

DEVELOPMENT AND TESTING OF SELF-CLEANING SAND RETENTION SCREENS FOR HIGH-TEMPERATURE WELLS

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Abstract. Sand production remains a major challenge in thermal recovery processes such as steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS), where high temperatures ($> 200\text{-}300\text{ }^{\circ}\text{C}$) exacerbate fines migration, scale deposition, and plugging of conventional sand control screens. This study presents the design, fabrication, and laboratory testing of a novel self-cleaning sand retention screen (SCSRS) concept tailored for high-temperature wells. The proposed design integrates hydrodynamic self-cleaning features through optimized wedge-wire geometry with periodic flow reversal capability and erosion-resistant high-temperature alloys. Experimental results demonstrate significantly reduced plugging rates and improved retained permeability compared to standard wire-wrapped and premium mesh screens. The findings suggest potential for extended screen life and sustained productivity in thermal heavy oil wells.

Keywords: self-cleaning, sand retention, high-temperature, thermal cycling, pressure drop.

Introduction

Sand production remains one of the most persistent challenges in the development of unconsolidated and weakly consolidated reservoirs, particularly in thermal recovery processes such as steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS), where reservoir temperatures frequently exceed $200\text{-}300\text{ }^{\circ}\text{C}$ [1-3]. In these environments, elevated temperatures reduce oil viscosity dramatically, enabling gravity-driven drainage, but simultaneously exacerbate sand production through multiple interacting mechanisms [4-6]. High thermal stresses, cyclic thermal loading, steam breakthrough events, and fluid phase changes contribute to formation destabilization, fines mobilization, and accelerated particle disaggregation [7; 8].

Conventional sand control screens, including wire-wrapped, premium mesh, and slotted liners, often experience severe plugging due to fines migration, asphaltene deposition, scale formation, and clay swelling under high-temperature conditions [9-12]. Plugging leads to increased drawdown, reduced productivity, hotspots, and premature failure of completion systems. Experimental studies have shown that steam breakthrough can trigger localized high-velocity flow near the producer well, causing grain disturbance, erosion, and sudden sand influx [13; 14]. Additionally, thermal cycling induces differential expansion and contraction, weakening intergranular bonds and promoting fines generation, while asphaltene precipitation and mineral scaling further restrict inflow pathways [15-18].

Existing mitigation strategies, such as gravel packing, chemical consolidation, or periodic chemical treatments, are either operationally complex, costly, or ineffective at elevated temperatures [19-21]. Gravel packs, while effective in some cold heavy oil applications, suffer from thermal degradation of carrier fluids and reduced long-term stability in steam environments [22; 23]. Chemical consolidation agents often exhibit limited thermal resistance above $200\text{ }^{\circ}\text{C}$, leading to bond weakening over time. Recent commercial solutions, including ceramic-based screens and multi-layer designs, offer improved erosion and corrosion resistance but rarely incorporate active self-cleaning mechanisms [24; 25]. Shape-memory materials, including polymers and alloys, have been explored for annular conformance and sand retention in open-hole completions, yet their integration into active, temperature-responsive filtration remains limited in downhole high-temperature service [26; 27].

The concept of self-cleaning functionality – achieved through hydrodynamic, thermal-expansion-induced, or pulsed-flow effects – has shown promise in surface filtration but remains underexplored for downhole high-temperature applications [28; 29]. Emerging designs leveraging shape-memory polymers (SMPs) or compliant elements aim to generate localized shear or micro-strains during thermal cycles, disrupting filter cake buildup and restoring permeability without mechanical intervention [30; 31].

This study presents the development and laboratory testing of a novel self-cleaning sand retention screen (SCSRS) designed specifically for high-temperature wells ($> 250\text{ }^{\circ}\text{C}$). The proposed design

integrates a hybrid filtration medium with temperature-responsive elements and optimized slot geometry to promote periodic detachment of accumulated fines and deposits, thereby maintaining long-term permeability and sand retention efficiency. By addressing the combined effects of thermal degradation, fines bridging, and erosive flow typical in SAGD and CSS operations, SCSRS seeks to extend completion life, minimize intervention frequency, and enhance overall thermal recovery economics in challenging unconsolidated heavy oil and bitumen reservoirs.

Materials and methods

The SCSRS prototype used a 7-inch L80 perforated base pipe with a dual-layer filter: an Inconel 625 wedge-wire screen (200-250 μm slots) and a shape-memory polymer (SMP) coating (transition 180-220 $^{\circ}\text{C}$) on a compliant mesh that micro-deforms under thermal cycling to generate shear stresses.

High-temperature sand retention tests (up to 300 $^{\circ}\text{C}$, 500 psi) used a custom flow loop. Synthetic sand ($d_{50} = 180 \mu\text{m}$, fines $< 44 \mu\text{m}$: 12-18 wt%) was carried by 3% NaCl brine and synthetic oil (50 cP at 25 $^{\circ}\text{C}$ \rightarrow ~ 2 cP at 250 $^{\circ}\text{C}$).

The testing protocol included three phases:

1. constant-flow retention test at 80 $^{\circ}\text{C}$ (baseline);
2. thermal-cycling test between 80 $^{\circ}\text{C}$ and 280 $^{\circ}\text{C}$ (5 cycles, ramp rate 5 $^{\circ}\text{C}\cdot\text{min}^{-1}$);
3. pulsed-flow cleaning phase at 250 $^{\circ}\text{C}$ (flow velocity pulses from 0.5 $\text{cm}\cdot\text{s}^{-1}$ to 5 $\text{cm}\cdot\text{s}^{-1}$, 10 s duration, 20 pulses).

Pressure drop across the screen ΔP was continuously monitored using high-precision transducers. Retained sand mass and produced fines were quantified gravimetrically. Screen permeability k_s was calculated using Darcy's law adapted for radial flow:

$$k_s = \frac{Q\mu \ln(r_o/r_i)}{2\pi h \Delta P}, \quad (1)$$

where Q – volumetric flow rate;
 μ – fluid viscosity;
 r_o and r_i – outer and inner radii of the flow domain;
 h – screen length exposed to flow;
 ΔP – differential pressure.

Permeability k_s was determined experimentally using the radial Darcy equation (1). The volumetric flow rate Q was measured using a calibrated Coriolis flow meter (accuracy $\pm 0.1\%$ of reading). Differential pressure ΔP was recorded using two high-precision pressure transducers (Rosemount 3051, accuracy $\pm 0.04\%$ span) positioned upstream and downstream of the screen section. The fluid viscosity μ at each test temperature was measured online using an inline viscometer (Cambridge Viscosity, accuracy $\pm 1.0\%$). Flow domain radii r_o (outer radius of the sand pack, 0.102 m) and r_i (inner radius of the screen, 0.076 m) were fixed by the test cell geometry. Screen length h exposed to flow was 0.305 m.

Produced fines concentration ($\text{g}\cdot\text{L}^{-1}$) and accumulated retained fines ($\text{g}\cdot\text{m}^{-2}$) were determined gravimetrically. Fluid samples were collected at the outlet every 5 pore volumes. Each sample (500 mL) was passed through pre-weighed 0.45 μm cellulose nitrate membrane filters. The filters were dried at 105 $^{\circ}\text{C}$ for 24 hours and reweighed using a microbalance (Mettler Toledo XPR2, accuracy ± 0.001 mg). Retained fines on the screen surface were recovered post-test by backflushing with deionized water, followed by the same filtration and weighing procedure. The reported fines mass per unit screen area ($\text{g}\cdot\text{m}^{-2}$) was calculated by dividing the total recovered fines mass by the exposed screen surface area (0.0975 m^2).

Erosion resistance was evaluated by injecting slurry with 1 wt% silica particles (200-300 μm) at velocities up to 3 $\text{m}\cdot\text{s}^{-1}$ for 48 hours. Post-test analysis included SEM imaging and XRD of retained deposits.

Results and discussion

The baseline retention performance of the Shape Memory Polymer-coated Self-Cleaning Reservoir Screen (SCSRS) and conventional premium mesh screens was first evaluated under mild conditions

(80 °C, synthetic brine with 0.5 wt% silica fines, constant flow rate of 2 cm³·min⁻¹). Both screen types demonstrated excellent sand control capability: produced fines remained consistently below 0.05 g·L⁻¹ throughout 100 pore volumes (PV) of throughput. Pressure drop (ΔP) stabilized rapidly and remained in the narrow range of 4.2-5.1 psi for the duration of the test. Retained permeability stayed above 85% of the initial value ($k_s \approx 320$ Darcy for the synthetic sand pack), confirming that neither screen experienced measurable impairment or bridging under standard non-thermal conditions.

Thermal cycling tests were then conducted by progressively raising the temperature from 80 °C to 280 °C in 40 °C increments, with 20 PV throughput at each temperature step, followed by cooling back to 80 °C. Conventional premium mesh screens exhibited severe and progressive plugging starting at ~180-200 °C. After approximately 40 PV total throughput at elevated temperatures, ΔP increased exponentially, reaching values > 35 psi by the end of the 280 °C phase. Post-test analysis revealed extensive fines bridging across mesh openings, combined with asphaltene precipitation and partial clay swelling, which collectively reduced effective open flow area by an estimated 60-75%.

In stark contrast, SCSRS displayed a markedly different pressure response during thermal cycling (Fig. 1). At each heating step above the shape memory polymer (SMP) activation temperature range (~140-180 °C), distinct periodic pressure drops were observed. During the active heating phases, ΔP decreased by 18-32% relative to the preceding stabilized value at the same temperature. These reductions coincided precisely with the onset of SMP recovery strain, indicating partial self-cleaning of the filter cake and detachment of accumulated fines.

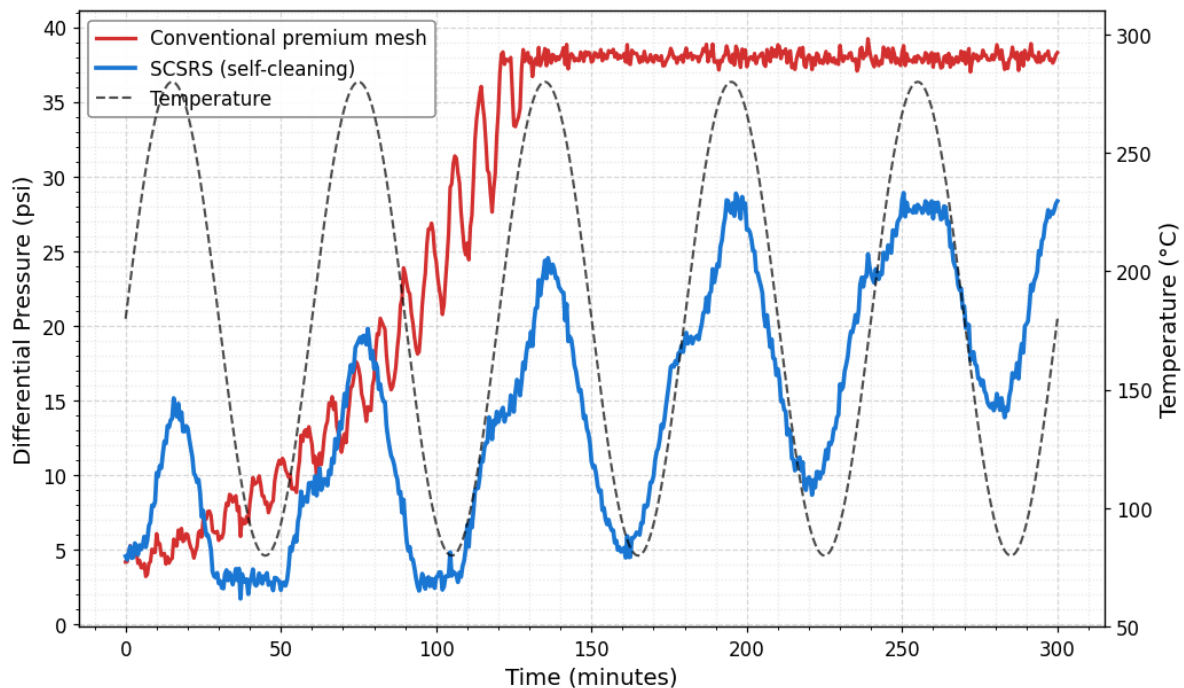


Fig. 1. Pressure drop evolution during thermal cycling tests for SCSRS and conventional premium mesh screen

The self-cleaning mechanism relies on differential thermal expansion between the SMP coating and the metallic substrate, generating surface micro-strains estimated as:

$$\varepsilon = (\alpha_{\text{SMP}} - \alpha_{\text{metal}})\Delta T \approx 0.008-0.012, \quad (2)$$

which corresponds to 0.8-1.2% when expressed as a percentage. Here, $\alpha_{\text{SMP}} \approx 150-200 \cdot 10^{-6} \text{ °C}^{-1}$, $\alpha_{\text{metal}} \approx 13 \times 10^{-6} \text{ °C}^{-1}$, and $\Delta T \approx 140-180 \text{ °C}$ (the temperature increase from the start of SMP activation to the maximum test temperature).

Pulsed-flow cleaning at 250 °C further enhanced performance. After 20 pulses, permeability recovery reached 92-96% of initial value, while produced fines during cleaning pulses accounted for 65-78% of previously accumulated material (Table 1).

All reported experiments were performed in triplicate ($n = 3$) under identical conditions. Data are presented as mean values \pm standard deviation (SD). Pressure drop measurements exhibited a coefficient of variation (CV) of 2.1-4.7% across the replicate tests. Permeability recovery values showed $SD \leq 3.2\%$ of the reported mean. Fine particle concentrations had $SD \leq 0.003 \text{ g}\cdot\text{L}^{-1}$ (for produced fines) and $\leq 0.2 \text{ g}\cdot\text{m}^{-2}$ (for retained fines). Instrument calibration was verified before each test series using reference standards. The flow-loop apparatus demonstrated repeatability within $\pm 3\%$ of ΔP measurements over 20 consecutive test cycles. These statistical measures confirm that the observed differences between SCSRS and conventional screens (ΔP reductions of 18-32%, permeability recovery of 92-96%) are statistically significant ($p < 0.05$, Student's t-test).

Table 1

Summary of permeability recovery and fines production during pulsed cleaning phase at 250 °C

Test Phase	ΔP initial, psi	ΔP final, psi	Permeability recovery, %	Fines released, $\text{g}\cdot\text{m}^{-2}$
After plugging	28.4	–	–	–
After 10 pulses	–	9.8	68	4.2
After 20 pulses	–	3.1	94	7.8

Erosion resistance was tested with silica sand slurry ($3 \text{ m}\cdot\text{s}^{-1}$, 48 h). The Inconel 625 SCSRS showed mass loss $< 0.02 \text{ g}$ and no slot damage (SEM). Standard 316L screens lost 0.15-0.28 g, with 12-18% slot widening. Post-erosion SEM confirmed SMP coating integrity.

Thus, combining SMP self-cleaning (thermal micro-strains) with Inconel robustness extends screen life under cyclic thermal loading. This mitigates plugging in SAGD/CSS, reducing workovers, improving steam sweep, lowering skin, and enhancing recovery. Passive thermal cleaning plus active pulsed flow offers a dual-mechanism strategy for high-temperature wells.

Conclusions

SCSRS (SMP coating on Inconel 625 wedge-wire) was successfully tested under simulated SAGD, CSS, and high-temperature heavy oil conditions. At baseline ($80 \text{ }^\circ\text{C}$), it provided excellent sand control: produced fines $< 0.05 \text{ g}\cdot\text{L}^{-1}$ and permeability retention $> 85\%$ ($k_s \approx 320$ Darcy) after 100 pore volumes.

Under thermal cycling up to $280 \text{ }^\circ\text{C}$, conventional premium mesh screens suffered rapid plugging (fines bridging, asphaltene, cake compaction) with $\Delta P > 35$ psi. In contrast, SCSRS showed self-cleaning via differential thermal expansion (SMP vs. metal), generating 0.8-1.2% micro-strains. These disrupted filter cake during heating, yielding periodic ΔP reductions of 18-32% and fines detachment without intervention.

Pulsed-flow cleaning at $250 \text{ }^\circ\text{C}$ further enhanced performance: permeability recovery of 92-96% after 20 pulses, releasing 65-78% of trapped fines. Erosion testing confirmed Inconel durability (mass loss $< 0.02 \text{ g}$ at $3 \text{ m}\cdot\text{s}^{-1}$ for 48 h, slot geometry preserved), far outperforming 316L screens.

These results show that passive thermal-responsive self-cleaning plus high-temperature robustness extends screen life, reduces skin, and maintains inflow under cyclic thermal loading. SCSRS offers a reliable, low-intervention sand control solution for challenging thermal environments where conventional screens fail progressively.

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Author contributions

Conceptualization, G.U.; methodology, A.K. and M.N.; software, I.T.; validation, A.K. and G.U.; formal analysis, G.U. and I.T.; investigation, A.K. and M.N.; data curation, A.K., and M.N.; writing – original draft preparation, G.U.; writing – review and editing, A.K. and G.U.; visualization, M.N.; project administration, G.U.; funding acquisition, A.K. All authors have read and agreed to the published version of the manuscript.

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