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Factors Affecting Sand Production from Unconsolidated Sandstone Saudi Oil and Gas Reservoir

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Abstract. In this work a physical model has been constructed to simulate sand production from oil and gas reservoirs. The model can accommodate unconsolidated as well as consolidated sandstone cores. The experiments were designed to investigate the effect of confining pressure, flow rate, and the displacing fluid viscosity on sand production mechanism in unconsolidated sandstone formations. Saline water (3.5% NaCl by weight), light (35° API) and heavy (27° API) crude oils were used as displacing fluids in the tests. The main goal of this study was to examine if controlling of the production rate alone can solve the problem of sand production in a Saudi oil reservoir. The oil reservoir is situated in an unconsolidated sandstone formation. A produced sand sample was obtained from this reservoir. Tests were conducted on sand packs having a similar granulometric distribution to that of the reservoir.

The experimental results showed that, the magnitude of sand production from the tested porous medium is strongly affected by both flow rate and confining pressure. Sand production decreases with increasing confining pressure and/or decreasing flow rate. Only very fine particles of the porous medium are produced at high confining pressures. When water, or low viscosity crude oil are saturating the porous medium, sand production problem can be managed by controlling the flow rate. In case of saturating the porous medium by heavy crude oil, sand production mechanism becomes different and therefore, controlling only the flow rate cannot stop sand production. Hence, alternative sand control measures must be applied to control sand production in heavy crude oil reservoirs such as down hole emulsification, gravel packing, screen liners, or down hole consolidation.

Introduction

Sand production is considered as one of the major problems in the petroleum industry. Every year, well cleaning and workover operations related to sand production and restricted production rates cost the industry millions of dollars. Additional expenses associated with sand production include, pump maintenance, well cleaning, disposal of dirty sands, etc. Sand production occurs when the induced in-situ stresses exceed the formation in-situ strength [1]. Formation strength is derived mainly from the natural cementing materials that hold (adhere) grains together. According to this strength, the sandstone formations can be classified as competent, weak and unconsolidated. In competent sandstone formations, sand production is due to shear failure. Shear failure occurs due to high shear stress on the surface of the rock (bore hole surface). During production, the existed shear failure surfaces are mobilized and sand debris produced due to drag forces caused by the flow of the reservoir fluids. The produced debris (sand) then will flow into the well along with the reservoir fluids [1; 2]. In weak and unconsolidated sandstone formations, sand is produced when the drag forces caused by the flowing reservoir fluids exceed the natural inherent cohesion of the formation. The movement of sand grains leads to the establishment of sand arches [1-6] as shown in Fig. 1. In general, sand production can be classified into three categories: [7]

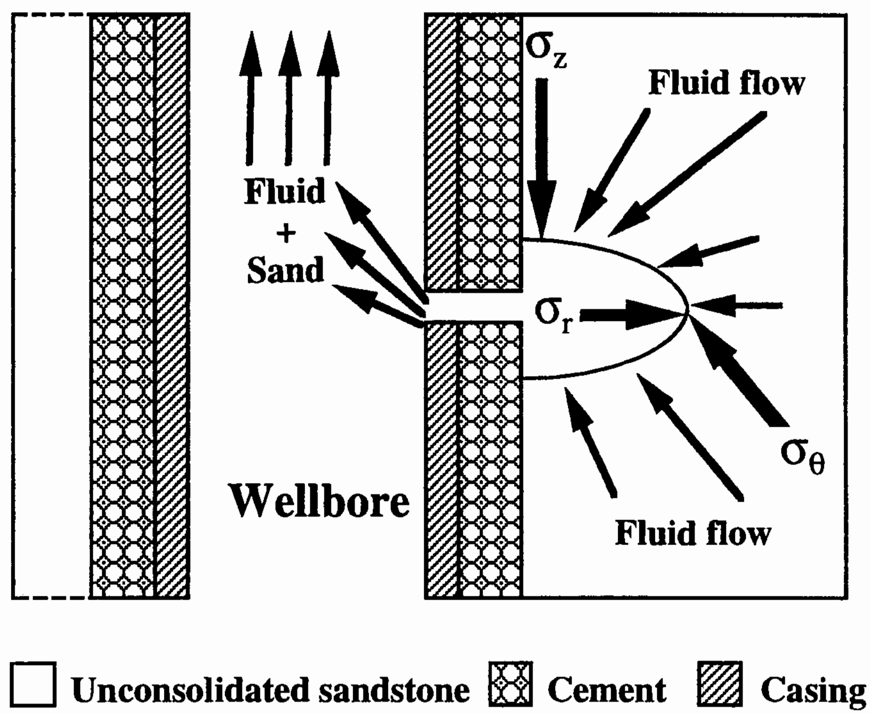


Fig.1. Sand arch failure mechanism [1].

(i) **Transient sand production** refers to a sand production decline with time at constant production rate. This type is normally encountered during clean-up after perforating or acidizing as well as after water breakthrough during secondary recovery operations.

(ii) **Continuous sand production** is observed during production from unconsolidated sandstone reservoirs that have no sand control equipment.

(iii) **Catastrophic sand production** is the worst and normally occurs when the reservoir fluids are excessively produced.

Several testing methods have been proposed to study the problem of sand production [8-28]. All of these methods are based on laboratory data. Table 1 summarizes these sand production testing methods.

Sand control techniques

Sand production from oil and gas reservoir formations can be controlled using several control methods. The choice of the best applicable method depends on several factors. Among these factors is the formation type. These methods are classified as follows:

(i) **Production rate control**: Several researchers have found that the control of oil production rate can minimize sand production [1-4]. This technique is based on the fact that high production leads to a low bottom hole flowing pressure. This reduction in the bottom hole flowing pressure causes the induced stresses acting on the productive formation to exceed the formation in-situ strength. Therefore, localized shear failures will occur in the case of consolidated sandstone and sand arch failure in the case of unconsolidated sandstones and the result will be sand production.

(ii) **Downhole emulsification**: This method involves the injection of an aqueous non-ionic surfactant solution into the well bore to convert the water-oil emulsion to oil-water emulsion to decrease the carrying capacity of the fluid and at the same time retain sands within the oil phase [8].

(iii) **Downhole sand consolidation**: In this method chemical solutions such as resins are injected down hole into the productive formation. When it reaches the productive formation, the injected solution will solidify and adhere sand grains together. As an alternative technique, hot air is injected down hole to oxide (cook) the oil phase and provides a cementing material [9-12].

(iv) **Mechanical sand control**: When the proceeding methods fail to control sand production, the mechanical methods are the only solution. These methods include: the installation of gravel packs, screen liners, or the gravel pre-packed screen liners [13].

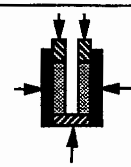
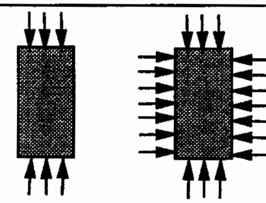
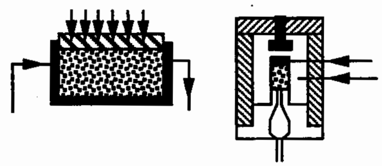
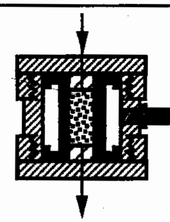
Objectives and Experimental Procedures

In the present work, a produced sand sample was obtained from a Saudi oil field. In this field, hydrocarbons are produced from very weak and/or unconsolidated sandstone formations. This field suffers a continuous sand production problem. Therefore, a complete research plan was proposed to choose the best sand control method to be applied to the oil field under consideration. The main objective of the plan is presented below. It consists of the following :

(i) Determining the amount of sand produced under different confining pressures and flow rates.

(ii) Carrying out part (i) using different crude oil viscosities.

Table 1. Schematic diagram showing sand production testing techniques

Characterisation method	Formation type	Set-up	Reference
Thick-walled cylinder strength (1) Failure mechanisms	Moderately weak and strong sandstones		[21]
Uniaxial and triaxial compressive strength (Failure criterion) (1) Failure mechanisms (2) Stress-strain relationship	Moderately weak and strong sandstones		[1-3] [14-15] [18-19] [25]
Hydrostatic physical models and Perforation cavity model	Unconsolidated sandstones		[7] [16-17] [20] [23]
Hoek-Frankline Cell	Consolidated and unconsolidated sandstones		This study

(iii) Conducting sand granulometric analysis before and after each run in parts (i) and (ii)

(iv) Classifying sand control methods according to crude oil and reservoir properties.

The possibility of applying the down hole emulsification technique to the studied field is published in a separate publication [8]. Currently, the down hole consolidation technique for sand control is being investigated.

The experimental work includes the granulometric analysis of the sand, formulating a porous medium analogous to that of the reservoir under consideration, analyzing the test fluids, and experimental setting-up and test procedures.

Granulometric analysis

In order to determine the granulometric analysis of the sand sample obtained from the field, a calibrated ASTM sieves plus pan has been stacked in series. A split of 650 g had been poured onto the top sieve. The set of sieves had been placed in a shaker and shaken for 15 minutes. After that, the sieves are unloaded and brushed thoroughly. The weight of sand retained on each sieve had been weighed and the percentage values had been calculated. Based on this analysis a mixture of sand with grain size distribution similar to that of the reservoir sand is used as a porous medium in this study.

Displacing and displaced fluids

Saline water and coils are used in this study. The saline water was formulated by dissolving 3.5% by weight sodium chloride (NaCl) in distilled water. Light oil (viscosity = 1.05 cp and 35° API) and heavy oil (viscosity changes with shear rate as shown in Fig. 2 and 27° API) are also used.

Sand Production Model Set-up

The experimental set-up is schematically shown in Fig. 3. It consists of three main parts: oil and water tanks, Hoek cell, and confining pressure system. The two steel tanks of oil and water had a diameter of 30 cm and 50 cm long. Each tank has three connections, two inlets on the top and one outlet from the bottom. One of the two inlets is used to pressurize the fluid inside the tank and the other for producing vacuum. The outlet connection is used to discharge the pressurized fluid. The Hoek cell is equipped with a sand pack, which has an inside diameter of 3.81 cm and 8 cm long. The sand pack can be subjected to different values of confining pressure. A hand pump is used to supply the confining pressure for the sand pack. Two pressure gauges are installed in the inlet and the outlet of the Hoek cell to measure the pressure drop across the sand pack. The fluid and sand produced from the Hoek cell is controlled by a valve.

Testing procedures

1. Saline water (3.5% NaCl by weight) was prepared using magnetic stirrer.

2. Oil and water tanks were filled with their respective fluids.

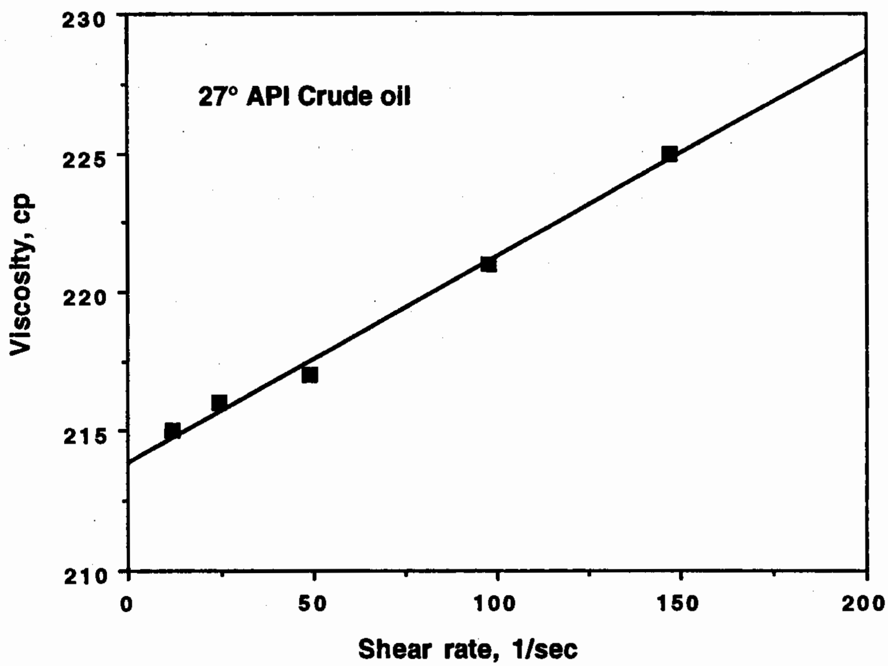


Fig. 2. Shear rate-viscosity relationship for a heavy crude oil.

3. The Hoek cell was cleaned and dried before each experiment.

4. Sand packing began by pouring 10 cc of the saline water inside the holder and then adding 25 g of sand mixture. A small hammer was used to tap the surface of the holder to prevent the formation of cavities. The packing was continued carefully until the sand holder was fully packed with sand and saline water.

5. In the case of crude oil, part 4 was repeated using the crude oil in place of the saline water.

6. After fully packing the Hoek cell with sand and fluid, the weight and volume of the remaining sand and saline water are determined.

7. The porosity of the sand pack was calculated using the following equation:

$$\text{Porosity} = (\text{pore volume} / \text{bulk volume}) \times 100 \quad (1)$$

Where, the pore volume is the volume of the saline water used for packing and the bulk

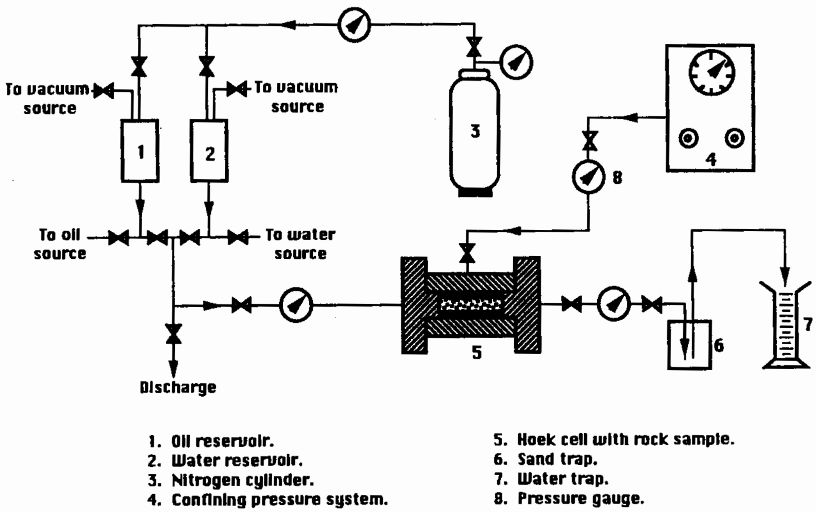


Fig. 3. Experimental set-up used in sand production problem study.

volume is the holder volume of the Hoek cell calculated using the cell dimensions (3.81 cm diameter and 8 cm long).

8. The sand pack was then mounted into the Hoek cell and the Hoek cell was connected to the set-up. The confining pressure was then increased gradually to the desired value.

9. A certain pressure was applied to the displacing fluid tank and the pressure drop across the sand pack is kept constant.

10. At the end of each run, the outlet fluid was filtered and separated. The separated sand was, then, dried in an oven at 200 °C. The volume of the dry sand was calculated and the grain size distribution was determined. The volume of the produced sand was then expressed as a fraction of the produced fluid volume.

11. Step 10 was repeated until sand production stops.

Experimental Results and Discussion

Since the sand mixture (porous medium) used in this study had no cementing material, the only affecting parameters were the flow rate and confining (compaction) as well as the displaced and the displacing fluids properties.

Effect of flow rate

The normal production status in oil and gas reservoirs is that, a well may produce a uniform amount of sand independent of production rate until some critical production rate is exceeded. Increasing the production rate above the critical rate results in increasing the amounts of sand production. Therefore, determining the critical flow rate above which sand production becomes excessive is very important. For the studied reservoir, it is found that, sand production is strongly affected by the flow rate. Figure 4 shows the percentage of the volume of sand per volume of water produced and the cumulative sand production plotted versus the flow rate. The cumulative sand production increases with increasing flow rate. The volume of sand per volume of produced fluid indicates that the sand production continues at a specific flow rate until a stable sand arch is formed (see Fig. 1). The arch will then stabilize and no more sand is produced if the flow rate is kept constant. If the flow rate is increased, then the sand arch will become unstable and sand production will commence. Thus, any further increase in the flow rate will lead to another sand production cycle. Figure 5 shows a comparison between the grain size distribution of the produced sand and that of the porous medium. Figures 4 through 11 shows the mechanism of sand production cycles using water as displacing and displaced fluids at various confining pressures. Figures 12 through 23 show sand production cycles when using light and heavy crude oils as displacing and displaced fluids. It can be seen that for a specific flow rate, the cumulative sand production decreases as the confining pressure (CP) increases when the fluid viscosity increases.

Effect of confining (compaction) pressure

It is evident that, higher sand-free production rates require higher confining pressures. Due to the absence of cementing material in the tested porous medium, the high confining pressure works as a cementing material by pressing the sand grains to each other. Upon contact, sand grains will hold each other by their apparent cohesion (friction). It is noticed that, unconsolidated sand becomes loose if there is no confining pressure and it can carry high overburden loads when it is sufficiently confined. The effect of confining pressure on flow rate and percentage of sand production is shown in Figs. 24 and 25, and Table 2. Figure 24. shows that at high confining pressure high flow rate can be achieved without sand production and the flow rate increases by increasing the fluid viscosity. Figure 25 gives the effect of confining pressure and the percentage of sand production. It shows that a reduction of 35% in sand production is achieved when the confining pressure is increased to 2.5 MPa for all tested fluids. Figure 25 also shows that at high confining pressures only the small particle sizes are produced from the porous medium. When using light crude oil, the percentage of fine sand becomes larger, which is attributed to the high lubrication action on sand grains caused by the crude oil when compared to saline water. As shown in Figs. 22 and 23, the largest given sand sizes (600 μm) are produced when heavy crude oil is used as a displacing fluid. The production of large particle sizes indicates that the formed sand arches (in the case of heavy crude oil) are completely destroyed by the fluid flow and takes a long period of time to be re-established. Therefore, controlling only the flow rate will not stop sand production from heavy oil reservoirs.

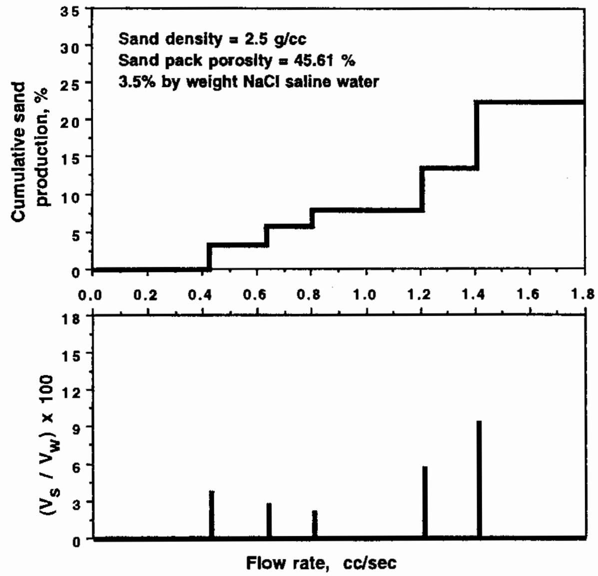


Fig. 4. Sand/Water ratio (by volume) and cumulative sand production % versus flow rate at CP = 0.0 MPa.

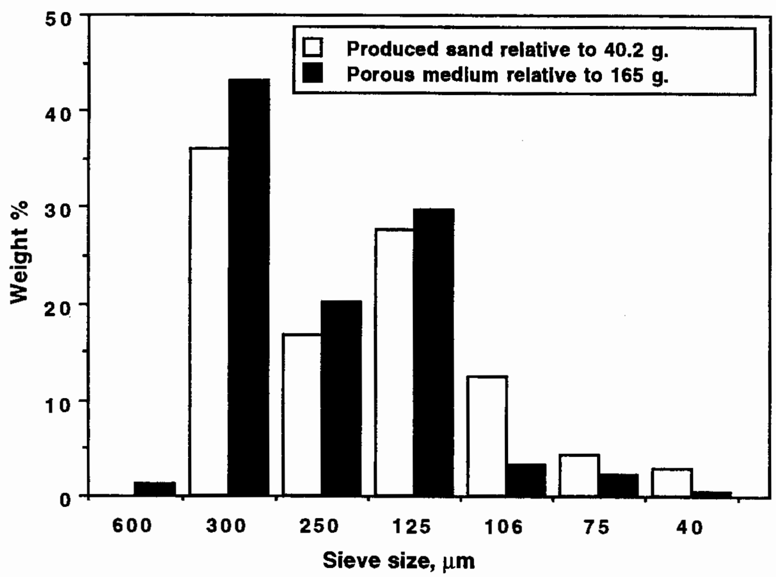


Fig. 5. Grain size distribution of sand produced and porous medium at CP = 0.0 MPa using saline water.

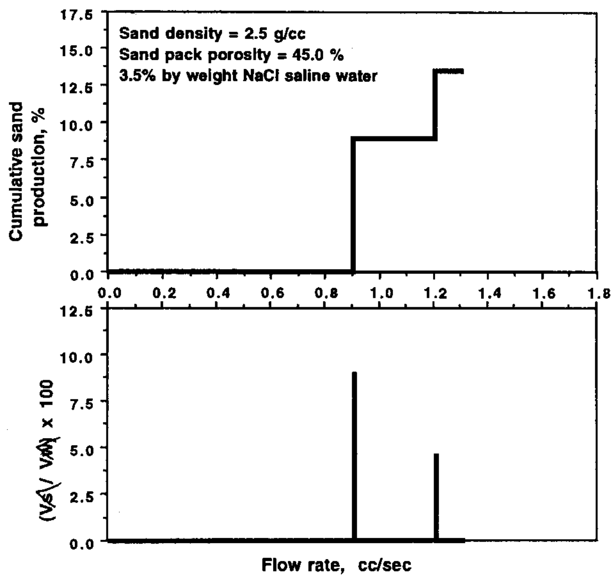


Fig. 6. Sand/Water ratio (by volume) and cumulative sand production % versus flow rate at CP = 2.5 MPa.

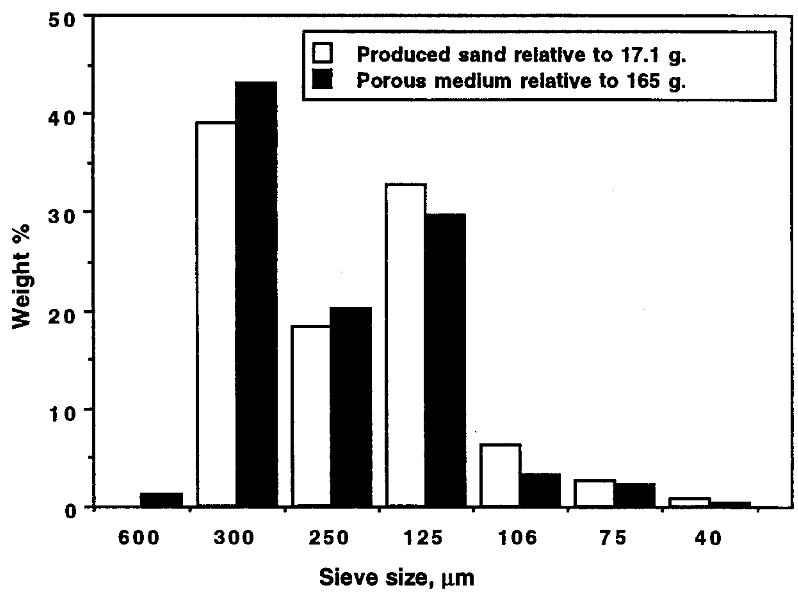


Fig. 7. Grain size distribution of sand produced and porous medium at CP = 2.5 MPa using saline water.

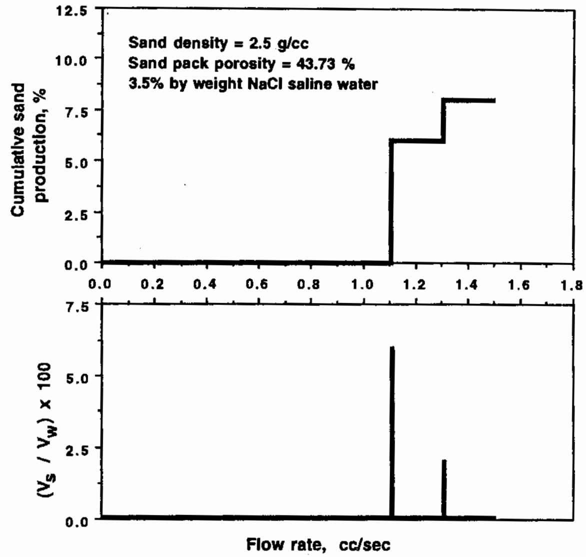


Fig. 8. Sand/Water ratio (by volume) and cumulative sand production % versus flow rate at CP = 5.0 MPa.

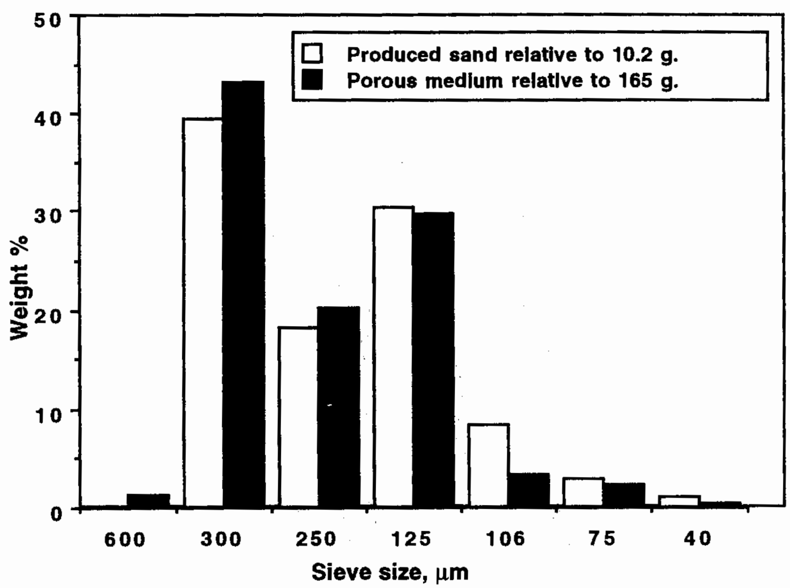


Fig. 9. Grain size distribution of sand produced and porous medium at CP = 5.0 MPa using saline water.

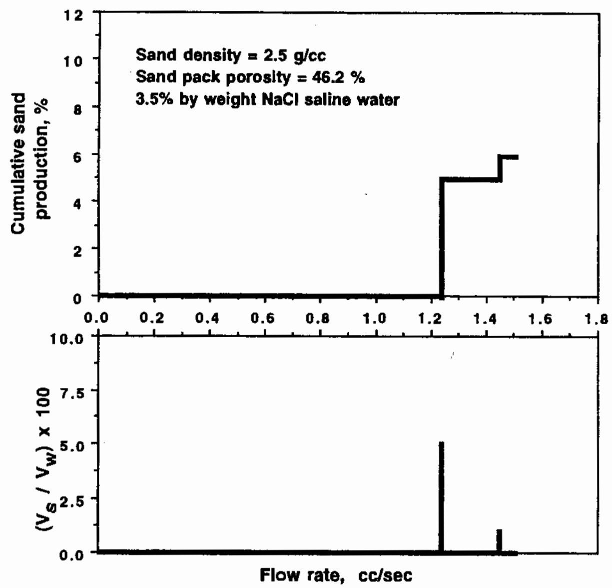


Fig. 10. Sand/Water ratio (by volume) and cumulative sand production % versus flow rate at CP = 8.0 MPa.

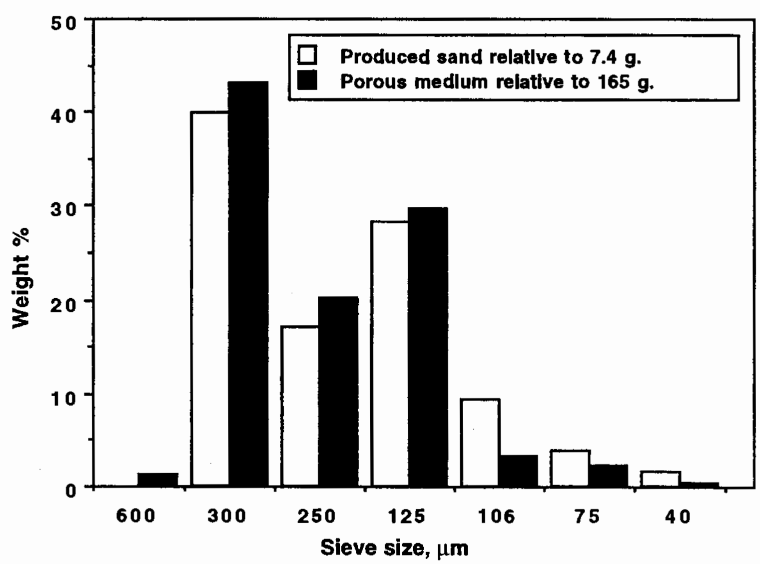


Fig. 11. Grain size distribution of sand produced and porous medium at CP = 8.0 MPa using saline water.

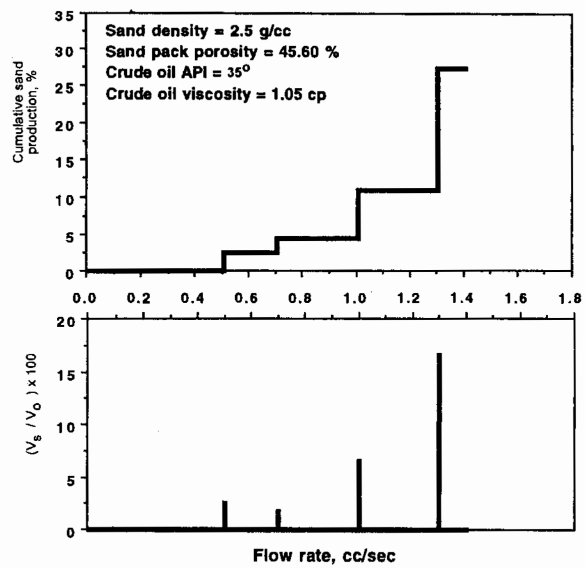


Fig. 12. Sand/Light oil ratio (by volume) and cumulative sand production % versus flow rate at CP = 0.0 MPa.

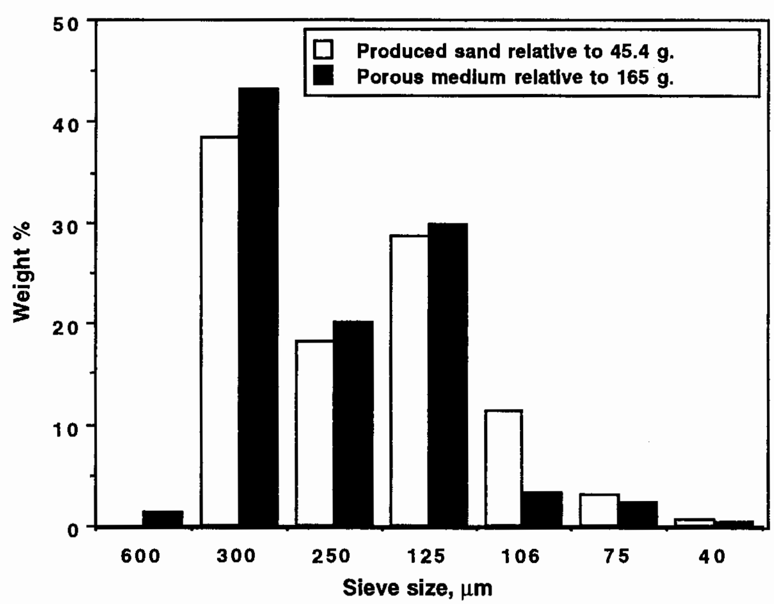


Fig. 13. Grain size distribution of sand produced and porous medium at CP = 0.0 MPa using light oil.

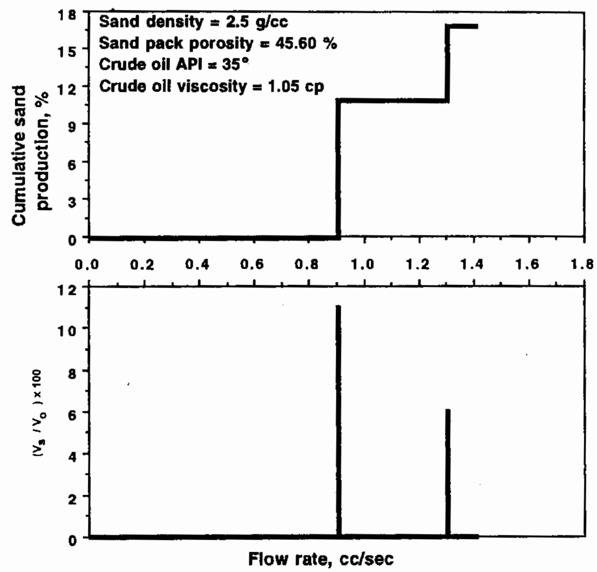


Fig. 14. Sand/Light oil ratio (by volume) and cumulative sand production % versus flow rate at CP = 2.5 MPa.

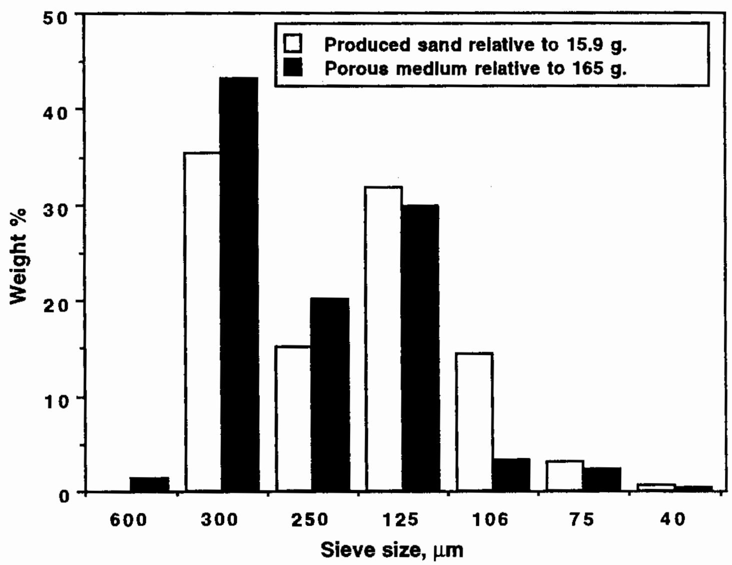


Fig. 15. Grain size distribution of sand produced and porous medium at CP = 2.50 MPa using light crude oil.

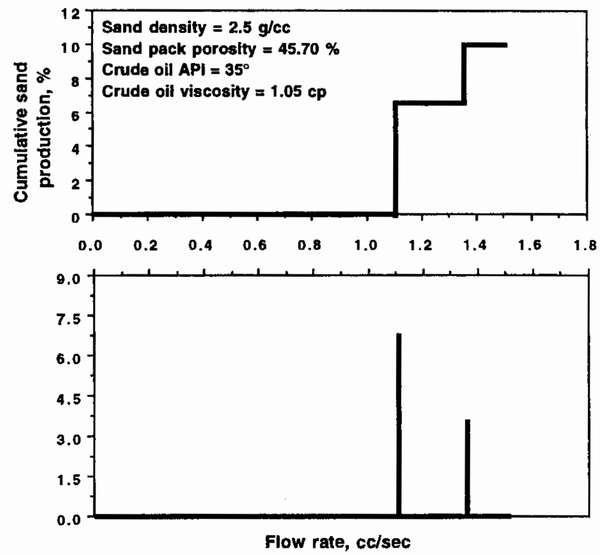


Fig. 16. Sand/Light oil ratio (by volume) and cumulative sand production % versus flow rate CP = 5.0 MPa.

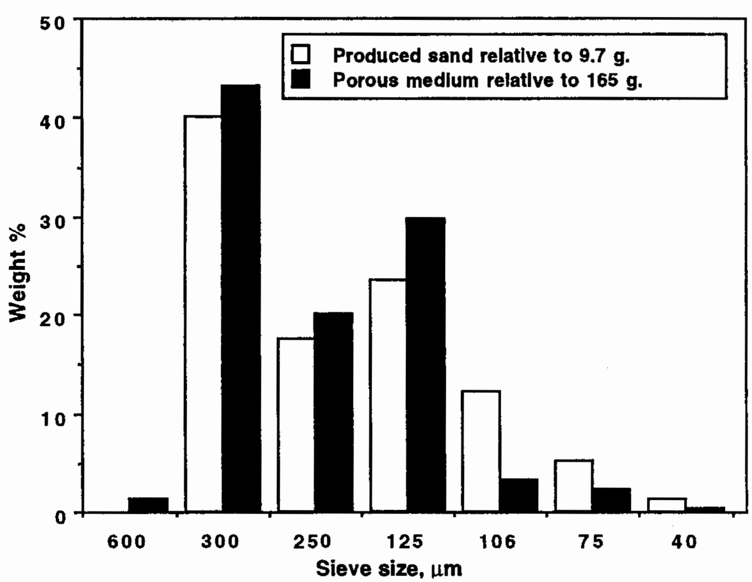


Fig. 17. Grain size distribution of sand produced and porous medium at CP = 5.0 MPa using light crude oil.

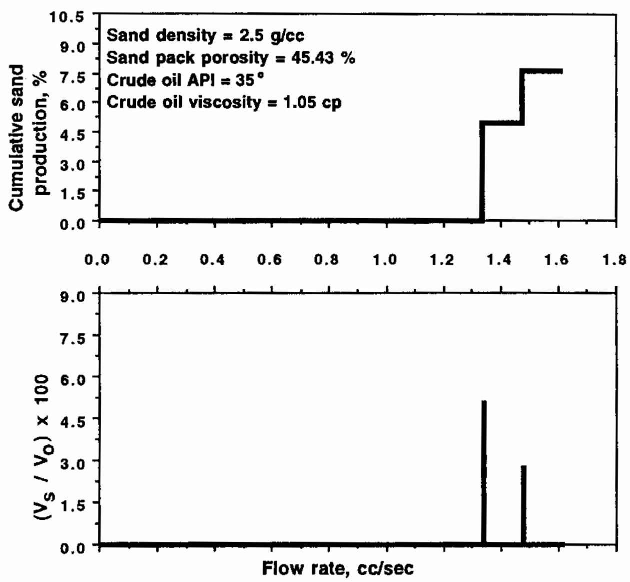


Fig. 18. Sand/Light oil ratio (by volume) and cumulative sand production % versus flow rate at CP = 8.0 MPa.

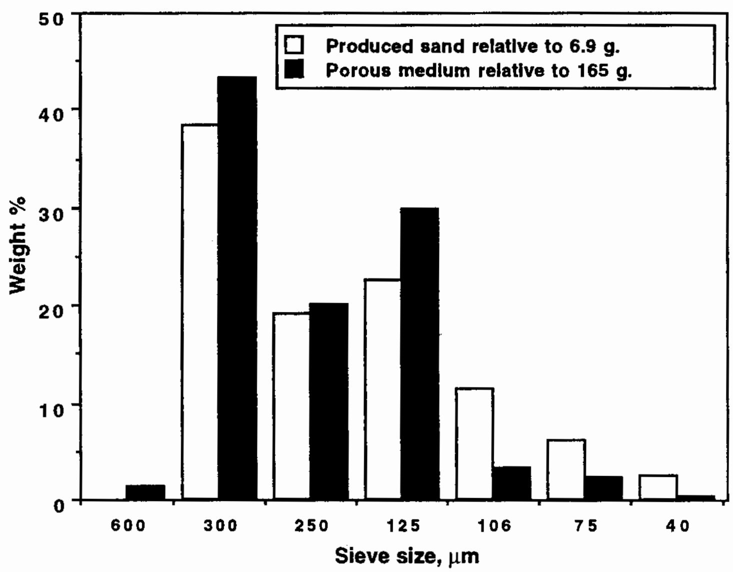


Fig. 19. Grain size distribution of sand produced and porous medium at CP = 8.0 MPa using light crude oil.

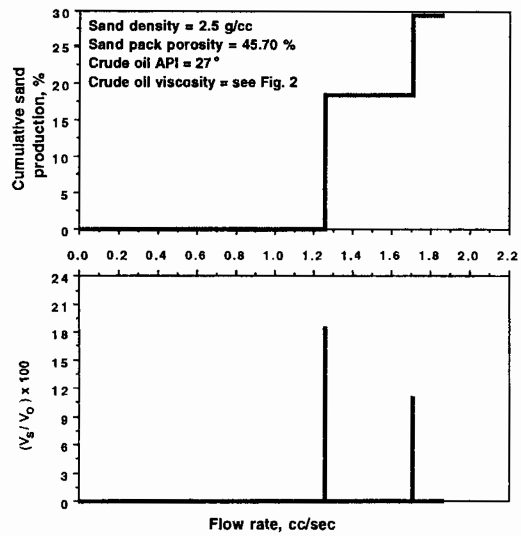


Fig. 20. Sand/Heavy oil ratio (by volume) and cumulative sand production % versus flow rate at CP = 0.0 MPa.

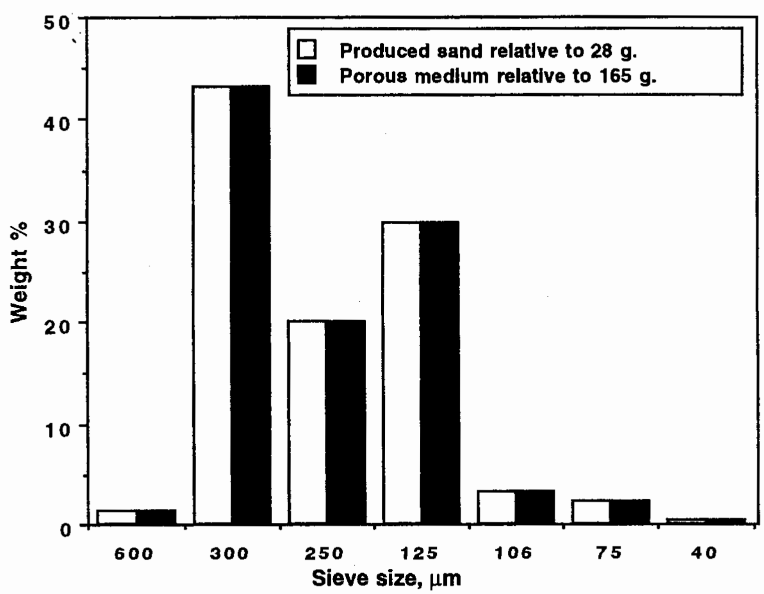


Fig. 21. Grain size distribution of sand produced and porous medium at CP = 0.0 MPa using heavy crude oil.

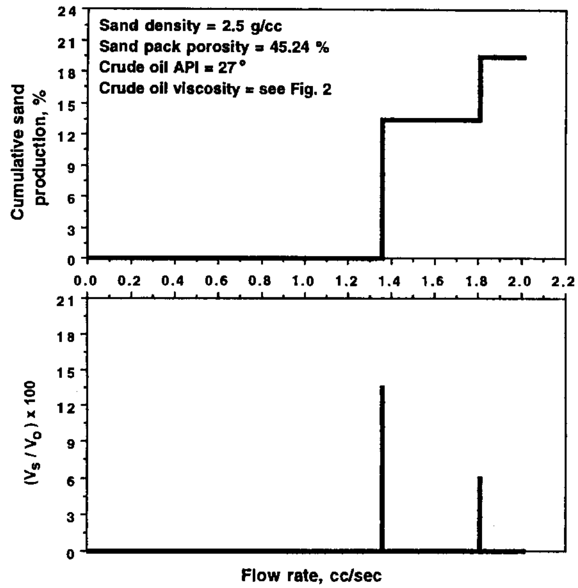


Fig. 22. Sand/Heavy oil ratio (by volume) and cumulative sand production % versus flow rate at CP = 2.5 MPa.

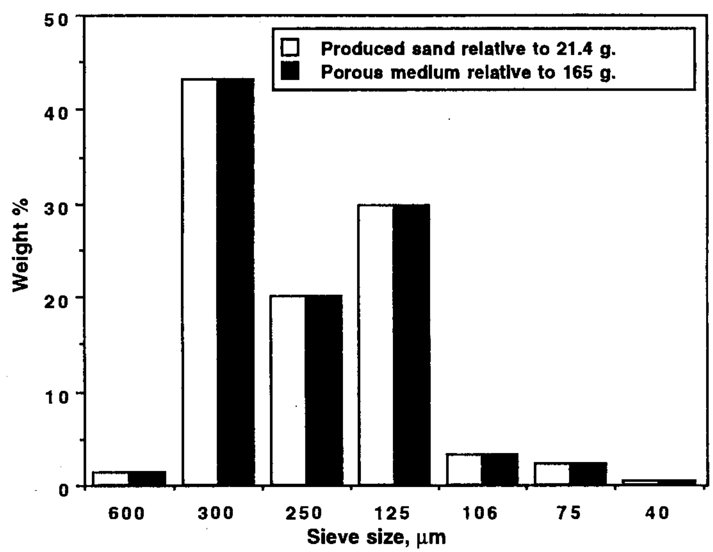


Fig. 23. Grain size distribution of sand produced and porous medium at CP = 2.5 MPa using heavy crude oil.

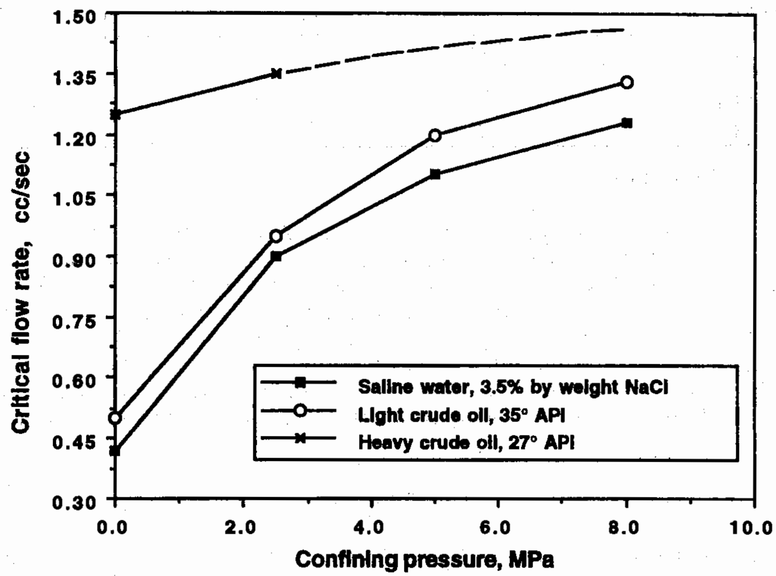


Fig. 24. Relationship between critical flow rate and confining pressure.

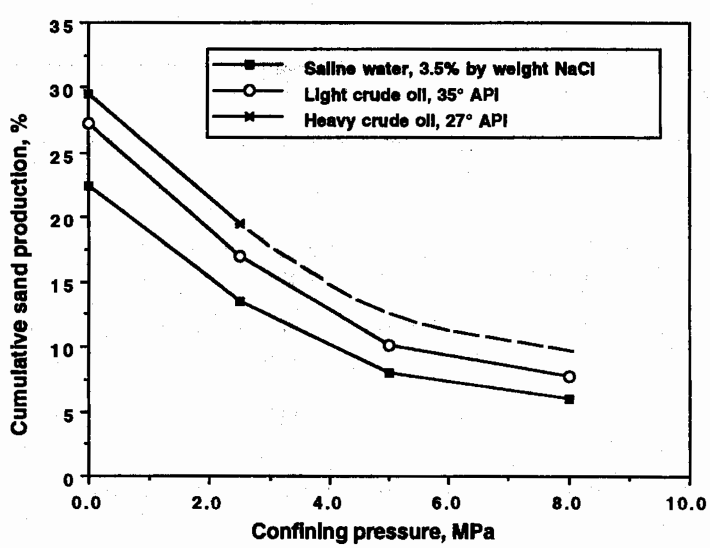


Fig. 25. Relationship between cumulative and production % and confining pressure.

Table 2. Summary of experimental results

Confining pressure, Mpa	Critical flow rates, cc/sec Saline water case	Light oil case	Heavy oil case
0.0	0.40	0.50	1.25
2.5	0.90	0.90	1.35
5.0	1.10	1.10	—
8.0	1.23	1.33	—

Effect of fluid viscosity

The formation fluid type (water or oil) greatly controls the sand production process. For constant flow rate and confining pressure, sand production using water as a displaced fluid is much smaller if compared to the case when heavy crude oil is used as the displaced fluid. This difference is attributed to the effect of higher drag forces generated by the more viscous crude oil as shown in Figs. 4 through 23. Thus, in the case of heavy crude oil, controlling sand production by controlling the flow rate is not effective because sand arches will collapse immediately after they have been formed. Therefore, the flow rate control method is not good enough to control sand production in heavy oil formations.

Conclusions

Based on the analysis of the experimental work conducted in this study, the following conclusions are arrived with:

1. Sand production from unconsolidated sandstone formations is strongly affected by the flow rate as well as the confining (com) pressure.

2. High sand-free flow rates can be achieved if the sand formation is mechanically confined (compacted).

3. The critical flow rates (saline water case) for sand production in the present study are 0.40, 0.90, 1.10 and 1.23 cc/sec for confining pressures of 0.0, 2.5, 5.0 and 8.0 MPa respectively.

4. The critical flow rates (light oil case) for sand production in the present study are 0.50, 0.90, 1.10 and 1.33 cc/sec for the same confining pressures.

5. The critical flow rates (heavy oil case) for sand production in the present study are 1.25 and 1.35 cc/sec for confining pressures of 0.0 and 2.5 MPa.

6. The grain size distribution of the produced sand in the laboratory is identical to that of the field sample.

7. At high confining pressure, only the small sand sizes are produced from the porous medium.

8. In case of water and light crude oil sand production can be controlled by managing the flow rate while it is impossible to control sand production from

heavy crude oil formation by managing the flow rate alone.

9. For unconsolidated sandstone formations containing heavy crude oil, it is necessary to apply other sand control methods such as down hole emulsification, gravel packing, or down hole solidification.

10. According to the confining pressure results, shallow formations results in larger sand production than those in deeper wells.

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العوامل المؤثرة علي إنتاج الرمل في مكامن النفط والغاز السعودية من الصخور الرملية المفككة

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(استلم في ١/٩/١٩٩٧م ؛ و قبل للنشر في ٧/١/١٩٩٨م)

ملخص البحث. تم في هذا العمل بناء أنموذج فيزيقي لمحاكاة إنتاج الرمل من مكامن النفط والغاز ، ويمكن للأنموذج احتواء عينات أسطوانية من الصخور الرملية المفككة والصلبة ،ولقد صممت التجارب لتوضيح تأثير كل من الضغط المحيط ومعدل السريان ولزوجة السائل المزاح علي ميكانيكية إنتاج الرمل من طبقات الحجر الرملي المفكك. استخدم في هذه الدراسة مياه مالحة بدرجة ٣,٥٪(ثلاث ونصف بالمائة) من كلوريد الصوديوم وزيت خام خفيف (٣٥درجة بمقياس معهد البترول الأمريكي) وزيت خام ثقيل (٢٧درجة) في تجارب الإزاحة . إن الهدف من هذا البحث هو اختبار مدي إمكانية التحكم في إنتاج الرمل بالتحكم في معدل الإنتاج في الحقول السعودية. وحيث إن المكمن المشار إليه موجود في طبقة حجر رملي مفككة ، فقد أحضرت عينة من الرمل المنتج من هذا المكمن وأجريت التجارب علي حشو رملي له نفس التوزيع التكراري لرمل المكمن.

أوضحت التجارب أن مقدار الرمل المنتج من الوسط المسامي المختبر تتأثر بدرجة كبيرة بكل من معدل السريان والضغط المحيط بالوسط، فإنتاج الرمل ينقص بزيادة الضغط المحيط ومعّدل السريان، كما أنه ينتج فقط الحبيبات الدقيقة من الوسط المسامي في حالة وجود ضغط محيط

مرتفع. وفي حالة تشبع الوسط المسامي بكل من المياه والزيت الخام الخفيف فإنه يمكن التحكم في كمية الرمل المنتج بالتحكم في معدل السريان . وفي حالة تشبع الوسط بالزيت الخام الثقيل تختلف ميكانيكية إنتاج الرمل ولهذا فإن التحكم في معدل السريان لا يوقف إنتاج الرمل من الوسط .لذا فإنه يلزم تطبيق وسائل أخري بديلة للتحكم في إنتاج الرمل من مكامن الزيت الخام الثقيل مثـــــل الاستحلاب في قاع الحفرة والحشو الحصوي والأنابيب المغطاة بشبكة دقيقة أو تصليد قاع الحفرة.