Numerical Assessment of the Impact of Sand Control Techniques on Production in a Vertical Well

ABSTRACT

This study considers a vertical well producing initially without sand control technique in sandstone reservoir in the Niger Delta region. The study uses the data and information of two wells and applied PROSPER to numerically quantify the impact of the extra flow restriction caused by the gravel pack and slotted liner systems respectively. Well model was constructed and several simulations runs performed on key influencing production parameters (production rates, superficial velocities, skin development, pressure losses) and sand control design variables (gravel pack length, gravel pack permeability, slot height and slot width). The study involved two different sand control for two wells (Well X1 and Well X2) which were similarly completed and subjected to the same reservoir and operational conditions. The influence of sand control parameters on the vertical lift performance and inflow performance characteristics of the wells were analyzed at varying first node pressure (500psig – 1400psig). The solution node was set at bottom hole to enable proper diagnosis of the influence of the sand control options on the VLP/IPR relationships. At base case scenario, the gravel pack oil and gas production rates were 8010.0STB/day (ORAT) and 6.008MSCF/day (GRAT) at a flowing bottomhole pressure of 4231.38Psig while the slotted liner was 8010.0STB/day (ORAT) and 6.008MSCF/day (GRAT) at a flowing bottomhole pressure of 4231.38Psig at a flowing bottomhole pressure of 4231.38Psig of 3902.46Psig. The resulting skin due to sand control were 0.0070375 and 0.18 respectively. Result shows that Slotted Liners provides better sand control than gravel packs but causes more pressure drop in the system due to sand control method. Furthermore, Gravel pack permeability and length and slot dimensions have most remarkable influence on the pressure drop due to sand control and can play a crucial role in the choice and design of any gravel pack system and slotted liners respectively. It's advisable or better that Gravel pack permeability should not exceed 500000md for optimal performance as a sand control device. The work recommends the use of higher slot width to slot height for more efficient production using slotted liners while smaller gravel permeability could be preferred for better sand control with gravel pack systems.

Keywords: Sand Production, Sand Control, Gravel Pack, Slotted Liners, Skin, Flow Rate

1. INTRODUCTION

In approximately 70% of the world's oil and gas fields, load bearing solids management is a critical challenge throughout field development. Sand management is about optimizing and maintaining output while controlling sand at appropriate rates, not merely about selecting sand control technologies. Operators pay millions of dollars each year to avoid formation sand production and to address other sand-related issues. Clearly, such large expenditures have a huge influence on profitability. Despite these expenses, successful sand-control measures have resulted in the production of oil and gas from wells that would otherwise have been shut down [1]. When it comes to sand management or formation solids control, it's important to distinguish between load-bearing solids and small particles (fines) that aren't normally a component of the formation's mechanical structure. Some fines are almost certainly always created with well fluids, which is good since fines that move freely through the gravel pack do not block it, and therefore "sand control" refers to the control of the loadbearing particles that sustain the overburden. The most important issue to consider when analyzing the risk of sand

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production from a well is whether or not the production of load bearing particles can be kept below an acceptable level at the projected flow rates and producing circumstances.
The resultant forces operate to hold sand grains in place, opposing the fluid forces. Inter-granular bonding (natural consolidation), inter-granular friction, gravity forces, and capillary forces all contribute to these forces. Internal pore pressure (reservoir pressure) aids in the weight support of the overburden, relieving part of the tension on the sand grain. The inter-granular connections are the most essential component in avoiding sand generation among these factors. The intergranular bond is most likely best measured by the compressive strength of formation sand [2]. A formation with a compressive strength more than 1000 psi will normally deliver sand-free results if proper completion and production methods are followed. The only exception is if the pressure decline surrounding the well is really significant. However, if the pressure drop is low enough, sands with lesser compressive strength may give sand-free results. The formation consolidation breaks down when an oil well is produced at a pace that causes the well flowing pressure to be lower than the formation collapse pressure, and sand tends to drift toward the wellbore [3-4]
The use gravel packs in sand control were originally restricted short formation length intervals due to technical issues associated with proppant transport its placement. With the advent of alternate path technology, it became possible to place gravel packs up to 1000meters interval [5-6]. More recently, Colbert et al [7] reported the use of gravel packs for formation interval 1000 – 2000 meters in heavy oil wells with aid of advanced friction reducers and light weight proppants. On a field scale, the use of gravel packs is targeted to vertical wells despite possible success stories shown by pilot investigations in horizontal wells [8]. On the other hand, slotted liners have found special applicability in horizontal well technology and wells producing at very high rates and/or associated with well sorted sands [9]. Besides flow restrictions due to excessive sand control, Romanova & Ma [10] has shown that corrosion is a severe threat to the use of slotted liners. This has necessitated the use of surface coatings such as High-Phosphorus Ni-P to reduce the corrosion tendency (Sun et al. 2018).
Despite extensive works already done on the issue of sand control and management, approach to these techniques mostly relies on recommended rule of thumb applicable to the field in question. It has already been established that the installation of gravel packs or slotted liners would remarkably impact the well. However, the specific extent of these impact on a particular well of consideration has barely received the needed attention by past experts thereby subjecting the field experts to excessive guess-works which in severe cases could result to the permanent loss of the well and its equipment.

2. METHODOLOGY

A numerical simulation technique has been proposed for assessing the potential impact of excessive sand production control measures of a two case study wells: **well X1** considered for gravel packing and **well X2** considered for use of slotted liners. The numerical simulator used is the Petroleum Experts ***Pro**duction **S**ystem **Per**formance* software (**PROSPER**). For the scope of this work and following recommendations from past literatures, the bottomhole point was selected for the analysis to provide key diagnostic insights on the contribution of the reservoir dominated system and the well/tubing dominated system on the production performance. Hence, the impact of sand control devices (gravel pack and slotted liner) on the IPR and ultimately, the VLP can be effectively characterized. The method of analysis used in this work is comparative. The two case study wells were similarly completed and subjected to the same reservoir and operational conditions. The influence of sand control parameters on the vertical lift performance and inflow performance characteristics of the wells were analyzed. The solution node was set at bottom hole to enable proper diagnosis of the influence of the sand control options on the VLP/IPR relationships. The summary of the parameters analyzed are presented in the Table 1 below.

Table 1: Optimization Parameters for Assessing Well Performance

Description	Parameter
Primary Variables	IPR-VLP plots
	Oil Rate
	Gas Rate
	Water Rate
	Last Node Pressure
	Solution Node Temperature
	Skin factors
Sensitivity Runs	Gravel pack length
	Gravel pack permeability
	Perforation density
	Slotted liner screen size
	First node pressure
	Pressure drops due to skin
	Mesh size/critical velocity plots

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3. RESULTS AND DISCUSSION

3.1 Analysis of Well Performance and Production Constraints

The case study well model used in the study produces via tubing flow from a cased hole. Several sensitivity runs were performed to analyze the impacts of key design parameters such as first node pressure; gravel pack length and gravel pack permeability. For the slotted liner option, the key design parameters analyzed included the slot height and the slot width. The parameters considered for comparative analysis were the oil flow rate, gas flow rate, flowing bottomhole pressure, pressure drop due to sand control, sand control skin, total skin, superficial liquid velocities and superficial gas velocities.

a. The Well Production Rates

Figures 1 and 2 show the IPR-VLP characteristics plots of the sand control option at base scenarios of Gravel pack option and Slotted liners respectively. As clearly shown in the figures, it could be easily understood that despite the efficiency of slotted liners in sand control, they may not always be the preferred sand control option as result of its significant impact of the well production.
The lack of intersection of the IPR curve with the Liquid Rate axis in Figure 2 suggests that the slotted liner option results in an infinite AOF. This value only has qualitative relevance and hence, indicate that the well's ideal potential has been remarkably impacted.

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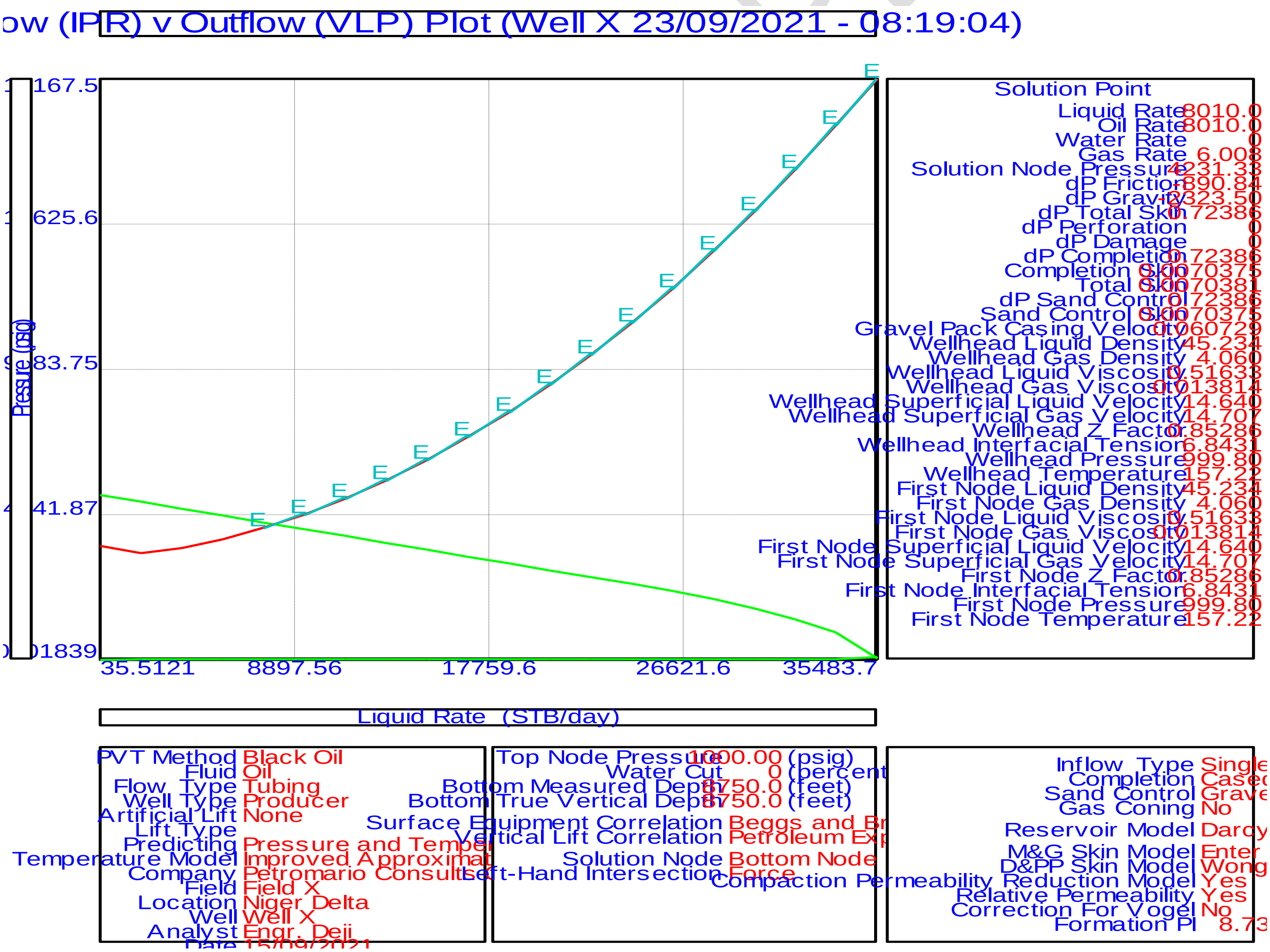

Fig. 1. **IPR-VLP Plot of Gravel Pack Option – Base Case**

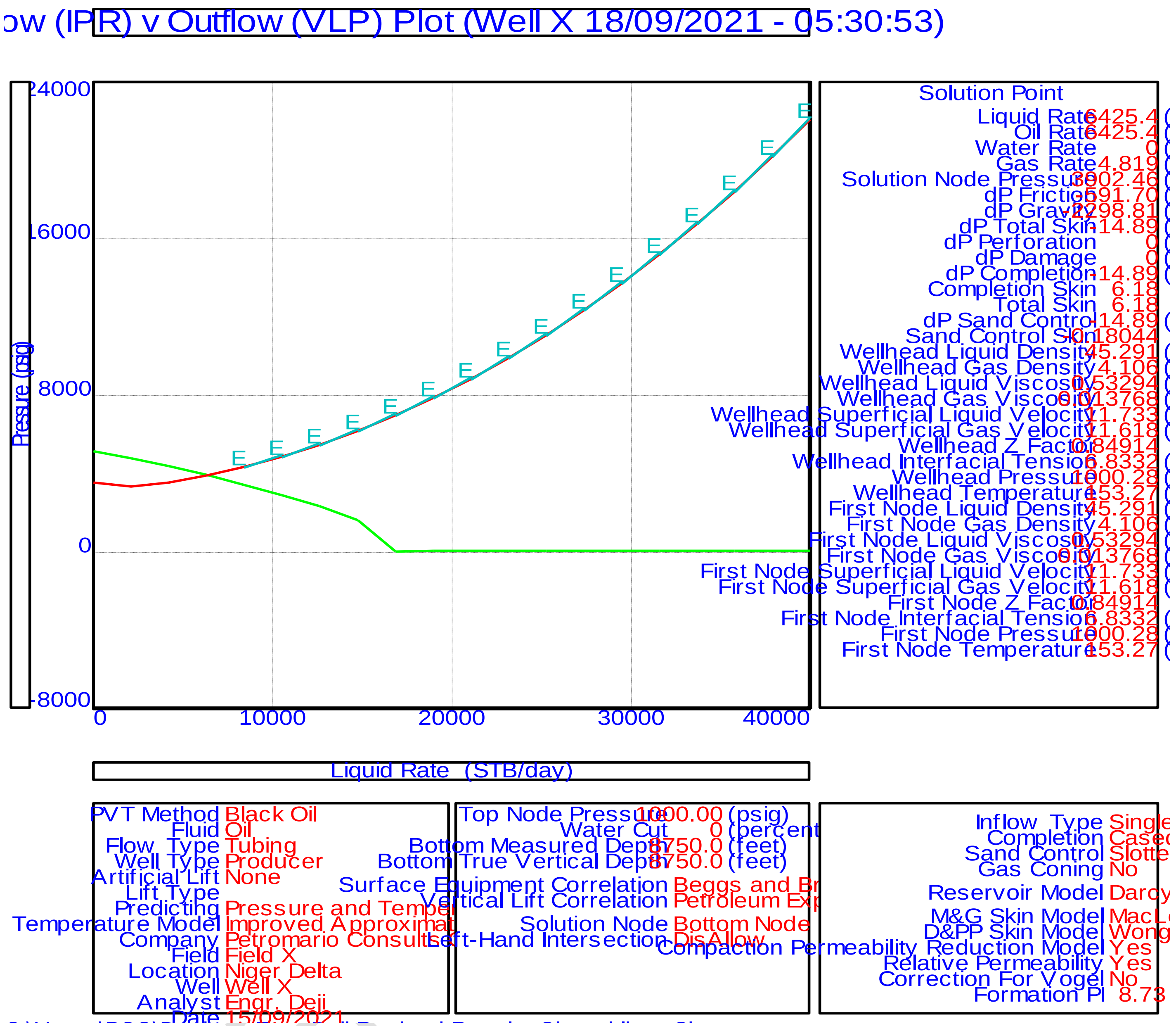

Fig. 2. **IPR-VLP Plot of Slotted Liner Option – Base Case**

The resulting effects on the oil and gas flow rates for both sand control options are presented in Figure 3 below. From the ongoing analysis, it has been shown that the gravel pack option exhibited consistent superior performance over the slotted liner option.

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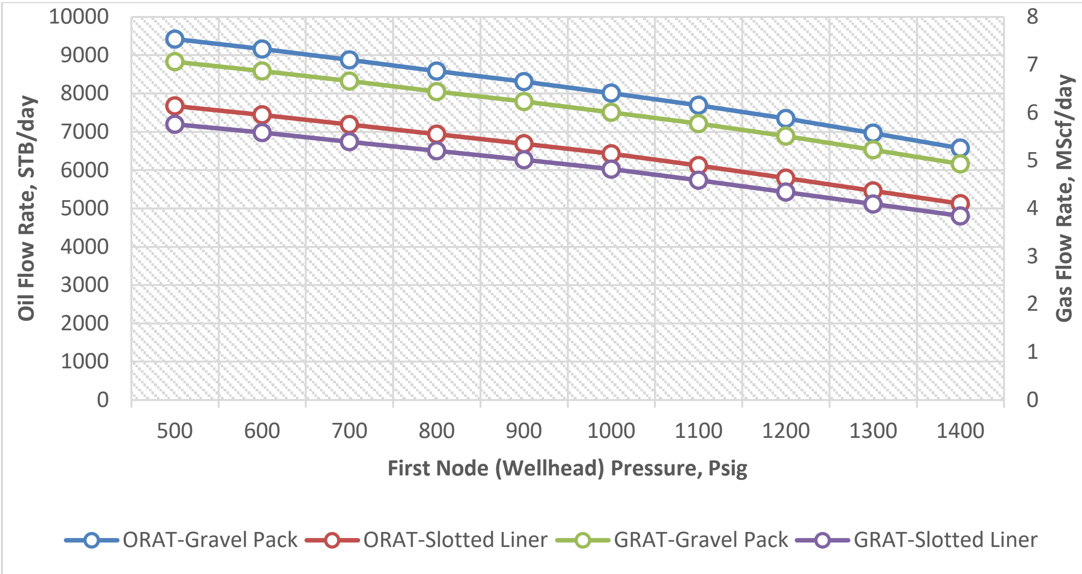

Fig. 3. Effect of Wellhead Pressure on Oil and Gas Production Rates

b. Effect of First Node Pressure on Pwf and ΔP Sand Control.

It is a known phenomenon that shutting down a well will result in pressure build in the liquid loaded well caused by flow-after-flow effect. Hence, increasing the value of Pwh characteristically increases the value of the Pwf as a result of back pressure effect. The result in Figure 4 depicts the typical behavior of Pwh-Pwf relationship for each of the two sand control options.

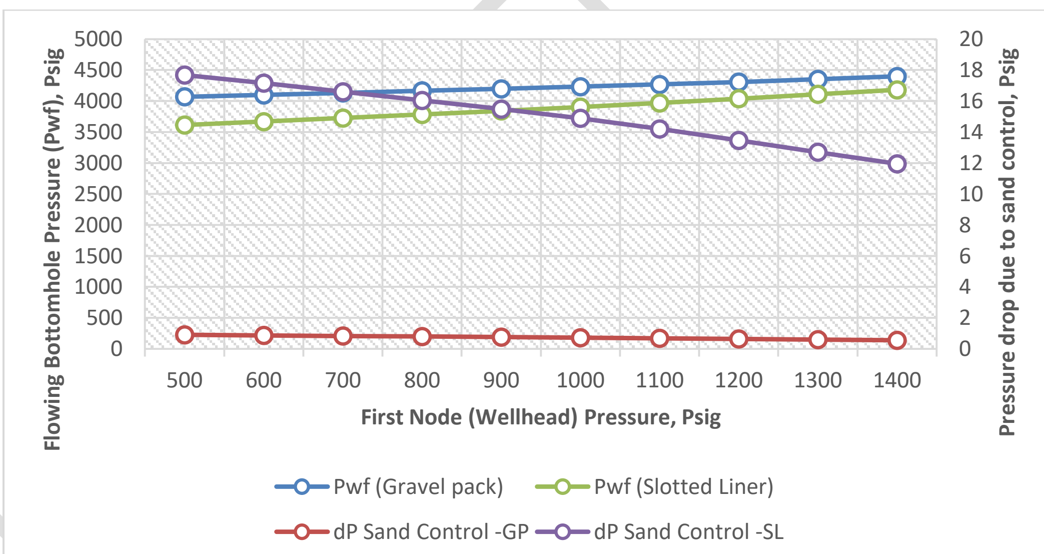

Fig. 4. Effect of First Node Pressure on Pwf and ΔP Sand Control

As has been shown above, the Pwf increases as Pwh increases for both sand control options. On the contrary, there is a relative drop in the pressure drop due to sand control. This is because less flow restriction will be created at lower flow velocity. Therefore, higher wellhead pressure will result in lower pressure drop due to sand control. As expected, the pressure in the gravel pack option seems negligible when compared to the slotted liner

c. Analysis of Skin Development

The results in Figure 5 show that despite increased flow restriction caused by higher wellhead pressures, the numerical value of skin effect was not sufficiently affected especially in the gravel pack option. This observation has helped to answer such questions as to whether wellhead back pressure effect may affect skin development in the well system.

Nevertheless, in extremely severe cases such as complete well shutdown, skin development in the reservoir may occur as a result of wellbore loading and storage which could lead to secondary pore blockage in a multiphase flow scenario.

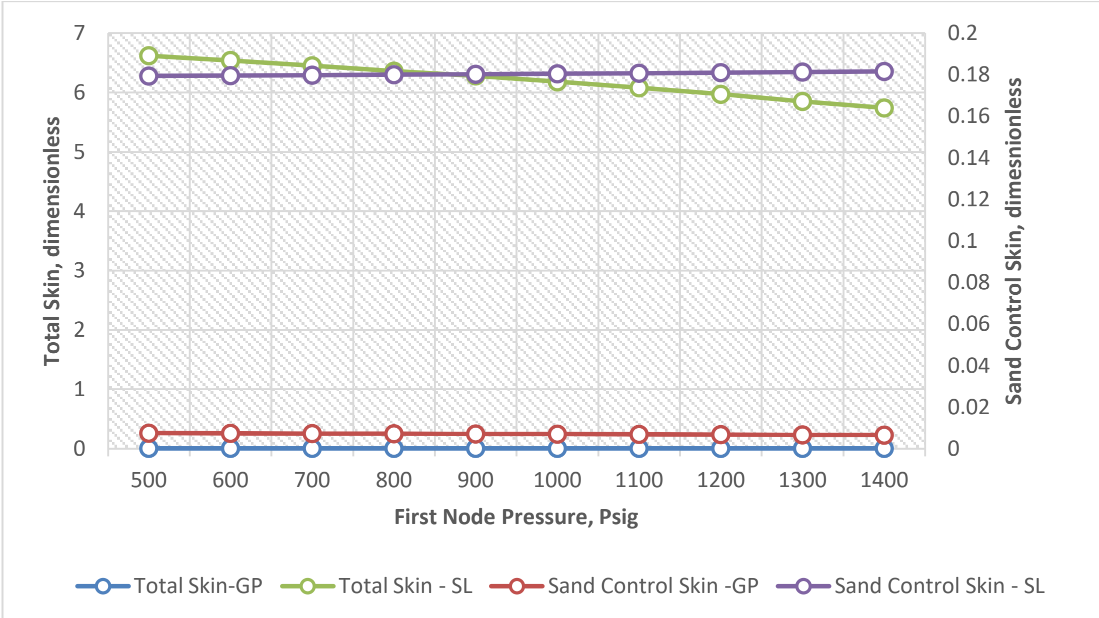

Fig. 5. Effect of First Node Pressure on Skin Development

d. Analysis of Fluid Superficial Flow Velocities.

The Figure 6 reveals that as first node pressure increases, the slip effect of the gas phase reduces as VSG approaches VSL. This observation is applicable to both sand control options. the gravel pack option showed higher superficial velocities for each of the phase. This is as a result of better fluid communication existing between the well and the reservoir. The gravel pack system impedes less flow as evidenced by higher production rates than the slotted liner option.

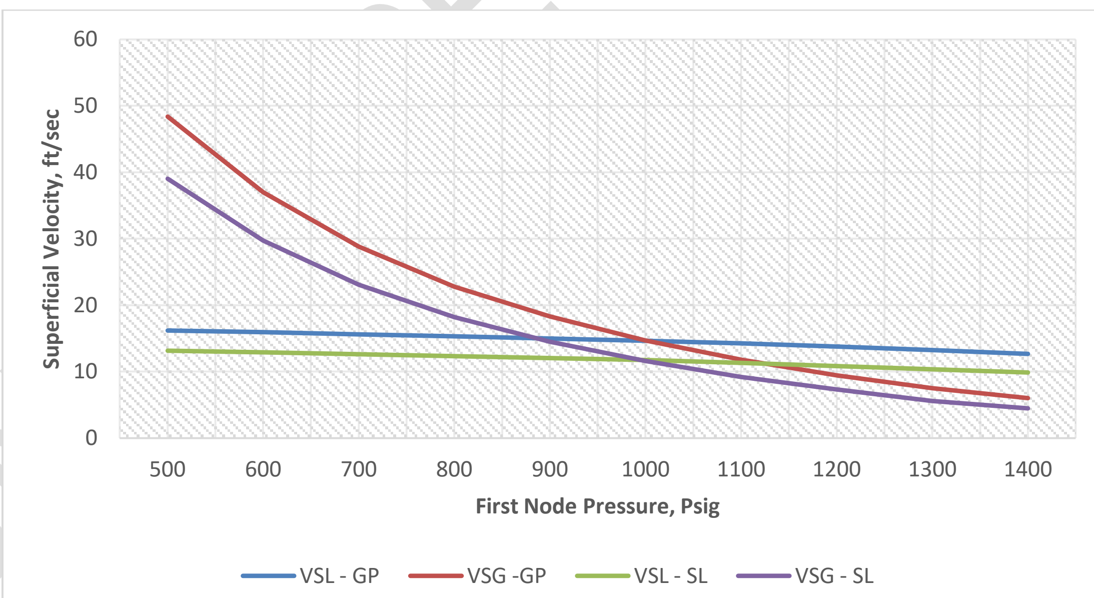

Fig. 6. Effect of First Node Pressure on Superficial Fluid Velocities

3.2 Sensitivity Study of Gravel Pack and Slotted Liner Parameter.

a. Effect of Gravel Pack Length on Production Rates and Skin Development.

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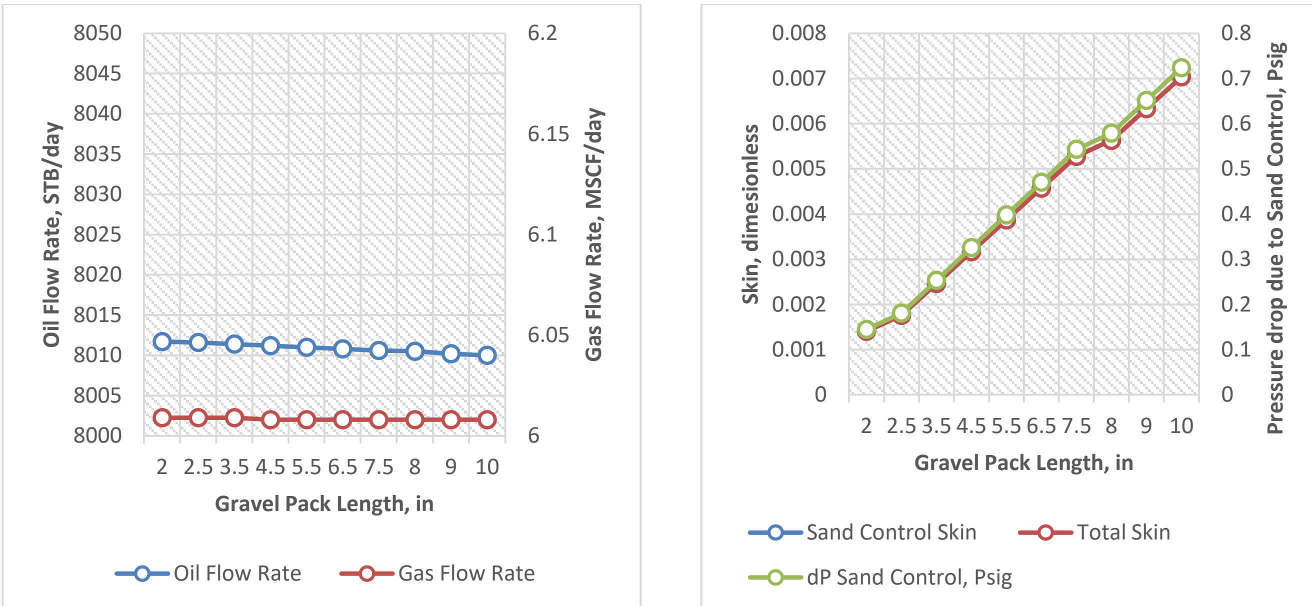
The gravel pack length influences production rates and skin developments as shown in Figure 7A and 7B respectively. The observed influence on well flow parameters shows that the length of the gravel pack section is critical consideration when designing a gravel pack sand control system against pressure losses and possible skin development caused by flow restrictions.

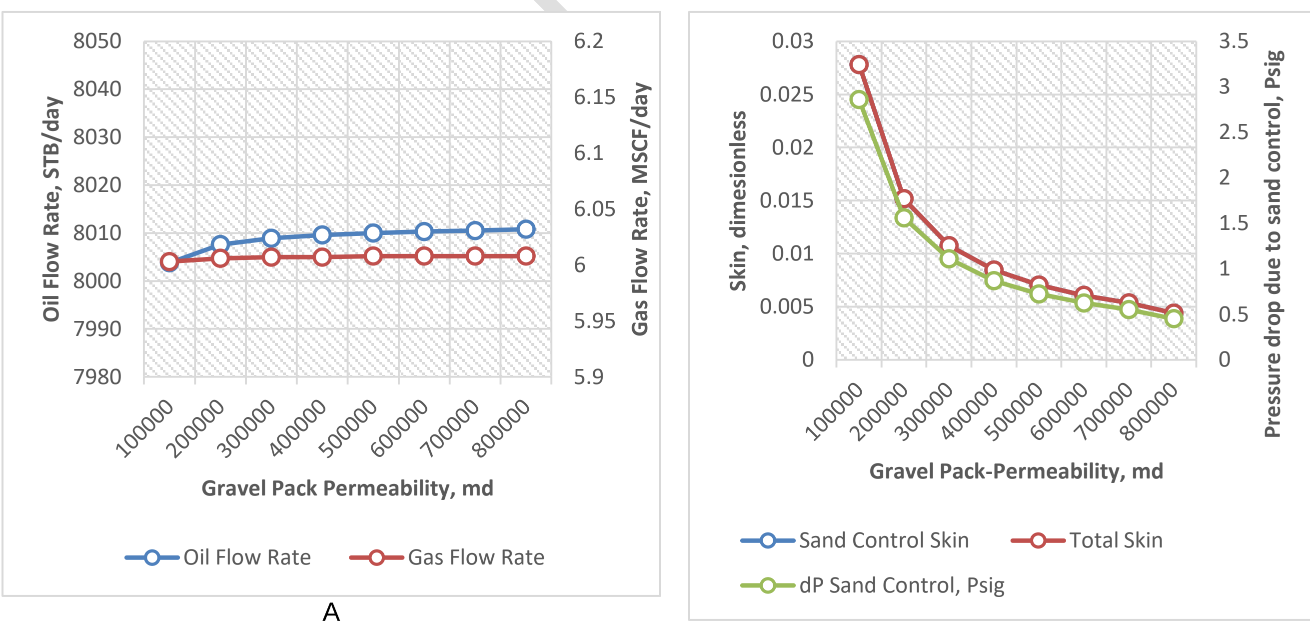


A B

Fig. 7. Effect of GP Length on: (A) Production Rates and (B) Skin Development.

b. Effect of Gravel Permeability on Production Rates and Skin Development.

As illustrated in Figure 8A, the gravel pack permeability increases, production rates also increase due to reduced pressure losses across sand face. As gravel pack permeability increases, both the pressure drop due to sand control and the resulting sand control skin generally decreases until an optimal gravel pack permeability is attained is shown in figure 8B.



A B

Fig. 8. Effect of GP Permeability on: (A) Production Rates and (B) Skin Development

c. Effect of Slot Dimensions on Production Rates.

The result of the impact of slot height and slot width on oil and gas production rates has been presented in Figure 9A and 9B. It shows that increasing the slot height negatively impacts production and a directly contrasting trend was observed in which the increase in slot width increased production from the well.

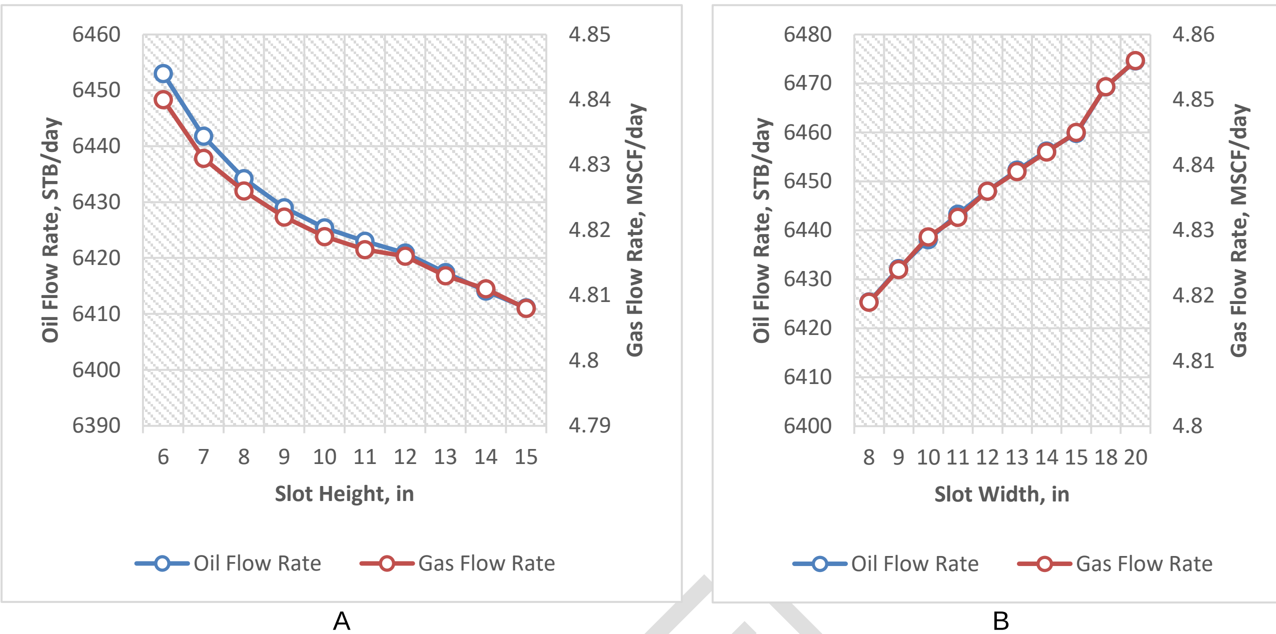


Fig. 9. Effect of Slot Dimensions on Production Rates: (A) Slot Height and (B) Slot Width

d. Effect of Slot Dimensions on Skin Development

In Figure 10A, the observed trend reveals that as slot height increases, both the resulting skin due to sand control and the associated pressure drop similarly increases. The result of Figure 10B is directly opposite but the trend is all the same similar. The increasing slot width causes less flow restriction as indicated by the consistently decreasing sand control skin and the pressure drop due to sand control as well.

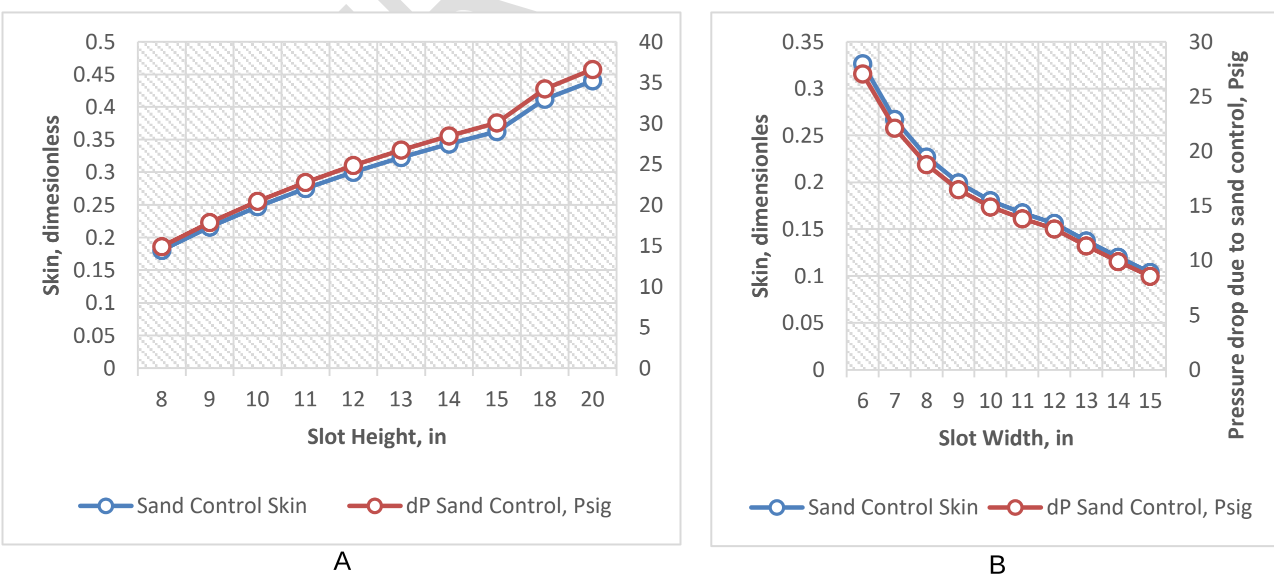


Fig. 10. Effect of Slot Dimensions on Production Rates: (A) Slot Height and (B) Slot Width

4. CONCLUSION

In this work, the effect of excessive sand control on production performance of a well has been studied. Two sand control devices were considered – a gravel pack technique and a slotted liner. The case study well model was constructed using Petroleum Experts PROSPER Simulator. The fundamental optimization technique employed was based on nodal analysis in which the first node was set at the wellhead and last node at the bottomhole. By performing many sensitivity runs on key design parameters, the following observations are enlisted as key findings from the work

i. Both gravel pack and slotted liners have been shown to be good sand control devices. However, the specifications of these devices have major influencing factor on the overall performance of the well
ii. Slotted Liners provides better sand control than gravel packs but causes more pressure drop across the sand face that resulted in lifting issues (lower Pwf)
iii. Gravel pack permeability and slot dimensions have most remarkable influence on the pressure drop due to sand control and can play a crucial role in the choice and design of any gravel pack system and slotted liners respectively
iv. The first node pressure remarkably impacts pressure loses in the production system and the ultimate recovery of the well fluids.

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NOMENCLATURE

ORAT = oil rate
GRAT = gas rate
WRAT = water rate
GOR = gas oil ratio
IPR = inflow performance relation
VLP = vertical lift performance

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Pwh = Wellhead pressure
Pwf = flowing bottomhole pressure
AOF = absolute open flow potential
VSL = superficial liquid velocity
VSG = superficial gas velocity
GP = gravel pack
SL = slotted liner
Pr = Reservoir Pressure
FVF = Formation volume factor
PVT = pressure-volume-temperature
J = productivity index
Q (q) = flow rate
S = skin factor
h = reservoir thickness
K = permeability
P = pressure

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