Liquid-Free CO₂ Sand Fracturing in Low-Permeability Reservoirs

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Liquid-Free CO₂ SAND FRACTURING IN LOW PERMEABILITY RESERVOIRS

CONTRACT INFORMATION

Contract Number
DE-AC21-90MC26025
Production Verification Tests

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Period of Performance
May 5, 1990 to November 10, 1995

Schedule and Milestones

FY95/96 Program Schedule

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OBJECTIVES

* To demonstrate the effectiveness of a non-damaging liquid, carbon dioxide (CO₂) in creating sand-propped hydraulic fractures in "tight" gas bearing formations within the Appalachian Basin.

* To compare and rank the gas production responses from wells treated with liquid CO₂ with other types of treatments (shooting, water based, nitrogen, etc.).

BACKGROUND INFORMATION

From a historical perspective, discussion in the public literature concerning the application of sand fracturing with CO₂ first appeared in 1982. It was reported that over 40 liquid CO₂/sand treatments had been performed by American FracMaster in the U.S. by 1982. Early results were encouraging, but frac equipment was moved out of the U.S. shortly thereafter eliminating the opportunity for operators to continue to test the fracturing process in the U.S. Of those 40 treatments, 60 percent were successful in gas wells, 25 percent were successful in oil wells, and 15 percent were considered noncommercial. Concurrently, during the early 1980's, more than 40 frac treatments were performed in Canada using gelled liquid CO₂/sand fracs. Early test results indicated a 50 percent increase in production response. Laboratory research proceeded in 1983 toward evaluation of different proppant mesh sizes using a proprietary gelling agent that added viscosity to the liquid CO₂. Subsequently, the continued use of viscous chemicals was suspended in future jobs executed in Canada. Research continued on understanding the mechanics of the CO₂ fracturing process and development of a suitable way to improve the rheology of liquid CO₂. Hydrocarbon based gelling agents were tested that would yield over a 2 centipoise viscosity.

During 1985, numerical simulation models were developed for proppant transport that included flow turbulency and its effect on proppant settlement and pressures in the fracture. These numerical simulation models for CO₂/sand fracturing are quite different from conventional stimulation models.

During 1987, additional efforts were focused on a method to create viscosity in the presence of liquid CO₂, which resulted in the testing of a blend of high molecular weight fatty alcohol, a sorbitan fatty acid ester and diesel oil representing 2 percent by volume. This component was then combined with liquid CO₂ to create a viscous emulsion. A selective number of stimulations were performed in Canada using this emulsion system with mixed results. Shortly thereafter, the use of viscous agents was abandoned in favor of injecting proppant into 10 percent liquid CO₂. The obvious benefit was the elimination of residue and formation compatibility associated with the hydrocarbon-based viscous agents. By late 1987, it was reported that more than 450 100-percent liquid CO₂/sand fracs had been performed primarily in Canada. Over 95 percent of the wells were gas wells at depths less than 8200 feet with the largest sand volumes used at approximately 44 tons. Typical sand volumes pumped ranged from approximately 10 to 22 tons.

INTRODUCTION

Review of the literature indicated that the technology was available to the U.S. operators for a short period of time in the early 1980's but has since remained outside the U.S. and not available
as a commercial service inside the U.S. In an effort to re-introduce this technology to U.S. operators and test the effectiveness of this stimulation technique in various geologic settings, a contract was developed with Petroleum Consulting Services to stimulate and test up to 27 wells using the CO₂/sand fracturing methods in the Appalachian Basin.

WELL SELECTION CRITERIA

A candidate well selection methodology was developed to improve the confidence in comparing technology results in various geologic settings. As a minimum requirement, emphasis was placed on providing an established background of production data from control wells to which the production responses from the candidate wells would be compared and an assessment made.

The candidate well selection criteria includes--

1. That the wells are located in accepted areas of legitimate, cost-effective, gas production.

2. That sufficient nearby background production information is available to enable the results of the procedure to be evaluated.

3. That any sand be removed from the wellbore immediately following the stimulation.

4. That the wells be turned in line no later than 30 days after treatment, and that the merits of using this technology be measured from production responses into the pipeline rather than interrupting operator plans for production by conducting an elaborate welltesting effort and forecasting indirect indicators of response.

PROCEDURE - FIELD EQUIPMENT

Sand proppant is combined with liquid CO₂ in a pressurized blender to generate a sand/liquid CO₂ slurry. The blender is operated at a pressure of approximately 300 psi, and, as presently configured, can store up to 47,000 pounds of sand. It can develop CO₂/sand slurries with densities of up to 5 pounds per gallon at outputs of 55 barrels per minute.

The slurry is discharged directly into the suction side of conventional pump trucks which increase the sand-laden CO₂ slurry to wellhead treating pressures and inject it into the wells.

The liquid CO₂ is stored in two (2) 60-ton portable storage trailers which discharge directly into the blender. They are filled via 20-ton transport trailers prior to these treatments.

During the treatment, the CO₂ is displaced from the CO₂ storage vessels and into the blender with gaseous nitrogen, which allows a constant pressure to be maintained.

The sand concentration is monitored with a densimeter throughout the treatment and is adjusted to create the desired sand schedule.

Following the treatment, the well is flowed back on a choke. Care is exercised to allow the formation stresses to close on the sand pack and for the CO₂ to change to a gaseous phase. Flowbacks generally require two (2) to three (3) days immediately following the treatment.
JOB EXECUTION

To date, thirteen (13) wells have been stimulated, four (4) have been treated with CO₂\text{sand} in two (2) stages. Eleven (11) wells are situated in eastern Kentucky and the other three (3) in western New York.

The three (3) Chautauqua County, New York wells were treated in the Silurian Age Whirlpool Sandstone, and turned in line in July, 1994. The operator has not furnished production data. The remaining wells were treated in the Devonian Shale. Six (6) wells were treated as single stage treatments and the remaining four (4) were treated with two (2) stage stimulations, as is the local practice.

The project, as originally proposed, included only single stage treatments but has been altered to accommodate local practices. These four (4) two (2) stage wells were compared with nearby wells which were hydraulically fractured with two (2) stages of either nitrogen gas and no proppant, or with nitrogen foam with proppant.

Fourteen (14) additional stimulations are planned in the Appalachian Basin over the next year. The treatment program has been temporarily delayed because the closed system blender necessary for these treatments has been unavailable for the past thirteen (13) months. Plans are underway to have a unit manufactured exclusively for U.S. operations and delivery is anticipated in July, 1995.

The concept of transporting sand in a closed pressure vessel has been under development outside the U.S. since 1981. Although the concept of hydraulic fracturing underground gas formations is not new, the equipment requirements have changed drastically over the years. The CO₂\text{sand} fracturing process differs substantially from conventional treatments in that job execution requires a pressurized blender that can combine liquid CO₂ with proppants under pressure.

DISCUSSION

Stimulation Treatments

There were three (3) types of stimulation treatments involved in a fifteen (15) well 2-stage Devonian Shale study group. Four (4) wells were stimulated with CO₂\text{sand}, seven (7) with nitrogen, and four (4) with nitrogen foam.

All fifteen (15) wells were stimulated with two (2) stages across the entire Devonian Shale interval to provide a common basis for comparison. The CO₂\text{sand} candidate well locations were selected to be close to wells with other types of stimulation to provide a comparison of production responses between CO₂\text{sand} treatments with those from other stimulation types.

The CO₂\text{sand} stimulations in all four (4) involved 120 tons of CO₂ per stage and up to 47,500 pounds of sand.

One (1) of the four (4) wells, FH179, differed significantly from the other fourteen (14) wells in the study area group because of the apparent high stress state which resulted in high breakdown and treating pressures, limited ability to increase sand concentration, and later associated liquid production. The first stage treatment was aborted, and the interval was reperforated with fresh acid which was subsequently swabbed and replaced with another volume of fresh acid prior to reinitiating the first stage treatment. The second attempt at treating the first stage
also experienced high treating pressures, which limited the rate and sand volume. These behaviors were non-typical and considered to be the result of an anomalous geologic environment. The second stage responded similarly and a reduced sand volume was placed.

Sand volumes ranged from 35,000-47,500 pounds for the other six (6) treatment stages (three (3) wells) - averaging 43,300 pounds per stage. Maximum pump rates ranged from 44.6 to 53.5 barrels per minute, averaging 50.7. The pad volumes were all 100 barrels (19.2T) and the average sand concentrations ranged from 2.1 to 2.8 pounds per gallon, the maximum sand concentrations ranged from 4.0 to 5.2 pounds per gallon, averaging 4.7.

Nitrogen Gas

The nitrogen treatments were all executed at 100 Mscf per minute with a total of 1.0 MMcf per stage. There was no proppant conveyed.

Nitrogen Foam

The nitrogen foam treatments ranged from 75 to 90 quality and from 50,000 to 120,000 pounds of sand were placed.

Production Comparison

The four (4) 2-stage CO₂ sand stimulated wells have been on production for sixteen (16) months. Cumulative production are compared on an individual group basis as well as a composite basis.

Production results from these fifteen (15) wells are compared and after sixteen (16) months of production, CO₂ sand fractured wells in the Pike County, Kentucky study area are nearly twice as productive as nitrogen gas fraced wells and greater than five (5) times better than the foam fraced wells in the study group. The per well incremental gas production after sixteen (16) months ranged from 21.9-33.1 MMcf for nitrogen gas and foam fraced wells, respectively.

Conclusions

1. After 16 months of production, CO₂ sand fractured wells in the Pike County, Kentucky, study area produce 2.0 times more gas than nitrogen gas treated wells and produce 21.9 MMcf additional gas per well.

2. After 16 months of production, CO₂ sand fractured wells in the Pike County, Kentucky, study area produce 4.4 times more gas than nitrogen foam treated wells and produce 33.1 MMcf additional gas per well.

3. For the Pike County, Kentucky, study area, payout times for the incremental cost of stimulation is estimated conservatively at less than 9 months.

4. Both groups of wells in the Pike County, Kentucky, study area show consistent relative production improvements compared to the overall study area results.