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Full Length Article

Innovative Technique to Control Sanding Tendency of Oil and Gas Wells

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ABSTRACT

Sand production is a worldwide problem facing thousands of oil and gas fields. A huge cost is directed annually to predict and control sand production and fix and replace equipment affected. This study aims to develop a new sand control technique that utilizes local low cost materials to build a form of high permeability filter that can prevent sand with minimum effect on formation productivity. Different mixtures of cement, sand and perlite were prepared to fabricate different filters. Petrophysical and mechanical properties of prepared filters were used to determine the optimum filter composition. Mixture of 69.4%, 11.6%, 5.2% and 13.8% by weight of perlite, class C Portland cement, sand and fresh water respectively was selected as the optimum filter compositions for the experimental conditions. The strength and durability of the filter were tested by aging it in reservoir fluids at 70º C for several weeks. No mechanical deterioration was observed with time and tested filter remain intact with the same unconfined compressive strength and petrophysical properties. The proposed sand control technique was tested experimentally at various major conditions known to elevate sand production including sand size, displacement rate and displacing fluid viscosity. The proposed technique was very effective in controlling sand production with minimum flow restriction except for the case of 90 cp crude displacement in medium size sand pack. Sand packs permeability in most of the experiment was not affected and remains close to initial packs permeability, proving the filter efficiency. Preliminary economic feasibility study was conducted to compare the cost of using the proposed filter with conventional gravel pack sand control method commonly used in petroleum and water wells. Outcomes indicate that after further testing in pilot scale, the cost effectiveness of the proposed technique makes it an attractive choice.

1. Introduction

Sand Production is the phenomenon of solid particles movement associated with reservoir fluids production. It occurs when the induced stresses exceed the formation strength. Sand production is caused either due to rock failure around the open pore hole or perforation, and/or detachment and transportation of sand particles into the wellbore and up to surface (Wu et al., 2006). Sand production is associated with unconsolidated formations and it can affect productivity. Although in most cases wells routinely experience manageable sand production, controlling excessive sand production is economically unattractive operation. According to recent experimental and review studies conducted (Muhammad and Ali Rasol, 2025; Salahi et al., 2021), sand production is significantly affected by the interplay between geomechanical failure and fluid-solid interactions. More recent researches have shifted from traditional sand control methods toward a deeper understanding of the fundamental weakening processes in sandstone formations. This is particularly evident in situations involving increased injection pressure, water breakthrough, and moisture content. It is revealed that increased injection pressure and moisture levels significantly accelerate the

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detachment and movement of sand (Abass et al., 2002; Adeyanju and Oyekunle, 2011; Al-Awad, 2001). Additionally, chemical-based methods like resin, hydrogel, and expandable sand screens can significantly enhance formation stability when they are designed and executed appropriately (Al-Baggal et al., 2006; Alameen et al., 2025; Safaei et al., 2023).

Safaei et al. (2023) presents an overview of both laboratory and filed studies investigations of chemical solutions for sand production. The study highlighted various chemical agents and laboratory tests used to evaluate the performance of sand consolidation treatments. Additionally, Asfha et al. (2024) provides an extensive review of the mechanisms, predictive techniques, and innovative technologies used in sand control. The research classified the mechanisms of sand production into geological, mechanical, and fluid-related factors, offering valuable insights into the causes of sand production and the effectiveness of various control approaches. Alameen et al. (2024, 2025) demonstrated that water saturation significantly influences the reduction of formation strength via silica dissolution at grain-to-grain interfaces, especially in weakly consolidated and semi-consolidated sandstones. These studies established a clear quantitative relationship between increased water saturation, enhanced silica dissolution, and a notable decrease in unconfined compressive strength (UCS), identifying chemical degradation as a significant contributor to sand production during water breakthrough.

Sand production can cause major downhole and surface complications. If flow velocity is high enough to lift the sand in the tubing, it may accumulate in surface facilities and well must be shut-in and manual cleaning must be performed. As a result, the cleaning cost in top of the cost of the production shut down must be considered. A cubic foot of sand accumulating in a separator for 2 min will slow its separation capacity by 128 bbl/day(Completion Technology for Unconsolidated Formations, 1995). If fluids lifting capacity is not enough, sand may block the tubing or fall and accumulate downhole covering the productive interval. In both cases, the production will slow down to cease later and clean-out operations are required. If sanding is continuous, cleaning process is required on a routinely basis resulting in increased well maintenance cost. At the pore scale, recent NMR and CFD–DEM studies conducted by Tang et al. (2024) have highlighted the significant impact of fines migration on modifying pore structure and permeability during production from unconsolidated reservoirs, the detachment and plugging of fines are highly sensitive to factors such as flow velocity, mineral composition, pore throat geometry, and fluid chemistry, reinforcing the need for sand control solutions that tackle both load-bearing particle failure and fines migration mechanisms. When sanding rate is high enough and continues over a long time, caving will develop behind the casing, leading to formation collapse and permeability damage. Poorly sorted sand or those characterized with high clay content are more susceptible to such condition, and in case of overlying shale collapse, complete productivity loss is probable (Completion Technology for Unconsolidated Formations, 1995).

The solid material produced can consist of both formation fines and load carrying rock particles. The fines production is inevitable and is considered beneficial. However, the production of load bearing particles and the capability to maintain it below an acceptable level at the anticipated production conditions are crucial in assessing the sanding risk. Factors that influence a well tendency to produce sand can be related to either rock strength effects or fluids flow effects. These factors are listed as degree of formation consolidation (Chin and Ramos, 2002), fluctuation in formation pore pressure (Al-Awad, 2001), production rate, fluids viscosity (Adeyanju and Oyekunle, 2011), and increasing water cut (Bianco and Halleck, 2001; Han and Dusseault, 2002; Han et al., 2002; Hall and Harrisberger, 1970; Skjaerstein et al., 1997). Four broad groups of sand control methods are available, these are production restriction, mechanical methods, in-situ chemical consolidation (Willson et al., 2002; Tague and Lewallen, 2002), and combination of two or more of these methods. With the exception of production restriction methods, the remaining methods provide some means of mechanical support to prevent formation movement. Xu et al. (2024) confirmed that while mechanical techniques are still frequently used, chemical-based sand control utilizing polymers, resins, and new nanocomposite materials offers promising alternatives, nonetheless, their study highlighted persistent challenges concerning permeability impairment, treatment durability, and operational complexity, underscoring the need for innovative and cost-effective sand control technologies with minimal formation damage.

There are many hydrocarbon reservoirs in Saudi Arabia with sanding tendency, among these are the Unayzah, Safaniyah and Khafji reservoirs, many of these are completed with screens and gravel packs. However, screen less completion is widely applied such as selective and oriented perforation and screenless FracPac (Abass et al., 2002; Al-Anazi et al., 2011; Rahim et al., 2010). The problem of sand production is not only restricted to oil and gas wells, but also it extends to water wells too. Enormous water wells for agricultural projects and drinking water supply for towns and cities are facing the sanding problem. Among these are the wells operated by the Ministry of Water and Electricity at Wasia field east of Riyadh. Currently gravel packing with screens are the control technique implemented in all the wells (Al-Baggal et al., 2006). Therefore, this study aims propose and test of an innovative cost effective sand control method to prevent sand production with minimum near wellbore damage, explore the impact of factors including productivity, fluid viscosity, formation particle size, and sorting on sand production, prove its full effectiveness in preventing sand production at different experimental conditions with minimum formation erosion and filter damage, and demonstrate its cost-effectiveness in comparison to commonly practiced gravel packing technique.

2. Experimental Setup, materials and Procedure

The experiments were performed using a flooding setup with schematic presented in Fig. 1. It consists of cylindrical PVC tube with a length of 31.93 cm and a diameter of 4.9 cm, in which the sand is packed wetly. This sand pack provides a simplistic representation of the unconsolidated downhole formation. The sand pack is connected to 1-L fluid accumulator that house the displacing fluids. The accumulator is connected to positive displacement pump, which inject distilled water to the bottom of the accumulator piston to displace its fluid content towards the sand pack. Pressure drop across the sand pack is measured using differential pressure transducer. Additional differential transducer is placed across the proposed sand control filter when placed for testing. Both transducers are linked to data acquisition system for continuous recording. The produced fluid and accompanied sand are collected at the outlet end in a glass tubes mounted in timely set fraction collector.

Two sands (A and B) were used to form the sand packs. Table 1 lists the statistical granulometric analyses and Fig. 2 present the incremental and cumulative particles size distribution of both sands. The analyses indicate very well sorted sands with two different grain sizes. Sand A is characterized by medium size sand, Sand B is characterized by fine size sand and is within Saudi Unayzah Formation, known for its sanding tendencies and size range. Darcy law was used to determine the sand packs permeability at the start of each experiment. Sand packs permeabilities were within the ranges presented in Table 1.

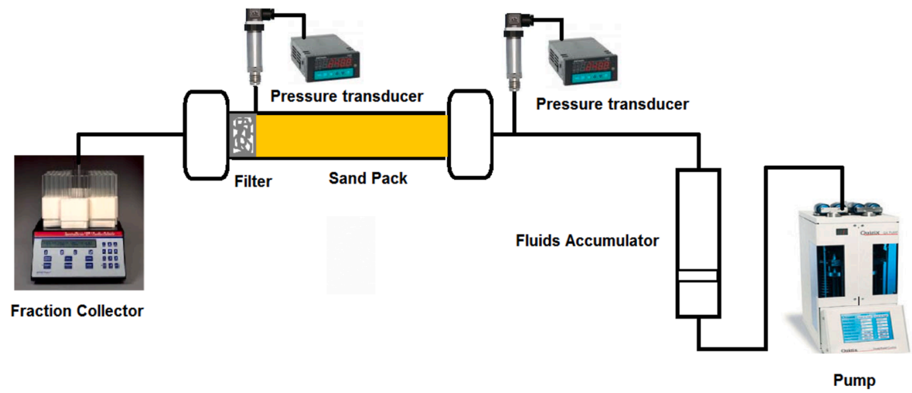

Fig. 1. Experimental setup.

Table 1
Sand packs granulometric analysis.

	Sand Pack A	Sand Pack B
Graphic Mean	Medium grained (1.714 Φ)	Fine Grained (2.823 Φ)
Graphic Standard Deviation	Very Well Sorted (−0.434 Φ)	Very Well Sorted (−0.334 Φ)
Inclusive Graphic Skewness	Near Symmetrical (−0.075 Φ)	Near Symmetrical (−0.115 Φ)
Kurtosis	Mesokurtic (1.045 Φ)	Mesokurtic (1.073 Φ)
Permeability (Darcy)	26–30	2-3 md

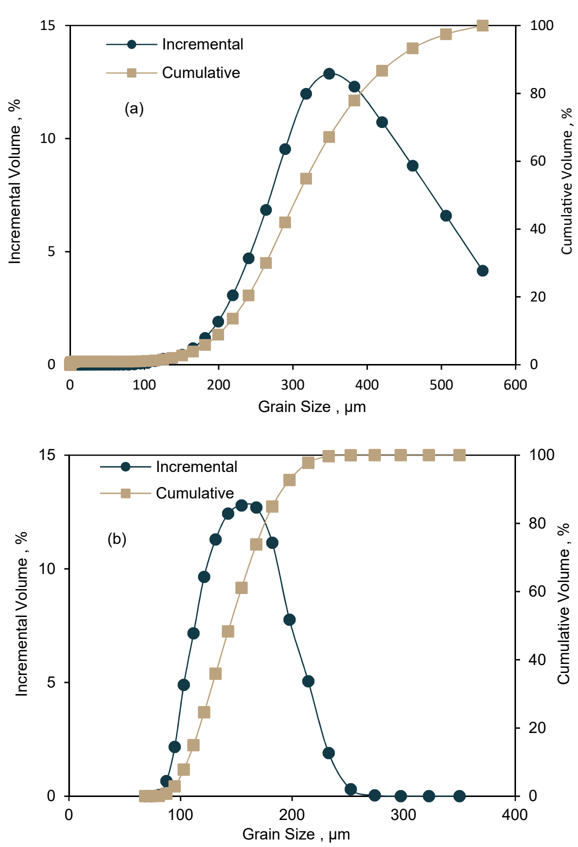

Fig. 2. Grain size distribution of Sand Pack A(a) and sand pack B (b).

Distilled water and two different Saudi crude oils with different viscosities (30 cp and 90 cp) were used as displacing fluids. Sand control filter investigated in this work are made of mixture of perlite, cement, sand, and water (Fig. 3). Care was taken to use filter sand size equivalent or bigger than that used for sand packs in order to increase the filter permeability. The cement was ordinary Portland cement. The third filter component and by far the most important is the perlite, a siliceous volcanic rock currently used as an extender for Portland cement in oil, gas, water and geothermal wells cementing. It is used to reduce the cement density which enable weak zones to be successfully cemented and isolated. It is also used as strength enhancer and help control lost circulation due to its excellent bridging properties.

Numerous mixtures at different weight percent of cement, sand, perlite and water were composed. The mixtures were prepared by carefully combining dry ingredients sand, cement, and perlite, using a laboratory mixer set at low rotational speed for a duration of 1 h to avoid degrading of perlite. Water was then added slowly while continuously mixing until a uniform consistency was reached. The fresh mixture was poured into cubic molds measuring 10 × 10 × 10 cm. The cubic specimen underwent natural sunlight curing for 7 days, during which they were consistently moistened with water to prevent early drying and to ensure adequate hydration. Following the curing period, cylindrical core samples measuring around 5 cm in diameter and 10 cm in length were drilled from the cubic mold for further mechanical and physical testing.

Accordingly, the appropriate mixture required for filter preparation was selected. Permeability of the filter to be implemented

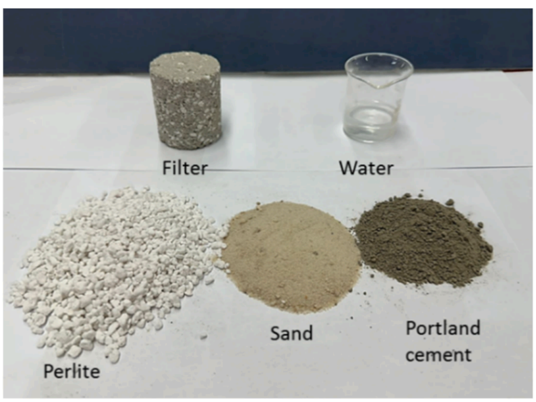

Fig. 3. Filter composition.

for sand control should be equivalent or exceed that of the formation to be tested in order to prevent damage at the sand face and increase the capability of the filter to hold the displaced sand within its network with minimum filter blockage. Additionally, it must have enough compressive strength to withstand downhole conditions during the wellbore installation as well as the drag forces created by reservoir fluids production. Table 2 lists three prepared filters composed of different composition and their petrophysical and mechanical properties. Sand packs formed had absolute permeability of 30 and 3 Darcy for sand packs A and B respectively; therefore, mixture 1 seems suitable to build the sand control filter since it provides high permeability, porosity and stable compressive strength.

Experimental runs were conducted in several stages, namely sand packing, sand pack permeability measurement, observation and analysis of sand production during displacement at different rates, repacking the sand with proposed filter placed at the sand pack outlet end and observation of sand production if any during displacement at different rates. The sand to be tested were packed wet with soft tapping using rubber mallet to ensure that well compacted porous medium is formed. Sand pack was then subjected to several flow rates and steady state pressure drops across the sand pack was recorded, and sand pack permeability was determined utilizing Darcy law. To prevent sand movement, fine silk screen was placed at the inlet and outlet ends of the sand pack. The silk screen at the outlet end was then removed, and displacement was conducted at different increasing rates (0.5–50 cc/min). Each rate was held for 5 min to detect sand production and critical velocity defined as the velocity at which sand starts to be produced. Pressure drop across the sand pack was measured continuously. The detected noise in pressure profile is an indication of cyclic formation and collapse of sand bridge at the outlet end throughout the displacement process. At the last stage, the sand was repacked with proposed filter disc placed at the outlet end of the sand pack, and displacement starts at the same increasing rates as stated above with 5 min holding time for each displacement rate imposed. Pressure drops across the sand pack and across the filter were measured continuously to monitor any fines migration and consequent blockage of sand control filter.

3. Results and discussion

3.1. Flowing sand packs without sand control

Experience indicates a critical production rate with minimum sanding tendency. The critical rate can be unfeasible; therefore, it is important to predict this rate to design a proper completion strategy. Production at a high rate above the critical rate can induce combined pressure differential and frictional drag forces that may overcome the formation in-situ strength. This may lead to localized shear failure in case of consolidated formations or sand arch failure in unconsolidated formations initiating sever sand production. Fig. 4 is a plot of the produced incremental and cumulative sand mass at wide range of injection rates in three runs conducted using medium sand pack A and three displacing fluids (i.e. water, 32 cp crude and 90 cp crude). The figure indicates insignificant sand production at low rates up to a critical rate where sand production peaks to drop later regardless of how high is the injection rate. The critical rate of different injection fluids varies, and as the fluid

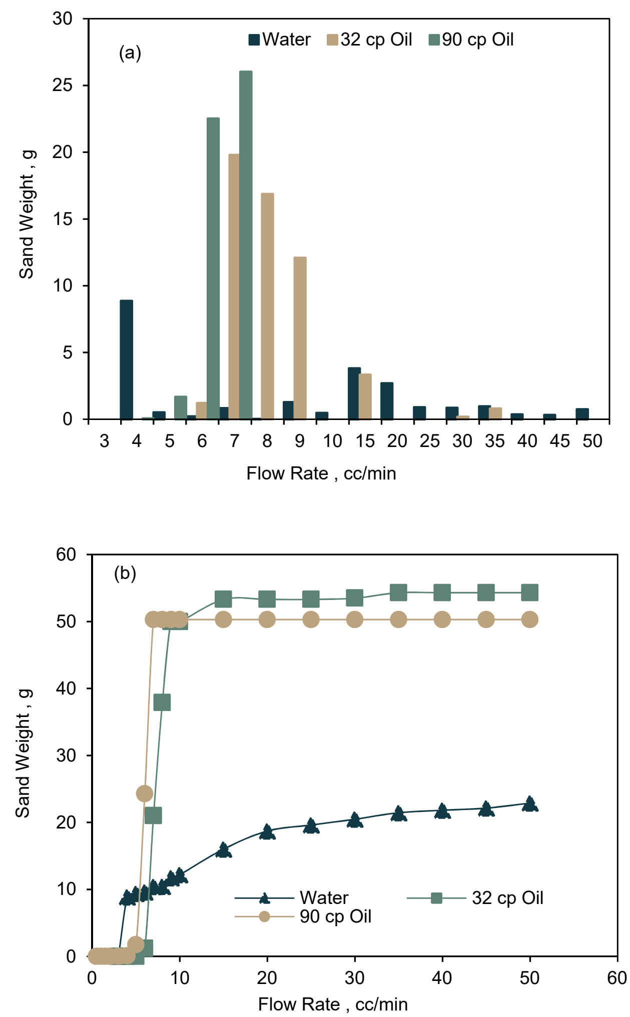

Fig. 4. Incremental (a) and cumulative (b) produced sand weight at different rates for sand pack A with different displacing fluids.

Table 2
Sand control Filter content and properties.

Mixture	Perlite[a] %	Cement[a] %	Sand[a] %	Water[a] %	D cm	Axial load at failure KN	UCS MPa	ϕ %	K Darcy
1	69.4	11.6	5.2	13.8	5.25	4.1	2.26	50.40	30
2	23.8	14.4	39.6	22.2	5.3	3.8	1.76	59.53	1.2
3	44.5	14.2	25.8	15.5	4.8	4.3	1.95	51.20	4.1

• Portland cement class C (density = 1.5 gm/cc).
• Perlite (density = 0.092 g/cc).
• Sand (density = 2.65 g/cc).
[a] Percent of total weight.

viscosity increases, the critical rate at which bulk sand production occurs increases. The critical rate in case of water was around 2.5 cc/min compared to 6–7 cc/min for both crude oils. Sand continued to be produced at low level as rates above the critical rate for water and low viscosity crude. Observation indicates episodic sanding with intervals of low to no sand production, and this can be attributed to the cyclic formation and collapse of sand arch at the production outlet. To the contrary, the sand production ceases abruptly beyond the critical rate with high 90 cp viscosity crude displacement. Cumulative sand mass production at different rates of fluids injection shows higher sanding tendency when both crude oils were injected. Again, the figure indicates initiation of sand production at higher critical rate when both crude oils were used as displacing fluids compared to water.

The displacement runs were repeated but with finer sand pack B using water and 90 cp crude oil as displacing fluids at different rates. Fig. 5 plots the incremental and cumulative sand mass production at wide range of injection rates. The incremental sand mass indicates close critical rate for both fluids with sand starts producing at rate as low as 1.5–2 cc/min regardless of displacing fluid viscosity. Displacement run with water shows cycles of sand production distributed throughout the range of rates imposed with very low quantities beyond 9 cc/min rate. Oil displacement run shows increasing sand mass as rate increases up to 9 cc/min to stop completely afterword. Cumulative sand mass during oil displacement is four times that produced with water. Although it is generally understood that increased flow rates lead to greater drag forces on sand grains, the observed decrease in sanding tendency beyond 9 cc/min can be attributed to two interrelated effects. Firstly, mobilized grains are quickly expelled at elevated flow rates during the initial phase, leading to more stabilized remaining structure. Secondly, the bridging and compaction of residual grains further limits mobilization due to the increased viscous drag force.

To investigate the effect of sand size on sanding tendency, Fig. 6 compares the cumulative produced sand mas of two sand packs displaced with water and 90 cp crude oil at different rates. When displaced with water, the critical rates for both sand packs were close and the produced sand mass is 50% higher in the fine sand B compared to the medium sand A. When displacing with 90 cp crude oil, the cumulative produced sand mass from these two sand packs indicates a critical rate of 1.5 cc/min for the fine sand compared to 6 cc/min for the medium sand, the cumulative produced sand mass in the fine sand was four times higher than that in the medium sand pack.

Fig. 7 presents the encountered pressure drop when the displacing water, 32 cp crude oil and 90 cp crude oil through the sand A. Similarly, Fig. 8 are the pressure profiles across the sand B when

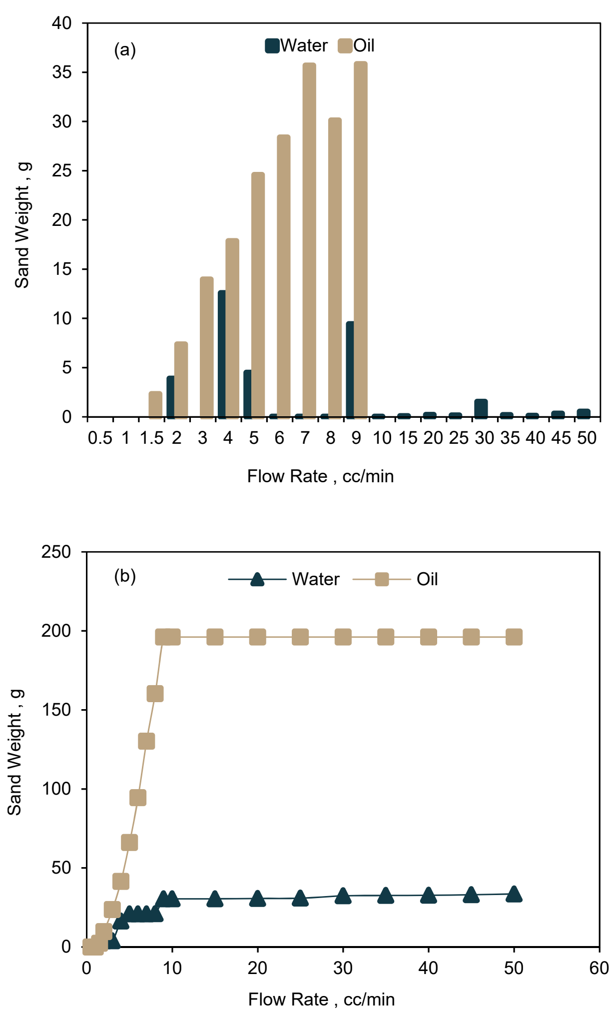

Fig. 5. Incremental (a) and cumulative (b) produced sand weight at different rates for sand pack B with different displacing fluids.

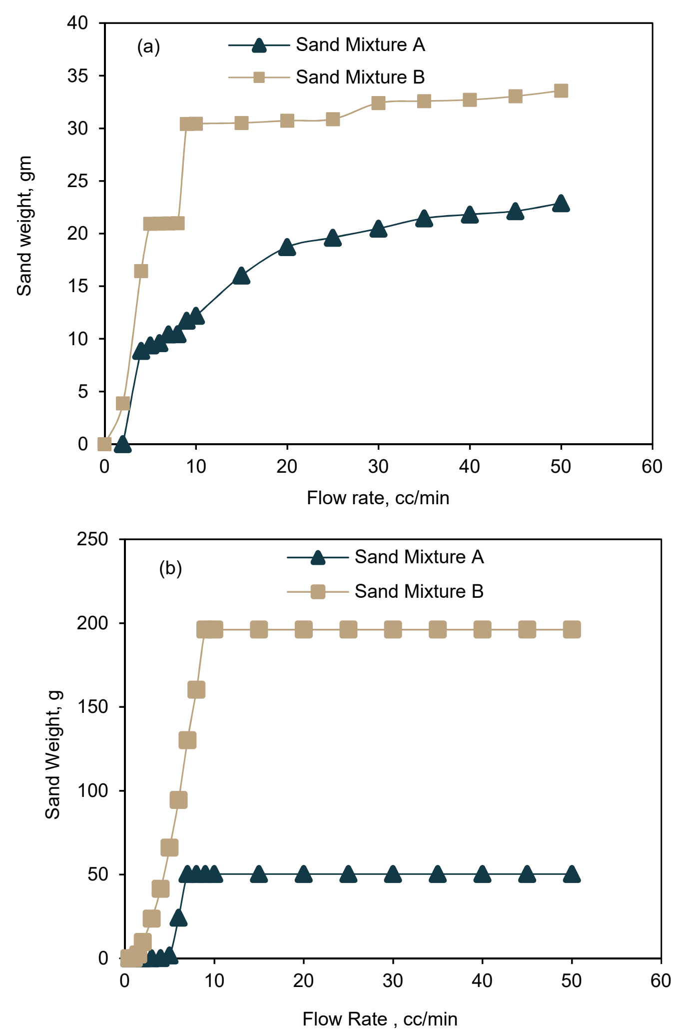

Fig. 6. Cumulative produced sand weight at different rates for two different sand sizes displaced with water (a) and 90 cp crude (b).

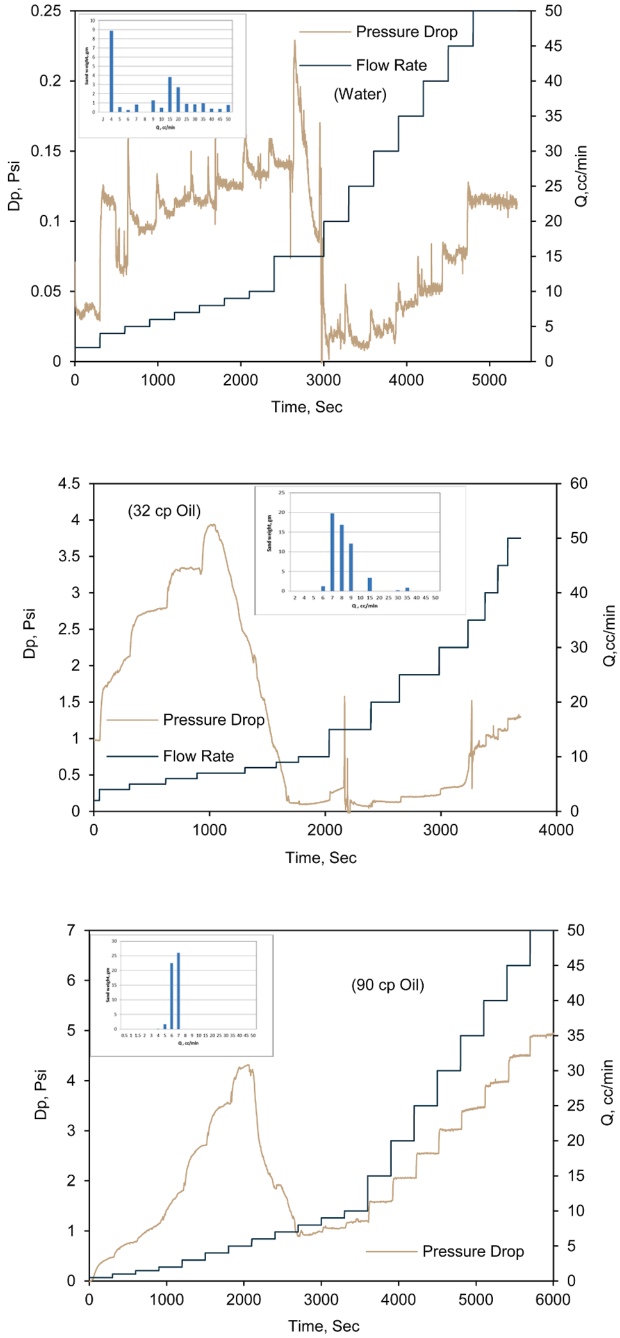

Fig. 7. Pressure profile of sand pack A using water, 32 cp and 90 cp crude oils as displacing fluid.

displaced with water and 90 cp crude oil. The incremental sand mass produced at different rates are embedded within each figure. Clearly, the pressure profile correlates well with the observed sand production and pressure increases during the formation of stable sand arch to drop if the rate is high enough to cause arch collapse. During the water displacement, several episodes of pressure increase and decrease were observed as the sand continues to be produced at wide range of displacement rates in both sand packs. To the contrary, the crude oil displacements show one major pressure drop at which bulk sand production was encountered to increase later when the sand arch was formed. The sand pack B shows gradual pressure drop as the sand is produced continuously within the range of crude oil displacement rate between 1.5 and

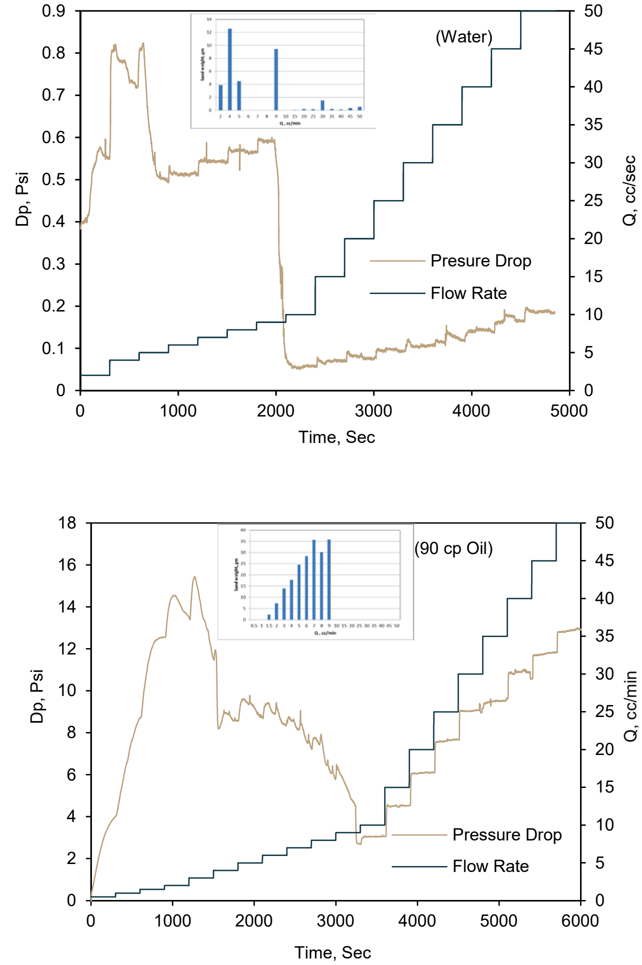

Fig. 8. Pressure profile of sand pack B using water and 90 cp crude oil as displacing fluid.

9 cc/min, compared to steep drop for the medium sand pack A. Clearly, the sequential pressure drop pattern during the initial phase of the test was dictated by the gradual weakening of the pore structure. During the post-peak failure, the hydrodynamic forces dictate the pressure drop reflecting the stepwise manner of flow rate conducted.

Sand production can be due to cavitation, wormholes development or combination of both. Fig. 9 presents pictures of the sand pack outlet at the end of water and 90 cp viscosity crude displacement through the sand pack B. The outlet profile indicates a dense oil sand pack with wormhole channel of higher permeability at the center when the viscous crude oil is displaced. No appreciable porosity change was observed in the wormhole vicinity. The test with water did not materialize in wormhole but instead resulted in cavity at the top of the sand pack, indicating sand collapse. The same profiles were observed with the medium sand pack A. Similar outlet profiles were observed by Tremblay et al. (1999) in their experimental work to simulate the development of wormholes in horizontal sand pack flown by heavy oil and water.

3.2. Flowing sand packs with sand control

The sand pack A and the sand pack B were repacked but with proposed sand control filter placed at the outlet end in order to test its efficiency in controlling/preventing sand production. Displacement was conducted with water, 32 cp and 90 cp crude

Fig. 9. Outlet end erosion profiles at the end of water and crude oil displacement without filter.

oils in the sand pack A and water and 32 cp crude oil in the sand pack B, all injected at different flowing rates. In all runs, we observed no sand production whatsoever and the placed filter proved its efficiency in controlling sanding tendency in all experiments conducted. As in the case of screens or gravel pack for sand control, one concern to consider is the reduced productivity due to filter blockage with moving fine particles accumulating at the inner face and/or penetrating deep within the filter pore network. Therefore, a pressure drop across the filter was measured to observe any filter blockage/damage. Fig. 10 presents plots of the pressure profile across the medium sand pack A in addition to that across the preventive disk throughout the displacement process of water, 32 cp and 90 cp crude oils. During the water displacement, we observed an increase in pressure drop across the sand pack in a step wise fashion as the flowing rate is increased. Plots of flow rate-pressure drop relationship across the sand pack, embedded within the pressure profile plots, show a perfect linear relationship, providing a pack permeability of 30 Darcy for water displacement. This value is equivalent to the initial sand pack permeability measured at the start of the experiment, proving the filter full efficiency in keeping sand pack compacted with no sand movement or production. Similarly, in the second case where 32 cp oil was used as the displacement fluid, straight line relationship of pressure drop-flow rate was obtained. Permeability calculation indicates the absolute permeability of the sand pack is 26 Darcy, which is again equivalent to the initial sand pack permeability used for this run. The pressure drop profile across the filter increases slightly with flow rate, and at a maximum displacement rate of 50 cc/min, the maximum pressure drop of 0.042 and 2.1 psi was obtained for water and 32 cp crude respectively. The small increase in the pressure drop across the filter is presumed mainly due to the stepwise increase of flow rate with minimum role for fine sand accumulation and/or penetration at filter face. The run conducted with 90 cp crude oil shows different behavior in which the pressure drop across the filter starts reasonably well to increase later in a stepwise fashion with the increased flow rate beyond 25 cc/min, such trend indicates a major blockage of sand filter due to major sand movement. The flow rate-pressure drop relationship of the sand pack indicates non-Darcy flow at high displacement rates, and the straight line portion of the curve indicates a drastic increase in sand pack permeability to 53 Darcy. Fig. 9 indicates the wormhole channel of higher permeability when the viscous crude oil is displaced, this explains the low pressure drop across sand pack with increasing flow rate which are close to that monitored during the low viscosity oil displacement. The filter was able to block the sand production as no particles in the produced fluid stream was observed. Visual observation of the filter at the end of the experiment (Fig. 11) indicates major sand particles penetration through the filter network, causing significant blockage and leading to consequence productivity damage.

Fig. 12 presents plots of pressure profile across the fine sand pack B displaced with water and 32 cp crude. Similar to the pressure trend seen in the sand pack A, when the sand was displaced with the water, the pressure drop increases as the flow rate increases in step wise fashion. The flow rate-pressure drop shows a straight-line trend, providing permeability of 2.6 Darcy, this value is very close to the initial sand pack permeability, indicating the filter efficiency. The same was noticed when the sand pack was displaced with 32 cp crude oil and the flow rate-pressure drop plot shows again a straight line, indicating the minimum increase of sand pack initial permeability (3.8 Darcy), which can be attributed to wormhole channeling, but no sand was produced.

3.3. *Economic feasibility analysis*

Several techniques are implemented to reduce sand production in oil, gas, and water wells. These include simple sand production management such as changes in production rate, as well as costly means (like sand consolidation, sand screens, or gravel packing). In order to explore the feasibility of proposed sand prevention mean, we conducted a comparison of estimated costs between the proposed method and gravel packing which is one the common completion technique. Tables 3 and 4 list the materials cost of the conventional gravel packing and the proposed method respectively. A simple economical comparison was made using three types of sand control completions for a hypothetical wellbore of drilled open hole in a sand productive formation of 150 m thick with casing inner diameter of 6 inches, reamed hole diameter of 12 inches and screen outer diameter of 4 inches. Assuming the sand stop packer length is neglected, compared to the total screen length, the three sand control completion cases are assumed as follows.

3.3.1. *Case 1: sand stop packer, screens and gravel pack*

In this case, the completion consists of a $32,000 sand stop packer, and a $88,000 of 150 m long screens ($586.6/meter). The annulus volume is to be filled with gravel at additional cost of $1975. The gravel is pumped in place as a slurry in polymer solution and it is estimated that 100 bags of polymer are needed costing a total of $13,000. Adding all of the above costs, the estimated completion cost of this type is $134,975.

3.3.2. *Case 2: sand stop packer, screens and proposed filter*

In this case, the cost of sand stop packer and screens is as presented previously in Case 1. The proposed sand control filter will replace the conventional gravel pack and the polymer solution used to pump the gravel downhole. The estimated cost to build the sand control is $533.5, accounting for 25% of the cost of the gravel pack implemented for the same annulus. Hence, the total cost for

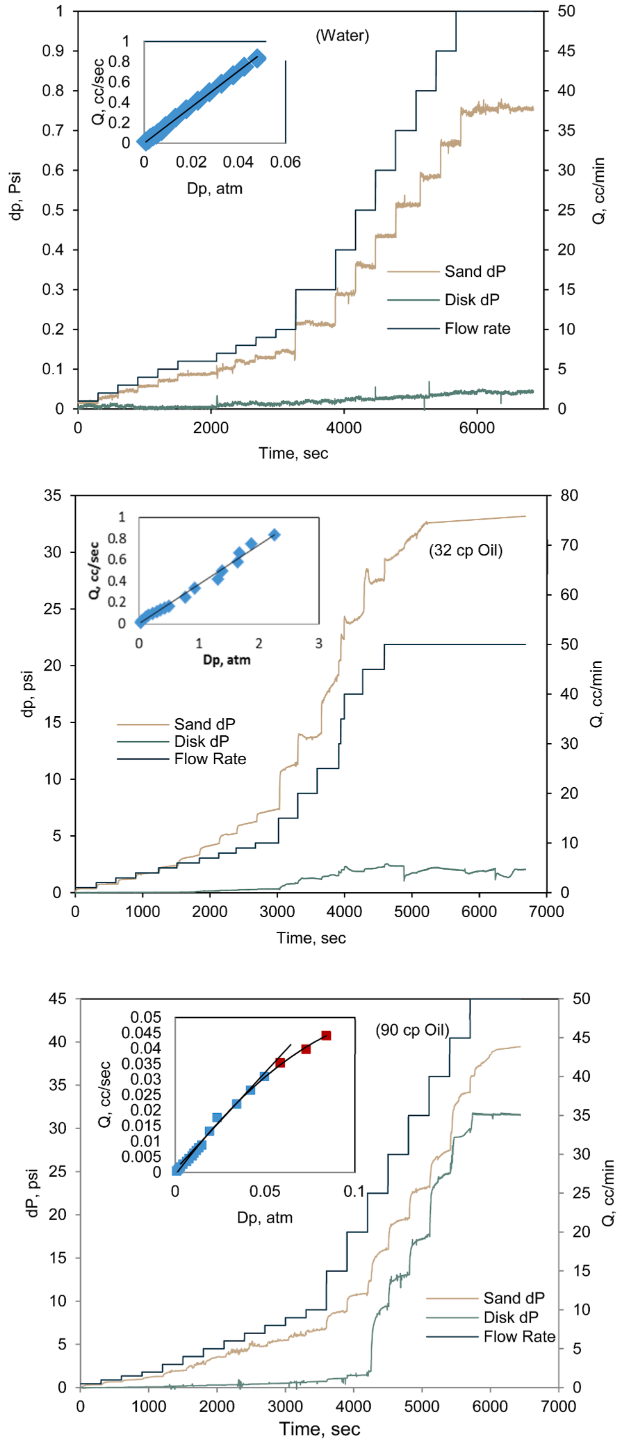

Fig. 10. Pressure profile of sand pack A using water, 32 cp and 90 cp crude oils as displacing fluid.

this case is estimated to be approximately $120,533. It is important to indicate that the proposed sand control mean is placed downhole by pumping the mixture in front of the sanding formation to harden in form of a sand control filter. The pumping cost is unknown for now, but it is equivalent to that of polymer-gravel slurry pumping. The filter, when harden downhole or prebuilt at the surface to be placed as consolidated porous and permeable filter, will eliminate the need for screen column, and this leads us to propose Case 3 discussed below.

Fig. 11. Filter condition after displacement of sand pack A with 90 cp crude oil.

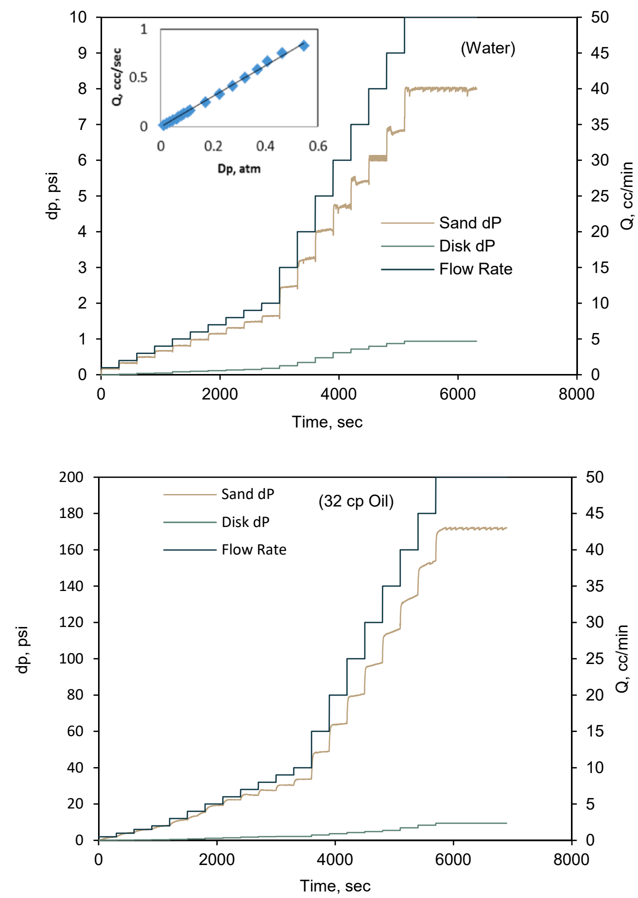

Fig. 12. Pressure profile of sand pack B using water and 32 cp crude oil as displacing fluid.

Table 3
Prices of materials used in standard sand control methods, supplemented by personal communication with the Ministry of Environment, Water and Agriculture.

Sand Control Method	Cost
Loose Gravel Pack	$133/Ton
Stainless Steel Screen	$586.6/meter
Sand stop packer	$32,000
Gravel Displacement polymer	$130/25 kg/Bag

3.3.3. Case 3: proposed filter Alone

In this case, the full reamed open hole as well as part of the cased hole is to be filled with the proposed sand control. This method will significantly reduce the completion cost to $600. The

Table 4
Cost of proposed sand prevention method materials.

Material	Cost
Portland Cement Class (C)	$4/50 Kg Sack
Moderate Sulfate Resisting Cement	$4.3/50 Kg Sack
Perlite	$31.5/50 Kg Sack
Sand	$0.3/50 Kg[a]

[a] 1000 kg sand of 2.65 g/cc density is equivalent to 1 m^3 volume.

Table 5
Comparison between suggested well completion scenarios.

Completion type	Advantages	Disadvantages
Case 1	Durable for long time.	✓ High cost due to the need for sand stop packer and screens. ✓ Screen may be damaged due to formation lateral stresses.
Case 2	Good hole mechanical support.	✓ High cost since sand stop packer is required as well as screens. ✓ Screen may be damaged due to formation lateral stresses.
Case 3	• Lowest costs since neither sand stop packer nor screen are required. • Excellent hole mechanical support. • In case of damage, the filter can be drilled out and replaced with fresh one at low cost and easy work over job.	✓ No support for the filter internally.

cost of placing the proposed sand control as prebuilt solid hollow cylinder or pumping as a slurry to set and harden downhole is not included. This was not included in the above cases, therefore, comparison between the three cases is valid. Table 5 summarizes the three well completion scenarios. Patent No. (SA 13656) was obtained from the Saudi Authority for Intellectual Property (SAIP) for this innovative technique (Alyami et al., 2023). However, it is important to indicate that solid conclusion relies on field trials.

4. Conclusions

This study aims to propose and test a new cost effective control method (filter) to prevent sand production with minimum productivity damage. This method utilizes local Saudi materials, which are easy and cost effective to build. Different factors that are known to influence sand production were tested, including displacement flow rate, displacement fluid viscosity, and sand size. The following conclusions can be obtained.

(1) Sand production is insignificant at the low rate up to a critical rate at which sand production starts. Sanding was episodic with cycles of low to no sand production, and this can be attributed to the cyclic formation and collapse of sand arch at the production outlet.
(2) In the medium sand, the critical rate of different injection fluids varies, and as the fluid viscosity increases, the critical rate at which bulk sand production occurs increases. To the contrary, the fine sand shows lower critical rate and it is independent of fluids viscosity.
(3) In the medium sand, the sand production continues to be produced at low level as the rate increased above the critical rate for water and low viscosity crude oil, but stops abruptly above the critical rate with high viscosity crude oil displacement. In the fine sand, the displacement with water shows cycles of sand production distributed throughout the rate range experienced and the quantity is low at high rates, whereas the oil displacement shows that as rate increases, the sand production increases until it reaches a certain rate and completely stops afterward.
(4) The cumulative produced sand mass of the two sand packs displaced with water at different rates indicates the sand mass production of the fine sand is 50% higher than that of the medium sand. Similarly, when displacing with high viscosity crude oil, the cumulative sand mass produced in the finer sand is four times higher than that of the medium sand.
(5) The pressure profile is closely related to the observed sand production and the pressure increases during the formation of stable sand arch to drop, if the rate is high enough to cause arch collapse.
(6) During the water displacement, several cycles of pressure increase and decrease were observed as the sand continues to be produced at wide range of production rates in both fine and medium sand packs. To the contrary, the displacement of crude oil show one major pressure drop, at which the sand production increases after the sand arch is formed.
(7) The outlet profile indicates a dense oil sand pack with wormhole channel of higher permeability at the center when the viscous crude oil is displaced. The test with water does not materialize in the wormhole, but instead results in cavity at the top of the sand pack, indicating wormhole collapse.
(8) The proposed sand control filter proves its full effectiveness in preventing sand production at different experimental conditions with minimum formation erosion and filter damage. The proposed sand control mean proves its cost effectiveness in comparison to commonly practiced gravel packing technique.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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