ABSTRACT

The Hawaii Natural Energy Institute of the University of Hawaii at Manoa has initiated and completed a program designed to confirm and stimulate geothermal resources development in Hawaii. The program initially involved the drilling of approximately six, 4,000-foot scientific observation core holes (SOH) on the Big Island of Hawaii and Maui, reservoir analysis research utilizing small-diameter observation holes, and the expansion of the research capabilities at the Puna Geothermal Research Center. However, institutional and political problems have reduced the scope of the program to the drilling of only four holes in the Kilauea East Rift Zone on the Big Island. Funding of $3.25 million has been provided by the State of Hawaii under the supervision of the Department of Business, Economic Development and Tourism (DBED). Private developers of geothermal resources on Hawaii and other private sector sources have raised an additional $5 million for reservoir analysis research and the drilling of two geothermal production wells. Drilling of the first hole (SOH-4) began in December 1988 and the final hole is expected to be completed by mid 1991.

INTRODUCTION

The Hawaiian Islands lie above a geological "hot spot" in the earth's mantle that has been volcanically active for the past 70 million years. The Big Island of Hawaii currently has three active volcanoes: Mauna Loa, Kilauea, which is currently erupting, and Hualalai which was last active in 1801; and has an obvious, large potential for geothermal energy.

Since the drilling and testing of the HGP-A geothermal well on the Big Island of Hawaii, the Kilauea East Rift Zone has been recognized to have the potential of producing approximately 500 megawatts of electrical energy. Recent calculations by Thomas (1987) indicate a continuous discharge of approximately 291 megawatts of thermal energy over a restricted area of thermal discharge along 10 kilometers of the rift and 1,455 megawatts of thermal loss along a 50 kilometer stretch of the rift zone, which supports the assumption of power generation. Dzurisin (1981) calculates a magmatic intrusive rate of 2,800 thermal-megawatts into the rift zone, which suggests that the energy source is indeed large and that the rate of convective heat loss to the shallow hydrologic system nearly balances the heat recharge for magmatic intrusion.

The Hawaiian Deep Underwater Cable Program was initiated in 1981, as a research and development program to explore the technical, environmental and financial aspects of a deep-water electric energy transmission cable system to deliver electrical energy from geothermal resources on the Big Island of Hawaii to Oahu, where the State's largest population and electrical energy demand exists, Sumida et al. (1986). This program will probably cost well over a half billion dollars to complete. The program is based on the assumption that the estimated reservoir potential exists and can be developed, and that 500 megawatts of electricity will be available for transmission to Oahu.

This assumption of power potential may well be correct, but, as yet, has not been confirmed by further exploration or production drilling. Current exploration drilling by the True/Mid-Pacific Geothermal Venture has yet to indicate a viable geothermal reservoir, and as of the writing of this paper, the Puna Geothermal Venture has not received final project clearance and has yet to commence drilling operations. Prudence now dictates that geothermal reservoir capacity be developed to be more in line with the development of the deep underwater cable program.

Although the HGP-A well produced in excess of two megawatts for a period of approximately seven and one-half years, the Kapoho State 1A well, which was drilled by the Puna Geothermal Venture approximately a quarter mile to the north, has not undergone extended flow testing or production. Even though this well evidently has a generating capability greater than the HGP-A well, it has different reservoir chemistry and flow characteristics, Thomas, et al. (1980), Iovenitti and D'Olier (1985), and has added little additional information as to the extent of the HGP-A/Kapoho reservoir except in the immediate vicinity of the two wells.

Although most of the Kilauea East Rift Zone and other rift zones associated with active volcanoes on the Hawaiian Islands may have subsurface temperatures in excess of the temperatures necessary to generate electrical energy, little or nothing is known of the other conditions such as rock porosity and permeability, water quantity and quality, and cap rock characteristics that are necessary for a reservoir to exist. Besides geological mapping and the identification of fractured rift zones, surface exploration techniques have proven unreliable in the identification of geothermal reservoirs in Hawaii. Shallow gradient drilling has proven unsuccessful in defining anomalous areas of elevated subsurface temperature, even in areas over known reservoirs. The only exploration technique utilized to date that has been successful in the discovery and definition of geothermal reservoirs has been the drilling of production wells to depths in excess of 6,000 feet within known rift zones. These wells are quite expensive, and historically have cost more than $2 million each.

In the area surrounding the current zone of production at the HGP-A site, exploration drilling suggests that nearly all indications of geothermal potential including elevated subsurface temperature and gradients, rock alteration, capping minerals, and reservoir fluid entries have been encountered at depths of approximately 4,000 feet. These depths are well within the capabilities of truck-mounted diamond-drill rigs currently operating on the Mainland. Total drilling costs utilizing these rigs to depths of 4,000 feet are approximately $100 to $125 per foot, or about $400,000 to $500,000 for a 4,000-foot hole - substantially less than the cost and environmental impact of drilling a production-size geothermal exploration well.

PROPOSED PROGRAM TO CONFIRM GEOTHERMAL RESOURCES IN HAWAII

Preliminary geothermal surface exploration already has been completed during the work that resulted in the Geothermal Resources of Hawaii Map, Thomas, et al., (1983). Active volcanoes and geothermal heat sources are known, rift zones have been identified and mapped, and areas of geothermal potential defined. However, the need remains to identify subsurface target conditions, so that production wells can be located to test for the existence of geothermal reservoirs. This can be accomplished most economically by drilling a number of deep, scientific observation holes in and along the known resource area in the Kilauea East Rift Zone and other rift zones associated with active or recently active volcanoes, such as the Kilauea Southwest Rift Zone, the Mauna Loa Southwest Rift Zone, and the Hualalai rifts on the Big Island of Hawaii, and the Haleakala Southwest Rift Zone on Maui (Figure 1).
The Hawaii Natural Energy Institute (HNEI), is planning a program that was initially budgeted at $8.25 million to confirm and stimulate geothermal resource development in Hawaii. This program was originally designed to fund the drilling of at least six deep geothermal observation holes to test reservoir potential in the Kilauea East Rift Zone and other areas of geothermal potential that can be developed commercially. The program is designed to be more practical in nature, rather than totally academic, and will emphasize obtaining as much real ground truth as possible rather than the collection of basic scientific information. An attempt will be made to obtain indications of reservoir potential utilizing the deep core holes alone, in pairs, or in combination with production wells to be drilled by private developers. Initially, provisions in the program would have permitted the Noi'i O Puna Research Center (PRC) to be expanded to provide additional space for technical and direct utilization research, and to initiate development of pipelines to supply adjacent private developments utilizing geothermal energy. This part of the program was subsequently dropped due to lack of support from the state funding agency.

To initiate a program to encourage and stimulate private development of Hawaii's geothermal resources, DBED has awarded a $250,000 grant to the University of Hawaii through HNEI to drill a 2,000 foot scientific observation hole on Maui or in one of the other active rifts on the Big Island. The 1988 State legislature funded a $3 million program to drill additional geothermal observation holes in one or more of the rift zones, and expand and improve the research capabilities of the PRC. This amount was to be matched by $5 million from the private sector for the drilling of additional scientific observation holes and production wells, and in the support of reservoir analysis research.

The $3.25 million supplied by DBED and the State will fund the mobilization and demobilization of a truck-mounted diamond-core drill rig to Hawaii, the drilling of core holes on the Big Island and Maui, and the expansion of the PRC. The core holes were to be drilled to a target depth of approximately 4,000 feet, but could be completed to lesser or greater depths depending upon the temperature and geologic conditions encountered in the hole. Assuming normal drilling conditions, drilling costs of approximately $100 to $125 per foot, and hole depths of 4,000 feet, the SOH holes could be drilled at a cost of $400,000 to $500,000 each. Subsequent changes in the SOH program at the State's insistence, however, has increased the nominal drilling depth to 6,000-6,500 feet, and increased the cost of the proposed holes to $600,000-812,500. The number of holes drilled will depend upon drilling conditions and depth of the holes, but with existing funds and additional funding likely to be available, at least four holes are now scheduled to be drilled in the Kilauea East Rift Zone.
The SOH program is a joint effort of the Hawaii State government, HNEI and the University of Hawaii, Electric Power Research Institute (EPRI), Bonneville Power Administration (BPA), the Hawaiian Electric Company (HECO), and private geothermal developers (Puna Geothermal Venture and True/Mid-Pacific Geothermal Venture). The private geothermal developers agreed to contribute a production-sized well deemed to have a value of $2 million to the program, and to make the data available to the University. EPRI, BPA, and HECO have funded grants totaling $648,000, and the State of Hawaii has provided $3.25 million to the SOH program, with an additional $5.6 million in funding for geothermal verification which could be used for SOH drilling. The following summarizes the source of current funding for the SOH geothermal assessment program:

**SOURCE OF FUNDS FOR SOH PROGRAM**

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<th>Source of Funds</th>
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<td>SOH Program</td>
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<td><strong>Total</strong></td>
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**SOH LOCATION AND DESCRIPTION**

The locations of the four SOHs, which are shown in Figure 2, have been sited on the basis of surface geological, geophysical, and geochemical observations, environmental considerations, residential locations, and existing access to minimize impacts of the program.

**DRILLING PLAN AND SCHEDULE**

The holes were originally planned to be drilled by a combination of cable drilling by a water well rig and rotary and diamond-core drilling by Tonto’s Universal 5000 diamond-core drill rig. However, permitting delays after the drill rig had been mobilized, necessitated the use of the core rig to drill the large diameter hole required for the conductor pipe. The time and cost of this operation proved to be less than that projected for the cable rig, and it was subsequently decided to omit the cable drilling from the program. The size of the drill sites, the capability of the diamond drill rig, and the total environmental impact is approximately one-tenth that of the rotary oil rigs normally used to drill geothermal production wells.
Drilling is continuous, 24 hours a day, seven days a week, with two three-men crews, once started, until the hole is completed. The first hole, SOH-4, took 152 days to complete to a depth of 6,562 feet, but subsequent holes are expected to be completed in approximately 120 days, if drilled to a similar depth, due to the development of more effective drilling techniques, and revisions in the original drilling plan, which initially was grossly overdesigned due to permitting requirements.

Casing and cementing programs and blow-out prevention (BOP) equipment provide protection from any potential over pressured zones and allow the hole to be shut in at any stage during the drilling after the upper 200 feet of conductor casing are in place. The drilling and casing program was largely dictated by regulatory stipulations, and is more suitable for a production well than a research hole for observation and monitoring that will not be produced. Figure 3 shows the current drilling/casing plan for the SOHs as approved by the Hawaii Board of Land and Natural Resources (1989).

The primary water source for drilling and testing operations, drinking, sanitation, work force safety and fire fighting measures is transported to the project site from an existing water point. A 20,000-gallon storage tank is located on the drill site. In addition, a sump pit with a total capacity of 60,000 gallons is located adjacent to the drill rig. Drilling fluids and excess drilling mud, as well as rainfall runoff, is directed to the sump pit. Every attempt is made to recycle all water used in drilling operations.

Assuming total loss circulation during core drilling and a drilling fluid pumping rate of five gallons per minute, a maximum of less than 7,500 gallons of water per day is used to replace that which is lost down the hole. During rotary drilling, water storage and haulage limitations restrict pumping rates to 50 gallons or less per minute. Water and water related costs were in excess of $100,000 for SOH-4, but are considerably less for SOH-1, as drilling water is currently being piped from the county water main with reduced water haulage trucking costs.

RESERVOIR ANALYSIS

Initial testing of the SOHs will involve taking geophysical logs and temperature gradients to determine the rate of increase of temperature with depth and absolute bottom hole temperatures. During drilling operations, temperature measurements are taken at least every 50 feet with maximum reading thermometers during core recovery, after downhole temperatures exceed 100°F. Temperature surveys will be made before and after the hole has reached thermal equilibrium, and temperatures will be monitored thereafter to note any changes in temperature which can be related to natural or production processes.

If reservoir conditions are encountered during drilling, reservoir analysis will be attempted by injecting water into the hole and measuring the rate of fluid acceptance, the pressures required to inject the fluids, the time required to achieve pressure equilibrium after pumping, and the zone or zones that will accept the fluids.

PERMIT STATUS

On the Big Island, three of the SOHs are sited on agriculture zoned land, and one, SOH-3, is sited on conservation zoned land. The four SOHs on the Big Island have been permitted and approved for drilling by the State Department of Land and Natural Resources (DLNR) under a Conservation District Use Permit (HA 12/20/85 - 1830) issued to the Estate of James Campbell. A Geothermal Resource Permit (GRP 89-1) from the County of Hawaii Planning Commission for the three SOHs on agriculture land has been issued to HNEI. SOH-3 is on conservation land and only requires a drilling permit from DLNR. The two holes (SOH-5M and SOH-6M) proposed for Maui have been permitted by DLNR, but county permitting activities have been halted due to the lack of county geothermal regulations and opposition by residents of the island to any geothermal activity or development.

**Figure 3.** SOH Drilling/Casing Plan
During the permitting process with the county of Hawaii Planning Commission, the local community requested mediation. Through a series of long and often bitter meetings, the basis of the permit conditions was discussed and revised. As a result of public hearings and discussions with state and county regulators, DLNR imposed 15 conditions and the County of Hawaii imposed 26 conditions on their respective geothermal permits. Most of these conditions are standard and reasonable, and have not caused any problems with compliance, but some have caused major problems in time delays and cost increases.

Flow testing or venting is prohibited. This prevents the collection of meaningful groundwater and reservoir brine samples, as well as precludes preliminary reservoir flow tests. Large vehicle (truck) traffic is also prohibited during the nighttime hours of 7 p.m. to 7 a.m. This has disrupted supply deliveries and caused considerable lost time while waiting on water.

Noise level limitations are 55 dBA during the day and 45 dBA at night, with daytime defined as 7 a.m. to 7 p.m. and nighttime from 7 p.m. to 7 a.m. These limitation levels are unrealistically low, and are often exceeded naturally by road noises, wind, frogs, and insects. Although the Universal 5000 diamond core rig that is used for the drilling is especially quiet, with normal operating noise levels of 64 dBA at approximately 70 feet, these limitations have provided grounds for continuing complaints and harassment from geothermal opponents.

PROGRESS TO DATE

Drilling commenced at SOH-4 on December 13, 1989, and continued until December 20, at which time drilling ceased for a 16-day Christmas break (Olson, et al. 1990). Drilling resumed on January 3, 1990 and continued until May 15, 1990 for a total drilling time of 141 days. Considerable difficulty and expense were incurred in reaming the hole to insert 990 feet of 9-5/8 inch and 1,999 feet of 7-inch casing. However, by the time the casing was inserted effective drilling techniques were devised, substantially reducing the time and expense of the operation. The hole was drilled with HQ bits to a depth of 5,290 feet, at which depth the rods became stuck, and the hole was completed with NQ bits from a surface elevation of 1,250 feet to a depth of 6,562 feet. The maximum equilibrated bottom hole temperature is 306°C (583°F). The standing water level in the hole is approximately 950 feet and preliminary injection testing indicates little apparent permeability.

SOH-1 was spudded-in on May 31, 1990 and is drilling ahead at a depth below 3,000 feet at the time of the writing of this paper. Seven-inch casing was set to a depth of 1,996 feet without incident, and the hole was drilled to a depth of 2,671 feet in a thick, unconsolidated to loosely consolidated section sand sized fragments intersected by basalt dikes with 101 mm bits, at which depth the upper portion of the hole below the casing string collapsed, sticking the rods in the hole. SOH-1 is tentatively scheduled to be completed at a depth of approximately 6,000 feet. Recorded temperatures in the hole to the depth measured are less than 100°F.

At the completion of SOH-1, an injection reservoir test will be completed at SOH-4, and a preliminary injection test conducted at SOH-1. As presently scheduled, SOH-3 will be drilled next, with SOH-2 being the last hole drilled.

CONCLUSIONS

To demonstrate that geothermal reservoirs may exist in other areas of the Kilauea East Rift Zone and the Haleakala Southwest Rift Zone, additional research or exploration holes must be drilled to test the geological conditions of rock type, alteration, zoning, temperature, fluid pressure, and permeability, and to determine what critical measurements must be made in future scientific observation holes and production wells.

REFERENCES


