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Application of Propellant High-Energy Gas Fracturing in Gas-Injector Wells at El Furrial Field in Northern Monagas State - Venezuela

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Abstract

The Furrial Field located in the Eastern Basin of Venezuela is characterized by large oil reservoirs with complex geology due to faulting and heterogeneity. To optimize oil production and oil recovery in the field, the operator, PDVSA, implemented a gas-injection project. Several wells were drilled and completed as cased-hole completions using through-tubing and casing-gun technology. However, the results obtained with the conventional perforating techniques yielded less than optimum injectivity indices, non-uniform injection profiles, and higher compression requirements on the gas injectors.

The primary damage mechanism in these completions was identified as asphaltene deposition, presenting the challenges of being able to identify the damaged zones, and then, to selectively treat them in a safe and economical method under the prevailing conditions. Another problem identified was the emulsion damage caused by the inverted mud system used during drilling operations. After review of the available perforation and stimulation methods, a propellant high-energy gas fracturing technique was selected for field trials to enhance injectivity. The propellant high-energy gas fracturing technique, although not a new technology, was the first application of this process on gas injectors in Venezuela.

This paper emphasizes the methodology used to validate the application of the propellant high-energy gas fracturing technique on gas-injection wells and the use of surfactant during propellant activation to further creating an additional stimulating effect in the formation. A computer simulator was used to design the propellant treatments and analyze the effects of generated pressures on the mechanical well configuration and wireline design. The primary benefit of propellant treatments is its capability to selectively create mild fracturing with minimal formation damage. This benefit was demonstrated with the improvements and changes obtained in the injectivity and productivity profiles.

The case histories from the Furrial field validate this technology and provide operational guidelines and results in the form of injectivity changes. Production log responses to evaluate effectiveness of selective propellant placement will demonstrate the changes in completion efficiency. The propellant high-energy fracturing technique offers a simple, cost effective, and time-saving alternative to more commonly known stimulation techniques for selective treatment of formations. The objectives of this document are to present the experience gained from applying the technique, the results obtained, and why this method was particularly beneficial to the wells included in this paper.

Introduction

El Furrial Field. The El Furrial field is located in east Venezuela, 50 km from Maturin, Capitol of Monagas State, in the North Monagas Area (see **Fig. 1**). The field, with 92 producers (38 dual completions), 43 water injection and 7 gas injection wells covering 14,330 acres, is one of the most prolific producing areas in the country with daily oil production of 387 MBOPD. Gas injection projects to maintain reservoir pressure are currently under way to maximize ultimate recovery of oil from the reservoirs in this field.

The oil production is from three distinct sandstone formations: Naricual Inferior, Naricual Medio, and Naricual Superior. The length of these three formations is approximately 1,300 ft each with an average depth of 14,000 ft. The Naricual formations are massive sands separated by thin shale sections with sand-grain sizing described as medium to coarse, (see **Table 1** for properties). In order to optimize the available gas supply and enhance oil recovery efficiencies of individual layers, a routine surveillance program consisting of production logging surveys (PLT) was implemented. The PLT surveys allow for determination of individual layer injectivities and help to explain unexpected gas oil ratio (GOR) increases in the producers. Following the PLT surveys, sands that were not accepting adequate amounts of injected gas were targeted for stimulation treatment. All intervention options under consideration, equipment, and procedures had to meet strict health, safety and environmental guidelines in order to meet acceptance in this environment.

The following treatments or techniques were considered to enhance injectivity profiles:

1. Thru tubing wireline perforating
2. Bullhead matrix acid treatment
3. Selective spotting of acid, solvents or surfactants with coiled tubing\inflatable packers
4. Injection of solvents and/or surfactants
5. Solid propellant assembly.

The through tubing perforating option had been attempted on several occasions with mixed results. The major disadvantages to wireline perforating with existing perforations open was the inability to effectively surge or underbalance the perforations to ensure good connectivity to the reservoir. The standard matrix acid job was also considered; however, having very long intervals, it was determined that proper diversion to ensure that targeted intervals would be treated properly could not be achieved. In addition, acid compatibility testing performed with Naricual formation fluids and cores revealed that conventional acids formed undesirable emulsions. The inverted mud system used to drill these completions also was determined to be incompatible with acids resulting in emulsion problems. The working depths and temperature's made the coiled-tubing pumping option less appealing due to potential operational difficulties. Finally solvent and surfactant treatments were pumped and yielded mixed results as well; proper diversion could not be achieved to ensure that the intervals with damage were treated along with the compatibility issues previously discussed.

Why the Propellant Technique?

The solid propellant assembly was identified as an alternative method to conventional stimulation methods that could selectively break down existing perforations and bypass any damage so that connectivity to the reservoir could be restored. Operationally, this option would not require the mobilization of special pumping equipment required with conventional acidizing, and the work could be performed using standard electric wireline equipment and procedures.

Propellants have been available to the industry for many years with thousands of applications primarily in the United States, Canada, China, and Russia. Review of the literature[1-13] reveals that propellants have been widely used in the industry with many types of applications and with varying degrees of success. The concept of using the solid propellant assembly as a perforation breakdown method on gas injection wells is a new application of this technology in Venezuela. Propellants are defined as "an oxidizer material that deflagrates as opposed to an explosive that detonates." Detonation propagates a shock wave through the explosive whereas deflagration chemically burns the material. The primary end product of the propellant burn process is the creation of high-pressure carbon dioxide gas and water vapors. The combustible gases and water vapor along with the well fluids are rapidly injected into the newly created perforations on a rate scale several orders of magnitude greater than can be achieved through conventional pumping operations. Since the wellbore fluids will be injected into the formation during the perforating process, it is, therefore, important that the selection of the wellbore fluids be considered carefully so as to not induce formation damage due to fluid incompatibilities. To obtain desirable burn characteristics with propellants, it is necessary to ignite the propellants in fluid with a minimum hydrostatic of approximately 500 psi.

The principle of the propellant stimulation is simple: as the wireline detonator is ignited, the detonating cord is ignited causing the solid propellant to fracture into many smaller pieces as described by Gilliat et al.[14]. **Fig. 2** illustrates a typical solid propellant assembly for a wireline-conveyed application. All standard wireline operations should adhere to the safe handling procedures for explosives when conducting field operations. The propellant burns as a function of pressure, temperature, and available propellant surface area exposed, with the detonating cord providing the necessary ignition source. At ambient conditions, the propellant material is basically inert and will not burn properly without some type of confinement to allow the gas pressures to accelerate. The generated gas pressure pulse is generally sufficient to overcome in situ stresses to create and extend short fractures from perforation tunnels in a cased-hole completion. It is conceptualized that all the perforations will be broken down regardless of charge phasing; however, at some point the only fractures that will propagate are the perforations aligned with preferred stress plane. Propellant-type treatments are designed to be near wellbore treatments, and narrow fractures on the order of 2- to 10 ft are typical to bypass any near wellbore problems. Propellants should not be used with the intent of replacing conventional hydraulic fracturing treatments that are normally required to sustain commercial production rates in reservoirs with low permeability. Pressure pulses ranging from 5,000 to 30,000 psi are attained within a 1 to 10 ms time regime, followed by a decay tail associated with expansion, cooling, and flow into the perforations and fractures. The loading rates and peak pressures are lower than with explosives but significantly higher than those that can be generated in conventional hydraulic fracturing. Peak pressures and burn characteristics of propellant tools are dependent on wellbore diameter, geometry, perforation area, formation properties, and confining fluid compressibility.

In the past, propellant treatments were designed based on experience and field observations. The availability of a computer model and high-speed pressure recorders, as described by Schatz et al[15], has validated this technology and greatly enhances the understanding and reliability of propellant stimulation techniques. Propellant treatments have been applied in many cases in either balanced or underbalanced conditions leading in most cases to zero or slightly negative skin completion responses. Whisonant and Hall,[16] Miller et al,[17] and Van Batenburg et al[18] describe specific applications of propellant techniques as a perforation breakdown method for pumping applications in competent formations.

Pre-Job Planning For Propellant Stimulation

A pre-job meeting was scheduled to discuss all the issues related to introducing new technology to this operator. Several key issues were identified as follows:

1. Selection of first well candidate for evaluation
2. Fluid selection to avoid emulsions and formation fluid compatibility
3. Propellant system to be used
4. Wireline-conveyance cable-type and risk assessment
5. Wireline string components
6. Well surface conditions at time of treatment
7. Computer modeling of propellant burn characteristics
8. Assessment of potential mechanical wellbore failure
9. Risk assessment and contingency plans.

Based on computer modeling to predict pressures generated downhole and potential tool movement, the decision was made to run 2-in. OD solid propellant tools using a 7/32-in. monoconductor cable for improved cable strength and pressure sealing capability. To ensure that perforations were correlated on depth properly, a toolstring consisting of a cable head, casing collar locator (ccl), and gamma ray tool was used, (reference **Fig. 2**). To minimize any potential damage to surface equipment during the propellant event due to hydraulic hammer effect, an air cushion of at least 100 ft was put in place at the surface for all treatments. The previously mentioned computer modeling was used to assess any mechanical wellbore failures; i.e., liner tops, bridge plugs or casing. Material Safety Data Sheets (MSDS) on the propellant were reviewed to confirm its safe operation, and standard wireline perforating practices were employed to ensure a safe and efficient operation. A surfactant additive was added to diesel and used as the tamp fluid to address the asphaltene problem and any other formation-fluid compatibility issues. Prior to the planned propellant treatment, the tamping fluid was pumped into the wellbore, and then, a pressure gradient survey was performed to determine static fluid level. This step was performed to make sure that adequate fluid or tamp was in place to obtain proper propellant burn characteristics.

Case Histories

Well FUC-36IG

This well was drilled to a total depth of 14,070 ft MD and completed with a 7-in. liner and 5-1/2-in. tubing in the Naricual Superior formation in November of 2000 (see **Fig. 3**). The Naricual Superior formation was perforated with 2-3/4-in. 6 spf DP guns conveyed on electric wireline from 13,290 to 13,670 ft with a total of 64 ft actually perforated (see **Table 2** for perforation record and **Fig. 4** for openhole log responses). The well was connected to the high-pressure gas plant to initiate the pressure maintenance program on the west block of the Upper Naricual reservoir. Review of **Fig. 5** shows that the initial gas injection peaked at 55 MMcfd at a surface injection pressure of 7,250 psi; however, over the next couple of months, the injection rate steadily declined. In January of 2001, when the gas injection rate had declined to 22 MMcfd, a PLT log was run to determine which zones were accepting gas. The PLT log confirmed that all the perforated intervals were still accepting gas (see **Fig. 6** and **Table 3** for log analysis).

A decision was made to perform a second perforating run to increase injected volume with a more uniform injection profile. In March of 2001, the second stage of perforating was executed with 2-3/4-in. 6 spf DP guns conveyed on electric wireline, adding 141 ft of perforations (see **Table 2**). Review of gas injection history in **Fig. 5** reveals that the addition of the 141-ft of perforations did not show any improvement in the injection volumes. Based on the necessity to improve the injection profile and increase gas volume, the use of the propellant stimulation technology was implemented. A simulation was performed to determine the peak pressures that would be generated and predicted fracture lengths with various size propellant tools, (see **Fig. 7**). Using 2.0-in. OD solid-propellant tools, it was determined that a peak pressure of 14,100 psi and a fracture length of 2.5 ft were possible, which would be more than sufficient to break down the existing perforations to increase gas injectivity. Based on simulation results, the decision was made to perform the propellant treatments with 2.0-in. OD solid propellant conveyed on electric wireline (see Table 2 for treated intervals and propellant tool lengths). The job was performed in May of 2001 with 12 successful runs on electric wireline with a total of 81ft of solid propellant conveyed. Prior to running the propellant, the well was loaded with a full column of diesel with surfactant additives to provide the proper tamping fluid for propellant burn characteristics and treatment of potential emulsions. The propellant treatment resulted in an increase in the pre-job injection rate of 7 MMcfd to a post-propellant gas injection rate of 55 MMcfd (see **Fig. 8**). An injection fall-off test was conducted following the propellant treatment as shown in **Figs. 9** and **10**. A unique fit was not possible with the falloff data due to the fact that the test duration was not long enough; and the early-time data is masked due to changing wellbore storage. However, from a qualitative standpoint, it appears that the late-time data of the falloff exhibits a half-slope typical of fracture flow, which would validate the near wellbore stimulation associated with the propellant treatment.

Well FUL-67IG

This well was drilled in August of 1997 to a total depth of 15,070 ft MD and completed as a 7-in. mono-bore with 5-1/2-in. tubing in the Naricual Inferior, Medio and Superior formations (see **Fig. 11**). The Naricual Inferior formation was perforated from 14,354 to 15,000 ft (see **Fig. 12** for openhole log response) and placed on production. After six months of production, the asset team made the decision to convert this well to gas injection to increase ultimate recovery of producers in the Naricual Medio and Superior formations. The Naricual Inferior was abandoned using a cast iron bridge plug located at 14,250 ft, and then, the Naricual Medio and Superior formations were perforated selectively in the intervals from 13,428 ft to 13,748 ft and 13,824 to 14,190 ft.

In August of 2000, a PLT survey was performed to determine which perforations were currently accepting gas and adversely affecting gas-oil ratios at the offset producers. The PLT survey indicated that the interval from 13,734 to 13,748 ft was receiving 91% of the injected rate of 40 MMscfd. To correct the early gas breakthrough at a nearby producer, a decision was made to isolate this zone by placing a sand plug in the wellbore at a depth of 13,715 ft. Following the placement of the sand plug, the gas injection decreased from 90 MMscfd to 10 MMscfd (see **Fig. 13)**. This occurrence initiated the use of the propellant stimulation technique to increase injectivity on seven perforated intervals between 13,430 and 13,631 ft (see **Table 4** for treatment intervals and propellant lengths).

A simulation was performed to determine the peak pressures that would be generated and to predict fracture lengths with various size propellant tools (see **Fig. 14)**. Using 2.0-in.-OD solid-propellant tools, it was determined that a peak pressure of 16,500 psi and a fracture length of 3.8 ft were possible which would be more than sufficient to break down the existing perforations to increase gas injectivity. The propellant treatment was successfully performed using electric wireline on Dec. of 2000, and seven successful runs with 10 ft of propellant per run were completed. Prior to running the propellant, the well was loaded with a full column of diesel with surfactant additives to provide the proper tamping fluid for propellant burn characteristics and treatment of potential asphaltenes. Review of **Fig. 13** indicates that the gas injection increased from 10 MMscfd to a stabilized injection rate of 65 MMscfd following the propellant treatment.

Discussion

It has been demonstrated with these case histories that the propellant stimulation technique is an effective-alternative to conventional stimulation methods. The benefits to this technique are that it does not require any special equipment or training; the operation can be conducted with standard electric wireline equipment, it is cost efficient, and it allows adherence to normal perforating safety procedures. The propellant tools can be positioned across from the selected intervals to be treated without requiring any special forms of isolation (packers, diverters, ball sealers, etc.) as would be required with conventional techniques. Conventional wireline perforating, in some cases, has been shown to be effective in restoring injectivity; however, not having the capability to re-perforate in an under-balanced situation severely limits the injectivity index. The propellant stimulation technique allows balanced perforating followed with the propellant treatment (extreme over-balance) to break down the perforation tunnels and create mild fracturing near wellbore to restore connectivity to the reservoir.

Unlike an ordinary perforating operation, the use of the propellant stimulation technique does require special planning. When working with propellants, very high-pressure loadings can be generated that can potentially compromise wellbore integrity in the form of casing, packers, bridge plugs, and potential tool loss as a result of wireline parting. Thus, special precautions need to be followed, and computer modeling should be performed for each instance of its use to optimize the propellant volumes in each treatment. When possible, special high-speed recorders that measure pressure, temperature, and acceleration should be used on these types of jobs to validate and optimize future propellant treatments. High-speed recorders were not available for this work because there is a temperature limit on the instruments of 250°F. The case histories that were presented did indicate that perforation break down was achieved and resulted in injectivity increases of 6 to 8 fold. PLT logs confirmed the propellant stimulation is effective in controlling the injection profile in some cases, and fall-off pressure transient analysis confirmed linear or fracture flow (negative skin) on the derivative log-log diagnostic plot.

Conclusions

1. The propellant high-energy gas fracturing technique is an excellent stimulation technique to improve the communication between the reservoir and well, providing improvement in the injection profiles in wells with where injection volumes have decreased.
2. It is very important that pre- and post-job evaluations using PLT logs be made to determine treatment efficiency.
3. It is important that tamping fluids be carefully selected to minimize further formation damage due to fluid incompatibility, as these fluids are rapidly injected into the formation during the propellant event.
4. Whenever possible, it is recommended that high-speed pressure recorders be used on propellant stimulation treatments to fully characterize the propellant-burn parameters in the formation or area under study.

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