BULLET PERFORATING

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Abstract

The oil industry typically selects perforators based on published performance specifications. Depth of penetration data, while readily available, can be misleading criteria. Larger charges provide deeper penetration but can have a detrimental effect. Bullet perforating, although an old technology, still has applications today. Furthermore, bullets can be superior to jet perforating in some circumstances. Quantitative data comparing bullets with jets have not been readily available. This paper presents a comparison of perforating and treatment data from nine wells completed with jets and eight wells completed with bullets. These comparisons are made on completion and stimulation data from the two sets of wells, all of which were in the same field.

Introduction

In the past few years, the general consensus of the oil industry concerning perforating has essentially been, "the deeper the penetration, the better." This philosophy has led many operators to choose their perforating methods based entirely on published depth of penetration, which can often be misleading. Standard API targets are not necessarily identical to the actual formation being perforated. Published penetration depths (Figure 1)[1] in an API target are almost certainly greater than will be achieved in the actual formation. Bullet and jet charges are not affected by these changes in the same way.

Several years ago, Sandia National Laboratories (Warpinski, 1983) conducted research on in-situ stress measurements and determined that, in general, increasing the perforating charge size had the effect of increasing the formation fracture pressure.[2] When various sizes of shaped charges were used and the formation fractured using a mixture of water and dye, subsequent excavation and examination indicated that the fracture fluids diverted immediately around the perforation and its associated high-stress halo. In other words, rather than being an advantage, the larger perforating charges were hindering the completion due to the large high-stress halo. The research was conducted in the Mesa ash-fall tufts at a depth of approximately 1,400 feet. Obviously, this is not the typical reservoir rock that the oil industry experiences.

However, accepting this concept, one operator, Harvey E. Yates Company (HEYCO) in Roswell, New Mexico, lowered the breakdown pressure by an average of 800 psi in the Bone Springs Sands of Eddy County, New Mexico.[3] This was accomplished by the simple expedient of using charges no larger than 12 grams, instead of the typical 22 to 24 gram charges that most of the industry uses. The compressive strength of the 2nd Bone Springs is 6,050 to 6,100 psi.[3] The significance of this test is it shows that the theory of "the deeper the penetration, the better" does not hold true for all formations.

The additional formation damage can offset any gain in penetration. HEYCO obviously obtained lower penetration with the smaller charges, but consequently lowered their breakdown pressure significantly. These data suggest that using larger charges to obtain deeper penetration is not necessarily advantageous, even in formations with compressive strengths significantly higher than those in the tests conducted by Sandia Labs.

The authors of this paper are not suggesting that jet perforating be abandoned and replaced by bullets. This is the mistake that was made when jets were first introduced; the industry adopted the "new is better" philosophy and basically discontinued the use of bullets. In low-porosity fractured or vuggy formations, where mud or cement invasion may be a significant factor, the deeper penetrating large jet charge may be advantageous. This assumption, however, needs to be tested.

Laboratory Measurements

Bullet shots offer advantages in lower compressive strength formations and in well stimulations. As shown in Figure 1, bullets will have deeper penetration than jets in formations with compressive strengths less than 2,500 psi.[1] Some may therefore conclude from this information that bullets have insufficient penetrating ability. This is not the case, however, when one considers that bullets penetrate, with ease, three concen-trically cemented strings of casing. In laboratory tests, 9.625-in., 7-in., and 5.5-in. concentrically cemented casings have been penetrated completely with a 15/32-in. bullet fired from a 4-in. gun (see Figure 2).[3] When the same test is made using 4-in. jet charges, they too completely penetrated the three strings of casing, but the hole size diminishes with each successive casing string, while the bullet holes in each casing string are each full diameter (Figure 3).[1]

The consistent entry hole diameter produced by bullet perforators offers several advantages over jet perforators. Perforations made by bullets provide a uniform pressure drop and predictable friction to fluid flow through the perforation. This is due to the smooth tunnel created through the casing by the bullet, whereas the jet produces a rugose hole (Figure 4).[4] The bullet hole size is a known dimension, irrespective of the casing weight or grade. A consistent, smooth entry hole is useful in well stimulation treatments, limited entry completions, and ball sealer applications.

Jet perforations, on the other hand, produce holes that vary in size and geometry, which can frequently have an adverse affect on ball sealers (Figure 5).[4] Perforation diameters also vary with changes in casing grade. The API 43 specifications for jet perforators report an average hole diameter. Because jet perforators do not necessarily produce a round hole, the diameter for one hole is obtained by averaging the short axis and the long axis of the perforation. The test data are typically an average of six to twelve shots. Also, because each jet shot fired varies randomly with respect to hole size and uniformity, the actual entry hole diameter may vary from the reported data.

There is an abundance of anecdotal testimony that bullet perforators have a significant advantage over jet shots. However, it has been difficult to obtain quantitative data that confirms this testimony.

Field Tests

An opportunity did present itself in 1991 when Birdcreek Resources completed several fracture-stimulated wells in the same field using jet shots to perforate half of the wells and bullets on the remaining half.

The original intent of this paper was to demonstrate the difference in breakdown pressures as well as treating rates and pressures for the two perforating techniques. However, because this paper was conceived after the project was complete, some of the necessary data were not collected.

For example, the pressures presented in Table 1 were not taken with a bottomhole bomb, but are calculated from surface pressures. This is admittedly a variable. However, the sudden increase in rate (basically doubling) coincides with the change from jet perforating to bullet perforating. The average flowrate from the jet perforations was 4.47 bpm @ 1,611 psi, while for bullet perforations, the average flowrate was 8.38 bpm @ 1,569 psi (Table 1).

An attempt was made to normalize the data for the varying numbers of perforations by expressing the flowrate as a function of the number of holes (bpm/hole). Note that the jets treated at an average of 0.0869 bpm/hole, while the bullets treated a 0.202 bpm/hole, an increase of approximately 132% (Table 1).

Another significant point from the data collected by Birdcreek Resources is that the bullets balled out 85.7 % of the time while the jets balled out only 12.5 % of the time, giving greater assurance that the entire prospective zone has been treated as planned when bullets are used. On the average, wells perforated with bullets had 296 psi lower breakdown pressure than the wells perforated with jets.

Hanson Operating (Roswell, New Mexico) reports experiencing lower breakdown pressures when using bullets in carbonates (San Andreas in Chaves County, New Mexico), but no detailed data are available at this time.[6] This same condition was previously reported in 1987 by Amoco.[7] In 1981, an in-house communication took place between W.L. Tressler and Paul Pausky[8] who compared conventional jet perforating and bullets in a situation where the pay was separated from water by only two feet. Bullets were chosen in order to reduce the breakdown pressure required for fracturing. According to Tressler,[8] "The bullet perforator produced the lowest breakdown pressure ever recorded in the Brown Niagaran formation in the Ingham county area." A second zone was subsequently completed that was believed to be comparable both in porosity and permeability. This assumption was based on well-log and DST data. When completed with premium jet charges, the zone broke down at 600 psi higher than the zone completed with bullets.

Summary

This study has shown that bullets clearly offer advantages over jets in some situations. The uniform, predictable, entry holes provided by bullet perforations are preferred over jet perforations in well completion situations such as limited entry completions and ball sealer applications. The lower formation damage resulting from bullets produces a lower formation breakdown pressure than would be achieved with jets.

References

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Acknowledgments

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Table 1 - Birdcreek Resources Field Test Results

	Well Name	DATE	PERF TYPE	NUM HOLES	NUM BALLS	BREAK DOWN PRESS	BALL ACTION	BALL OUT?	RATE BPM	TREAT PRESS	PSI/BPM	BPM/HOLE
1	"CARRASCO ""14"" NO. 1"	6/89	JETS	54	75		GOOD	NO	4@	1,400	350	0.07407
2	RGA NO. 1	8/89	JETS	48	72		GOOD	NO	4@	1,500	375	0.08333
3	RGA NO. 2	11/89	JETS	50	72	2400	GOOD	NO	4@	1,500	375	0.08000
4	TELEDYNE NO. 1	1/90	JETS	50	75	2400	GOOD	NO	4.2@	"1,600	381	0.08400
5	TRACHTA NO. 1	5/90	JETS	54	72	1900	GOOD	NO	4@	"1,600	400	0.07407
6	TELEDYNE NO. 2	5/90	JETS	54	75	2400	GOOD	YES	4@	1,600	400	0.07407
7	SIEBERT NO. 1	6/90	JETS	44	75	1400	GOOD	NO	4@	1,300	325	0.09091
8	CAVINESS-PAINE NO. 1	6/90	JETS	54	75	2400	GOOD	YES	4@	"1,600 "	400	0.07407
9	RBO REID NO. 1	1/91	JETS	54	80		POOR	NO	8@	"2,400 "	300	0.14815
10	RGA NO. 3	8/90	BULLETS	48	50	2000	GOOD	YES	8@	"1,500 "	188	0.16667
11	TRACHTA NO.2	9/90	BULLETS	34	45	2900	GOOD	YES	8@	"1,500 "	188	0.23529
12	CAVINESS-PAINE NO.2	9/90	BULLETS	46	62	1600	GOOD	YES	7@	"2,000 "	286	0.15217
13	QUEEN NO. 1	11/90	BULLETS	43	62	1430	GOOD	NO	8@	"1,350 "	169	0.18605
14	WITT NO. 1	11/90	BULLETS	35	70	1700	GOOD	YES	8@	"1,200 "	150	0.22857
15	CAVINESS-PAINE NO. 3	11/90	BULLETS	35	70	2700	GOOD	YES	8@	"1,200 "	150	0.22857
16	MARKHAM NO. 1	1/91	BULLETS	34	60	1100	GOOD	YES	8@	"1,800 "	225	0.23529
17	OGDEN NO. 1	1/91	BULLETS	64	75	1400	GOOD	YES	12@	"2,000 "	167	0.18750

BALL ACTION

12.50% OF JET PERFS BALLED OUT
85.71% OF BULLET PERFS BALLED OUT

AVE TREATING PRESSURE AND AVE RATE

JETS	1611 @	4.47
BULLETS	1569 @	8.38

	JETS	BULLETS	DIFFERENCE
AVERAGE BREAKDOWN PRESSURE	2,150 PSI	1854 PSI	13.78% BULLETS LOWER BREAKDOWN PRES
AVERAGE RATE	4.5 BPM	8.4 BPM	87.50% BULLETS HIGHER RATE
AVERAGE TREATING PRESSURE	1,611 PSI	1,569 PSI	2.63% BULLETS LOWER TREATING PRESSURE
AVERAGE PRES/RATE	367 PSI/BPM	190 PSI/BPM	48.24% BULLETS LOWER PRES/RATE
AVERAGE RATE/HOLE	0.087 BPM/HOLE	0.2025 BPM/HOLE	132.87% BULLETS HIGHER RATE PER HOLE

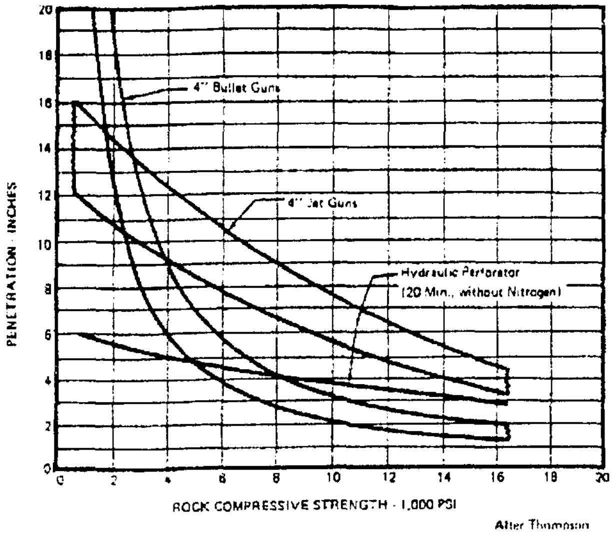

Figure 1 - Bullet, Jet, and Hydraulic Perforator Performance [1]

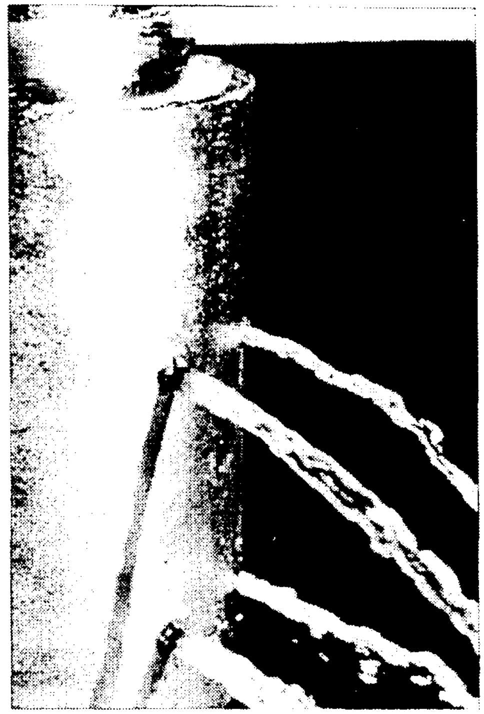

Figure 2 - Fluid Flow through Three Concentric Casing Strings
Note how the fluid flow is affected by perforation shape. Injection rates and pressure drops through the bullet perforations (left) can be predicted and controlled. Irregular shapes and size of jet perforations (right) result in unexpected pressure drops and additional turbulence.

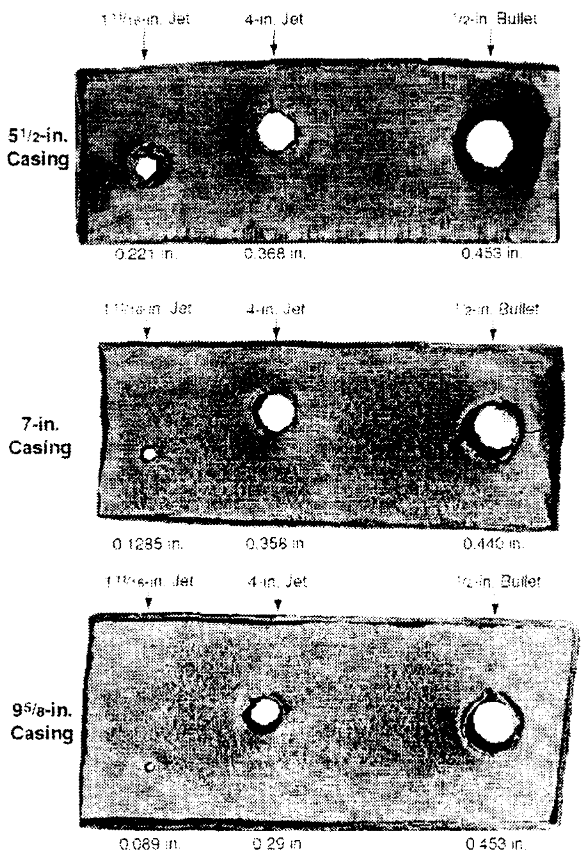

Figure 3 - Perforating Hole Diameters of Three Concentrically Cemented Casing Strings

Note: Diameters were determined by passing drill rods of known dimensions through the holes. Some of the holes were somewhat elliptical and the presence of burrs also caused some measuring difficulty. Additionally, entry and exit holes typically were different in size. In short, there is some subjectivity to these "measurements."

Figure 4 - Adjacent Bullet and Jet Perforations in Casing Sample

The E-Gun bullet perforator creates a smooth cylindrical tunnel through the casing (left), whereas the jet perforator leaves a tapered, rough tunnel (right).

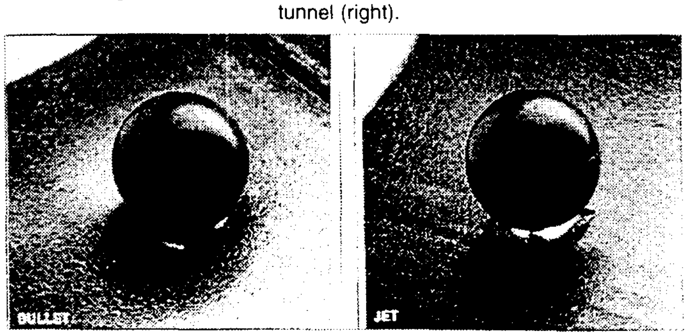

Figure 5 - Jet Perforations Produce Holes that Vary in Size and Geometery