A Potential Multiple-use, Environmentally Safe Energy Resource for the Twenty-first Century: the Geopressured-geothermal Reservoirs of the Gulf of Mexico Basin[1]

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Abstract

In order to evaluate and develop alternate energy resources to decrease the country's dependence on imported fossil fuels, the U.S. Department of Energy established and funded a geopressured-geothermal energy program that began in 1976 and ended in 1992. The program was authorized by Congress under the Geothermal Energy Research, Development, and Demonstration Act of 1974 (P.L. 93–410). Aspects of the geopressured-geothermal energy resource investigated in this program encompassed reserve estimates; definition of the geopressured-geothermal fairways and prospects in Louisiana and Texas; brine flow rates and gas content; production problems, including scaling, sanding, and corrosion; viability of commercial exploitation of this resource; potential multiple uses, such as generation of electricity; and the environmental concerns associated with resource development. This paper is a summary of the main findings of this research program.

Introduction

The U.S. Department of Energy (DOE) established a geopressured-geothermal energy program in the mid-1970's as one response to America's need to develop alternate energy resources in view of the increasing dependence on imported fossil fuel energy. This program continued for 17 years, and approximately $200 million were expended for various types of research and well testing to thoroughly investigate this alternate energy resource. A comprehensive summary of the research program can be found in John et al. (1998).

The main goals of this program were (1) to define the extent of the geopressured reservoirs; (2) to determine the technical feasibility of reservoir development, including downhole, surface and disposal technologies; (3) to establish the economics of production, (4) to identify and mitigate adverse environmental impacts; (5) to identify and resolve legal and institutional barriers; and (6) to determine the viability of commercial exploitation of this resource (Division of Geothermal Energy, 1980).

The geopressured-geothermal reservoirs are essentially subsurface reservoirs containing hot, pressurized brine saturated with dissolved methane at the temperature, pressure, and salinity of the formation. They contain three forms of energy: (1) chemical energy: methane dissolved in brine under pressure; (2) thermal energy: hot brines with temperatures from over 225°F, which could be utilized for direct heating secondary hydrocarbon recovery or generation of electricity, and (3) mechanical energy: high brine–flow rates (over 20,000 bbl/d), and high wellhead pressures could be used for driving turbines to generate electricity. During the course of this research program involving industry contractors, private sector consultants and companies, university research groups, and national laboratories, there were 16 wells tested in Louisiana

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and Texas to achieve the main goals of this research program enumerated earlier.

Geopressured-geothermal reservoirs occur in the United States most prominently along the northern Gulf of Mexico basin and the Pacific West Coast. Other areas containing such reservoirs are also found in other deep sedimentary basins elsewhere in the United States and around the world. The most intensely studied basin containing geopressured-geothermal energy is the northern Gulf of Mexico basin because of the intensive hydrocarbon exploration and production activities in this area. In the mid-1960's it was suggested (Hottman, 1966) that the geothermal heat and pressure of the saline fluids of these formations might be used for process heat or power generation, and the methane entrained in these fluids could be produced as a third energy source.

Various estimates have been made regarding the recoverable natural gas from the geopressured-geothermal resources of the northern Gulf of Mexico basin and Dorfman (1988) states that, on an average, approximately 250 Tcf, equivalent to about 137% of known conventional methane reserves in the United States, can be potentially extracted from this resource. The DOE objective in undertaking the geopressured-geothermal research program was to gather and to provide sufficient reliable information for defining the resource and to provide answers to economic concerns regarding the scientific, engineering, resource recoverability, and environmental issues by well drilling and testing (Wallace, 1982).

The structure and geologic history of the northern Gulf of Mexico basin is well documented in the geologic literature as a result of this area being a prolific producer of oil and gas. In this area the sediment depocenters have shifted laterally and vertically in space and time, and rapid sedimentation was accompanied by subsidence and growth faulting (Ocamb, 1961). The oldest growth faulted and geopressured sediments were deposited seaward of the lower Cretaceous shelf margin (Bebout, 1982). The abnormally pressured Cenozoic sedimentary formations in this area occurring over 10,000 ft below the surface and having temperatures above 225°F contain the largest potential for the geopressured-geothermal energy resources.

Resource Characterization

During the course of the DOE geopressured-geothermal research program, 16 wells were tested (Figure 1) under 2 testing programs to provide data on reservoir and fluid properties for assessing the resource magnitude and potential, its direct and indirect uses, environmental impacts and the commercial viability of developing these resources. These wells were termed as (a) wells of opportunity—those drilled by industry that have penetrated through geopressured reservoirs in the search for oil and gas that were made available to DOE for testing, and (b) design wells—those drilled on sites in potentially favorable geopressured-geothermal prospects as determined by the best available geological and geophysical data. Initial investigations delineated the geopressured-geothermal corridors in south Louisiana and the Texas Gulf Coast and provided information on the subsurface structure, regional sandstone distribution, porosity, permeability, temperature, formation pressures and salinity. A summary of the important test results available is shown in Table 1.

Figure 1—Location of wells investigated for the DOE geopressured-geothermal research program in the Gulf Coast (from John et al. 1998).

Well Name	Depth (ft)	Pressure (psi)	Temp. (°F)	Salinity (ppm TDS)	Dissolved Gas (SCF/bbl)	Gas Saturation (SCF/bbl)	Flow Rate (BPD)	Methane (mol%)	CO_2 (mol%)	Other Gases (mol%)	Porosity (%)	Permeability (mD)
Delcambre 3sd	-12,869	11,012	238	133,300		24.0	10,333	92.8	1.1	6.1	26.0	44.0
Delcambre 1sd	-12,573	10,858	234	113,000		24.0	12,653	95.4	2.0	2.6	29.0	364.0
F.F. Sutter	-15,781	12,220	270	190,904	22.8	24.9	7,747	89.6	7.9	2.5	19.3	14.3
Buelah Simon	-14,722	13,015	266	103,925	24.0	24.0	11,000	88.9	7.7	3.4	17.4	11.6
P.R. Giroud	-14,744	13,203	274	23,500	40.0	44.5	15,000	91.3	6.0	2.7	26.0	220.0
P. Canal	-14,976	12,942	294	43,400	45.0	47.0	7,100	88.4	8.4	3.2	22.5	90.0
C. Zellerbach	-16,720	10,144	330	31,700	32.0	55.7	3,887	71.0	23.5	5.5	17.0	14.1
Sweet Lake A	-15,387	11,974	298	160,000	26.5	34.0	34,000	88.7	8.6	2.6	20.0	400.0
Sweet Lake B	-15,250	11,794	293									
Parcperdue	-13,395	11,410	237	99,700	20.0	30.0	10,000	94.0	2.5	3.5	29.4	500.0
Gladys McCall A	-15,508	12,936	298	95,500	32.0	30.4	36,500	86.9	9.5	3.6	24.0	90.0
Gladys McCall B	-15,158	12,821	288	94,000	31.0	30.4	36,000	85.9	10.6	3.5	22.0	130.0
Pleasant Bayou Well No. 2	-16,465	9,800	302		34.0	24.0	25,000	85.0	10.0		19.0	200.0

Table 1—Summary of test results from the geopressured-geothermal test wells (from John et al., 1998).

The well tested for the longest period of time (4 years) was the Gladys McCall #1 well, located in a marsh area in Cameron Parish, Louisiana. It was drilled under the "design well" program. In this well, 11 potential production zones (Figure 2) were defined before testing, but only zones 8 and 9 were flow tested. After zone 9 was plugged, zone 8 was tested for 4 years, beginning in December 1983, before being shut in to observe pressure buildup at the end of 1987.

During this period the well produced over 27 million barrels of brine and 676 million MCF of gas from the brine, which was disposed by subsurface injection through a brine disposal well in the vicinity of the test well. During the test period the well was flowed at various rates with an average flow rate of 20,000 bbl/day, almost continuously. Scaling problems encountered during initial production were solved by injection of phosphonate pills. This well test and others proved that long-term, high-volume brine production was feasible and that gas-extracted brine could be successfully disposed of subsurface injection.

Another design well test, the Pleasant Bayou #2 well in Brazoria County, Texas, was significant in that a direct-use application of the geopressured-geothermal energy resource was successfully tested. This was the site for the installation and successful operation of a binary cycle, hybrid-power electrical generation system (HPS), which was operated for several months at the site. The system utilized the geothermal energy of heat and gas from the well fluids, as well as using exhaust heat from the gas engine generators utilizing the produced gas as a fuel.

This system successfully demonstrated that the geopressured-geothermal resource could be used for electrical generation. The Frio (Oligocene) age sandstone reservoirs tested at Pleasant Bayou had a temperature of 300°F and well testing was performed from April 1988 through August 1990. The reservoir was perforated from 14,644 to 14,700 ft, and the well produced a total of approximately 12 million bbl of brine and 231,600 MCF of gas.

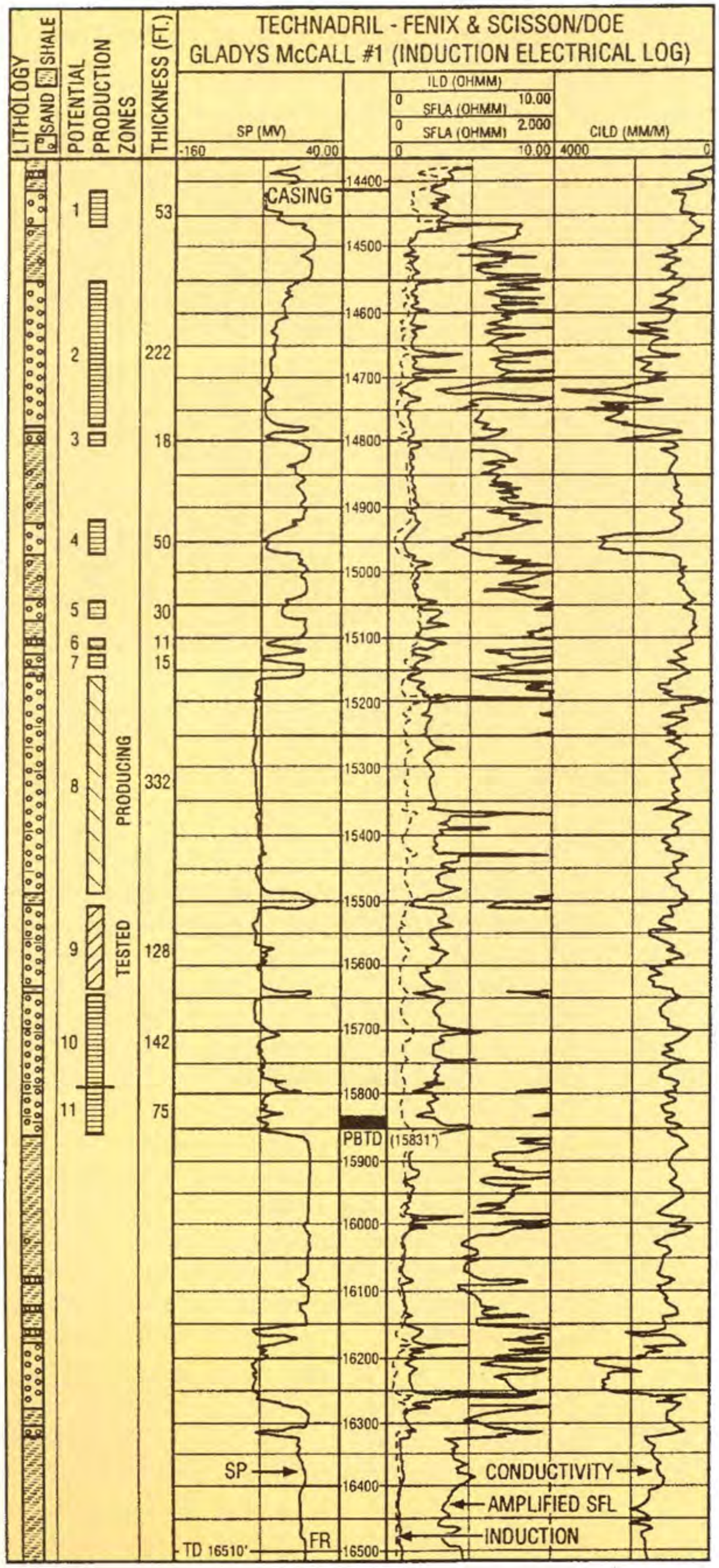

Figure 2—Electrical logs, potential production zones, and lithology of the Gladys McCall test well (from John, 1988)

Environmental Issues

The main environmental concerns associated with production testing and development are land subsidence growth fault activation and water-quality impacts. Environmental monitoring consisted of microseismic, subsidence and water-quality monitoring. Continuous microseismic monitoring was carried out by a network of recording stations set up near and around the design well test sites, and no microseismic activity attributable to well testing was recorded at these sites. To determine subsidence, networks of closely spaced first-order elevation benchmarks were installed around the design well sites, which were surveyed and tied in with the National Geodetic Survey (NGS) regional control networks. Again, no subsidence related to well testing was observed. Water quality was also monitored at the test sites to determine contamination resulting from any well testing activities. Surface and ground-water samples were analyzed quarterly, but these analyses did not show any problems arising due to well testing activities.

Direct and Indirect Uses

Geopressured-geothermal energy has been successfully used to generate electricity by using a hybrid binary power system at the Pleasant Bayou No. 2 design well site, located in Brazoria County, Texas. Thermal-enhanced oil recovery (TEOR) is another potentially near-term applicable use, especially in the case of heavy oil in areas where the two occur in close proximity. The hot geopressured-geothermal fluids under high pressure could be moved to shallower oil reservoirs through suitable piping thus providing a self-propelled method of heat transfer to the target reservoir. As in the case of conventional

Potential Applications of the Geopressured-geothermal Resource

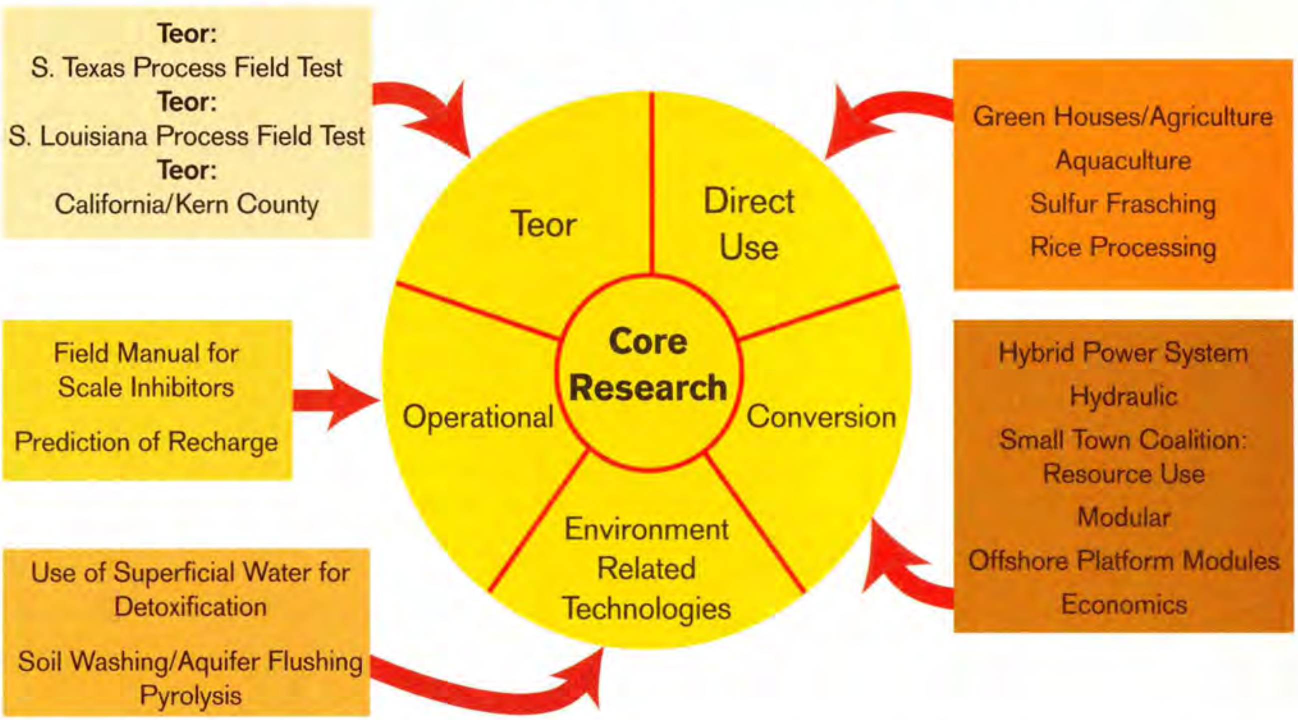

Figure 3—Schematic illustration of the multiple uses for the geopressured-geothermal energy resource (modified from Negus-de Wys and Dorfman, 1990).

TEOR, the heat from the brine will reduce the residual oil saturation and lower its viscosity, leading to better recovery of oil. A summary of the potential direct and indirect applications of the geopressured-geothermal resource is shown in Figure 3.

Potential industrial uses suggested for the geopressured-geothermal resource, using the heat for direct uses, require temperatures ranging from 35 to 350°F. These include direct heating of houses, sulphur extraction, coal desulfurization, chemical processing, extraction of chemicals from brine, water desalination, fish rearing, greenhouse heating, cane sugar processing, and lumber drying.

Conclusions

The significant accomplishments of this program were (1) identification of the geopressured-geothermal onshore fairways in Louisiana and Texas, (2) determination that high brine flow rates of 20,000–40,000 bbl/d can be obtained for long periods of time, (3) brine, after gas extraction, can be successfully reinjected into shallow aquifers without affecting the surface waters or the freshwater aquifers, (4) no observable subsidence or microseismic activity was induced due to the subsurface injection of brine, and no detrimental environmental effects attributable to geopressured-geothermal well testing were noticed, (5) sanding can be controlled by reducing flow rates, (6) corrosion controlled with inhibitors, (7) scaling controlled by phosphonate scale inhibitors, (8) demonstrated that production of gas from saturated brine under pressure was viable and (9) a hybrid power system can be successfully used for conversion of the thermal and chemical energy contained in the geopressured-geothermal resource for generation of electricity.

The DOE geopressured-geothermal research program in the Gulf Coast achieved many significant findings and disproved and clarified many historical perceptions that had previously limited industry's interest in developing this resource. Though in today's economic market it may not be commercially profitable to exploit this resource, the rapid advance of technology in all its different aspects could potentially make this resource attractive in the not-too-distant future. The ideal situation would involve the development of a total energy system in which all three associated forms of energy—chemical, thermal, and mechanical—are utilized. The extraction of gas from brine, combined with the large number of potential direct and indirect uses of this resource, will add to its economic profitability. This visionary research program of the DOE has essentially laid the foundations for characterization of this resource and all aspects connected with its development.

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