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IMPROVED FRACTURING

THIRD QUARTERLY REPORT

OCTOBER 1979 THROUGH DECEMBER 1980

(BLACK #1 WELL EXPERIMENT RESULT)

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Prepared by Sandia Laboratories, Albuquerque,
NM 87185 and Livermore, CA 94550 for the
United States Department of Energy under
Contract DE-AC04-76DP00789

FEBRUARY 1980

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Unconventional Natural Gas Program
Eastern Devonian Shales Diagnostic Program
(Black #1 Well Experiment Result)

Third Quarterly Report
October 1979 through December 1979

ABSTRACT

During the last quarter of 1979, Sandia National Laboratories participated in an experiment with Thurlow Weed and Associates and the Morgantown Energy Technology Center. This Devonian Shale gas stimulation experiment was conducted in an area north of Columbus, Ohio. One purpose of the experiment was to apply the diagnostic instrumentation that is available for fracture mapping and characterization to increase our understanding of the stimulation technique. The induced fracture apparently followed a pre-existing fracture vertically from the borehole with an orientation of the N 62° E and in the latter stages of the stimulation turned into a shallower horizontal fracture. This fracture behavior was confirmed by several diagnostic analyses and demonstrates the insight that can be gained by fully instrumented stimulation experiments.

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APPENDIX A

I. EXECUTIVE SUMMARY

Early in 1979 Sandia National Laboratories (SNL) was given a contract through the Albuquerque Operations Office of the Department of Energy by the Gas Research Institute (GRI) to conduct diagnostic experiments in the Eastern Devonian Shales Gas Program as managed by the Morgantown Energy Technology Center (METC). During 1979 the planning for three experiments was completed and one of these experiments was conducted on the Black #1 Well located near Mount Vernon, Ohio. This quarterly report will completely document and describe the results of this experiment. As this quarterly report is an interim report, the progress and plans for the other two experiments will be covered in later reports. An attempt will be made in this quarterly to bring together all of the important historical events on this well and the diagnostic data that has been collected by the operators Thurlow Weed and Associates (TW), by METC, by SNL, and by M. D. Wood, Incorporated (MDW) on contract with SNL. The Black #1 Well was drilled in 1975 by TW and produced gas during 1976 and 1977. The initial production started at a level of 32 mcf per day and declined to 0 by the end of 1977. This well, in addition to several others, were offered to DOE as an experimental package for doing stimulation technology research by TW. The old production from this well was all natural flow as no stimulation treatment had been conducted. In late 1978 METC through their contractors conducted a logging program, a lineament analysis, and a seisviewer analysis on this well. In addition to this activity, METC also cored a well through the Devonian Shale section in an offset well in the immediate area. The stimulation experiment was conducted during October, 1979. Haliburton Services performed the stimulation by pumping 968,000 standard cubic feet of nitrogen into the formation without any proppant in approximately 28 minutes. Sandia installed their bore-hole seismic system for the stimulation, and MDW installed a surface array of tiltmeters to monitor the fracture dynamics. Both of these techniques indicated an initial vertical fracture with an orientation of N 62° E and the tiltmeters further indicating that approximately 18 minutes into the experiment the fracture

turned over and became horizontal. The high pressures involved in both pumping and after shut-in also indicate that the in situ stress were high and the fracture could have grown vertically until the minimum stress field turned over and caused a horizontal fracture. The tiltmeter data also suggest that the fracture growth in the horizontal plane continued after shut-in for approximately 6 minutes. Shut-in pressures at this time indicate a minimum in situ stress measurement of approximately 900 psi. Assuming a fracture depth of 1,082 ft, this would indicate a fracturing gradient of 0.83 psi per ft. Another indication of the horizontal nature of the fracture was the nitrogen that was produced from the Wade #1 and #2 well locations. These wells were located 1,300 ft east and 600 ft south from the Black #1 Well. Sufficient nitrogen was received to cause these wells to be disconnected from production and blown down for several days. The nitrogen content in these wells did go down to the normal percentage in a short time while the Black #1 Well continued to have large amounts of nitrogen present. Also, long term high shut-in pressures of the Black #1 Well would indicate that the nitrogen was contained in a "closed" fractured reservoir and that the Black #1 Well, after the initial contact to the Wade Wells, had little or no conductivity to those wells. After a few weeks of blow-down the Wade Well was turned into the production line and is presently producing gas at a rate of 8,000 cubic ft per day. It is not known whether or not this production can be sustained in the future.

II. INTRODUCTION

METC through contracts with industry and independent operators has a program to stimulate shale gas production in the Eastern United States. Their Devonian Shale Program contains stimulation experiments to be conducted in wide areas jointly funded by government and private industry. SNL, through their contract with GRI, established a coordinated diagnostic program for measuring fracture characteristics. This quarterly report will contain a summary of the data collected and the data analysis of one of these experiments. METC has in their data bank all of the reports and logs generated for this experiment as

well as the entire Eastern Devonian Shales Gas Program.

III. BLACK #1 WELL DATA BANK

Listed in Appendix A are all of the reports and logs that were available relative to the Black #1 Well and the stimulation experiment. All of these reports have been used as reference material in compiling this diagnostic report. The results and conclusions presented here may not represent a consensus of all the interested parties, however, they are presented for your consideration. The contents of this data bank is summarized below with the conclusions drawn from the set of data.

A. History

The Black #1 Well was drilled in 1975 with a cable tool rig and had an initial open-flow production of 50 mcf per day. This well was not stimulated and was turned on to the production line in January, 1976. Production records indicate an initial flow of 32 mcf per day declining over the next two years to essentially 0. It has been speculated that this production was just from natural fractures and essentially none from the matrix. This well was drilled to a total depth of 1,175 ft with surface casing set to 568 ft with the entire Devonian Shale section left as open-hole. Shut-in periods during and following this production history indicated a shut-in rock pressure of 325 psi. For a typical gas pressure gradient in this area 0.46 to 0.48 this would indicate a gas-producing interval from 677 to 706 ft. This well and two additional wells that were drilled in the area and untreated were offered to METC as a part of a 4-well program by TW for stimulation experiments in the Devonian Shale. The fourth well was to be a new well drilled and cored through the shale section in the surrounding area. The locations of these and other wells in the area are shown in Figure 1.

2. Logging Program

In October and November, 1979 a complete set of logs was run by Birdwell in the Black #1 Well. The list of these logs is shown in Appendix A. These

○ YAUGER #1

SCALE: 1" = 1,000'

NORTH

BLACK # 1

N 62° W

○ WADE #1

○ WADE #2

PEAIRS #1

BECKHOLT #1

FIGURE #1. WELL PLAT FOR KNOX COUNTY, OHIO
DEVONIAN SHALE EXPERIMENT SITE

logs indicated a black shale within the Heron member located from 1,000 to 1,130 ft would be considered for stimulation. The stimulation log that was run indicated kicks at 625 ft, 1,008 ft, and at 1,076 ft. It was interesting to note that these stimulation kicks were received after the well had been shut-in for almost a year and was opened with some relatively small natural flows. The shut-in pressure of 325 psi suggests that the upper zone was probably producing and/or receiving gas from the lower zones during the two years of production.

C. Coring Program

An offset well (Beckholt #1) was cored through the Devonian Shale interval for analysis and fracture definition. This well analysis had not been completed at this time, however, preliminary data is available. This data indicates natural fractures average orientation is N 60° E from 680 to 1,013 ft in depth. This fracture orientation agreed quite well with the seismic and tiltmeter data as will be described later.

A complete analysis of other cores will be available at a later date from METC.

D. Lineament Analysis

Shafer Exploration Company prepared a lineament analysis of the area for TW under contract to METC. This analysis was conducted with LANDSAT images obtained from EROS Data Center and other regional maps. The lineament analysis has been conducted in several areas of the Eastern United States in an attempt to correlate these lineament zones with natural gas productions. A complete description of this rationale will not be included in this report and the author refers you to METC for any publications that exist in this area. Figure 2 is the result of the regional lineament analysis and shows the number of lineaments per each 10 degrees. The measured fracture orientation of N 62° E is superimposed on this analysis for your information. Figure 3 shows the lineaments in the specific area of the Black #1 Well. Also, superimposed on this is the fracture orientation. Although the lineament analysis may be of

FIGURE #2. REGIONAL LINEAMENT ANALYSIS WITH INDUCED
FRACTURE OVERLAYED

FIGURE #3. LOCAL LINEAMENT ANALYSIS WITH INDUCED FRACTURE OVERLAYED

value for determining hydrocarbon production capabilities, the regional analysis did not give a clear indication of the induced fracture orientation. The local analysis does contain a lineament at approximately the same orientation and offset from the Black Well by 3/4 mile. No conclusion has been drawn because of this one lineament among many that apparently has the same orientation as the induced fracture.

E. Seisviewer Imagery

Shafer Exploration Company also conducted a seisviewer experiment in the open hole section of Black #1 Well for TW under contract with METC. This tool survey was conducted from the bottom of the surface casing at 580 ft down to 700 ft. Technical difficulties precluded them from conducting the survey to total depth. One fracture was found that intercepted the wellbore from 640 to 649 ft. This fracture had an average orientation of N 73° E and assuming a vertical wellbore crossed the wellbore with a dip of 88-1/2° SE. This fracture depth probably corresponds to be sibilant activity at 628 ft and also relates to the shut-in rock pressures of 325 psi. It is also interesting to note that this natural fracture orientation is in fair agreement with the induced fracture orientation

F. Borehole Television System

Deep Venture Diving Service, Incorporated conducted a television survey of the fracture well immediately following the setting of casing in Black #1 Well. The TV pictures show direct evidence of gas bubbling from a fracture located from 1,082 to 1,085 ft and 1,089 to 1,090 ft. These fractures appeared to be nearly vertical. The camera, however, was not oriented and therefore the fracture orientations could not be determined. The shallower fractured zones were now behind pipe and could not be seen. A TV camera run was also made following the stimulation treatment and detected an additional fracture located from 1,126 to TD of the well. It could not be determined if this was a new fracture at the bottom of the well that had not been there prior to the

stimulation and just not visible to the TV or if it was in fact a new fracture induced in the stimulation treatment.

G. Nitrogen Analysis

A nitrogen analysis had been conducted on the Black #1, Wade #1 and Wade #2 wells in 1975 or 1976. This analysis indicated a natural nitrogen content of 6 to 10% in the natural gas. Following the nitrogen stimulation in Black #1, several samples were obtained from these wells and analyzed. The results of these analyses are contained in Table I.

TABLE I

<u>DATE</u>	<u>WELL #</u>	<u>PERCENT NITROGEN</u>
10/24	Black #1 Well	62%
10/27	Black #1 Well	56%
10/31	Black #1 Well	52%
10/31	Pearis #1	6%
10/31	Wade Well #1	40%
11/5	Wade Well #2	16%

It is believed that the nitrogen reached the Wade wells during or shortly after the stimulation treatment, but evidently the amount of nitrogen available to the Wade wells was significantly less than for the Black #1 Well. A large amount of nitrogen has not been recovered and it is believed to have been trapped possibly in the horizontal fracture that was created and sealed in when the horizontal fracture collapsed on itself. The long duration of high-pressures observed in the Black #1 Well would indicate that the fractured reservoir is probably not continuous to the other wells in the area. This is also substantiated by the Pearis well not receiving any nitrogen through the natural or induced fracture system. It is interesting to note that 968,000 standard (scf) cubic feet of gas was injected with a shut-in at 900 psi and historically

the well produced 2,793,000 scf from a rock pressure of 325 psi. This would imply that the nitrogen filled up a volume equal to 1/8 of the total reservoir for this well.

IV. STIMULATION EXPERIMENT

On October 22 Haliburton Services performed a nitrogen stimulation treatment on Black #1 Well. This stimulation did not contain any proppant. It was conducted using 968,000 scf of nitrogen gas. This volume of gas was pumped in approximately 28 minutes at an average injection pressure on the surface of 1,200 psi. This stimulation treatment would be equivalent to 2,500 barrels of fluid being pumped at a rate of 95 barrels per minute. The instantaneous shut-in pressure after the tiltmeters ceased to show surface deformations was approximately 900 psi. The shut-in pressure on the following morning with very little flow-back was at 870 psi. This high pressure after this long shut-in period would seem to indicate a closed fracture system with very low permeability to either the matrix or other fracture systems. The rock pressure after a month of flowing and testing had a stabilized shut-in pressure of approximately 405 psi. This increase in the rock pressure in the well could be attributed to either the well being caused or by new rock being fractured. The new shut-in pressure was not determined after the casing was set and it may not be possible to determine the reason for the new rock pressure. An attempt was made late in the fracturing treatment to drop some radioactive sand or tracers into the fracturing wellbore. However, a gamma tool run after the fracture was not able to determine, because of high background level, where this sand was located. Speculation is that it was smeared the entire length of the casing and the open hole section.

V. SANDIA BOREHOLE SEISMIC SYSTEM

Sandia installed their borehole seismic system in the Black #1 Well prior to the stimulation being conducted. Data was recorded before any nitrogen had been pumped and the borehole seismic system remained in place during the

stimulation treatment. Data was also recorded immediately following shut-in. Seismic signals were observed both pre- and post-fracture, however, the seismic noise level was too high during the treatment for seismic signals to be analyzed. The numbers of seismic signals analyzed are shown in Figure 4. The large number of seismic signals received prior to stimulation indicate a fracture system did exist prior to the stimulation experiment. This fracture system may not have been natural but could possibly have been induced by prior workover operations. The large in situ stress measurement, however, probably precludes this from having occurred and supports the idea of a natural fracture system. The orientation of the seismic system was obtained utilizing an on-board magnetic compass and camera unit. By knowing this orientation, the orientation of the received seismic signals can be analyzed. The results of this analysis prefracture are shown on Figure 5 and postfracture are shown on Figure 6. Two sets of fractures are indicated by these data. Without corroborating data the induced fracture orientation could not be directly predicted from this data. It is apparent though that the preexisting fractures probably received the stimulation treatment without a new set of fractures being created. However, the larger fracture activity appears to be in the N 62° E direction as determined by the tiltmeter data.

VI. M. D. WOOD, INCORPORATED TILTMETER ARRAY

M. D. Wood, Incorporated installed an array of tiltmeters radially around the well to be stimulated at 390 ft. These instruments were installed prior to the stimulation treatment to allow them to reach thermal and environmental stability. Tiltmeter data indicates three distinct phases within the stimulation treatment. The first phase lasting for the first 19-20 minutes clearly indicates a vertical fracture oriented N 62° E and S 59° W with the major axis to the NE. The cumulative tilt vectors for this period are shown in Figure 7. At this time a sudden and dramatic change in the tilt field commenced. This change in the tilt field continued for 8 minutes until shut-in and for approximately 6 minutes after shut-in. The tilt vectors from this 14-minute

FIGURE #4. SEISMIC EVENTS DETECTED (SOLID LINE) AND ANALYZED (DASHED LINE)

FIGURE #5. ORIENTATION OF SEISMIC EVENTS FROM
1520 TO 1640 HOURS PREFRAC

NUMBER OF EVENTS PER 10 DEGREES

FIGURE #6. ORIENTATION OF SEISMIC EVENTS
FROM 1720 TO 1800 HOUR POSTFRAC

FIGURE #7. TILTMETER VECTOR RESIDUALS AT THE END OF 18 MINUTES

period indicate a horizontal fracture that probably grew and was centered in an area to the NE of the well. Had the fracture grown vertically in the first phase and upward, it is quite possible that the minimum stress field at shallower depths was in the vertical direction and caused the fracture to turn-over and grew horizontally. This horizontal growth had to be quite substantial if it was the cause of the nitrogen gas being seen in the Wade wells.

VII. SUMMAR AND CONCLUSIONS

A significant insight into the fracturing phenomena has been obtained in this experiment. In order to evaluate stimulation technologies not only are production numbers important but a thorough understanding of the fracturing behavior is necessary. The fracture heights, lengths, orientations, relationships to induced, and relationships to natural fractures are all important for evaluating stimulation technologies. The following summarizes the conclusions drawn from this experiment.

- 1) Induced fracture orientation was N 62° E and originated vertically from the wellbore.
- 2) The vertical fracture was sustained from the first 2/3 of the experiment and grew shallower and turned over vertically during the remainder of the stimulation.
- 3) Regional lineament analysis did not predict fracture orientation.
- 4) Core analysis, seisviewer and possibly borehole television if it had been oriented could have determined fracture orientation in this particular well because the measured hydraulic fracture orientation was the same as the natural fracture orientation.
- 5) Surface jointing and remote sensing data collected in an area 30 miles to the north would not have predicted the hydraulic fracture orientation (Appendix A, Reference 11).
- 6) No diagnostic prediction capability existed to predict the vertical techniques. This experiment has shown that by utilizing diagnostics a better understanding of in-situ processes can be obtained.

APPENDIX A

The following reports, logs and data have been utilized in compiling this quarterly report. These items will be on file at both METC and SNL for reference.

1. Thurlow Weed and Associates, "Technical Proposal for Devonian Shale Test Wells."
2. Birdwell Set of Logs:
 - a) Differential Temperature and Sibulation
 - b) Neutron Borehole Compensated
 - c) Induction
 - d) Density Borehole Compensated
 - e) 3-D Velocity
 - f) Epithermal Neutron Porosity
 - g) Elastic Properties Log
 - h) Depth Corrolation Log
 - i) Computer Process Log (CP-4)
 - j) Computer Process Log (Gas Shale)
3. Shafer Exploration Company, "Lineament Analysis."
4. Shafer Exploration Company, "Seisviewer Analysis."
5. Thurlow Weed and Associates, "Progress Report, October, 1979."
6. Thurlow Weed and Associates, "Progress Report, November, 1979."
7. M. D. Wood, Incorporated, "Final Report - Fracture Characterization Program for Eastern Devonian Shale Experiment on Black #1 Well."
8. Analytical Research Associates, Incorporated, "Nitrogen Analysis."
9. Haliburton Services, "Nitrogen and Gas Frac, Black #1 Well."
10. Fracture Analysis Section of Cleveland Cliff Phase II Report on Beckholt Well. Mt. Vernon, Ohio.
11. "Relationship of Earth Fracture Systems to Productivity of a Gas Storage Reservoir," W. K. Overly et al., RI7952, Bureau of Mines.

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