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THE IMPACT OF PERFORATION GEOMETRY ON OIL WELL PRODUCTIVITY

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ABSTRACT

The increase in demand for oil and gas today requires oil operators to maximize productivity. In order to produce more fluid from the reservoir into the wellbore, perforations must penetrate considerably beyond invaded zone with impaired permeability. The production engineers must take advantage of the perforation controllable parameters to maximize the well productivity. In this study, a simple analytical model incorporating perforation length, radius, and shot density was used to analyze oil well productivity. The results shows that the production rate can be increased by the perforation length, radius, and shot density. The drawdown pressure was reduced with increase in the perforation length and shot density. Higher fluid velocity was controlled with increase in the shot density, length and radius of perforation. The length of perforation and shot density are better in optimizing well productivity. Optimum perforation parameters are required as further increase result in increase in cost relative to the productivity.

Keywords: Perforation pressure, perforation length, perforation radius, shot density, pressure drawdown.

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1. INTRODUCTION

The current trend in the demand for oil and gas requires oil operators to maximize production from prolific fields. This can be achieved by making better connection path ways between the wellbore and the reservoir for the ease of hydrocarbon production. A key link in well completion operations is the perforation which plays a vital role in oil and gas production from the reservoir. It is the act of making holes into the formation to allow fluid flow into the wellbore. This is done by making holes through the casing, cement region, and into the formation for fluid flow. Completion and production engineers must ensure optimum perforation parameters such as the shot density, radius of perforation, length of perforation, and phasing angle to maximize the flow of reservoir fluid [9]. Perforation patterns usually done with the aid of a perforating gun, are usually created through the well casing, cement region, and into the productive zone of the formation [8]. This is done to provide effective flow communication between the wellbore and reservoir.

The perforation hole has been used in controlling the fluid flow channels connecting the wellbore and the reservoir. In 1932, the first well reported to be gun perforated was carried out by Union Oil Co. of California in the Montebello field, Los Angeles County, California. Since that time, many types of special bullets and jets have been introduced to improve the perforation job. The use of gun perforation gained industry acceptance in those years as a practical completion technique for cased hole. However, production engineers were not satisfied with the observed productivities due to the negative effect of the perforation operation on the formation. The reduction in productivity observed was tied to deficiencies in design and procedures of perforation. The poor perforation job causes impairment of permeability which reduces the productivity of the reservoir. This zone of reduced permeability is called skin. [1] investigated the effect of perforation job on formation damage. Reduced productivity of the reservoir as a result of the impairment of the permeable zones was observed. The design of perforation is of utmost importance as the cavity influences the production of sand in the well, resulting in unintentional shutdown of well for workover operations [6].

Experimental analysis using linear perforated cores was investigated by [5], the reduced productivity caused by migration of fines or debris from the crushed zones in the tunnel was discovered. Perforating beyond the invaded zone of drilling fluid is key to maximizing productivity from perforations. Perforations can significantly affect the total completion efficiency. The high explosive activity during perforation can damage the formation permeability around perforation tunnels. Hence the perforation controllable parameters such as the penetration depth of perforation, perforation hole diamter, shot density or number of shots, and the phasing angle must managed. The perforation interval is the portion of the wellbore reserved for the fluid production by the creation of channels between the wellbore and the reservoir. The perforation controllable parameters are as follows:

2. PERFORATION LENGTH

It's been discovered that deeper penetration into the formation is as a result of the crushing and compaction of the casing, cement, and formation. Increase in the length reduces the effect of skin and improves the flow productivity of oil and gas well, this makes the perforation length the most productive perforation parameter amongst all [2]. Deeper penetration into the formation opens up and capture more flow area for fluid, this enhances the well productivity.

2.1. Perforation Diameter

The diameter of Perforation is dependent on the design of the charges that will be used and also the clearance of the gun during the perforation operation. [4] showed the negligible impact of the perforation diameter on the well productivity amongst other perforation parameters. However, optimum diameter has effect on the fluid flow, it generally reduces frictional pressure losses and turbulent effect.

2.3. Perforation Density

This is the number of holes expressed in shot per foot (Spf). Adequate shot density can reduce skin due to perforation and produce fluid at lower pressure differentials. The density of perforation, if properly managed, is one of the important factors that enhances well productivity, hence, balances the increased cost of well [3].

2.4. Perforation Phasing

There are different phasing angles used during the detonation of shaped charges. For example, 60°, 90°, 120° for fracturing, and 60° may be used for gravel packing.

3. METHODOLOGY

The selection criteria used in this analysis were defined based on the perforation controllable parameters. The parameters were varied in order to determine the sensitivity of production rate, fluid velocity, drawdown, and perforation pressure.

During the production of reservoir fluids from the well, the flow rate through the perforated hole is affected by the perforation size parameters as stated in equation 1 below [7].

$$q_o = \frac{l_p n_p k_c}{\Delta \overline{P}_{pD} 1695} \left[\frac{1}{2P} \left(\frac{k_{ro}}{\mu_o B_o} \right) \right]_{p=\overline{p}} \left(P_c^{\,2} - P_p^{\,2} \right) \tag{1}$$

Introducing fluid flow velocity, V and area of perforation open to flow, A. The area open to flow is calculated based on the perforation radius and length. The velocity of flow is also controlled by the perforation size parameters as shown in equation 2 below.

$$V = \frac{q_o}{A}$$

$$V = \left[\frac{\frac{1}{2P}\left(\frac{k_{ro}}{\mu_o B_o}\right)\left(P_c^{\,2} - P_p^{\,2}\right) L_p n_p K_c}{1695 \Delta P_{pd}} \right] / A \tag{2}$$

Assuming a cylindrical perforated hole area (A) expressed in equation 3.

$$A = 2\pi r^2 + 2\pi r l \tag{3}$$

The effect of the perforation parameters, differential pressure $(P_C - P_P)$ across perforation hole on the flow rate is determined using equation 1, the flow rate equation (q_o). The effect of the above factors is also evaluated on the fluid velocity across the perforation hole. The procedure for using the mathematical modelling procedure is presented in the appendix.

4. DISCUSSION AND ANALYSIS

Figure 1 shows a plot of perforation pressure against flow rate at different perforation length. Increased allowable perforation length leads to increase in the achievable production rate at a particular perforation pressure. The increase in the perforation length into the formation captures more flow area, thereby increasing the flow rate and well productivity. This causes a decrease in the perforation pressure despite the increase in the flow rate. The decreased perforation pressure is an indication of less potential for sand production. The increase in the well productivity suggest a reduction in the skin factor which is inversely proportional to the deliverability of the oil well. However the increase in the flow rate as the penetration into the reservoir increases, an optimum length will be reached where further increase in the length may produce less significant productivities. The productivity difference as length changes from 6.5 in to 7.0 is less compared to 5.5 in to 5.5 in. Hence, beyond the optimum length of perforation, the yield of productivity may relatively not be needed in comparison to cost of perforation.

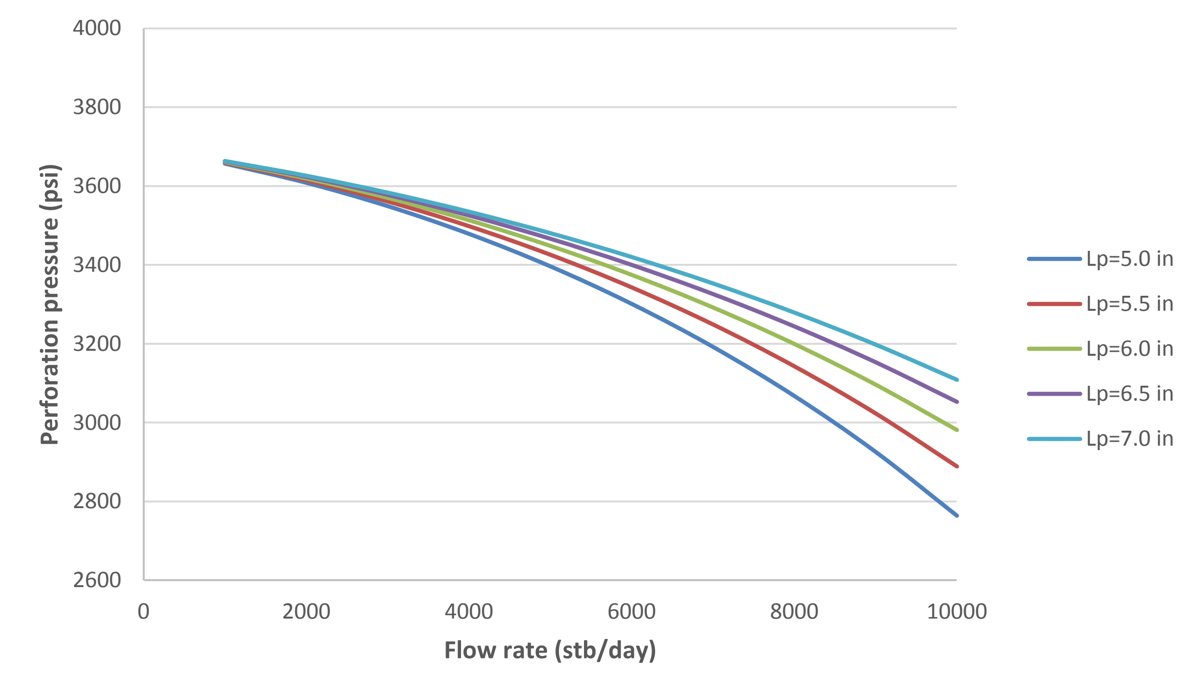

Figure 1 Impact of perforation length on perforation pressure and flow rate.

The drawdown pressure is responsible for the fluid flow from the reservoir into the wellbore, it is the difference between the reservoir pressure and the wellbore flowing pressure in the perforated hole. From **Figure 2**, it is observed that higher pressure drawdown is required to pull out higher flow of fluid, however, increase in the drawdown beyond threshold value can influence the production of sand in the reservoir. The flow rate of fluid is optimized by the increase in the length of perforation which reduces the drawdown pressure required for a particular flow rate. The longest perforation length has the lowest drawdown pressure, this implies less drag force on the formation is expected thereby reducing tendency for sand production. The impact of the perforation length shows that higher flow rate can be achieved with less drawdown pressure.

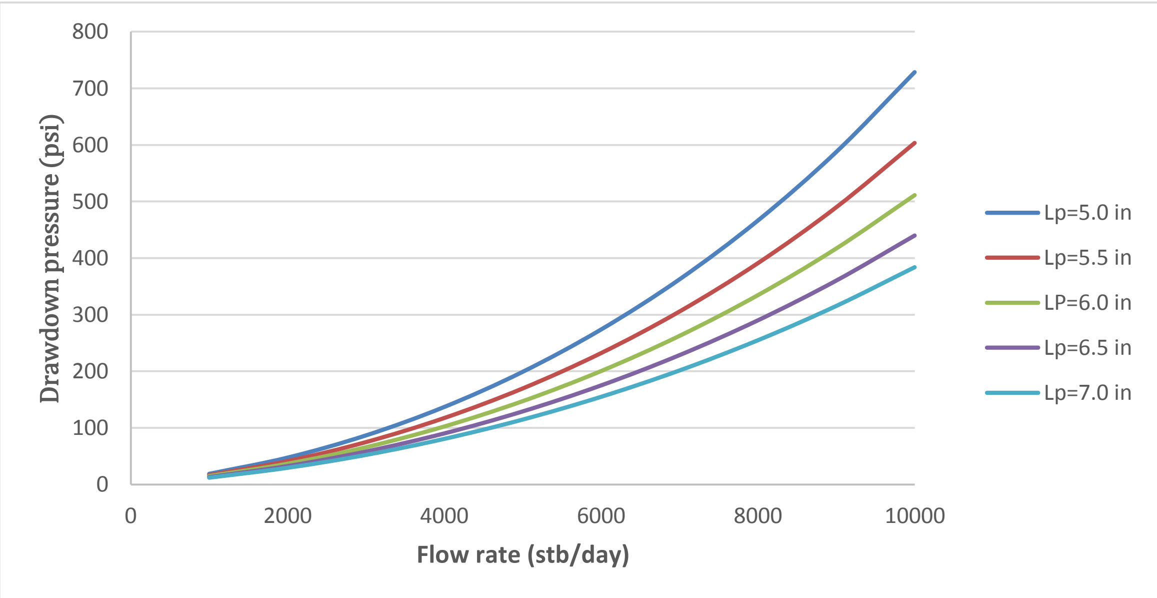

Figure 2 Impact of perforation length on drawdown pressure and flow rate.

Figure 3 shows the effect of the perforation length on the fluid velocity in improving the flow rate. The higher the velocity of the fluid, the higher is the flow rate. For a desired flow rate, an increase in the perforation length reduces the fluid velocity. Hence, the fluid velocity can be controlled by the length of perforation. It should be noted that increase in the fluid velocities obeys non-Darcy law (inertia effects), and this causes higher tendencies for turbulence in the perforated region that can cause higher pressure losses, with fines migration. Higher fluid velocities of reservoir fluid result in additional pressure losses and increased inertia pressure gradients.

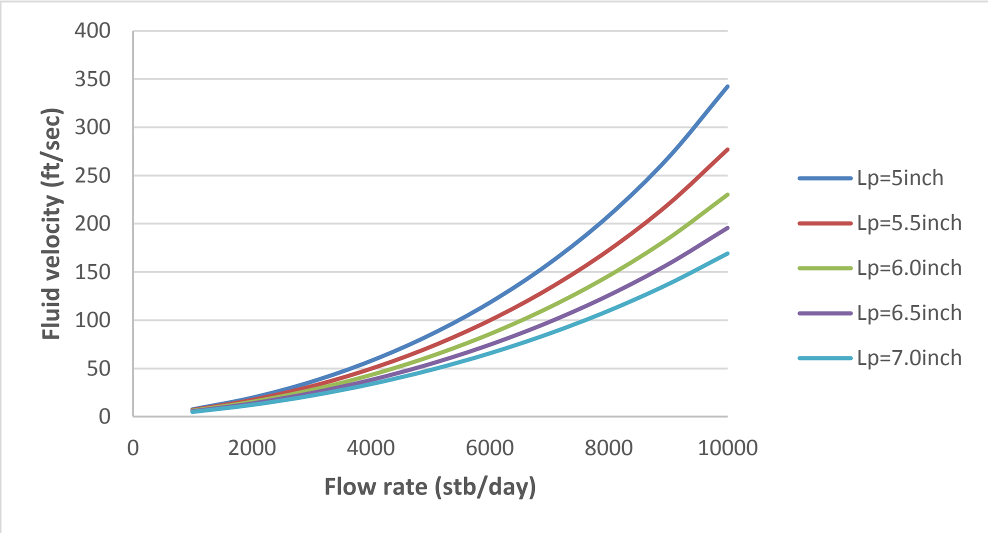

Figure 3 Impact of perforation length on the fluid velocity and flow rate.

Figure 4 relates perforation pressure to flow rate at varying perforation radius. The effect of perforation radius is not as similar to the effect of the perforation length. Hence it's the least of all perforation controllable parameters in enhancing well productivity. At a particular perforation pressure, increased allowable perforation radius leads to increase in the achievable production rate. The flow rate increases with decrease in the perforation pressure at varying perforation diameter.

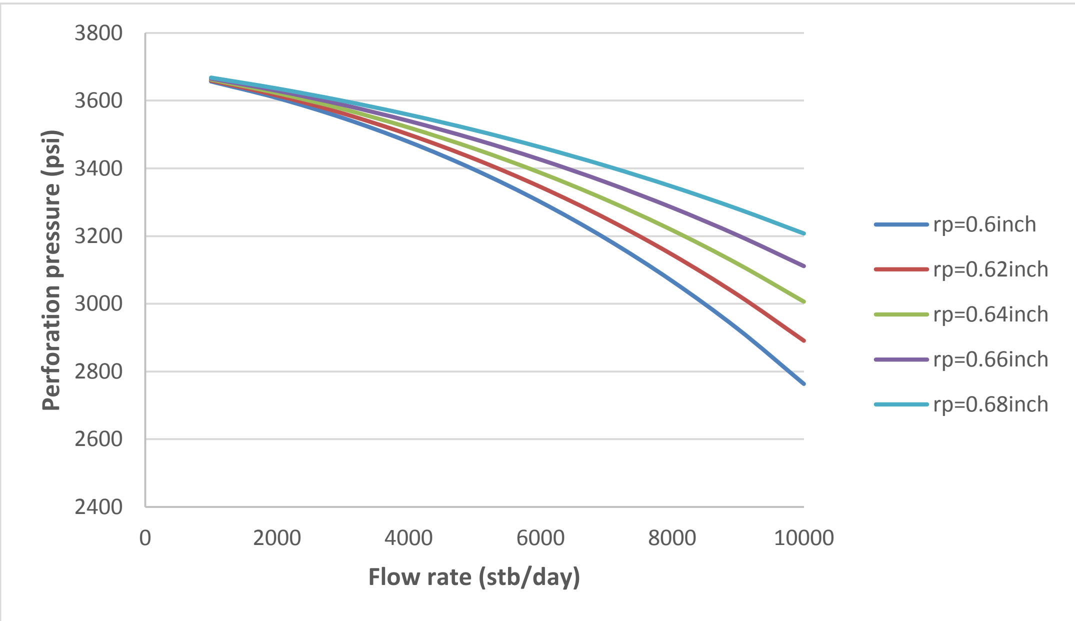

Figure 4 Impact of perforation hole diameter on the perforation pressure and the flow rate.

Figure 5 shows that the larger the perforated hole, the lesser the drawdown pressure required to drive in fluid from the reservoir to the wellbore. The drawdown pressure required to draw in the fluid increases as the flow rate increases. As the radius of the perforation increases, the drawdown pressure reduces

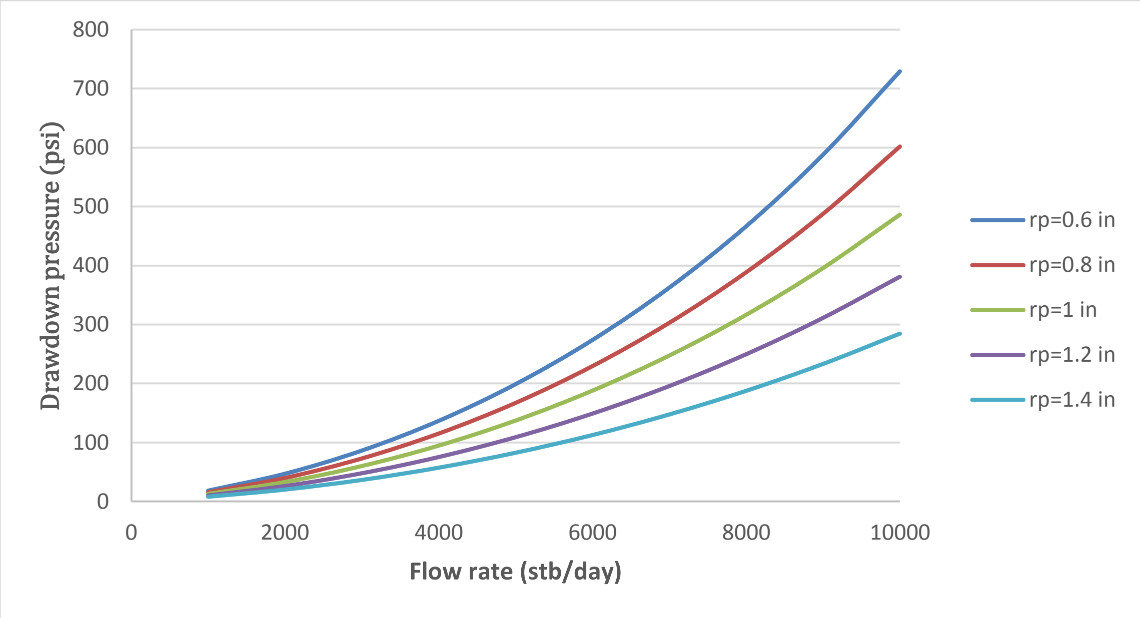

Figure 5 Impact of perforation hole diameter on the drawdown pressure and the flow rate.

The fluid velocity as seen in **Figure 6** is inversely proportional to the perforated hole diameter at a particular flow rate. This indicates that for a larger perforation hole diameter, the area open to flow is wider, and less fluid restriction is encountered.

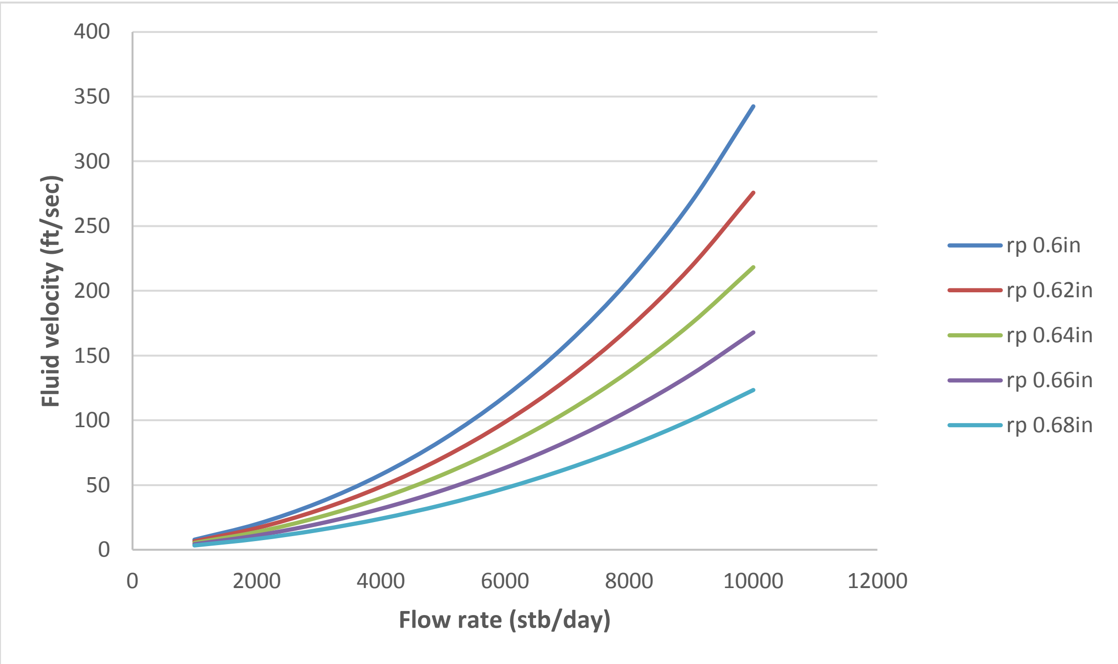

Figure 6 Impact of perforation hole diameter on the fluid velocity and flow rate.

The number of shot in the pay-zone is also a controllable parameter that influences the well productivity. This parameter depends on the strength of formation amongst other factors. Increase in shot density can be seen to give better connection between the wellbore and the formation, and this is evident in the achievable flow rate in **Figure 7**. The flow rate increases significantly at the initial increase from 2 to 8 shot per foot, and flow rate increase beyond the 8 shot per foot is less compared to the initial increment.

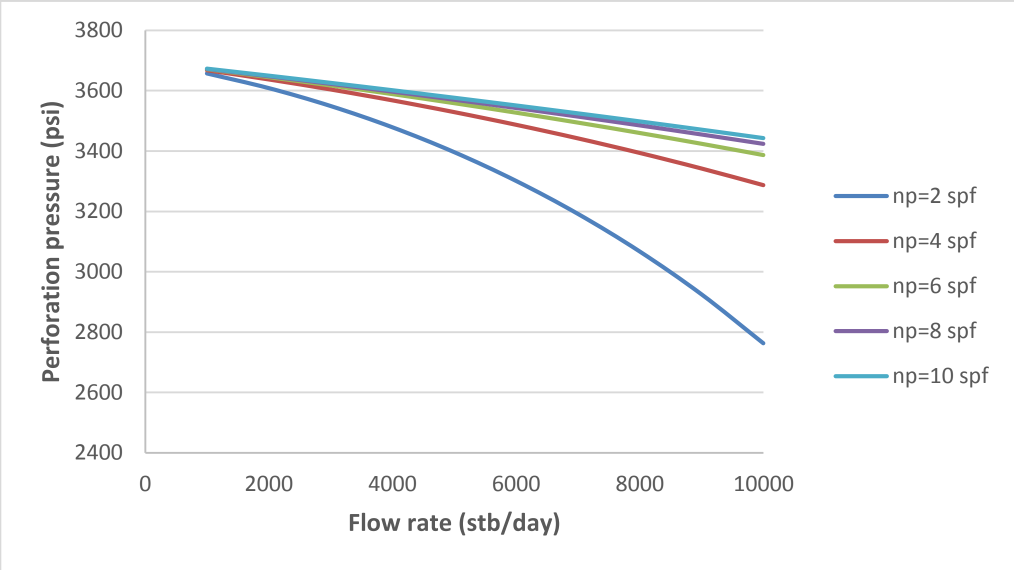

Figure 7 Impact of shot density on the perforation pressure and flow rate.

Figure 8 shows that at higher shot per foot, the fluid velocity required to bring about flow is less. Increase in the shot per foot opens more flow area with less tendencies for increased skin factor. Hence higher productivity is expected with higher number of shot per foot.

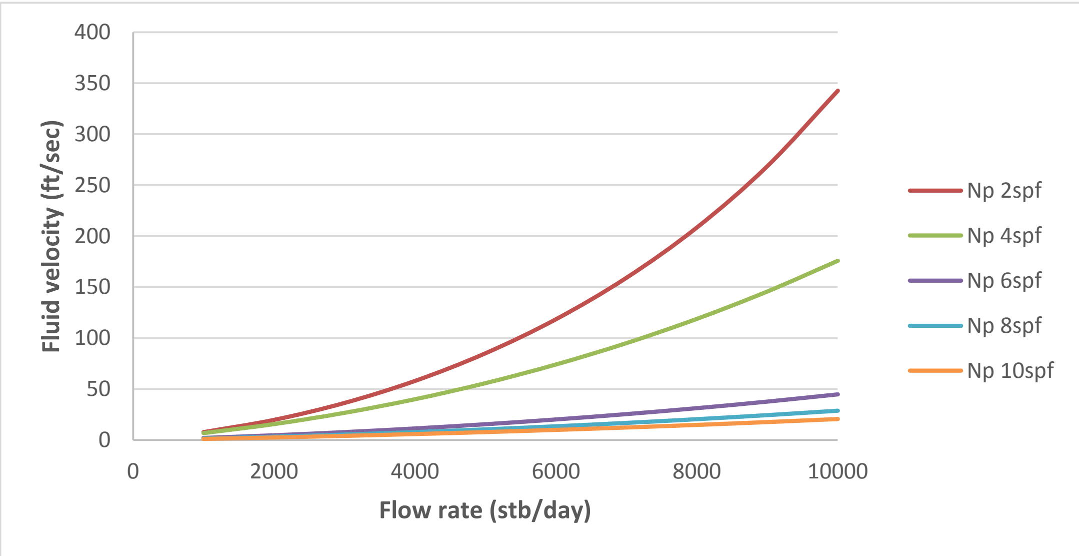

Figure 8 Impact shot density on the fluid velocity and flow rate.

5. CONCLUSION

The following are evident conclusions made from this study.

- The deeper length of perforation improves the productivity of the well by capturing fluid flow areas even at a maintained perforation pressure which reduces the drawdown pressure that may cause potential sand production.
- Higher fluid velocities and potential turbulence of fluid causing high pressure losses can be controlled by the increase in the length of perforation.

- The drawdown pressure responsible for increased flow rate can however cause sand production, this is controlled by the perforation parameters most especially the length of perforation and the shot density
- The larger perforation hole opens up passage route for the fluid with less tendency for increased fluid velocity and pressure drawdown.
- The higher the number of shots in the pay zone, the more area and passage route open to flow of the fluid, thereby increasing the flow rate of fluid and reducing pressure drawdown.
- Optimum perforation parameters are required as further increases result in lower productivity compared to the cost of perforation

Nomenclature

P Pressure, psi

P_r Reservoir pressure

l Length, in

K Permeability, md

n_p Number of perforations per foot

K_{ro} Oil relative permeability, md

$\Delta\overline{P}_{pD}$ Approximate dimensionless pseudopressure drop

ΔP_{pD} Dimensionless pseudopressure drop

q Flow rate, STB/d

β Oil formation volume factor, rb/stb

v Velocity of fluid flow, ft/sec

r Radius of hole, ft

A Cross-sectional area, ft^2

μ Viscosity, cp

$\overline{\mu}_{oD}$ Approximate dimensionless pseudopressure drop

N_{Re} Reynolds number

h_p Perforation interval, ft

R_s Solution gas oil ratio, scf/STB

h Height, ft

Subscript

o Oil

c Crushed zone

p Perforation

b Bubble point

D Dimensionless

wf Well flowing

d Dead

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APPENDIX

The following procedures shows the mathematical modelling to obtain pressure drop across the perforated hole. It is a direct substitution method that requires three iterations. The data used in this work corresponds to a field case as discussed in the [7]. It describes the steps involved in calculating the pressure drop across perforations at different flow rates (example at 1000 stb/day).

Calculating the crushed pressure assuming the $P_{wf} = P_c$

$$P_c = \sqrt{(P_r)^2(\text{psia}^2) - \left[\frac{q_o(\frac{\text{stb}}{\text{d}})}{0.006857\ \text{stb}/(\text{d} - \text{psia}^2)}\right]}$$

Calculate $\Delta\overline{P}_{pD}$ assuming $\overline{\mu}_{oD} = 1.0$

$$\beta_o = \frac{2.33 * 10^{10}}{(K_c)^{1.201}(\text{md})}$$

$$l_o = 1.062 * 10^{-14} * K_c(\text{md}) * \beta_o(\text{ft}^{-1})$$

The number of perforations, $n_p = \text{shot density (shot/ft)} * h_p(\text{ft})$

$$N_{Re(oc)} = \frac{2.216 * \rho_o\left(\frac{\text{lbm}}{\text{ft}^3}\right) * l_o(\text{ft}) * q_o}{l_p(\text{ft}) * n_p(\text{shot}) * r_c(\text{in}) * \mu_{(oc)}(\text{cp})}$$

$$r_{cD} = \frac{r_c(ft)}{r_p(ft)}$$

$$\Delta\overline{P}_{pD} = \ln(r_{cD}) + \frac{N_{Re(oc)}}{\overline{\mu}_{oD}}(r_{cD} - 1)$$

In calculating the perforation pressure from the equation below

$$\overline{P} = P_b = 4743 \text{ psia}$$

$$B_{ob} = 1.6622\frac{bbl}{stb}$$

$$k_{ro} = 1$$

The saturated oil viscosity is calculated using the Beggs-Robbinson Correlation

$$\mu_{ob} = (10.715 * (R_s + 100)^{-0.515}) * (\mu_{od})^b$$

where $b = 5.44 * (R_s + 150)^{-0.338}$

$$q_o = \frac{l_p n_p k_c}{\Delta\overline{P}_{pD}1695}\left[\frac{1}{2p}\left(\frac{k_{ro}}{\mu_o B_o}\right)\right]_{P=\overline{p}}(P_c^{\,2} - P_p^{\,2})$$

P_p can now be estimated from the above rate equation

Calculating the $\overline{\mu}_{oD}$ with the perforation pressure

$$\overline{\mu}_{oD} = \frac{\mu_{ob}}{\mu_{(oc)}}$$

Calculate $\Delta\overline{P}_{pD}$ with $\overline{\mu}_{oD}$ gotten from step 4

Calculate the new estimate of the perforation pressure using the $\Delta\overline{P}_{pD}$ gotten from step 5.

The pressure drop across the perforations is calculated using $\Delta P = P_c - P_p$

Repeat step 4 through 7 with the perforation pressure calculated in step 6 as the new estimate until convergence is obtained.