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PENETRATION DEPTH CONSIDERATION FOR BETTER PERFORATION PERFORMANCE

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ABSTRACT

For optimum perforated well productivity, perforation must be deep enough to overcome any damage or barrier, cause minimum damage, clean, effective and stable. The importance of penetration depth to the perforated well productivity is determine by the completion type, gun, charge, formation rock properties, stress, gun clearance, casing and cement thickness. Generally, the productivity will be increased with increasing penetration depth, but, on the other hand, the perforation stability and/or the perforated wellbore stability decreases as the penetration depth increases, and deeper perforations are more difficult to clean.

INTRODUCTION

Perforation is a hole to provide a good and effective communication channel between the wellbore and the productive zone to give optimum well productivity. To obtain the optimum gain in perforated well productivity, perforations must be deep enough to overcome the formation damage or barrier caused by drilling operations, cause minimum damage, clean, be effective and stable. On the other hand, very deep perforation of small diameter are more difficult to clean effectively.

The primary objective in perforating job for natural completions are to produce deeper penetration depth to overcome formation damage, higher shot density to reduce pressure drop around the perforation and increased perforation efficiency. For natural completion, penetration depth and shot density are very important geometrical factors, followed by phasing. Perforation diameter is relatively insignificant (Bell, 1982).

The perforating job objective for sand control completions are to reduced velocity, the pressure drop in the perforations and sand carrying capacity of the production fluid. Therefore shot density becomes a most important geometrical factor, followed by perforation diameter, phasing angle and penetration depth (Bell, 1982). Morita et. al (1989) concluded that one of the method to reduced a sand production problem in a weak rock is to avoid too long or too short penetration depth. For intermediate rock, sand problems can be minimized by deeper penetration depth.

If the formation is to be fractured, especially in a low-permeability reservoir, the perforation job should be planned to allow communication with all the desired zones with a minimum pressure drop across the perforation. It is necessary to perforate with deeper penetration and higher shot density in order to maximize the well productivity (Bell, 1982 & 1984; King, 1987).

FACTORS AFFECTING PENETRATION DEPTH

Gun Size

The purpose of a gun is to create a hole in the casing, cement and to extend the hole into the formation rock to allow efficient fluid flow between the formation and wellbore. Guns for the casing operations normally are big, i.e. diameter ranges from 63.50 mm to 184 mm. They may produce deeper penetration depth than the guns for through tubing operations. The guns for through tubing operations are normally small; i.e. diameter less than 63.50 mm. In general, the penetration depth for the particular gun will increase with an increase in the gun size (Week, 1974).

Charge

Generally, charges can be considered as the key element to the perforation and they have several important pre-requisites: the design, manufacturing procedure, storage and handling facilities. The ability of shaped charge to produce a deep penetration depends on its ability to concentrate its energy along a single axis, that is to produce a single round hole (King, et.al, 1986). The charge alignment in the gun is important for proper gun clearance, and to produce a round entrance hole and deep penetration.

For each particular gun, the penetration depth will increase as the charge load increases, depending on the gun clearance. The average penetration depth of the smaller charges is roughly 65 % of the larger charges. The powdered metal liner charges produce better penetration depth than the wrapped metal liner charges. The big hole charges produce a shorter penetration depth.

Shooting with the proper alignment, the charge can produce greater penetration depth. On the other hand, misalignment may produce a penetration depth of 20 to 50 % less than properly aligned charges. Misalignment of the charges can be caused by improper installation, faulty alignment equipment, jaring the charge or non-symmetric charge design. The charge will produced a deep penetration hole if its energy is concentrated along a single axis. If the charge elements are asymmetric, there may be multiple penetration axes and double jetting, resulting in a decrease of about 50 % in penetration depth.

Generally, charges with a sharp liner angle may produce a larger penetration depth, depending on the gun size and clearance. Charges with an imperfect surface can produce less penetration depth depending upon the nature of the surface; charges with a very small liner surface crack have same performance as undamaged charges but charge with larger cracks may produce only 75 % of penetration of undamaged liner surfaces.

When the charge is fired, it generates pressure that propels the liner toward its axis and the resulting jet penetrates casing, cement and formation rock. Larger penetration depth could be expected if stronger pressure were generated by the charge.

Formation Properties

Formation properties affect the charge performance in terms of penetration ability. Generally, penetration depth decreases as formation rock compressive strength increases. Based on laboratory shot tests, Thompson (1962) showed that the relationship between penetration depth and formation compressive strength for the shaped charge guns can be expressed by Equation (1).

$$\ln Lp = \ln Lp1 + 0.086(C1 - C)/1000 \qquad (1)$$

where;

Lp = penetration depth into the actual formation
Lp1 = penetration depth into the testing formation (1)
C1 = compressive strength of the testing formation (1)
C = compressive strength of the actual formation

By using Equation. (1), gun penetration depth from API-RP 43 (Section II) data can be used to estimate the gun penetration depth into the actual formation rock provided the compressive strength of the formation rock is known.

The API-RP 43 test is based on a compressive strength ranging from 41.34 MN/sq.m to 55.12 MN/sq.m, but the actual formation compressive strength ranges from 6.89 MN/sq.m to 10.34 MN/sq.m for the shallow sand to more than 137.8 MN/sq.m for some of the older, deeper formation (Week, 1974).

In-situ Effective Stress

Based on laboratory studies, Saucier et.al. (1980) concluded that the penetration depth also decreases as the in-situ effective stress increase until a penetration plateau (minimum limit) is reached at an effective stress ranging from 34.45 to 41.34 MN/sq.m, after which there is no penetration reduction with increasing in-situ effective stress. Based on field data, Bell (1984) also found that if the bottom hole temperature is higher than 340 degree F, penetration depth of most commercial guns (maximum temperature equal to 340 degree F) will be decreased by 10 - 20 % by a decrease in the effectiveness of the charge. Normally, these guns produce about 203 mm penetration depth.

Gun Clearance

The gun clearance is the distance between the gun and the inside wall of the casing. Generally, if the gun clearance increases, the penetration depth will decrease depending on the gun size and charge weight. Zero gun clearance produces a slightly larger entrance hole diameter and deepest penetration depth than any other gun clerance values. The effect of gun clearance on the penetration depth is almost insignificant with larger guns and greater charge weight. Generally, casing gun penetration is about twice that of through-tubing guns.

Casing & Cement Thickness

The actual performance of the gun and charge depends on how far they can penetrate into the formation rock. This depends on the thickness of the casing and cement in the annulus, and the gun clearance. Penetration depth into the formation rock decreases with increasing casing and cement thickness.

EFFECT OF PENETRATION DEPTH TO THE PERFORATION STABILITY

In general, the perforation system stability depends on penetration depth. Fig. (1) shows that 4 SPF, inline perforation pattern with a penetration depth of 89 mm fails at 33.33 MN/sq.m vertical stress, while the perforations 125 mm in depth (40.45 % increase) fail at a lower vertical stress, equal to 23.61 MN/sq. m. This indicates that the perforation system stability decreases as the penetration depth increases.

Fig. (1) also shows that 6 shots per foot, 60 degree phasing spiral perforation pattern with 78.5 mm depth appears to fail at a vertical stress equal to 46.32 MN/sq. m, while the 130 mm depth perforation (65.61 % increase) fails at 23.52 MN/sq.m. The results show that the perforation penetration depth effect on the perforation system stability also depends on shot density, phasing and pattern.

The perforation stability analysis for various perforation penetration depth, as summarized in Table (1), show that the perforation appears to fail at lower pressure differential or the perforation stability decreases as the penetration depth increases, because of the redistributed stress. Fig. (2) shows that the pressure differential at failure versus penetration depth plot (typical plot) for various penetration depth. This figure also shows that the stable region becomes smaller as the penetration depth increases, particularly for penetration depth greater than 150 mm. The analysis also shows that the effect of the penetration depth on the perforation stability becomes greater as the shot densities increases.

Fig 1
Effect of Penetration Depth On Perforation Stability

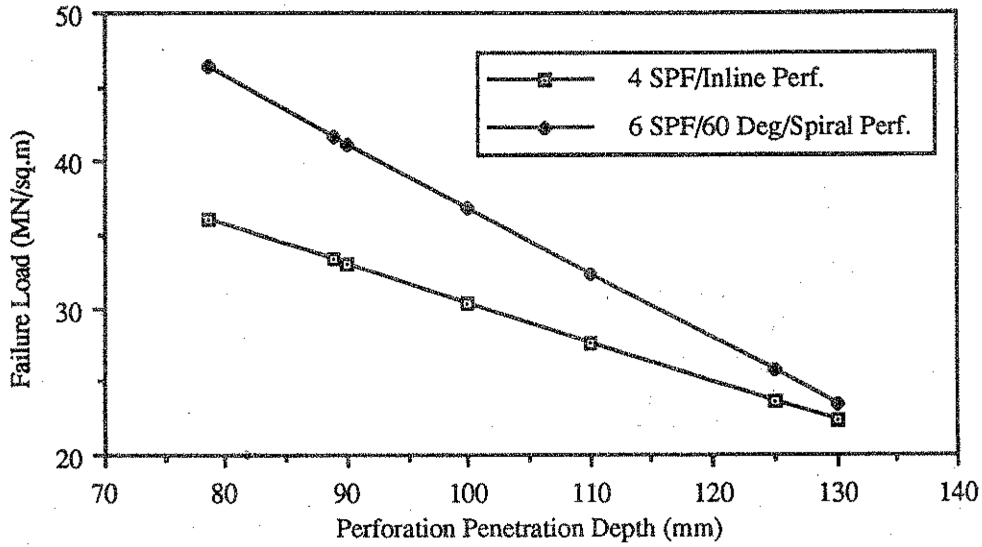

Fig. 2
Pressure Differential At Failure for Various Penetration Depth

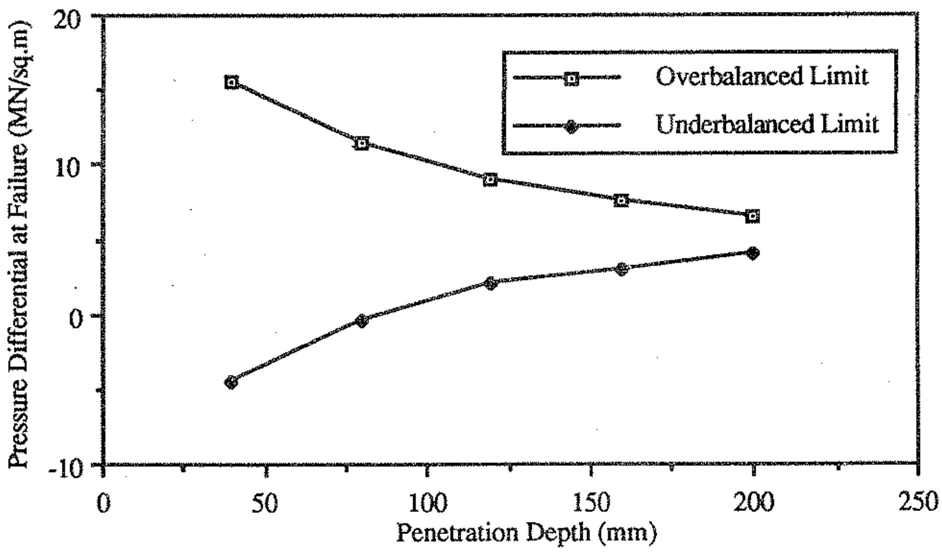

Table 1
Effect of Penetration Depth on Perforation Stability

Penetration Depth (mm)	Shot Density (SPF)	Rock Type	Underbalanced Press. Diff. (MN/sq.m)	Overbalanced Press. Diff. (MN/sq.m)
76	2	Rock A	-22.81	17.83
114	"	"	-15.89	14.15
152	"	"	-9.56	10.22
76	4	"	-5.13	16.69
114	"	"	0.46	11.04
152	"	"	2.36	8.39
190	"	"	3.42	7.29
228	"	"	4.08	6.49
76	6	"	-5.77	16.78
152	"	"	2.28	8.43
228	"	"	4.06	6.5
76	2	Rock B	15.23	23.45
114	"	"	9.92	18.61
152	"	"	5.65	13.44
190	"	"	2.10	10.40
228	"	"	0.41	8.78
76	4	"	1.03	11.64
114	"	"	1.89	9.58
152	"	"	2.62	8.17
190	"	"	4.13	6.61
228	"	"	4.22	5.93
76	6	"	1.89	13.43
114	"	"	1.79	9.75
152	"	"	2.49	9.65
190	"	"	4.06	6.61
228	"	"	4.93	5.86

EFFECTS OF PENETRATION DEPTH ON WELL PRODUCTIVITY

Within realistic ranges and practical limits, penetration depth is more critical and important to the perforated well productivity than other parameters providing the minimum perforation diameter is about 6.4 mm. The productivity of the perforated well will be increased with increasing penetration depth, depending on the damaged zone, completion type, shot density, phasing and gun clearance (Locke, 1981; Klotz et.al.,1980 & Harris, 1968). The alteration in pressure distribution around the wellbore caused by perforation, will be extended to 3 - 5 times the penetration depth (Harris's, 1966).

Penetration depth becomes important to productivity because the greater penetration depth allows more fluid to flow into the perforation and wellbore. When formation damage from the drilling operation exists, it is critical that the perforation penetrates beyond the formation damaged zone radius in order to get the maximum well productivity.

Theoretically, perforating with 150 mm depth and 4 shots per foot produces a capacity equal to openhole completion, (Klotz et.al,1980 & Hong, 1975) but for actual operations, this rule of thumb is not valid (Leod et.al.,1983). If the damaged zone is severe, and penetration depth is less than the damaged zone radius, the perforated well productivity is significantly reduced until the penetration depth extends up to 4- 50 % of the damaged zone, where the flow rate starts to increas significantly. For common formation damage, a penetration depth greater than 150 mm is required to reduce the effects of the damage (Bell, 1984 & Hong, 1975). In addition, that deep penetration can cause the perforated well productivity to increase especially when the perforation spacing is large or when the phasing is small (Harris, 1968).

As mentioned earlier, penetration depth effects on the well productivity also depend on the completion type, that is, for natural and stimulation completion, it is necessary to perforate with deeper penetration depths, but for sand control completion, it is necessary to perforate with larger perforation diameters in order to maximize the well productivity (Bell, 1982). Bell (1984) also found that the penetration depth will be reduced by up to 10 to 20 % if the perforating job was done in multiple strings. In addition, deeper penetration is required to increase the perforated well productivity in crossbedded formation (Ichara, 1987).

CONCLUSION

From the study, it can be concluded that there are several factors must be considered in designing the optimum perforating operation for optimum perforation performance. These factors are inter-related and the penetration depth is a critical factor, depending on the type of completion. Penetration depth itself is strongly influenced by other factors. Generally, deeper penetration depth may increased the perforated well productivity but decreased the perforation stability and difficult to clean. There are limitations to increase the penetration depth for optimum productivity.

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