TIGHT GAS RESEARCH FROM GRI
A STATUS REPORT

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ABSTRACT

Past studies by DOE, NPC, and GRI confirm that an enormous volume of gas is trapped in low permeability reservoirs. However, neither current technology nor price is adequate to allow widespread development of these reservoirs. To better understand the fracturing process and, thus, be able to eventually improve technology, it is first necessary to improve our understanding of the low permeability reservoirs that are being fracture treated. The Gas Research Institute (GRI) is sponsoring research in which comprehensive efforts are being undertaken to perform geological, coring, logging, well testing, fracture treatment monitoring, and fracture diagnostic studies on selected wells in two targeted basins, the Travis Peak formation in East Texas and the Corcoran and Cozette formations of the Piceance Basin.

This paper summarizes the research effort which has as its ultimate goal to learn how to measure and analyze data so that fracture dimensions can be calculated in real time, or as the fracture treatment is being pumped. Eventually, we hope to be able to alter the design during a treatment in order to control fracture shape. Engineers and scientists are being placed in the field with computers so they can analyze the data while the job is being pumped. Several cooperative wells in East Texas have been drilled and analyzed. Additionally, the first of four Staged Field Experiments has been completed. The Staged Field Experiments are wells drilled where GRI is in complete control of the entire operation allowing more latitude with experimentation not possible in cooperative wells.

Conventional whole cores (up to 400 feet per well) have been taken. The cores have been used to determine regional and local environments of depositions. Complete suites of open hole logs have been run and used to calculate rock and mechanical properties. Log interpretation results have been found to compare favorably with the core analysis results. *In-situ* stress tests have been run and compared to the log and core data. Fracture treatments are being monitored and analyzed. Post-fracture well tests are run to estimate the effectiveness of the fracture treatments.

Also included in the paper is a documentation of the monitoring equipment that has been designed and developed by GRI contractors. Included are mobile Quality Control (QC) laboratories and a new generation rheology unit that measures both couette and capillary viscosity at bottomhole temperatures. The unit also is designed such that fluid leakoff anticipated in the formation can be simulated.

INTRODUCTION

Over the past few years, the Gas Research Institute (GRI) has conducted a field operations and analysis program to study what data and data analyses techniques are needed to fully define the three-dimensional shape of a hydraulic fracture. Originally two producing horizons were selected for study by GRI contractors. One formation, the Corcoran/Cozette in Colorado, has had little study and analysis because of lack of activity in that area. Virtually all of the field operations during the past three years have been in the Travis Peak formation in east Texas. Large quantities of data have been collected and analyzed using whole cores, open hole logs, in-situ stress tests, pre-fracture production and pressure transient tests, measurements made during a fracture treatment, and post-fracture production and pressure transient tests. Up until mid 1986, all of this work had been conducted in what were termed cooperative wells. These were wells which were operated by independent or major oil companies who allowed the GRI contractors to conduct research. The operating companies benefited from the fact that GRI funded various logging and coring operations and supplied that data to the operating companies. Monitoring of fracture treatments and pre- and post-fracture formation evaluation data was also supplied to the operating company.

The cooperative well program has been successful. The close participation of the operating companies and their willingness to allow various GRI contractors to core, log, and test their wells has resulted in the collection of a vast amount of high quality data. The evaluation and analysis of most of this data has yielded a better understanding of the geological and petrophysical properties of the Travis Peak formation. The data are used to obtain a better understanding of hydraulic fracture growth and the parameters controlling the shape and extent of the hydraulic fracture. All of this information is available to the public through quarterly, annual and topical GRI reports written by the various GRI contractors.

Although the cooperative well program is continuing, emphasis since mid-1986 has now been placed upon what is termed the Staged Field Experiments (SFE). In the staged field experiments, all GRI contractors come together on a strategic well to utilize all possible means to improve our understanding of tight gas reservoirs. The first of four Staged Field Experiments has been completed. The Staged Field Experiments will be conducted once each year through 1989. In a Staged Field Experiment, GRI contractors can collect the basic data needed to evaluate the formation and the fracture in a manner similar to a cooperative well and also gather data that are not normally collected due to either high cost or high risk. An example of high risk data collection are open hole stress tests measurements.

The general objectives of the GRI Tight Gas Sands Project are (1) correlate core analysis, log analysis, and well test analysis in an effort to increase the amount and quality of data from these sources, and to use these data directly in design of hydraulic fracture treatments, and (2) to apply and improve the use of real time fracture treatment diagnostic tests and post-fracture well tests in evaluation of the shape and extent of the hydraulic fracture.

The ultimate objective will be to develop a system that can be used to accurately predict and, possibly, control the shape and extent of a hydraulic fracture.

With these goals in mind, we have set specific targets for each SFE. These goals are summarized as follows:

SFE No. 1 1986

* Bring together all GRI tight gas sand contractors to study a common formation and wellbore. To date, the attention of fracture diagnostics and cooperative well contractors has not been focused on the same well simultaneously.

* Drill, complete and stimulate a highly instrumented well to collect and analyze one of the most comprehensive data sets ever obtained in our industry.

* The data collection methods which will be structured to benefit the GRI contractors working on fracture diagnostic techniques and fracture modeling efforts. We want to be sure these particular experimentors get as much information as possible so each technique can be fairly evaluated.

* The information obtained during the SFE will be presented in an integrated form to transfer the technology to industry in a useful manner. The various analyses will not be linked and will not necessarily be consistent between any two of the contractors.

SFE No. 2 1987

* A three-dimensional fracture design and evaluation model will be able to analyze the data in real-time and offer suggestions concerning changes one should consider to improve the treatment results.

* The fracture diagnostics experiments will be evaluated to focus future research efforts on the most promising of the techniques. All fracture diagnostic methods will be separate from the fracture modeling efforts.

* The field measuring and monitoring systems of the GRI Mobile Testing and Control Facility will be superior to all other field systems in terms of versatility, accuracy, and reliability.

* The experimentors will focus their attention on the determination of fracture height and fracture length measurements and/or calculations of these parameters.

SFE No. 3 1988

* The fracture modeling system will be computing fracture shape with precision and applying partial control of the fracture treatment automatically using the computer.

* The best fracture diagnostic systems will be functional and providing input to the fracture models in real time.

SFE No. 4 1989

* Move to a new location and prove the technology developed can be transferred to a different environment.

SFE No. 1 has essentially been completed with post-fracture well testing being conducted in the first quarter of 1987. Essentially all of the goals set forth for SFE No. 1 were achieved. At the present time, the data are being analyzed by the various GRI contractors. The data and the analyses will be furnished to the industry as soon as possible.

GRI CONTRACTORS AND THEIR AREAS OF RESPONSIBILITY

A group of consulting firms and research organizations, all under contract to GRI, are implementing the tight gas sand research. Table 1 summarizes the participants and their main responsibilities.

To insure successful implementation of the four SFE wells, GRI has provided for project management by a Lead Technical Contractor (LTC) and an Operations Management Contractor (OMC). The Lead Technical Contractor selected was S. A. Holditch & Associates, Inc. They are responsible for all technical matters dealing with the SFE including well design and well site supervision of drilling and completions operations. The OMC selected was CER Corporation. They are responsible for such duties as filing for and obtaining required drilling permits, procurement of supplies and administration of payment for drilling and completion costs. In addition, CER will assist the LTC in day to day well site activities.

S. A. Holditch & Associates, Inc.

In addition to being the Lead Technical Contractor for SFE wells, S. A. Holditch & Associates, Inc. is currently responsible for GRI Mobile Testing and Control (T&C) Facility. The Mobile T&C facility is capable of conducting, measuring, recording, and analyzing data from pre-fracture well test, in-situ stress test, fracture stimulation treatments and post-fracture well tests. Dresser Petroleum Engineering Services acts as a subcontractor and provides field engineers and operators necessary to conduct many of these tests. The objective of these tests will be to characterize the formation properties before a fracture treatment and characterize both the reservoir and hydraulic fracture after the treatment.

The Mobile T&C facility consists of a Data Acquisition Trailer, a Main Computer Trailer, portable production test units, portable fracture monitoring instrumentation, a GRI Rheology Unit and mobile van, and a mast truck lubricator for running downhole pressure and temperature gauges. Illustrations 1 through 9 show pictures of the GRI Mobile T&C equipment.

S. A. Holditch & Associates, Inc. also performs all the reservoir evaluation necessary to characterize the formation and the hydraulic fracture. Sophisticated software is used to analyze both pre-fracture and post-fracture well tests. Also, research is being conducted by the Holditch Engineers in methods to better understand and analyze layered, complex reservoirs such as the Travis Peak.

CER Corporation

In addition to being the Operations Management Contractor, CER is responsible for the coordination, monitoring and quality control of coring operations. In a typical SFE well, 400 ft of 4" O.D. whole core are cut. CER processes the core and prepares it for shipment to the core storage facilities. CER is directly responsible for organizing and supervising orientation techniques; e.g. multi-shot or paleomagnetic measurements.

CER also supervises and is directly responsible for maintaining quality control of the logging services. To assure quality control, CER adheres to a strict checklist which includes calibration details, logging speeds, data formatting and numerous other provisions for insurance of quality log data.

ResTech Inc.

ResTech Inc. is the principal Log Analysis Contractor for the Gas Research Institute. ResTech's responsibilities include the direct supervision of open hole logging operations with CER to insure quality log data. In addition ResTech will work with CER and the logging service company to provide onsite analysis of openhole logs.

ResTech's primary research objectives are directed at the continued analysis of tight gas sands properties with specific emphasis on the calculation of in-situ stresses, primary fracture azimuth and the correlation of electrically measured properties to other reservoir properties determined from core analyses and well tests.

ResTech is in charge of coordinating all core analyses for the Cooperative wells and Staged Field Experiments. This includes both routine and special core analyses conducted either by other tight gas sand contractors or by independent core laboratories. ResTech integrates all of these data into a complete graphical display of the vertical formation properties by means of their FRACLOG and CORELOG analysis products.

Bureau of Economic Geology

The Bureau of Economic Geology (BEG) at Austin has been conducting geologic studies in the East Texas Basin (specifically the Travis Peak/Hosston Formation) for several years. Their studies have centered around the depositional history of the Travis Peak with special emphasis on the origin of individual sandstones, sandstone continuity, reservoir geometry, porosity and permeability distribution, and overall reservoir quality.

During the Staged Field Experiments, the Bureau of Economic Geology is responsible for selecting the actual sites for the SFE wells. BEG develops the coring program for the SFE wells and provides on-site geological evaluations to assist in the selection of coring points.

Using a slab cut from the core, BEG reconstructs the depositional environments in the areas of interest to determine the effect of sandstone origin on reservoir geometry. BEG also has investigated the porosity and permeability distribution associated with Travis Peak depositional environments. Structural geologic and remote sensing studies, to help determine the localized trend of stress distribution is also a part of the BEG effort.

One of BEG's primary responsibilities is to perform thin section petrographic analysis and SEM analysis for rock composition and internal structure. The data generated from these studies are used to calibrate and correlate open-hole logs, explain reservoir heterogeneities, and to design completion and fracture stimulation fluid systems.

Resources Engineering Services

Resources Engineering Systems (RES) is responsible for developing the software and hardware for the Main Computer Trailer of the Mobile T&C Facility and for supervising and operating the trailer during fracture treatments. This computerized field system is devoted to the monitoring, analysis, and control of hydraulic fracture treatments. The system includes data acquisition facilities, a complete and fully integrated computer model of the fracture treatment process, and an interactive, graphics-based operator/system interface.

During a fracture operation, the measured fracturing variables (e.g., pumping rate, proppant concentration pressure, etc.) are continuously compared to the values predicted by the three-dimensional fracture model in order to modify estimates of certain key parameters (e.g., in-situ stresses, reservoir moduli and fluid loss coefficient). The fracture model uses this information to determine current three-dimensional fracture geometry and proppant distribution. The interactive operating system allows predictions of final propped fracture geometry based on either the planned fracture treatment or for a different pumping schedule.

Through their fracture modeling research, RES is evaluating the reservoir conditions and parameters which influence the complex three-dimensional shape of the fracture; the results of which are continually being incorporated into the hydraulic fracture model.

Teledyne Geotech

Teledyne Geotech has recently developed a Borehole Fracture Mapping Sensor (BFMS) which can be used to determine the directional azimuth of a hydraulic fracture and which eventually may be able to provide information concerning the three-dimensional fracture geometry. The BFMS, which is run into the wellbore on wireline, can measure microseismic activity which occurs during and after the creation of a hydraulic fracture.

During the Staged Field Experiments, Teledyne is responsible for mapping the hydraulic fracture which is created during a mini-frac treatment. From this test, fracture azimuth can be determined and the fracture geometry can be estimated. The results from their analysis will be compared to other indirect fracture mapping techniques and fracture calculation techniques so that the most accurate geometry may be determined.

Applied Geomechanics, Inc.

Applied Geomechanics measures and interprets high-frequency pressure oscillations in the hydraulically fractured well. This method of fracture evaluation is based on a theory that the behavior of pressure waves in a well is a function of fracture geometry. Two types of pressure oscillations are evaluated: free oscillations and forced oscillations. AGI generates the free oscillations by "pulsing" the well to initiate a transient pressure wave that interacts with the hydraulic fracture. Forced oscillations are provided by the reciprocating action of the pumps during fluid injection.

AGI hopes to be able to determine estimates of fracture height, fracture length, fracture closure pressure and continuity of fracture growth using the pressure oscillations.

Stanford University

The Electrical Engineering Department of Stanford University uses surface geophone arrays to monitor the subsurface seismic activity associated with the creation of a hydraulic fracture. These measurements have been performed on the cooperative and SFE wells during both the mini-frac treatment and the hydraulic fracture treatment.

Current experiments in this area have revealed subsurface seismic activity associated with a hydraulic fracturing operation at very shallow depths. To date, interpretation of these seismic signals has allowed for estimates of fracture azimuth and, to some extent, fracture length. Additional data collection and processing are necessary to better estimate these fracture characteristics and to determine if the technique is applicable in deeper formations.

SUMMARY OF RESEARCH EXPERIMENTS

A brief summary of the proposed research experiments for the cooperative and first SFE wells is presented below. In addition, Table 2 summarizes each of the experiments and the main purpose for the research.

Pre-Fracture Formation Evaluation

To maximize the chances for success, it is critical that a formation be thoroughly characterized prior to the hydraulic fracture treatment. As such, a comprehensive pre-fracture formation evaluation is performed on the cooperative and SFE wells. This evaluation includes the analysis of whole cores, open-hole logs, in-situ stress measurements, production testing, and pressure transient tests. Although some of the data collection processes may involve third party companies, most of the analyses are performed by GRI contractors.

Ideally, the cored interval in the cooperative and SFE wells include shales, silts, and other nonproductive zones in the Travis Peak, as well as representative sections of productive reservoir sands. The core from nonproductive sands will provide valuable information concerning depositional environment and mechanical properties to determine potential barriers to fracture height growth. Core analysis performed on productive sands helps to characterize the rock composition and the reservoir flow properties. Extensive routine and special core analyses are planned for the SFE wells. Routine analysis includes porosity, permeability and grain density. Special core analyses include restored state porosity and permeability, cementation factor, saturation exponent, Dean Stark water saturation, elastic moduli, cation exchange capacity, and compressional and shear wave velocity measurements.

A comprehensive suite of open-hole logs is run on the cooperative and SFE wells. These logs include electrical, nuclear, and sonic waveform measurements which are necessary to completely characterize the saturations, porosity, and mechanical properties of the formation. Well logs are also run which characterize natural fractures, formation lithology, and wellbore ellipticity. In zones of interest which are not cored using conventional techniques, sidewall core plugs are cut using a mechanical coring tool.

Emphasis on log analysis research is to study the effects of mineral composition on porosity and saturation calculations, the determination of permeability from logs, the determination of mechanical properties and in-situ stress distribution in the formations, statistical analysis for the identification of productive zones and the analysis of mud filtrate invasion profiles for reservoir permeability.

In-situ stress tests are conducted on the SFE wells to determine the actual stress gradients in the reservoir sands and the nonproductive rock surrounding the completion interval. These data are used in the analysis of potential barriers to vertical fracture growth and in the calibration of log analysis techniques and other calculation techniques which are available for mechanical properties and in-situ stress analysis. High-frequency pressure measurements have also been made during the stress tests to characterize the well and formation prior to the development of a large hydraulic fracture.

Production tests and pressure transient tests are conducted to determine the in-situ permeability to gas, the extent of any formation damage, and the initial reservoir pressure. All of these data are critical to optimize the hydraulic fracture treatment.

Hydraulic Fracture Analysis

The principle objective of the GRI research program is to evaluate techniques that can be used to describe hydraulic fracture geometry. Collection of data for these analysis techniques come from direct and indirect measurements of both surface and downhole parameters. The experiments provide a critical evaluation of current analysis techniques on the mechanics of hydraulic fracturing.

A large mini-frac treatment is performed on each research well. The objectives of the injection test are to provide a means by which to calibrate remote sensing fracture mapping techniques, obtain bottomhole pressure histories under different rates of injection or different types of fluids, and to obtain data related to the fluid leakoff characteristics of the formation. In addition, a strong emphasis is placed on the evaluation of logging techniques used for fracture height determination.

Transient pressure pulses are used to generate free oscillations in the well both before and after a hydraulic fracture has been created. Behavior of the transient waveform and pressure decay is thought to be related to the dimensions of the hydraulic fracture. The post-treatment behavior should deviate from pre-fracture conditions and comparison of the two cases may provide information concerning the fracture size. High frequency pressure response during pumping operations are also being measured. Spectral analysis of this response provide an indication of fracture growth patterns; e.g., a gradual and continuous growth, as opposed to abrupt changes in shape.

A downhole geophone was installed during the mini-frac treatment of SFE No. 1 in order to measure the microseismic activity induced by the hydraulic fracture. The direction of the seismic activity indicates the fracture azimuth and the distribution of the seismic activity is related to the overall fracture geometry. Sufficient research has already been performed in this area of fracture mapping to know that three-dimensional processing of these seismic data could eventually result in an accurate description of the fracture geometry.

Surface geophone arrays were set up around the SFE No. 1 well site in order to map the subsurface seismic activity while the fracture is being created. Even though this technique is still in its early stages of development and has been hampered by extensive surface noise due to pumping operations, it will be evaluated for its potential in both fracture azimuth and fracture length determination in deeper formations.

Before and during the hydraulic fracture treatment on the SFE wells, every effort will be made to actually measure the gelled fluid properties under simulated downhole conditions. Current research is being conducted in the construction and testing of a real-time fluid rheology unit. With the successful development of this unit, we can fulfill two fundamental needs. First, the actual crosslinked, sand-laden fluid viscosity can be measured and subjected to conditions expected in the fracture. Second, we will also correlate friction pressures associated with the tubular goods so that accurate predictions of bottomhole treating pressures can be determined from surface pressures, thus yielding an accurate bottomhole pressure history for the treatment.

The data measured during a fracture treatment include total injection rate of both "clean" fluid and "dirty" fluids, bottomhole and surface injection pressures, fluid densities and proppant concentration, base fluid viscosity, pH and temperature of the fluid. Liquid additives, such as crosslinker or diesel, are also measured and recorded. Analysis of these data will hopefully lead to an understanding of the relationship between injection conditions and the final fracture geometry. In addition, the decay of transient pressure waves in the well (before, during and after the treatment) will also be measured in an effort to determine the average apparent fluid viscosity and its relationship to fracture geometry.

Using data from the pre-fracture formation evaluation of the reservoir and surrounding formations, as well as data collected during the hydraulic fracture treatment, a fully three-dimensional hydraulic fracture simulator is being used to calculate the expected shape of the fracture during the actual treatment. The 3-D model and other fracture diagnostic software are being used to project the expected fracture geometry under either current pumping conditions or under a alternative set of pumping conditions. In this way, an understanding of the fracture growth patterns can be achieved so that decisions can be made regarding necessary changes in the pumping schedule.

Post-Fracture Analysis

A thorough post-fracture analysis is performed on each cooperative or SFE well in order to gain a better understanding of the effective fracture dimensions and their influence on reservoir flow performance. The results from these analyses are used to better design future fracture treatments and to make future performance projections for the SFE wells.

After the fracture treatment, gamma ray and temperature profile logs are run in an effort to determine the point of fluid injection and provide an estimate for minimum vertical fracture height. It is understood that the gamma ray and temperature anomalies associated with the hydraulic fracture treatment can be detected with these logging techniques at only very short distances from the wellbore. Thus, if the fracture plane deviates from the wellbore axis, a true estimate of vertical fracture height cannot be obtained. On the hopes that the fracture plane will be near the wellbore axis, a study of the logging profiles are conducted under various injection rates, fluid viscosities, and also before and after fracture closure. Because it appears that so many different factors can influence these profiles, there needs to be a better understanding of these techniques.

If any cooperative and SFE well is completed in two or more sands, production logs are run during the post-fracture flowback to determine the relative flow contribution from each of the zones as well as to determine if the zones are in communication by a single vertical hydraulic fracture. A study of the flow capacity of each sand is very important in the post-fracture analysis of fracture length. Determining whether multiple fractures exist would be a critical factor in the study of fracture geometry; specifically the influence of surrounding formations on vertical fracture containment.

Production tests are conducted on the cooperative and SFE wells by producing the well at a constant rate for approximately two to three weeks. Bottomhole flowing pressures are measured for most of the flow test, after which, the well is shut in for an extended pressure buildup survey. In the event that more than one sand is completed, individual production tests and pressure buildup surveys can be conducted on each of the intervals. In this way, reservoir flow characteristics and pressure transient behavior can be studied for multi-layered systems with either a single vertical fracture or multiple vertical fractures.

Using the most probable three-dimensional fracture shape obtained from fracture mapping techniques or fracture simulation modeling and the individual reservoir properties determined from the pre-fracture formation evaluation, an analysis of the SFE well is conducted using multi-phase, multi-dimensional, finite difference reservoir simulation models. With the models, a history match of the actual post-fracture production performance and pressure transient behavior is conducted in an effort to determine the most probable three-dimensional characteristics of the reservoir and hydraulic fracture.

FUTURE RESEARCH

Over the past three years, fifteen cooperative wells have been included in this research program. The first Staged Field Experiment has been successfully completed and the second Staged Field Experiment is being planned. A large amount of information has been gathered on the Travis Peak formation in the northeast Texas and northwest Louisiana area. Significant advancements have been made in correlating formation data gathered from log analysis with similar data gathered from cores and stress tests. We are moving much closer to our goal of being able to evaluate all of the basic geological and in-situ stress parameters from open hole log information. Further core data and stress tests in SFE Well Nos. 2, 3 and 4 will be used to confirm and perfect our methods.

It is, of course, the ultimate goal of the GRI Tight Gas Sand Research Program to not only characterize fracture geometry in real time but to control the treatment to optimize the fracture shape. With the development of onsite, devices that can be used to measure the viscosity characteristics of the fracture fluid at in-situ conditions, we feel confident of being able to alter fracture geometry in real time by either varying viscosity or varying properties of the fracturing fluid to reduce a buildup of net fracture pressure. The technology to vary viscosity in real time is presently available and the ability to vary other properties is part of ongoing GRI research.

The GRI Tight Gas Sand Research Program has proven to be a very useful objective testing area for evaluating new technologies. We have been able to utilize technology developed by service companies and GRI contractors. Additionally, as the work progresses new equipment and tools are developed for onsite fracture fluid monitoring and real time fracture growth determination. We anticipate further developments which will lead us to our ultimate goal of real time control of fracture geometry.

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48) Finley, R.J.: "Reservoir Properties and Gas Productivity of the Corcoran and Cozzette Tight Sandstones, Colorado," Texas Bureau of Economic Geology, May 1985.

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Table 1
Staged Field Experiment Consultants

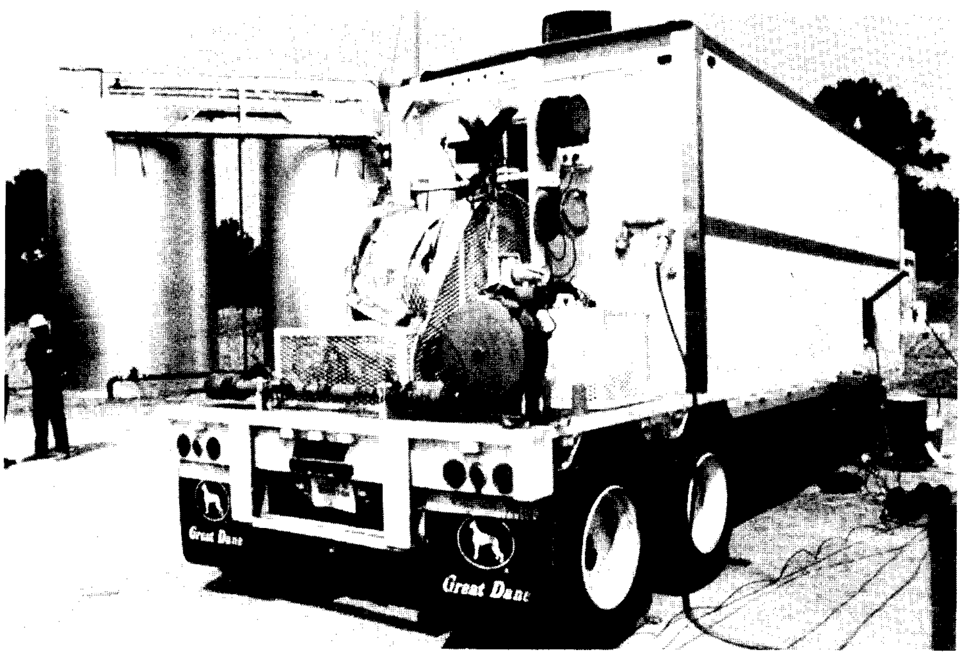
Organization	Main Responsibilities
Applied Geomechanics, Inc.	* High-frequency pressure analysis for fracture geometry
Bureau of Economic Geology (University of Texas at Austin)	* Geologic interpretation * Depositional analysis * Core analysis
CER Corporation	* Operations Management Contractor * Coring supervision * Field processing of cores * Logging quality control
ResTech, Inc.	* Logging supervision and log analysis * Core analysis coordinator
Resources Engineering Systems	* Fracture geometry simulation and analysis
S. A. Holditch & Associates, Inc. * Dresser Petroleum Engineering Service	* Lead technical contractor * Operation of the Mobile Testing & Control Facility * Petroleum engineering
Stanford University	* Surface seismic analysis for fracture mapping
Teledyne Geotech	* Borehole microseismic analysis for fracture geometry

Table 2
Purpose of Recommended Research Experiments

Research Description	Purpose
Seismic Borehole Tomography	* Determine vertical seismic profile around wellbore
Whole Cores	* Deposition and Geologic descriptions * Petrographic analysis * Compositional analysis * Routine Core measurements * Special Core measurements * Mechanical properties and stress * Fracture azimuth
Open hole logs	* Porosity and fluid saturations * Lithology * Mechanical properties & stress * Fracture azimuth * Invasion profile analysis
In-situ stress tests	* Fracture pressure (stress) of each type of formation * Calibration of log analyses * Compare open hole stress values to cased hole
Production Testing	* Determine pre-fracture flow potential * Necessary for pressure buildup analysis * Study dual-permeability analysis techniques on commingled zones * Compare effects of various type treatments on wellbore damage
Pressure Buildup Tests	* Calculate permeability, skin factor and reservoir pressure of each zone * Study dual-permeability analysis techniques on commingled zones * Compare effects of various type treatments on wellbore damage
Mini-Frac Treatment	* Calculate fluid loss coefficients * Provides actual fracturing data for fracture mapping and calculation projects * Study of vertical fracture height
Hydraulic Pressure Transients	* Calculation of created fracture length * Compare to other techniques
Borehole Microseismicity	* Fracture azimuth * 3-D fracture geometry * Compare to other techniques
Surface Geophone Seismicity	* Fracture azimuth * Fracture length * Compare to other techniques
Fracturing Fluid Rheology	* Actual fluid properties under downhole conditions for fracturing models * Correlation of tubing friction pressures
Surface and Downhole Fracturing Parameters	* Provide actual treating data for fracturing models and diagnostics research
Three-Dimensional Fracture Geometry Simulation	* 3-D fracture geometry * Diagnosis of fracturing parameters * Fracture growth projections
Gamma Ray-Temperature Profile logs	* Injection intervals * Minimum vertical fracture height
Production Logs	* Flow contribution from individual sands * Use in pressure transient analysis
Post-Fracture Production Tests	* Productivity increase * Necessary for pressure buildup analysis * Study of hydraulically fractured, multi-layered reservoirs * Determine if single or multiple fractures exist
Post-Fracture Pressure Buildup Tests	* Permeability, propped fracture length and fracture conductivity (in each zone) * Study of hydraulically fractured, multi-layered reservoirs
Reservoir Simulation Modeling	* 3-D reservoir and fracture properties * Production forecasting

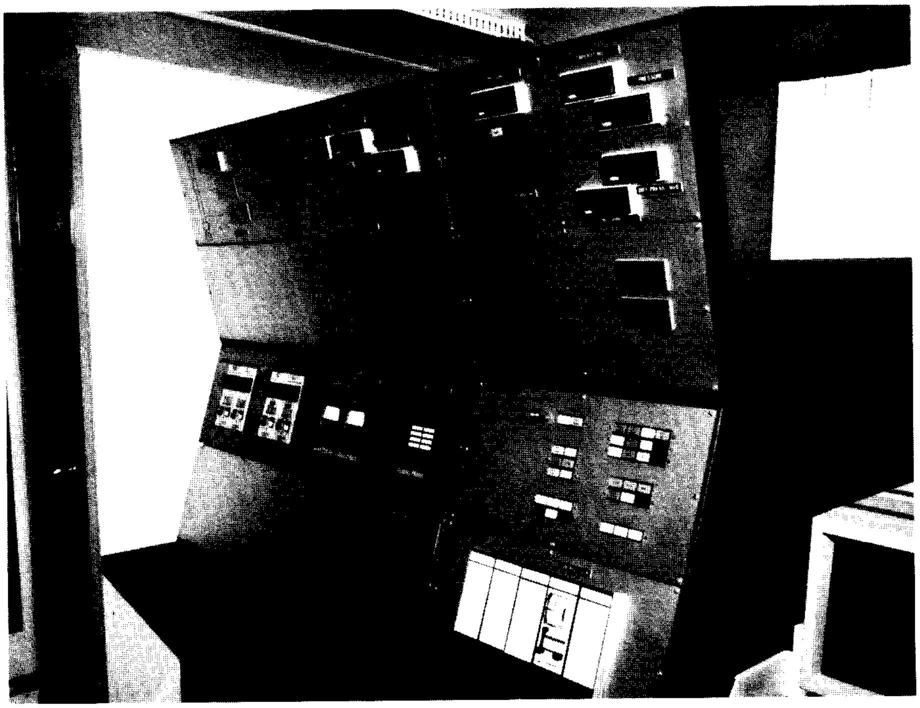
Illustration 1

Front view of DAT Trailer. Shown is hydraulic power pack,
air compressor, and Isoreg power system.

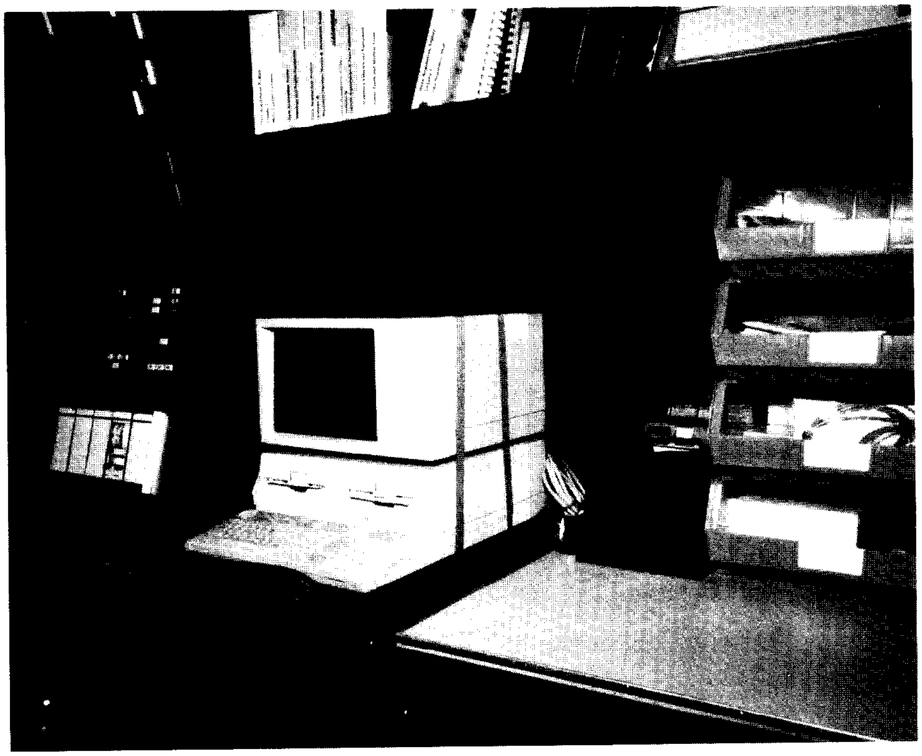


Rear view of DAT Trailer. Shown is wireline spool shieve and grease head.

Illustration 2

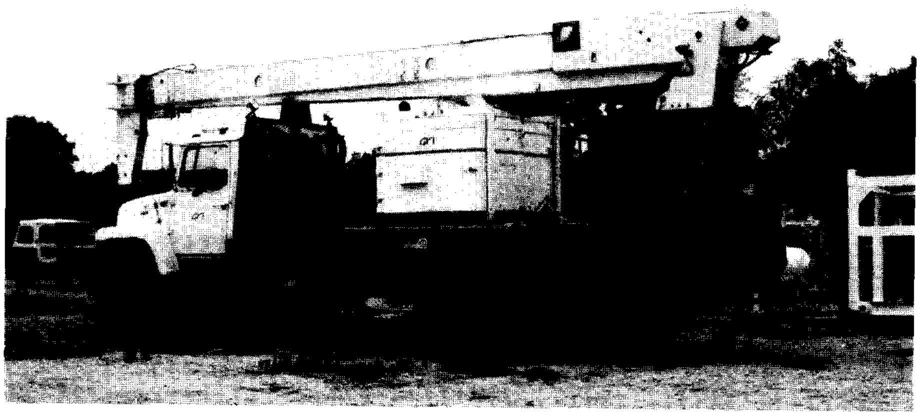


Interior view of right front DAT Trailer. Shown is monitoring panel. Primary function of panel is for monitoring separator data with minor use for surface pressure and rate information.



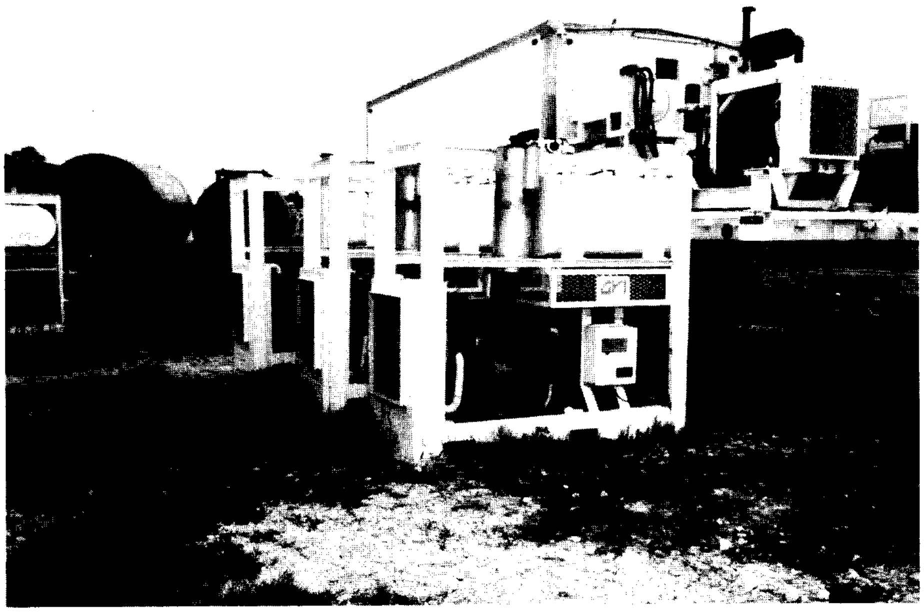
Interior view of right side of DAT Trailer. Shown is H.P. No. 1 computer which monitors all incoming data. To the left is monitoring panel for both downhole and surface data.

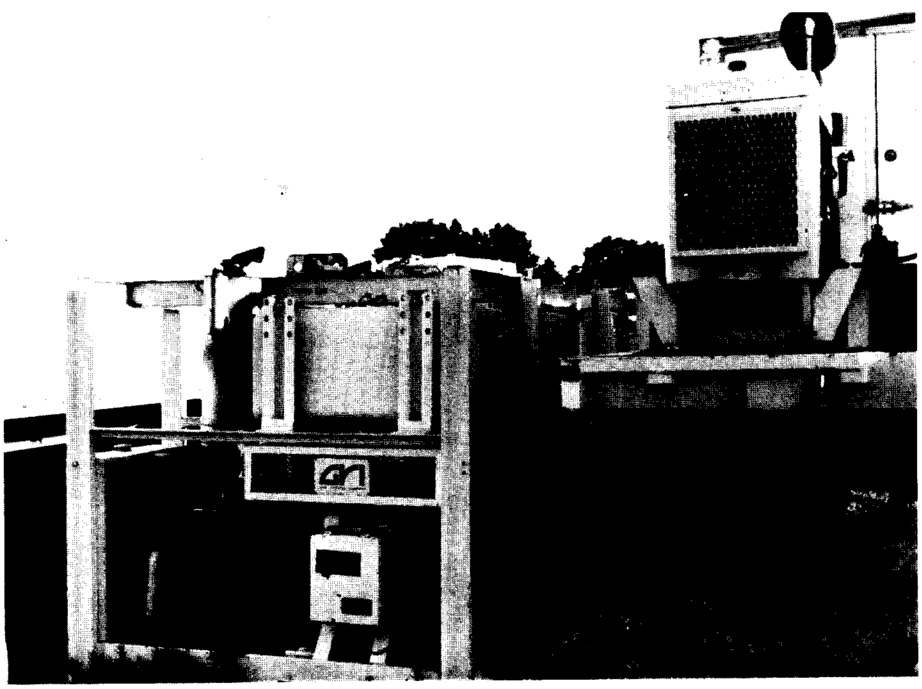
Illustration 3



Side view of crane truck with grease pump mounted and crane in traveling position.

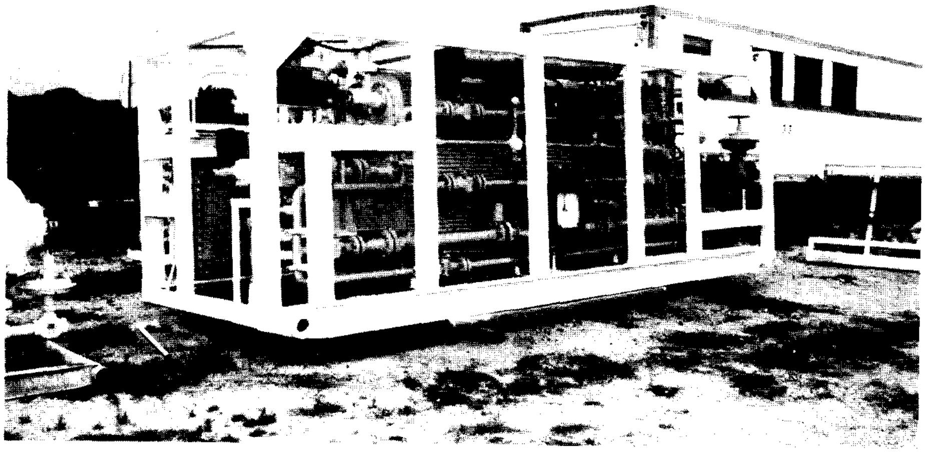
Illustration 4

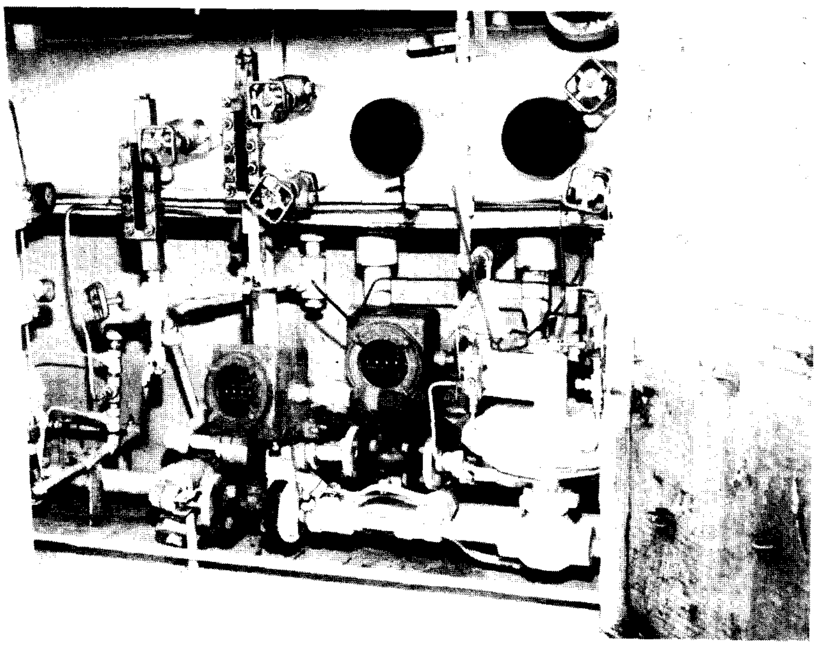




Two views of three 30 kw Onan generators positioned near the DAT Trailer.

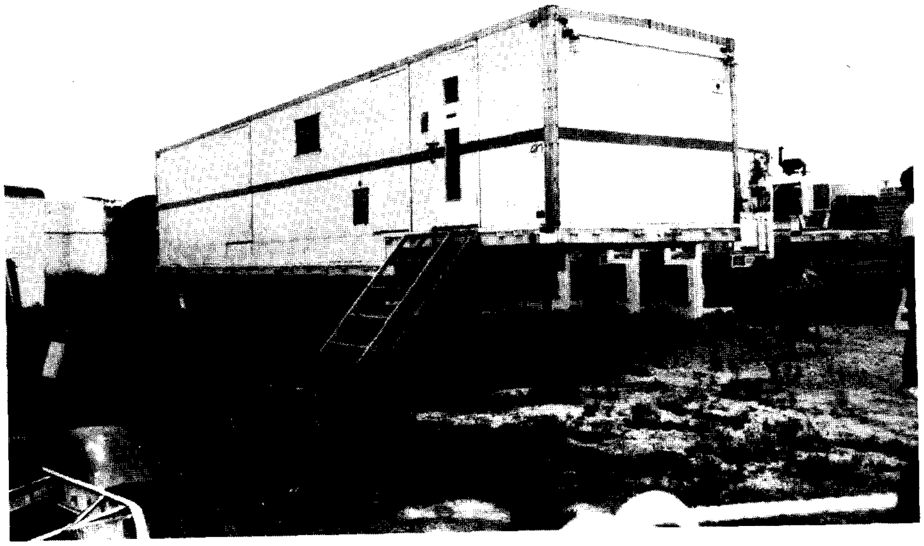
Illustration 5

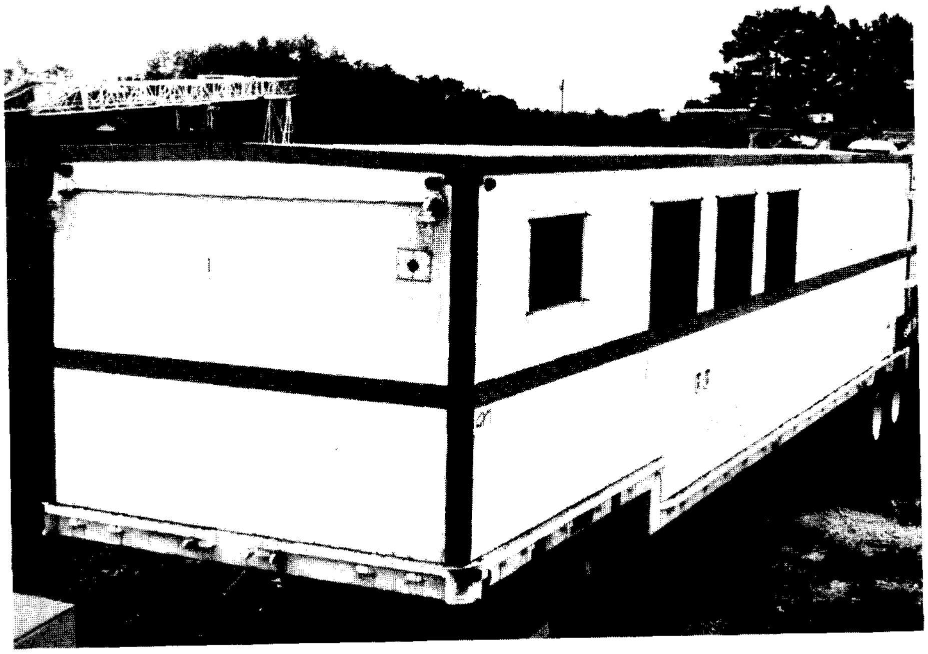




Side view of automated gas separator and metering skid. Note valve actuators (top) and high pressure regulator (bottom).

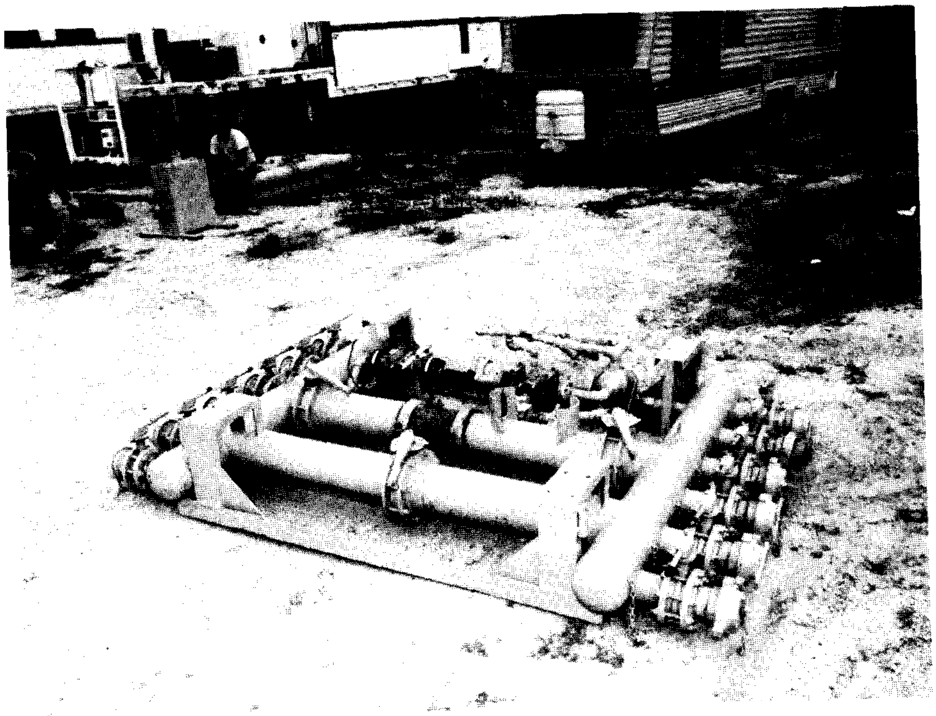
Illustration 6



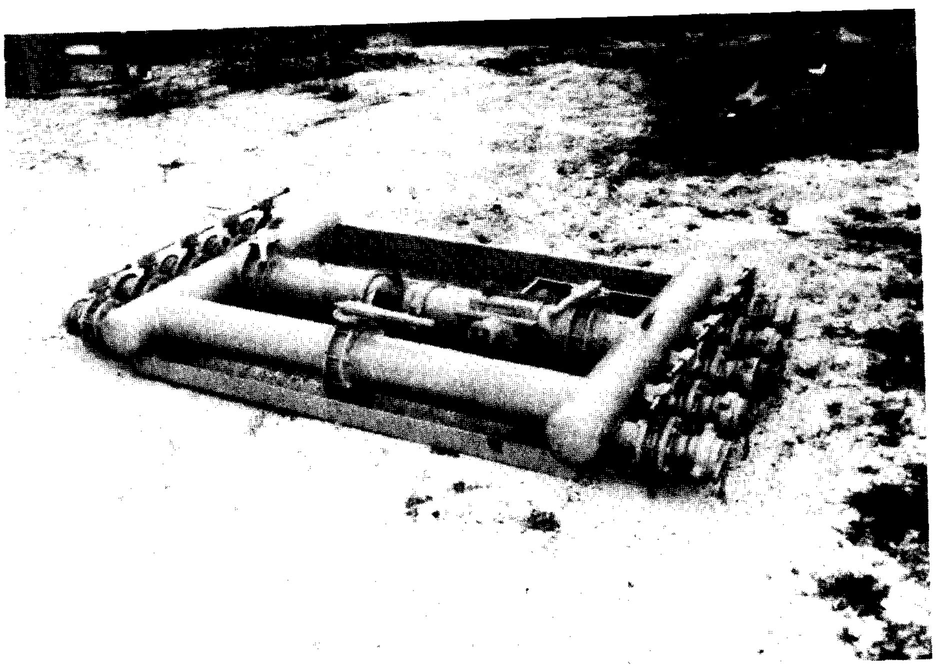


External view of Main Computer Trailer.

Illustration 7

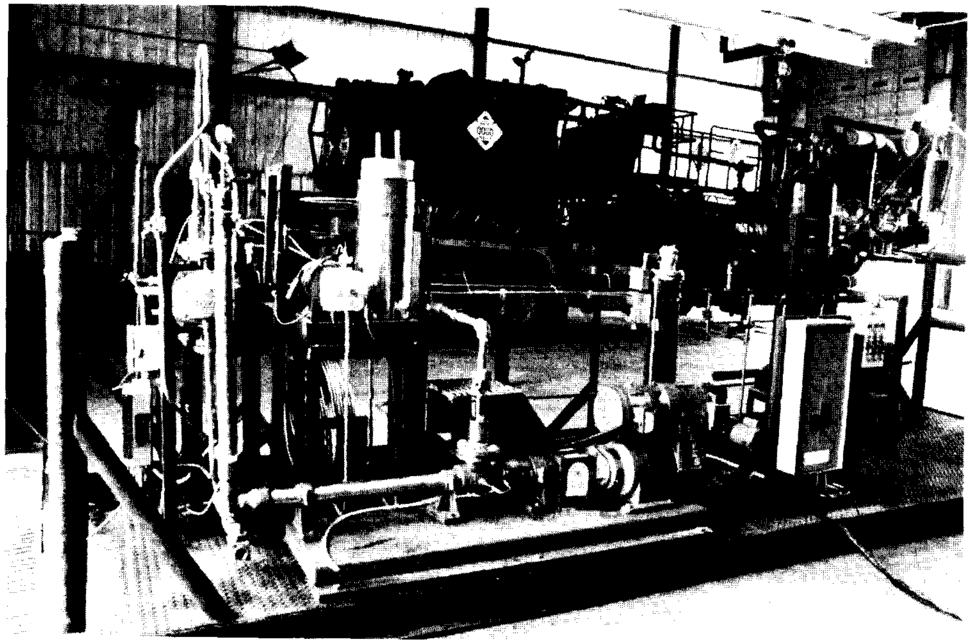


Picture illustrating suction side data acquisition skid. Included on the skid are turbine flow meter, pH probe and two in-line viscometers.



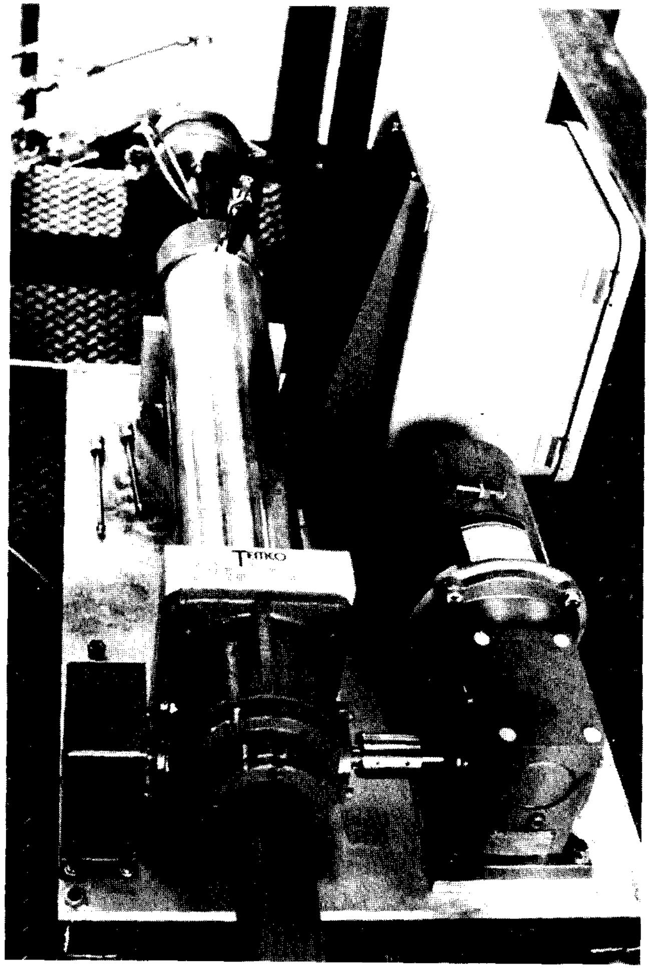
Picture of the discharge side data acquisition skid. Note the radioactive densiometer, turbine flow meter and pH probe outlet.

Illustration 8



Picture illustrating GRI Rheology Skid.

Illustration 9



Picture illustrating top view of floating cell fluid loss control device. Note fluid loss cell, top of picture, with inlet for circulating fluid and effluent line to floating cell.