Proceedings of the
International Conference on Mechanical Engineering 2003
(ICME2003) 26- 28 December 2003, Dhaka, Bangladesh

ICME03-TH-30

EXPERIMENTAL INVESTIGATION OF NATURE OF FORMATION DAMAGE AROUND PERFORATIONS IN PETROLEUM WELLS

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ABSTRACT

The objective of perforating is to cost effectively maximize well productivity and establish good connectivity between the wellbore and the formation. It is known that conventional method of perforation- perforating by shooting or explosive charge does not achieve expected well productivity due to a region of reduced permeability around the tunnel. This paper summarizes the results of an experimental program developed to investigate the impact of perforating by shooting in cylindrical sand samples with varying amounts of strength and porosity. The program contains several perforation tests, with each cylindrical sample (5.72 cm ID, 10 cm length) made from sand and cement. In order to simulate the perforation by shooting in petroleum wells, the sand samples were shot by a bullet (1.36 cm OD). Experimental results showed no uniform round perforation cavity in the sand samples. It was found that the creation of perforation tunnel through bullet shooting created a zone of low permeability around the tunnel. The low permeability of this compacted zone is a result of grain crushing and fine accumulation that are trapped at pore throats.

Keywords: Formation damage, perforating, permeability, drilling.

1. INTRODUCTION

An ever-expanding range of reservoir scenarios continues to challenge oilfield operators and service companies to provide optimum completion efficiency. Unfortunately developers and scientist often overlook a very important component of the completion scenario - the perforating process. This paper demonstrates the extent of the perforation damage created by conventional shooting technique (PS-perforation by shooting) and proposes a new alternative perforation technique - perforation by drilling (PD). This paper focuses on the performance of PS and PD techniques from the perspective of reservoir productivity rather than the traditional discussion on shot density, shoot phasing, surging and optimum underbalance condition. Inadequate flow efficiency of PS completions has been a major problem since the first use of PS technique in the 1930s [1]. The problem was initially attributed to restricted perforation area through the casing compared to the larger surface area of an openhole completion of the same length. In 1950, however, experimental studies [2,3] indicated that, with proper penetration and shot density, perforated system flow efficiency should be higher than that of a comparable-length openhole completion. Unfortunately, even with proper geometry, experimental and field performance fell short of predicted results [4,5,6]. Continued investigation indicated that perforation by PS technique reduces permeability around the perforation tunnel by approximately 75 percent compared to undamaged formation.

2. THE PROBLEM

Most of oil and gas wells are cased, cemented and perforated as part of their completion for oil production. PS technique involves firing of gun projectiles that propels metallic particles in the form of a jet, through the casing, cement sheath and formation matrix in the pay zone at extremely high velocities (~7000 m/sec). PS technique is known responsible for the damage of rock matrix around the perforation tunnel by grain fragmentation and creating small particles that reduces pore throat size, thus, permeability in a region around the perforation tunnel known as "crushed" or "perforation damaged zone"[7,8]. The amount of permeability reduction and its extent has an important impact on the productivity of the well. The secondary damage is caused due to residual sand blocking the perforation tunnel itself. The tertiary damage is caused due to the impact force of the shooting. The fourth damage is caused by transient injection of explosive products and wellbore fluid into the formation. The fifth damage is caused by creating a non uniform entrance hole diameter in the casing. The characteristics of burrs and irregularities of the entrance hole have significant effect on coefficient of discharge and perforation friction of the flow. The process of perforation in the formation by PS technique is shown in Figures 1 and 2.

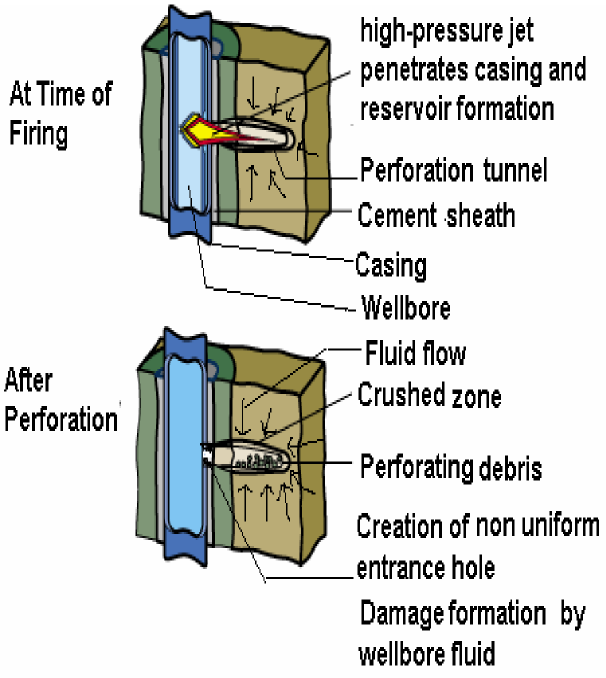


Figure 1. Perforation process by PS technique, adapted from [9].

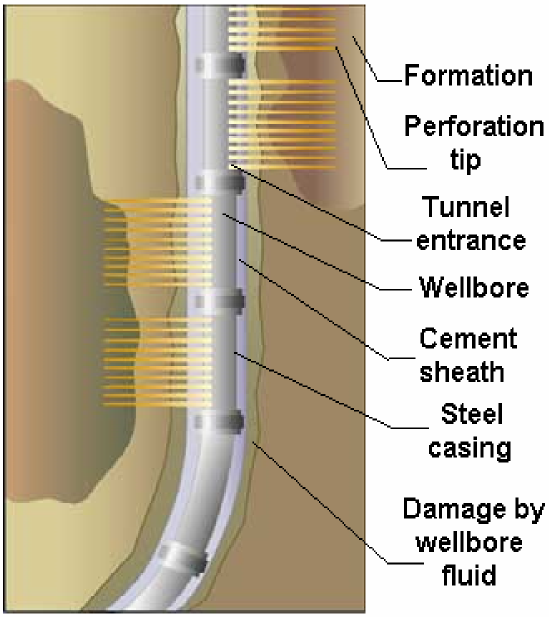


Figure 2. Perforation process by PS technique in a vertical wellbore, adapted from [9].

3. OBJECTIVE

The overall objectives of this study are:

- To carry out an experimental study to observe the effects of shooting by PS technique.
- To describe and propose a new perforation technique for petroleum wells-PD technique.
- To carry out an experimental study to compare the performance of PD technique with PS technique.

4. EXPERIMENTAL SET-UP AND PROCEDURE

The experiments consisted of flow rate and pressure gradient measurements through sandstone samples (which simulate the reservoir formation) perforated by PS and PD techniques. All tests were performed on 5.72 cm diameter and 10 cm length sandstone samples. To prepare the samples, cement was used to bind sand grains. Three different samples (A, B, C) were prepared by varying the amount of sand, cement and water proportions. Fluid flow experiments were conducted with the three samples individually. The properties of the samples is shown in Table 1. The samples were saturated with water before being tested. The unconfined compressive strength of the samples was measured by uniaxial compression test machine and found to be in the ranges of 9-14 MPa. The porosity of the samples was measured in two steps. In the first step, each sample was immersed in water to make it 100% saturated. The weight of the saturated sample was then measured. In the second step, to make it 100% unsaturated, the sample was heated in an oven for 24 hours at 110^0 C. The amount of void space, porosity, was then obtained from the difference between the weights of saturated and unsaturated samples. The difference between the two weights gave the amount of void space that contained fluids. The porosity of the samples varies between 15%-28% as shown in Table 1.

Table 1. Properties of the samples used in the experiments.

Type	Porosity	Ingredients		
	%	Sand (g)	Cement (g)	Water (ml)
Sample A	28	500	200	130
Sample B	24	650	100	130
Sample C	15	600	150	130

A schematic of the test set-up is shown in Figure 3. The system is capable of feedback control and continuous displays of axial load, pattern displacement, back pressure as well as confining pressure. Three pumps were used to induce radial seepage in the perforated cylindrical sand samples, to sustain desired pressure at the receiving end of cylindrical sample and to provide confining pressure around the cylindrical sample. In all cases water was used as the working fluid. Each sample was enclosed in the mesh material and a rubber sleeve to facilitate radial flow and to prevent any fluid flow

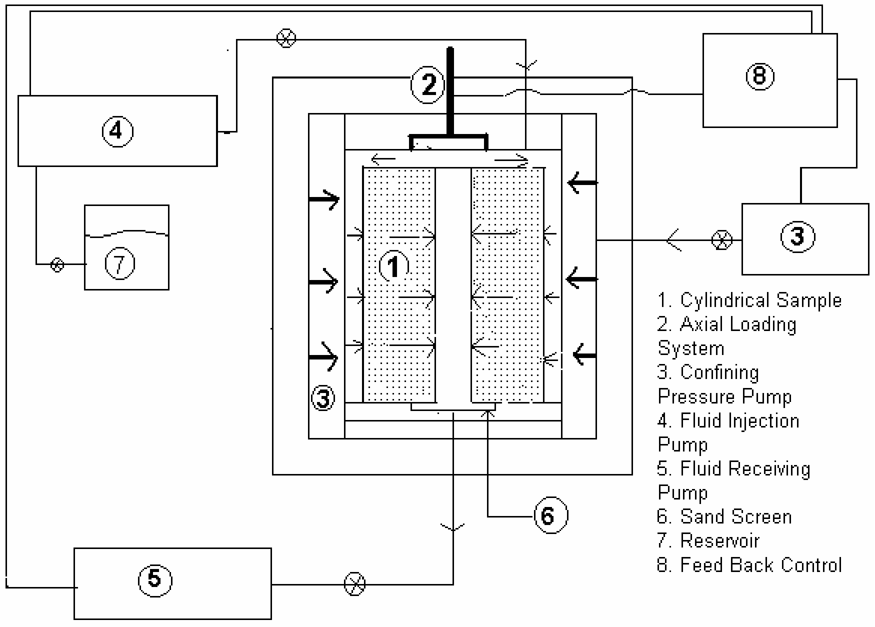
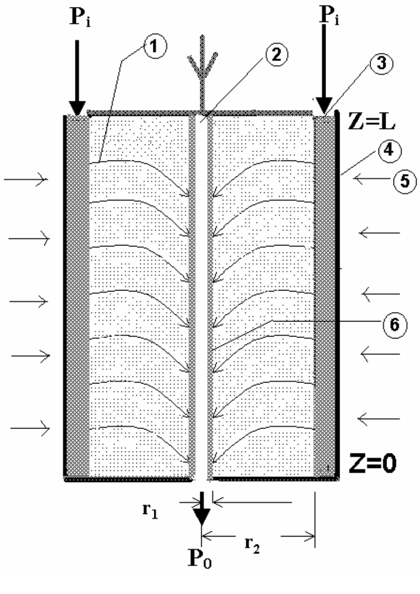


Figure 3. Schematic of experimental set up.

communication between the confining fluid and the injection fluid. Axial loading system was used to prevent any fluid communication other than radial direction. Fluid flow patterns through the samples perforated by PD and PS technique are shown in Figure 4. The perforation tunnels (1.36 cm OD) were created in the sand samples by two techniques. In PS, the sand sample was mounted inside the confining pressure vessel and single shot perforation was done by sudden impact force hitting the heat-treated steel bullet (1.36cm OD). In the second technique, the perforation was done by drilling. Drilling was done by drill coring machine with masonry drill bit (1.36cm OD). After doing perforation by PS and PD technique the perforated samples were mounted in a GDS (Geotechnical Digital Systems) triaxial system. The system was used to measure the flow rate and pressure differential through the perforated sample.



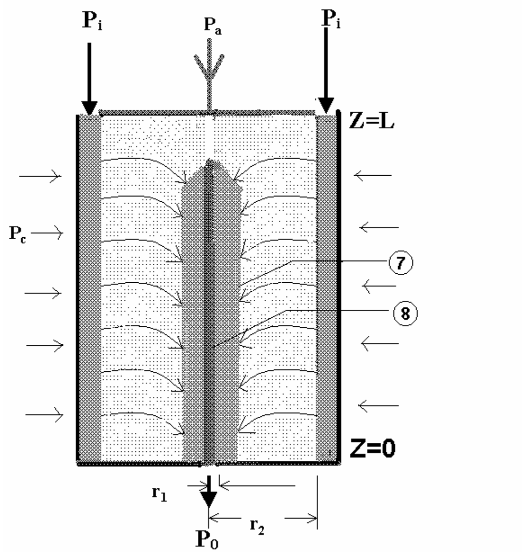


Figure 4. Schematic of the perforated samples. 1. Fluid flow pattern 2. Perforation tunnel 3. Mesh Material 4. Rubber sleeve 5. Confining pressure 6. Damage caused by PD technique Perforation debris 7. Damage caused by PS technique 8. Perforation debris. P_i= Fluid injection pressure, P_o= Receiving end pressure, P_a=Axial load, P_c=Confining pressure, Z= Height of the sample, L= Length of the sample, r_1= Radius of the perforation, r_2= Radius of the sample.

5. RESULTS AND DISCUSSION

The efficiency or productivity, of a perforated completion can be defined as (1) productivity index, which is a measure of fluid flow capability form reservoir to perforation tunnel at constant pressure differential. (2) skin factor, which is a measure of pressure differential requirement to achieve a specific flow rate through perforation tunnel. Figure 5 shows the variation of flow rate with pressure gradient across sand samples perforated by PS and PD techniques. The figure clearly indicates that at a given pressure gradient, for all samples tested, the PD technique results in a higher flow rate compared to PS technique. This difference becomes more pronounced at increasing pressure gradient values. The reduced flow rate and increased pressure gradient for the PS technique can be attributed to mainly two types of damage observed: the primary damage caused by the grain fragmentation, creating small particles that reduces pore throat size and thus permeability and the secondary damage due to the residual sand blocking the perforation tunnel itself.

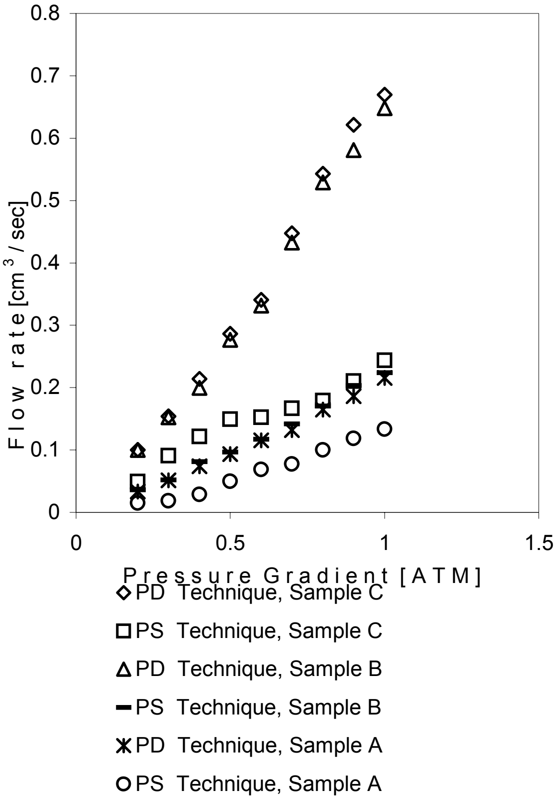


Figure 5:Comparison of flow rates between PS and PD techniques with varying pressure gradient for three different type of samples.

Before perforation sample C had the highest permeability (22.71 md), followed by sample B (20.07 md) and sample A (7.29 md). After perforation the permeability of sample C, B and A were 10.04 md, 7.69 md and 3.86 md respectively. But the degree of decrease in permeability was not equal for all the samples. Figure 6 shows that the decrease in permeability in the sample C, B and A. As can be seen from the figure, sample B results in the lowest decrease in permeability (62%), followed by samples C (56%) and A (47%).

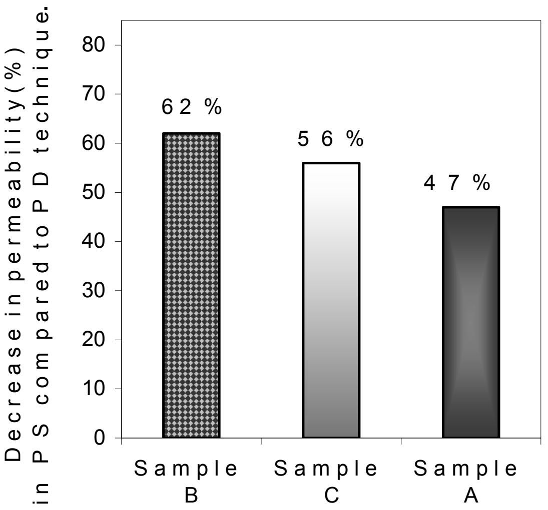


Figure 6. Percentage decrease in permeability for samples A, B and C.

The difference in the decrease of permeability measured among the samples can be related to the unconfined compressive strength of each sample as seen in Figure 7. Figure 7 shows that the decrease in permeability due to PD technique decreases with the strength of the samples. The measured unconfined compressive strength for the samples were 46 MPa for the sample A, 14 MPa for the sample B and 9 MPa for the sample C. It is also evident that the decrease in permeability in low strength sample is higher than that of high strength sample.

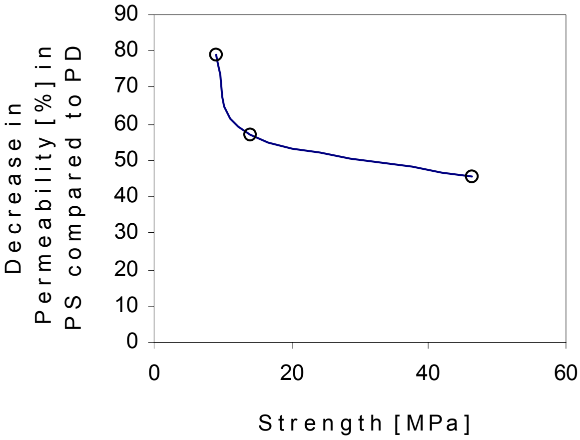


Figure 7. Percentage decrease in permeability due to different strength.

In Figure 8, it is observed that to obtain same the flow rate in the perforation tunnel the pressure gradient between the formation and welbore is higher in the PS technique than in the PD technique. This is due to increased skin effect around the crushed zone of the perforation tunnel created by PS technique.

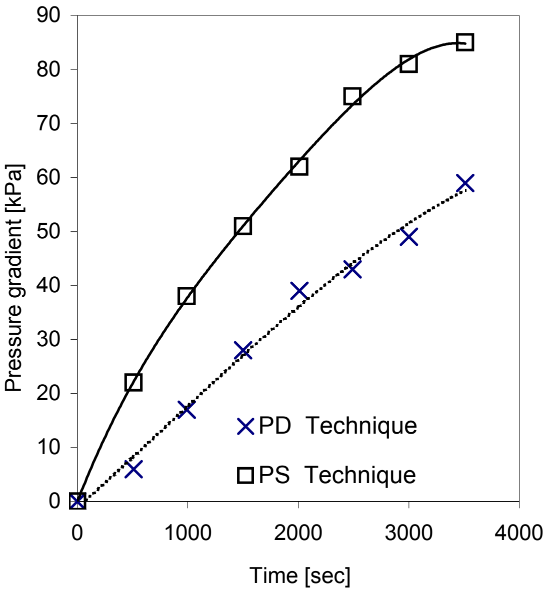


Figure 8. Pressure gradient with changing time at constant flow rate.

6. CONCLUSIONS:

The following conclusions can be reached from the investigation presented in this paper:

1. Uniform round perforation tunnel was not achieved in perforation process done by PS technique.
2. Due to mainly permeability deterioration and sand production during PS technique less fluid flow rate was obtained compared to PD technique at the same pressure gradient.
3. The variation of strength of the sand sample plays an important role in determining the perforation damage that remains around the perforation tunnel.
4. Future work is directed towards investigating other perforation technique including laser drilling, abrasive water cutting.

7. ACKNOWLEDGMENTS

The authors wish to acknowledge the financial support used to carry out this study provided by various Canadian governmental and industrial organizations.

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