# GEOPRESSURED-GEOTHERMAL TECHNOLOGY

**Chairperson: Allan J. Jelacic**
**Geothermal Division**
**U.S. Department of Energy**

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# OVERVIEW OF GEOPRESSURED-GEOTHERMAL

**Allan Jelacic**
**DOE Geothermal Division**

Dr. Mock began the session by paying tribute to Dr. Myron Dorfman, Professor of Petroleum Engineering at the University of Texas, who had just passed away after a protracted illness. Dr. Dorfman, more than other any individual, was responsible for bringing the geopressured-geothermal state-of-the-art to its present technological readiness for commercialization by industry.

Allan Jelacic, Geosciences Team Leader, Geothermal Division, chaired the formal session and gave a historic overview of the conference that defined research needs and economic potential of the resource. First the Nevada Field Office and later the Idaho Field Office took the lead in setting research directions and managing the program. The major research activity was to flow-test ten Wells of Opportunity, provided by industry, as well as the Design Wells, of which four were drilled. Initial problems with calcium carbonate scale deposition and the safe handling and disposition of up to 30,000 barrels of geopressured brine per day were solved. A series of seminal conferences followed so that by the mid-eighties, the resource's extent and productivity were understood, and DOE's Geothermal Division was proceeding with technology transfer to industry. Allan Jelacic pointed out that currently the program is phasing down, with only three active wells remaining: Hulin, Pleasant Bayou, and Gladys McCall. Nevertheless, environmental monitoring, which to date has yielded no significant water quality or seismicity problems, will continue for several more years. The $190 million spent on the program yielded a number of major accomplishments, not the least of which was confirming USGS's initial estimate of the resource, which turned out to be the largest source of natural gas in the US. The economics of power production, however, are not attractive at this time, given the relatively low brine temperatures and current economic conditions in the energy sector.

The next speaker, Ben Eaton, of Eaton Operating Company, concentrated on the operating history of Gladys McCall and Pleasant Bayou Wells. Ben Eaton noted that early problems with scaling and acidification required frequent shutdown -- driving costs up. He stated that once these problems found solutions and proper injection techniques were adopted, the wells demonstrated reliable, long-term flow.

Michael Shook of INEL spoke next about the numerical modelling of the Pleasant Bayou well. The object of this INEL research was to check the accuracy of a currently used model for geopressured reservoirs referred to as 'the leaky fault model'. Data from transient pressure tests covering ten years of production from the Pleasant Bayou well should provide the corroboration. Mr. Shook noted that preliminary analysis strongly suggests the model to be accurate.

Michael Kramer of the California Energy Commission then analyzed the Geopressured resource in the State of California and pointed out a number of suspected geopressured basins throughout the State. Mr. Kramer noted that the Commission was proposing that GeothermEx identify the geopressured basins through an explicit exploration program with the goal of possible economic development of the resource.

Jane Negus-de Wys closed the session with a review of the organizations and mechanisms available for technology transfer -- organizations such as the American Association of Petroleum Geologists, the Industrial Consortium for the Utilization of the Geopressured Geothermal Resource, and the GRC, and mechanisms such as CRADAs and research consortia. Jane Negus-de Wys exhorted the attendees to give serious thought to "the best way to reach the market". She closed by acknowledging her debt to the leadership of Dr. Myron Dorfman.

# GEOTHERMAL WELL OPERATIONS AND AUTOMATION IN A COMPETITIVE MARKET

**Dr. B. A. Eaton, C. R. Featherston and T. E. Meahl**
**(Eaton Operating Company, Inc., Houston, TX)**
**Dr. P. L. Randolph**
**(Institute of Gas Technology, Chicago, IL)**

## ABSTRACT

America's increasing dependence on foreign energy sources, and the national environmental initiatives, based on the increasing awareness of the need for protection of environment, have led to the development of the Department of Energy's (DOE) domestic U.S. alternative energy programs.

One of these programs is the current U.S. Gulf Coast Geopressured-Geothermal Program, conducted at three sites in Louisiana and Texas. Excellent results have been obtained in reaching the objectives for this production operation and energy conversion project, which are:

- To determine the size of geopressured-geothermal reservoirs and the drive mechanisms by long-term, high volume, flow testing;
- Prove long-term injectability of large volumes of spent brine;
- Develop modified scale inhibitor treatment procedures;
- Develop methods for reduction of erosion/corrosion;
- Develop technology for automated operation of geopressured-geothermal production systems; and
- Develop technology to produce power economically from the geopressured-geothermal resources.

The long-term flow test at the Gladys McCall site has shown the producing reservoir is many times its original, projected size. Flow tests are being conducted at the Pleasant Bayou site in Texas. Another reservoir, at the Hulin site in Louisiana, remains for initiation of testing, at a time to be determined.

Gas sales and electrical power generation from the geopressured-geothermal resources have proven that these are reliable alternative power sources. Continuing work is being done for field automation to improve the economics of these operations.

## INTRODUCTION

The United States is becoming ever more dependent on foreign energy, primarily oil imports. This is presently the cheapest source of supply. If this source of energy supply is seriously curtailed or interrupted in the future, the economic costs of energy would escalate very rapidly. In view of this, the search must be continued for economic, environmentally acceptable, reliable domestic U.S. energy resources. The U.S. Department of Energy (DOE) Alternate Energy Research Programs are focused on identifying and developing the feasibility of these energy sources. One of the successful programs is the Gulf Coast Geopressured-Geothermal Program being conducted in Texas and Louisiana.

The geopressured (high pressure) - geothermal (hot) energy is found in this area in the form of high pressured salt water (brine) and gas, which is dissolved in the brine in these wells, but may also exist in a free state in other reservoirs. The geopressured-geothermal reserves in the Gulf Coast region occur from about ±12,000 feet to more than 21,000 feet (±3,659 to 6,402 m). The brine temperatures generally range from ±250° to ±400°F (±121.0° to ±204.4°C). The formation pressures range from ±7,800 psi to ±18,500 psi (±53.78 MPa to ±127.55 MPa).

Eaton Operating Company, Inc. (Eaton) (Houston, TX) and its subcontractors, the Institute of Gas Technology (IGT) (Chicago, IL) and The Ben Holt Co. (BHC) (Pasadena, CA), have conducted the field site operations. In Texas, this is producing a well at the Pleasant Bayou site (Alvin, TX) (Brazoria County) and operation of an Electrical Generation System. Two sites are operated in Louisiana, the Gladys McCall site (Cameron, LA) (Cameron Parish) and the Willis Hulin site (Abbeville, LA) (Vermilion Parish). All of these sites have a producing well and a brine disposal well. The geothermal brine and gas are produced in large volumes, 6,000 to 35,000 Bbl/day (954 to 5,565 $m^3$/day). The gas is separated and sold, or as during the electrical generation experiment, utilized for power generation. The brine is then injected into shallower formations at ±2,000 feet to 6,600 feet (610 m to 2,012 m).

Geoscience and engineering support for the program is provided by The University of Texas (Austin, TX), with S-Cubed (La Jolla, CA) and the Bureau of Economic Geology (Austin, TX), Louisiana State University (Baton Rouge, LA) with the Louisiana Geological Survey (Baton Rouge, LA), University of Southwest Louisiana (Lafayette, LA), and EG&G Idaho, Inc. (INEL, Idaho Falls, ID).

The flow testing to date has provided excellent data for reaching the objectives for this production and energy conversion project, which are:

- To determine the size of geopressured-geothermal reservoirs and the drive mechanisms by long-term, high volume, flow testing.

- Prove long-term injectability of large volumes of spent brine.
- Develop modified scale inhibitor treatment procedures.
- Develop methods for reduction of erosion/corrosion.
- Develop technology for automated operation of geopressured-geothermal production systems.
- Develop technology to produce power economically from the geopressured-geothermal resources.

This paper will focus on the activities which have taken place at these well sites during the period FY 1986 through the present, FY 1992.

## DISCUSSION

The DOE began its Geopressured-Geothermal Gulf Coast Program in the early 1970's. Nine "Wells of Opportunity", acquired from the oil and gas industry, were tested for short terms, usually of a few days, to determine the producibility of the brine and estimates of gas available with the brine. The second program consisted of four "Design Wells" drilled especially for the program, which were to be tested for longer periods. The Gladys McCall and Pleasant Bayou wells are two wells from this program. The Hulin well is a "Well of Opportunity" that was not tested in the original program. These well tests have shown the following in relation to the goals of:

A. **To Determine the Size of Geopressured-Geothermal Reservoirs and the Drive Mechanisms by Long-Term, High Volume Flow Testing**

1. Gladys McCall (Perforated Zone: 15,160-15,470 ft) (4,622-4,716 m)

This well was on production when operations were assumed by Eaton and its subcontractor, the Institute of Gas Technology (IGT) in October 1985. The well was then produced for total production of almost twenty-seven and a half million barrels of brine (4,343,380 $m^3$) by October 1987, when it was shut in for a pressure buildup test (Figure 1). It produced associated gas of 676,783 MCF (1,916.4 $m^3$). At the time it was shut in, it was producing ±18,000 BPD with very little pressure drop (Figure 2). The well remained shut in until November 1991. The well pressure almost fully recovered to its initial value (Figure 3). A short, 4-day flow test and pressure buildup test was completed in November 1991. The results of the long-term flow test and pressure buildup test caused the initial estimated reservoir size to be increased almost threefold to the present estimated volume of 7.8 billion barrels (1.24 x $10^9$ $m^3$). The well is in a shut-in mode at the present time.

A final decision has not been made as to whether to continue long-term testing, or to plug and abandon the well.

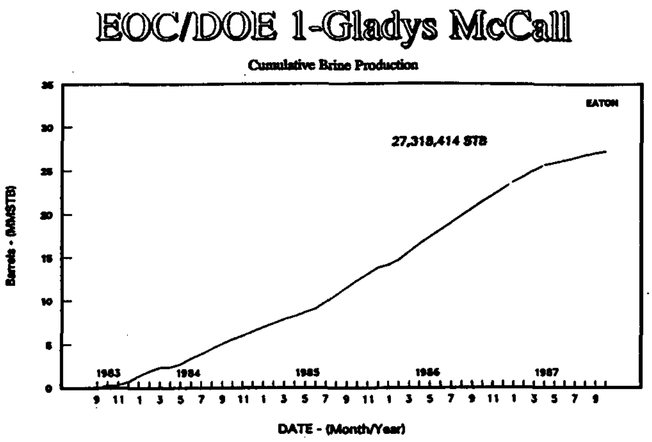



FIGURE 1

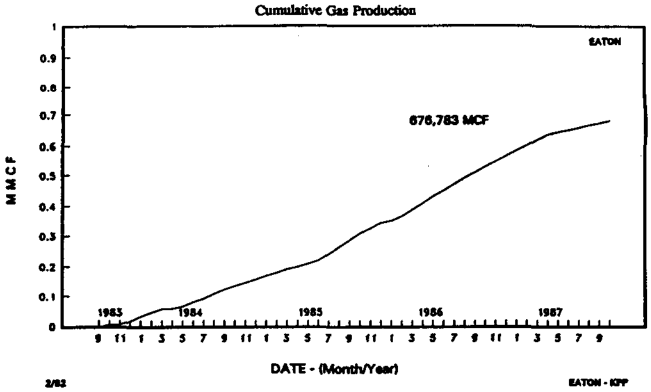



FIGURE 2

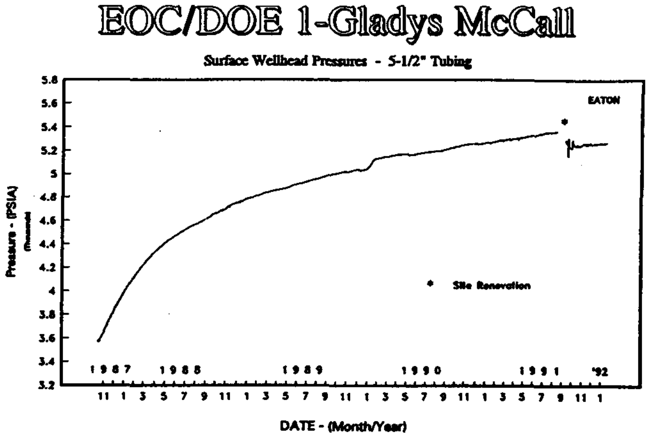



FIGURE 3

2. <u>Pleasant Bayou Well</u> (Perforated Zone: 14,644-14,704 ft) (4,465-4,483 m)

Prior to this contract, this well had been produced for several short tests and junked. Upon assumption of operations in October 1985, Eaton cleaned out and restored the production well, and disposal well, to operational status. Production facilities were installed and the well placed on production in March 1988. The well has been produced since that time at rates up to ±26,000 BPD (±4,134 $m^{3/day}$). As of January 31, 1992, it had produced over 21,700,000 Bbl (3,450,018 $m^3$) of brine (Figure 4). It had produced over 408,700 MCF (11,574 M $m^3$) of gas (Figure 5). The flowing pressure was 1,748 psi (12.05 MPa). This reservoir is now estimated to be ±6.26 billion barrels. Flow tests are continuing; the rate will be increased to ±30,000 BPD (4,770 $m^3$/D) to determine the effects of rapid withdrawal rates. A long-term, shut-in pressure buildup test will then be performed.

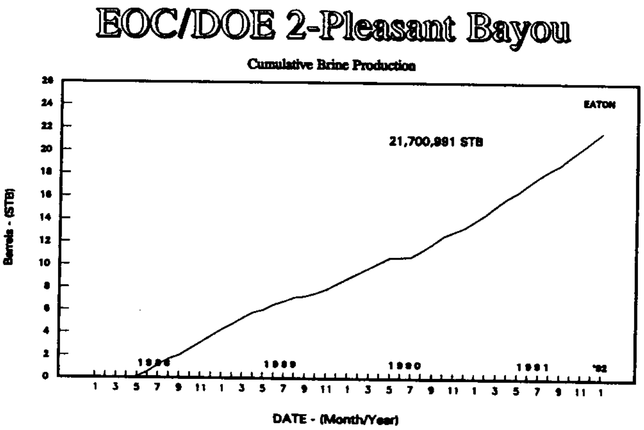



FIGURE 4

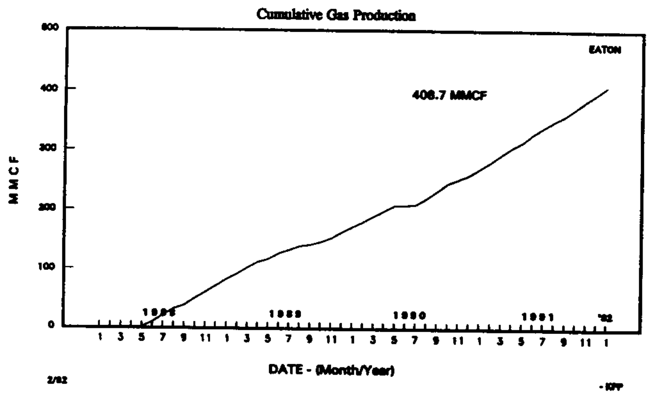



FIGURE 5

3. <u>Willis Hulin Well</u> (Perforated Zone: 20,220-20,690 ft) (6,165-6,308 m)

This well was in a mechanically damaged condition when given to DOE by the Superior Oil Company as a "Well of Opportunity" in 1984. The well was cleaned out and recompleted. The well was not given a significant flow test until December 1989. A total of 40,163 Bbl (6,385 $m^3$) of brine and 1,205 MCF (34.1 M $m^3$) of gas were produced.

The well is shut in. It requires the installation of a new wellhead, and possibly larger tubing. Production facilities must be installed before a long-term, high volume flow testing can be initiated for determination of reservoir size and producibility. The deeper sands in this well are hotter (±340°F) (171.1°C) and higher pressured (±17,130 psi) (118.1 MPa) than the other two wells, and provide more opportunities for geopressured-geothermal power generation.

B. <u>Prove Long-Term Injectability of Large Volumes of Spent Brine</u>

All sites have proven that these large volumes of produced brine, 6,000 to 30,000 Bbl/day (954 to 4,770 $m^3$/day) can be successfully disposed of in formations ranging in depth from ±2,000 to 6,600 ft (610-2,012 m). Injection pressures, depending on volume, have ranged from 0 to ±800 psi (5.5 MPa) through injection tubing of 5-1/2" to 7" (14 to 18 cm) in diameter.

The initial major problem was flowback of sand, plugging the wellbore, when injection was shut down for equipment repairs, etc. This problem has been almost eliminated by setting up storage tanks near the disposal well. These tanks are filled prior to shutting down production. A small stream of brine is flowed from the tanks into the well during the shutdown, preventing the loss of hydrostatic pressure, which would allow sand to flow back to the wellbore. Where the well has sanded up, the use of coil tubing and aeration of the fluid with nitrogen, to clean the sand from the wellbore, has been quite successful.

C. <u>Develop Modified Scale Inhibitor Treatment Procedures</u>

Prior to Eaton's assumption of the project, severe scaling occurred in the Gladys McCall and Pleasant Bayou wells during initial testing. These required extensive acid jobs to remove the scale from the tubing. The production tubing had scale deposits as thick as ±.25" (.6 cm). Initiation of chemical squeeze treatments developed by Dr. Mason Tomson, of Rice University, in which phosphonate, scale inhibiting, chemicals were injected into the producing formations for reaction with the formation, were attempted in the Gladys McCall well, but were unsuccessful due to high injection pressures. Eaton continued the development of this procedure with Dr. Tomson. With some surface injection of chemical in the low pressure part of the system during part of the production, almost nineteen million barrels of brine were produced with no scaling prior to the well being shut in for the pressure buildup test in 1987.

This experience was transferred to the Pleasant Bayou well. It has now (February 1992) produced almost 22 million barrels of brine with no significant scaling.

With the reduction of temperature and pressure, some slight scaling does occur in the disposal well perforations, causing an increase in injection pressure. In October 1990, this disposal well was acidized with 1,050 gallons of 15% HCL with inhibitor, at a cost of $1,327. The injection pressure dropped from 680 psi to 625 psi at a flow rate of 23,000 Bbls per day (Figure 6). The effects lasted approximately 2 weeks.

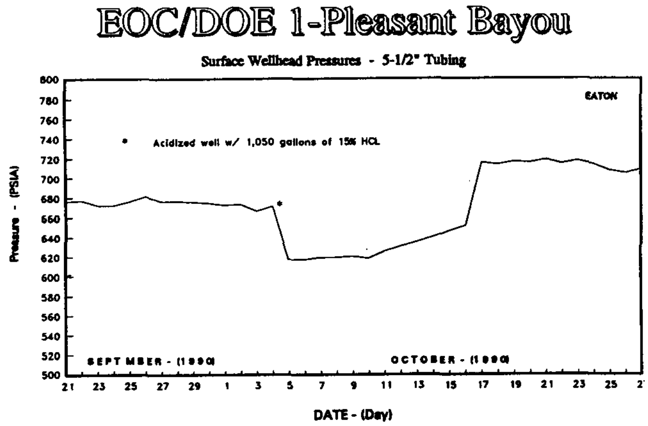



FIGURE 6

In December 1991 and January 1992, the same well and the same multiple perforations were acidized (Figure 7) with 3 gallons of 15% HCL with inhibitor, and 5 gallons of 15% HCL with inhibitor. The pressure dropped from 765 psi to 675 psi in the first case, and from 765 psi to 665 psi in the second case. These acid jobs lasted approximately the same amount of time; however, they are done by adding the acid to one filter pot after it has been filled with fresh water and flushing it down the hole with the disposal brine. The flow rate during this time was slightly more than 23,000 STB/D. The costs of these jobs were $16 and $30, respectively.

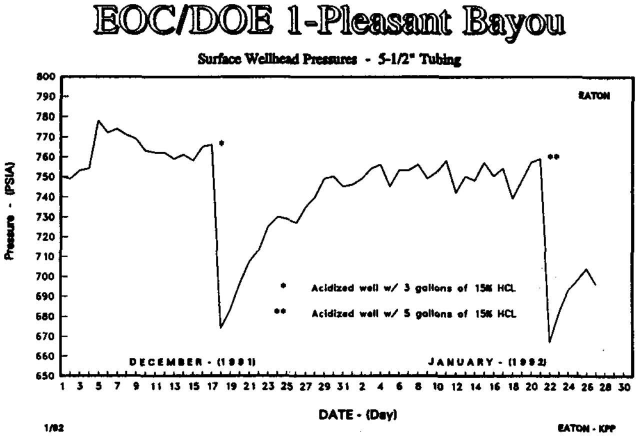



FIGURE 7

It appears that the very small acid jobs are as effective as the larger acid jobs, and that the injection pressure can be controlled for ±$360 per year, which will allow lower separator pressure and better gas separation from the brine.

The Hulin well, with its higher temperatures and pressures and its brine composition, presents new problems, as it will have more scaling tendencies. Cooling of the brine prior to injection may be required at high flow rates. Much is still to be learned from this research project.

D. <u>Develop Methods for Reduction of Erosion/Corrosion</u>

Related to scaling, are erosion/corrosion problems. They both affect operational downtime, efficiency of operations, and costs.

Soon after Eaton took over the operations of the geopressured-geothermal wells in October 1985, one of the first tasks to be accomplished was the repairing of the surface piping at the Gladys McCall site. Erosion/corrosion was very bad, and several lengths of surface piping had to be replaced. The scale inhibitor squeeze that had been done was effective in that the tubing was clean. Surface injection of scale inhibitor was effectively keeping the surface piping and equipment scale-free. Critical sections were replaced with stainless steel piping, and corrosion inhibitors were injected. These actions almost eliminated the erosion/corrosion problems.

Surface facilities were designed for the Pleasant Bayou site, utilizing the Gladys McCall experience. In an effort to reduce the erosion/corrosion damage to the surface piping, the maximum flow rate in the piping was established at 15 feet/second, and larger piping was used to limit the flow rate. Stainless steel was used at the points of maximum turbulence. However, it was necessary to use some of the existing older piping.

Continuous production of the Pleasant Bayou site was started in June 1988. A scale inhibitor pill was injected prior to start-up, and the well was on production 93.2% of the time. By September 1988, the first leak in the production piping occurred upstream of the separators. This old piping was replaced, and the use of a corrosion inhibitor was started. In October 1988, 5 days after starting the corrosion inhibitor, a second leak occurred in the old production piping. This piping was also replaced, and the inhibitor use continued. No significant leaks in the production piping have occurred to date.

X-rays of various suspect points have been taken periodically, and no deterioration of the metal has been seen. At the flow rate of 23,000 barrels per day, the cost for the corrosion inhibitor is $98.50 per day.

During 1989, the Hybrid Power System (HPS), which is the electrical generation system utilizing the heat and gas, was built. Many days were spent in safety inspections and component testing to ensure all equipment was to top industry standards.

During the year of 1989, this well was produced 78.4% of the time.

During July, August and September of 1989, the production wellhead valves and the production wellhead flow loop were reconditioned due to internal damage, as determined by periodic inspections. The flow loop was repaired, and a special stainless steel ring gasket, slightly longer, was installed. At this time, a preventive maintenance of all wellheads was begun, using special high temperature, high pressure grease every three months. This procedure costs approximately $1,000 per treatment. No repairs have been necessary since this time.

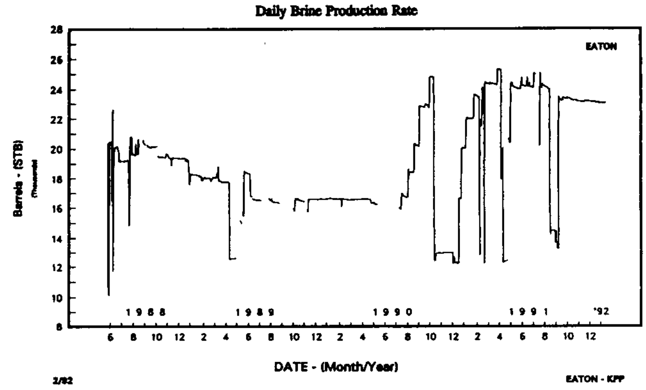
A scale inhibitor pill was injected into the well during November 1989. With the use of a surface scale inhibitor, scale has not been a problem to date. At the rate of 23,000 barrels per day, the cost of this inhibitor is $33.00 per day.

In June 1990, the disposal well developed a leak in the tubing. During July, the well was worked over and the tubing and packer replaced. In order to remove the turbulence created by the collared pipe, the lower 2,500' of the 5-1/2" tubing was replaced with internal flush (smooth) joint pipe.

The well was produced 84.1% of the time.

During 1991, the well was operated 96.7% of the time. The only downtime was due to the recalibration of surface gauges and relief valves. (Operations and downtime are shown on Figure 8.)

EOC/DOE 2-Pleasant Bayou




DOWN TIME - Occurrences

| | | |
|---|---|---|
| Sept | 1988 | Leak in production piping, Hurricane Gilbert. |
| Oct | " " | Choke replacement & general preventive maintenance. |
| May | 1989 | BHP & flow splitter installation. |
| June | " " | Tropical Storm Allison. |
| July | " " | Production wellhead flow loop and wellhead valve repair. |
| Aug | " " | Production wellhead valve repair. |
| Sept | " " | Production wellhead valve repairs. |
| Oct | " " | Safety inspection - system component testing. |
| Nov | " " | Inhibitor pill. |
| June | 1990 | Disposal well tubing/casing communication. |
| July | " " | Disposal well workover. |
| July | 1991 | Yearly calibration. |
| Aug | " " | Recalibration of surface gauges & relief valves. |

FIGURE 8

It now appears that the well can be operated ±98% of the time, with only the yearly recalibration and possible hurricane shut-ins. Scale pills and bottom hole pressure surveys will be planned to coincide with the recalibration procedure whenever possible.

E. **Develop Technology for Automated Operation of Geopressured-Geothermal Production Systems**

Based on the production experience at the Gladys McCall well, many improvements were made to the design of the Pleasant Bayou system when it was installed in 1988. In addition to the scaling, erosion/corrosion areas, additional data collection and automation systems were installed. These include data logging and real time calculation of flow rates with desk top computers. The data system operates off an uninterruptable power supply that provides several hours of backup 110 volt, 60 cycle power. The computer system scans the outputs of all sensors every 10 seconds.

With the existing computer software, up to 16 of these values are compared with user selectable high and low alarm levels on every scan. Whenever an alarm level is exceeded, a real-time printout of the event is made on the printer output, the triggering of the alarm is recorded on computer discs, and "beeping" of the computer is initiated. The beep repeats every 10 seconds until the alarm is reset by the operator, independent of whether the sensor output has returned to the normal range.

A card in the computer system provides a separate relay closure for the triggering of each of the alarms. The relay remains closed until reset by the operator, the same as the "beeping". The relay closures can, in turn, be used to activate other devices, such as warning lights, sirens, or automatic telephone dialing. With minor changes in the existing software, data values could also be provided to an automatic telephone system.

The first use of an automatic telephone dialing system would involve alarm levels that provide early notice of deviation from normal operation, so that a person could drive to the location and initiate corrective action before an emergency condition existed. If an emergency condition should develop, the pneumatic/hydraulic emergency shutdown (ESD) system, that is independent of the computer system, would automatically shut in the production well.

As operating experience provides a tangible basis for confidence, it is visualized that changes would be made in the software and field hardware such that some corrective actions could be initiated over the telephone lines. Possible actions are turning on of a backup air compressor, starting a backup generator, or reducing the brine production rate. If reliability of telephone service provides a concern, a separate radio link communication could be provided for a modest increment in cost.

The computer at Pleasant Bayou was set up for alarm systems, etc. at the initial installation. By adding an automatic phone dialing system with micro-alarm hardware, automatic telephone dialing can be accomplished. The cost and installation of this system is estimated to be $10,000.

After shakedown of the system, the operator load could conceivably be reduced from 24 hours per day to 40 hours per week for 2 men, and reflect a possible savings of up to $150,000/year for the operation.

The risk would be slightly more in that failures of the surface equipment could occur. These risks are minimal, because the emergency shutdown system for the surface equipment would be activated, shutting in the well.

Utilizing the experience from Gladys McCall and Pleasant Bayou, a more automated system could be designed and installed for the Hulin well, for its long-term flow test. This system would probably not be activated for at least one year, due to the unknown nature of the production problems at this location. After a satisfactory shakedown, the system could be activated and operated similarly to the Pleasant Bayou site. The possible reduction in operating costs should be similar.

F. <u>Develop Technology to Produce Power Economically from the Geopressured-Geothermal Resources</u>

A prime obstacle to economic utilization of these resources has been maintenance of efficient operations. As discussed above, the early problems of scaling and erosion/corrosion have now almost been eliminated. The development of automated systems is well on its way. These will allow reduction of operating personnel and costs when implemented. The Electrical Generation System was the first use of a Hybrid System, utilizing the flashing of liquid hydrocarbon, by geothermal heat, through a turbine and driving generators by gas powered engines, utilizing the exhaust heat from the engines for additional brine heating. Even though most of the equipment was obsolete, it was proven that this was a viable means of power generation.

By the use of automation of operations and utilizing modern power generation equipment, with the hotter temperatures and pressures of the Hulin well, the goal of economic power generation will be much closer to realization.

## CONCLUSIONS

In the early days of this program, the production wells could only be produced a few days before scaling occurred, requiring shutdown and acidizing. This was accompanied by frequent sanding up of the disposal wells, requiring clean-out. Leaks in the production system were frequent. All of these increased costs and reduced time on production. During operation of the project by Eaton and its subcontractors and support groups, many accomplishments have been made, such as:

- Long-term, high volume production has established that high volume reservoirs, with good productivity, are present at Gladys McCall and Pleasant Bayou. Additional testing is required for full definition of these reservoirs and Hulin.
- Injection problems have been almost eliminated at all sites.
- Development of effective scale inhibitor squeezes and surface treatment methods have eliminated scale problems at Gladys McCall and Pleasant Bayou. New problems exist at Hulin.
- Design for critical flow piping, utilizing larger diameters and stainless

steel at critical points in conjunction with scale inhibitor treatments, has almost eliminated erosion/corrosion problems at Gladys McCall and Pleasant Bayou. This experience will be utilized for the design of the Hulin facilities.

- Significant progress has been made in automating electronic data collection. Designs have been made and equipment identified for more automation of operations. When implemented, this can reduce the number of personnel required on site.
- The successful operation of the Electrical Generation System, with old equipment, shows the potential for use with modern equipment on the Hulin well.

These accomplishments are positive steps toward satisfying the DOE Geopressured-Geothermal Program objectives. The flow test, at higher rates, of the Pleasant Bayou well and flow testing of the Hulin well are critical to the identification and qualification of these resources.

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# Reservoir Modeling and Prediction at Pleasant Bayou Geopressured-Geothermal Reservoir

Mike Shook
Idaho National Engineering Laboratory

## ABSTRACT

Modeling and prediction of geopressured-geothermal reservoirs is an excellent example of an engineering problem that can be solved through many different means. The problem may be approached from a purely numerical viewpoint, where a successful history match "demonstrates" the validity of the reservoir model, or from an analytical point of view. Each method has its own inherent limitations and weaknesses. Such limitations can be minimized by using some combination of both numerical and analytical methods, taking advantage of the strengths of each without the attendant weaknesses.

This paper describes a combined numerical/analytical approach to reservoir engineering at the Pleasant Bayou geopressured-geothermal reservoir. A reservoir description had previously been developed, through which a successful history match was performed. Certain details of the reservoir can also be obtained through analysis of pressure and flow transients; these can then be used to constrain the numerical model. Methods for extracting such reservoir data are discussed, and the manner in which they can be used as constraints in the numerical models are presented.

## INTRODUCTION

Reservoir engineering is a branch of engineering that seeks to quantify the relationships between a given fluid reservoir in the subsurface and that reservoir's response to exploitation. The most important step in this process is development of an accurate reservoir description. It is interesting to note that reservoir engineering is among the few branches of science that relies almost exclusively on indirect measurements to develop a working model. Historically, the reservoir engineer has relied on core analysis, electric logs, and pressure transient testing for the reservoir model.

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In the last decade more and more reservoir engineers have come to the realization that additional data is, in general, available. Geologic maps can be incorporated in the engineering work, as can seismic information. Simulation studies are also useful in developing a reasonable reservior description. Thus, the successful reservoir engineer has evolved into one that incorporates data from a variety of sources in developing his reservoir model.

In geopressured reservoirs, this incorporation of data is not just useful, it is crucial. The lack of well data (usually one per reservoir) means that little or no core or log data can be obtained areally. The only avenue open to the engineer is to incorporate reservoir information from geologic work and seismic profiles, and data from single well pressure transient tests. Failure to incorporate any available data places excessive limitation on the engineer's ability to develop a realistic reservoir model. The goal of the reservoir engineer is to predict future reservoir response to exploitation; an incorrect model will ultimately lead to incorrect predictions.

This paper is intended to describe the approach taken to develop a reservoir model for the Pleasant Bayou geopressured reservoir. This approach takes advantage of a numerical model of the reservoir developed previously, and incorporates transient test analysis to constrain and improve upon the numerical model.

## A NUMERICAL MODEL

A numerical model of the Pleasant Bayou reservoir was developed at INEL in FY 91. This numerical model incorporated data from a variety of sources: reservoir geometry based on geologic interpretation by U. Texas Bureau of Economic Geology (UT-BEG) (Hamlin and Tyler, 1988), production data (rates and pressures) and fluid composition from Eaton Operating Co. and

IGT (EOC, 1990), and estimates of permeability (based on transient analysis) from S[3] (Riney, 1991). Fluid properties based on composition were taken from a various sources in the literature. These properties are detailed in INEL's 1991 annual geopressure-geothermal report, and are summarized in Table 1.

After incorporating realistic geometry and geology in the Pleasant Bayou reservoir model, a history match of 1988-1990 production was attempted. This effort was also presented in the FY91 report, and is shown graphically in Figure 1. It can be summarized by noting that a successful history match for the complete period required a pressure-dependent flow boundary southwest of the test well. This boundary is proposed to be a geopressured compartment boundary. It is a no flow boundary as long as the pressure drop across the boundary remains small; for a sufficiently large pressure drop, the integrety of the boundary fails, and fluid can flow. There is no well control data southwest of the test well, nor has seismic work been performed in this area. While this lack of evidence certainly does not support a presence of a leaky compartment boundary, it does not preclude its presence either. The final working model developed in this earlier study is shown in Figure 2.

Despite the good production history match obtained, there is no guarantee that the reservoir description used in the model was accurate. This type of a problem is known as under-constrained — that is, the data is so sparse that many different reservoir descriptions could conceivably lead to similarly successful history matches. It would seem, then, that additional work is required before concluding that an accurate reservoir description has been developed.

## TRANSIENT TESTING

Fortunately, a great deal of data is available from pressure transient tests performed since 1980. This data is in the form of downhole pressures and rates versus time. Some analysis of these data have been done; in fact, transient analysis (Garg et al., 1981) yielded the value for permeability used in the numerical model, and further suggested the presence of a flow boundary near the well. While this analysis has been extremely useful, additional data may be gleaned from these tests. In particular, one may extract reservoir size and shape from late time behavior of the reservoir during these tests. These data can then be used to further enhance the numerical model, and to test certain details of the model. Examples of the analyses are summarized below. Details of the techniques that are used are given in (eg) Earlougher (1977).

### Drawdown Testing

Testing that is performed while the reservoir is flowing is known as drawdown testing. In its simplest form, a well is produced at a constant rate, and downhole pressures are measured through time. After accounting for wellbore storage, the plot of bottomhole pressure versus log time becomes linear. From the slope of this line one may extract reservoir permeability. The well skin can be obtained from the intercept of the pressure-time plot. This period is known as the "infinite acting period", in that the reservoir acts as though it were alone in an infinite reservoir.

If the well flow rate is not held constant, as is often the case, a similar, though more complicated, relationship holds for permeability (Earlougher, 1977). Care must be taken in the application of these techniques, since the method most often used is applicable for infinite acting periods of time only (Dake, 1978). Multi-rate analysis can still be done; however, more complex methods of superposition must be used.

If a drawdown test is conducted for sufficiently long a period of time, the reservoir is said to enter "pseudo steady state", wherein the pressure everywhere in the reservoir declines at a constant rate. When this occurs, a plot of pressure vs time is linear. From the slope of this line, and the intercept, one can extract the reservoir size and approximate shape.

Finally, a flow barrier, such as a fault, is indicated by the doubling of the slope in the infinite acting period. It should be noted, however, that many other causes can appear to double the slope. For example, a permeability transition away from the well, or neglecting to account for wellbore storage can also "look" like a fault.

### Buildup Testing

Shutting a well in causes another pressure pulse in the reservoir. Measurements of pressure vs shutin time can again lead to estimates of permeability and well skin. Fault detection is another feature of pressure buildup testing. If the well is shut in for a sufficient period, additional analyses can also be performed to estimate reservoir size and shape. Methods of analysis are extremely dependent on the rate history of the well (Earlougher, 1977; Dake, 1978). Various methods of superposition are required when well rates vary appreciably, or when shutin times are the same order of magnitude as production times.

It should be obvious that an appreciable amount of information may be gleaned from transient test analysis. Furthermore, these techniques may be applied to periods of "normal" production (that is, periods when a test was not planned). An example of this is given in a following section.

**STATUS OF THE COMBINED ANALYSIS**

To date, seven periods of time have been identified that are amenable to transient testing, including the 1980 reservoir limits test, the1988 multi-rate test, and three pressure buildup tests when the well was shut in. Other possible time periods exist. For example, Oct 1989 - May 1990 consitutes a period of time in which the flow rate was held essentially constant. This period of flow was preceeded by over 1000 hours of pressure buildup, so the reservoir can be assumed to be essentially static. The flow period was followed by a 60 day buildup, and therefore we can also do a buildup analysis. Because this was not a designed test, appreciable pressure data was not collected; however, daily production rates and pressures were reported. Because of the difficulty in predicting wellbore storage effects without early time pressure data, care must be exercised in analysing the data.

Pressure-time plots are given in Figures 1 and 2. Times over which these plots were made were selected such that relevent analyses could be made from the available data. In particular, pseudo-steady state behavior was considered, and a buildup analysis was performed.

Some reservoir information is required to perform the relevent tests. In particular, the static reservoir pressure must be known. This can be estimated through material balance:

$$QB/V_p = c(P_I - P)$$

where Q is the cummulative production to data, B is the fluid volume factor, c is the reservoir pore compressibility, and PI is the initial pressure. From the reported data, the reservoir pressure at the beginning of this flow period is estimated to be 10,136 psia.

This estimate of reservoir pressure involved the use of the reservoir pore volume, Vp. Vp was found from the drawdown analysis, from the relationship:

$$Vp = 0.23395qB/(m^*c_t)$$

where $m^*$ is the slope of the pressure-time curve and $c_t$ is the total compressibility. The total connected pore volume from this test was found to be $2.31 \times 10^{10}$ $ft^3$. It should be noted that this is approximately half of the pore volume reported by Hamlin and Tyler (1988).

From the buildup portion of this analysis, a reservoir permeability is found to be 181 md, consistent with the values published by Garg et al. (1981). The well skin from this data is 3.8 larger than suggested by Garg et al., but smaller than other reported values for skin (Riney, 1991). More importantly from the context of this paper, an apparent fault is identified, at a distance 5740 feet from the well.

When interpreting these test results, and applying the results to the numerical model, several features are interesting. First, the pressure-dependent flow boundary to the southwest of the test well extends from the fault mapped by Hamlin and Tyler (1988) to the southern boundary of the reservoir. This boundary does not begin to leak in the model until later in 1990; therefore this would act as a linear flow boundary. This boundary (and the mapped fault) are at a distance of approximately 6000 feet from the well. The similarity between this value and the transient result is startling. Furthermore, this boundary effectively seals off the reservoir to the southwest. If this portion of the reservoir is not in communication with the well, the total communicating pore volume is approximately 55% that of the volume suggested by Hamlin and Tyler. Again, the similarity between this fraction and that from the transient test is extremely good. While these comparisons do not "prove" our numerical model, good agreement between these analyses tends to support the numerical model as feasible.

Reservoir properties estimated from these two approaches are summarized in Table 2.

## CONCLUSIONS

A study in underway that incorporates analysis of transient pressure tests in an existing numerical model. From analysis of several different time periods, covering over ten years of production at Pleasant Bayou, reservoir properties, including reservoir size and shape, will be extracted. These estimates will be used to enhance and improve the numerical model. Analyses over time will allow us to comment on the "appropriateness" of the current leaky fault model proposed in the INEL reservoir description of Pleasant Bayou. Analysis done to date shows that the numerical model developed is a reasonable model of the correct reservoir description.

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**Table 1. Summary of Parameters Used in Pleasant Bayou Reservoir Model**

| | |
|---|---|
| **Rock Properties** | |
| Pore Volume ($ft^3$) | $4.2 \times 10^{10}$ |
| Pore compressibility ($psi^{-1}$) | $3.2 \times 10^{-6}$ |
| Porosity | 0.09 top, bottom layers (distal)<br>0.18 middle (proximal volume) |
| Permeability (md) | 25. distal volume<br>172. proximal volume |
| **Fluid Properties** | |
| Bubble point pressure at $T_R$ (psia) | 6500. |
| Viscosity (cp) | 0.27 |
| Standard density ($lb/ft^3$) | 69. |
| Formation Volume factor | 1.045 |
| **Initial Conditions** | |
| Pressure (psia) at 14,000 ft SS | 10,708. |
| Temperature (°F) | 306. |

**Table 2. Summary of Reservoir Parameters from Well Test Analysis and Numerical Studies.**

| Property | Transient Analysis | Numerical Model |
|---|---|---|
| Connected Pore Volume ($ft^3$) | $2.31 \times 10^{10}$ | $2.2 \times 10^{10}$ |
| Permeability | 181 | 172 |
| Distance to fault (ft) | 5740 | 5900 |

Figure 1. History Match of 1988-1991 Production.

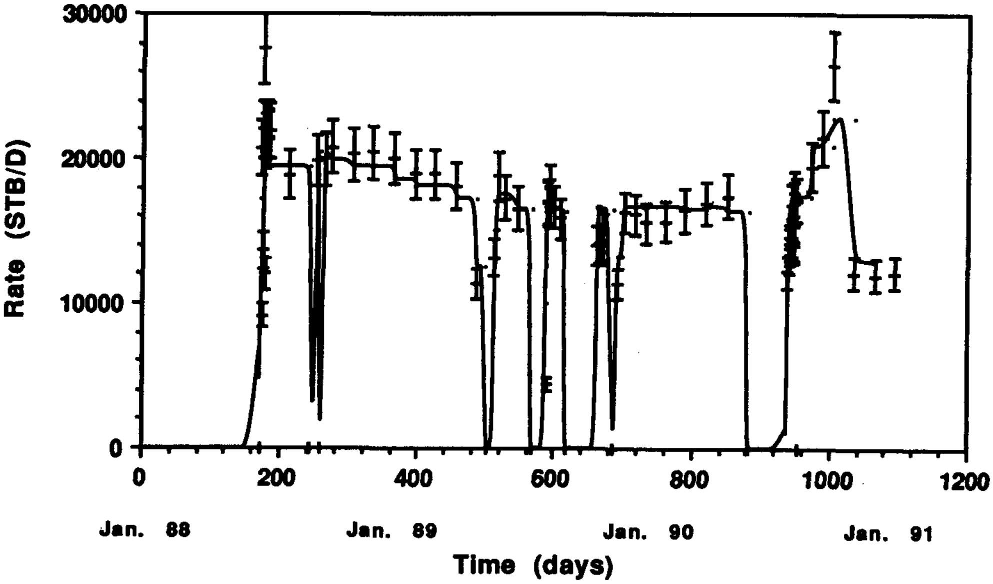
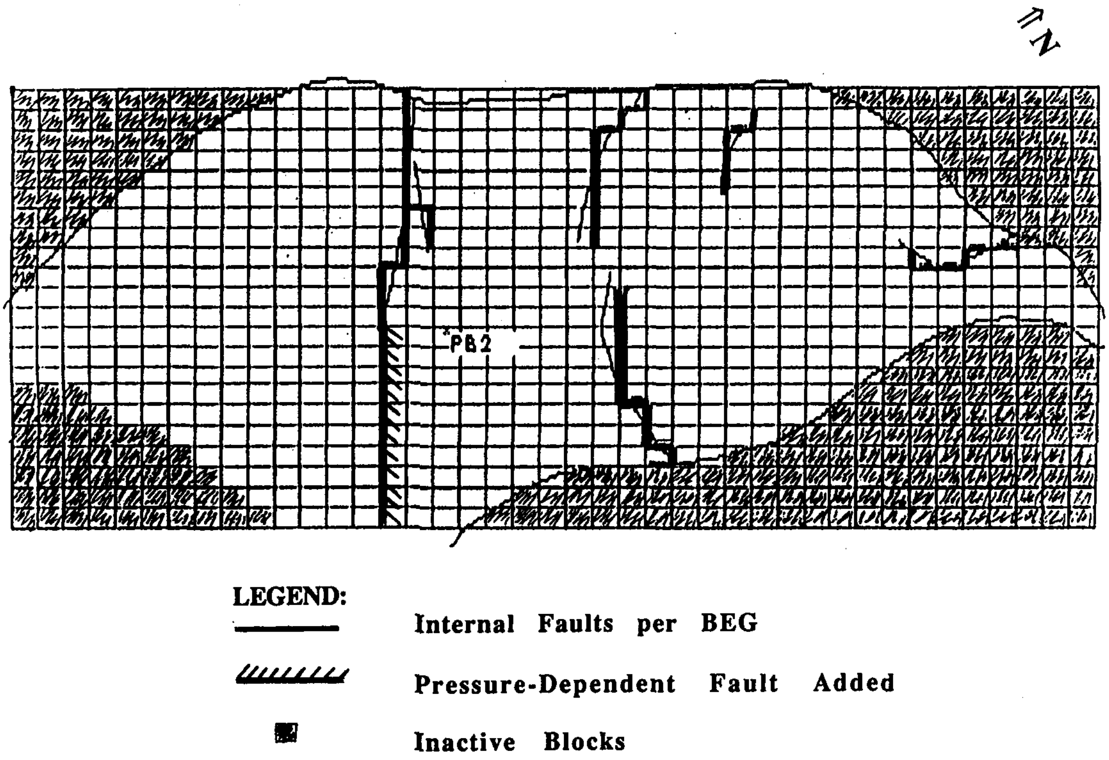


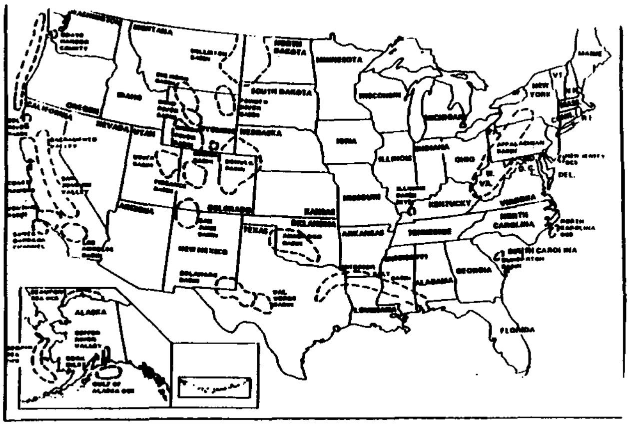

Figure 2. Working Map of Pleasant Bayou, Plan View.



# Survey of California Geopressured-Geothermal Potential

Kelly Birkinshaw
California Energy Commission

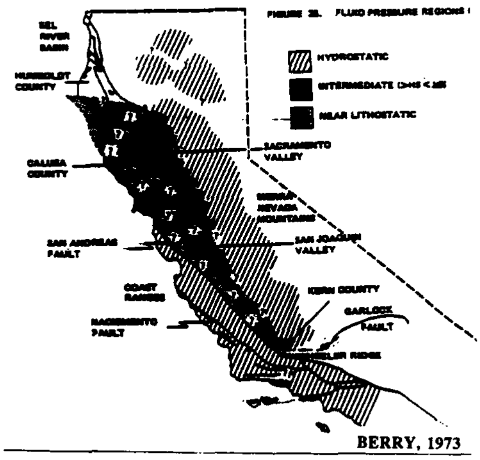
Geopressured reservoirs contain three types of energy: thermal, hydraulic, and methane gas. The thermal energy generally is a function of depth of burial. It can be converted to electricity using the binary or flash power plant cycle, the flash technology being commercial only if the fluid temperature exceeds about 340°F. The hydraulic energy can be converted to electrical power using a hydraulic turbine. The dissolved gas can be separated and either used to produce electricity using a gas turbine or sold commercially.



GEOPRESSURED LOCATIONS IN
US OUTSIDE OF THE GULF COAST
STRONGIN, USDOE FINAL REPORT, PHASE I, 1980

**FIG. 1**
**STRONGIN, O., USDOE/NV/10133-1, 1980**

These reservoirs occur in many states in the USA, including California. (Fig.1,2) An overburden pressure is caused by the combined weight of the formation rock and the fluids (water/gas/oil) present in the pore spaces overlying the formation of interest. The overburden pressure, in general, increases relatively uniformly with depth, whereas the hydrostatic gradient is mainly a function of two variables: the dissolved solids concentration and the temperature gradient. The hydrostatic pressure gradient for fresh water is 0.433 psi/ft. Geopressured reservoirs are overpressured; that is, the fluid pressure in the reservoir exceeds the pressure corresponding to the local hydrostatic pressure gradient. (Fig. 3) Confining bed or cap rock is necessary in order for a formation to be geopressured. Otherwise, the pressure would equalize to hydrostatic through upward flow. The pressures in a geopressured reservoir may approach the overburden pressure of about 1 psi/ft.



BERRY, 1973

GENERALIZED MAP OF GEOPRESSURED POTENTIAL IN CALIFORNIA
- WEST SIDE OF CENTRAL VALLEY
- NORTHERN COAST RANGE
- LOS ANGELES BASIN
- VENTURA BASIN

**FIG. 2**
**BERRY, F.A.F., 1973, BULL. AAPG, V.57, NO. 7**

Gulf Coast geopressured reservoirs typically exist between 12,000 to 20,000 feet below the surface. Flow rates of between 10,000 to 40,000 barrels per day, temperatures from 270° to 500°F, bottom hole pressures from 12,000 to 18,500 pounds psi, salinities of 20,000 to 200,000 milligrams per liter, and gas contents of 23 to 100 standard cubic feet per barrel, have been reported from geopressured wells.

There are several suspected geopressured basins in California. Some of these are prospects for commercial development of the geopressured-geothermal resource, for example parts of the Sacramento Valley, San Joaquin Valley, Los Angeles Basin, and the Ventura Basin. (It is in the interest of the people of California to assess the geothermal potential of these geopressured basins.)

The Commission proposes that GeothermEx, Inc., identify the basins in California that are geopressured. GeothermEx will:

1. Gather all publicly available information on the suspected geopressured basins of California.

2. Develop a map of California showing the sedimentary basins with prospects for the occurrence of geopressured reservoirs overlain on a temperature gradient map of the state. From this map and the supporting database, identify the most favorable geopressured geothermal prospect areas in California.

3. Based on the data available publicly from the files of the California Division of Oil and Gas, and other published and unpublished sources, prepare a list of the deep wells (oil, gas, geothermal, water, or waste disposal) existing within the prospect areas and the type of well pressure, temperature, and gas content information available on each well. (Other sources of such information include the Rocky Mountain Well Log Service.) From each basin choose several wells with the most complete suite of well logs and pressure, temperature, and gas content information available from public sources. Collect the database on these wells. Several dozen such wells are expected to be available for study.

4. From the well logs of the selected wells in each basin, prepare suitable profiles of such variables as measured pressure, temperature, resistivity, sonic travel time, density, neutron capture cross-section, etc., versus depth. (Fig.4,5) Use these plots to define the location of the top and bottom of the geopressured reservoirs, if any, encountered by these wells and estimate the amount of overpressure, temperature, and gas content, if practicable. (Fig.6,7)

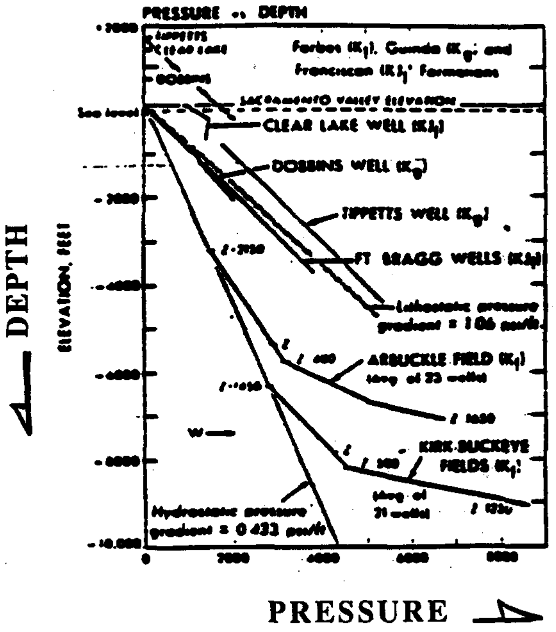
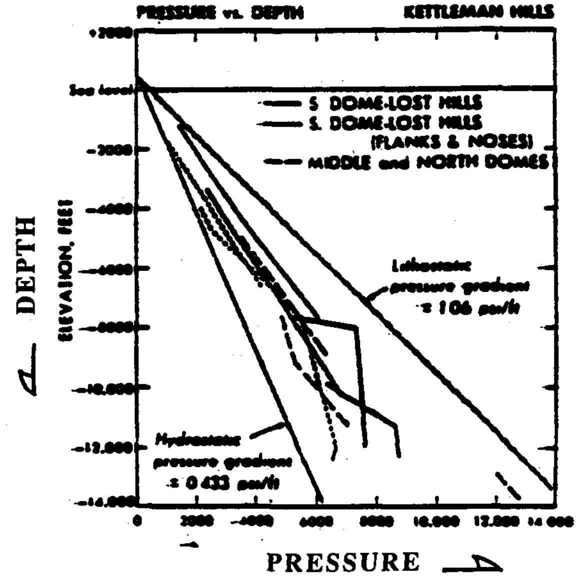



**Fig. 37. Pressure gradients in selected wells and fields in Sacramento Valley (Berry, 1973)**

FIG 3 (A & B)
BERRY, 1973, BULL. AAPG, V.57, NO.7




PRESSURE ABOVE NORMAL GRADIEN
TEMPERATURE AT OR ABOVE NORMA
GRADIENT

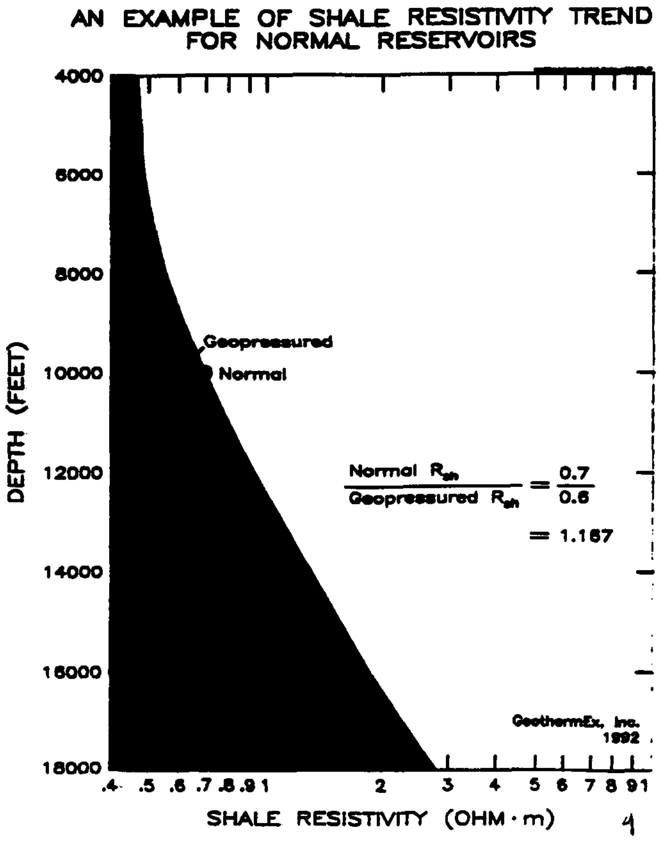
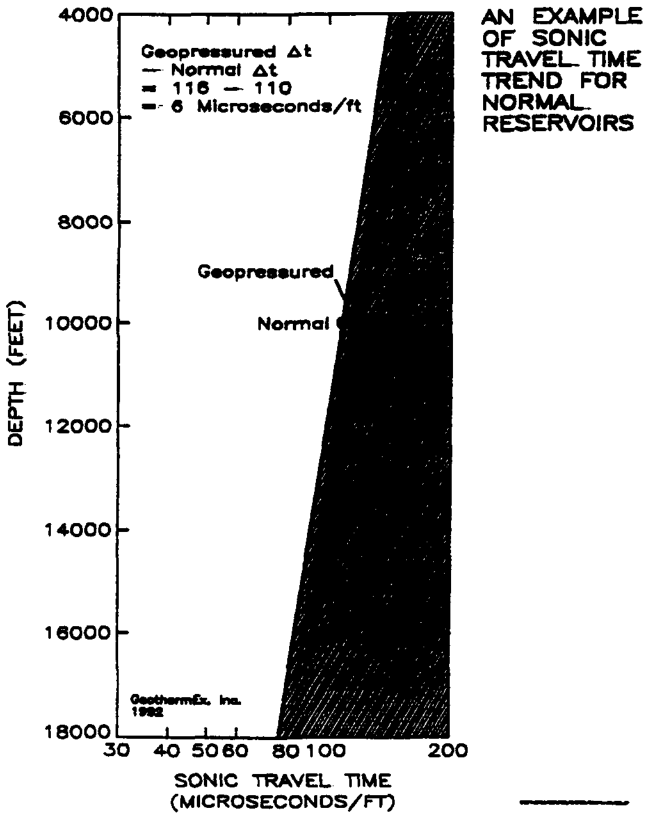



FIG. 4 (ABOVE), 5 (BELOW) DR. S. SANYAL, GEOTHERMEX, RICHMOND, CA.



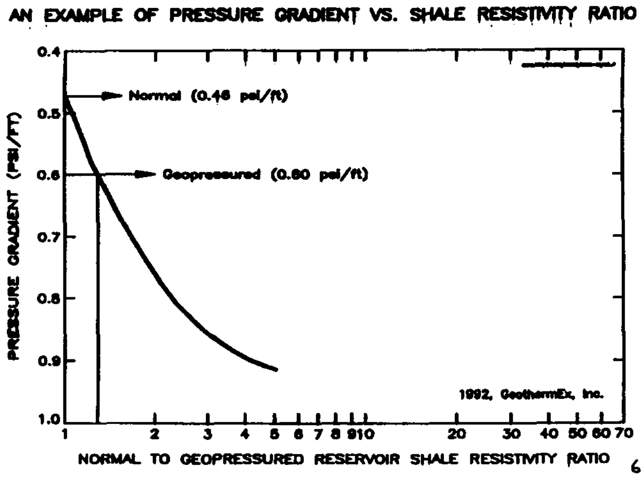
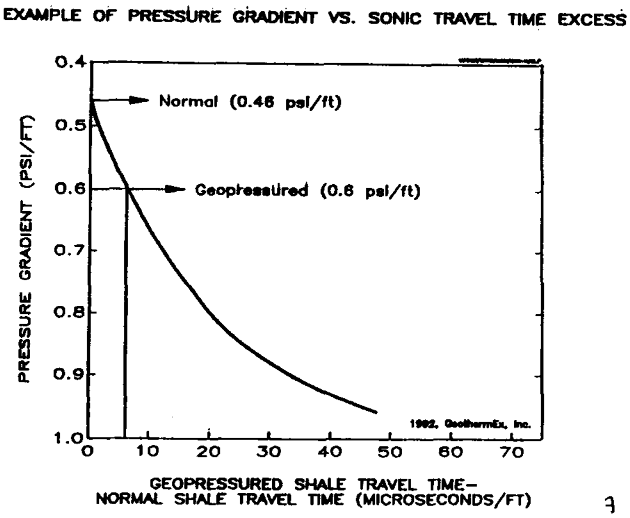




FIG. 6 (ABOVE), 7 (BELOW) DR. S. SANYAL, GEOTHERMEX, RICHMOND, CA.




5. Based on the results of Task 4, identify the geopressured geothermal basins in California and estimate the depth of occurrence of geopressure in each.

The staff at the California Energy Commission will, while GeothermEx is investigating, make inquiries to the operators of various large gas and oil fields in the state for voluntary information on the occurrence of geopressured resources in those fields. The responses will be concatenated with the results from GeothermEx for ultimate release as a publication from the CEC for public use. Follow up by the CEC may include, as warranted, close commercial cooperation with field operators in the development of pilot programs.

# TECHNOLOGY TRANSFER, REACHING THE MARKET FOR GEOPRESSURED-GEOTHERMAL RESOURCES

J. Negus-de Wys, PhD
Idaho National Engineering Laboratory

**Abstract**

Technology transfer to the industrial sector for geopressured-geothermal technology has included diverse strategies, with successes and obstacles or roadblocks. Numerical data are tabulated in terms of response to the various strategies. Strategy categories include the following: feasibility studies and reports, consortium activities and proceedings, the Geothermal Resource Council, national and international meetings of the American Association of Petroleum Geologists, other societal and organizational meetings and conferences, Department of Energy solicitation of interest in the Commerce Business Daily, industry peer review panels, and the Secretary's Technology Initiative. Additionally, the potential of a 12-page color brochure on the geopressured-geothermal resource, workshops, and cooperative research and development agreement (CRADA) is discussed.

In conclusion, what is the best way to reach the market and what is the winning combination? All of the above strategies contribute to technology transfer and are needed in some combination for the desired success. The most successful strategy activities for bringing in the interest of the largest number of industries and the independents are the consortium meetings, one-on-one telephone calling, and consortium proceedings with information service followup. The most successful strategy activities for bringing in the interest and participation of "majors" are national and international peer reviewed papers at internationally recognized industry-related society meetings, and on-call presentations to specific companies. Why? Because quality is insured, major filtering has already taken place, and the integrity of the showcase is established. Thus, the focussed strategy is reduced to a target of numbers (general public/minors/independents) versus quality (majors). The numerical results of the activities reflecting four years of technology transfer following the 15 year lead in the early phases of the geopressured-geothermal program under the leadership of Dr. Myron Dorfman, reflect a dynamic surveying of what works in technology transfer with industry in the area of geopressured-geothermal resources. The identified obstacles can be removed and future efforts can benefit by this cataloging and discussion of results.

**Introduction**

The Department of Energy has conducted a Geopressured-Geothermal Program for the past seventeen years, concentrated on the onshore Gulf Coast of Texas and Louisiana. In the early years of the program technology transfer was accomplished through annual conferences at the University of Texas at Austin, coordinated and led by Dr. Myron Dorfman.

In the last four years other strategies have been employed to accomplish technology transfer to industry and encourage participation in commercialization of the resource. These strategies include the following: feasibility studies and reports, consortium activities and proceedings, Geothermal Resource Council meetings, meetings of the American Association of Petroleum Geologists, other societal and organizational meetings and conferences, DOE solicitation of interest in the Commerce Business Daily, industry peer review panels, a color brochure on the resource, and the Secretary's Technology Initiative. Additionally, the potential of workshops and CRADAs has been explored.

**Feasibility Reports**

Following an economic report issued in 1989, Economic Review of the Geopressured-Geothermal Resource with Recommendations, EGG-2581, four feasibility studies were conducted by the INEL as follows: 1) The Feasibility of Recovering Medium to Heavy Oil Using Geopressured-Geothermal Fluids, 2) The Feasibility of Hydraulic Energy Recovery from Geopressured-Geothermal Resources, 3) The Feasibility of Applying Geopressured-Geothermal Resources to Direct Uses, and 4) Feasibility Study: Application of the Geopressured-Geothermal Resource to Pyrolytic Conversion or Decomposition/Detoxification Processes. These reports represented the results of many contacts by phone and mail to obtain the necessary information to develop meaningful industry-based data. The information gathering phase was in itself a technology transfer activity that added many interested parties to the mailing list. The response to these reports was positive and extensive. See Table 1.

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U.S. Department of Energy
Assistant Secretary for Conservation and Renewable Energy
Under DOE Idaho Field Office
Contract DE-AC07-76ID01570

Table 1. Number of mailings and requests in response to feasibility studies and reports, and continuing requests for related information

| Report | Number of mailings and requests |
|---|---|
| Thermal Enhanced Oil Recovery | 650 |
| Direct Use | 50 |
| Hydraulic | 50 |
| Supercritical Fluid Processing | 50 |
| Economic Study | 350 |
| Information Requests | on-going 1-2/week |
| Total as of February 1992 | 1150 plus 50-100/yr |

## Consortium Activities and Proceedings

In 1989, an Industrial Consortium for the Utilization of the Geopressured-Geothermal Resource was initiated. Meetings were convened twice a year and proceedings of the presentations were compiled and made available. As many as 75 participants attended the meetings as long as they were held in the Houston vicinity. Presentations and responses were enthusiastic and the interest in obtaining copies of the proceedings has continued to the present time. About 800 copies of the first two-volume proceedings were mailed out and about 750 of the second two-volume set were distributed. The mailing list is in a constant state of flux. At present it includes 544 names. The proceedings have been the source of many new requests to be added to the consortium mailing list. One of the latest requests is from the Wall Street Stock Market Luncheon Club, who requested the proceedings and any other papers on the geopressured-geothermal resource. Most requests comé from independent operators in the oil industry, or entrepreneurial business interests. Many requests are triggered by presentations, especially to the American Association of Petroleum Geologists and major oil companies.

## Geothermal Resource Council (GRC)

The meetings of the GRC have been the showcase for the emerging technologies of the geothermal industries, and as such have attracted mainly the electricity-generating industrial partners. Some aquaculture and agriculture interest has surfaced at these meetings but little interest specifically in the geopressured-geothermal resources. However, the GRC has been a geopressured-geothermal source of technology transfer for those in related endeavors, and for agency leaders in Washington, D.C.

## Meetings of the American Association of Petroleum Geologists (AAPG)

Recovery of heavy and medium oil is of major interest. The feasibility studies identified thermal enhanced oil recovery (TEOR) using the geopressured-geothermal fluids as the most viable use of the geopressured-geothermal resource from an economic standpoint. When this knowledge is coupled with the fact that the oil and gas industry has dealt with geopressures since the early years of oil and gas field development, it is understandable that the greatest interest would come from this industrial segment. The geopressured-geothermal wells are usually step-outs from hydrocarbon-producing fields, but are wells that missed the target for oil and gas. Thus, an economic use for the high temperature brine under high pressure with a considerable methane content is of interest to oil companies if it can be shown to be economically viable. The papers presented at meetings of the AAPG brought more spontaneous interest by major oil companies than any other technology transfer activity in the program. A steady stream of interested participants listened to the fall AAPG presentation and asked for contacts, reports and additional data. These respondents included Exxon, Unocal, British Petroleum, Chevron, Texaco, Amoco and others. Invitations to speak in Russia, Iceland, and China quickly followed. Additional letters and requests came from Japan, Australia, Greece, and Europe. An invitation to present an hour lecture came from Exxon Production Research Company, Houston, Texas, which in turn resulted in an expressed interest in collaboration in a cost-shared use project in supercritical fluid processing of hydrocarbon waste. The key to attracting the interest of the major companies at the AAPG meetings involved the following:
1) the audience was right for the resource uses, 2) the participants were decision makers usually at the president, vice president or exploration manager level, 3) the papers were filtered by peer selection and thus represent a quality controlled technical product, and 4) the integrity of the AAPG as a showcase for new technology is well established. This was the most successful strategy activity for bringing in the interest and participation of "majors." See Table 2 for a comparison of activities, response, and perceived obstacles.

Table 2. Technology transfer activities, response and perceived obstacles

| Activity | Numerical Response | Excellent | Good | Fair | Obstacles |
|---|---|---|---|---|---|
| Special Reports | 1150 | X independents, minors, few majors | | | obtaining reliable industry data |
| Consortium Proceedings (2 Volumes) | 1550 | X independents, minors, few majors | | | Houston location required for consortium |
| GRC Meetings | 200 to 300 | | | X | unfocused audience |
| AAPG Meetings | 3000+ | X majors | | | funding support |
| SPE Meetings | 50 to 100 | | | X | focus of audience interest |
| CBD Solicitation by DOE | 17 | $53 Million cost-share | | | restricted implementation |
| Workshops and CRADAs | | | | | restricted audience |
| Brochure | high interest | X high interest | | | not yet available |
| News Articles | general public | X | | | technology jargon |
| Secretary's Technology Initiative | too early to judge | | | | targeting the proper audience |

## Spin-off Projects

A number of spin-off projects are in various stages of implementation as a result of Technology Transfer related to the Geopressured-Geothermal Program. See Table 3.

Table 3. Projects and Status

| PROJECT | STATUS |
|---|---|
| Desalination, South Texas | $80K Texas State Funding 1st phase |
| Review of California GPGT Resources California Energy Commission (CEC) Cost-share with DOE | $25K industry cost-share in progress |
| Thermal Enhanced Oil Recovery Using GPGT Fluids: | |
| 1. Fanion Oil - South Texas Co-op with Desalination | Seeking Texas State oil overcharge funds and Texas Water Board funding |
| 2. Chevron - California Collaboration with CEC | March 1992 proposal for joint project |
| Supercritical Fluid Processing of Waste (SCWO) | 1st phase - Rocky Flats proposal by INEL for 300 gallon test plant at INEL<br>Presentation of proposal 2/21/92 |
| SCWO Test Stages - Exxon Production Research & Tom Hyde UT-Midland Consortium of Oil Companies | Interest in industry cost-share |

In addition to those shown in Table 3, there are 17 proposed industry cost-shared projects totalling $53 Million in offered industry cost-share. Numerous aquaculture and agriculture projects are waiting for the opportunity to prove the concepts of their processes.

### DOE Solicitation of Interest in the Commerce Business Daily

In 1991, the DOE published a solicitation of industry interest in the Commerce Business Daily (CBD) notice of the solicitation was distributed to the consortium members. Twelve respondents proposed seventeen industry cost-shared projects in four major regions: the Midwest Region, the Rocky Mountain Region, California, and the Texas Gulf Coast. Most projects involved thermal enhanced oil recovery. Texas and California also expressed an interest in desalination. The use of supercritical fluid processing of organic waste was of intense interest in Ohio, Texas, and California. As a result of the response to the solicitation the DOE has cost-shared a project by the California Energy Commission to review the geopressured-geothermal resources in the State of California. However, more needs to be done if the credibility of the DOE in the implementation of such solicitations to industry is to be maintained. In January 1992, Chevron announced to DOE their intent to propose a Thermal Enhanced Oil Recovery Project in California in collaboration with the California Energy Commission in March 1992. These activities are all the results of the industrial consortium and a DOE solicitation in the CBD. These activities do not go on in a vacuum. Continuous one-on-one telephone conversations and conference calls contribute to actions, participation, and industry teaming.

**Workshops and CRADAs**

Several independent companies have evinced an interest in workshops on simulation of the reservoir behavior and prediction of the resource life. This has been a restricted interest but one we hope to cover in conjunction with a future consortium meeting. The possibility of a CRADA was discussed with two different companies. However, they were not interested in pursuing the topic.

**Conclusions**

In conclusion, what is the best way to reach the market and what is the winning combination? All of the above strategies contribute to technology transfer and are needed in some combination for success. The most successful strategy activities for bringing in the largest number of industries and independents are consortium meetings, one-on-one telephone calling, and consortium proceedings with information service followup. The most successful activities for encouraging the interest and participation of major oil companies are presentations at internationally recognized industry-related society meetings, and on-call presentations to specific companies. Why? Because quality is assured, major filtering has already taken place, and the integrity of the showcase is established. Thus, the focussed strategy is reduced to a target of numbers (laymen/minors/independents) versus quality and power (majors). The numerical results of the activities reflecting four years of technology transfer following the 15 year lead in the early phases of the geopressured-geothermal program under the leadership of Dr. Myron Dorfman, reflect a dynamic survey of what works in technology transfer to industry in the area of geopressured-geothermal resources (Table 2). The identified obstacles can be removed and future efforts can benefit from cataloging and discussion of results (Table 3).