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**THE FEASIBILITY OF NO-PROPPANT STIMULATION TO ENHANCE REMOVAL
OF METHANE FROM THE MARY LEE COALBED**

By
Stephen W. Lambert
Michael A. Trevits

MASTER

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Carbondale Mining Technology Center
Carbondale, Illinois

U. S. DEPARTMENT OF ENERGY

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TO ENHANCE REMOVAL OF METHANE
FROM THE MARY LEE COALBED

REPORT OF INVESTIGATION

BY

STEPHEN W. LAMBERT

AND

MICHAEL A. TREVITS

CARBONDALE MINING TECHNOLOGY CENTER

CARBONDALE, ILLINOIS

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to Enhance Removal of Methane
From the Mary Lee Coalbed

by

Stephen W. Lambert¹

and

Michael A. Trevits²

ABSTRACT

One experimental approach to hydraulic stimulation is to use fluid to propagate fractures but not to incorporate solid proppant material in the design. The elimination of solid material negates problems related to wellbore sand proppant influx and allows better fracture height control since extremely low injection rates can be used.

The Mary Lee Coalbed was stimulated using a 53,000 gallon no-proppant treatment at a 1,150 foot deep test well located approximately 1,600 feet in advance of mining. The well produced for 147 days and gas flow rates declined sharply, ceasing when intercepted by mining. Underground examination showed injected fluids penetrated the coalbed and roof rock horizontally through distinct bedding planes, and vertically through natural fractures.

Production comparison of the no-proppant test with another test incorporating sand proppant indicates that the 53,000 gallon no-proppant treatment was less effective than the more conventional 21,000 gallon treatment. Gradual closing of the hydraulically induced fractures is one possible explanation for the sharp production decline observed at the no-proppant test well. Another explanation involves the mine's continued underground advance to the wellbore during production.

The results from the no-proppant test indicate that very few roof rock fluid penetrations occurred during the course of hydraulic stimulation. It cannot be determined, however, if sparsity of roof penetration was due to the use of very low injection rates or because roof rock in the physical test area was less jointed and, therefore, less prone to stimulation fluid invasions.

Because gas flow results gathered are inconclusive, the application of no-proppant stimulation designs for other than research is not recommended at this time. The lower injection rate approach to fracture height control is, however, theoretically sound and because limiting upward fracture growth in coalbeds may be desirable to future borehole gas drainage activities, no-proppant experiments could be justified on a limited scale.

1/ Geologist, Carbondale Mining Technology Center, Carbondale, Illinois
2/ Geologist, U.S. Bureau of Mines, Bruceton, Pennsylvania

INTRODUCTION

Hydraulic stimulation is a standard well completion technique used to increase gas flow from coalbeds when natural flow is unsatisfactory. Based on methods developed by the oil and gas industry, Government research began designing stimulation treatments for coalbeds about 1969. Since then, approximately 70 treatments have been applied in several areas of the United States.

The mechanics of stimulation involve generation of hydraulic pressure at the wells surface location by pumping fluid down the borehole. The hydraulic force is applied to a selected rock unit (coalbed) to cause a fracture or a widening of an existing fracture within that unit. Continued injection of fluid extends this fracture into the coal strata out away from the wellbore. At some pre-established time during the treatment, sized particles, such as sieved sand, are usually added to the fluid. These particles are included so as to prop or hold open the fracture after the hydraulic pressure is released. The basic intent of stimulation is to create highly conductive pathways from the wellbore to a point up to several hundred feet within the coal strata. The area of wellbore drainage is thus expanded and gas and water flow rates increase accordingly.

The solid material; i.e., sand, incorporated into several recent stimulation treatments in the Mary Lee Coalbed, have been identified as the cause of severe operational difficulties. Recent field work shows that some of the sand used during stimulation is carried back to the wellbore. Downhole water pumps exposed to this material area are almost always damaged, resulting in mechanical failures or losses in pumping efficiency. Such chronic sand-related dewatering problems result in significant pump repair costs and decreased gas production.

One experimental approach to hydraulic stimulation is to use fluid to propagate fractures, but not to incorporate a solid proppant material in the design. The elimination of solid material not only negates the problem of wellbore sand influx, but might also minimize the possibility of extending fractures upward into future mine roof rock. Since there is no proppant to be carried, extremely low injection rates could be achieved and, theoretically, allow for better control of induced fracture height. Given that the probability of maintaining fracture propagation within a coalbed is increased when low injection rates are used, no-proppant type stimulation offers an excellent opportunity to minimize potential damage to mine roof strata.

The no-proppant stimulation technique is not commonly used because the consensus has been that the fractures will close after the induced hydraulic pressure is released. Even though the continued influx of sand into several wells completed in the Mary Lee Coalbed may suggest that compressional forces acting to close induced fractures are small, it is important to note that there is yet no definitive information to indicate that natural forces presently "pushing rock together" are eliminated as a result of hydraulic stimulation. The common notion that induced fractures tend to close appears to be quite reasonable at the present time.

PREVIOUS WORK

The oil and gas industry has conducted numerous field tests which show the production decline rate from wells stimulated using no-proppant is much higher than from wells stimulated using propping agents. Only two coalbed gas drainage wells have been treated using no-proppant stimulation, produced and mined through. The first coalbed treatment was conducted on February 7, 1959, in the Pittsburgh Seam at a depth of 645 feet (2)^{3/} Approximately 10,000 gallons of fresh water containing a fluorescein dye tracer were injected through a 6-5/8 inch diameter cased hole at rates ranging from three to five bpm at a maximum pressure of 600 psig.

There is little information available about this well's production history but records indicate that prior to stimulation, the well produced at a rate of 60,700 cfd during very short intervals after water had been bailed from the hole. Post-stimulation measurements indicated the well produced 150,000 cfd in the first 10 days but then declined sharply to an average rate of 32,000 cfd during the next 30 days of well operation. Unfortunately, it cannot be determined whether this sharp production decline was due to partial healing of the induced fracture(s) or due to the mine's progressive advance to the wellbore. Thus, the potential gas drainage benefit or non-benefit of this no-proppant water treatment test was masked by "overloading" the experiment with too many variables.

No induced fractures were observed until the coal had been removed from the crosscut in which the hole was located. The following is Spindler and Poundstone's description of what was observed (3):

"The fracture in the top coal (Pittsburgh Rider Seam) began at the hole and followed the face cleavage for a distance of about 12 feet when it became indistinct. There was, however, general evidence of roof damage and it was necessary to timber heavily in the vicinity of the borehole. The green tint of fluorescein dye was not detected until the faces were within 120 feet of the borehole, and became increasingly obvious as the hole was approached.

It also was observed that the hole casing had not been cemented by the grouting from the surface to its total depth with the effect that the fracture fluid had not been confined definitely to the coal horizon, but had been given access to the overlying strata. Some of the roof damage may have been due to this circumstance, which probably can be remedied by pressure grouting from the bottom in accordance with standard oil and gas well practice."

3/ (2) Underlined numbers in parentheses refer to items in list of references at the end of this report.

The fact that casing had not been tightly cemented might have caused the fracture to propagate into the roof. Since this cannot be determined from this particular test, neither can the potential benefits of using very low injection rates be determined.

If nothing else, this early no-proppant coalbed stimulation test demonstrated the value of making every effort to minimize the number of variables that may eventually cloud the ultimate usefulness of the test results.

MARY LEE COALBED TEST

The second no-proppant coalbed stimulation test was conducted almost 20 years later on December 16, 1978, at U.S. Steel's Oak Grove Mine, Alabama. The coalbed treated was the lower bench of the Mary Lee. The hydraulic fluid used to propagate fractures was a nitrogen-charged water/surfactant mixture that is commonly called "foam".

Well Completion

An eight-inch diameter borehole was drilled from the surface down to the 1,150 foot deep coalbed approximately 1,600 feet ahead of a projected six-entry section. This hole was the fifth in a series of test wells completed near the mine and is thus referred to as Test Well No. 5 (TW5). The borehole was cased with seven-inch diameter steel pipe set 43 feet above the lower 5.5 foot thick coal bench. The 2.5 foot thick upper bench of coal, located six feet above the lower bench, was "shielded" from stimulation using a string of small diameter high pressure tubing and a 10 foot long inflatable packer (Figure 1). The bottom of the tubing string was placed near the center of the lower bench while the bottom of the packer element was set at the top of this lower coal unit.

The coalbed was treated with 53,000 gallons of 75 percent quality foam (25 percent water, 75 percent nitrogen) at an average injection rate of 4.7 bpm. Breakdown pressure was recorded to be 1,000 psig at the surface and average treating pressure was about 1,800 psig. Fluorescein dye and fluorescent paint were added to the treatment fluid to aid recognition of the propagated fracture(s) when underground inception occurred. Specific details of TW5 completion are included in the Appendix.

Production

After clean-up, TW5 was equipped with a sucker-rod dewatering pump and a surface production monitoring system. Water pumping operations began on February 13, 1979, and continued until June 27 when the pump was removed from the well. Gas continued to flow from the test well until July 11, 1979. Production from TW5 is presented on Figure 2. A number of mechanical adjustments were made at the test site which had significant influence on the well's production characteristics. These adjustments are indicated on Figure 2.

Figure 1

Detail of **TW5** well showing open hole interval and areas protected during stimulation treatment.

FIGURE 2 - DAILY PRODUCTION FROM TW5, MARY LEE COALBED, JEFFERSON COUNTY, ALABAMA.

Underground Examination

Mining operations intercepted the TW5 wellbore on July 13 and physical results of the stimulation procedures were examined underground periodically until mining had progressed 350 feet beyond the test site. Fluorescent material included in the stimulation treatment at TW5 was identified using an ultraviolet lamp and the locations where this material was found were recorded. The results of this work show that injected fluids penetrated the coalbed and/or roof rock horizontally through distinct bedding planes, and vertically through natural fractures. A plan view of the horizontal component of penetration shows the form of an ellipse; the long axis extending approximately 360 feet and roughly coincident with the coalbed's primary natural fracture (face cleat) direction; the short axis extending approximately 180 feet and roughly coincident with the coalbed's secondary natural fracture (butt cleat) direction (Figure 3). The vertically-oriented component of fluid penetration, as shown on Figure 3, extended outside the ellipse for distances up to 130 feet.

Fluorescent stimulation material was generally limited to the coalbed (especially upper three feet) and the first foot of overlying shale/coal rock. Exceptions to this were: one vertically oriented fracture extending upward (5.5 feet) to the upper coal bench and outward 8 to 10 feet from the wellbore; and one vertically oriented fracture in shale roof located near the southwest extremity of fluid penetration.

"Openings" that were observed to contain fluorescent material were all less than 1/16 inch wide. The majority of vertically-oriented penetrations were contained along coal cleat fracture faces extending N 61° E and N 29° W from the wellbore's location. The majority of horizontal penetrations were contained within overlying shale/coal/shale interfacial areas (Figure 4).

Evaluation of Production

It is difficult to assess production characteristics of TW5 because a number of mechanical adjustments were made at this test well site during its 147 day production life (see Figure 2).

Stabilized daily water flow rates from TW5 started at about 7 bpd and ended at 4 bpd. Past experience indicates that initially low rates and the gradual decrease in flow over time are typical water production characteristics for boreholes placed close to mining. The few occasions when water flows show sharp increase can be attributed to pump changes or slight alterations of the method used to measure water at the surface (Figure 2).

FIGURE-3

LOCATION OF TW5 WELLBORE AND THE AERIAL CONFIGURATION OF FLUORESCENT
MATERIAL CONTAINED IN THE STIMULATION TREATMENT FLUID

Scale: 1 inch to 100 feet

FIGURE 4 - SKETCH SHOWING POSITION AND ORIENTATION OF INDUCED FRACTURES FROM TW5 (HORIZONTAL PENETRATIONS)

It is important to note that gas flows produced from TW5 were much less than those measured from a previous test well (TW3), placed a similar distance from the same mine (2). Production from TW3 is presented on Figure 5. TW3 was stimulated using 21,000 gallons of foam and 25,000 pounds of sand proppant. Underground, the TW3 treatment was found to have induced fractures approximately 300 feet long and 1/4 inch wide. An induced fracture height of 40 feet is required if the entire 250 cubic feet of sand injected into TW3 is to be accounted for. Given the geometry of the TW3 fracture and the known presence of upper coal units, the largest coal area exposed to the TW3 wellbore was 6,000 square feet (this includes the five foot thick Mary Lee lower bench, the 2.5 foot thick upper bench, and the 2.5 foot thick New Castle coalbed, approximately 40 feet above the Mary Lee). The total amount of gas produced from this exposed coal during TW3's first 147 of production was approximately nine million cubic feet or 1,500 cubic feet of gas per square foot of coal exposed by stimulation. The total coalbed area containing stimulation fluid from TW5 was 7,800 square feet of vertical "fracture" and 57,000 square feet of horizontal "fracture" for a total of 64,800 square feet. The amount of gas produced at TW5 was 6.6 million cubic feet which equates to 102 cubic feet per square foot of coal "exposed" by the 53,000 gallon no-proppant treatment. Assuming the horizontal component provided no gas to TW5, then the 7,800 feet of vertical "fracture" would have yielded a total unit flow of 846 cubic feet gas per square foot of coal exposed, still only 56 percent of the unit gas flow drained by the 21,000 gallon sand-proppant treatment at TW3.

Production from TW5 was complicated by several outside factors. One of these complicating factors is that a back pressure of approximately 20 psig was left on the well until the end of April, 1979, and then afterwards reduced to atmospheric pressure (see Figure 2). This best explains the broad double-cycled appearance of TW5's gas flow curve. The most significant characteristic to note about both "cycles" is that gas flows declined each time, and at roughly the same rate. Although not necessarily, the gas flow declines observed at TW5 may have ultimately been caused by gradual closing of hydraulically induced fractures.

Another complicating factor which may have affected TW5's production performance is the mine's advanced toward this well. By the beginning of March, 1979, the mine was 1,100 feet away. From that time on, mining closed the gap between itself and the test well at a rate of about 280 feet per month. It may be theorized, therefore, that the approaching mine continually shortened the test well's drainage radius, causing a decline in production at TW5.

FIGURE 5 - PRODUCTION CURVES FOR TW3

There were two coal units left uncased to receive flow into TW5 - the upper and lower benches of the Mary Lee. Since it is not known how much gas can be produced from these coal units when the two are left unstimulated, there is no way to realistically measure the effects of the no-proppant stimulation performed at TW5.

Evaluation of Test on Coal Strata

Induced vertical and horizontal fluid penetrations from TW5 were generally so thin that they could not have been located without using an ultraviolet light to identify fluorescent blue "marker" paint that had been included in the stimulation fluid.

U.S. Steel mine personnel inspected the area of the mine containing the stimulated borehole and presented their findings in a Special Technical Progress report on December 4, 1979 (4). The following statements are excerpts from this report:

"After observing the roof conditions in the vicinity of the borehole, mine personnel have expressed their satisfaction that the unique stimulation technique (no-proppant treatment at TW5) employed has not, and probably would not, present any complications to coal extraction."

"To date, mining operations in the First West-Main South section (containing TW5) have progressed unimpeded by any condition that might be attributed to the stimulation treatment used at No. 1. West (TW5). Mine personnel have carefully inspected the roof condition in the vicinity of the borehole and cannot, at present, detect any disturbance that may significantly affect future activities in this area."

The vertical fracture contained in roof rock and extending from 8 to 10 feet from TW5's wellbore appeared not to present any obvious mine roof control problems. Although there was no visible damage or excess water or gas drainage from this fracture, precautionary supplemental roof support (steel H-beams) was installed for short distances away from this underground test site. The vertical fracture observed to contain marker paint near the southwest extremity of TW5 fluid penetration (Figure 3) was so thin that it nearly went unnoticed during underground examination. No supplemental roof support was installed. Similar to the roof fractures near the wellbore, it too did not appear to alter roof stability in the area.

Stimulation fluid that spread horizontally away from TW5 (Figure 4) was found to have typically done so through interfacial areas between the coalbed and overlying shale units. These surfaces were observed to mark the locations of highly polished and striated natural surfaces called slickensides which result from frictional movement between two rock layers. The presence of slickensides indicate that bonding between these rock layers was not present under natural rock conditions. The horizontal penetration of fluid, therefore, did not change the original character of this bond.

The results gathered indicate that the stimulation of TW5 caused no significant fracturing of mine roof or floor. It would be quite premature to assume, however, that the sparsity of induced roof fracture penetration in the vicinity of TW5 is primarily related to the no-proppant stimulation technique. This is because geologic rock conditions near the underground test site were generally much more stable than at other test sites where stimulation "damage" was more apparent to mine personnel (2).

CONCLUSIONS

1. The no-proppant stimulation technique is considered to be a very highly experimental method of increasing coalbed gas drainage rates to vertical boreholes.
2. Potential benefits of no-proppant treatments include elimination of sand flow-back problems and theoretically greater fracture height control by using very low fluid injection rates.
3. There is no evidence firmly indicating that rock closure forces are eliminated as a result of any type of hydraulic stimulation technique and the probability of sharply declining well flow rates due to fracture healing remains very high.
4. Prior to 1978, only one no-proppant treatment was complete; i.e., in the Pittsburgh Coalbed in 1959. No definitive conclusions pertinent to gas production or effects to mine roof can be formulated as a result of this early test.
5. The TW5 test of production was complicated in that:
 - a. A number of mechanical adjustments were made at the test site which had a significant influence on the well's production characteristics.
 - b. The mine approached TW5 during its productive life, lessening the coalbed reservoir area drained by the test well.
 - c. Two coal units were exposed and it is not known how much gas is produced from these coal units when the two are left unstimulated.
6. A comparison of TW5 production versus an earlier test using sand proppant indicates TW5's 53,000 gallon treatment drained considerably less gas than drained by a conventional 21,000 gallon fracture treatment using sand proppant.
7. The gradual closing of the hydraulically induced fractures propagated from TW5 during stimulation is one possible explanation for sharp decline in gas production measured at the well. Another explanation of this production decline involves the mine's underground advance to the wellbore.

8. The TW5 test results indicate that very few roof rock penetrations occurred during the course of hydraulic stimulation. It cannot be determined whether this sparsity of fluid in roof penetrations is due to the use of very low injection rates or because TW5's physical underground test area contained very few natural roof joint and was, therefore, "less prone" to treatment fluid penetration.

RECOMMENDATIONS FOR FUTURE RESEARCH

Since no-proppant stimulation allows the use of very low injection rates, this method serves to maximize surface operational control over induced fracture height. Because limiting upward fracture growth in coalbeds is important to borehole gas drainage activities, future experiments may be justified.

The potential benefit of no-proppant stimulation in terms of eliminating sand proppant influx is also significant; yet, the actual realization of these benefits is doubtful, at best. This is because the process appears to be inconsistent with presently accepted rock closure stress theory. In other words, borehole gas flows may be severely limited because induced fractures may close.

The two past experiments offer little information regarding viability of the no-proppant technique since major objectives or essential controlled conditions were not emphasized as part of these tests. A general suggestion for future research is to design no-proppant tests to specifically measure long-term production or physical effects on mining but not both simultaneously. Long-term production tests are required in locations several thousand feet away from existing mine sites or other large openings which may alter native rock stress conditions during the course of testing. No-proppant experiments, specifically designed to determine this technique's physical effects on mining should be run in areas which are geologically representative of the coalbed being mined. When comparing this technique to more conventional stimulation treatments, it is particularly important to conduct comparative studies in closely similar geologic settings.

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Appendix

History of Test Well No. 5 in the Mary Lee Coalbed Near Oak Grove, Jefferson County, Alabama

Drilling

<u>Drilling Depth,</u> <u>ft</u>	<u>Bit Type</u>	<u>Bit Diameter,</u> <u>in.</u>	<u>Circulation</u> <u>Medium</u>
0 to 38.3	Tri cone	12	Air
38.3 to 1103.3	Air Percussion	8	Air Mist (Foam Flush)
1096 to 1158.9	Roller	5-7/8	Air

Casing

<u>Casing, ft.</u>	<u>Casing Type</u>	<u>Weight, lb/ft</u>	<u>Diameter, in.</u>
0 to 38	Surface Pipe	28	8-5/8
0 to 1102	J-55	15	6-5/8

NOTE: The open hole interval is from 1102.0 to 1158.9 foot deep. The upper bench of the Mary Lee coalbed is from 1137.2 to 1139.6 feet and the lower bench is from 1145.4 to 1150.9 feet deep. TW5 is in Section 34, T185, R5W. Drilling was started November 14, 1978, and it was completed November 27, 1978, to a total depth of 1158.9 feet. The total depth of the casing is 1102 feet.

Cement

Date	November 22, 1978
Zone Cemented	0 to 1101.0 feet
Number of Sacks	108
American Petroleum Institute Class	H
Yield	1.22 ft ³ per sack
Mixed Weight	15.9 lb/gal
Additives	836 lb salt
	20 lb defoamer
	1% calcium chloride
Circulating Pressure	0 lb/in ² gage
Displacement Pressure	200 lb/in. ² gage
Maximum Pressure	1000 lb/in. ² gage
Treating Rate	2 bbl/min
Displacement Rate	2 bbl/min

NOTE: Prior to cementing, the well was cleaned with a 200 bbl chemical wash.

Appendix (Continued)

Geophysical Logging

Date	December 1, 1978
Type of Log	Gamma-ray, density, caliper
Interval Logged	1093 to 1058 feet

Date	December 10, 1978
Type of Log	Gamma-density
Interval Logged	1133 to 1152 feet
	1126 to 1153 feet

Slotting the Coalbed

Date	December 9, 1978
Type of Tool Used, Number of Ports, Spacing	Jet slotting, two, 180° apart
Abrasive Medium	Water, 20- to 40-mesh sand
Interval Treated	1148.3 feet
Perforation Type	Horizontal slot

Isolating the Lower Bench

Date	December 10, 1978
Type of Seal Used Above Lower Bench	Resettable packer
Interval Sealed	1136.0 to 1146.3 feet
Type of Seal Below Lower Bench	20- to 40-mesh sized sand
Interval Sealed	1150.9 to 1158.9 feet

Stimulation - Initial Propagation

(treatment aborted due to leakage around packer)

Date	December 10, 1978
Treatment Fluid	Water, 1350 gallon
Maximum Pressure	1250 lb/in. ² gage
Treatment Rate, range	1/4- to 2-bbl/min

Isolating the Lower Bench

Date	December 16, 1978
Type of Seal Used Above Lower Bench	Resettable packer
Interval Sealed	1134.9 to 1145.2 feet
Interval Exposed to Stimulation Treatment	1145.2 to 1158.9 feet

Appendix (Continued)

Stimulation Treatment

Date	December 16, 1978
Treatment Fluid	Foam
Fluid Viscosity	22.7 cp (apparent viscosity at 75° F)
Treatment Volume	52,920
Maximum Pressure	2,000 psig surface
Treatment Rate, range	2 to 6 bpm
Average Treatment Rate	2 for 0.5 hr, 3 for 0.5 hr, 4 for 0.5 hr, 5 for 1.5 hr, 6 for 1.5 hr = average of 4.67 bpm
Nitrogen Volume	359,100 scf used

Dye Usage

First Treatment	December 10, 1978
Paint (red)	3 gallons/10 barrels (near end of treatment)
Fluorescein dye	1 pound/10 barrels (near end of treatment)
Second Treatment	December 16, 1978
Paint (blue)	1 gallon/20 barrels (throughout treatment)
Fluorescein dye	1 pound/20 barrels (throughout treatment)