Chemical Explosive Fracturing For Well Stimulation: A Review

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INTRODUCTION

The use of explosives in the oil fields certainly is not new. As early as 1865, wellbore shooting with nitroglycerin was attempted.[1] It became a routine completion practice to run a torpedo shell filled with nitroglycerin to bottom and drop a "go-devil" for impact detonation. The ensuing (nontamped) explosion created an enlarged, fractured wellbore that served as a sump to collect oil as it flowed from the formation. This technique was successful in stimulating for commercial production many of the shallow, low-pressure, low-temperature wells of that time.

The search for oil and gas progressed to greater depths with the associated higher temperatures and pressures. Petroleum reserves were being discovered in formations with low permeabilities, too low to produce naturally without some form of stimulation. The "nitro shooting" technique was pushed into the background during the early 1950's as petroleum technology introduced formation hydraulic fracturing, and emphasis was placed on altering the formation characteristics instead of only the wellbore. This method proved successful, and the recovery of millions of barrels of crude oil can be attributed to it; in fact the availability of modern hydraulic fracturing techniques has increased the Nation's recoverable crude oil reserves by more than 7.3 billion barrels.[2] Today, hydraulic fracturing is considered a standard completion technique in oil, gas, and injection wells to improve recovery, deliverability, and injectivity. Still, many reservoirs known to contain vast quantities of oil or gas or both, have not responded to conventional stimulation methods and cannot be exploited economically. It is these low-permeability, thick, petroleum and natural gas-bearing formations that have stimulated industry and Government to develop new stimulation tools through research to complement proved technology.

As early as 1936, the concept for explosive fracturing technology had been conceived;[3] however, the major impetus in developing explosive products for this application was delayed until the early 1960's, evidenced by the several patents issued at that time.[4,5,6] Explosive fracturing companies, oilfield service companies and government agencies began concerted efforts to develop explosive products and techniques for field applications in low-permeability formations.

This report reviews the state-of-the-art of explosive fracturing, with particular emphasis on field applications. Typical wellbore and fracture applications for the two basic types of explosives being used and the explosive displacement techniques being employed are described. Stimulation results achieved with the various explosive products are summarized.

EXPLOSIVE FRACTURING MECHANICS

The mechanism for formation fracturing by detonating an explosive in the wellbore is relatively simple. Rock is generally less resistant to tension than to compression. The high pressure developed by an explosion shatters the rock adjacent to the wellbore, and a shock wave is generated that moves outward through the formation. The pressure in this shock wave is initially positive when it arrives at a free surface and then falls rapidly to negative values. This implies a change from compression to tension with resulting rock fracturing.[7]

When detonating an explosive within an existing hydraulic fracture system, one encounters two distinctly different conditions. If a detonation occurs within a horizontal fracture, the high-pressure shock wave should shatter the adjacent faces of the fracture, with the shock wave traversing the medium and reflecting back from stratigraphic heterogeneities above and below the pay zone. The rock would be subjected to a compression wave followed by a tension wave and fracturing should occur. However, extension of the fracture radially in the horizontal plane would be limited, because the ever-increasing area at the perimeter of the system would be available for energy dissipation.

It is suggested that if detonation occurs in a vertical fracture, the faces of the fracture again should be shattered, but the traversing shock wave usually has no immediate vertical reflection boundary and the energy is quickly dissipated. The stratigraphic boundaries above and below the interval may confine the expanding gases and contribute to extending the vertical fracture. In this environment, only a few explosively created fractures may be expected.

FIELD APPLICATIONS AND TECHNIQUES

The explosive products described in this review have been classified into two basic types: (1) Viscous slurries or semisolid blasting agents designed primarily for wellbore application. The products have explosive critical diameters greater than average fracture widths; that is, the explosion will not propagate from the wellbore through a fracture system, (2) Viscous slurries or liquid explosives designed for displacement from the wellbore and subsequent detonation within the formation fractures.

Wellbore Explosives

One of the earlier entrants into the explosive fracturing field was Dowell Div., Dow Chemical Co.[8] Its product, called Stratablast "A," is a viscous slurry comprised of ammonium nitrate, water, metal, and encapsulated air in glass microbeads. Air encapsulation is needed for the explosive to be effective under elevated pressures. This product reportedly is extremely safe to handle, provides good borehole coupling, and has an excellent power rating.

Following earlier attempts to place the explosive in the wellbore with flexible plastic bags lowered on a wireline shooter's hook or by a dump bailer, Dowell developed a pressure-displacement technique for injection through tubing. The procedure requires that tubing be run to the zone to be stimulated, explosive displaced under pressure through the tubing, and the tubing pulled. A timing device-detonator then is lowered into the explosive-filled borehole, and the charge is tamped with gravel and detonated.

In 60 field tests where production data were available for stimulation evaluation, 90 per cent showed a production increase and 75 per cent of these were reported to be profitable. These data are included in Table 1.

The Western Company, a major oilfield service company, conducted extensive research in the explosive fracturing field [9,10] and developed a product for wellbore application. This explosive is described as a slurry comprised of ammonium nitrate with other oxidizers, TNT, water, and aluminum. The product is relatively safe, temperature stable to 180° F, and has been detonated at 6800-ft depths. It is reported to be one of the most powerful commercial explosives available.

Placement techniques for this explosive have included pumping the product down casing between rubber plugs, lowering in plastic bags on wireline, dropping explosive-filled plastic bags from the surface, and placing with a dump bailer. Detonation is accomplished either electrically through a wireline attached to blasting caps or with a timing device. A cap sensitive booster charge is used to ensure detonation. Total containment of the explosive is recommended and can be accomplished by stemming with gravel and cement.

Results of field tests reveal the product has been used in quantities to 8500 lb at 6800 ft maximum depth. Results of stimulation from several field tests are shown in Table 1.

Controlled Reaction Corp. in a joint program with Petroleum Tool Research, Inc. has tested an explosive fracturing system that is unique in that the application is based on controlled yield through multiple treatments.[11] The explosive is a proprietary formulation of nitrates, chlorates and perchlorates tailored to yield desired detonation velocities and pressures. A complete stimulation treatment consists of four "subsystems," each designed for a specific purpose. Subsystem A, an electrically fired wireline device initiates the fracture or fractures at selected intervals. Subsystem B, a solid explosive, then is employed for fracture extension. Subsystem C follows with a high-detonation-rate solid explosive for wellbore enlargement. Finally, through Subsystem D, a massive quantity of solid explosive is displaced into the cavity and detonated for maximum rock breakage and formation fracturing. The largest treatment attempted has been with 35,000 lb of explosive.

Two field tests have been reported using this technique. Results of these applications are shown in Table 1.

Fracture Explosives

In 1963 the Bureau of Mines initiated a petroleum engineering research program to develop a technique for stimulating low permeability oil and gas formations by displacing and detonating a liquid explosive within a fracture system. The only commercially available explosive capable of detonating and propagating through thin fractures was du Pont's desensitized liquid nitroglycerin, EL-389-B. This explosive, referred to as NG1, met the basic criteria established for explosive stimulation, as follows: Safety in handling and onsite usage, immiscibility in formation fluids, density greater than that of water, capability of displacement and explosive propagation within a thin fracture, and high energy for maximum fracturing.

After extensive surface and near-surface testing to characterize the NG1 and develop field handling procedures, three field tests were performed.[12,13,14] Charges of 890 and 1000 qt were displaced and detonated in openhole and in cased and perforated completions, respectively, in two shallow gas wells in Oklahoma. One 1700-ft producing oil well was treated with 1500 qt of NG1. Explosive placement in all three tests was relatively simple. The wells were temporarily "killed" with water, and NG1 was lowered through the water column in a dump bailer and placed on bottom. By overbalancing the bottomhole formation pressure with fluid, the NG1 was slowly displaced from the wellbore into existing hydraulic fractures. A detonator comprised of a timing device and an explosive booster was placed in the small quantity of NG1 that remained in the wellbore, and a sand tamp placed above the charge protected the well casing. Results of the three field tests are summarized in Table 1.

Talley-Frac Corp., a subsidiary of Talley Industries, Inc., was formed in the late 1960's with the explicit purpose of developing and marketing an explosive product for oil and gas well stimulation. A patented formulation[15] was developed and is offered commercially under the trade name TAL-1005C. This product is an explosive slurry with a critical diameter of less than 1/64 in. Although very viscous, 30,000 to 50,000 cp, its thixotropic properties permit displacement into formation fractures without excessive hydraulic pressures.

Although loading techniques may vary according to the well completion and formation conditions, a typical procedure for placement through casing has been described.[16] After fluid injection has shown that the formation fractures will accept the slurry, the wellbore is plugged back with sand to about two feet below the producing interval. The explosive and detonating device are pneumatically transferred into the casing between two rubber cement-wiper plugs. This explosive column then is hydraulically displaced down the casing and into the fracture system. A sand or cement tamp, 20 to 50 ft, is placed above the top wiper plug and the well filled with fluid to the surface to protect the casing.

Several field tests using this product have been performed in both oil and gas wells. Size of treatments have ranged from 1500 to 18,000 lb at depths of 1000 to 5900 ft. Production responses have varied from no improvement to a 14-fold improvement. Field test data and results are listed in Table 1.

The latest known entrant into the explosive fracturing field is Petroleum Technology Corp., a subsidiary of Explosives Corp. of America. Their process, called Astro-Flow, is being tested under an exclusive agreement with Austral Oil Co.; therefore, it is not now being offered commercially.

Although similar in several respects to the separate techniques developed by the Bureau of Mines and Talley-Frac, Astro-Flow possesses certain unique characteristics of merit. Reportedly, the liquid explosive can be used to hydraulically fracture the formation at pressures to 10,000 psi. The explosive is mixed at the site from nondetonable chemical ingredients. Fluid stemming or tamp is added simultaneously with the explosive, and the entire column is hydraulically displaced downhole. A self-contained downhole monitor initiates detonation as the final amount of explosive is leaving the wellbore and while the fluid still is in motion. No details on the monitor-detonator are available.

One field test performed on a 1200-ft water well has been reported,[17] and results are summarized in Table 1. Oil and gas well tests are in progress, but no results are available.

DISCUSSION OF RESULTS

The authors have reported briefly on the state-of-the-art of explosive fracturing for formation stimulation and have summarized the efforts of industry and Government in developing this new technology. As shown in Table 1, oil and gas reservoirs have been stimulated for increased recovery with liquid, slurry, and solid types of explosives. Maximum quantity of explosive was 35,000 lb. Stimulation efforts have been attempted at well depths of 6800 ft and bottomhole temperatures in excess of 175° F. Industrial research is currently developing techniques for the safe handling and placement of fracture explosives that are tailored to specific applications. Both wellbore explosives and fracture explosives have been field tested with production successes and failures attributed to both. It is important to note that explosive fracturing is in its early development and consequently, like any other new technique, must prove its merit under less than ideal conditions. Most tests have been in marginal wells that offer little promise of improvement in production. Understandably so, an operator is reluctant to experiment with an unproved technique of high risk in better wells that afford the opportunity of maximum improvement. Once the technique is proved and accepted by industry, however, the real potential of explosive-fracturing stimulation should ensue.

Evaluation of Explosive Fracturing

The number of companies and research organizations engaged in explosive fracturing technology certainly indicates the amount of interest in this stimulation technique. Our Nation's increasing energy demand and decreasing petroleum reserves make it mandatory to develop new stimulation methods and improved recovery systems. The large sums of money spent in the two nuclear stimulation tests, Projects Gasbuggy and Rulison, are indications of the desire and willingness of industry and Government to experiment with novel stimulation ideas.

The future for explosive fracturing appears promising; however, many problems and questions remain to be solved or answered. 1. More research in developing a reliably safe explosive product is needed. 2. More field tests are necessary to develop criteria for selecting potential well candidates for stimulation. 3. The limited quantity of field results has not proved the superiority of a wellbore explosive over a fracture explosive. 4. Rock mechanics theory has not been developed to predict reliably the in situ effects of explosive fracturing. 5. Efforts are needed in developing field testing methods to provide an understanding of what has occurred in an explosively stimulated reservoir. 6. Pressure and temperature limitations of the explosive product must be determined for safe field application.

In summary, explosive fracturing is in its infancy with many of the inherent problems associated with a new technology. Extreme caution must be exercised in laboratory or field application using any of these types of explosives. Only through continued research and development on new products and improved techniques can this "tool" prove valuable to petroleum technology.

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TABLE 1.—Summary of Explosive Stimulation Field Applications

Company and/or product	Quantity	Depth, ft.	Type well	Production/day Before	Production/day After
WELLBORE EXPLOSIVE					
Dowell - Stratablast "A"	60 wells tested — 90 percent increased production — 75 percent were profitable				
Western Co.	420 lb	5,000	dry hole	1/	1/
	150	5,000	do	1/	1/
	2,000	5,000	oil	3 BO	6.5 BO
	1,100	6,800	do	1	2
	5,600	4,000	do	19	225
	8,500	4,000	do	78	215
	980	3,800	do	10	10
	1,800	4,400	do	25	25
Controlled Reaction Corp. and	35,000	1/	gas	lt. show	5.3 Mcf
Petroleum Tools Research, Inc.	1/	1/	oil	lt. show	2 BO plus emulsion
FRACTURE EXPLOSIVE					
Bureau of Mines	890 qt	500	gas	235 Mcf	235 Mcf
liquid nitroglycerin	1,000	500	gas	350 Mcf	415 Mcf
	1,500	1,700	oil	12 BO	6 BO
Talley-Frac Corp.	16,500 lb	1,800	oil	11 BO	24 BO
TAL 1005-C	18,000	5,900	gas	0.8 MMcf	2.8 MMcf
	4,000	2,100	oil	3 BO	21 BO
	5,000	1,000	gas	100 Mcf	490 Mcf
	1,500	2,000	gas	10 Mcf	94 Mcf
	3,500	2,600	oil & gas	20 BO	30 BO
				20 Mcf	100 Mcf
	3,000	3,350	oil	100 Mcf	150 Mcf
	5,000	4,150	oil & gas	2 BO	10 BO
				5 Mcf	10 Mcf
	3,500	2,400	oil	1 BO	7.5 BO
Petroleum Tech. Corp. Astro-Flow	1/	1,200	water	256 percent increase over initial flow capacity	

1/ Data not available.