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FRACTURE MAPPING HAS BECOME A VIABLE TECHNOLOGY*

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ABSTRACT

Sandia Laboratories has continued the development of massive hydraulic fracture mapping techniques and has participated in several experiments where all the existing technology was applied. The development of the surface electrical potential system has been completed and tested at several locations. Because of the complexity of the potential array, the electrical system will probably be replaced in the future with borehole mapping measurement systems. A wall-clamped geophone system has been tested on several experiments and did detect seismic signals related to the fracture. By knowing the orientation of the seismic detonators, the orientation of the fracture can be ascertained. Nevada Test Site fracturing experiments are being used to study close in seismic signals and enhancing the interpretation of the borehole received signals. An array of hydrophones is being built into a borehole tool for detecting the seismic signals. This will be a means for determining fracture heights away from the wellbore. This data will greatly increase the understanding of the properties that are required for fracture containment.

INTRODUCTION

Sandia Laboratories has continued to perform diagnostic experiments on massive hydraulic fracture stimulations during the previous year with Amoco Production Research. These experiments were concentrated in the Wattenberg area northeast of Denver, Colorado. The purpose of this experimental program was to correlate several different techniques for determining fracture orientation and to evaluate these techniques one against the other. Two of the techniques developed by Sandia were deployed on these experiments. These included the surface electrical potential system and the borehole seismic system. M. D. Wood, Inc. deployed their tiltmeter array and Amoco provided wellbore diagnostic and core correlations with Texas A&M. This intensive program has resulted in all techniques providing a measure of fracture orientation determination and excellent agreement between all these techniques.

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The surface electrical potential system has been the primary means for determining fracture orientation and has been developed over the previous four years. The system has undergone a continuing development program and improvements in the data collection and analysis systems. The electrical system is an adaptation of a four-element resistivity array where the fracture well acts as one of the current electrodes and the electric potential field is measured around the fracture well. The geometry of the fracture well changes as the pumping of conductive fluid progresses and the resulting change in the electrical potential pattern is thus measured. The orientation and asymmetry of the fracture can then be determined from the surface.[1]

Extensive testing of the surface electrical potential system has been conducted over the previous four years, and these experiments are summarized in Table 1. Although the results of the electrical system have been encouraging, the deployment of the system, data acquisition and data analysis problems tend to make this system rather cumbersome to use. The onset of the borehole seismic system has produced some encouraging results.

Seismic recording of signals associated with hydraulic fracturing was initiated on the original hydrofrac mapping experiments. The results of this were less than satisfactory as seismic signals from the fracture interval were not received with sufficient amplitude at the surface for their source location to be determined. The surface seismic efforts have been shifted to a borehole seismic package. This package can be emplaced in the fracturing wellbore during non-proppant pumping times or post-fracturing time and record seismic signals associated with the fracture. Four experiments were conducted in 1978 utilizing the borehole seismic package in the Wattenberg area, and a series of experiments was conducted at the Nevada Test Site to evaluate the system. It is significant that a considerable amount of seismic activity is occurring within the fracturing interval and can be detected during quiet periods. Analyses of these signals have resulted resulted in determining fracture orientations away from the wellbore.

BACKGROUND

The Massive Hydraulic Fracture Diagnostic and Characterization Program was initiated at Sandia in 1974 when a joint experiment was conducted with El Paso Natural Gas in their Pinedale field. Initial effort utilized Sandia's instrumentation capability in an attempt to detect the fracture location. These initial experiments utilized both a surface electrical potential system and a surface seismic recording system. These initial experiments did establish the feasibility of diagnostics being useful in determining fracture orientation and asymmetry.[2] This fracture diagnostic effort was continued under the Energy Research and Development Administration and now by the Department of Energy. Sandia's participation has included both the Eastern Devonian Shales Program and the Western Tight Gas Sands Program as well as experiments with other industrial companies on a non-transfer-of-funds basis. The development of fracture diagnostic systems is an on-going and continuing process.

Surface Electrical Potential System

The surface electrical potential system has been evolving over the last several years by the continual testing, improving, and updating of the system. The basic system description, block diagrams, and software are given in reference 3; however, the system has undergone some minor changes and improvements since its publication. The system is comprised of a current generator, the potential measurement system and the data collection and analyses system. The current generator, which was designed to provide the capability of bi-polar current pulse of 50 amperes, is controlled by the PDP-11 computer. The computer not only controls the current pulse but collects the electrical potential data, normalizes it, analyzes it and stores it in a retrievable data system. The potential system allows for 48 sets of potential measurements to be collected simultaneously using two separate current injection schemes.

Two examples of the surface electrical potential data are given in references 4 and 5. The data collected from the shallow experiment, as presented in reference 4, was later verified by actually drilling and locating the fracture with injection flow tests. This sort of independent verification of the electrical analysis has led to an increased credibility of this technique. On deeper experiments, as given in reference 5, this direct verification cannot be obtained; however, excellent agreement in determining fracture orientations from the electrical data has been obtained using tiltmeter analysis, core analysis, and the seismic signals received by the borehole seismic system.

BOREHOLE SEISMIC SYSTEM

The borehole seismic system uses a three-axis geophone package that amplifies and multiplexes the three-axis signals to the surface. The configuration and systems design of this system is given in reference 6. The use of a wall clamped system with an orientation device allows for the direction of arriving seismic signals to be determined. This pointing vector provides the orientation of the seismic source that is assumed to be associated with the induced hydraulic fracture. By determining the coda of the incoming seismic wave and locating the compressional and shear wave arrival, the distance to the seismic source can also be determined. The two experiments conducted early in 1978 resulted in the detection of a significant number of seismic events associated with the fracturing phenomena during the quiet periods or non-flowing periods in the wellbore. It was also determined that even the smallest amount of fluid flowing past the wall-clamped geophone package induced extreme seismic activity and no other signals could be detected. During the quiet periods, though, several seismic signals were observed. These signals were observed during both shut-ins at the early breakdown stages of hydraulic fracturing as well as at the conclusion of, and for several hours after, a massive fracture treatment. These first two experiments indicated not only a large number of seismic signals received, but, in addition, that the frequency content of these signals was such that it induced oscillations in the geophone mounts and overall systems.

The second set of two experiments was conducted late in 1978 with a somewhat improved geophone mounting system. The system at this time was also upgraded to include operation in a higher temperature environment as the fracturing horizon was considerably deeper. Although the orientation device was not designed to operate at these high temperatures, sufficient film was recovered to allow the system orientation to be determined. On both these experiments, sufficient seismic data were obtained to determine fracture orientation. The fracture orientation was determined by plotting the Lissajous pattern of the arriving wave on two orthogonal horizontal geophones. An example of this is shown in Figure 1. As can be seen, the orientation to the seismic source is determined by the relative amplitude of the signal on each of the horizontal geophones and the arrival of the compressional wave and the shear wave can be readily determined. The time difference between these two arrivals, knowing the seismic velocities, can give the distance to the seismic source. The orientation determined by this method was in excellent agreement on these experiments with all other methods deployed for fracture orientation determinations. As all these techniques rely on different physical phenomena for determining fracture orientation, their agreement lends credence to the overall program for determining fracture orientations.

The borehole seismic system was also taken to the Nevada Test Site and installed in a vertical hole drilled from the floor of G-Tunnel. A triaxial geophone mount was co-located with the seismic system and grouted into place for use as a reference for receiving seismic signals. The purpose of this experiment was two-fold: to evaluate the determination of detecting source locations and for evaluating the system resonance problems associated with the borehole mounting. The preliminary results indicate that excellent agreement is obtained between the grouted package and the borehole package for determinations of source locations; however, several system resonant problems do exist and need to be examined for methods of reducing this problem.

BOREHOLE STACKED HYDROPHONE SYSTEM

A new borehole tool is being designed and fabricated presently by Sandia to further investigate seismic signal arrivals. The stacked hydrophone array uses four detectors on ten-foot spacings. The hydrophone, being a pressure sensitive device, does not require clamping to the side of the wellbore and, being a much smaller transducer allows for the design of a system that can be installed through tubing. This system will detect the same signals as the borehole seismic system and will be able to determine the elevation from which these signals arrived. Hence, this tool can be used for determining fracture heights out away from the borehole but will not be able to determine fracture orientations. The prototype tool is nearing completion and should be deployed during FY 79. Hopefully, this tool will add to the understanding of the properties required for fracture containment and give some insight into fracture heights.

CONCLUSIONS

The surface electrical potential system design has been carried from its inception to a fieldable system for determining fracture orientation. This system will probably continue to be deployed as a baseline for evaluating follow-on borehole systems for detecting fracture orientations. The system has been operated at a wide range of fracture depths and treatment volumes and is limited as depths become greater and treatments become smaller. The borehole seismic package appears to be a valuable diagnostic tool and its development and evaluation will continue. This tool has the potential for being utilized on a commercial basis as it lends itself to easily being included in the fracture design. It offers the ability to obtain fracture orientation without a major fielding effort. The borehole hydrophone system development will hopefully contribute a viable way of determining fracture heights.

REFERENCES

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Table 1. Fracture Diagnostic Experiments

Operating Company	Date	Systems Deployed	Location
EPNG	9/74	S&E*	Pinedale, WY
EPNG	7/75	S&E	Pinedale, WY
EPNG	10/75	S&E	Pinedale, WY
AMOCO	11/75	E	Wattenberg, CO
AMOCO	12/75	E	Wattenberg, CO
AMOCO	1/76	S&E	Wattenberg, CO
COLUMBIA GAS	8/76	E	Lincoln County, W.VA
AMOCO	11/76	E	Tulsa, OK
GPE	3/77	E	Vernal, UT
CONOCO	3/77	E	Casper, WY
GPE	4/77	E	Vernal, UT
GPE	6/77	E	Vernal, UT
SANDIA	8/77	S	Nevada Test Site
SHELL	8/77	E	Larado, TX
NUMAC	10/77	E	Alberta, Canada
GPE	11/77	E	Vernal, UT
PTC	12/77	S	Lincoln County, W.VA
AMOCO	1/78	B&E*	Wattenberg, CO
AMOCO	2/78	E	Wattenberg, CO
AMOCO	3/78	B&E	Wattenberg, CO
AMOCO	11/78	B&E	Wattenberg, CO
AMOCO	11/78	B	Wattenberg, CO

* S = Surface Seismic System
E = Electrical Potential System
B = Borehole Seismic System

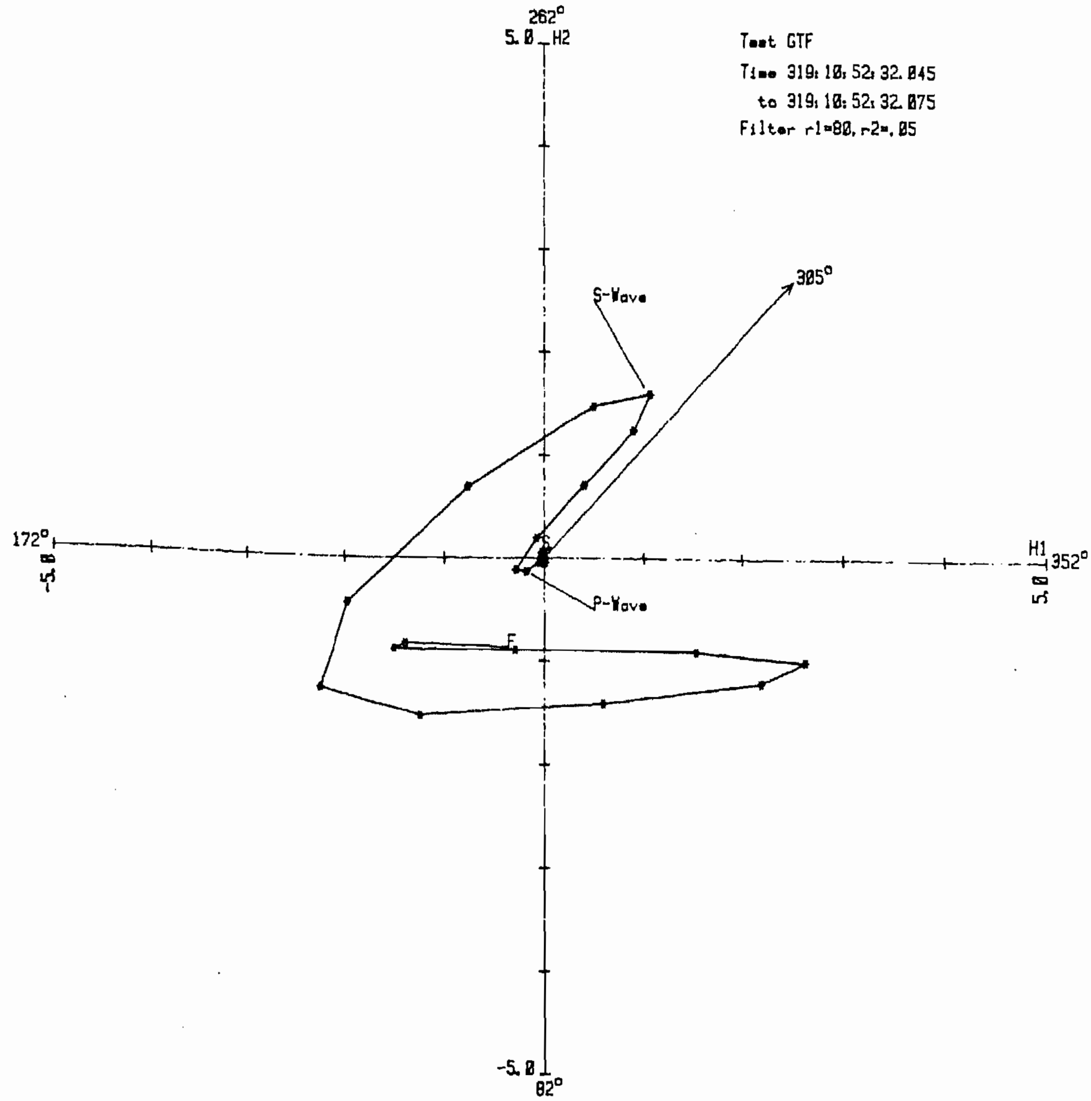

Figure 1. Lissajous pattern of two horizontal seismic signals showing received vector orientation and time-of-arrivals.