Table 1

Experimental erosion rates and opening enlargement for wire-wrapped screens

Velocity ($m \cdot s^{-1}$)	Sand type	Conc., $g \cdot L^{-1}$	Mass loss, mg per 8 h	Δ Opening, %	Erosion rate, $mm^3 \cdot kg^{-1}$
1.2	Coarse	1.0	8.2	4.1	$0.9 \cdot 10^{-6}$
1.6	Fine-inclusive	1.0	18.5	9.8	$2.1 \cdot 10^{-6}$
2.0	Fine-inclusive	3.0	58.4	28.6	$2.4 \cdot 10^{-6}$
2.5	Fine-inclusive	3.0	112.7	47.2	$3.8 \cdot 10^{-6}$

Opening enlargement was more pronounced in premium mesh screens due to localized cutting of wires, often leading to accelerated passage of larger particles as measured by MPP and FCP metrics per API 19SS standards.

CFD predictions using the Oka model showed the best agreement with experiments (deviation < 18% for mass loss). Erosion was concentrated at wire leading edges and mesh intersections, with peak rates at impact angles 25-45° (Fig. 1).

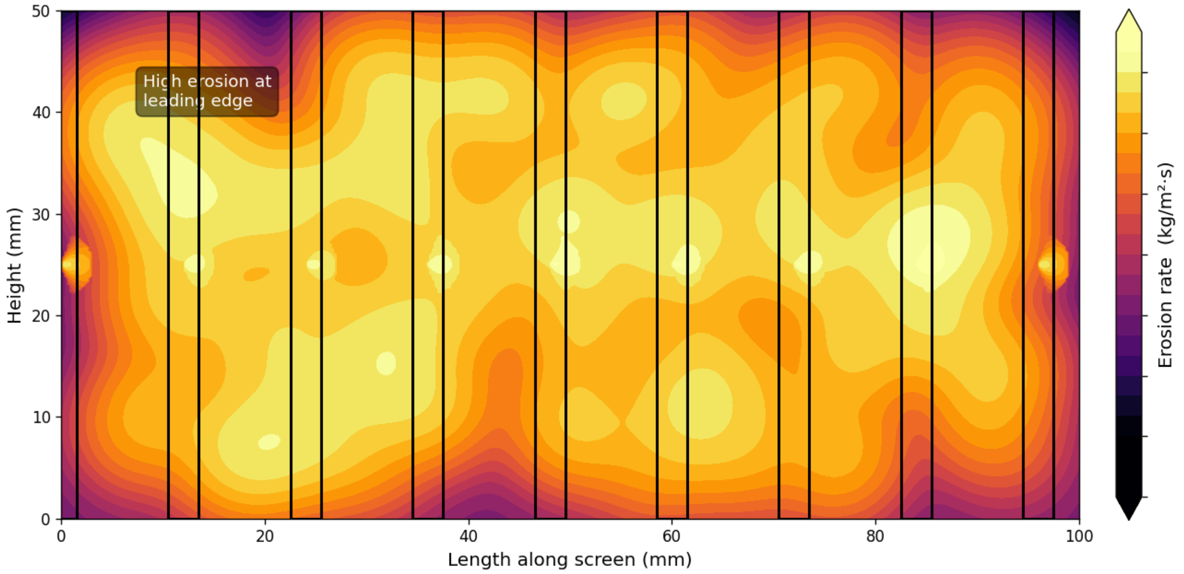

Fig. 1. **Contours of predicted erosion rate ($kg \cdot m^{-2} \cdot s^{-1}$) on wire-wrapped screen surface at 2.0 $m \cdot s^{-1}$ (high erosion at impingement zones)**

The presence of fines increased the turbulence kinetic energy near the screen by 30-45%, enhancing particle-wall collisions.

The results confirm that fines significantly amplify erosion through increased number of impacts and secondary rebound effects, consistent with previous findings. Velocity exponent n in erosion models ranged 2.4-2.8, aligning with Oka and Vieira models rather than classical Finnie ($n \approx 2$).

CFD captured localized wear patterns missed by bulk mass loss measurements, highlighting the advantage of hybrid experimental-numerical approaches for resolving “hot spots” at wire edges and intersections – patterns that correlate well with reported failures in premium mesh screens under high-rate conditions. The Oka formulation superior performance (deviation < 18%) stems from its inclusion of particle size effects, reference velocity scaling, and angle-dependent functions calibrated over broad experimental ranges, making it particularly suitable for fines-inclusive slurries.

Limitations include idealization of screen geometry in CFD (e.g., porous jump vs. fully resolved wires), which may underestimate edge effects, and neglect long-term corrosion-erosion synergy observed in CO_2-rich gas wells. Particle-particle interactions at higher concentrations (> 3 g·L^{-1}) and potential viscosity effects from produced fluids were also not fully replicated.

Practical implications: for velocities > 2 m·s^{-1} with fines > 10%, premium screens with diffusion shrouds (to lower local approach velocity) or ceramic-enhanced media should be considered to reduce the impact energy and extend service life. These recommendations align with industry practices in high-rate gas wells, where rate limits below critical thresholds and material upgrades have mitigated failures. Integrating real-time sand monitoring and predictive CFD tools can further optimize production while minimizing intervention risks.

Conclusions

This study demonstrated that erosive wear of sand control screens at high flow velocities is strongly exacerbated by fine sand particles, leading to rapid opening enlargement and potential failure, as evidenced by multiple field cases in gas-prone reservoirs, water supply wells in rural areas, irrigation systems with abrasive particles, and small-scale agricultural pumping stations. Notable examples include deepwater gas wells in the South China Sea (S field), where high production rates combined with CO_2-rich flow and sand entrainment caused severe erosion-corrosion, resulting in accelerated screen degradation and predicted service lives as low as 14-23 years under severe conditions. In the Tarim Basin high-yield gas fields, slotted screens exhibited progressive erosion due to increasing sand output in mature production stages, contributing to production declines and necessitating flow rate controls and optimized screen designs to mitigate wear. Offshore wells worldwide have similarly reported erosion as the dominant failure mechanism for standalone and premium mesh screens, often linked to high-velocity annular flow, fine particle impingement, and velocities exceeding safe thresholds (typically > 1.5-2 m·s^{-1} approach velocity), leading to localized “hot spots”, wire cutting, and eventual loss of sand retention. These real-world observations align closely with the experimental and CFD findings, where fines content (> 10-15%) and nonlinear velocity dependence (exponents 2.4-2.8) amplify damage through multi-angle turbulent impingement and secondary rebounds.

The combination of laboratory slurry testing and CFD modeling with the Oka erosion formulation provided reliable predictions of erosion rate and damage distribution, capturing localized wear patterns at wire leading edges and mesh intersections that bulk measurements alone cannot reveal. The hybrid approach offers a robust framework for forecasting screen performance under aggressive conditions, bridging the gap between controlled experiments and complex field environments.

Future work should incorporate multiphase (gas-liquid-solid) flows to better simulate high-rate gas well dynamics, integrate corrosion effects (especially in CO_2/H_2S environments), and conduct extended-duration tests to account for cumulative degradation and potential synergy between erosion and chemical attack. Additional validation against long-term field monitoring data from ongoing high-rate gas projects would further refine model accuracy and applicability.

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Author contributions

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