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Oriented Perforating Using Abrasive Fluids Through Coiled Tubing

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Abstract

Abrasive fluids have been applied in mechanical cutting and perforating systems for years, the result is a precise cut in any size tubular. In abrasive perforating, the entry hole created reveals no tubular deformation or presence of flow obstructing debris. Consequently, the sand-laden fluid moves past cement, damaged zone or filter cake and into virgin formation. At that instant, velocity generated through the nozzles propagates abrasive fluid into multiple reservoir layers creating numerous pathways. Optimizing the direction of perforations allows for cost effective stimulation through conventional fracturing techniques. Therefore, as an alternative to conventional perforating, oriented abrasive perforating is applied specifically for creating channels to natural fractures.

This paper discusses the development of abrasive perforating coupled with orienting technology for penetrating tubing, casing, drill collars, and drill pipe, all of which is deployed using coiled tubing or jointed pipe in re-completions. In addition to conventional coiled tubing tools, this system utilizes an engineered weight bar connected to a high velocity perforating sub.

This paper begins with the development of this technology and existing perforating methods, then a description of tests conducted with the abrasive perforator and subsequent results. Benefits and applications with applied case histories are also discussed including multiple stage plug setting and perforating as well as pipe recovery, followed by conclusions and recommendations.

Development of Technology

Based on evolving requirements from Oil and Gas Operators, the need to develop a more economical perforating system arose. As wells with larger horizontal sections are completed, the inability to reach zones of interest further substantiates the use of coiled tubing and related tools. This technology was developed from using abrasive fluids to cut tubulars with a motor and high velocity cutting head[1].

Currently, wells are perforated using explosive means such as Tubing Conveyed Perforating (TCP) and Electric line. Although these systems are industry standard, challenges and limitations such as extensive rig-ups, the presence of debris post firing and restricted ability in extended horizontal sections do exist. While both systems have been around for years, their inability to completely orientate perforations is inherent.

To maintain simplicity, this system utilizes conventional thru tubing equipment allowing for jet orientation using an engineered weight bar placed below a free rotating swivel joint as illustrated in Figure 1. The engineered weight bar is eccentric based, allowing for weight transfer to the low side of the tubular as shown in Figure 2. This method of application was referenced from a registered patent, describing single trip wellbore isolation and oriented perforating[2].

Based on pump rate and pressure, orifice selection is crucial to maximize jetting velocity. Hydraulic calculations determining pressure drop and velocity at the exit point allows for precision cutting. For example with one 0.125inch orifice, maintaining a pump rate of 0.5bbl/min at 2500psi produces an exit velocity of 540ft/sec.

The sand slurry is not fully abrasive until it enters the orifice gaining momentum at which point the stage of abrasion commences. The 100mesh particles recommended exhibit less momentum in non-divergent fluid streams and consequently less damage to the inside of the coiled tubing. In a jet stream, smaller particles retain impact/kinetic energy through reduced mutual interference[3].

Testing of System

Based on global success in field applications, the purpose of this study was to substantiate the technology and verify the theory of oriented perforating using abrasion methods. The goal of this experiment was to evaluate the effectiveness of this system by analyzing the effects to the tubular, cement sheath and formation rock. These tests were a collaborative effort with the University of Oklahoma at The Well Construction Technology Center.

To simulate downhole conditions a test apparatus was built using a 4.50inch 13.5lb/ft P-110 casing sample placed between two pieces of shale, and fully encapsulated with 16.5ppg neat Class H cement as presented in Figures 3 and 4. Jack Fork Sandstone was chosen due the non-homogenous structure and geological properties listed in Table 1.

Shown in Figure 5, using a batch-mixer similar to field operations maintained a consistent sand laden fluid. The test fluid included 100mesh sand blended with a guar gel and fresh water mixture to a density of 1ppg. Although other sand sizes and types are available, using 100mesh through coiled tubing creates minimal effects from erosion. In terms spherecity and roundness, 100mesh sand falls within a mid range category allowing for improved material removal and has been documented to provide a sound cutting environment[3]. Prior to pumping, viscosity and sand settling tests were conducted to deem the fluid adequate.

The dimensions and jet phasing of a perforator is case specific and can be manufactured for any size tubular and application. Shown in Figure 6, the perforator used was dressed with two 0.125inch orifices phased at 0 and 180DEG. The phasing of the perforator would be such that holes are oriented along the top and bottom of the casing, as is recommended in horizontal completions[4,5].

Results and Discussion

Upon removal of the casing from the cement sheath, a smooth wear pattern around the entry hole is noted. A non-obstructed entry hole produces a decreased coefficient of friction and proportional drag force. Previous studies with explosive perforating have shown that the exponential pressure and velocity creates a vacuum at the point of entry compacting debris into the perforating tunnel. As detonation occurs no material is removed from the tunnel, in fact it is deposited toward the formation creating flow obstructions[6]. Elevated circulating pressures, post explosive perforating reveal restricted communication within the damaged zone toward formation.

As shown in Figure 7, a 3/8inch hole was formed between interface of the casing and cement. The entry hole through both the cement sheath and formation rock was measured to be 3/4inch presented in Figure 8. The larger entry hole to the cement and rock is attributed to the effect of erosion as both areas contain sedimentary properties.

Depicted in Figure 9, particle velocity is greatest at the center of the fluid stream and dissipates along the outer edges creating a tear drop pattern, indicative of reverse flow regimes[7,8]. This reverse flow behaviour allows for efficient debris removal at the localized area of the cut.

As shown in Figures 10 and 11, using two 0.125inch jets at 1bbl/min, a penetration depth of 27inches was measured from the centerline of the casing to the edge of the cement wall. Furthermore, the sand slurry migrated throughout the entire formation sample, revealing substantial damage throughout. After a certain elapsed time, the effect of abrasion decreases as sand particles reach a certain penetration depth. At which point, increasing the pump rate will not produce larger holes or extend perforating tunnels[9].

Previous studies have shown that using 3/16inch and larger jet nozzles create 600 to 700ft/sec velocities and perforations in 10 to 12minutes[8,9,10]. Using a reduced fluid rate, 0.125inch nozzles and 100mesh sand slurry, cutting velocities of 540ft/sec generate entry holes in 10min revealing substantial penetration and fragmented rock.

Benefits and Applications

Employing abrasive methods to create perforations presents numerous benefits. For example, standard equipment such as a coiled tubing unit, crane and fluid pump are used, depending on sand slurry requirements, a mixing system may be considered. Using abrasive methods eliminates the use of explosives at surface, therefore extra safety policies and training are not required. Although the tool length of the oriented perforator is substantially smaller, high shot density for cluster perforating is achievable.

Accessing multiple zones in one horizontal well is analogous to completing multiple vertical wells in the same field. Previous studies have documented the behavior and effects of transverse fracture stresses comparing horizontal to vertical completions. Maximum stresses act perpendicular to a horizontal wellbore, therefore the need to penetrate the multiple layers is desired[4,5,10]. The simplicity of this eccentric weighted perforating system allows for increased penetration through jet phasing at 0 and 180DEG.

As stated earlier, using two 0.125inch orifices at 1bbl/min generates 540ft/sec resulting in 27inches of penetration. If the same cutting velocity is maintained, these results can be achieved in cases where increased shot density is required. For example six orifices phased at 0 to 180DEG, (three on top and three on bottom) requires 3bpm to sustain 540ft/sec, and therefore the same degree of penetration would be seen for each perforation tunnel.

As perforating is a critical step in well completion, applying the benefits of this technology becomes evident. Using coiled tubing to isolate intervals by setting a bridge plug and oriented perforating in a single trip, reduces costs associated to multiples runs and mechanical fatigue to coiled tubing. With coiled tubing already in the wellbore, a post perforating cleanout through the perforator minimizes operating time prior to a stimulation treatment. Additionally removing the abrasive fluid used from perforating, will provide non-obstructed fracture throats allowing the passage of the stimulation and production fluids[4,11].

In fishing and pipe recovery applications where the ability to establish circulation is critical, the use of this system can be two fold, the first being able to create circulation points to aid in establishing free points. The second is the ability to cut tubulars with a motor and cutting head[1].

Case Histories

1. **SONATRACH-AGIP. Hassi Messaoud, Algeria**. *Horizontal "B" Level Sandstone Formation.* Oriented Abrasive Perforating after unsuccessful stimulation using TCP perforating. Perforated 4.50inch 12.6lb/ft P-110 casing using six 0.125inch orifices, phased at 0 and 180DEG. Four simultaneous stages successfully perforated and stimulated.

2. **JW Operating. East Texas**, *Horizontal Cotton Valley formation*. Oriented Abrasive Perforated 4.50inch 13.5lb/ft P-110 casing after unable to fracture using conventional TCP perforating. Successfully fractured zone post Oriented Abrasive Perforating.

3. **PetroHunt. West Texas** *Vertical* Chirt *formation*. Oriented Abrasive Perforated 4.50inch 13.5lb/ft P-110 casing after unable to fracture using conventional TCP deployments. Zone was successfully stimulated and completed after Oriented Abrasive Perforating.

As presented in the case histories, oriented abrasive perforating was employed as a secondary measure. In each case, explosive perforating was first used with unsuccessful results as injectivity test pressures forecasted premature screeenout. Each deployment using oriented abrasive perforating resulted in the incremental decrease in near wellbore friction not only in horizontal and vertical shale but also in sandstone formations.

Conclusions and Recommendations

The purpose of the backyard test was to validate this technology to understand the effects and benefits of using abrasive fluids for oriented perforating. Based on the results from analysis of the tubular, cement sheath and rock, substantial damage occurred showing the erosive effects of the sand slurry and its benefits to create channels in a wellbore.

Using two 0.125inch orifices and pumping an abrasive fluid at 1bbl/min generates 540ft/sec causing 27inches of penetration. As particle velocity is the determining factor for abrasion to occur, increasing the number of jets would produce the same results as the pump rate is proportional. Adversely, damage to the tool face from back splashing also increases and should be considered for applications requiring multiple zone perforating.

Employing abrasive mediums to create perforations presents three essential benefits. Firstly, it minimizes the amount of obstructive debris at the entry point and within the perforation tunnel, which reduces treating pressures as seen with field applications in horizontal and vertical formations.

Secondly, performing a clean out through the perforator using non-abrasive fluids removes any residual sand prior to pulling out of the hole. This is an essential step so as not to jeopardize a following stimulation treatment. Failure to do so may cause the perforation tunnels to fill up with smaller sand particles creating fluid restrictions.

Thirdly, with abrasive perforating, there is no handling of explosives therefore additional safety regulations are not required. Furthermore, the tool length is substantially reduced as the desired shot density can be accomplished with multiple settings in the zone of interest.

In conclusion, this system is designed for a multitude of applications, such as single trip plug setting and oriented perforating used extensively for multiple stage completions in horizontal wells. As presented in the case histories, applying the oriented abrasive perforating system reduced near wellbore friction and concerns with premature screeenout, thus reducing associated time and operating costs.

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Metric

inch	x 25.4	= mm
ft/sec	x 0.3048	= m/s
psi	x 0.00689475	= Mpa
lb/ft	x 1.488	= kg/m
bbl/min	x 0.158987	= m^3/min
ppg	x 119.826	= kg/m^3

Table 1 – Properties of Test Shale

ASTM C-127:	
Bulk Specific Gravity =	2.521
Bulk Specific Gravity (SSD) =	2.560
Apparent Specific Gravity =	2.625
Absorption =	1.6%
L.A. Abrasion ASTM C-131:	
Grading A Percent Loss:	35.3%

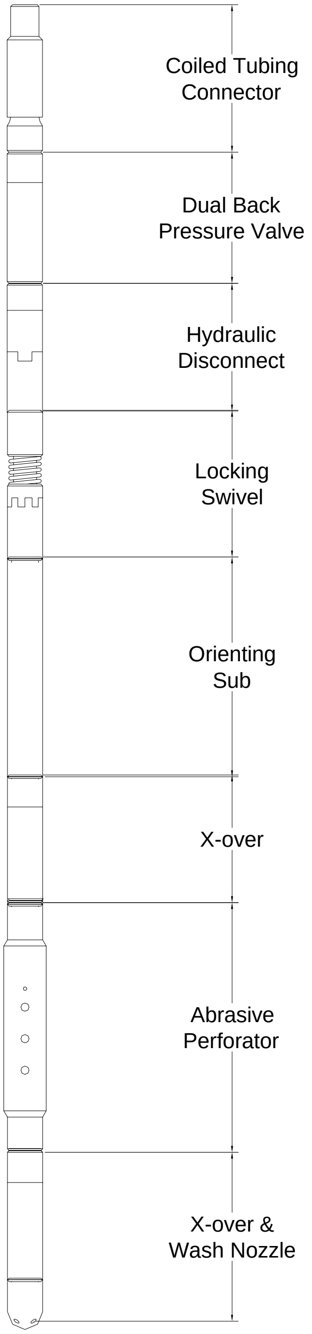

Figure 1 – BHA Schematic of Oriented Perforating System

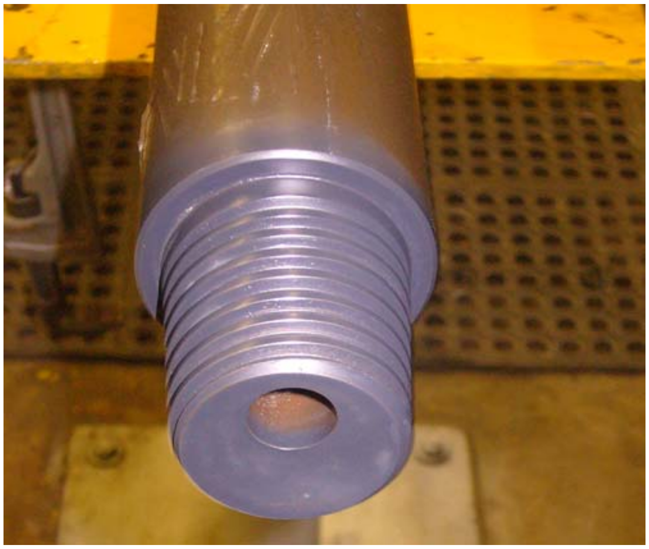

Figure 2 – Eccentric Weight Bar

Figure 3 – Casing and Shale Samples within test assembly

Figure 4 – Completed test assembly with cement

Figure 5 – Batch mixer used for sand slurry mixture

Figure 6 – Perforator dressed with two 0.125inch Orifices

Figure 7 – Entry hole of Casing Sample

Figure 8 – Entry hole to Cement and Shale

Figure 9 – Tear Drop Pattern of Erosion Effects

Figure 10 – Penetration depth from Casing center to cement edge

Figure 11 – Depth of Penetration Post Perforating