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Choosing an optimum sand control method

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Abstract Formation sand control is always one of the main concerns of production engineers. There are some different methods to prevent sand production. Choosing a method for preventing formation sand production depends on different reservoir parameters and politic and economic conditions. Sometimes, economic and politic conditions are more effective to choose an optimum than reservoir parameters. Often, simultaneous investigation of politic and economic conditions with reservoir parameters has different results with what is expected. So, choosing the best sand control method is the result of thorough study. Global oil price, duration of sand control project and costs of necessary equipment for each method as economic and politic conditions and well productivity index as reservoir parameter are the main parameters studied in this paper.

1. Introduction

The production of formation sand into a well is one of the oldest problems plaguing the oil and gas industry because of its adverse effects on well productivity and equipment. It is normally associated with shallow, geologically young formations that have little or no natural cementation to hold the individual sand grains together. As a result, when the wellbore pressure is lower than the reservoir pressure, drag forces are applied to the formation sands as a consequence of fluid production. If the formation's restraining forces are exceeded, sand will be drawn into the wellbore. The produced sand has essentially no economic value. On the contrary, formation sand not only can plug wells, but also can erode equipment and settle in surface vessels. Controlling formation sand is costly and usually involves either slowing the production rate or using control techniques [1].

Often, reduction in the production rate is not an economic approach to overcome sand production problem. So, it is preferred to use sand control techniques. Using sand control techniques accompany with additional equipment for well completion. Although this equipment prevents formation sand entering the wellbore by various mechanisms, it decreases the reservoir productivity. On the other hand, additional skin factor is caused due to sand control technique. This indicates that the magnitude of the skin is also an important parameter to choose a sand control method for a sand producer well. So, before choosing a method to prevent sand production, it is important to know the skin factor of the method and evaluate well production economically for a specific period. In this paper, skin factors of different sand control methods are investigated and indicated the best method for real case economically.

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Nomenclature

B_o	oil formation volume factor	r_l	length of gravel penetration into reservoir
D_{perf}	perforation diameter	r_w	wellbore radius
h	reservoir thickness	S_g	skin factor due to gravel pack
h_p	interval open to flow	S_{pp}	skin factor due to pre-packed screen
K_g	gravel pack permeability	S_{sl}	skin due to slotted liner
K_r	reservoir permeability	S_{ww}	skin due to wire wrapped screen
m	the number of slot rows	p_s	pressure drop due to skin factor
n	the number of perforation	μ	viscosity
q_o	oil rate	Ω	fraction open area

2. Skin factor due to sand control method

The aim of this section is investigation of skin factor formula for each common method of sand control which contains gravel pack method, slotted liner method, wire wrapped screen and prepacked screen.

2.1. Gravel pack method

Gravel pack is a common sand control technique used in many formations with unconsolidated or poorly consolidated sands. Sand production can often be readily achieved by proper sizing of the gravel with respect to formation sand size using well established rules. Sometimes, well consolidated formations can produce sand and hence gravel pack is employed in such formations for sand control.

There is a main factor which influences the production in gravel packed wells. It is flow restriction imposed by features of gravel pack. This factor affects the permeability and reduces it. So, gravel pack causes an excess skin which produces an extra pressure drop as a consequence of excess skin factor.

In fact, pressure drops because of the permeability changing from reservoir permeability to gravel permeability. The additional pressure drop across the gravel zone is [2,4]:

$$\Delta P_s = \frac{141.2 q_o B_o \mu_o S_g}{k_r h} \tag{1}$$

where S_g is:

$$S_g = \frac{h}{h_P} \ln\left(\frac{r_w}{r_l}\right)\left(\frac{K_r}{K_g} - 1\right) \tag{2}$$

In the above equations, K_r is reservoir permeability, K_g is gravel permeability, h is reservoir thickness and h_P is interval open to flow. The above equation for gravel skin is not completely correct. There is another equation for this skin that is more precious [3]

$$S_g = \frac{96 \frac{K_r}{K_g} h L_P}{(D_{perf}^2) n} \tag{3}$$

where L_p is gravel perforation length, D_{perf} is perforation diameter and n is number of perforations.

Table 1 Fluid and reservoir data.

Reservoir pressure	27.74 MPa
Solution GOR	323 m^3/m^3
Oil gravity[a]	37°API
Gas gravity[a]	0.73 sp gr
Oil viscosity[a]	0.0017 Pa s
Oil FVF[a]	1.954 m^3/Sm^3
Reservoir temperature	110 °C
Bubble point pressure	16.71 MPa
Drainage area	7.65 km^2

[a] Measures at reference pressure 3100 psi

Table 2 Well Data.

ID producing tubing	0.08 m
Top of producing sand face	2868.168 feet
Wellhead temperature	25 °C
Production fluid	Oil
Thickness of producing layer	45.72 m
Wellbore radius	0.1524 m
Wellhead pressure	4.82 MPa

2.2. Slotted liner method

Slotted liners have been used for many years to provide sand control in many oil industry applications. This consists of steel pipe (e.g. tubing) where a series of parallel slots have been cut through the metal. The width of these slots is normally made as small as mechanically practical so that they will retain a large fraction of the formation sand as much as possible. The inflow area is low (2–3% of pipe surface area). Due to the restriction of the inflow area, the flow pattern will deviate from idealized redial and uniform axial distribution. One can represent a skin factor for the deviation of ideal flow as follows:

$$S_{sl} = \frac{2}{n} \ln \frac{2}{\pi \Omega} \tag{4}$$

where n is the number of slot rows and Ω is the open fraction of the pipe. Usually this method is cheap and easy to apply but it does not work well for sand controlling projects.

Table 3 Well test data and correlations.

Skin factor	8.3
Reservoir permeability	53 md
P_b, R_s, B_o correlations	Standing method
Viscosity correlation	Beggs et al. method

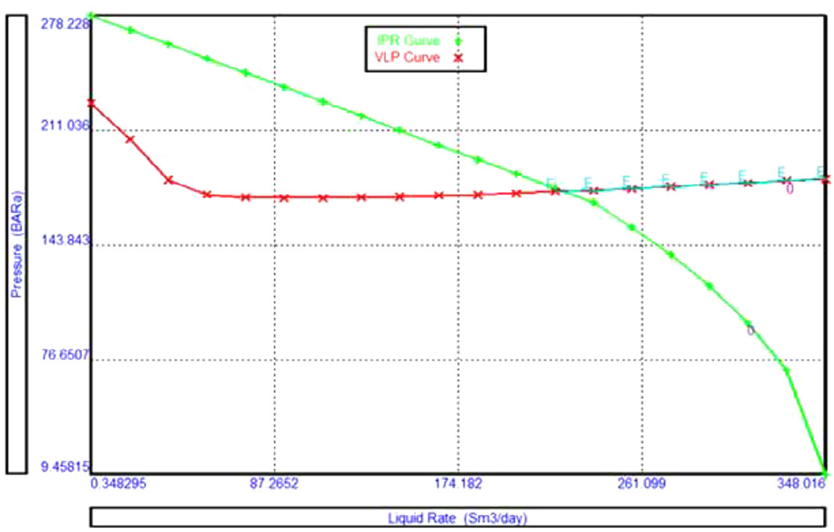

Figure 1 Production system for open-hole state.

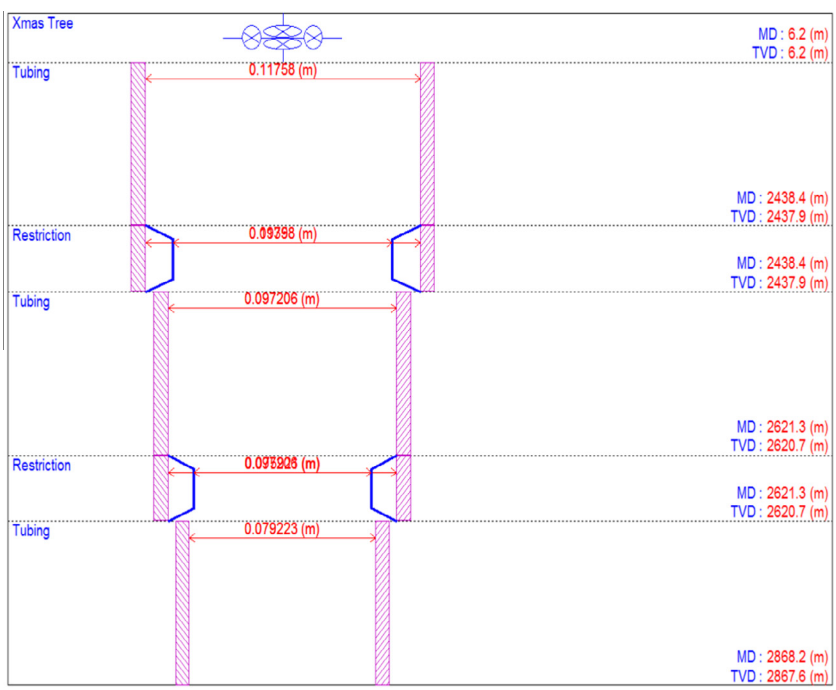

Figure 2 Situation of downhole equipment.

2.3. Wire wrapped screen

This method consists of a triangular shaped wire which is carefully wound so that there is a constant gap between successive turns. It is held in place by spot welding the wire to vertical formers placed at 1 cm intervals around the internal diameter of the screen. Wire wrapped screens have the advantage over a slotted liner that the gap between the wires can be made smaller and be held to the target value with a much greater accuracy; allowing the screen to retain finer grained formations than the slotted liner [4].

In the literature, there is no explicit formula to calculate the skin due to applied wire wrapped screen in the wellbore. In fact, wire wrapped screens are a kind of slotted liner with horizontal slots but they have more inflow in open area. Wire wrapped screens have horizontal gap between them and one

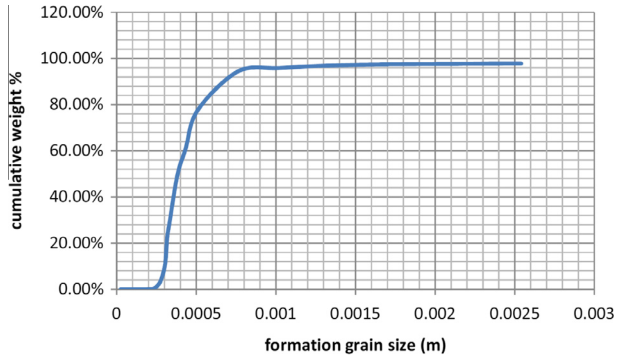

Figure 3 Formation grain size distribution (adapted from Iranian offshore oil company).

can use Eq. (4) for skin factor due to wire wrapped screens. Eq. (2) can be used too. But outside permeability of screen is used instead of gravel pack permeability.

2.4. Pre-packed screen

Pre-packed screens are constructed from two concentric screens with a layer of gravel placed in between them. The gravel had been coated with a layer of thermosetting resin. The construction process is as follows [5]:

(i) The dual concentric screens have been welded onto the base pipe.
(ii) The gap between them is filled with the resin coated sand and the final welds made.
(iii) The completed screen is placed in an oven where the thermosetting resin, hardens creating a strong ring of gravel.

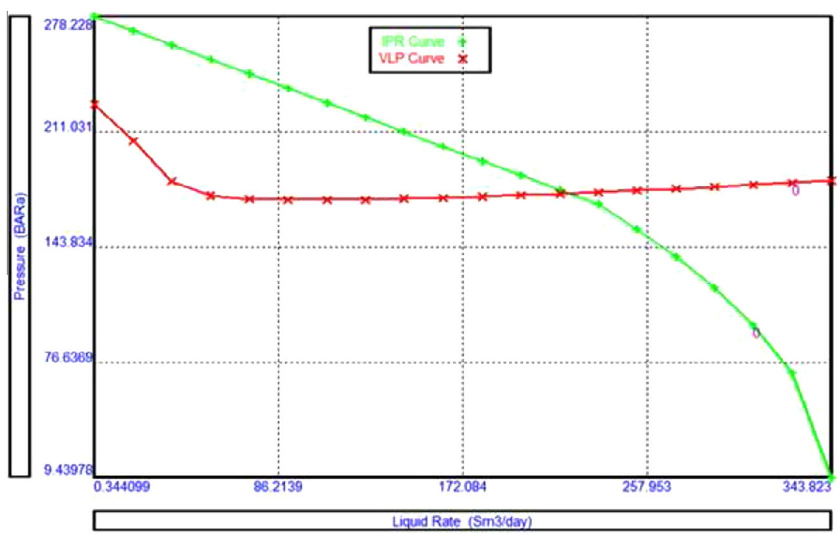

Figure 4 Production system for gravel packed completion.

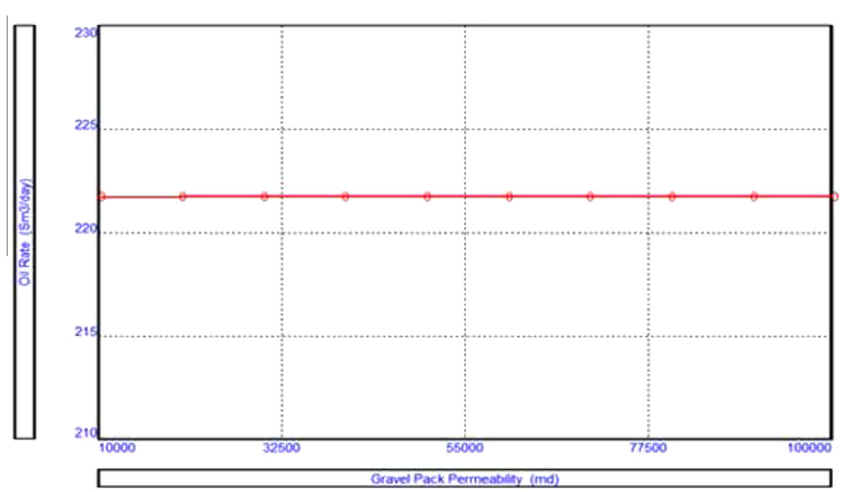

Figure 5 Variation of operating oil rate vs. gravel pack permeability.

Table 4 Gravel pack properties for sand control completion.

Mesh size	30/50
Permeability	90 D
Length of penetration	0.0508 m

Table 5 Slotted liner properties for sand control completion.

Liner inner radius	0.0762 m
Liner outer radius	0.0814 m
Slot height	0.1524 m
Slot width	0.000762 m
Number of slot rows	10

The pore throats of the consolidated gravel provide a series of narrow openings which provide the sand exclusion and retain the formation in place. The presence of the gravel, with its narrow pore throat diameter, provides a greater flow restriction than the wire wrapped screen alone; as well making the screen susceptible to plugging by formation fines etc. The greater complexity of the prepacked screen increases the cost [6].

The skin due to pre-packed screens is the combination of skin due to gravel and skin due to screen around the gravel (whether wire wrapped screen or slotted liner screen) [4]

$$S_{pp} = S_g + S_{ww} \quad (5)$$

3. Model description

In this section, the production system of the real well of Iranian field will be investigated which has potential of sand production and causes many problems on the surface equipment. Different strategies for completion of this well can be designed; however, the purpose is to design a way which results in maximum economic profit. In other words, the difference between costs of implementation of sand control completion and the benefits of oil production after that should be maximized. This is not true that the method for less skin effect is

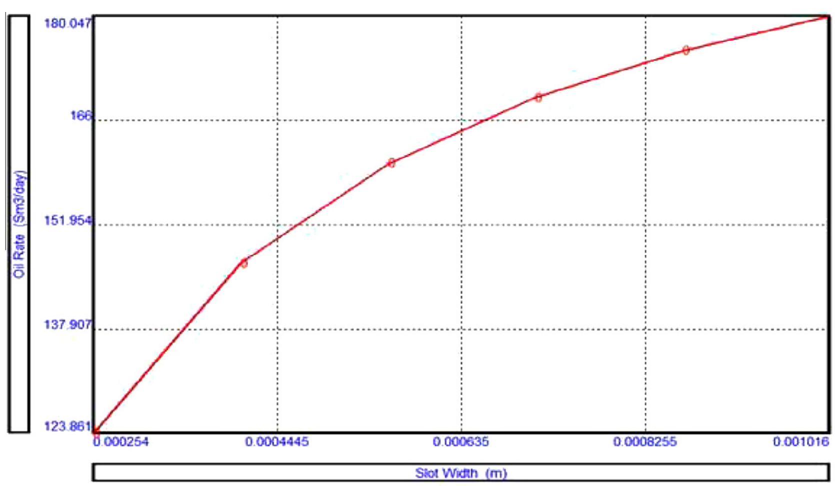

Figure 6 Variation of oil rate vs. slot width.

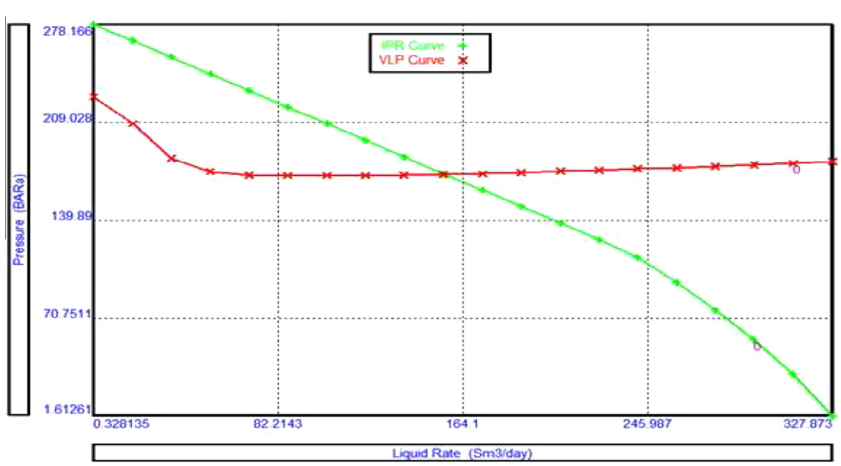

Figure 7 Production system for slotted liner completion.

Table 6 Wire wrapped screen and pre-packed screen properties.

WWS properties	
Screen inner radius	0.067 m
Outside permeability	1000 md
Pre-packed screen properties	
Screen inner radius	0.054 m
Screen outer radius	0.08128 m

the best one for completion and as said before, an economic evaluation is the last and the most important step for choosing.

For this work, reservoir data and well data are available in Tables 1 and 2 respectively. Also, well test data and correlations that are used for calculation of PVT properties and pressure drop in well are available in Table 3. Inflow and outflow performance relations are calculated by a common well and reservoir simulator and its results are shown in Fig. 1. Also, Fig. 2 shows the situation of down-hole equipment.

The well history production shows that the completion needs equipment for sand control; so, skin due to sand control method, costs of implementation of sand control completion, and cumulative oil production after using the methods must be evaluated simultaneously and then the best scenario is chosen.

3.1. Open-hole completion (without sand control equipment)

As regards history data, sand production is almost 910 lb per day. Simulation of oil production through downhole equipment shows that there is erosional flow at operating rate due to sand production (Fig. 1). So, sand production must be omitted and sand control methods are required.

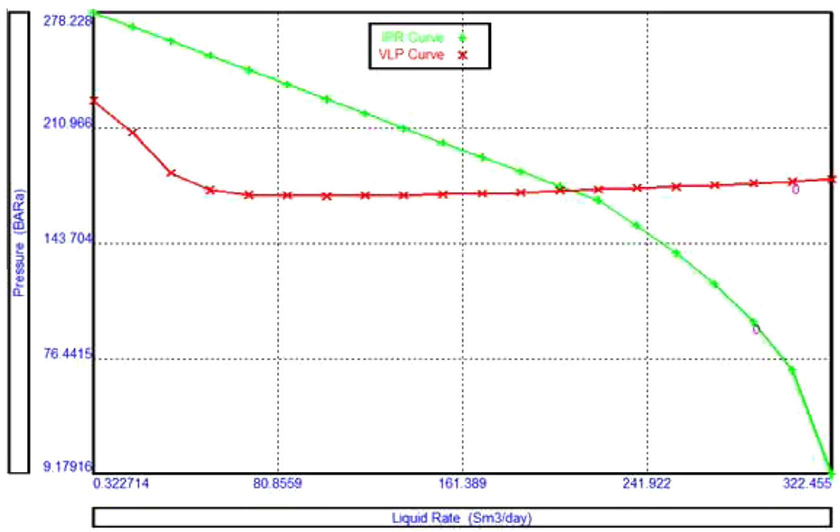

Figure 8 Production system for wire wrapped screen completion.

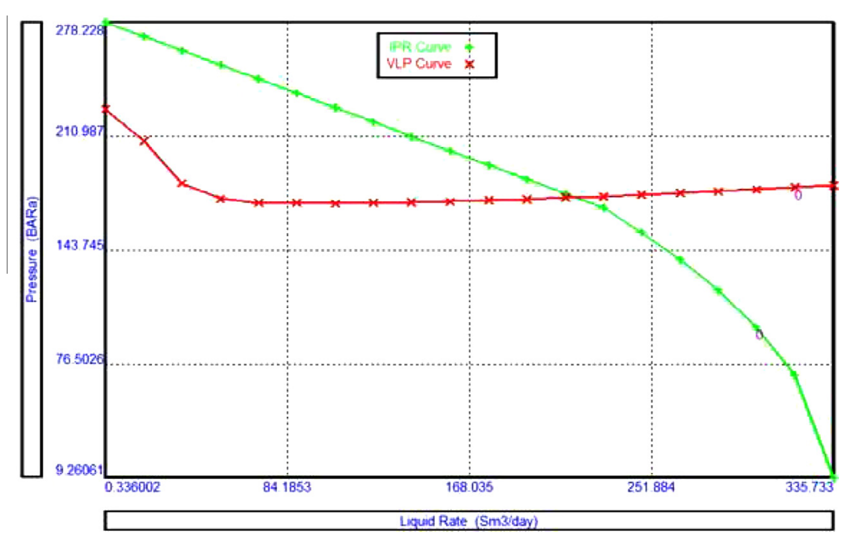

Figure 9 Production system for pre-packed screen completion.

Table 7 Summary of calculated data for all of the sand control methods.

Sand control type	Production rate at operating point	Total skin factor
Gravel pack method	1410	8.7
Slotted liner method	1078	14.8
Wire wrapped screen method	1310	10.2
Pre-packed screen method	1370	9.5

3.1.1. Gravel packed well completion

Important parameters in design and investigation of gravel packed well are gravel size or mesh size and gravel pack length or penetration of gravel in formation. These parameters directly influence gravel pack permeability and consequently affect oil production rate. Existence of gravel in the well causes additional skin (gravel pack causes non-Darcy flow which can be neglected for oil flow).

According to Fig. 3, formation sand size is about 0.00032–0.00125 m in diameter which indicates formation has a sort of coarse grains. As regards this information, gravel pack is chosen by properties available in Table 4. Using a simulation of gravel pack application in the well, skin factor due to the sand control method equals to 0.4 and IPR and OPR curves show that the operating rate reduced to 225 m^3/day (Fig. 4). Results show that skin factor due to gravel is more sensitive to non-Darcy coefficient than gravel permeability. Because of oil flow in gravel pack non-Darcy effect is negligible and as it can be seen in Fig. 5 operating oil rate does not change with a variation of gravel permeability in long range. It can help the designers to choose cheaper gravel for gravel packing operation because gravel permeability is one of the parameters which effects gravel price.

Table 8 Approximate costs of sand control equipment and operations.

Equipment and operations	Cost (1000$)
Gravel pack method	
Necessary tools	400
Perforation or under reaming	600
Fluids and gravels	1000
Pump	1500
Rig time (30 days)	30×20
Gravel pack placement operation	6000
Man power	300
Gravel pack replacement (total cost)	8000
Slotted liner method	
Slotted pipe (3 branches)	3×300
Rig time (10 days)	10×20
Man power	80
Work-over operation	400
Wire wrapped screen method	
Screen (3 branches)	3×800
Rig time (10 days)	10×20
Work-over operation	400
Pre-packed screen method	
Screen (4 branches)	4×1200
Rig time (10 days)	10×20
Work-over operation	400

3.1.2. Well completion with slotted liner

As said in the previous section, slotted liners are pipes including horizontal or vertical slots. Slot width, slot height, number of slot per foot, and inner diameter of the screen are the main parameters which have considerable effect on the production rate. It is obvious if changing these parameters increases production rate, decreases skin due to presence of slotted liners. In designing of slotted liners, slot width must be small enough

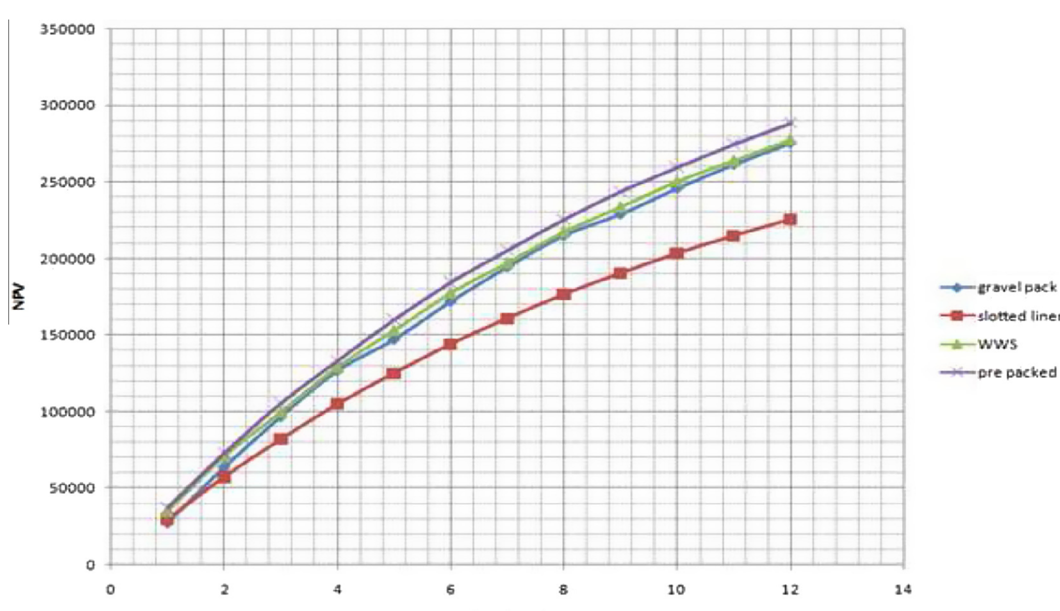

Figure 10 NPV plot for 12 years and discount rate of 10%.

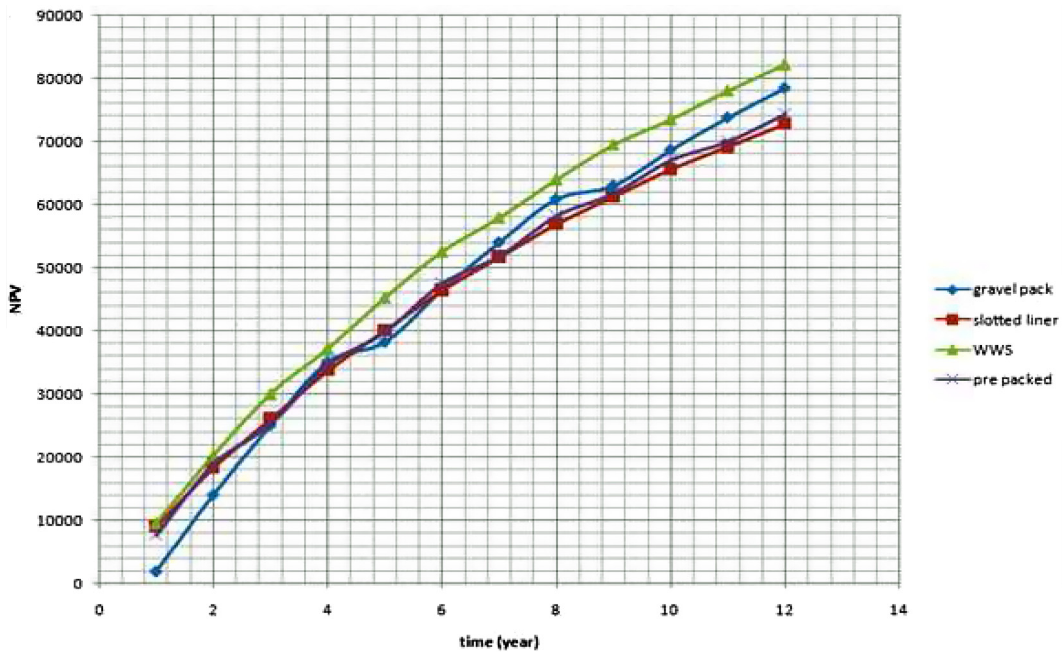

Figure 11 NPV plot for a low PI reservoir.

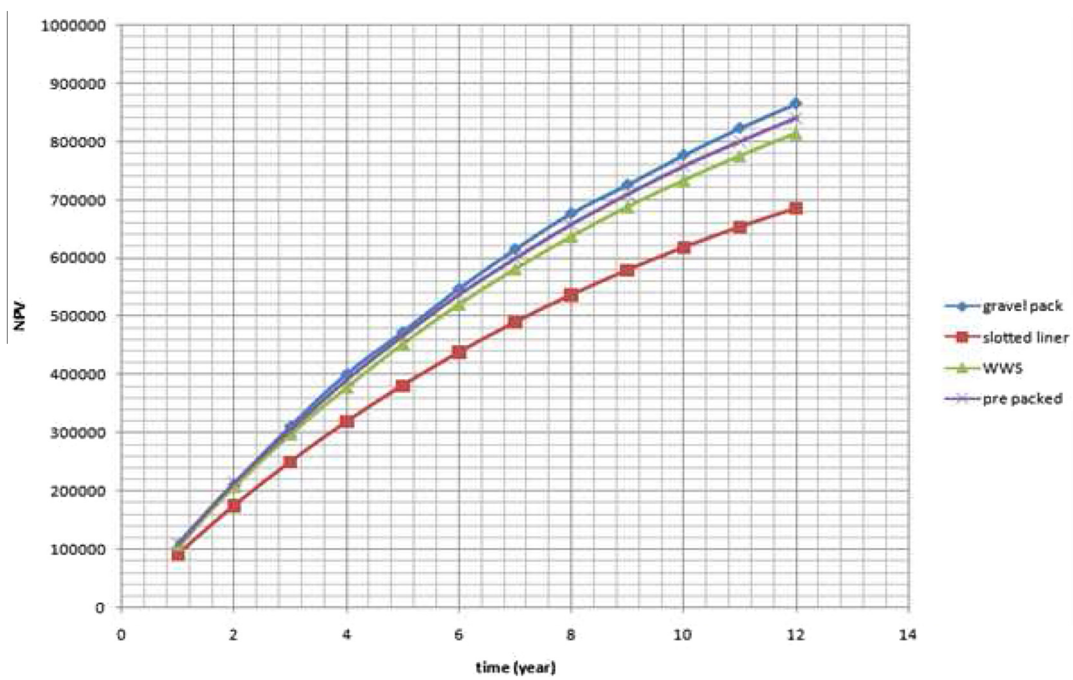

Figure 12 NPV plot for a high PI reservoir.

to prevent sand production properly. On the other hand the smaller the width, the larger the skin. So, slot width must be in optimum size. Fig. 6 shows the relation between slot width and rate of operating point.

According to formation grain size distribution and relation which is shown in Fig. 6, the proper slot width will be 0.003 m. The properties of designed slotted liner for sand control project are available in Table 5.

As regards simulation of sand control project using slotted liner, production rate at operating point and the skin caused by sand control, is 171.5 m^3/day and 6.1 respectively (Fig. 7).

3.1.3. Well completion using wire wrapped screen

Using wire wrapped screens causes skin like other methods which depends on inner diameter and open fraction area of

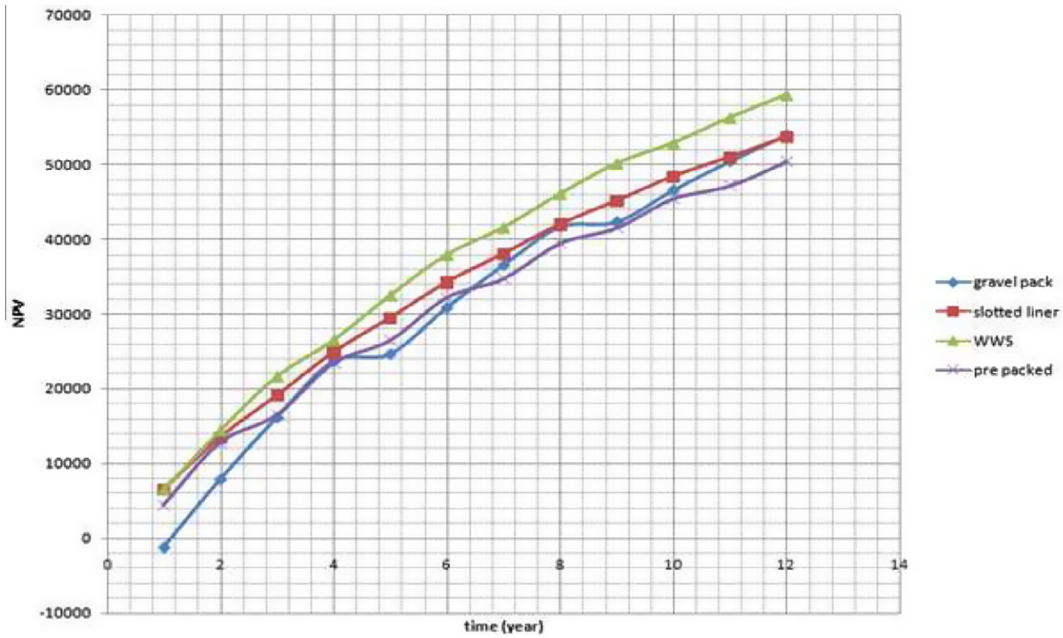

Figure 13 NPV plot for 20 $/bbl oil.

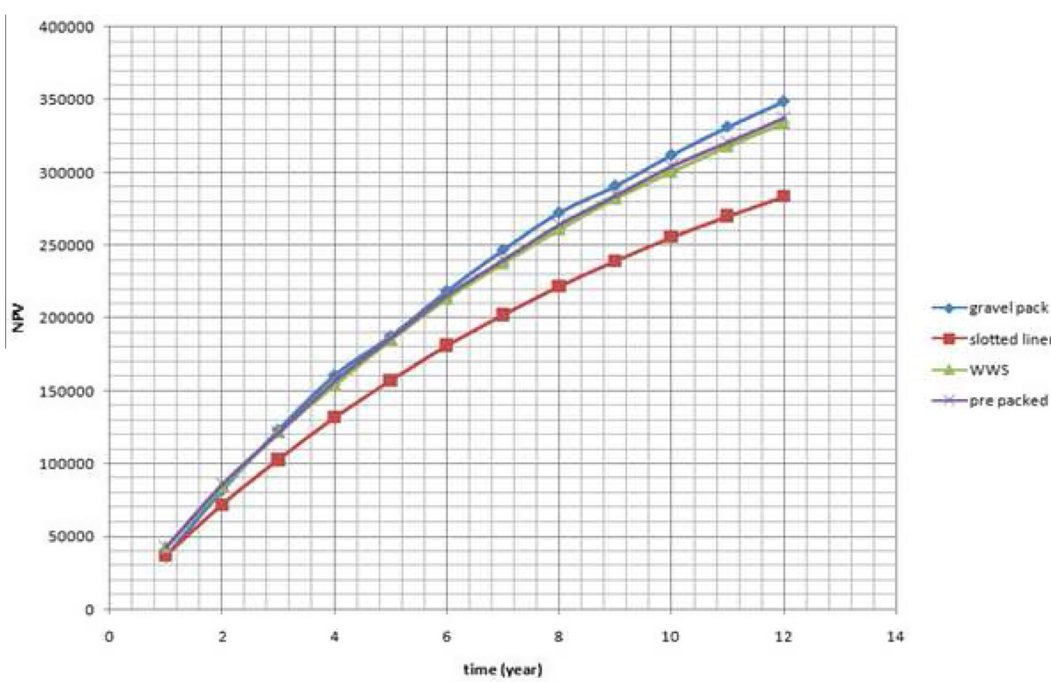

Figure 14 NPV plot for 100 $/bbl oil.

the screens. Usually, the skin of wire wrapped screen is less than slotted liner's, because open fraction area of WWSs is higher than slotted liners. The characteristics of wire wrapped screen used in wellbore are available in Table 6.

Fig. 8 shows the inflow and outflow performance relations when wire wrapped screen is used for sand control. As it can be seen, production rate at operating point is 208 m^3/day and its skin is 1.9.

3.1.4. Sand control using pre-packed screens

This method is more expensive compared to others. Using pre-packed screens with characteristics available in Table 6, causes reduction of production rate to 218 m^3/day, as it is shown in Fig. 9. All of the important calculated data for each method are available in Table 7 and a general comparison is possible. This table says the best method is gravel pack completion while it is not true.

4. Economic evaluation

As said before, the skin value and the operation rate are not the only main parameters for choosing the best project. Economic evaluation is the most important step of deciding. In this section, it is tried to compare all methods economically by using approximate operating cost of any method. Finally, the best project will be found.

Table 8 provides the typical approximate operation expenditures, which are necessary for economic evaluation, for all sand control methods. Also, oil barrel price should be known. It is assumed as 80 $/bbl. Other assumptions are as follows:

- Gravel packed completion is required for replacing gravel pack every 4 years.
- For maximizing the efficiency, slotted liners should be replaced by other liners every 2 years.
- Wire wrapped screens should work over operation every year and must be replaced every 2 years.
- Pre-packed screens should work over every year and should be replaced every 2 years.
- Discount rate is assumed to be 10%.

Figs. 10–14 are Net Present Value (NPV) plot of 12 years for different parameters. Fig. 10 shows the pre-packed screen method is the best while according to simulation the operating rate of gravel pack completion is higher than its. Fig. 11 is NPV plot for a reservoir with less productivity index value rather than the described reservoir in this paper. Results show wire wrapped screen is the best sand control method and the pre-packed screen method is the worst one.

Fig. 12 is NPV plot for a reservoir with high PI value rather than described reservoir. As it can be seen gravel packing is an acceptable method. Figs. 13 and 14 show the effect of oil price on choosing the best sand control method. When benefits are low the wire wrapped screen is the best while for high benefits gravel pack will be chosen. These analyses show that global oil price, time of capital return, and reservoir productivity index are more important than the sand control skin effect, especially for low oil production rate.

5. Conclusion

1. Any sand control equipment has some characteristics that their variations will affect both their price and magnitude of skin caused by them.
2. A method with less skin effect is not essentially the best sand production control method.
3. At low production rate and for low PI reservoirs, choice of suitable method is influenced by global oil price and investment interest rate. In other words, choice of suitable method is not directly affected by the well skin.
4. At high PI reservoirs and for long-time project, the best method is the one that has higher oil production. So, the skin value has an intense effect on choosing the sand production method.
5. According to economic condition the best sand control project for the described well and reservoir is the wire pre-packed screen method.

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