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The influences of perforation parameters to wellbore instability and sand production

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ABSTRACT: This paper presents a series of laboratory experiment had been performed to see the influences of perforation parameter to wellbore instability and sand production. Shot density and perforation pattern has been varied for entire laboratory work and the stability test conducted to see the effects on the wellbore instability of the sandstone wellbore model. The results show that as the shot density increases the wellbore stability decreases. Whereas as the perforation pattern changes from spiral to inplane and inline the wellbore stability decreases. The sand particles produced were found by sieve analysis to be oversized 500 micron. Generally, stable perforated wellbore produced less sand particle, therefore minimizing the sand production problem.

1 INTRODUCTION

In petroleum production, the formation fluid have to go through the wellbore before collected at the surface. Therefore designing the wellbore would be an important factor that should be considered during the field development period. Knowning that a reservoir is in the equilibrium state between overburden and pore pressure in triaxially stressed state.

When perforation was created in the production zone, the stresses intended to redistribute to the surrounding rock. Hence the surrounding rock has to carry the redistributed stress. In other word the formation will be in fully stressed condition with maximum on the perforation tunnel correspond to Jaeger's conclusion on a hollow cylinder (Jaeger et.al (1979) and Obert et.al (1967)). This situation will lead to formation failure or collapse as the production continue. In other word the pore pressure had been reduced which will increase the effective stress as suggested by Tegazhi where $\sigma_{eff} = \sigma - cp$. This phenomenon also will lead to a situation where crushed material will be produced on the perforation face which will be produced as sand production. As the results it may cause the total casing collapse, increased in the rig time and not cost effective. Therefore maintaining the wellbore stability is primarily important and depends on the controllable and uncontrollable factors. The uncontrollable factor are such as overburden pressure, pore pressure. The controllable factor are such as the shot density, perforation pattern, borehole inclination angle and flow rate. In this paper the perforation parameter has been varied to see the effects of shot density and perforation pattern to the wellbore instability and sand particle produced under the static condition.

2 METHODOLOGY

Laboratory work has been conducted in determining the basic rock mechanical properties such as porosity, permeability, compressive strength, tensile strength, Young Modulus, Poisson ratio, triaxial shear strength and angle of friction. All tests were conducted correspondence to American Standard Testing Method (ASTM - Suggested Method by Brown).

Sandstone samples were cored for 2 inches diameter and cut for 5 inches length (for the compressive strength and triaxial shear strength). As for the tensile strength the 2 inches diameter core sample was cut for 1 inch length. All the specimen then tested under a Servo Controller machine at constant loading rate of 0.7 $MN/m^2/sec$ and the Brazilian testing method was used for the tensile strength test where the specimen was loaded with constant rate of 0.2 $MN/m^2/sec$ until failure.

2.1 *Wellbore model preparation*

The 6 inches diameter coring bit was used to core the cylindrical wellbore model which was then cut into 6 inches length. In addition the 2 inch borehole was cored at the center of the core after which the model then has dried in an oven to remove the moisture. The model then saturated with glycerol which represent formation fluid. The steel pipe of 1 inch OD was then cut into correct length to represent the casing.

The correct casing dimension was then placed in the middle of the borehole and the G Class Cement has been squeezed into the annulus as the bonding agent between casing and formation. The G Class Cement slurry was prepared according to API Spec.

10 with the cement water ratio was 2 to 1. The system then left over in the ambient condition for 24 hour in order to allow the cement to set. As final procedure in preparing wellbore model, the sandstone were perforated with different shot density and perforation pattern i.e. 6 SPF, 8 SPF and 16 SPF of spiral, inplane and inline.

2.2 *Special platen preparation*

For the stability test, a special platen has to be designed. Cylindrical steel bar with 6 inches diameter were cut into 5 inches length. Then a hole of 2 inches where drilled at the center of the steel bar. Since the steel bar not been treated yet, the hardening process should be done before the stability test in order to avoid the error during the stability test due to the platens. The two platens were prepared weretop and bottom platens..

The platens were fired in a kiln at temperature of 500 °C then quenched in water. After cooling, again the platens then were put in the kiln for second heat cycle about 2 hours and left to cool down to room temperature. The platens surface were cleaned and smoothed including the center hole.

A temperature of 550 °C is necessary because, the platens must get the maximum tensile strength, ductility and toughness due to increasing coalescence of carbides. The 2 hours period for second heating (tempering) is also necessary in order to aid in restoring the toughness as recommended by Garmo et. al.

2.3 *Stability test*

Servo Controller Compression Machine was used for the stability test. The machine is fully computerized and a program has been created in order to run the correct stability test. The machine software will be able to detect the failure by itself correspondence to the program.

The wellbore model was then put at the centre of the servo machine. The fabricated platens were then placed carefully on the top and bottom of the wellbore model. The wellbore model was then loaded at rate of 0.7 $MN/m^2/sec$ until the wellbore model failed. In other part a plot of axial load versus displacement was plotted by the software on top of the raw data. Thereafter the model failed, any sand particles produced were carefully collected for the sieve analysis.

2.4 *Sieve analysis*

The sand particles produced after the wellbore model failure were collected and weighed before being sieved. This weight will be recorded as recovered weight. The laboratory disc of the sieve machine was then carefully emptied and clean on the nested sieves. As precaution and minimizing the experiment error the sieve column was closed off with cover to avoid contamination by dust or loss of sand particles.

The nested sieve column was then shaken for 10 minutes by using electric sieve shaker (Vicker (1978), Craigh (1978) and Wills (1979)). After 10 minutes, the content of each sieve was carefully brushed off and then weighed. Consequently, the weighed for each particle size range as defined by the mesh size range of successive sieves was calculated. The amount of oversized and undersized sand particles were then calculated. Cumulative percentage oversized is defined as cumulative percentage of particle retained on the sieves. The cumulative percentage undersized is the cumulative percentage of particle passing through all the sieves and collected at bottom of the sieve shaker.

3 RESULTS AND DISCUSSION

Table 1 shows details of the sandstone basic mechanical properties.

In general, all the perforated wellbore models failed and sand particles were produced. Basically, the perforated wellbore stability, sand particles produced and the particles size distribution depends on the shot density and perforation pattern. Table 2 shows the summarize results of laboratory results.

Table 1 - Mechanical properties of sandstone

PARAMETER	AVERAGE VALUE
Density, ρ	2.03 g/cc
Porosity, ϕ	11 %
Permeability, K	8.63 mD
Compressive Strength, C_o	32 MN/m^2
Tensile Strength, T_o	1.82 MN/m^2
Young Modulus, E	6.95 GN/m^2
Poisson Ratio, ν	0.3
Triaxial Shear Strength, S_o	12.90 MN/m^2
Angle of Friction, Φ	39.39°

Table 2 - Summary of the results

Factor Increased	Aspect		
	Perforated Wellbore Stability	Sand Particles Produced	Size Distribution (> 500 µm)
Shot Density	Decreases	Increases	Increases
Spiral Pattern	Strongest	Lowest	Lowest
Inplane Pattern	Intermediate	Intermediate	Intermediate
Inline Pattern	Weakest	Highest	Highest

3.1 Effects of shot density to wellbore stability

From observation found that all models with various shot density failed under compression and shear stress. In general, it can be said that the wellbore stability decreases as the shot density increases.

Figure 1 shows the effect of shot density to wellbore instability. Found that, for 6 SPF the model failed at 24.14 MN/m^2 for spiral pattern, 15.83 MN/m^2 for inplane pattern and 14.08 MN/m^2 for inline pattern. As for the 8 SPF the spiral pattern failed at 19.55 MN/m^2 followed with 13.61 MN/m^2 for inplane pattern and the inline pattern failed at 10.97 MN/m^2. Finally the for 16 SPF model exhibit the weakest model which failed at 16.85 MN/m^2, 10.15 MN/m^2 and 7.69 MN/m^2 for spiral, inplane and inline pattern respectively.

The shot density increases can be defined as reducing the amount of the rock mass. Thus more stress have to be redistributed. As the results, the rock mass strength being reduced since have to carry the rearrange stress due to perforation process. Greater stress concentration in the rock between perforation tunnel can be experienced as the number of shot density increases.

Therefore, 16 SPF shot density will be exposed to more stress concentration compared to 8 SPF and 6 SPF. Thus the 16 SPF wellbore model failed at lower axial stress since the wellbore couldn't hold much higher stress and the yield point has been achieved earlier compare to 8 SPF and 16 SPF models.

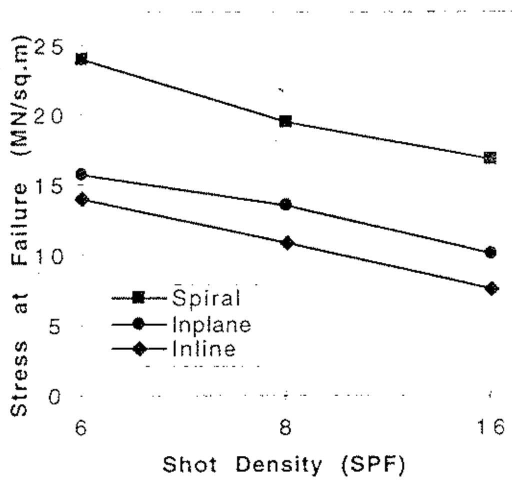

Figure 1 - Relationship between shot density and wellbore stability

3.2 Effect of perforation pattern to wellbore stability

Perforation pattern has a great effect on the wellbore stability. As can be seen in Figure 2, the stresses at failure are changing correspond to the perforation patterns depending upon the shot density. These results show that the spiral pattern gives the most stable wellbore. Then followed by inplane pattern and the inline pattern gives the least stable welllbore.

The above phenomenon understandable since, the perforation tunnels in the inline pattern are in one vertical line which is parallel to the applied load. Thus, resulting in a rock mass stress to the applied vertical stress which is lower than for an inplane

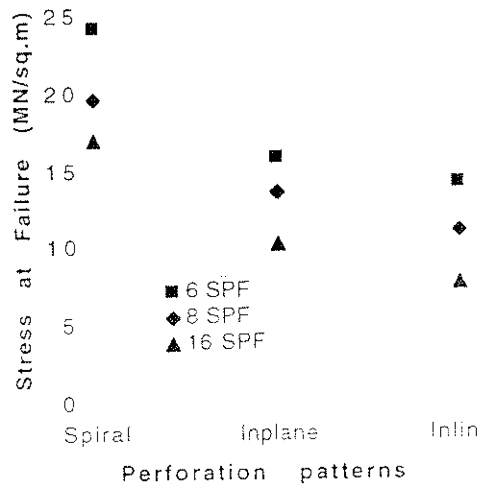

Figure 2 - Relationship between perforation pattern and wellbore stability

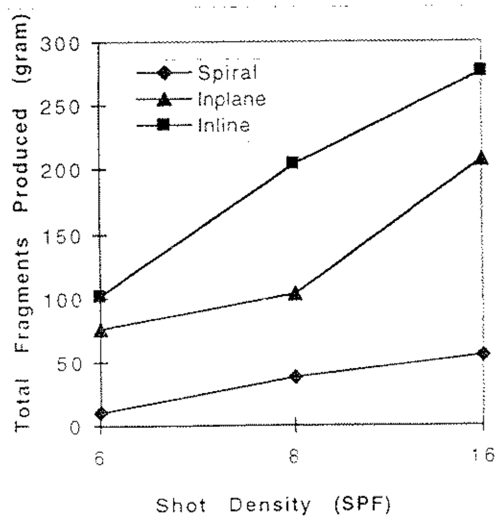

Figure 3 - Relationship between shot density and sand fragments produced

pattern where the perforation tunnels are in one horizontal line perpendicular to applied vertical/axial load. Therefore. the rock mass stress to the applied vertical stress is higher in inplane pattern than inline pattern.

As for the spiral pattern, the perforation tunnels are in a plane inclined to the applied vertical stress, resulting in higher rock mass stress to the applied vertical stress than for the other two previous patterns. The spiral pattern also produces the greatest distance between each successive perforation and therefore a stronger perforated structure.

3.3 Effect of shot density to sand fragment produced.

Figure 3 shows that increasing the shot density from 6 to 16 SPF will increases sand fragment produced from 11.08 gram to 55.28 for spiral pattern. Whereas for inplane pattern the increment was from 74.67 gram to 208.25 gram. Sand fragment produced for inline pattern was from 101.15 to 275.91 gram.

The results show that the amount of sand fragment produced by collapse perforated wellbore

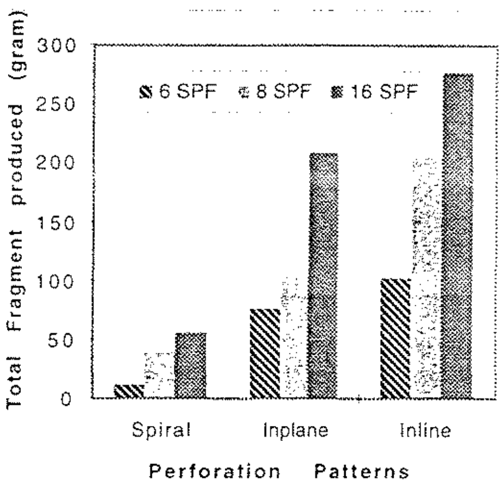

Figure 4 - Relationship between perforation pattern and sand fragments produced

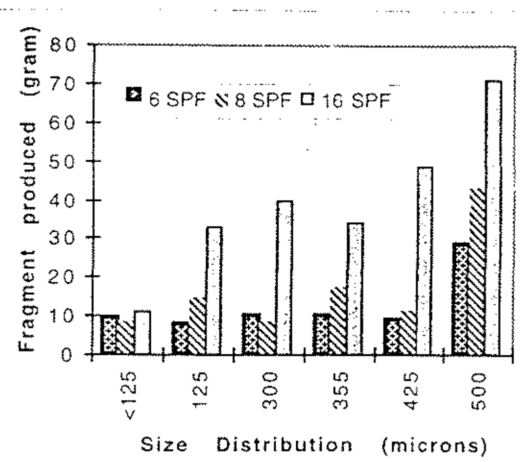

Figure 6 - Size distribution for inplane pattern

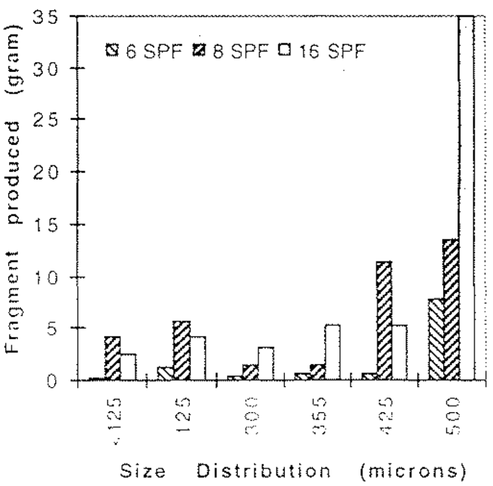

Figure 5 - Size distribution for spiral pattern

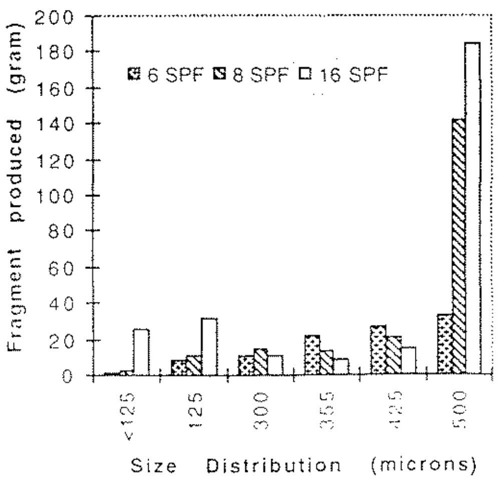

Figure 7 - Size distribution for inline pattern

increases as the shot density increases. The overall results also shows that the sand fragments produced depends on perforation pattern and phasing angle.

3.4 Effect of perforation pattern to sand fragment produced.

Changing the phasing angle of perforation is actually changing the perforation pattern. For instant phasing angle changes from 0° to 90° also means changing the perforation pattern from inline to inplane or spiral.

Figure 4 shows that as the perforation changes from inline to inplane and spiral (which also changes of phasing angle from 0° to 90 °) the amount of sand fragments produced at failure decreases, since the perforated wellbore stability increases. The effect of perforation pattern/phasing angle also depends on the shot density. The effect becomes greater as the shot density increases.

As the results it can be said that the sand fragment produced has close relationship with wellbore instability. Where as the perforated wellbore stability increases the amount of sand fragment produced decreases.

3.5 Size distribution of sand fragments produced

Understanding the sand fragment size is important for further studies and application or controlling of the sand production. The size distribution of the sand fragments produced are as shown in Figure 5, 6 and 7 for spiral inplane and inline, respectively.

For spiral (Figure 5) pattern, the oversized 500 micron of sand fragments produced increases as the shot density increases. The increment is 10.63% to 33.58%. The inplane pattern also exhibit (Figure 6) the same phenomenon where the 500 microns size sand particles increased from 6.43 % to 15.9 % as the shot density increases. As for the inline pattern (as shown in Figure 7) the oversized fragments increases from 5.57 % to 31.73 % as the shot density increases from 6 SPF and 16 SPF.

Generally, less 500 microns sand fragments were produced by decreasing the shot density and by changing the perforation pattern from inline to inplane and spiral. Thus, it can be concluded that the spiral perforation pattern with 6 SPF shot density produced the least large sand particles.

4 CONCLUSIONS

It can be concluded that all perforated wellbore failed as the in-situ stress increases and produced sand fragments depending on shot density, perforation pattern and phasing angle. The wellbore stability decreases as the shot density increases. The spiral pattern appears to be most stable pattern followed by inplane and inline pattern.

The sand fragments produced increases as the wellbore stability decreases i.e. shot density increases. The amount of sand fragments produced also increases as the perforation pattern changes from spiral to inplane and inline. Whereas the same phenomenon occured as the phasing angle changes from 90° to 0°.

Big portion of the sand fragment produced were found by sieve analysis to be oversized 500 microns. The sand fragments created within the perforated wellbore or the rock adjacent to the perforation tunnel surface will contribute to any sand production problems.

Generally, stable perforated wellbore can minimizing the sand fragments production in the wellbore, therefore minimizing the sand production problems.

Understanding the effect of the perforation parameters i.e. shot density and perforation pattern to the wellbore stability and sand production, optimization of production and minimizing the sand production problem can be done. Consideration of the wellbore stability effects in designing phase of petroleum field development can be accomplished the optimizations program.

REFERENCES

Craigh, R.F," Soil Mechanics ", 2nd. edition, Van Nostrand Reinhold Co., 1978

Jaeger, J.C, Cook & N.G.W., " Fundamental of Rock Mechanics", 3rd edition, Chapman & Hall London, 1979.

Obert, L & Duvall, W.I., " Rock Mechanics & The Design of Structure in Rock", John Wiley & Sons Inc., 1967.

Vickers,B , " Laboratory Work in Civil Engineering", Granada Pub., London, 1978.

Wills, B.B. " Mineral Processing Technology " , Pergaman Press, Oxford, 1979

Samsuri. A. A study of Perforation Stability by Physical and Numerical Modelling. PhD Thesis, University of Straytlyde. 1990

Subbiah,S.K. Wellbore Instability Studies by Physical Modelling. MEng. Thesis, University Technology Malaysia.1997.