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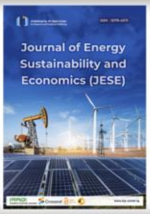

Evaluation of Gravel-Pack Completion Characteristics on the Performance of a Producing Well in an Iraqi Oil Field

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Keywords:

x Field; completion skin; gravel pack; nodal analysis; sand control;

Abstract

Sand production is one of the main completion challenges in weakly consolidated and friable producing formations because it can reduce well deliverability, accelerate equipment erosion, increase cleanout frequency, and shorten the productive life of the well. Gravel-pack completion is commonly applied as an effective sand-control technique; however, its hydraulic influence on well performance must be carefully evaluated because an improperly selected or poorly placed gravel pack may introduce additional near-wellbore pressure losses. This paper evaluates the effect of gravel-pack completion characteristics on the performance of a producing well in a selected Iraqi oil field while maintaining the confidentiality of field and well identification. The study integrates available field completion data, pressure-volume-temperature fluid properties, reservoir parameters, perforation data, tubing configuration, and gravel-pack design variables into a well-performance evaluation model. The inflow performance relationship was developed by separating the total pressure loss into reservoir, perforation, and gravel-pack components, while the vertical lift performance was obtained from pressure-traverse calculations through the production string. The operating point was determined from the IPR–VLP intersection, and sensitivity analysis was performed for gravel-pack permeability and gravel-filled tunnel length. The results show that the studied well has good reservoir deliverability, but completion-related restrictions, especially perforation damage, crushed-zone effects, and gravel-pack resistance, reduce the effective inflow performance. Increasing gravel-pack permeability improved the operating rate, with the best hydraulic response obtained in the high-permeability range. Reducing the gravel-filled tunnel length from 0.95 to 0.38 in increased the operating rate from approximately 8398.6 to 8679.0 STB/day. These findings indicate that gravel-pack design should not be selected only according to sand-retention ability, but also according to hydraulic efficiency. A high-conductivity, properly placed gravel pack with minimum unnecessary flow-path length provides a better balance between sand control and well productivity.

Introduction

Sand production is a common production problem in oil and gas wells completed in weakly consolidated, poorly cemented, or mechanically unstable formations. It occurs when formation grains or fine particles lose mechanical support and are transported with the produced fluids into the wellbore. The onset and severity of sand production are controlled by the interaction between rock strength, grain cementation, effective stress, pressure depletion, drawdown, perforation geometry, local flow velocity, and fluid properties. Once sanding begins, it may appear as transient, continuous, or severe sand production. Transient sanding may decline after the unstable particles near the wellbore are removed, whereas continuous sanding can persist during the producing life of the well and gradually reduce well productivity. Severe sand production is more critical because it can fill the wellbore, plug the perforations or tubing, damage downhole equipment, and lead to production interruption.

The near-wellbore mechanism of sand production usually starts around individual perforation tunnels where stress concentration, high drawdown, and fluid acceleration weaken the formation. As production continues, failed grains may be removed from the perforation cavities, and neighboring weakened zones may connect to form a larger unstable region around the wellbore. This process changes the original flow geometry, increases local flow velocity, and may accelerate additional formation failure. Therefore, sand production should not be treated only as a rock-mechanics problem; it is also a completion-performance problem because the stability of the producing interval and the hydraulic efficiency of the well are directly connected. [1], [3].

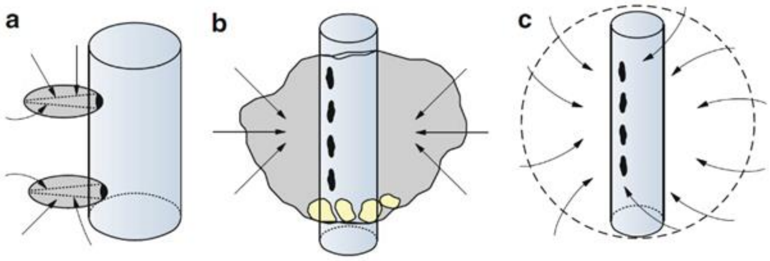

Figure 1: Development of sand production and cavity formation around the wellbore [1], [3].

The consequences of sand production extend from the reservoir face to the entire production system. Produced sand may accumulate inside the wellbore, reduce the available flow area, increase workover and cleanout requirements, and damage downhole and surface equipment. At high production rates, sand particles may behave as abrasive solids and cause erosion in screens, tubing, chokes, valves, and flowlines. This erosion can reduce equipment life and increase operational risk, especially when the well is required to produce at high drawdown or high flow velocity. For this reason, sand-control completion must be designed to protect both the reservoir and the production system [1], [2].

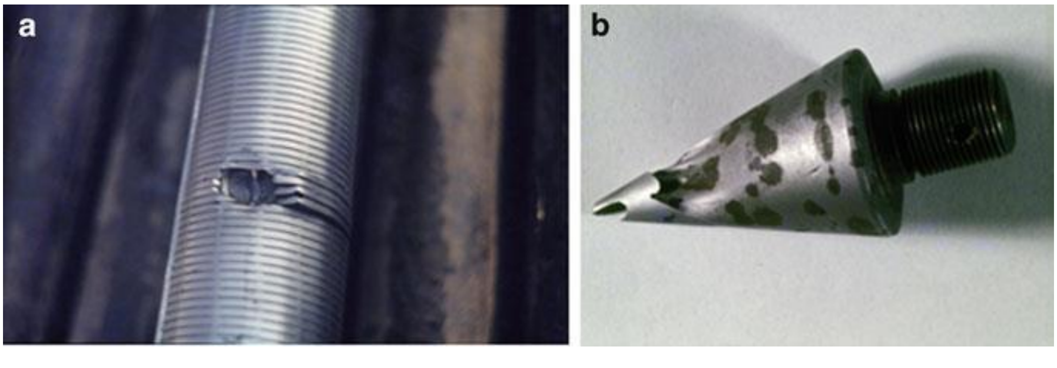

Figure 2: Erosion damage caused by uncontrolled sand production in downhole and surface equipment[1], [2].

Several sand-control methods are used to reduce or prevent sand production, including stand-alone screens, slotted liners, chemical consolidation, frac-pack completions, and gravel-pack completions. Among these methods, gravel packing is widely applied because it provides mechanical support near the wellbore and creates a porous filtering medium that prevents formation sand from entering the production string. In a cased-hole gravel-pack completion, gravel is placed between the screen and the perforated casing interval, while the screen retains the gravel and allows reservoir fluids to flow into the tubing. The gravel pack must be fine enough to retain formation sand but permeable enough to allow fluids to pass with minimum pressure loss [1], [2], [4].

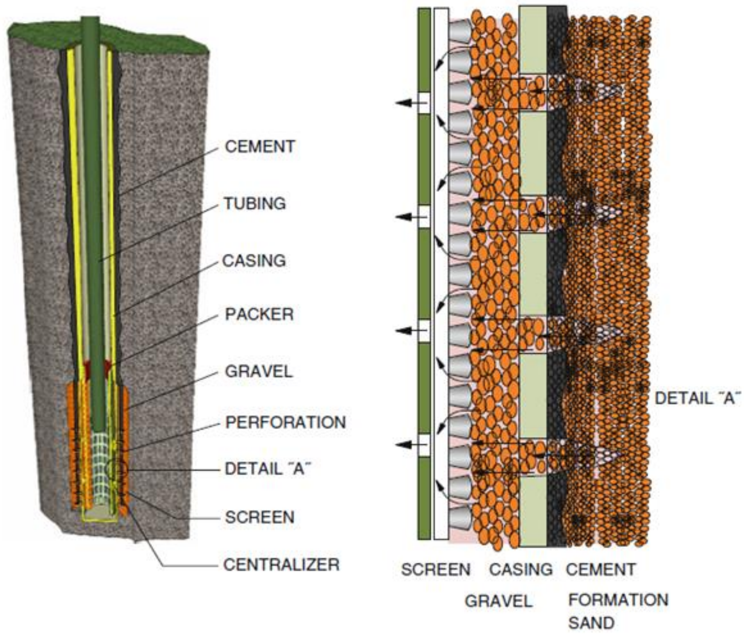

Figure 3: Schematic of a cased-hole gravel-pack completion showing sand retention and fluid flow path [2].

Although gravel packing is effective for sand control, it may introduce additional pressure losses near the wellbore. These losses depend on gravel permeability, gravel size distribution, pack quality, screen selection, perforation geometry, gravel-filled tunnel length, and the degree of damage around the perforation tunnels. If the selected gravel is too fine or the pack is poorly placed, the completion may become restrictive and reduce well deliverability. If the gravel is too coarse or poorly matched with the formation sand, formation fines may invade the gravel-pack pore space and reduce long-term permeability. Therefore, gravel-pack design requires a balance between sand retention and flow capacity rather than selecting the most restrictive sand-control option.

In Iraqi oil fields, producing wells may be affected by near-wellbore instability, fines migration, and completion-related productivity impairment, especially when high drawdown is required to maintain commercial production. For this reason, evaluating sand-control completions under local field conditions is important for protecting equipment, reducing workover frequency, and improving long-term well deliverability. However, many gravel-pack applications are evaluated mainly from the sand-retention side, while the hydraulic effect of gravel permeability, packed flow length, perforation damage, and tubing lift requirement is often underestimated. This creates a practical gap between sand-control design and well-performance evaluation.

The motivation of this work is to evaluate gravel-pack completion not only as a sand-control method but also as a hydraulic element that can change the operating point of a producing well. The study focuses on the effect of gravel-pack permeability and gravel-filled tunnel length on completion pressure losses, inflow performance, flowing bottom-hole pressure, and final production rate. The well, field, and formation names are kept confidential, and the analysis is presented using a selected producing well from an Iraqi oil field.

The paper is organized as follows. The literature review summarizes the development of sand-control and gravel-pack studies, with emphasis on gravel sizing, hydraulic performance, completion skin, research gaps, and future directions. The theoretical background presents the concepts of gravel-size selection, reservoir–completion pressure-loss modeling, perforation damage, Darcy and non-Darcy flow losses, and IPR–VLP nodal analysis. The methodology describes the field data, PVT model, wellbore model, inflow model, and sensitivity procedure. The results and discussion analyze VLP behavior, reservoir and perforation inflow coefficients, cased-perforated operating point, gravel-pack permeability sensitivity, gravel-filled tunnel length sensitivity, and the overall engineering interpretation. Finally, the conclusions summarize the main findings and provide recommendations for field application and future research.

Literature Review and Research Development

Development of Sand-Control and Gravel-Pack Design

The development of sand-control technology has been closely related to the need for maintaining stable production from weakly consolidated reservoirs. Early sand-control practices were mainly directed toward preventing formation grains from entering the wellbore by using mechanical barriers such as screens and slotted liners. These methods provided a simple retention mechanism, but their performance depended strongly on the relationship between screen opening size and formation grain-size distribution. If the opening was too large, sand could pass through the completion. If it was too small, plugging and productivity impairment could occur.

Gravel packing was later developed to improve sand retention by placing a selected granular material between the formation and the screen. The gravel pack acts as an intermediate porous medium that prevents formation sand from moving into the production string while maintaining a flow path for reservoir fluids. The effectiveness of a gravel pack depends mainly on the relationship between the median gravel size and the median formation sand size. Sieve analysis is commonly used to determine the formation grain-size distribution, and the selected gravel size is then chosen to provide both sand retention and acceptable permeability.

A major step in gravel-pack design was the use of a pack-to-formation grain-size ratio. According to the commonly used Saucier design concept, the median gravel diameter is selected as several times the median formation sand diameter. This approach provides a practical compromise because very fine gravel may retain sand effectively but can create high pressure drop, while very coarse gravel may allow formation sand or fines to invade the pack. Therefore, gravel sizing is not simply a matter of choosing the largest or smallest available gravel size; it is an optimization problem between filtration stability and hydraulic conductivity.

Hydraulic Performance of Gravel-Pack Completions

Later studies showed that gravel-pack completion should not be evaluated only from the sand-retention point of view. The gravel pack is a porous medium added to the near-wellbore flow system, and it can create additional pressure loss before the fluid reaches the wellbore. The magnitude of this pressure loss depends on gravel permeability, pore geometry, packing quality, flow velocity, fluid properties, and the length of the packed flow path. When the gravel pack has low permeability or contains damaged and invaded pore spaces, the completion skin increases and the inflow curve shifts downward.

The hydraulic performance of the gravel pack is also affected by fines invasion. Even if the gravel size is properly selected, formation fines may partially invade the pore throats of the gravel pack and reduce its effective permeability. This effect may be gradual and may not appear immediately after completion. As fines accumulate inside the gravel-pack pore space, the connection between pores becomes weaker, the pressure drop increases, and the well deliverability decreases. This behavior is important in cased-hole gravel-pack completions because the produced fluid must pass through the formation, perforation tunnel, gravel pack, and screen before entering the tubing.

The permeability of the gravel pack is therefore one of the most important parameters controlling well deliverability. High gravel permeability reduces Darcy and non-Darcy pressure losses and allows a larger portion of the available drawdown to be used for reservoir inflow. However, high permeability alone is not enough if the gravel is too coarse to retain formation sand. The best design is the one that provides stable sand control while keeping the completion resistance as low as possible.

Perforation Damage, Non-Darcy Flow, and Nodal Analysis

In cased-hole completions, the perforation system introduces additional restrictions because fluids must converge toward perforation tunnels before entering the wellbore. This convergence creates pressure loss even in clean perforations. In addition, the perforation process can create a crushed or compacted zone around the tunnel where permeability is lower than the original reservoir permeability. This damaged zone may become a major source of completion skin, especially when the crushed-zone permeability is low or when perforation cleanup is incomplete.

At low to moderate flow rates, the pressure loss through the reservoir and completion is mainly controlled by viscous or Darcy flow. At higher rates, inertial or non-Darcy effects become more important, especially near perforations and inside restricted flow paths. Non-Darcy pressure loss is rate-dependent, which means that its influence increases rapidly as production rate increases. For this reason, completion evaluation should include both linear and quadratic pressure-loss terms, especially for high-rate wells.

Nodal analysis provides a suitable method for evaluating the interaction between reservoir inflow and wellbore outflow. The inflow performance relationship describes the ability of the reservoir and completion to deliver fluids to the bottom of the well, while the vertical lift performance describes the pressure required to lift those fluids through the tubing to the surface. The intersection between the IPR and VLP curves represents the operating point of the well. This operating point is not controlled by reservoir properties alone; it is controlled by the combined effect of reservoir deliverability, perforation condition, gravel-pack resistance, tubing size, fluid properties, and surface pressure.

Research Gaps and Limitations

Although gravel-pack completion has been widely studied and applied, several practical limitations remain. Many studies and field applications focus mainly on selecting gravel size for sand retention, while the hydraulic penalty caused by the gravel pack is sometimes treated as a secondary issue. In actual producing wells, however, gravel-pack permeability, gravel-filled tunnel length, perforation damage, and tubing lift performance can interact and change the final operating point. A gravel pack that is effective for sand control may still reduce production if its flow capacity is not sufficient.

Another limitation is that gravel-pack performance is often evaluated under simplified assumptions. Field wells may contain non-uniform packing, partial fines invasion, perforation damage, variable fluid properties, and multiphase-flow effects. These factors make the actual performance different from the ideal design condition. In addition, long-term field validation is often limited because complete sand-production history, gravel-pack condition, and downhole pressure data may not be continuously available.

For Iraqi oil fields, the need for integrated gravel-pack evaluation is important because field development often requires maintaining production while minimizing workover operations and protecting equipment. Local studies related to well productivity, nodal analysis, completion performance, and formation damage can support better design decisions, but more research is needed to connect sand-control design with measured well deliverability under local field conditions. Therefore, this study contributes by integrating completion pressure losses, perforation damage, gravel-pack variables, and IPR–VLP analysis in one well-performance evaluation workflow.

Emerging Trends and Future Directions

Recent developments in sand-control technology are moving toward more integrated and data-based completion design. Advanced screen designs, improved gravel materials, ceramic or high-strength proppant-based packs, expandable screens, alternate-path gravel packing, inflow control devices, and real-time sand monitoring systems are increasingly used to improve both sand retention and flow performance. These technologies aim to reduce the risk of incomplete placement, improve pack uniformity, control fines movement, and maintain well productivity for longer periods.

Future research should focus on combining laboratory sand-retention testing, core-based grain-size analysis, field pressure data, and numerical well-performance modeling. More attention should also be given to long-term permeability reduction due to fines invasion and scale deposition inside the gravel pack. In addition, digital workflows using real-time production data and machine-learning-based sand prediction may help identify early signs of sanding and completion impairment before severe production losses occur.

The main research gap addressed in this paper is the hydraulic evaluation of gravel-pack completion characteristics under a confidential Iraqi field case. Instead of treating the gravel pack only as a sand-control barrier, the study evaluates how gravel permeability and gravel-filled tunnel length affect pressure loss, inflow behavior, flowing bottom-hole pressure, and operating rate. This approach provides a more practical basis for selecting gravel-pack conditions that can control sand while preserving well deliverability.

Theoretical Part

Gravel-pack completion performance is controlled by two connected functions: sand retention and hydraulic conductivity. The gravel pack must be properly sized to prevent formation sand from entering the wellbore, while still maintaining enough permeability to allow reservoir fluids to flow with minimum additional pressure loss. Therefore, gravel-pack design is not only a sand-control decision, but also a productivity-control problem. In this study, the theoretical analysis is based on gravel-size selection, pressure-loss modeling through the reservoir–completion system, and nodal analysis to evaluate the effect of gravel-pack permeability and gravel-filled tunnel length on well performance [1], [2].

The arrangement of gravel grains affects both pore geometry and flow capacity. As shown in Figure 5, tight packing creates smaller pore throats and may improve sand retention, but it can reduce flow area and increase pressure loss. In contrast, loose packing creates larger pore spaces and higher conductivity, but may provide less effective support against fine-particle movement. Therefore, the physical arrangement, roundness, sorting, and strength of gravel grains are important factors in maintaining long-term gravel-pack permeability [1].

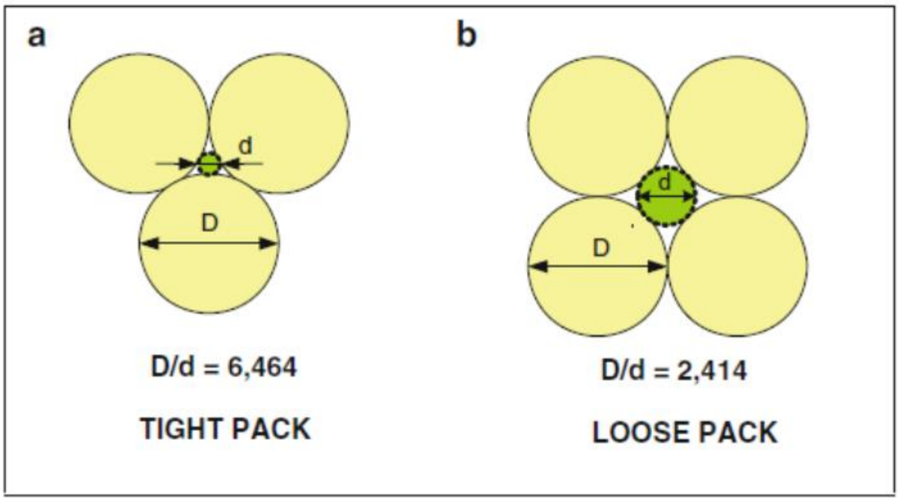

Figure 5: Possible gravel grain arrangements in tight and loose packing systems [1].

The first design step is to select the gravel size based on the formation sand-size distribution. Sieve analysis is used to determine the median formation grain diameter, d50, and then select the corresponding median gravel-pack grain diameter, D50. Figure 6 shows the relationship between formation sand and gravel-pack size distribution on a cumulative-weight basis. According to Saucier’s criterion, the median gravel size can be estimated as:

$$D50_{gravel} = 5 - 6 \times d50_{formation} \qquad (1)$$

where D50_gravel is the median gravel-pack grain size and d50_formation is the median formation sand grain size. This criterion provides a practical balance between sand retention and flow capacity because the gravel should be large enough to maintain permeability, but not so large that formation sand can pass freely through the pack [1], [2].

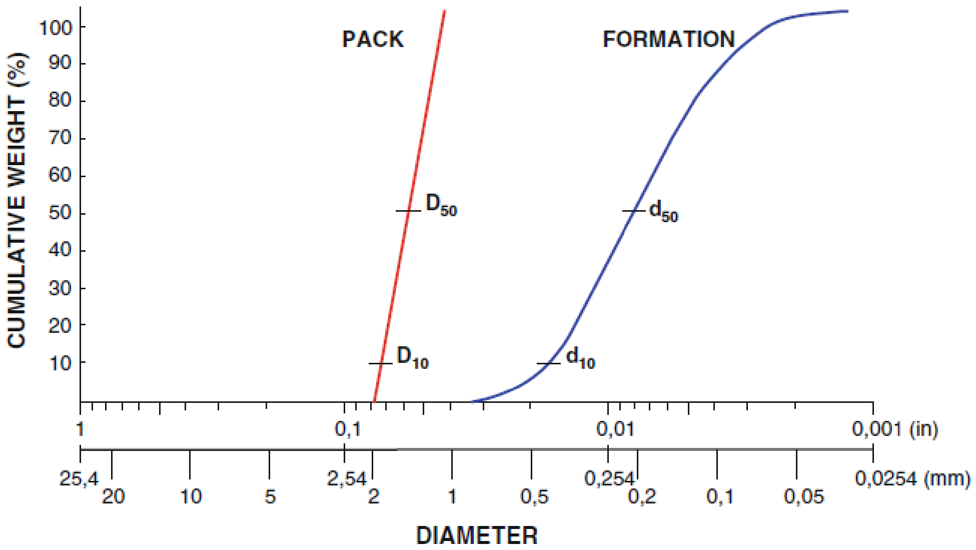

Figure 6: Formation sand and gravel-pack size distribution used for gravel selection [1].

The effect of the pack-to-formation median grain-size ratio on gravel-pack performance is illustrated in Figure 7. When the ratio is too small, the gravel pack may retain sand effectively, but its absolute permeability becomes low and the completion may cause excessive pressure drop. Within the recommended ratio range, the pack provides a better compromise between retained permeability and sand control. However, when the ratio becomes too large, formation sand may not be restrained and unrestrained sand production can occur. Therefore, the optimum gravel size is not necessarily the coarsest available size, but the size that provides stable sand control with acceptable hydraulic conductivity [1], [2].

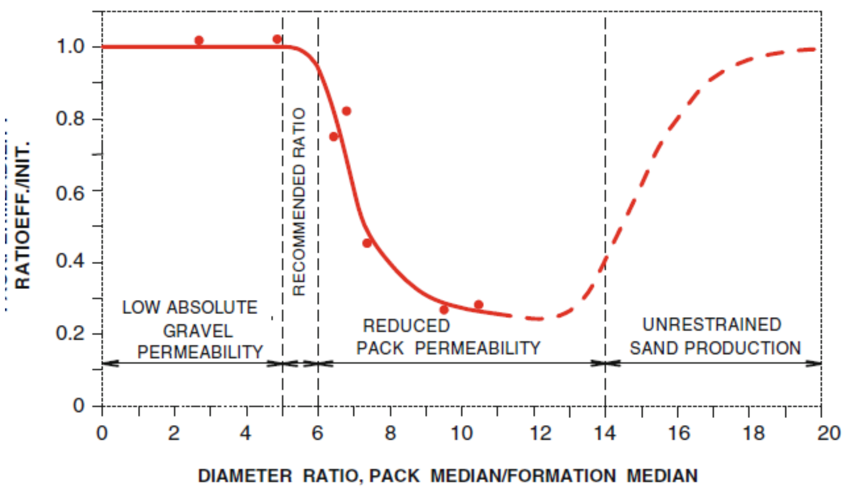

Figure 7: Effect of pack-to-formation median grain-size ratio on gravel-pack permeability and sand control [1].

Even when the gravel size is properly selected, fine particles may partially invade the gravel-pack pore space and reduce its effective permeability. Figure 8 shows partial invasion of formation fines into the gravel pack. This mechanism is important because fines accumulation reduces pore connectivity, increases completion skin, and may gradually decrease well deliverability. In cased-hole gravel-pack completions, this effect becomes more critical because the produced fluid must pass through the formation, perforation tunnel, gravel pack, and screen before entering the wellbore [1], [3].

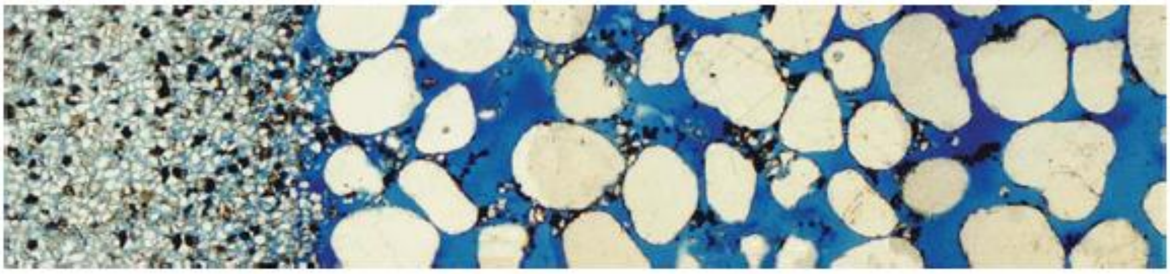

Figure 8: Partial invasion of formation fines into the gravel-pack pore space [1].

Nodal analysis treats the well as an integrated production system in which reservoir inflow, completion losses, tubing losses, and surface restrictions interact with each other. The total pressure available from the reservoir is consumed through several flow restrictions, as illustrated in Figure 9. Therefore, the actual production rate is not controlled by the reservoir alone, but by the balance between inflow performance and vertical lift performance [4].

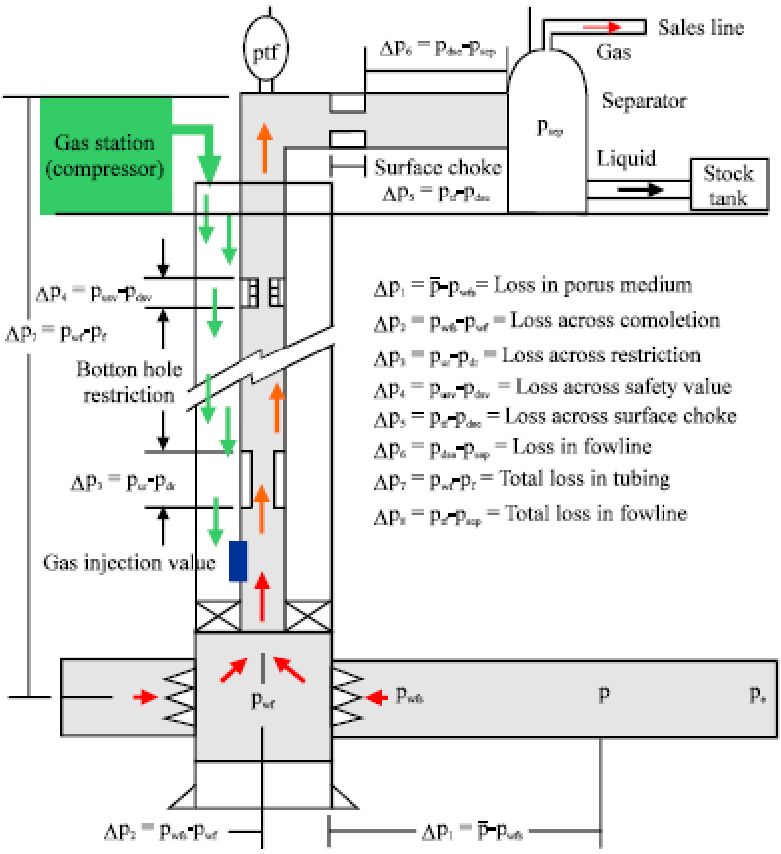

Figure 9: Schematic representation of possible pressure losses in the complete production system [4].

The productivity index is commonly used to express the relationship between production rate and pressure drawdown:

$$J = \frac{q}{\Delta P}, \qquad (2)$$

where J is the productivity index, qo is the oil production rate at stock-tank conditions, Pr is the average reservoir pressure, and Pwf is the flowing bottom-hole pressure. For a cased-hole gravel-packed completion, the total inflow pressure loss can be expressed as the sum of reservoir, perforation, and gravel-pack losses:

$$\Delta P = (AR + AP + AG)qo + (BR + BP + BG)qo^2, \qquad (3)$$

where AR, AP, and AG are the linear pressure-loss coefficients for the reservoir, perforations, and gravel pack, respectively. BR, BP, and BG are the corresponding quadratic non-Darcy coefficients. The linear term represents viscous or Darcy flow losses, while the quadratic term represents rate-dependent inertial losses that become more important at high production rates [4], [6].

For the gravel-filled perforation tunnel, the Darcy pressure-loss coefficient is:

$$A_G = \frac{(282.4 * \mu_o * B_o * L)}{(k_G * N * r_p^2)} \qquad (4)$$

where μo is oil viscosity, Bo is oil formation volume factor, L is gravel-filled perforation tunnel length, kG is gravel-pack permeability, N is the total number of active perforations, and rp is perforation tunnel radius. Equation (4) shows that increasing gravel permeability, number of perforations, or perforation radius reduces gravel-pack resistance. In contrast, increasing the gravel-filled tunnel length increases the viscous pressure loss.

The non-Darcy gravel-pack pressure-loss coefficient is:

$$B_G = \frac{(9.20E{-}14 * \beta_G * B_o^2 * \rho_o * L)}{(N^2 * r_p^4)} \qquad (5)$$

where ρo is oil density and βG is the gravel-pack inertial coefficient. The inertial coefficient is estimated as:

$$\beta_G = \frac{1.47\times10^7}{(k_G^{0.55})}. \qquad (6)$$

Equations (5) and (6) show that lower gravel permeability increases the inertial resistance of the gravel pack. Also, because BG is inversely proportional to N^2 and rp^4, a small perforation radius or low perforation count can significantly increase high-rate completion losses [4], [6].

The perforation system also introduces pressure losses due to flow convergence, partial penetration, crushed zones, and damaged material around the perforation tunnel. The linear perforation coefficient is expressed as:

$$Ap = \left(\frac{141.2 * muo * Bo}{(koR * h)}\right) * (Sp + Sdp) \qquad (7)$$

where koR is the effective oil permeability of the undisturbed reservoir, h is net pay thickness, Sp is geometric perforation skin, and Sdp is damaged-zone perforation skin. The geometric perforation skin can be estimated as:

$$Sp = \left(\frac{h}{hp} - 1\right) * \left(\ln\left(\left(\frac{h}{rw}\right) * \left(\frac{kR}{kv}\right)^{0.5}\right) - 2\right) \qquad (8)$$

where hp is perforated interval thickness, rw is wellbore radius, kR is undisturbed reservoir permeability, and kv is vertical permeability. The damaged-zone contribution around the perforation tunnel is:

$$Sdp = \left(\frac{h}{(Lp * N)}\right) * \left(\left(\frac{kR}{kdp}\right) - \left(\frac{kR}{kd}\right)\right) * \ln\left(\frac{rdp}{rp}\right) \qquad (9)$$

where Lp is perforation tunnel length, kdp is permeability of the crushed or compacted zone around the perforation, and rdp is the outer radius of the crushed zone. The non-Darcy perforation coefficient is:

$$\boldsymbol{Bp} = \frac{(2.3e{-}14 * beta_{dp} * Bo^2 * rhoo)}{(rp * Lp^2 * N^2)} \qquad \textbf{(10)}$$

where βdp is the inertial factor for the crushed or damaged perforation zone. It is calculated as:

$$\boldsymbol{beta_{dp}} = \frac{2.33e10}{(kdp^{1.2})} \qquad \textbf{(11)}$$

These equations indicate that perforation performance improves when perforation radius, penetration length, and shot count increase. However, low crushed-zone permeability and near-perforation damage increase skin and make the completion more restrictive [4], [6].

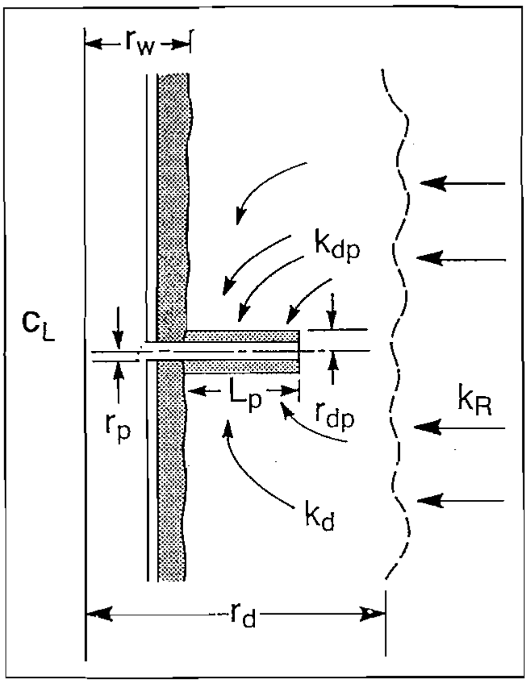

Figure 10**:** Schematic representation of perforation geometry and near-wellbore damage zone [4].

The reservoir-side pressure loss is represented by the radial-flow component. The linear reservoir coefficient is:

$$\boldsymbol{AR} = \left(\frac{141.2 * muo * Bo}{(koR * h)}\right) * \left(\ln\left(0.472 * \frac{re}{rw}\right) + Sd\right) \qquad \textbf{(12)}$$

where re is drainage radius and Sd is the near-wellbore damage skin. The damage skin is calculated as:

$$\boldsymbol{Sd} = \left(\left(\frac{kR}{kd}\right) - 1\right) * \ln\left(\frac{rd}{rw}\right) \qquad \textbf{(13)}$$

where kd is damaged-zone permeability and rd is the outer radius of the damaged zone. The non-Darcy reservoir coefficient is:

$$\boldsymbol{BR} = \frac{(2.3e{-}14 * betaR * Bo^2 * rhoo)}{(h^2 * rw)} \quad \textbf{(14)}$$

where βR is the reservoir inertial coefficient. These expressions show that reservoir productivity decreases when near-wellbore permeability is reduced or when the damaged-zone radius increases [4].

Vertical Lift Performance (VLP) represents the outflow requirement of the wellbore. It defines the flowing bottom-hole pressure required to lift produced fluids through the tubing at different production rates. The pressure gradient along the tubing is the sum of hydrostatic, frictional, and acceleration components:

$$\frac{dp}{dL} = \left(\frac{dp}{dL}\right) elev + \left(\frac{dp}{dL}\right) fr + \left(\frac{dp}{dL}\right) acc \quad \textbf{(15)}$$

where dp/dL is the total pressure gradient, (dp/dL)elev is the hydrostatic component, (dp/dL)fr is the frictional component, and (dp/dL)acc is the acceleration component. At low to moderate flow rates, hydrostatic pressure may dominate, while at high rates friction losses become more important. Therefore, the VLP curve must be combined with the IPR curve to determine the operating point of the well [4], [7].

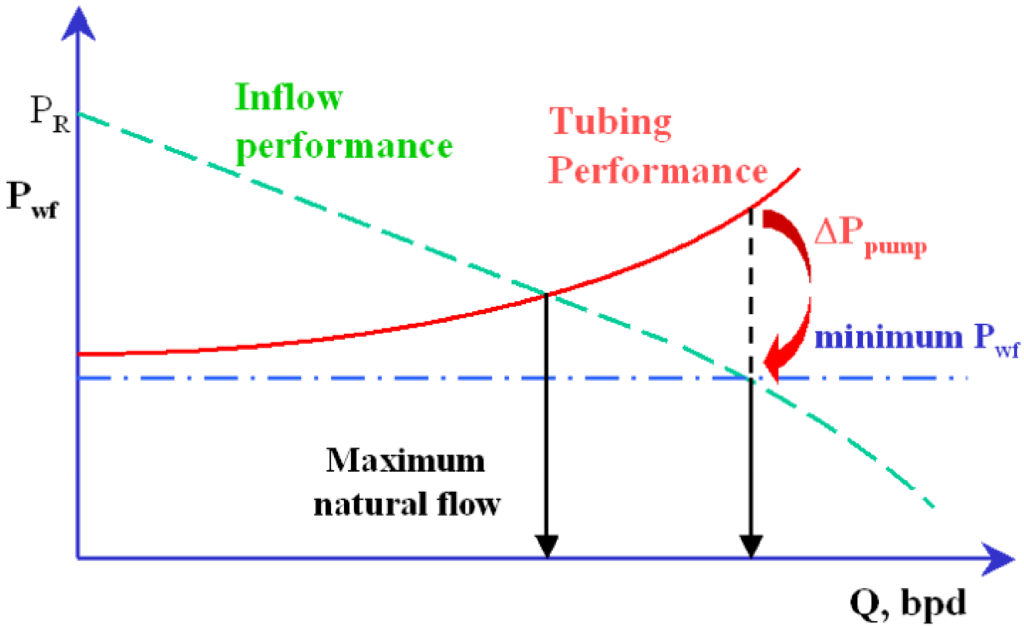

Figure 11: Inflow and tubing performance curves showing the operating point from IPR–VLP intersection [4].

Table 1 summarizes the gravel-pack permeability values used in the theoretical and sensitivity analysis. These permeability cases represent different gravel sieve sizes and were used to evaluate the influence of gravel conductivity on completion pressure loss and well deliverability.

Table 1 Standard gravel sieve sizes and corresponding gravel-pack permeability values.

Sieve Size	k_G, md
10–20	5.00×10^5
16–30	2.50×10^5
20–40	1.20×10^5
40–60	4.0×10^4

Overall, the theoretical model shows that gravel-pack completion performance is mainly controlled by gravel permeability, gravel-filled tunnel length, perforation radius, number of perforations, and near-wellbore damage. A low-permeability gravel pack or an unnecessarily long gravel-filled flow path increases AG and BG, shifts the inflow performance downward, and reduces the final operating rate. Thus, the best gravel-pack design is the one that provides reliable sand retention while preserving high hydraulic conductivity and minimizing completion-induced pressure losses.

Experimental Procedure

Workflow of the Study

The procedure of this study was designed to evaluate the effect of gravel-pack completion characteristics on the production performance of Well x-6 in the x Oil Field. The workflow began with collecting the required field and laboratory data, followed by constructing the fluid and wellbore models, calculating the inflow and outflow performance, and finally performing sensitivity analysis for the main gravel-pack parameters. The study was based on a nodal-analysis approach, where the well was treated as an integrated production system consisting of the reservoir, perforations, gravel-pack completion, tubing string, and surface node. The general workflow followed in this work is shown in Figure 12.

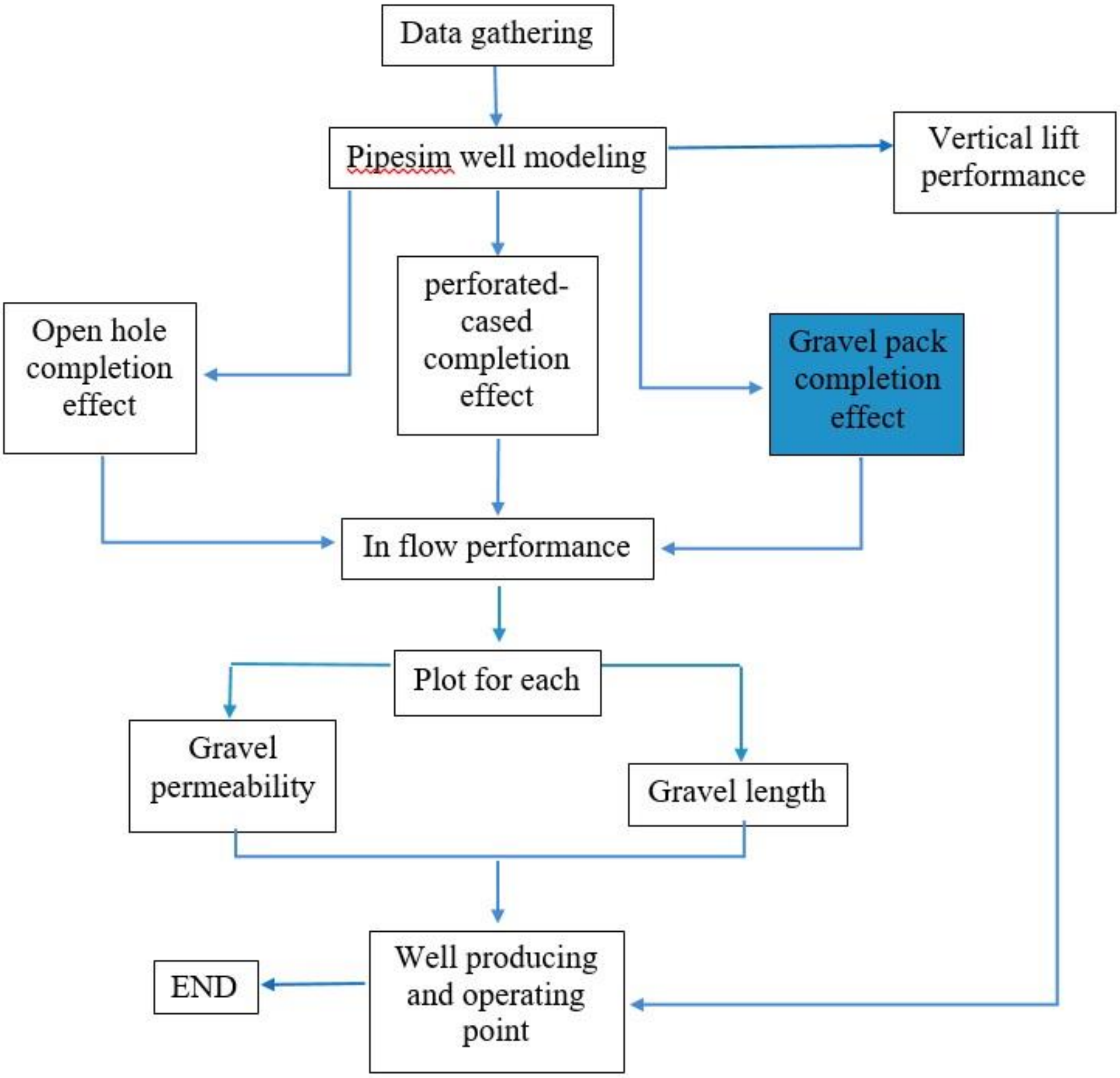

Figure 12: Workflow used for evaluating the effect of gravel-pack completion characteristics on x-6 well performance.

Data Collection and Well Description

The input data were collected from the available x-6 field reports, completion records, pressure surveys, production-test data, and pressure-volume-temperature (PVT) information [8]–[16]. The collected data included reservoir pressure, reservoir temperature, oil properties, net pay thickness, reservoir permeability, wellbore geometry, tubing and casing sizes, perforated intervals, perforation design, damaged-zone properties, and gravel-pack parameters. These data were prepared in consistent field units before being used in the analytical calculations and PIPESIM model. The final completion configuration of x-

6 was used to define the actual production path and downhole equipment arrangement, including tubing, casing, packer, bridge plugs, and active perforated intervals, as illustrated in Figure 13.

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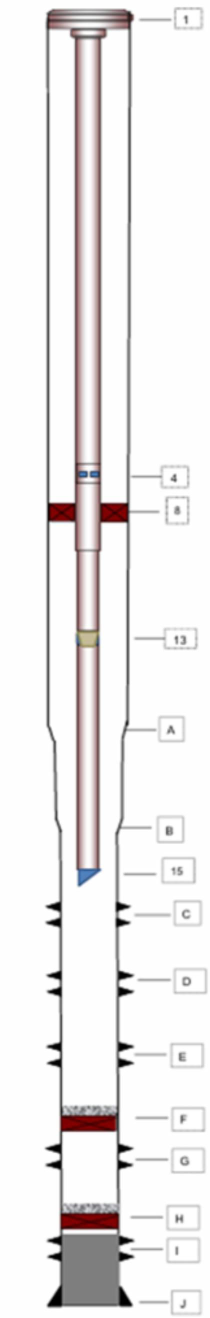


[redacted] NF Well Completion Diagram_Final			OD (in)	Depth (m)	Weight (ppf)	Grade	Thread
Oilfield	[redacted]	Casing	7.000"	~ 2727.5	32.00	C-95	API BTC
Well ID	[redacted]	Casing	5-1/2"	2727.5 ~ 2735.5	/	/	/
Well Type	Vertical	Casing	5.000"	2735.5 ~ 3076.5	18.00	C-75	API BTC
ORKB	6.35m (Forex Super-15)	Tubing	3.500	6.61 - 2703.5	9.20	L80-13Cr	VAM TOP
Workover Rig	BHDC-102	Tubing	2.875	2703.5 - 2896.11	6.40	T-95	JFE Bear
Workover Supv.	Mr. Najeeb Niaz	Reservior	[redacted]	A1 (2922.0 ~ 2926.0m), A1+A2 (2931.0 ~ 2949.0m), A2+A3 (2954.0 ~ 2970.0m), A3 (2977.5 ~ 2979.0m) B1 (2992.0 ~ 2996.0m)			
Filing Date	23-Apr-21						

Item	Description Of Equipment	OD (in)	ID (in)	Length (m)	Top Depth (m)
	ORKB to top of Tubing Spool	N/A	N/A	6.26	0.00
1	Tubing Hanger, 11" X 3-1/8", MSP/Drilex, 3-1/2" OD API EUE Box Up x 3-1/2" OD JFE Bear Box Down, P/N: 290-01-274 A0, S/N: N120011	**11.000**	**2.992**	**0.26**	**6.26**
2	X/O Sub, L80-13Cr, 3-1/2" OD 9.20ppf JFE Bear Pin x 3-1/2" OD 9.20ppf VAM TOP Pin, M/N: 10557262, PO# 4510645246	3.500	2.992	0.452	6.52
3	3-1/2" OD Tubing Joint, L80-13Cr, 9.20ppf, 3-1/2" OD 9.20ppf VAM TOP Box × Pin, total 275 joints	3.500	2.992	2669.798	6.97
4	Baker 2.812 SSD (CMD), F Profile, 375 Degree F Working Temperature, L80-13Cr, 3-1/2" OD 9.20ppf VAM TOP Box x Pin, M/N: H810800240, SN:106960056, S/N: 01	4.280	2.812	1.451	2676.765
5	3-1/2" OD Tubing Joint, L80-13Cr, 9.20ppf, 3-1/2" OD 9.20ppf VAM TOP Box × Pin, total 2 joints	3.500	2.992	19.455	2678.22
6	X/O Sub, L80-13Cr, 3-1/2" OD 9.20ppf VAM TOP Box x 3-1/2"OD 9.20ppf VAGT Pin, P/N: 10519030, P/O: 4510392395	3.930	2.930	0.505	2697.67
7	3-1/2" OD Tubing Pup Joint, T-95, 9.20ppf, 3-1/2" OD 9.20ppf VAGT Box x Pin	3.500	2.992	1.421	2698.18
8	Baker HS Hydraulic-Set Packer for 7.0"OD 29.0-32.0ppf casing, 3-1/2" OD 9.20ppf VAGT Box x Pin, 5.910" OD, 2.919" ID, L80-13Cr, 7500psi Working Pressure, 80-300 Degree F Working Temperature, 50klbs Shear Ring, M/N: H784600240, S/N: 106653301 SN04	5.890	2.965	1.969	2699.597
9	3-1/2" OD Tubing Pup Joint, T-95, 9.20ppf, 3-1/2" OD 9.20ppf VAGT Box x Pin.	3.500	2.992	0.920	2701.57
10	X/O Sub, L80-13Cr, 3-1/2"OD 9.20ppf VAGT Box x 3-1/2"OD 9.20ppf VAM TOP Pin, M/N:10508254, P/N:350X3502754-12CR, PO#:4508944722	3.890	2.992	0.379	2702.49
11	X/O Sub, L80-13Cr, 3-1/2"OD 9.20ppf VAM TOP Box x 2-7/8"OD 6.40ppf JFE Bear Pin, M/N:10553595, PO#: 4510815157	3.930	2.441	0.541	2702.87
12	2-7/8" OD Tubing Joint, T-95, 6.40ppf, 2-7/8" OD 6.40ppf JFE Bear Box x Pin, total 2 joints	2.875	2.441	19.20	2703.41
13	Baker 2.250 F Profile Landing Nipple, L80-13Cr , 2-7/8" OD 6.40ppf JFE Bear Box x Pin, M/N:10537693, P/N: 225GF6292-A, PO#: 4510132052	3.173	2.250	0.33	2722.607
14	2-7/8" OD Tubing Joint, T-95, 6.40ppf, 2-7/8" OD 6.40ppf JFE Bear Box x Pin, total 18 joints	2.875	2.441	172.90	2722.94
15	2-7/8" OD Half Mule Shoe, L80-13Cr, 6.40ppf, 2-7/8" OD 6.40ppf JFE Bear box up	3.189	2.441	0.18	2895.84
				End of NF Production String	2896.02
Note 1	HS Packer Shear Value = 50klbs Shear Ring				
Note 2	P/U Weight = 33 MT and S/O Weight= 33 MT, inckluing Block Weight 3 MT				
A	X/O Sub (7" x 5-1/2")				2727.50
B	X/O Sub (5-1/2" x 5")				2735.50
C	Newly added Perforation/Production Intervals	2922.0~2926.0m, 2931.0~2949.0m, 2954.0~2970.0m.			
D	Perforation/Production Interval	2977.5~2979.0m (A3)			
E	Perforation/Production Interval	2992.0~2996.0m (B1)			
F	5" 11.5-20.8# SLB Permanent Bridge Plug w/ 3m Cement on Top	3.937		1.00	**3002.00**
G	Perforated Intervals (Already isolated)	3005.0~3010.0m, 3014.0~3016.5m, 3026.0~3028.0m			
H	5" 11.5-20.8# SLB Permanent Bridge Plug w/ 3m Cement Plug on Top				**3036.00**
I	Perforated Intervals (Already isolated)	3040.0~3042.0m, 3043.5~3047.5m			
J	5" OD 18.0ppf C-75 Casing Shoe	**3076.5m**			

Figure 13: Final completion configuration of x-6 well used for well-performance modelling [10].

Fluid Model Preparation

A black-oil fluid model was prepared using the available x-6 PVT data. The main fluid properties used in the model included oil gravity, solution gas-oil ratio, gas gravity, oil formation volume factor, oil viscosity, oil density, and bubble-point pressure. The PVT model was first prepared and matched in PVTP, then imported into PIPESIM for well-performance simulation. This step was necessary because multiphase-flow pressure losses and vertical lift performance depend strongly on the variation of fluid properties with pressure and temperature. The matched fluid model was then used as the fluid basis for all pressure-traverse, inflow, and sensitivity calculations [7], [8].

Wellbore and Production-System Modeling

After preparing the fluid model, the x-6 wellbore was constructed in PIPESIM using the actual mechanical configuration of the well. The tubing and casing sections were entered according to their depths and internal diameters, and the downhole completion components were defined according to the final completion report. The well was modeled as a naturally flowing oil well producing through the tubing. The pressure-traverse calculation was then used to generate the Vertical Lift Performance (VLP) relationship, which represents the bottom-hole pressure required to lift the produced fluid through the tubing at different production rates [7], [10].

Inflow Performance Modeling

The inflow model was developed by dividing the total inflow pressure loss into three components: reservoir pressure loss, perforation pressure loss, and gravel-pack pressure loss. The reservoir component was calculated using the reservoir permeability, net pay thickness, drainage radius, wellbore radius, and near-wellbore damage parameters. The perforation component was calculated from the perforation geometry, shot density, perforation tunnel length, crushed-zone permeability, and damaged-zone properties. The gravel-pack component was then added using the selected gravel permeability, gravel-filled tunnel length, perforation radius, and number of active perforations. These components were combined to construct the final Inflow Performance Relationship (IPR) curve for each completion case [4], [6].

Nodal Analysis and Sensitivity Procedure

The operating point of the well was determined by intersecting the IPR curve with the VLP curve. This point represents the stable production condition at which the reservoir inflow capacity equals the tubing lift requirement. After establishing the base model, sensitivity analysis was performed to evaluate the influence of gravel-pack permeability and gravel-filled tunnel length on well performance. Four gravel permeability cases were considered according to common gravel sieve sizes, and several gravel-filled tunnel lengths were tested to represent different completion-geometry scenarios. For each case, the gravel-pack flow coefficients were recalculated, the IPR curve was reconstructed, and the new IPR–VLP intersection was determined. This procedure allowed the effect of each gravel-pack characteristic to be evaluated under the same reservoir, fluid, perforation, and tubing conditions.

Results and Discussion

The results were analyzed by combining the vertical lift performance, reservoir inflow performance, perforation losses, and gravel-pack completion losses. This approach was necessary because the production rate of x-6 is not controlled by the reservoir alone, but by the interaction between reservoir deliverability, near-wellbore completion restrictions, and tubing lift requirements. Therefore, the discussion was divided into four main parts: VLP behavior, reservoir and perforation inflow coefficients, cased-perforated operating point, and gravel-pack sensitivity analysis.

Vertical Lift Performance Behavior

The Vertical Lift Performance (VLP) curve represents the flowing bottom-hole pressure required to lift the produced fluid through the tubing at different production rates. The calculated VLP data showed a clear U-shaped behavior, as illustrated in Figure 14. At very low flow rates, the required bottom-hole pressure decreases as production rate increases because the multiphase flow becomes more stable and the lifting condition improves. After reaching a minimum region, the curve begins to rise again because frictional pressure losses become dominant at higher flow rates.

This behavior is important for x-6 because the well contains a tapered production string, including a smaller lower tubing section. As flow rate increases, fluid velocity inside the restricted tubing section increases, causing a rapid increase in frictional pressure loss. Therefore, although the well can lift moderate rates efficiently, high production rates require a significantly higher flowing bottom-hole pressure. This means that the tubing system becomes one of the main limitations when the well operates at high rates [7].

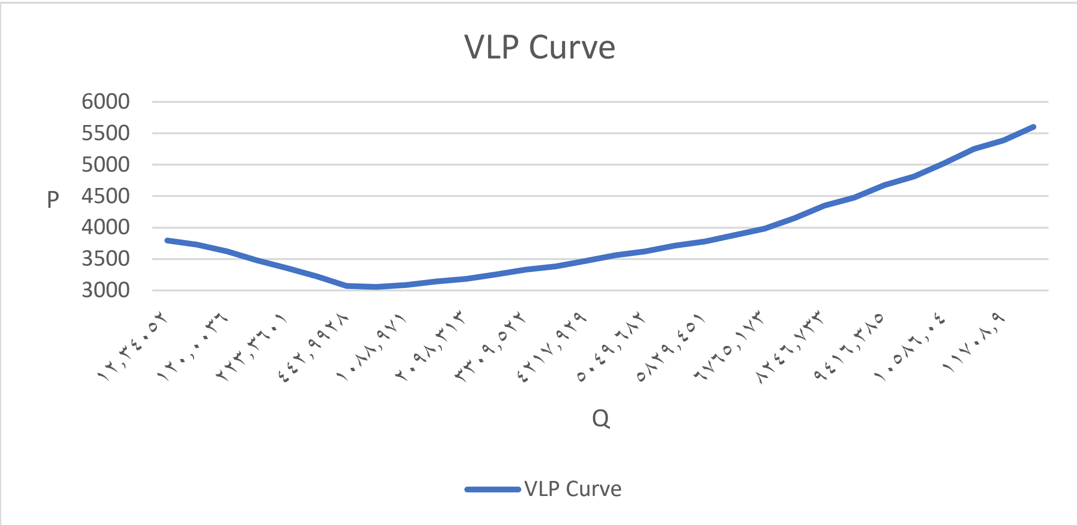


Figure 14**:** Vertical Lift Performance curve for x-6 well.

Reservoir and Perforation Inflow Coefficients

The reservoir inflow coefficients showed that the y interval in x-6 has good flow capacity. The calculated reservoir damage skin was Sd = 0.95497, which indicates moderate near-wellbore damage. This value suggests that the reservoir is not severely damaged, but the well still requires additional drawdown compared with an undamaged case. The linear reservoir coefficient AR = 0.01053 was relatively low, while the quadratic coefficient BR = 7.3 × 10^-12 was very small. This indicates that viscous reservoir flow is the main reservoir-side pressure-loss mechanism over most of the studied rate range, while reservoir non-Darcy effects become significant only at very high rates.

The perforation analysis showed a stronger restriction than the reservoir-side calculation. The geometric perforation skin was Sp = 0.95545696, which represents moderate flow convergence and partial-penetration effects. However, the damaged-zone perforation skin was Sdp = 6.24022463, which is much higher than Sp. This indicates that the main perforation restriction is caused by the damaged or crushed zone around the perforation tunnels rather than the perforation geometry alone. In addition, the perforation inertial factor βdp = 3.134 × 10^7 and the quadratic coefficient BP = 2.85545 × 10^-10 confirm that rate-dependent non-Darcy losses become important at high rates, where fluid acceleration through the perforation tunnels increases completion pressure loss. The main calculated coefficients are summarized in Table 2.

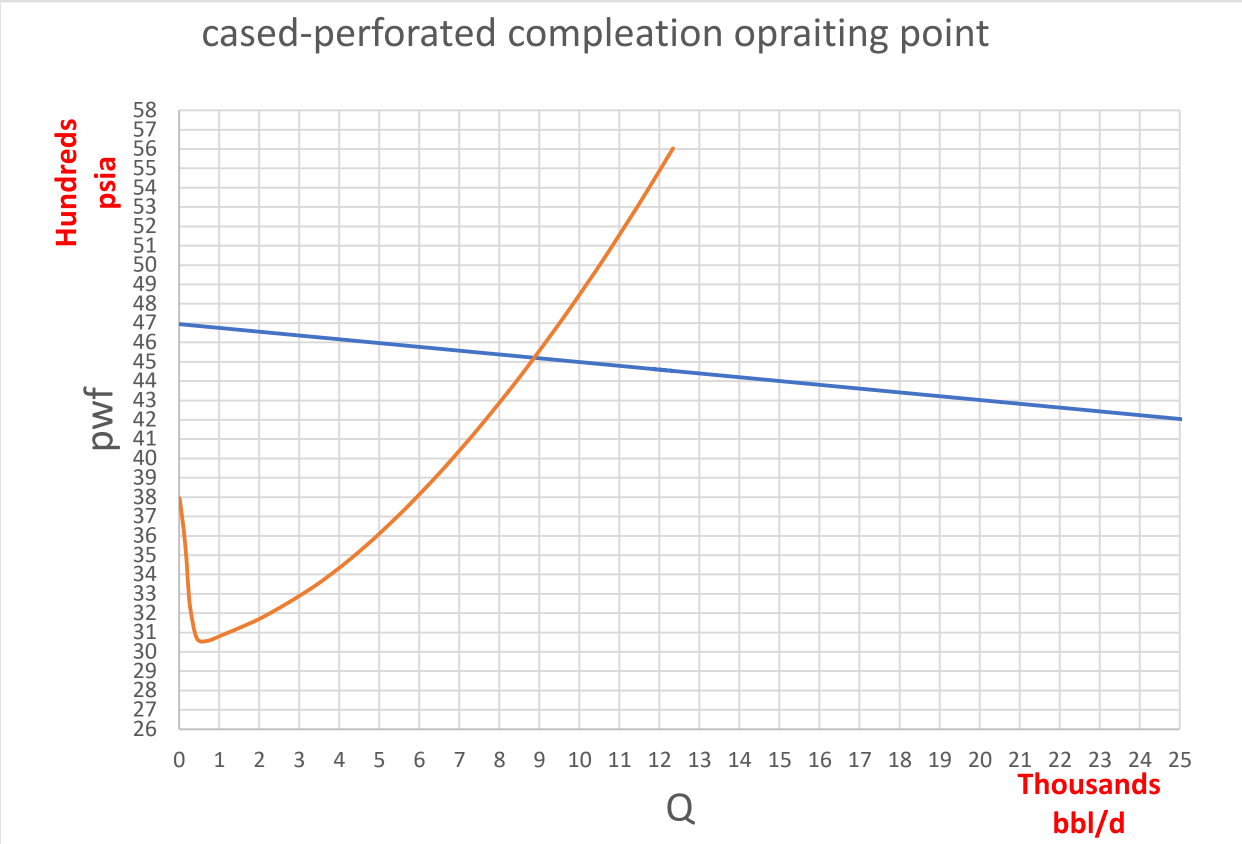
Table 2 Calculated reservoir and perforation inflow coefficients for x-6 well.

Component	Parameter	Value	Interpretation
Reservoir	Sd	0.95497	Moderate near-wellbore damage
Reservoir	βR	3,213,714	Reservoir inertial factor
Reservoir	AR	0.01053	Linear reservoir pressure-loss coefficient
Reservoir	BR	7.3 × 10^-12	Quadratic reservoir pressure-loss coefficient
Perforation	Sp	0.95545696	Geometric perforation skin
Perforation	Sdp	6.24022463	Damaged-zone perforation skin
Perforation	βdp	31,341,485.50	Perforation inertial factor
Perforation	AP	0.00908132	Linear perforation pressure-loss coefficient
Perforation	BP	2.85545 × 10^-10	Quadratic perforation pressure-loss coefficient

The comparison between the reservoir and perforation coefficients indicates that x-6 has good reservoir deliverability, but the inflow efficiency is reduced by completion-related restrictions. The damaged zone around the perforations is the most important near-wellbore restriction because Sdp is significantly higher than Sp. Therefore, any improvement in perforation cleanup, perforation tunnel quality, or near-perforation permeability would be expected to improve the inflow behavior of the well.

Cased-Perforated Completion Operating Point

The base cased-perforated completion case was evaluated by intersecting the calculated inflow curve with the VLP curve. The resulting operating point is shown in Figure 15 and summarized in Table 3. The well reached



an operating rate of 8653.492 STB/d at a flowing bottom-hole pressure of 4470.119 psia.

Figure 15: Cased-perforated completion operating point from IPR–VLP intersection.

Table 3: Operating point of x-6 well for the cased-perforated completion case.

Operating Point	
Q(stb/day)	Pressure (psia)
8653.492	4470.119

This operating point represents the stable production condition at which reservoir inflow equals tubing outflow requirement. The result indicates that x-6 can produce at a relatively high rate with moderate drawdown. However, the calculated perforation coefficients show that the well performance is not controlled by reservoir transmissibility alone. Perforation damage and rate-dependent losses still consume part of the available drawdown, especially as the production rate increases. Therefore, this cased-perforated case was used as the reference condition for evaluating the additional hydraulic effect of gravel-pack completion parameters.

Effect of Gravel-Pack Permeability on Well Performance

The gravel-pack permeability sensitivity was performed to evaluate how different gravel sieve-size cases affect the IPR–VLP operating point. The tested gravel permeabilities were 40,000, 120,000, 250,000, and 500,000 mD. The operating-point results are summarized in Table 4 and illustrated in Figure 16.

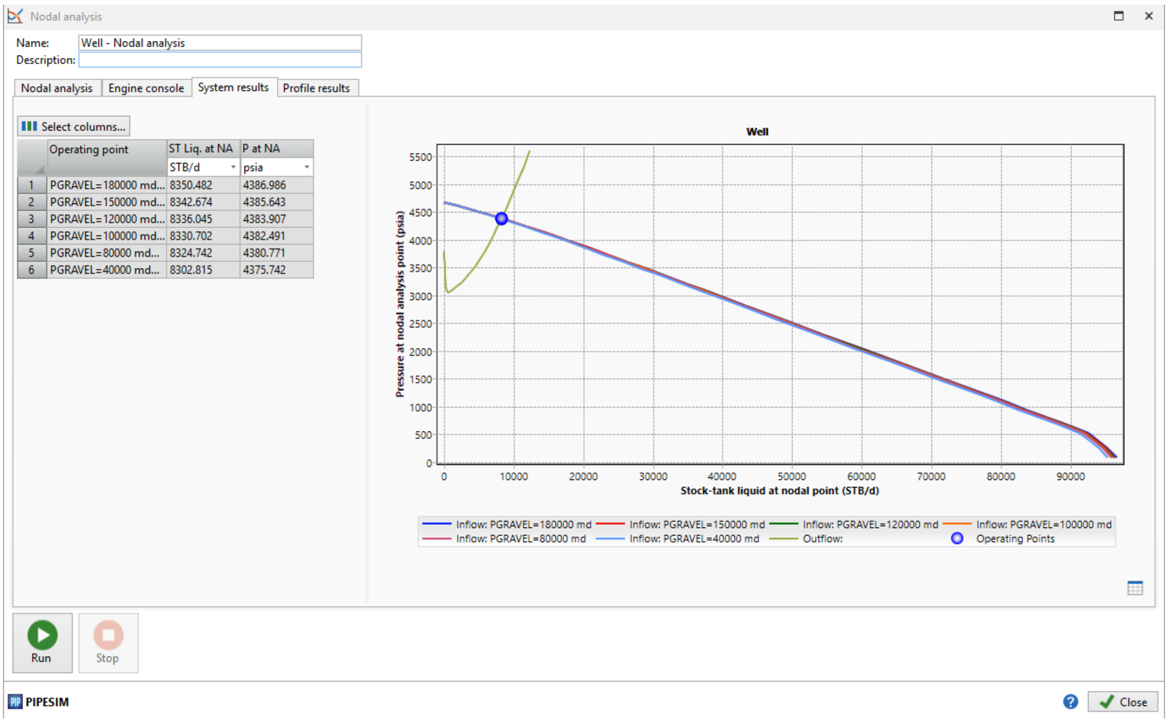


Figure 16: Nodal analysis results for gravel-pack permeability sensitivity in x-6 well.

Table 4**:** IPR–VLP operating point results for each gravel-pack permeability case.

Gravel-pack permeability case (kG)	Operating rate, q	Operating pressure, Pwf
40,000 mD	8793.534	4499.132
120,000 mD	8618.427	4451.084
250,000 mD	9350.261	4655.543

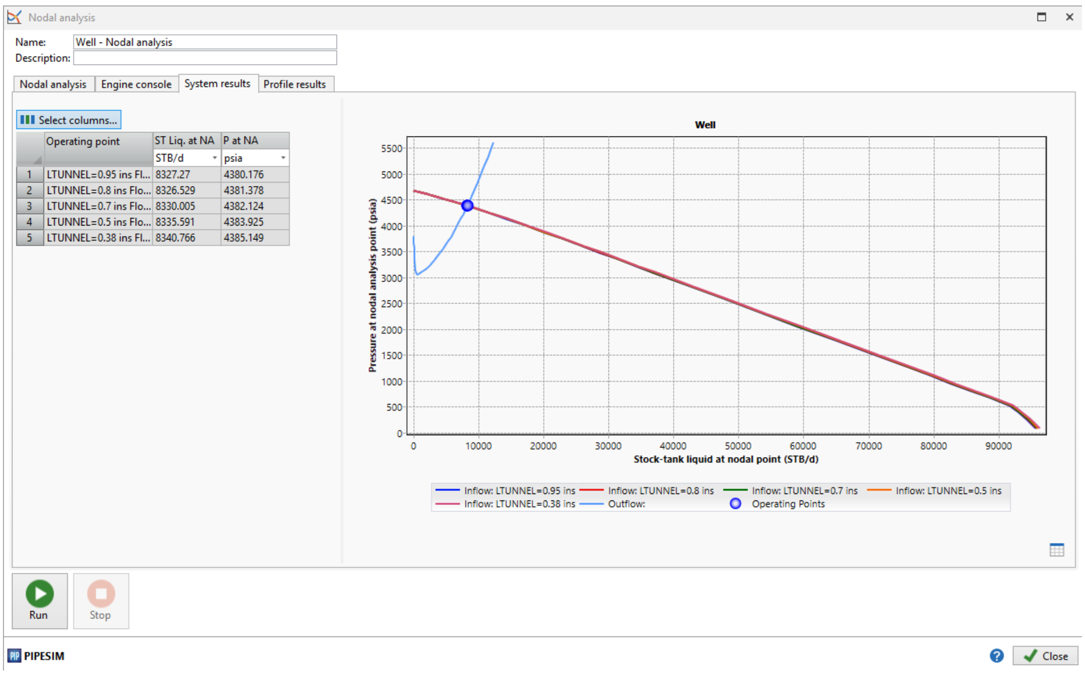
500,000 mD	9418.695	4674.796

The results show that gravel-pack permeability has a direct influence on well deliverability because it controls the additional pressure loss through the packed perforation tunnel. In general, higher gravel-pack permeability reduces both the Darcy and non-Darcy gravel-pack resistance, allowing a larger fraction of the available drawdown to be used for reservoir inflow rather than being consumed across the completion. The highest operating rate was obtained for the 500,000 mD case, where the well reached 9418.695 STB/d at 4674.796 psia. The 250,000 mD case also gave a high rate of 9350.261 STB/d, which is close to the 500,000 mD result.

The small difference between the 250,000 and 500,000 mD cases indicates that after the gravel pack becomes sufficiently conductive, further permeability improvement gives smaller production gains. At this stage, the well response becomes controlled more by other system restrictions, such as perforation damage and tubing lift performance. This is an important practical observation because selecting a very high-permeability gravel may improve well deliverability, but it must still satisfy sand-retention requirements. Therefore, the most suitable gravel is not necessarily the most permeable one, but the one that provides adequate sand control with minimum productivity impairment.

The lower-permeability cases produced lower operating performance compared with the high-permeability cases. The 120,000 mD case gave the lowest operating rate among the tested cases, which confirms that excessive gravel-pack resistance can shift the inflow curve unfavorably and reduce the final operating rate. The slight non-uniform trend between the 40,000 and 120,000 mD cases may be related to the combined effect of linear and quadratic pressure-loss terms and the interpolation of the IPR–VLP intersection. However, the overall engineering trend remains clear: the 250,000–500,000 mD range provides the most favorable hydraulic performance for x-6

Effect of Gravel-Filled Tunnel Length on Well Performance The gravel-filled tunnel length sensitivity was carried out at fixed gravel-pack permeability to evaluate the effect of flow-path length through the packed gravel. The tested lengths were 0.95, 0.80, 0.70, 0.60, 0.50, and 0.38 in. The operating points are summarized



in Table 5 and shown in Figure 17.

Figure 17: Nodal analysis results for gravel-pack tunnel length sensitivity in x-6 well.

Table 5: IPR–VLP operating point results for each gravel-pack tunnel length.

Gravel-pack length, L (in)	Operating rate, q	Operating pressure, Pwf
0.95	8398.611	4391.954
0.8	8470.611	4411.321
0.7	8519.31	4424.42
0.6	8568.577	4437.674
0.5	8618.435	4451.084
0.38	8679.03	4467.387

The results show a consistent improvement in well deliverability as the gravel-filled tunnel length decreases. When L was reduced from 0.95 to 0.38 in, the operating rate increased from 8398.611 to 8679.030 STB/d, which represents an increase of about 280.4 STB/d. The corresponding flowing bottom-hole pressure increased from 4391.954 to 4467.387 psia. This increase in Pwf does not indicate poorer performance; instead, it means that less pressure is lost across the completion, so the well can operate at a higher sandface pressure while producing at a higher rate.

This trend is consistent with the theoretical gravel-pack pressure-loss equations, where both AG and BG are directly proportional to the gravel-filled length L. A longer packed tunnel creates a longer flow path through porous gravel, increasing both viscous and inertial pressure losses. As a result, more drawdown is consumed inside the completion before fluids enter the wellbore. In contrast, reducing unnecessary gravel-filled length decreases completion resistance and shifts the inflow curve toward a more favorable operating point.

The improvement caused by length reduction is moderate compared with the improvement achieved by increasing gravel-pack permeability. This indicates that gravel permeability is the dominant gravel-pack parameter in the present case, while tunnel length has a secondary but still measurable effect. From a design point of view, the preferred hydraulic condition is a short, clean, and uniformly packed gravel path, provided that the completion still provides stable sand retention and full coverage of the perforated interval.

Overall Engineering Interpretation

The results confirm that x-6 has good reservoir flow capacity, but the final production performance is strongly affected by completion-related pressure losses. The reservoir-side coefficients indicate moderate damage and good transmissibility, whereas the perforation analysis shows that crushed-zone and damaged-zone effects around the perforations create a significant additional restriction. The VLP curve further shows that the tubing system becomes increasingly restrictive at high flow rates due to frictional pressure losses.

The gravel-pack sensitivity analysis demonstrates that gravel-pack design must balance sand control and productivity. A low-permeability gravel pack or an unnecessarily long gravel-filled tunnel increases completion pressure loss and reduces the operating rate. Conversely, a high-conductivity gravel pack with minimum unnecessary flow length improves well deliverability and preserves more of the available drawdown for reservoir inflow. Based on the sensitivity results, the best hydraulic performance was achieved with the 500,000 mD gravel-pack permeability case, while the shortest tested gravel-filled tunnel length of 0.38 in gave the best length-sensitivity result. However, the final completion selection should not be based on hydraulic performance alone; it must also satisfy gravel-sizing and sand-retention criteria for the y formation.

Overall, the analysis shows that gravel packing is a suitable sand-control option for x-6, but its effectiveness depends strongly on the selected gravel properties and completion geometry. The optimum design is the one that can prevent sand production while maintaining high flow capacity, minimizing near-wellbore pressure loss, and preserving stable long-term well productivity.

Conclusions and Recommendations

Conclusions

This paper evaluated gravel-pack completion characteristics as both sand-control and hydraulic-performance factors in a confidential producing well from a selected Iraqi oil field. The analysis combined completion data, PVT properties, perforation parameters, IPR, VLP, and gravel-pack sensitivity cases using nodal analysis.

The results showed that the studied well has good reservoir deliverability, but completion-related restrictions reduce the effective inflow performance. The damaged or crushed zone around the perforation tunnels was the main source of additional pressure loss, indicating that well performance is controlled by both reservoir quality and completion condition.

The VLP curve showed a concave behavior because of the balance between hydrostatic and frictional pressure losses. At low rates, lifting conditions improve, while at high rates, friction losses dominate and increase the required flowing bottom-hole pressure.

Increasing gravel-pack permeability improved well deliverability by reducing Darcy and non-Darcy losses. The best response was obtained in the high-permeability range, although the improvement became smaller when other restrictions, such as perforation damage and tubing lift performance, became dominant.

Reducing gravel-filled tunnel length also improved performance. When the length decreased from 0.95 to 0.38 in, the operating rate increased from about 8398.611 to 8679.030 STB/day because the shorter flow path reduced completion resistance.

Overall, gravel-pack design should be evaluated based on both sand retention and hydraulic efficiency. A high-conductivity, properly placed gravel pack with minimum unnecessary flow-path length gives the best balance between sand control and productivity.

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