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IDAHO NATIONAL ENGINEERING LABORATORY

GEOTHERMAL R & D PROJECT REPORT FOR PERIOD JANUARY 1, 1976 TO MARCH 31, 1976

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GEOTHERMAL R&D PROJECT REPORT FOR

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AEROJET NUCLEAR COMPANY

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ABSTRACT

Progress in the first calendar quarter of 1976 is reported on the geothermal energy projects conducted by and/or under the direction of the Idaho National Engineering Laboratory of the Energy Research and Development Administration. These include the Raft River well developments, reservoir testing, and surface testing; the Boise Space Heating Project; the design and analysis of power conversion concepts for generating electricity from moderate temperature (approximately 150°C or 300°F) resources; advanced heat exchanger research and testing; and studies relating to a variety of direct uses of geothermal heat energy.

ACKNOWLEDGEMENTS

The cooperative efforts of numerous organizations outside of INEL have been most important in the development and progress to date. In particular, the following deserve particular mention:

The U.S. Geological Survey (Menlo Park, Denver, and Boise Offices)
Reynolds Electric and Engineering Company and the Nevada Operations Office of ERDA
Lawrence Berkeley Laboratory's Geothermal Energy Division
The Raft River Rural Electric Coop.
The State of Idaho Department of Water Resources
The Northwest Public Power Association and Public Power Council
The U.S. Bureau of Land Management, Boise and Burley Offices

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1.0 SUMMARY

The Idaho National Engineering Laboratory (INEL) is operated by the Energy Research and Development Administration to help provide the engineering research needed to bring new energy schemes into the nation's economy. The location of the laboratory, near Idaho Falls, Idaho, is on the Snake River Plain, a geologically active rift zone with geologically recent volcanic activity, and an abundance of ground water. The area is thus a natural location for the occurrence of hydrothermal energy at relatively shallow depths, as indicated by the numerous hot springs along the borders of the plain and in the intersecting valleys. The relatively recent age of the near surface geological changes and the characteristic volcanism instead of old sediments implies that a continuum of temperatures of hot water will be present, and their salinities should be relatively low compared to the resources in older sediments. This trend has been confirmed from hot spring measurements, indicating the presence of numerous reservoirs (or aquifers) at low to moderate temperatures (below 150°C or 300°F). Such temperatures are currently not attractive economically to compete in the electric power production market, nor have such resources found much use in direct heat applications in this nation.(1)

The INEL has, therefore, aimed its program at developing techniques, through engineering and research, to make it possible to harness such resources more economically, thus allowing this form of geothermal energy to compete effectively with other forms of energy. The principal site chosen for the experiments and testing work is in the Raft River Valley, an adjunct to the Snake River Plain. Principal reason for the choice were the average geothermal characteristics of the valley (water no hotter than 150°C appears to lie at depths of 1 to 2 km), plus the desired industrial involvement of the local utility (Raft River Rural Electric Cooperative) and the entire association of 110 public and municipally owned utilities of the Northwest (Northwest Public Power Association). The State of Idaho offered its full cooperation, both in the research phases as well as the regulatory aspects. It was through the latter association that the beginnings of a space heating demonstration effort involving lukewarm water of approximately 75°C (167°F) developed. ERDA is conducting the front-end design and exploration work on a demonstration project which would be completed by the State on state-owned buildings at Boise, Idaho.(2)

The following summarizes work conducted in the first calendar quarter of 1976.

1. A series of pump tests were conducted on RRGE-1 using a submersible 100 HP pump set at a depth of 650 ft. Steady state flow with a 450 ft drawdown was increased approximately 50% over the natural steady state artesian flow of 600 gallons per minute (gpm). The pump was operated briefly at a peak pumping rate of 1900 gpm until drawdown necessitated reduction in speed.

2. The RRGE-2 well was deepened from 5988 ft to 6543 ft. The purpose was to determine if the formation below was responsible for the near zero temperature gradient over the 800 ft above, a region from which little flow seemed to be developing. Drilling return samples and one small piece of core confirmed that this newly drilled 550 ft was basement quartz monzonite, very impermeable except for one region near 6200 ft. However, it

was not apparent that much contribution to the total artesian flow was coming from the formations below 5200 ft.

3. Drilling began on a third well, RRGE-3, some 1-1/3 miles southeast of the other two, in a region presumably far away from major faults.

4. In Boise two demonstration wells were completed to depths of 967 and 1222 ft, drilled into apparent fault zones along the northeast edge of the city. Both wells achieved temperatures of 165°F downhole, within 5° of the target. The first well was stimulated with a small pump until it developed a small natural geothermal flow. (The second well was awaiting flow testing permit approval.)

5. Examination of the potential for direct applications of geothermal heat (non-electric) in the Raft River Valley area, and discussions with several potential industrial participants to demonstrate the use of the low-to-intermediate temperature (<300°F) geothermal water at this location has continued. Acquisition of private lands by the participants near the existing ERDA well sites does not appear to be a problem; mechanisms for obtaining fresh water supplies in the Raft River critical water area are being pursued with the State; and a policy of geothermal water distribution from the existing ERDA wells for a trial period has been formulated for ERDA approval. An examination of the economics of a geothermal project of this type has been shown attractive from an entpreneur's viewpoint, but the necessary institutional support is needed for industry to obtain the expertise and assurance to proceed in such non-electric geothermal development practices.

6. Engineering and economic studies on a heating system for Boise office buildings was completed. Originally aimed at supplying heat for 10 state-owned and operated buildings, the systems pipeline (1-1/2 to 3 miles of supply piping, 1-1/2 miles re-injection piping) was found to comprise the bulk of the capital expense. The full capacity of the pipeline could supply nominally 40 buildings with heat from 170°F geothermal water, using fossil fuel peaking to supply the needed additional 10% of the heating season needs for the very few cold days. (Boise has 5800 degree days of heating.) With such an arrangement, the system has a five year pay-back based on present costs for fuel saved.

7. Plans and conceptual design were completed on a test facility arrangement which would test performance on both state-of-the-art and highly advanced components for generating electricity from moderate (approximately 150°C or 300°F) temperature geothermal reservoirs. The facility options emphasize advanced heat exchangers and concepts for significantly lowering heat sink temperatures for small sized modules of power plants (50 MW(e) or less).

8. Studies continued on both the fluidized bed and the direct contact heat exchangers, including field tests on the Raft River wells. Higher fluidizing velocities than previously considered possible and higher than expected measured heat transfer coefficients on the bed-side have substantially improved the economic potential of the fluidized bed concept. Measurements in the laboratory of carry-through of organic secondary fluid by the geothermal water in the direct contact concept are being conducted to aid in assessing the economics of that device.

2.0 RESOURCE DEVELOPMENT AND ENERGY SUPPLY SYSTEMS

2.1 Raft River Wells

2.1.1 RRGE-1

The first well, RRGE-1,[3] has been pumped several weeks in various pump tests to determine formation characteristics replacement pump and reservoir testing. For a 450 ft drawdown, the well will produce 900 gpm. Replacement pump design is completed and will be ordered next quarter. In addition to pumping, the well free flows thru the pipeline to No. 2 reserve pit at greater than 400 gpm were delivered for several months this winter. Over 10 million gallons have been delivered from No. 1 well to No. 2 reserve pit, with 8-1/3 million gallons reinjected into RRGE-2 over the four winter months.

2.1.2 RRGE-2

During March, RRGE-2 was deepened from its original 5988 ft depth to a 6543 ft depth and followed by nearly a week of flow testing. Well temperature was considerably lower due to the 8-1/3 million gallons of reinjection water previously put into the well, but temperature plots each day indicated a general temperature and flow increase approaching the previously measured production well value. Although the deepening operation was expected to find further faulting, nothing but relatively impermeable quartz monzonite was found in the bottom of RRGE-2. One region near 6200 ft accepted considerable cool drilling fluid, but did not seem to discharge it rapidly, implying it was not an outstanding production zone.

2.1.3 Geology and Geophysics of RRGE-1 and RRGE-2

The lithological sequence of RRGE-1 is depicted in Figure 1 and that of RRGE-2 in Figure 2. Figure 3 illustrates the geological cross section through both wells. There was some uncertainty as to whether or not RRGE-2 had penetrated the Bridge Fault Zone as shown in Figure 3. The deepening of RRGE-2 from 5988 to 6543 feet was completed in late March.

The additional 555 ft of drilling was accomplished entirely in the basement rock, quartz monzonite. The drill cuttings and core samples failed to show any indication of significant faulting in this interval. There has been no indication of any significant additional geothermal production but full confirmation must await later testing under full heated conditions. The Bridge Fault Zone was believed to have, in fact previously been penetrated around the 5,000 ft depth but was less extensive and distinctive than anticipated. The extensive evidence of faulting that occurred between 3750 and 4500 ft in RRGE-1 is believed to be a result of the Narrows Structure and to a lesser degree, the Bridge Fault Zone.

Soon after the additional drilling was completed in RRGE-2, the drilling rig facilities were used to complete the well and install wellhead equipment. The rig was then moved to the RRGE-3 drilling site.

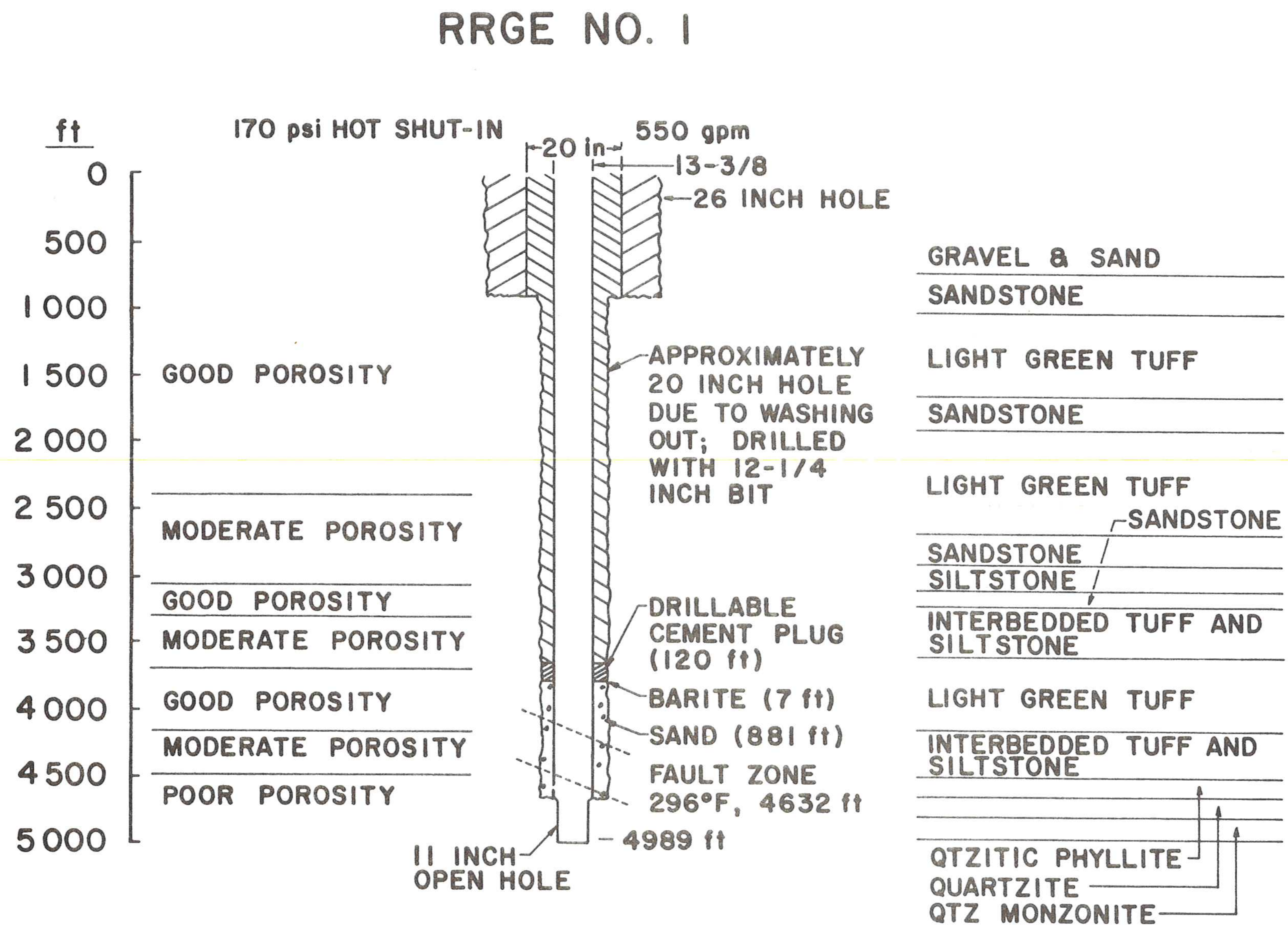


Fig. 1 Raft River Geothermal Exploratory Well No. 1

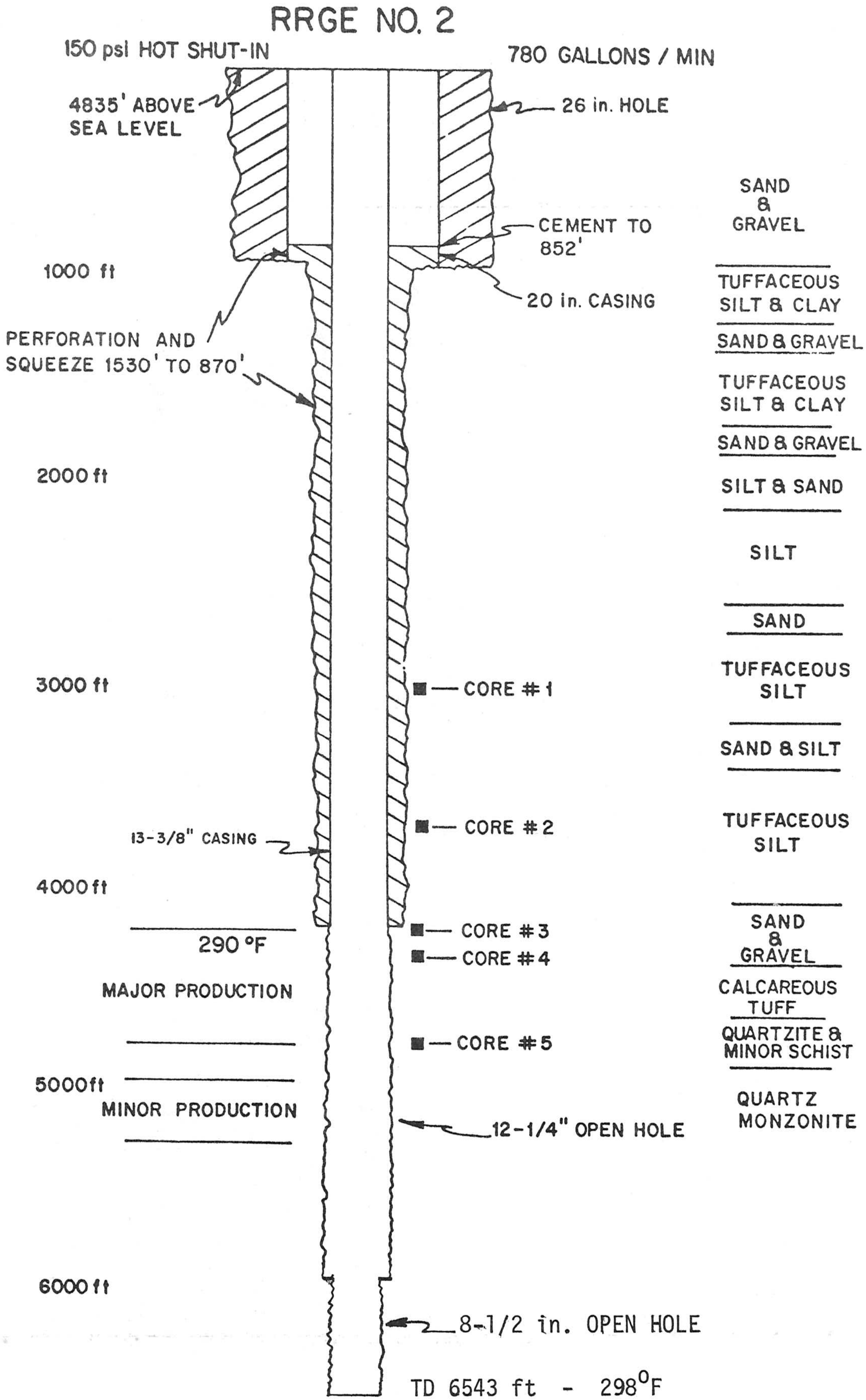


Fig. 2 Raft River Geothermal Exploratory Well No. 2

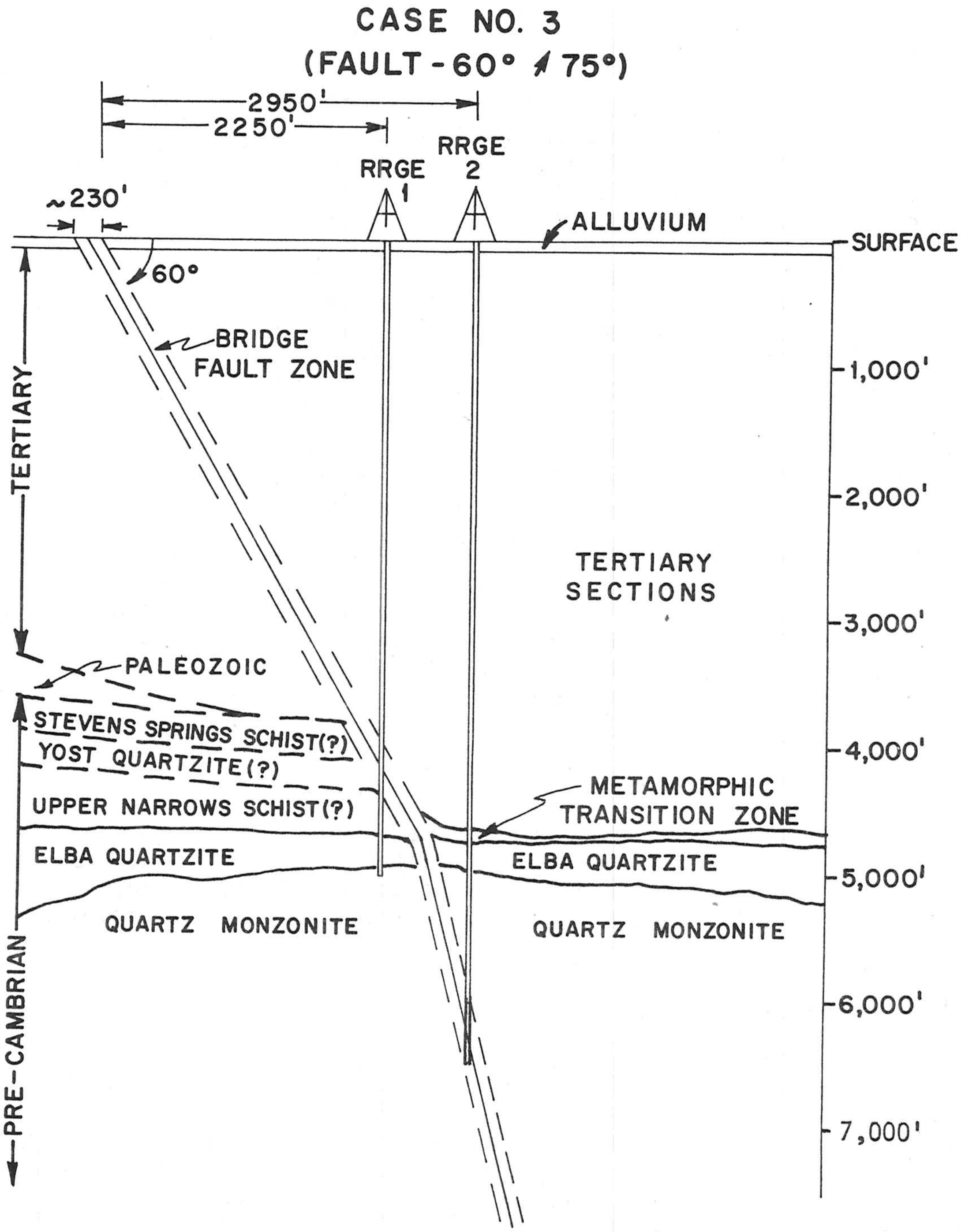


Fig. 3 Cross Section through RRGE-1 and RRGE-2

2.1.4 Well Logging of RRGE-2

The bottom of RRGE-2 was logged by both the USGS and INEL. The INEL logging was confined to detailed temperature scans as the reinjected water and drilling fluid came out of formation and the well continued on its long, slow process of being returned to production status. Neither the INEL nor USGS flowmeter tools worked satisfactorily on the deepened hole.

The USGS flow meter data (run in RRGE-2 during prior quarter, before deepening) was partially evaluated, but was not suitable for release. The identified production zones correlate closely with those identified previously from the examination of drill cuttings, core samples and electric logs. However, the calibration of the flow meter has not been satisfactory and consequently relative quantities of flow are still unknown. The apparent bottom hole production that was indicated (then from 5988 ft) of RRGE-2 has been re-evaluated and does not now appear to consist of more than minor production. The bulk of the production is from 5200 ft and above.

The temperature logging conducted by the INEL equipment gave the most revealing information to date on the production zone regions of the well. This occurred because the well head received 8.5 million gallons of cool reinjection water over the prior three months, plus 3.1 million gallons of cool drilling fluid circulated during the deepening operation. A week of unstimulated flow testing followed, during which 2.5 million gallons were flowed out of the well. The progress on recovering of the well can be seen in Figure 4.

2.1.5 Component Test Facility Provisions

Design was completed and bids were submitted for general construction work at sites 1 and 2. When completed, the system will allow the testing of the component test trailer and other loop tests at operating temperatures, pressure and chemistry. All weather design will allow year around operation of the test facility.

2.1.6 RRGE-3

Selection of RRGE-3 was made on the basis of several criteria. A major critera was the need for a triangulation of three wells for basic reservoir analysis data. To develop the triangulation in relation to RRGE-1 and RRGE-2, an area of resistivity low based on resistivity work by the USGS which lay to the southwest was chosen. This area is farther out in the sedimentary basin away from the major fault structures, which should be at least 200 ft structurally lower than the two existing deep wells. Another criteria was to determine the extent of the geothermal reservoir, if in fact it is covering a large aerial extent as data now shows or more fault controlled. There could be reservoir barriers which are not defined in the basin which could significantly change the lithology and characteristics of the reservoir. Also lithologies compatible for large scale reinjection need to be determined for reinjection wells to support the power plant.

The design and drilling plan for RRGE-3 has been completed. The well has been designed with smaller and less casing to reduce costs. Several side track holes dyna drilled below the casing should increase production.

Temperature vs Depth

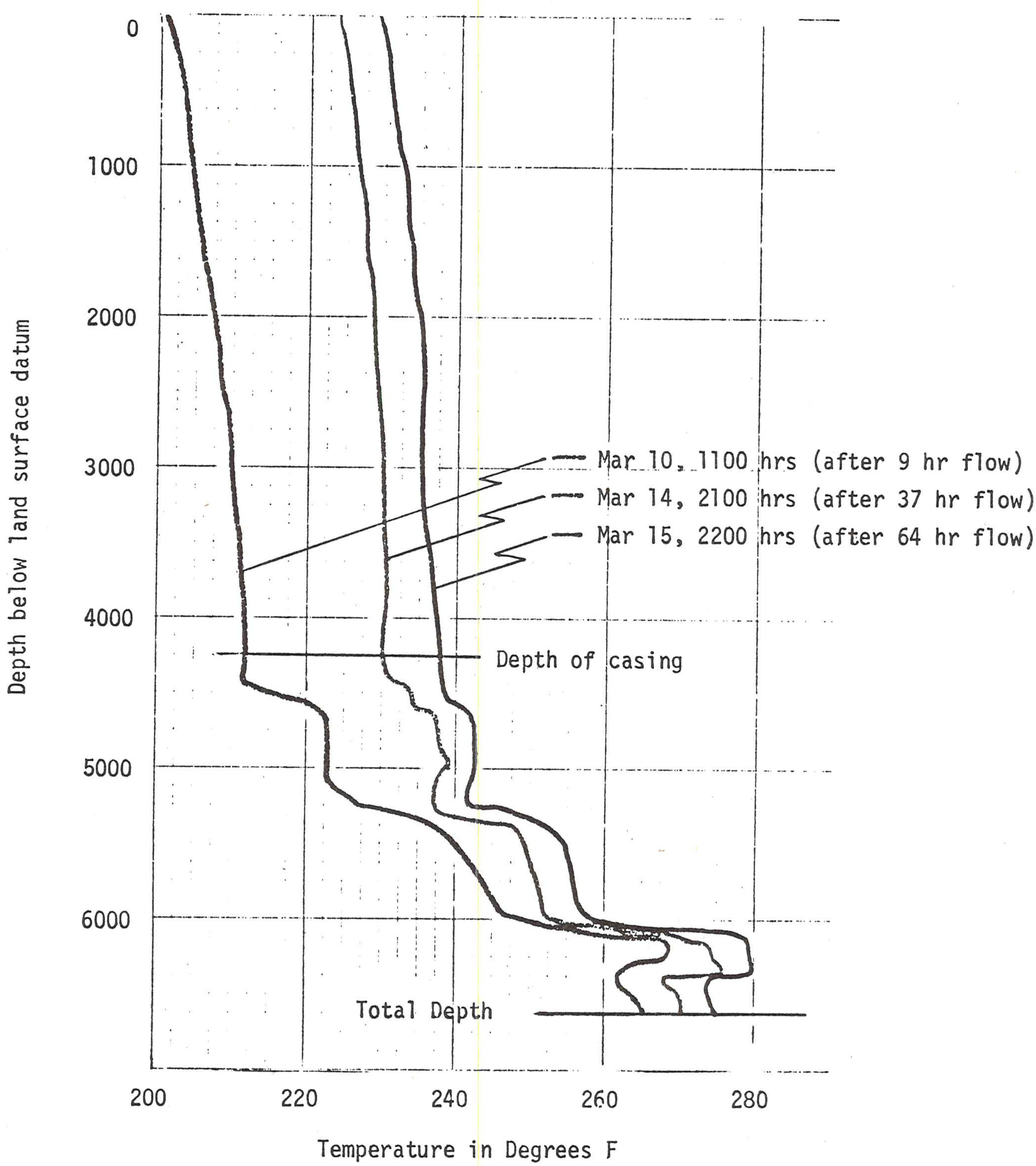


Fig. 4 Raft River Geothermal Exploratory Well No. 2

Upon completion of the deepening of RRGE-2, the rig was moved to RRGE-3 location in the SW 1/4, NW 1/4, Sec 25, T15S., R26E. RRGE-3 was spudded March 28, 1976. The rat and mouse holes and 120 ft of 20 in. conductor pipe were completed in late February. A 17-1/2 in. hole was drilled with mud to a depth of 1386 ft for the 13-3/8 in. surface casing. No lost circulation was incurred during the drilling. Sediments drilled were alluvium valley fill comprised of unconsolidated small gravel and sand. No significant clay or shale was encountered in the lower section. Temperature caliper and dual induction logs were run. Bottom hole (1386 ft) temperature at 1386 ft was 158^{o}F showing a temperature gradient of 6^{o}/100 ft.

A domestic well was drilled at the SW corner of RRGE-3 location to a depth of 200 ft for the purpose of locating water supply. The drilled section consisted of unconsolidated sand and gravel and sandy clay. It was set with 10-3/4 in. stolled casing. The well produces 80 gpm water at approximately 76^{o}F.

2.2 Boise Exploratory Wells and Holes

2.2.1 Boise Slim Hole - 3 (BSH-3)

The site for BSH-3 (2-7/8 in. diameter, wire-line core retreival) was selected on the basis of the area geology and geophysical data. It was completed at 550 ft with broken drill rod and core barrel in the hole. Several attempts were made at hooking onto the "fish," but all proved unsuccessful as the drill rod has leaned over to the extreme side of the enlarged hole. The BSH-3 drill site is shown in Figure 5.

Drilling operations progressed smoothly during the early portion except for wet cold weather. Toward the bottom of the hole however, unconsolidated sandstone and clay were encountered which caused considerable drilling difficulties. Coring operations are best conducted in consolidated formations with this particular drilling rig. Core retrieval was very poor and the sandstone and clay tended to wash out below 450 ft where it occurs at this location.

Much valuable core was retrieval however and evaluation is continuing at present. The basalt and cemented sandstone show a particularly high degree of alteration in the upper reaches of the hole.

2.2.2 Boise Exploratory Hole-1 (BEH-1)

BEH-1 was drilled on the same location as the slim hole BSH-2. See Figure 5. An attempt to set 8-in. casing to 610 ft failed when the casing became stuck at 340 ft. The 7-in. casing was then run inside the larger casing and successfully set at 610 ft. The 8 in. casing was then removed and the 7-in. casing cemented in place. See Figure 6 for the stratigraphic section of this well.

BEH-1 was then drilled to a total depth of 1222 ft and terminated as the drill rig was approaching an overload condition due to the weight of the drill rod. The rig was then moved off site and the well was closed in. No attempt was made to flow the well, however indications are that the well will

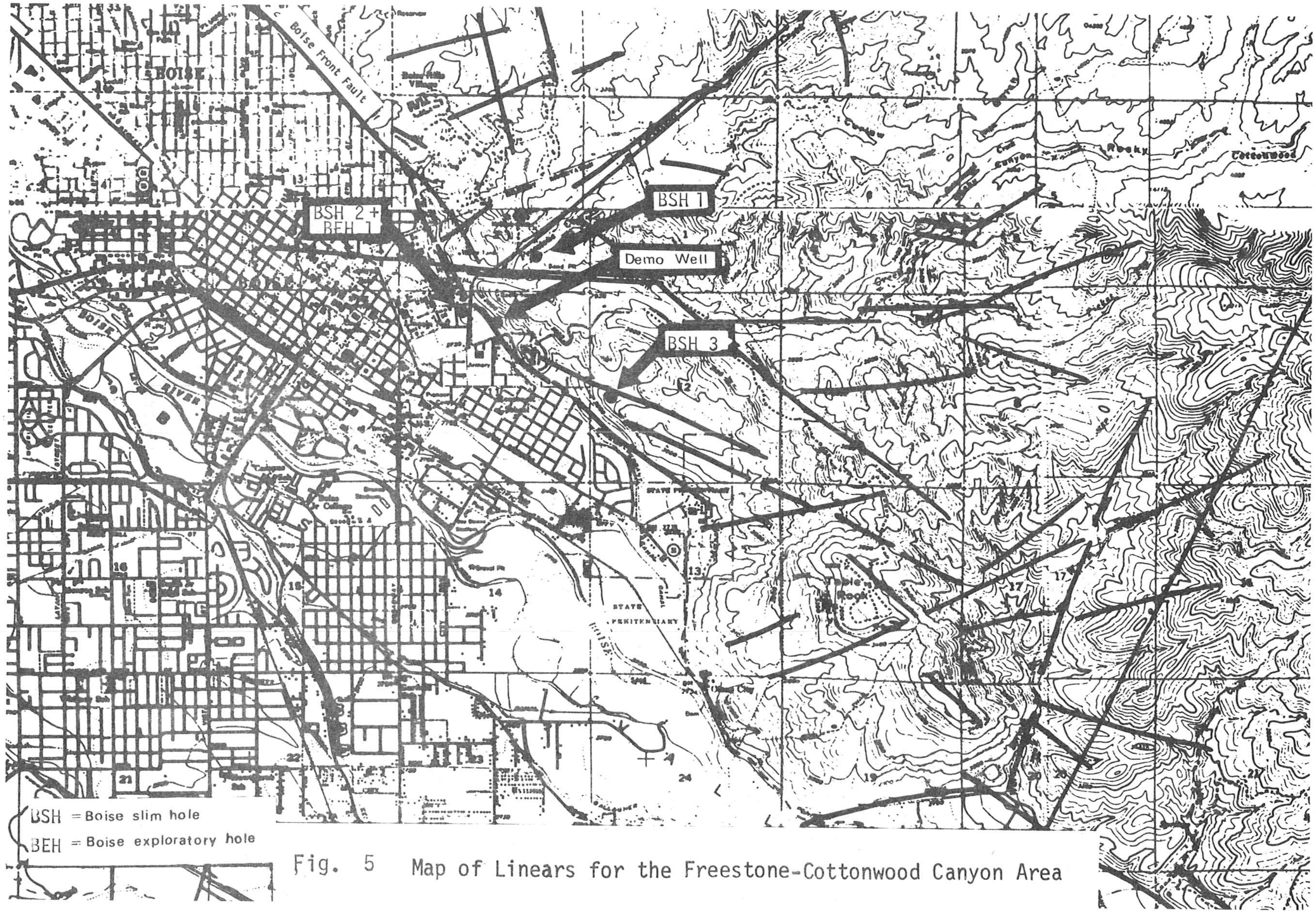


Fig. 5 Map of Linears for the Freestone-Cottonwood Canyon Area

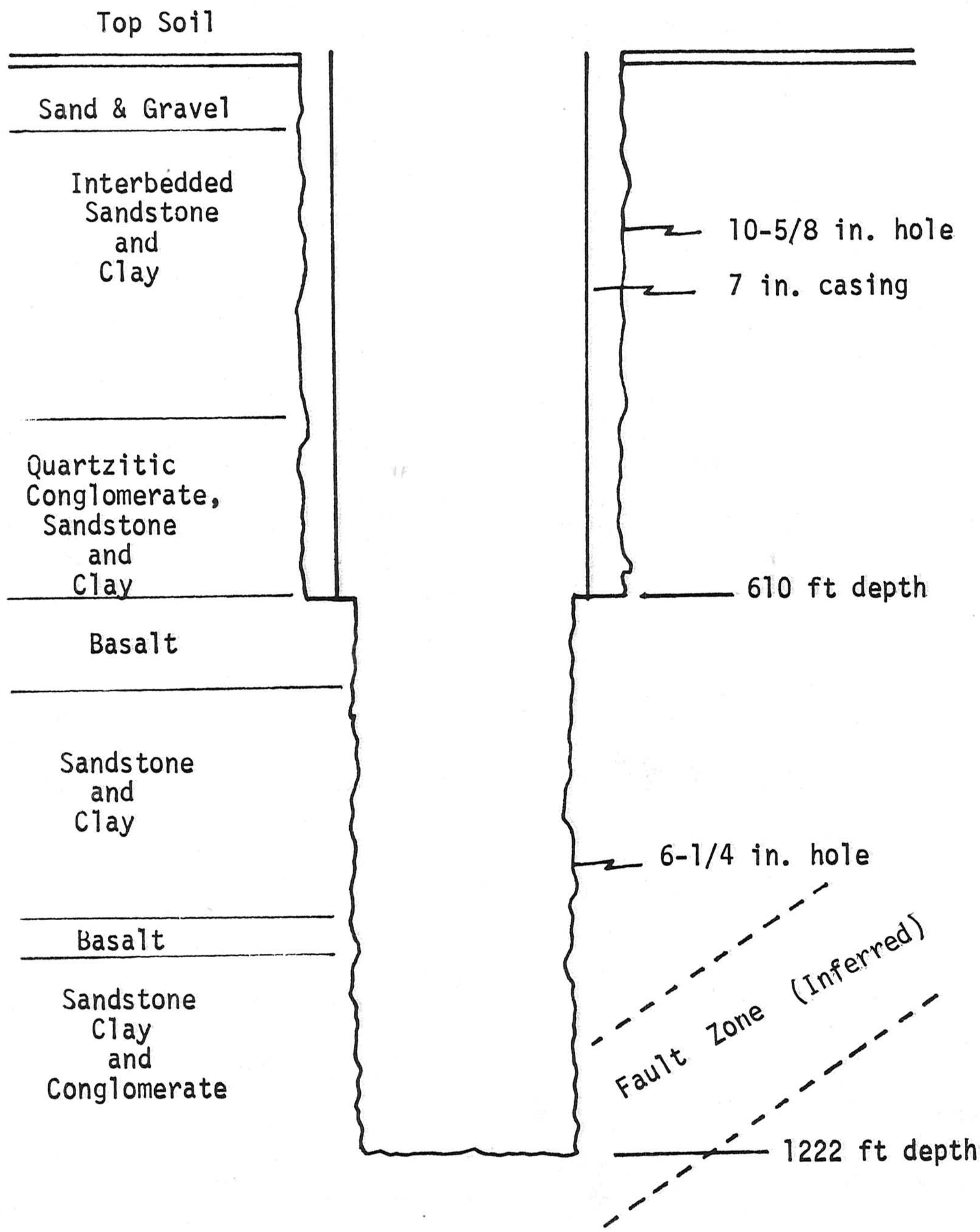


Fig. 6 BEH-1 (Preliminary) well and stratigraphic section

flow when the cold drilling fluid is removed. Testing of this well is imperative and plans are progressing to that end. See Figure 7 for BEH-1 Temperature Gradient.

2.2.3 Boise Hot Water-1 (BHW-1)

This well is also known as the Demonstration Well and was drilled by Beard Brothers Drilling under contract to INEL. The site was selected on the basis of the area geology and information gained from the other drilled holes. See Figure 8 for the general cross section.

Extreme difficulty was encountered in penetrating the boulders and gravel in the upper 200 ft of the hole. The hole also made mud from the benlonitic clay beds encountered and tended to plug up the bit cones and seize the drill string.

A final depth of 967 ft was attained at which point drilling was suspended in the upper portion of the Front Fault Zone. A pump was installed for flow evaluation purposes but the well began to free flow at 30 gpm before it was ever started. Pumped flow testing was then begun and drawdown data taken. The well flowed at 100 gpm (capacity of pump) but the data acquired was questionable as the well surged intermittently due to a high percentage of extremely fine sand being pumped out along with the water. The maximum temperature recorded was 164^{o}F at 890 ft as shown in Figure 9.

The well "sanded in" (plugged up) during flow testing in the early part of April. It is unknown at this time if it has bridged off uphole from the extremely fine sand or plugged up in the bottom of the hole due to the sloughing of this sand. Remedial action plans have been made and should be implemented in the near future as well as further extensive testing.

2.2.4 Boise Area Geology

The early geologic mapping in the area and the location of warm wells indicated that the Boise Front Fault was a major structural control influencing the geothermal resource. An analysis of the limited hydrologic study, geophysical study, remote sensing imagery study and the knowledge gained from drilling BSH-1, BSH-2, BSH-3, BEH-1, and BHW-1 has resulted in a modification of the original concept. The Boise Front Fault apparently is not as important a structural control as are the intersecting linears (or fault zones) that occur in the immediate area of investigation although the fault carries the hot water fed by the linears. These linears generally trend NE-SW and are visible all along the foothills to the north of Boise. However, several linears cut across the general trend and appear to have a major influence in the area around both the Warm Springs Penitentiary wells and this area of investigation.

2.2.5 Well Drilling Summary

The drilling operation at Boise presented many unique problems that were overcome and in general brought to a successful conclusion. The difficulty of drilling through boulders and gravel can best be overcome by added weight to the drilling string, proper bit selection and formation

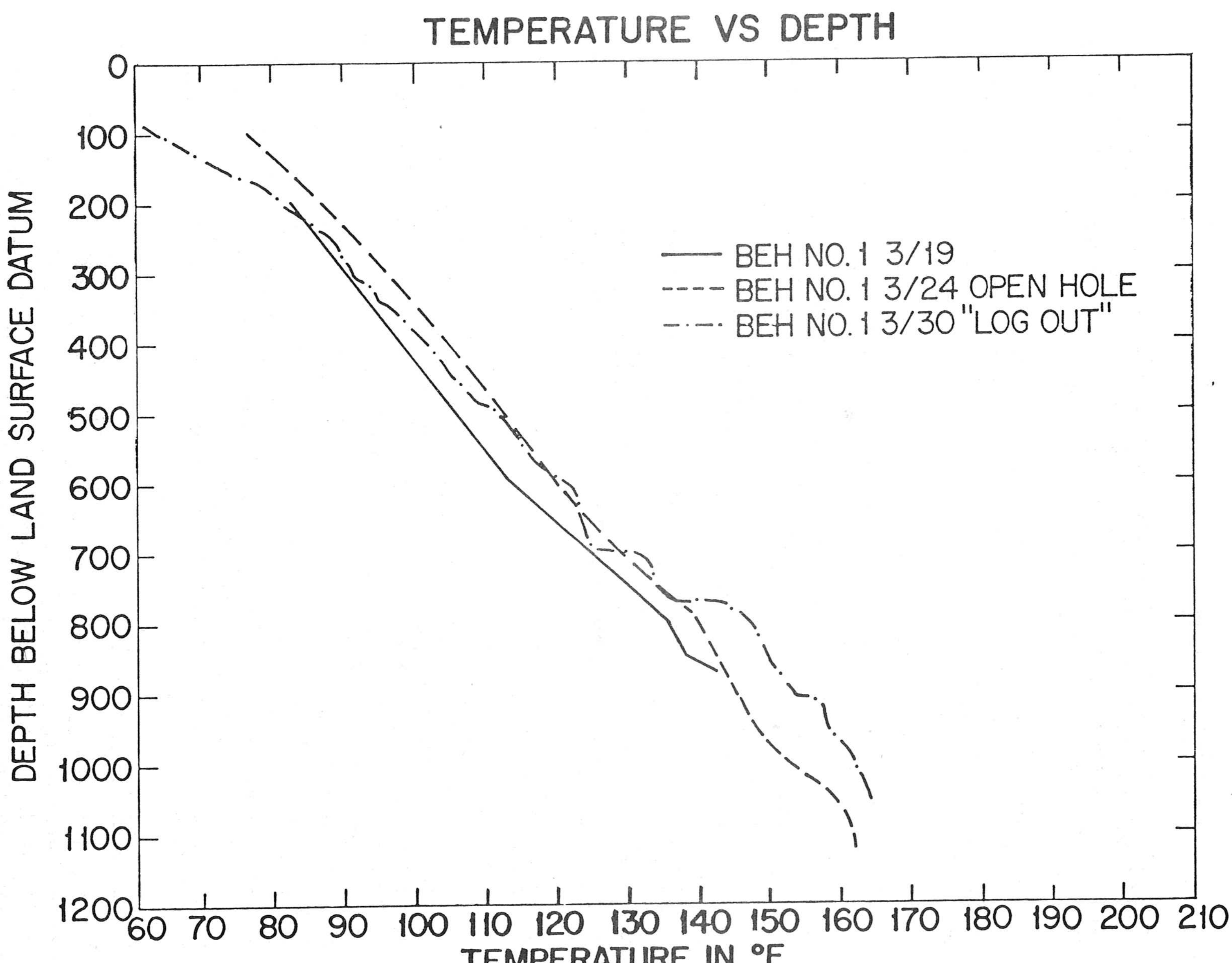


Fig. 7 Boise Geothermal Well Temperature Gradients

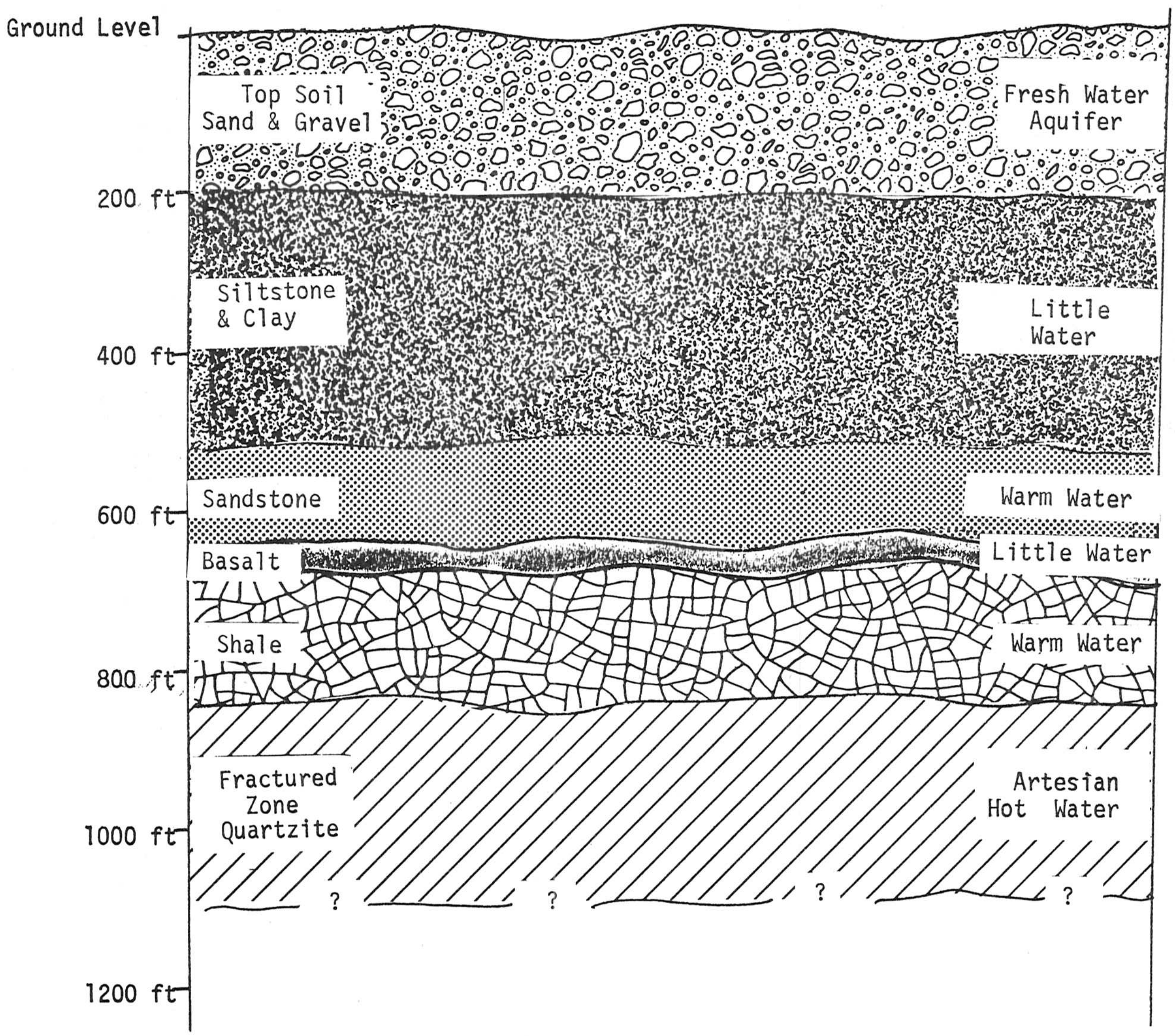


Fig. 8 BHW-1 General Cross Section

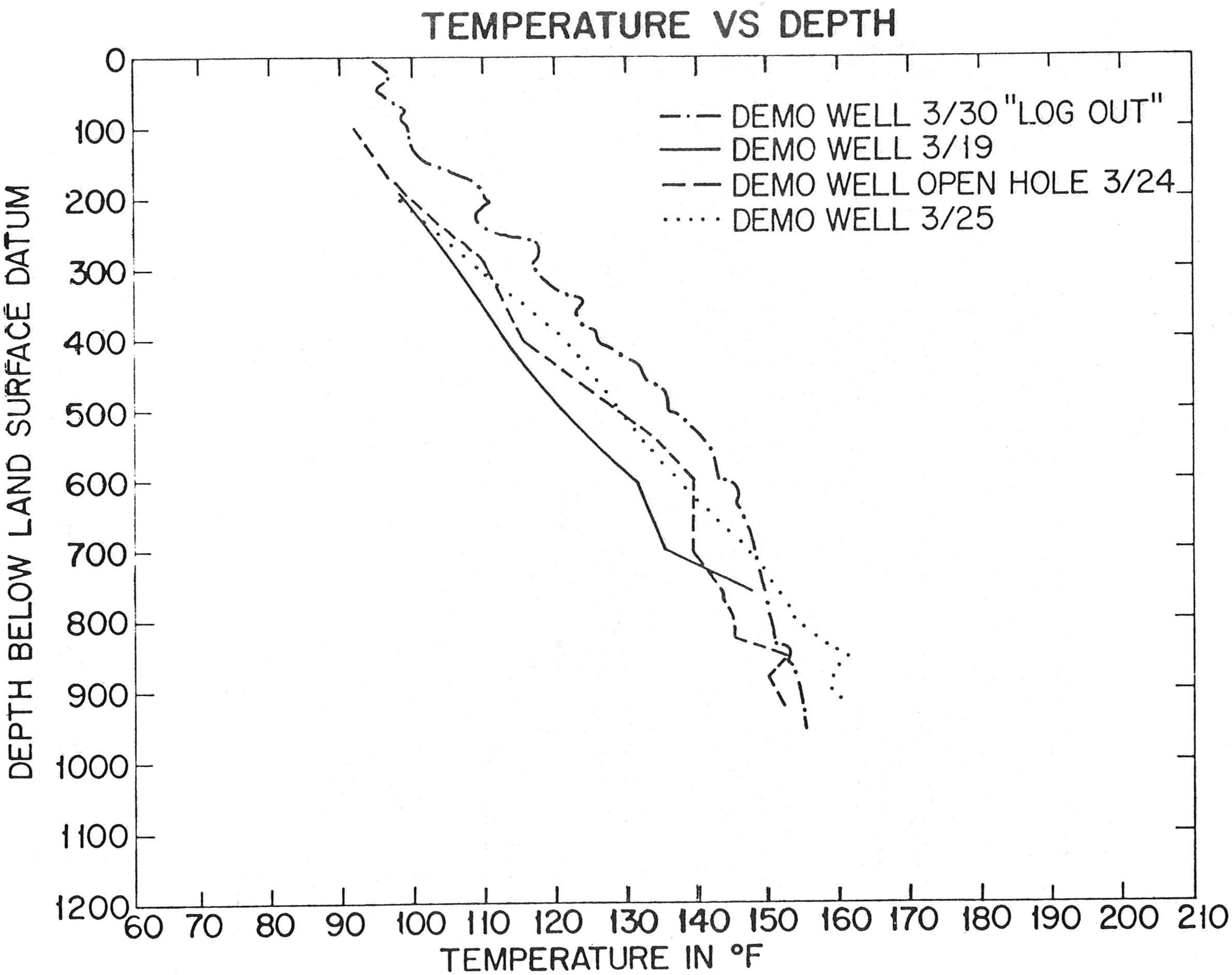


Fig. 9 Boise Geothermal Well Temperature Gradients

cementing if necessary. The bentonitic clay problem can best be counteracted by proper bit selection, using light drilling fluid and smaller than normal casing for the bit size. Being aware that the clay exists will also modify some standard drilling techniques. Drilling into these particular faulted zones necessitates the use of button or insert type bits.

The temperature profiles of BEH-1 and BHW-1 reveal that the gradient in both wells are approximately the same at depth. Moreover these temperatures (165^{o}F plus) are adequate to support the space heating project proposed for the Boise area.

The Boise Well Drilling Summary is shown in Table I and consolidates the pertinent information about each well.

2.3 Hydrology and Reservoir Engineering

There has been no testing during this quarter. However, plans for downhole pressure testing and evaluation of data for RRGE-3 are complete. Further ground water aquifer testing is scheduled by both the USGS and INEL. The ground water is of practical interest to INEL as a possible means of providing lower heat sink temperatures by once through aquifer cooling, a non-consumptive water use. The drilling of a few shallow test wells and further pump test, drawdown, and well interaction measurements are scheduled for this summer.

2.4 Raft River Area Subsidence Check

Elevation markers on a quarter-mile grid were established in late spring 1975, around RRGE-1 and RRGE-2. Elevation points were rechecked in December 1975 and March 1976, in the immediate three square mile area around the well sites. There has been no observable ground subsidence in the nine month period.

2.5 Environmental and Area Impact Considerations

The final stage of the baseline environmental data collection program was initiated this quarter. All baseline information required to prepare the environmental statement for the geothermal pilot plant facility and to provide a base for evaluating the long-term impact of geothermal operations in the valley will be collected by the end of this year, at which time the baseline data collection will be considered complete. Because much of the baseline work is seasonably restricted, only minor active collection was accomplished. Migratory species that winter in the valley were inventoried. The Gerrugenous Hawk, which is being recommended for a threatened species status, began its critical nesting period in the valley this quarter. Approximately 12 nests have been located within six miles of the drill sites. Those nests which are active this year are being protected from disturbance until after the young have fledged. Hawks banded during previous years are being located; this information will aid in the preparation (in conjunction with the U.S. Fish and Wildlife Service) of a management plan for geothermal development. The bulk of data for the flora and fauna studies will be obtained this spring, summer, and fall when the majority of species are in evidence.

Table I

Boise Drilling Summary

Hole or Well	Location*	Total Depth (Feet)	Maximum Temperature
BSH-1	Freestone Canyon	250	82°F
BSH-2	BLM Compound	650	132°F
BSH-3	Foothills East	550	94°F
BEH-1	BLM Compound	1222	164°F @1050 ft
BHW-1** (Demo. Well)	Freestone Canyon	970	164°F @ 890 ft

* The location of these exploratory holes and demonstration well are shown in Figure 5.

** This well developed 25-30 gpm artesian flow on March 31, 1976, during pump tests. Outlet temperature reached 162°F after very limited flowing. Pump testing is continuing.

The analysis of the results of the baseline microseismic study conducted during the summer of 1974 was received. During 90 days of recording, only seven events with S-P times of less than 2.0 seconds (epicentral location of less than 17 km) were seen. This corresponds to a rate of 0.2 events per day with magnitudes greater than 0.0, which is within a fractor of two of the ten-year seismic rate. The scarcity of events and their extremely low magnitudes (rare for geothermal areas) indicates that the valley is more closely related to the aseismic Snake River Plain than to the active Basin and Range and Intermountain Belt.

Other activities this quarter include the preparation of an environmental report to accompany the 5,000 acre land withdrawal request to the Bureau of Land Management; the initial outlining of the environmental statement for the pilot plant; the design of an environmental monitoring station to be located just northeast of RRGE-2; additional analyses of various pilot plant cooling options; and the set-up of a test geothermal irrigation program to determine the salt buildup, nickel damage to crops and the foliar absorption of fluoride and its implications.[4]

3.0 MODERATE TEMPERATURE CONVERSION TO ELECTRIC ENERGY

The following sections report work related to the conversion of the geothermal energy to electrical power. This work consists primarily of pilot plant design, testing and miscellaneous studies.[5]

3.1 Thermal Loop - Pilot Plant

Systems design work on the first 5 MW(e) unit has been started. This system will utilize nominal conventional state-of-the-art components. These are as yet untested in actual practice, but the facility incorporates the capability to evaluate floating power and coolant storage as methods of increasing the total kW-hr output of a power plant. Figure 10 shows the test facility concept being planned, with principal emphasis on advanced heat exchanger utilization and various methods for disposing of the waste heat while significantly lowering the heat sink temperature. Systems analysis work implies that, ideally, total power produced (kW-hr) can be increased on the order of 30% by permitting the power level to float with sink temperature.

System optimization analysis has shown that the dual boiler system increases power output on the order of 20%, when compared to a single boiler system, when used with moderate temperature brines. These analyses also indicate that the point of minimum power cost occurs approximately when utilization of the brine is maximized.

3.2 Results of Miscellaneous Power Plant Studies

3.2.1 Wellhead Power Units

A brief study was conducted to evaluate the small wellhead power plant. Both flash steam and the binary cycles were considered. It was throught that smaller units, mass produced, might offer some advantages and in the case of the binary cycle might permit the use of "compact" heat exchangers. A relatively non-conservative estimate of cost was made to provide a lower bound on the costs. The results in terms of $/kW (net) in 1975 dollars without escalation are shown in Table II with that of a 50 MW plant for comparison.

From the results shown in Table II, it is clear that no cost advantage is achieved, even under the rather optimistic assumptions. It was found that even at the small powers, the physical size of the plant was large enough that their consideration as shed mounted mobile power units was questionable. Perhaps with the development of direct contact heat exchangers, the small size plant would be more attractive economically.

3.2.2 Fossil/Geothermal Combination

Moderate temperature geothermal water is marginal at this time for power production, however, it could potentially be used to an advantage in a normal fossil plant for feed water heating. In a modern fossil plant, feedwater undergoes an enthalpy increase of about 1,400 Btu/lb between the condenser outlet and the boiler outlet. Geothermal water, possessing enthalpies on the order of 300-330 Btu/lb, of which only about 200 Btu/lb or less is usable, can contribute on the order of 10-15% of the heat to be

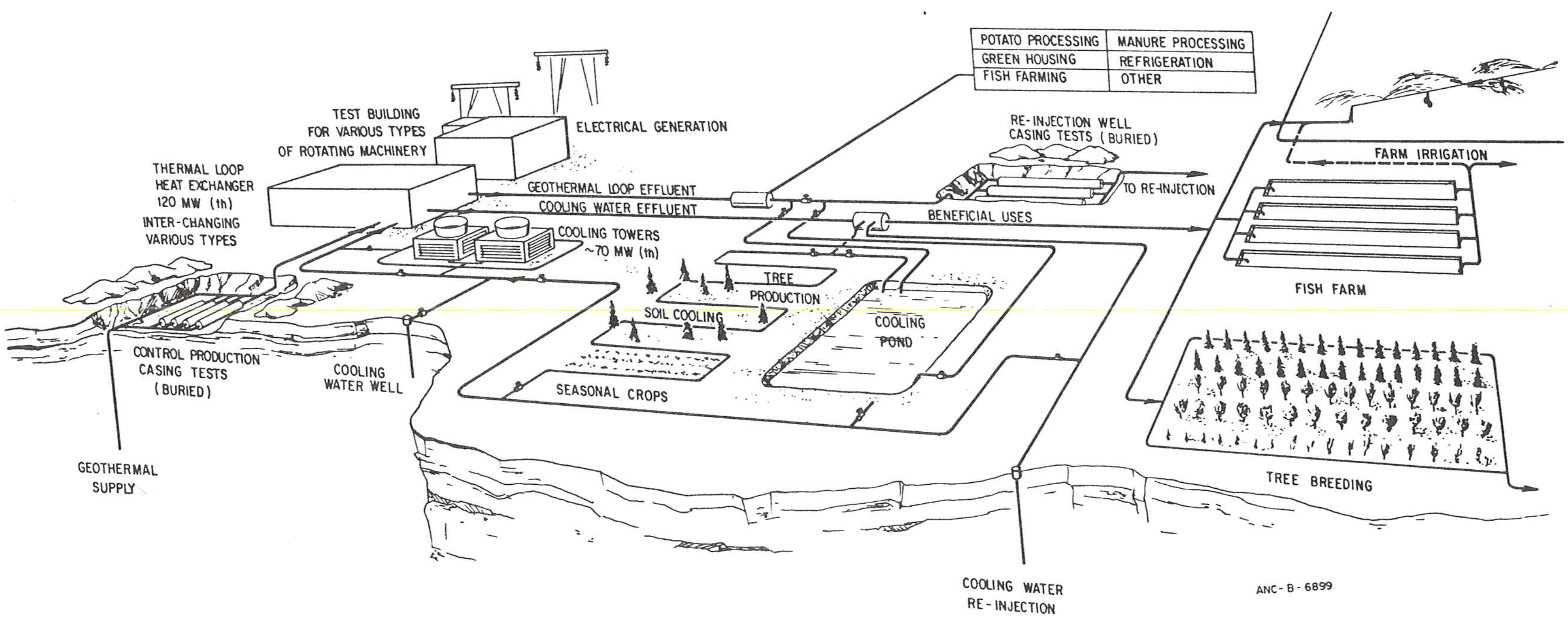


Fig. 10 Artist's Concept of Test Facility and Its Applications

Table II

Wellhead Unit Cost Comparison

Type of Plant	$/kW(net)
1.4 MW Double Flash Steam	
Power Plant	$ 648
Energy Supply	1300
	$ 1948
1.8 MW Single Boiler Binary (Isobutane)	
Power Plant	$ 670
Energy Supply	1000
	$ 1670
50 MW Dual Boiler Binary (Isobutane)	
Power Plant	$ 640
Energy Supply	540
	$ 1180

added. However, in a normal plant, a portion of this energy is added reversible. Thus, the potential geothermal contribution is much less. To determine more accurately the real gain that might be realized, an "old" 100 MW plant which utilized several stages of regeneration feed water heating was examined. Regenerative feed water heating stages were replaced by geotehrmal preheaters and an estimate of the percent of oil savings was made. Using the current cost of oil, a present worth calculations was made, which is presented in Figure 11, to provide an order of magnitude estimate of the investment that could be justified. At an oil cost of $12/bbl and assuming a 15% return on the investment, it would appear that savings incurred by using geothermal preheating would be more than sufficient to warrant the drilling of the necessary wells to supply and dispose of the geothermal brine. Calculations showed that approximately 1,500 gpm of geothermal fluid would be required. No analysis was made of additional costs that would be incurred in making the necessary plant modifications, i.e., additional condenser and cooling tower capactiy, brine supply and disposal systems, heat exchanger costs as opposed to feed water heater costs. From this initial analysis, it would appear that the savings in fuel costs over a 30 year period might warrant consideration of geothermal for feed water heating, particularly if dissolved solids are low enough to not create any problems in the heat exchanger.

The potential brine effectiveness for the utilization of a geothermal fluid for preheating is shown in Figure 12. As would be expected, the brine effectiveness increases significantly with increasing fluid temperature. Also shown in this figure is the potential ideal brine effectiveness if the brine were used to generate power through a dual boiling isobutane cycle and a more conventional dual flash steam cycle. Two cases were considered for the dual flash steam. The first case allowed for expansion of the steam through a turbine down to the same condenser conditions (1 in. Hg) as used in the 100 MW plant design. Since this is probably unrealistic, a second case where the steam was expanded down to condenser conditions of 3 in. Hg is presented. The flash steam analysis did not consider subatmospheric flashing, as it was considered to be impractical. A turbine stage efficiency of 85% was assumed. No plant parasitic losses were included in the brine effectiveness calculations; thus, these curves represent idealized conditions. From these plots, one can see that the brine is used most effectively at the lower temperatures if it is utilized for preheating in a fossil fuel fired plant. At temperatures above approximately 360°F, it appears that the brine utilization is about the same whether or not it is coupled with a fossil plant

From this initial analysis it appears that the utilization of geothermal heat in conjunction with a fossil fired power plant has a potential utilization (effectiveness) advantage. Also given the current cost of oil, the potential savings in oil consumption would seem to more than offset the cost of drilling the wells necessary to supply and dispose of the geothermal fluid. It should be noted that this analysis was made for a particular power plant, and will change if applied to another power cycle, such as a coal-fired plant.

This analysis is intended only to provide insight relative to the potential of coupling geothermal with a fossil plant. It has shown that definite advantages may exist and that economic value is not unreasonable.

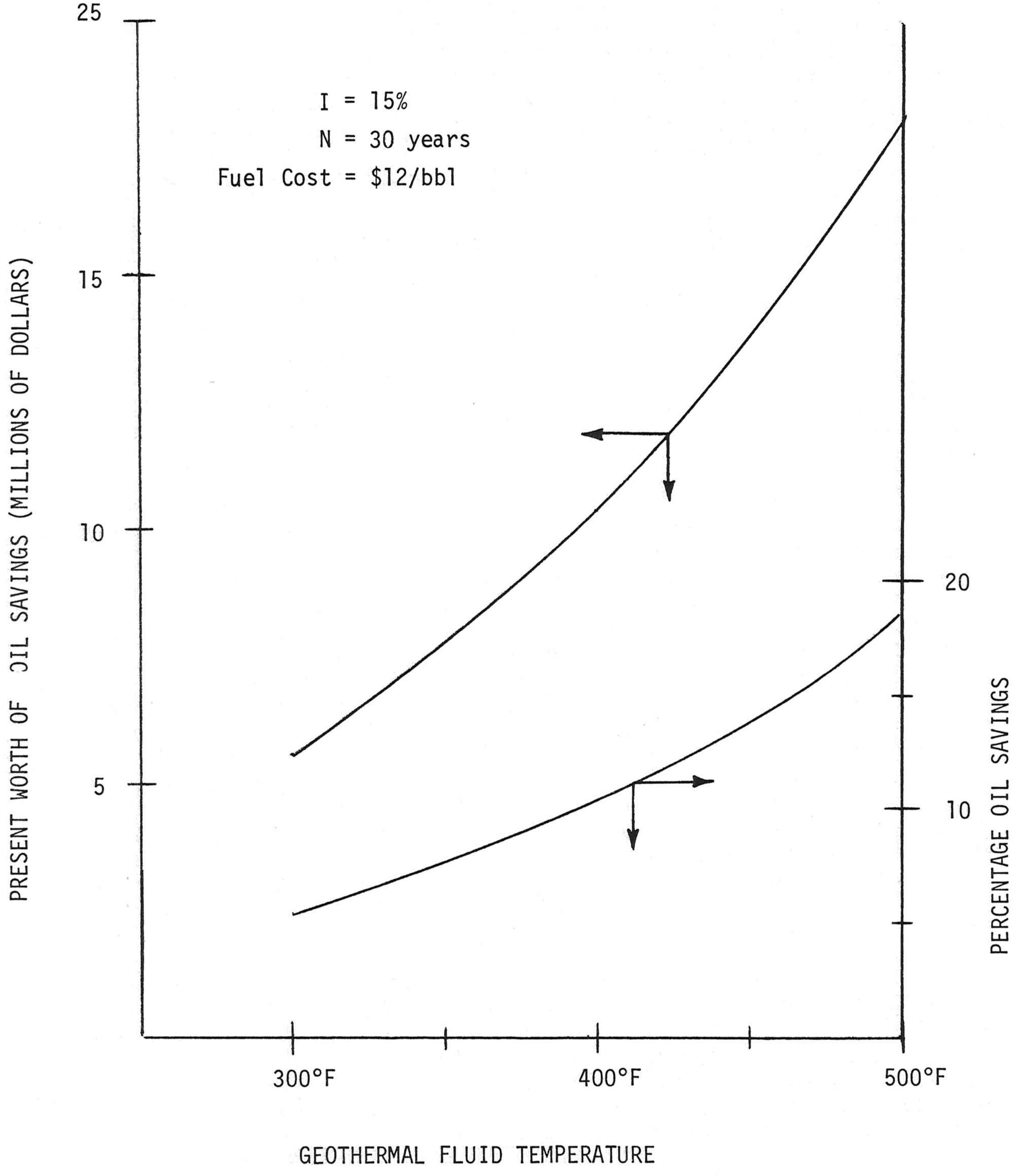


Fig. 11 Potential Fuel Savings for Fossil Fuel Geothermal Augmented Power Plant

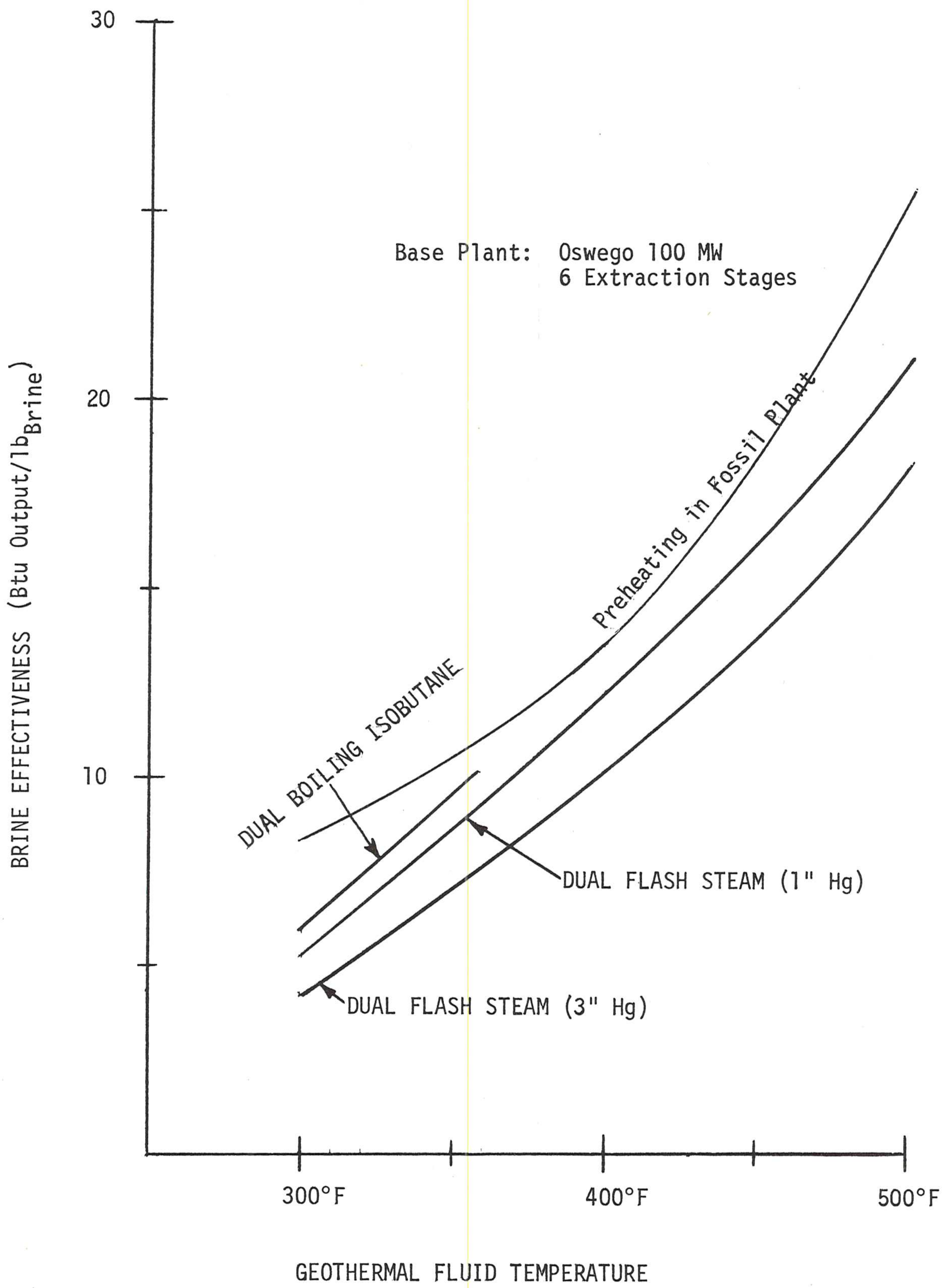


Fig. 12 Brine Utilization Comparison

3.3 Testing Related to Pilot Plant

Preliminary material tests to screen prospective candidate materials were initiated during February at RRGE-1. These tests were scheduled to be run for a two month period. However, the deepening of RRGE-2 temporarily eliminated the means of disposing of the geothermal fluid, and the tests were terminated after three weeks. Of the several materials tested, the aluminum alloys (as expected) showed the greatest corrosion rate. Because of the relatively short test period, the results obtained to date are inclusive and the test series will be continued when the well reinjection system again becomes operable.

During the same period the material tests were being run, a small tube (1/8 in.) forced fouling heat exchanger test was also performed. This test was designed to promote scale deposition and thus provide some insight on scale control. After a three week test period, pitting appears to have started and developed to a depth of about 0.001 in. in addition to a general corrosion film about 0.001 in. thick. The samples are currently undergoing more detailed examination to characterize the corrosion and provide the most information prior to specification of the thermal loop heat exchanger. Figure 13 shows the general corrosion and pitting that occurred within the tube.

In February, the instrumentation package for the Mobile Components Test Trailer was received and checked out. This package included the digital recorder, the signal conditioning equipment, and the instrument sensors. It is anticipated that the instrumentation package and the test trailer will be installed at the Raft River test site during May and June when the site preparation work has been completed on RRGE-1. Long term testing is then expected to commence, with fluid disposal in one of the other two wells, and/or via evaporation from the reserve pits during the hot summer months.

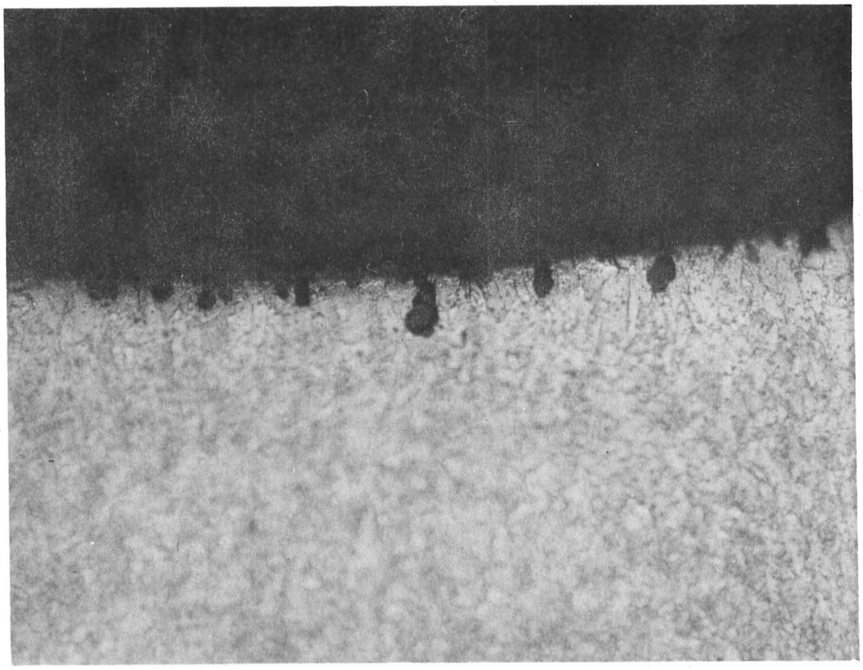


Fig. 13 Tube showing corrosion and pitting

4.0 MODERATE TEMPERATURE CONVERSION TO ELECTRIC ENERGY

4.1 Direct Contact Heat Exchanger Development Studies - University of Utah H. R. Jacobs and R. F. Boehm

4.1.1 Raft River - Direct Contact Heat Exchanger - Contract No. E(10-1)-1523

During the reporting period, a large amount of data has been obtained on the operation of direct contact boilers at the Raft River Geothermal Site both for volume and surface type boilers. The data needs further reduction before a final scaling law can be presented; however, it can be concluded that both the surface and volume boilers met and, to a degree, exceeded expectations as to their efficiency.

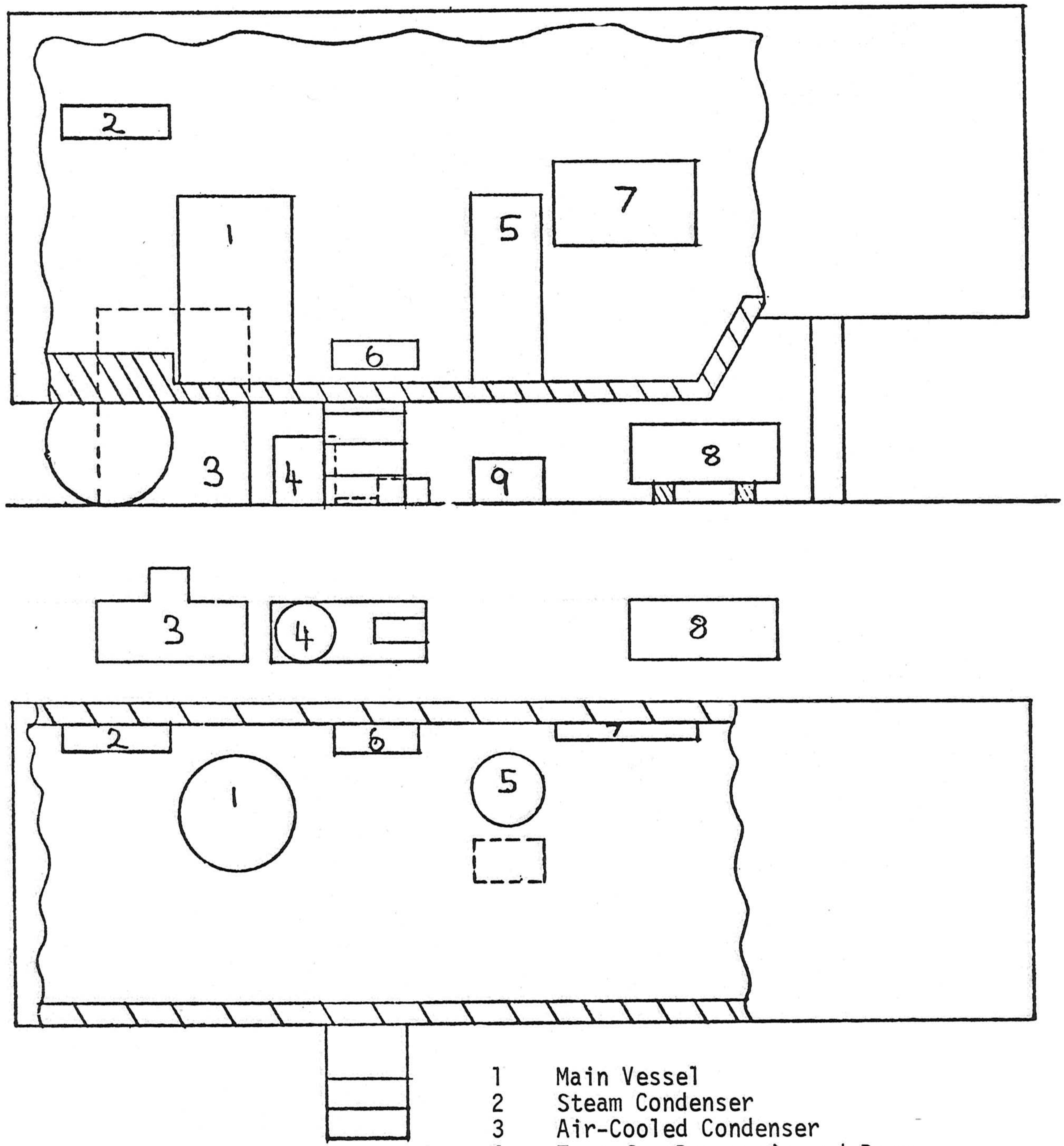
The data obtained during this reporting period were primarily obtained at the No. 1 Raft River well. While operating at RRGE-1 site, the high cooling water temperature (approximately 90^{o}F) required a change in the condenser system. (Figures 14, 15, and 16 indicate the present and past total system layout) An air-cooled condenser was installed the week of January 12, 1976. In addition, a "carryunder" detector was added to the system to determine whether liquid working fluid was building up in the bottom of the primary vessel. The detection system, which is based on utilizing water in the bottom of the boiler as an electrical conductor, signals the operator when freon builds up in the bottom since the freon, an excellent dielectric, breaks the circuit if it builds up in the vessel.

Initial testing on a weekly basis continued to January 28, 1976. During this period, procedures were established to obtain data over a range of operating conditions. Typically, the experiments were conducted from 8:00 AM until 7:00 PM with the system being shut down over night. The primary testing was carried out using a volume boiler configuration. (See Figure 17) The shut-down operation cycle provided some additional complications for the volume boiler systems that were investigated.

When the volume boiler was shut down for the evening, no attempt was made, at first, to eliminate the water setting in the trays. This allowed evaporation of the water on the trays as well as allowing water to seep down the injection orifices and evaporate. Since these orifices were only 0.025 in. in diameter, a number of them became clogged. Both larger diameter orifices and anodizing of the trays were tried to avoid this problem, however, the most successful technique was to blow air through the tray orifices until the system was cold. The anodizing of the trays was successful in preventing corrosion of the aluminum components. Aluminum had been used (although it was known to be subject to corrosion in these brines) due to its ready availability and the planned short testing period.

Testing of a surface type boiler (see Figure 18) utilizing several different types of commercially available spray nozzles was initiated the last part of January and continued to February 6, 1976. Testing was restarted on February 10, 1976, but had to be terminated on February 11, 1976, due to freezing of a condenser tube. This problem could not be alleviated until February 17, 1976.

Component Layout



1 Main Vessel
2 Steam Condenser
3 Air-Cooled Condenser
4 Transfer Reservoir and Pump
5 Water/ Freon Separator
6 Freon Preheater
7 Control Panel
8 Freon Supply
9 Freon Pump

Fig. 14 Direct Contact Trailer Layout

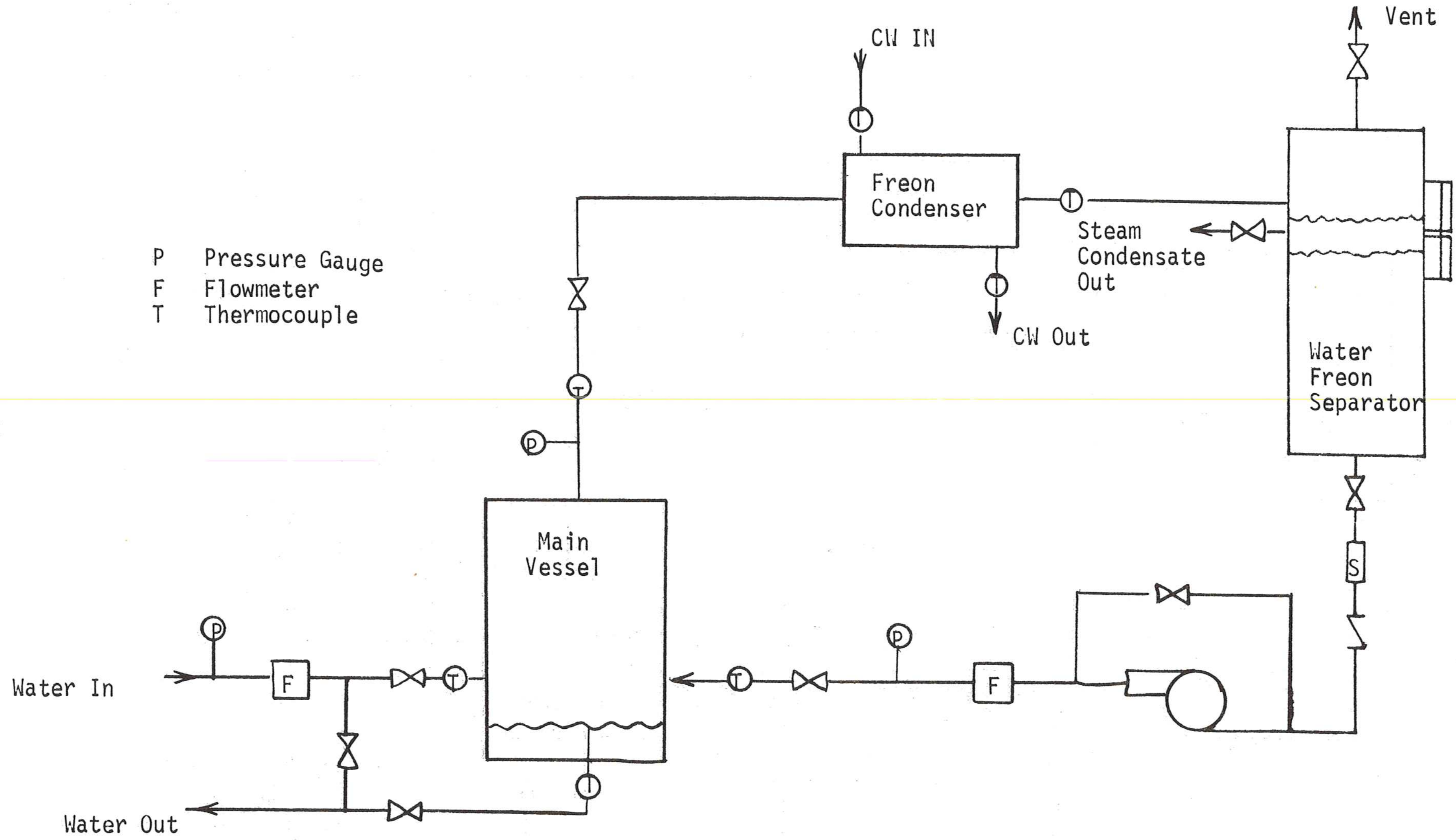


Fig. 15 Direct Contact Heat Exchanger (12-31-75)

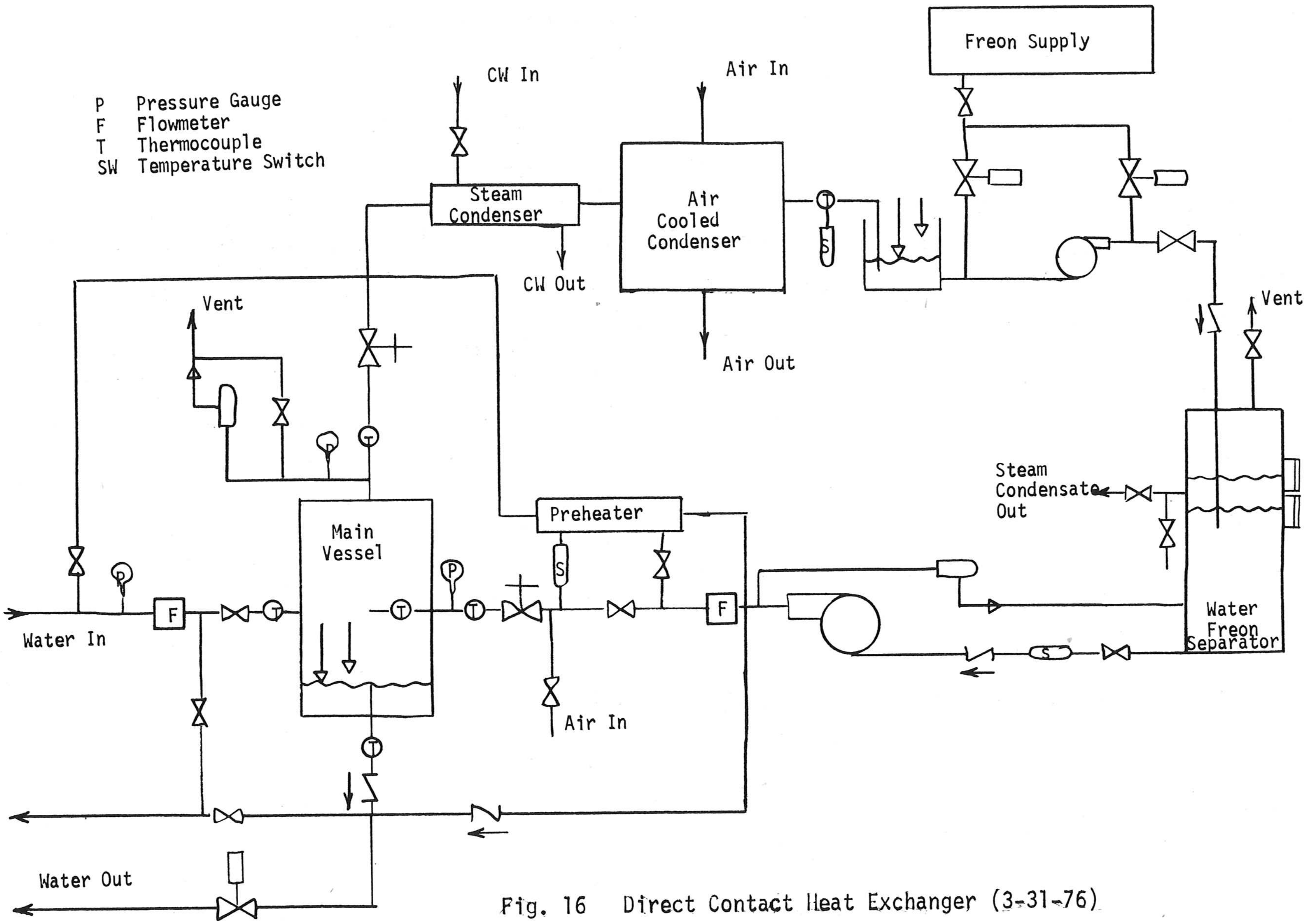


Fig. 16 Direct Contact Heat Exchanger (3-31-76)

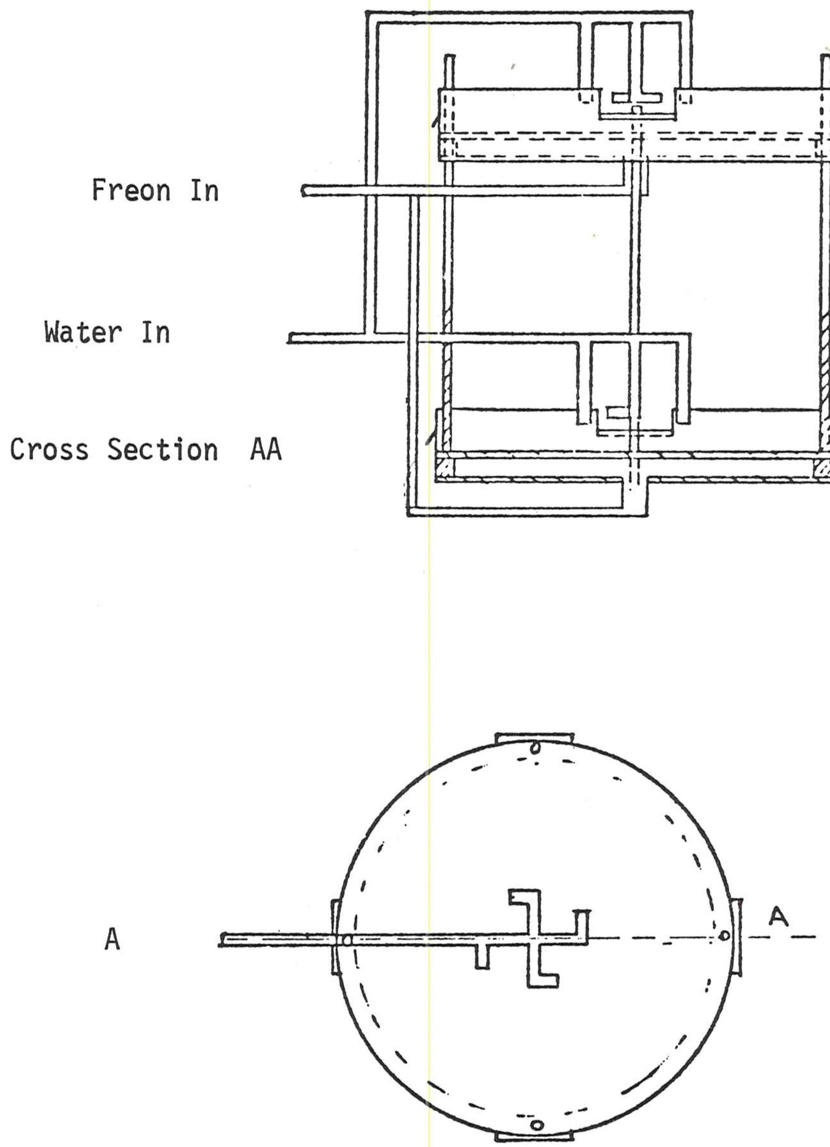
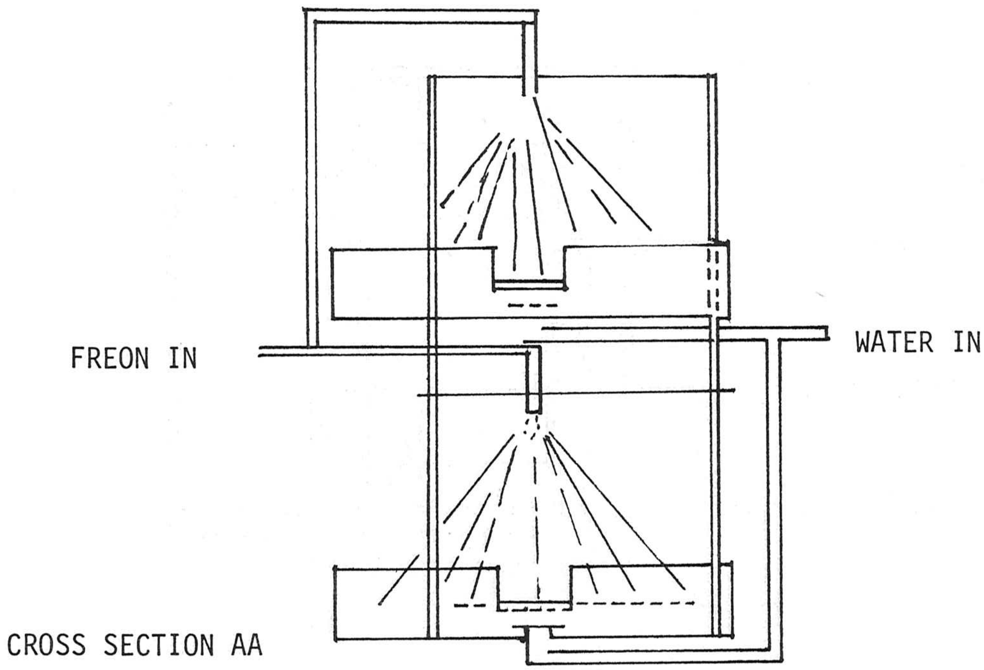
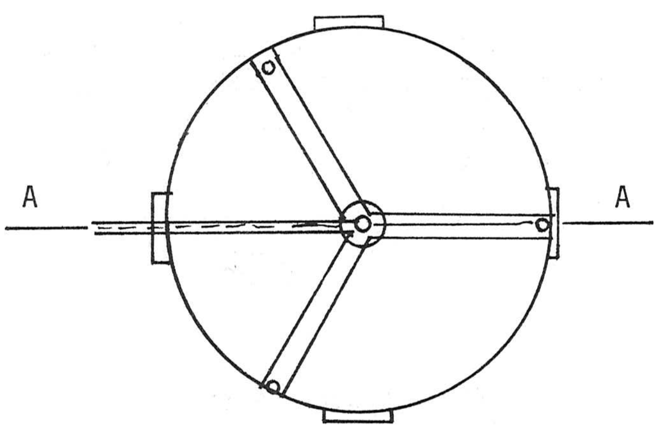


Fig. 17 Volume Boiler





SURFACE BOILER

Fig. 18 Surface Boiler

Typical data obtained from a spray nozzle test and a volume boiler test are shown in Figures 19 and 20, respectively. The data indicated little effect of UA on the type of spray nozzle. The data is consistent with that of Jacobs, Deeds, and Boehm (Reference 6) obtained on the laboratory model when the effect of subcooling and size of the trays are considered.

A preheater was installed as is shown in Figure 16 to minimize subcooling of the freon upon entering the boiler so that a more direct comparison could be made with the data and correlation of Reference 6. Here it should be recalled that the data of Reference 6 was obtained with Freon entering at near saturation conditions so that the heat transfer could be correlated in the form of the Stanton number.*

$$St = f\left\{Ja,\ Pr,\ \left(\frac{m_{\text{disperse phase}}}{m\ H_2O}\right)\right\}$$

$$\text{where}\quad Ja = \frac{C_p\ \rho_f\ \Delta T_{sh}}{\Delta h_{fg}\ \rho_g}$$

$$Pr = \frac{C_p\ \rho}{k}$$

When significant subcooling is present there are two heat transfer mechanisms that are influential. First the fluid is heated to saturation. During this phase, the heat transfer is independent of the Jakob number, Ja, and is dependent on the Reynolds number instead. During the ebullition phase, the primary dependence of the Stanton number is on the Jakob number. Thus it would be expected that data obtained for high subcooling would not correlate in quite the same manner as for the negligible subcooling condition.

In March, the heat exchanger test trailer was moved to the University of Utah for modification and continued testing with various geometrics. Data reduction facilities at the University of Utah have been reprogrammed to facilitate more rapid reduction of data. It is now possible to have hourly reduction of data which will allow for adjustment in the testing program daily.

Alternate design schemes for possible tray configurations were carried out in March. Schematics of new volume and spray type trays are shown in Figures 21 and 22, respectively. These trays are now constructed and will be installed in the near future. These trays may allow for a more compact design.

* Stanton Number

$$St = \frac{Nu}{R_e P_r} = \frac{h}{\rho C_p V}$$

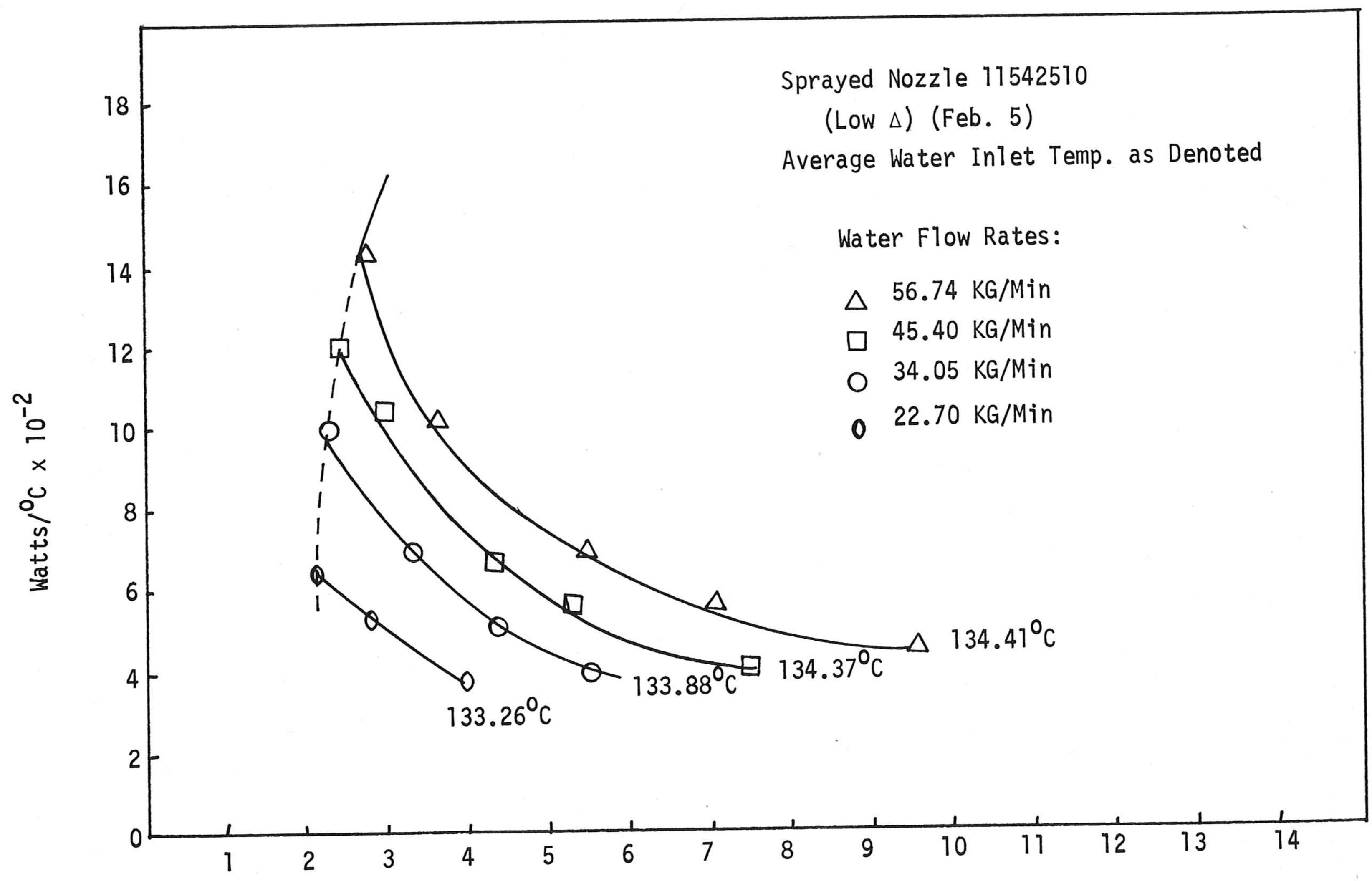


Fig. 19 Mass Flow Ratio Water to R-113 MW/M

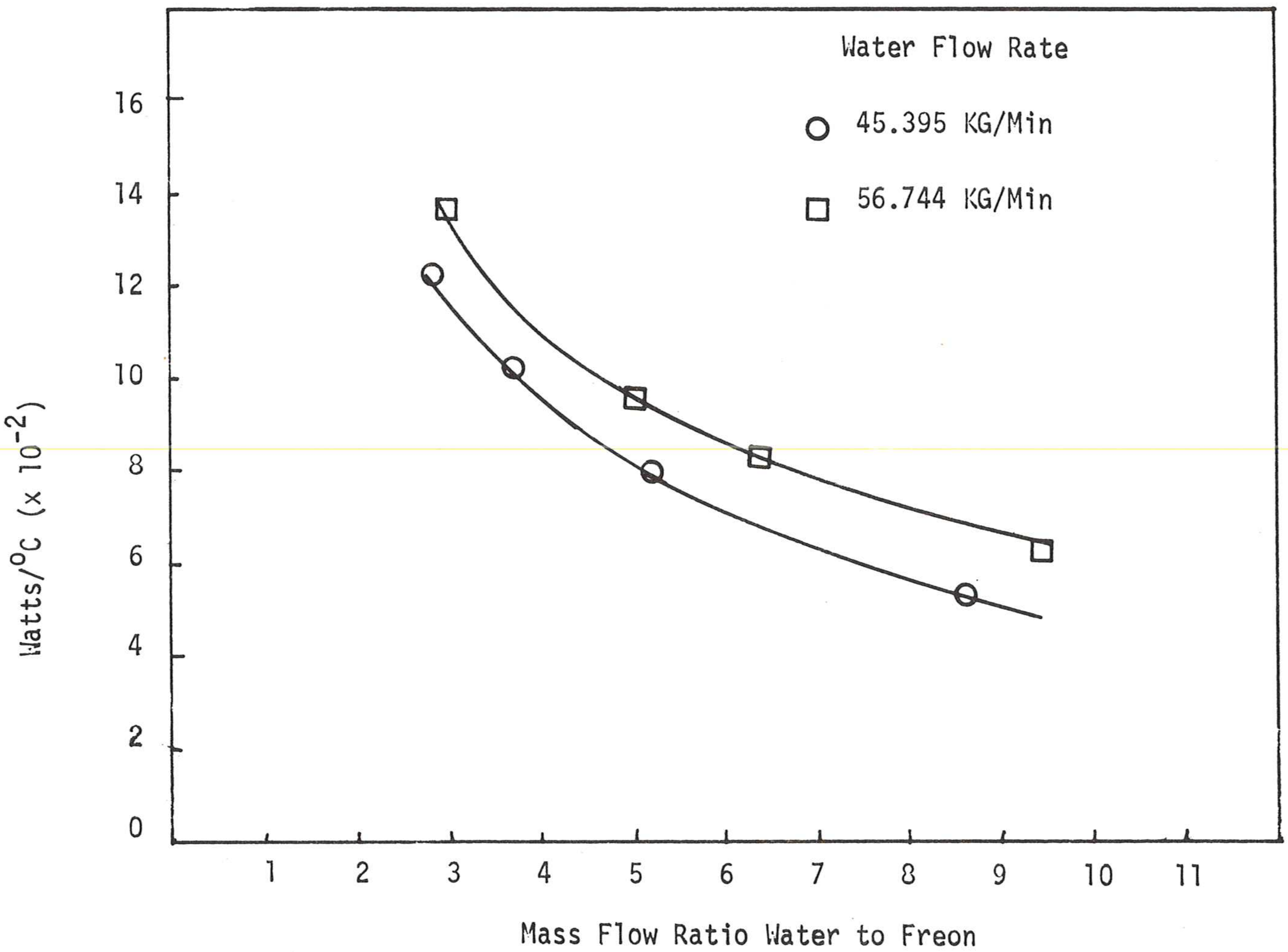


Fig. 20 Volume Boiler

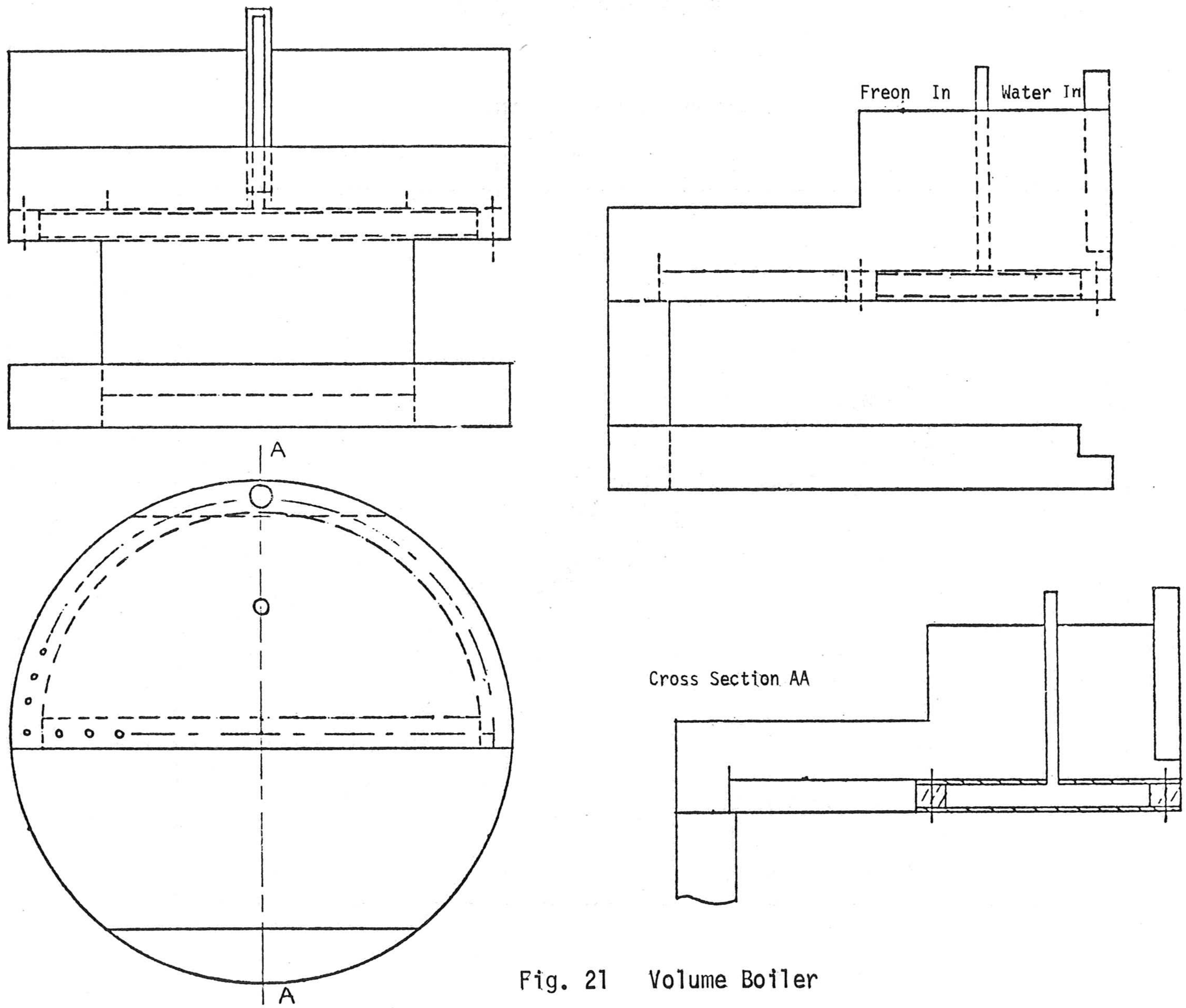


Fig. 21 Volume Boiler

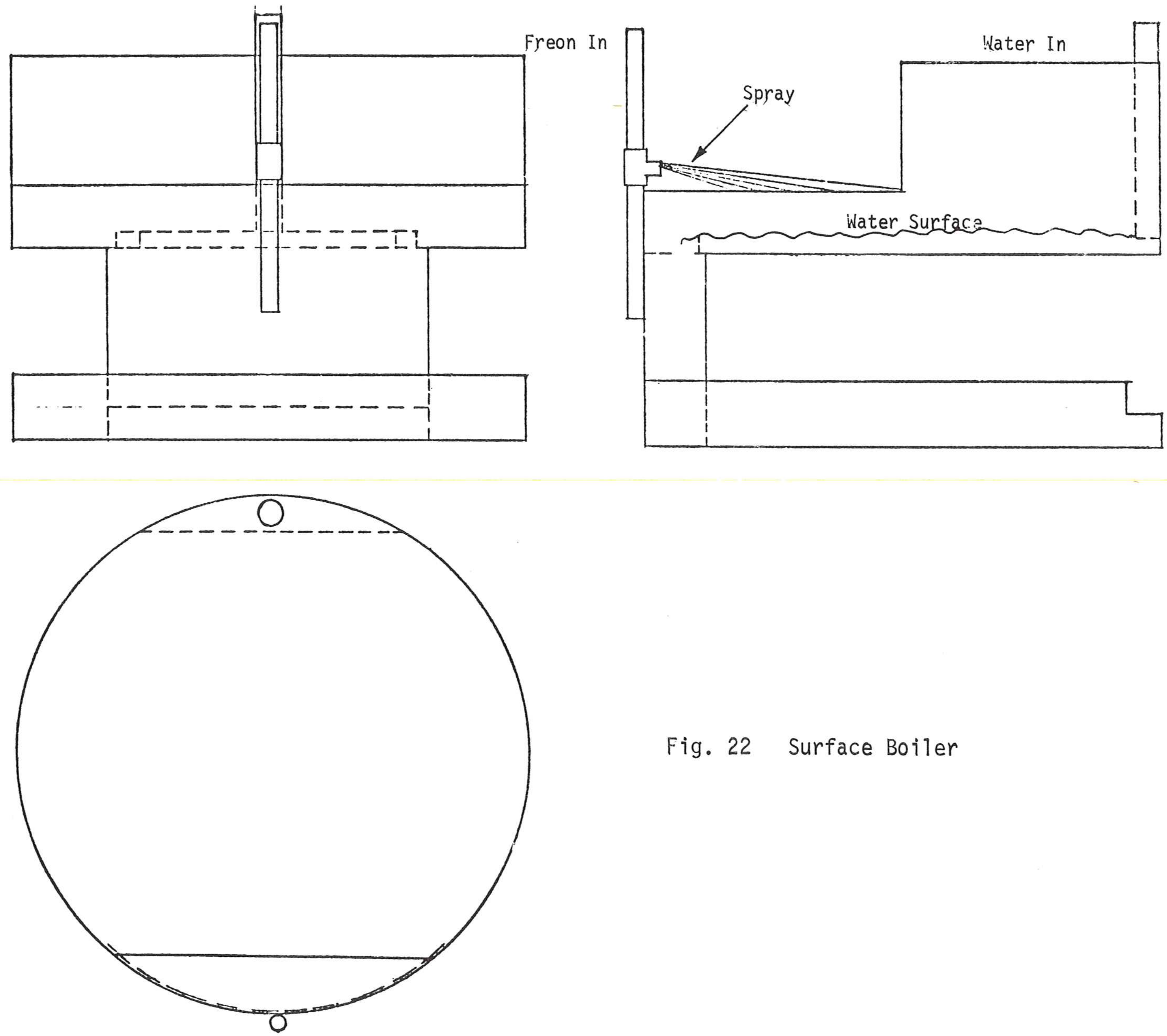


Fig. 22 Surface Boiler

Based on the test data obtained at Raft River, a spray-type boiler of 4 MW(th) capacity was designed to get a rough estimate of the physical size. A schematic is shown in Figure 23. This heat exchanger is simpler and no larger than a conventional tube and shell heat exchanger using the best overall heat exchange reported by San Diego Gas and Electric (Reference 7) assuming no degradation due to scaling or corrosion, which of course, will occur.

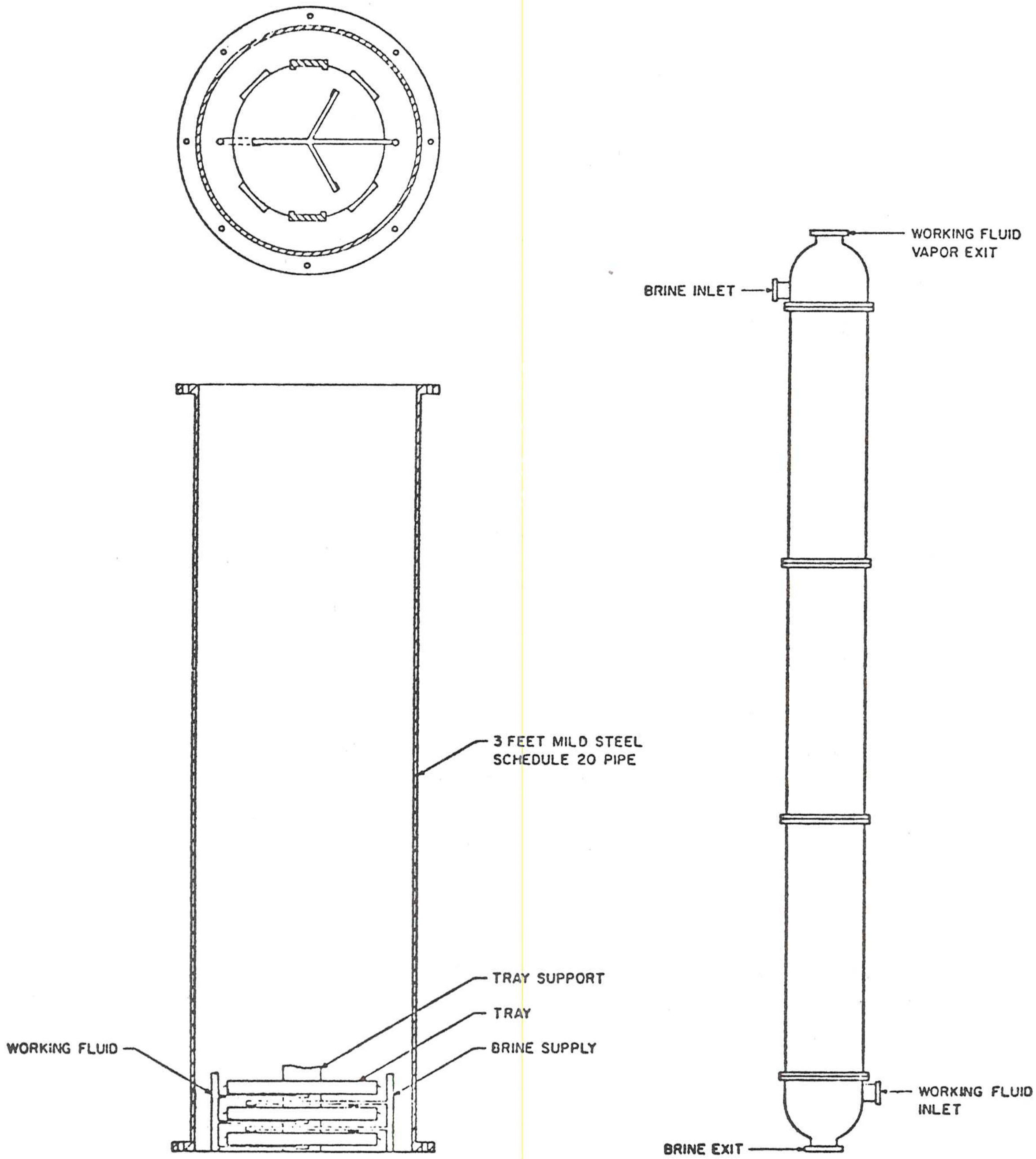
4.1.2 Feasibility of Direct Contact Heat Exchangers for Geothermal Power Production - Grant No. AER 75-01039

To date, work has progressed in four areas: 1) Solubility Measurements, 2) Thermodynamic Cycle Analysis, 3) Turbine Characterization for Direct Contact Cycles, and 4) Heat Transfer Characterization.

1. Solubility measurements are being conducted utilizing a Hewlett-Packard Gas Chromatograph System using both flame ionization and electron capture detectors. The flame ionization detectors are being used for standard hydrocarbons while the electron capture detector is being utilized for halogenated hydrocarbons. The sampling procedures and system design have been of primary concern as it is desired to be able to reproduce measurements to within 1% or less relative values. It is expected that initial reports will be available by June 30, 1976.

2. In order to carry out the thermodynamic cycle analyses for geothermal binary power plants and select optimum cycles, it has been necessary to develop basic property computer subroutines for water, hydrocarbons, and halogenated hydrocarbons. The water property subroutine basically utilizes the equations of state of the 1969 Keenan and Keyes steam tables. A report on this subroutine is written and should be released by May 10, 1976. The thermodynamic properties of hydrocarbons are calculated using the Starling modified Bennedict-Webb-Rubin equation of state. This subroutine is currently being documented and should be released by May 30, 1976. The halogenated hydrocarbon properties are calculated using the Martin-Hou equation of state and this subroutine has been checked out and will be released shortly. Documentation on these subroutines will be available to all ERDA contractors as soon as possible. The primary thermodynamic cycle computer program for direct contact and ordinary binary cycles is currently being programmed. It is expected that it will be completed and documented by July 30, 1976.

3. Preliminary turbine sizing for direct contact geothermal power plants was carried out by a modification of the basic theory of Balje to account for the fact that the fluid expanding through the turbine is always a mixture of water and working fluid. Typical results are shown in Figures 24, 25, and 26, assuming a single stage axial turbine. Implicit in these curves is operation at the maximum efficiency of 90%. A comparison of turbine diameters and speeds for several fluids is shown in Table III.[8]



TYPICAL VOLUME BOILER TRAYS
2 IN. DEEP - 2 IN. SPACING
10 FT. SEGMENT

4MW THERMAL DIRECT CONTACT
FREON 113 BOILER

Fig. 23 4MW Thermal Direct Contact Freon 113 Boiler

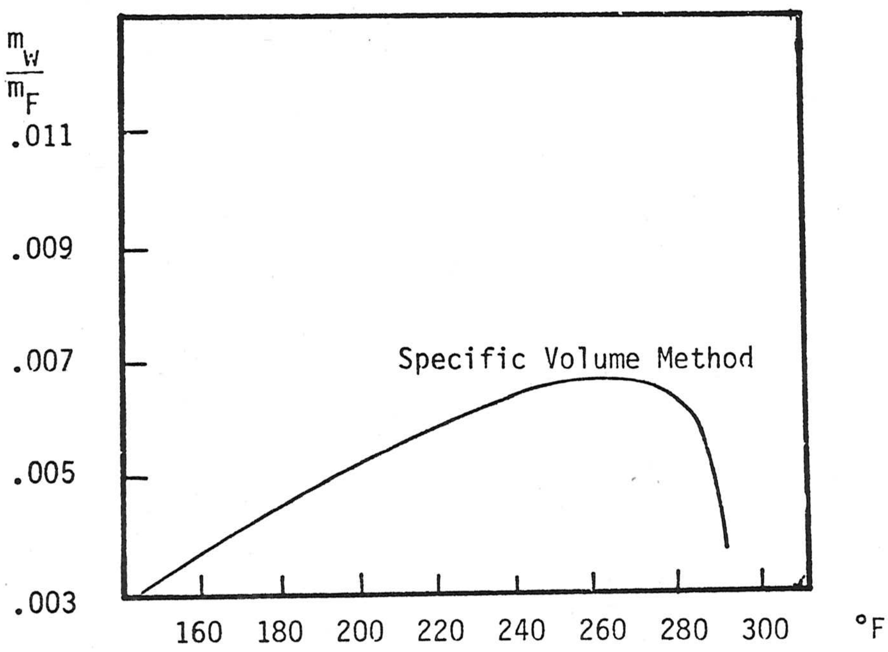


Fig. 24 Ratio of water to Freon 114 in vapor as a function of Temperature where $P_T = P_{H_2O_{SAT}} + P_{Freon\ 114_{SAT}}$

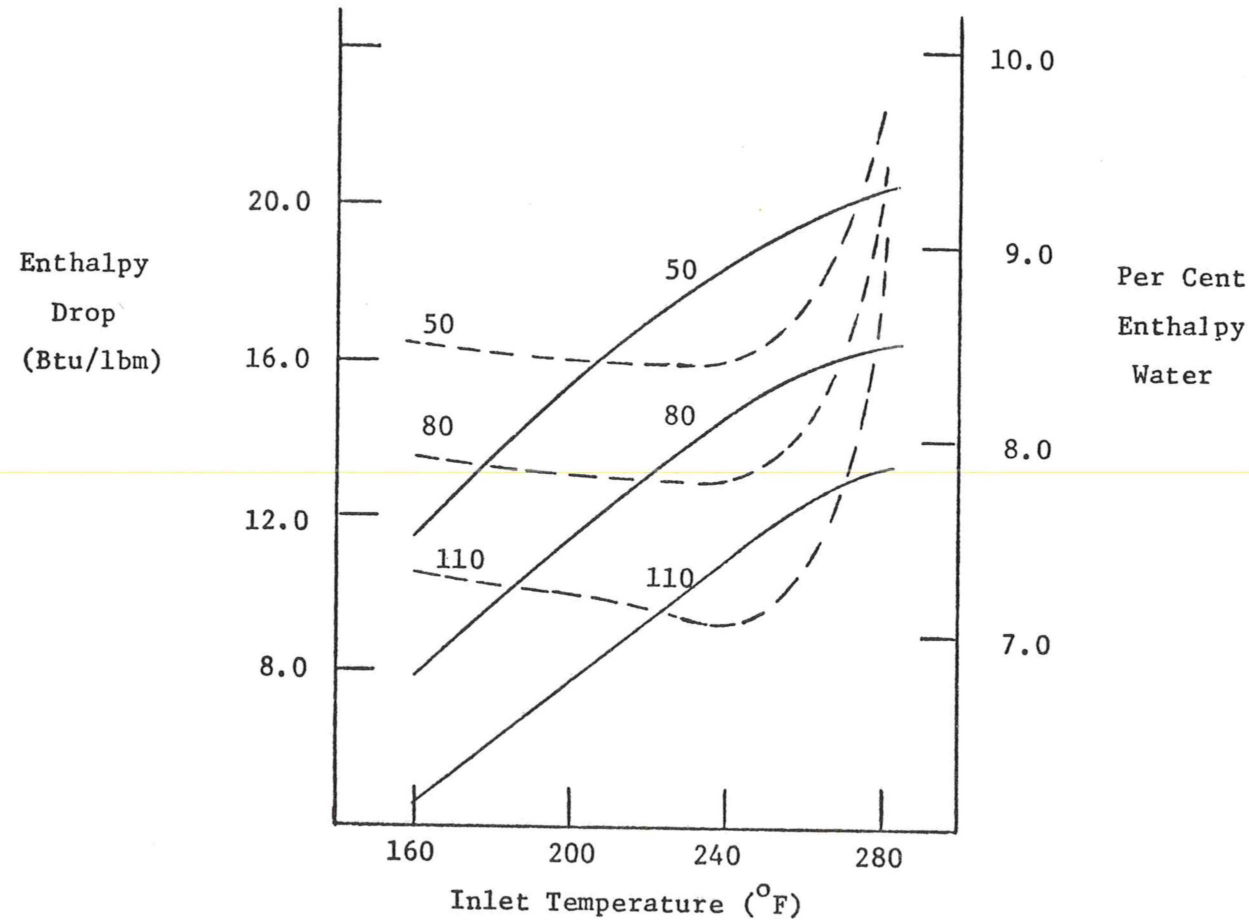


Fig. 25 Dashed lines indicate the per cent enthalpy drop provided by the water vapor. Solid lines indicate the total enthalpy drop. Each line is for a particular condensor temperature (°F).

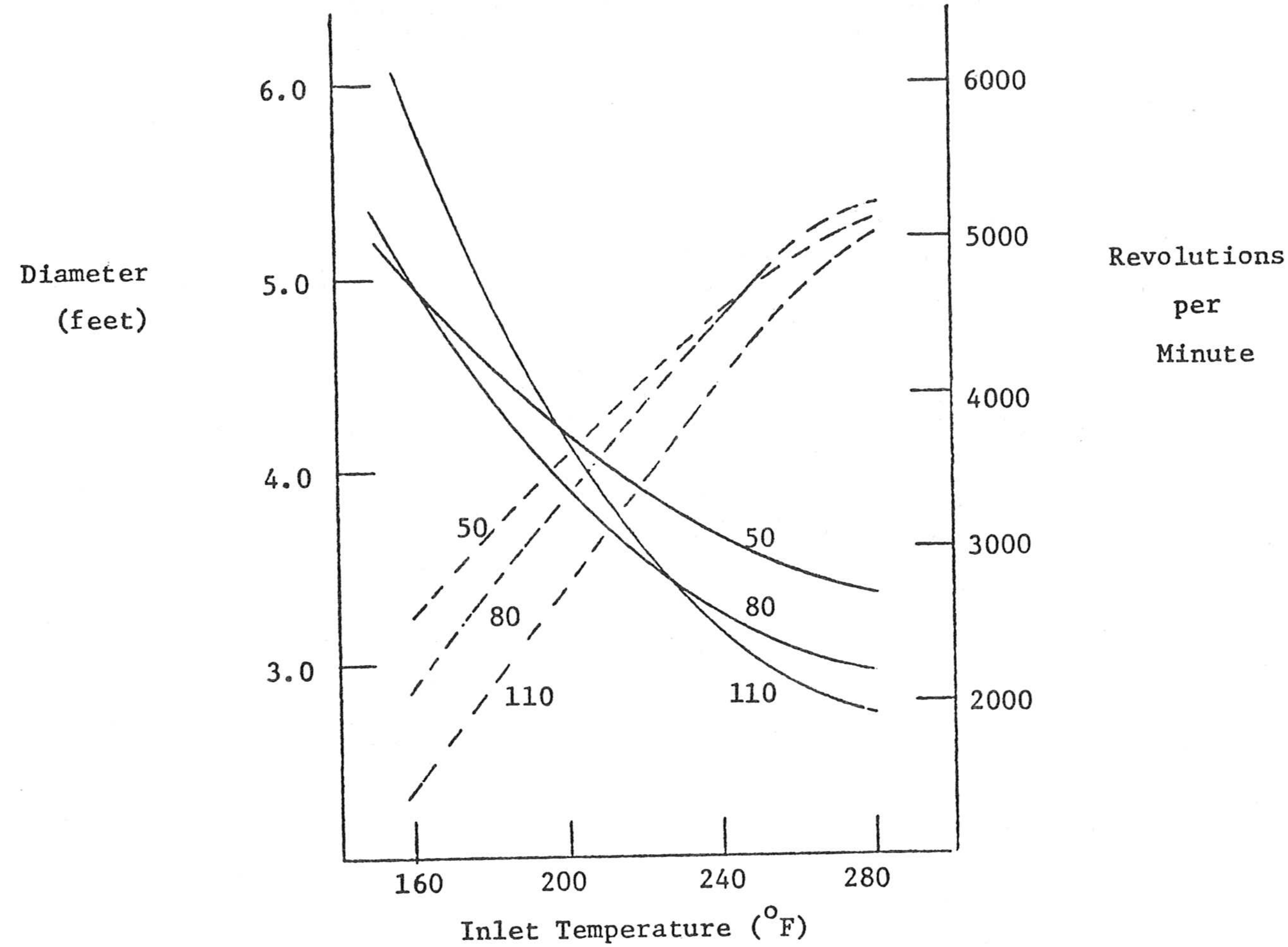


Fig. 26 Dashed lines indicate the optimum rotor speed. Solid lines indicate the optimum diameter. The design is for a ten megawatt unit at the various condensor temperatures (°F).

Table III

Turbine Diameters and Speeds

Ten Megawatt Turbine

	Freon 113	Freon 114	Isobutane	Butane	Propane	Pentane
Exit Volume Flow Rate (ft^3/sec)	2030	638	438	600	187	1861
Diameter (feet)	4.48	2.84	1.85	2.36	1.22	3,486
Rotative Speed (rpm)	4412	5412	13,512	11,370	20,265	8576

Fifty Megawatt

	Freon 113	Freon 114	Isobutane	Butane	Propane	Pentane
Exit Volume Flow Rate (ft^3/sec)	10,120	3185	2,184	3,835	934	9287
Diameter (feet)	10.0	6.36	4.13	5.28	2.72	7.79
Rotative Speed (rpm)	1,974	2,422	6,047	5,090	9,070	3840

4. Heat transfer analyses were carried out for a parallel flow, two dimensional, laminar, liquid-liquid, direct contact heat exchanger. The results were submitted and accepted for publication and presentation by H. R. Jacobs, R. W. Johnson, and R. F. Boehm at the 1976 National Heat Transfer Conference (Reference 9). Copies were distributed at the ERDA Geothermal Meeting on Heat Exchangers in Washington, D.C. in February 1976. Other heat transfer work carried out and reported in Washington, D.C. were the papers by Blair, Boehm, and Jacobs (Reference 10) and the work of Jacobs, Deeds, and Boehm (Reference 6). Laboratory investigations on single bubble ebullition, bulk exchangers using pentane and liquid-liquid heat transfer work using standard extraction columns was initiated.

4.2 Fluidized Bed Heat Exchanger Development Studies

(K. L. Wagner, R. E. McAtee, C. A. Allen, E. S. Grimmett - Allied Chemical Corporation, Idaho National Engineering Laboratory)

Scale deposition on heat transfer surfaces represents a major barrier to economic exploitation of many geothermal resources. The action of particles in a liquid fluidized bed appears to be an attractive method of scale control. Research and development of liquid fluidized bed heat exchangers is being conducted at the INEL. Benchscale tests demonstrated that with this system, scale deposits were prevented, corrosion was inhibited and heat transfer coefficients nearly doubled in comparison to tube in shell exchangers operated without a fluidized bed. Recent tests in a pressurized unit operated at the maximum temperatures and pressures available at Raft River confirmed the high heat transfer rates.

4.2.1 Pressurized Six-Inch Fluidized Bed Heat Exchanger

Following 60 days of operation at well No. 1, the pressurized, single-stage liquid fluidized bed test in the 6-inch vessel was terminated for post-test examination and evaluation. The objective of this test was to compare heat exchange in a pressurized vessel to previous experimetns in an unpressurized benchscale unit and to gather preliminary scale formation and corrosion information. Cold water (30°C) passed through a helically wound 1/2-inch stainless steel tube comprised the secondary system. The heat exchanger shell is a 6-inch diameter by 60-inch long vertical vessel. The top of the fluidized bed of one millimeter diameter silica sand particles was maintained 18-inches above the support plate. Thermocouples were placed at inlets and outlets of both fluids and in the bed. Flowrates were continuously monitored by turbine flow meters. Two series of stainless steel and other corrosion resistant alloys were suspended in the vessel, one just below the top of the bed and the other near the geothermal outlet.

Heat transfer coefficients (h_o) were measured as a function of geothermal flow rate with superficial fluidizing velocities varied between 0.8 and 8.7 ft/min. These data are shown in Figure 27 compared to experiments conducted in a 3-3/4 inch unpressurized vessel. Heat transfer coefficients are higher in the pressurized system, but this may be related to the higher geothermal temperature permitted in the pressure vessel. Average bottom bed temperatures in the pressurized vessel averaged about 115°C while those in the unpressurized system averaged about 85°C. In other experiments, the geothermal flow was increased to 13 ft/min without elutriating the bed. These data are

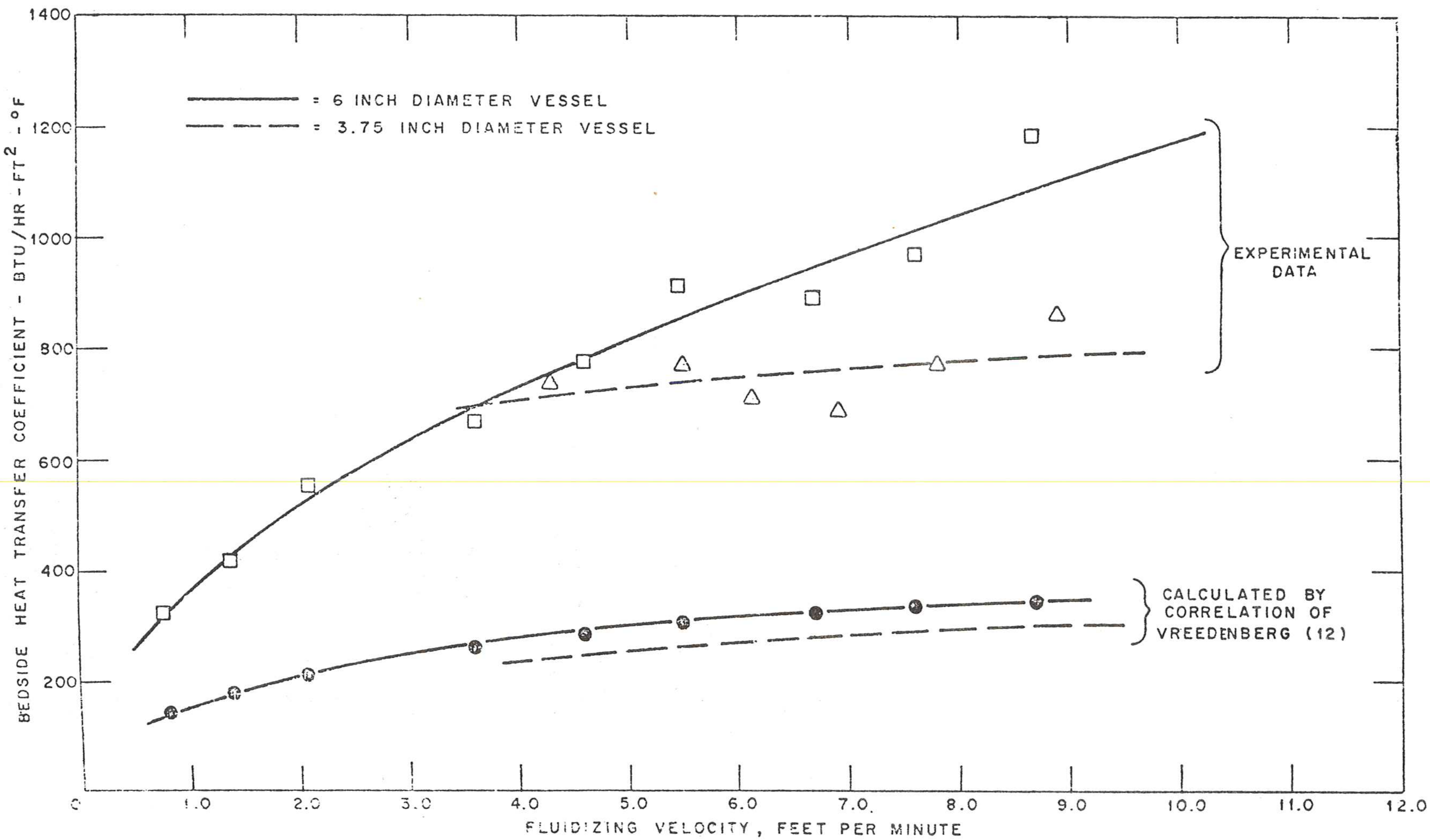


Fig. 27 Experimental Bedside Heat Transfer Coefficients Compared to Those Calculated by Vreedenberg (6)

not included in Figure 27 since fouling on the inside of the tubes prevented accurate calculation of heat transfer coefficients.

Also displayed in Figure 27 are heat transfer coefficients calculated using a correlation developed by H. A. Vreedenberg (Reference 11) for gas fluidized beds. For both vessels, the actual heat transfer coefficients were two to three times those predicted by the correlation. This could be expected because the physical properties of the fluid in the experiment differ greatly from the properties of the fluid used in obtaining the correlation, even though these dimensionless groups should be applicable to all "fluids." Sufficient data are not yet available to allow calculation of values of h_o which can be used to design a liquid-fluidized bed heat exchanger.

Results from scale and corrosion tests were not clearly defined since a flow rate excursion one week before the test was terminated, emptied the bed. Two useful pieces of information were obtained, however.

1. Corrosion plus ersoion on all the alloys tested was less than 0.1 mil/yr, in and above the bed.

2. A thin scale identified by X-ray analysis as muscovite coated the coupons and heat transfer surfaces. This apparently formed after the bed was elutriated since beneath the scale the heat exchange exhibited the characteristic polish of an active bed.

Program plans for the next quarter include installation of a bench-scale unit at the East Mesa Site in Imperial Valley, California to determine specific problems associated with operating a fluidized bed heat exchanger in fluid containing 25,000 ppm solids. Raft River geothermal fluids contain less than 2,000 ppm. The new horizontal vessel concept will be tested with a bench-scale multistage unit at Raft River. An 8-inch carbon steel, single-stage, horizontal unit was constructed for experiments in Imperial Valley. This will be first tested at Raft River then moved to the East Mesa Site by October 1, 1976.

4.2.2 Bench-Scale Laboratory Studies

During this quarter, the first preliminary silica deposition experiment was conducted at INEL as a part of the liquid fluidized bed heat exchanger development program. The purpose of this initial test was to determine procedures and preliminary data for studying deposition from a synthetic silica-carbonate solution onto the cooling coils and other parts of the bench scale model liquid fluidized bed heat exchanger.

Synthetic geothermal fluids were recirculated through the fluidized bed heat exchanger apparatus during the course of the experiment. This apparatus consisted of a 4,000 W stainless steel heater unit, a variable speed pump, a glass heat exchanger vessel (150 mm in diameter), a helical stainless steel cooling coil, a flow distributor of stainless steel balls and shot, and a silica sand bed (particles $\leq$ 0.707 mm $\geq$ 0.500 mm). The fluid entered the bottom of the heat exchanger tank at 147^oF and exited from the top at 130^oF. The experimental apparatus is shown in Figure 28.

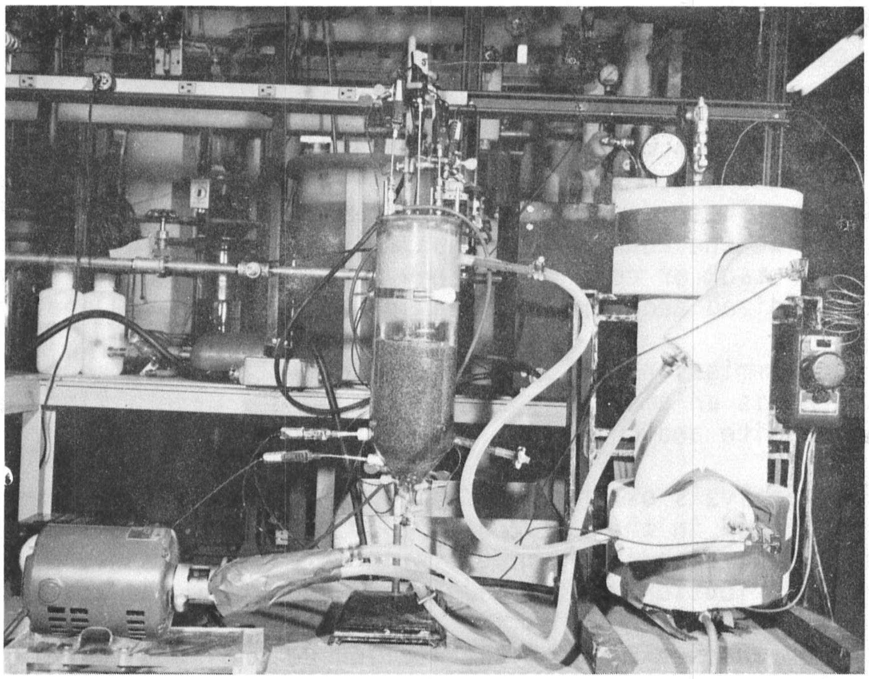


Fig. 28 Bench Scale Liquid Fluidized Bed Heat Exchanger Apparatus

Ground calcite scale from the Crank well at Malta, Idaho was suspended in the heater tank to create a saturated $CaCO_3$ solution. A gelled solution of 12.5g $Na_2SiO_3 \cdot 9H_2O$ (Sodium metasilicate) to which 5 ml of concentrated HNO_3 had been added to reduce the pH to approximately 8, was introduced into the $CaCO_3$ solution that was circulating in the heat exchanger apparatus. This resulting mixture which had a calculated SiO_2 concentration of 528 ppm, based on the disassociation reaction $Na_2SiO_3 \cdot 9H_2O \rightarrow 2NaOH + SiO_2 + 8H_2O$, was circulated through the heat exchanger for 27 days. At that time, an additional 12.5g of $Na_2SiO_3 \cdot 9H_2O$ was added directly to the system and then partially neutralized with concentrated HNO_3. The solution with the additional silica present was circulated for an additional three days when the experiment was shut down. A silica concentration of 528 ppm corresponds to a quartz geothermometer temperature of 285°C.

At the conclusion of the experiment, scale had deposited on the walls of the heat exchanger tank and the cooling coil above the level of the fluidized bed. These deposits can be seen in Figures 28, 29, 30, and 31 as well as inside the connecting tygon tubing. No scale was observed on the heat exchanger tank or coil where they were exposed to the scrubbing action of the fluidized bed particles as shown in Figures 32 and 33.

X-ray and emmission analyses of the deposited scale showed that the main component is an amorphous silica compound. Crystalline $CaCO_3$ in the form of calcite and α quartz was also present.

A screen analysis of the bed sand after fluidization shows that some attrition occured in the $\leq 0.710 \geq 0.500$ mm sand during fluidization. No evidence of silica deposition on the sand particles was found. Table IV shows the size distribution of the bed before and after the test.

Comparison measurements of the cooling coil diameter where it was exposed to the fluidized bed and the diameter of the coil which was above the bed were made. The scale covered upper part of the cooling coil was 0.003 in. larger in diameter than the non-fouled, fluidized portion. The cooling weight increased 0.1 g. An increase in weight of 1.0 g was measured for the glass heat exchanger tank during the run.

Analyses of the daily samples showed that the Si concentration fell off quickly and seemed to reach a steady state within approximately four days after addition. Within this time, the Si concentration fell from 247 to 118 ppm. After the fourth day, the decrease in Si concentration in solution approximated the decrease expected from sampling dilution. This is shown in Figure 34. When the additional sodium metasilicate was added to the circulating solution, an even faster drop in Si concentration was observed as shown in Figure 35.

X-ray and emission analyses were performed on the synthetic geothermal fluid at the conclusion of the experiment. These analyses showed that the principal solid dissolved in the fluid was sodium nitrate, but a residue of amorphous iron silicate was also circulating in the system.

Fluidized Bed
Level

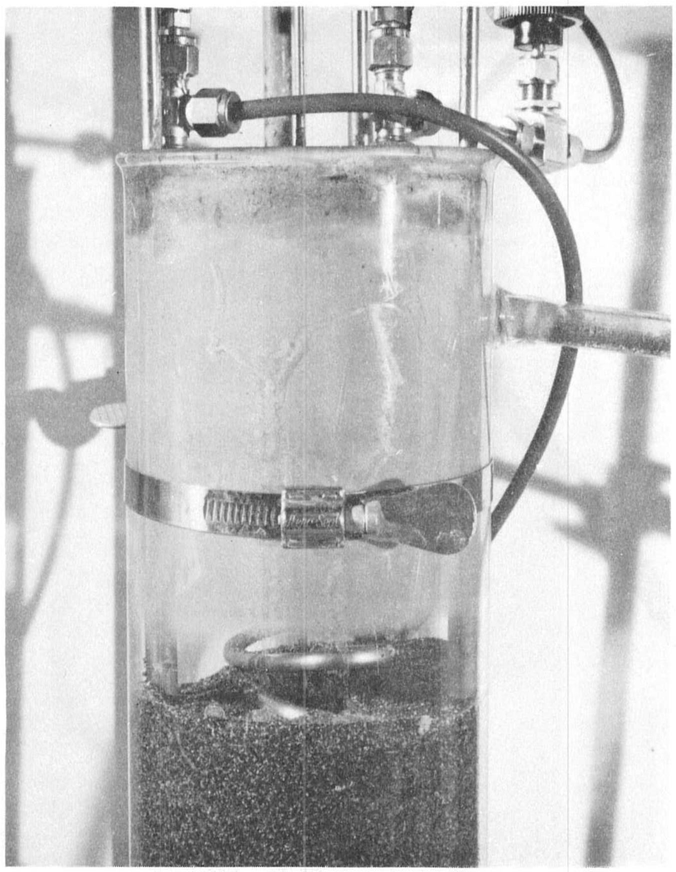


Fig. 29 Scale Deposition on Model Heat Exchanger Tank Above the Level of the Fluidized Bed

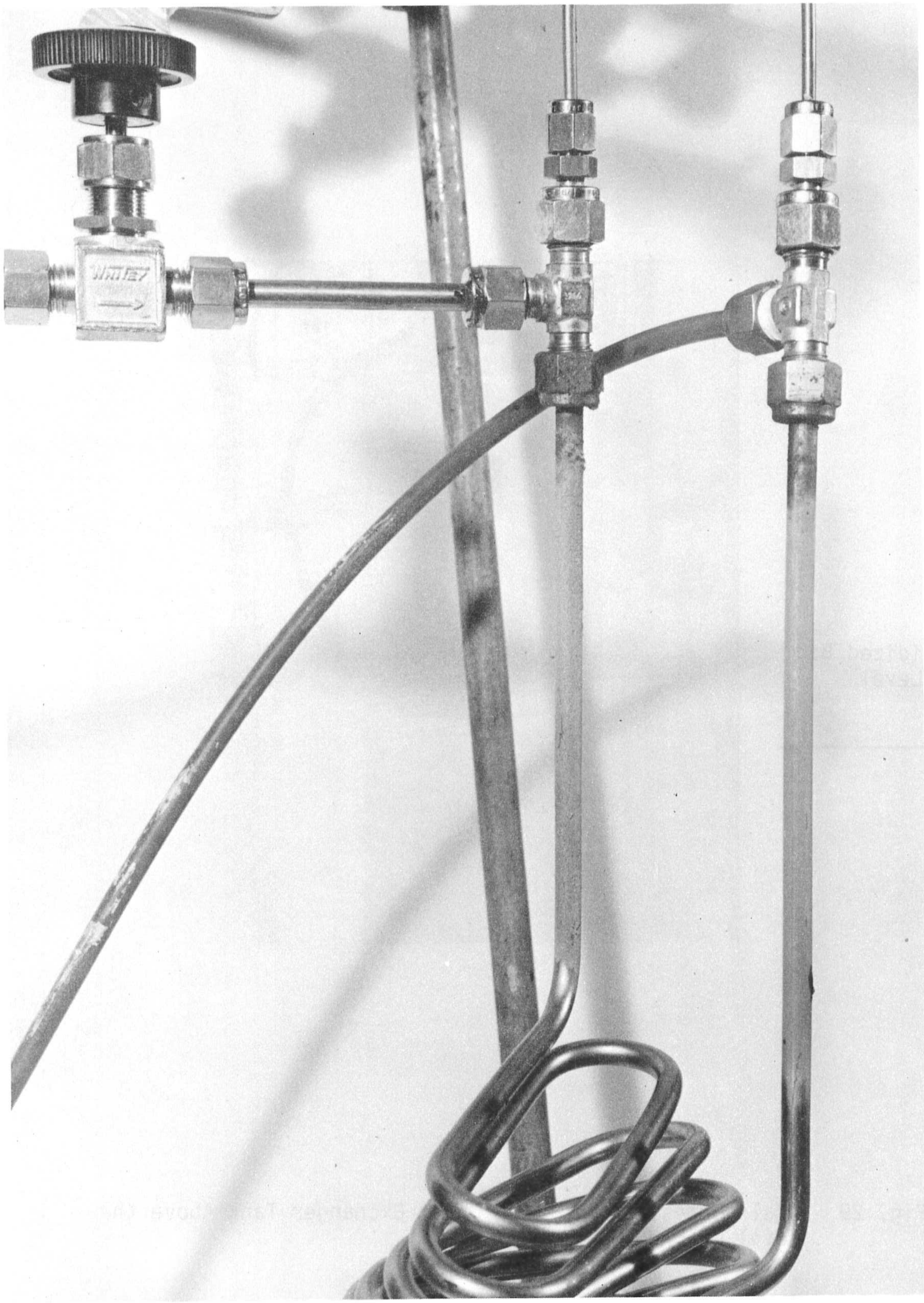


Fig. 30 Scale Deposition on the Cooling Coil Above the Level of the Fluidized Bed

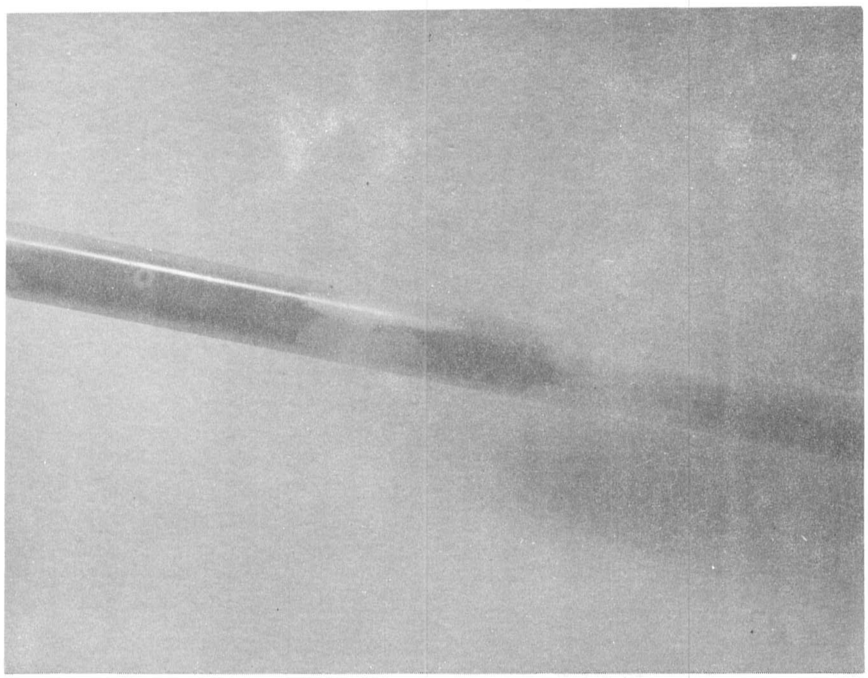


Fig. 31 Scale Deposited Inside Tygon Tubing

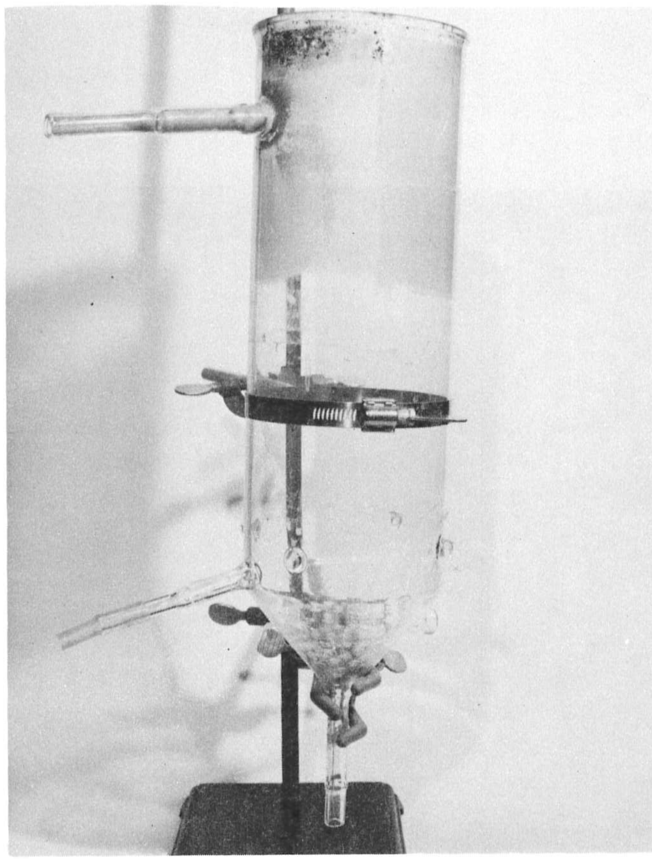


Fig. 32   Heat Exchanger Tank Showing Scale Deposition Only Above the Level of the Fluidized Bed

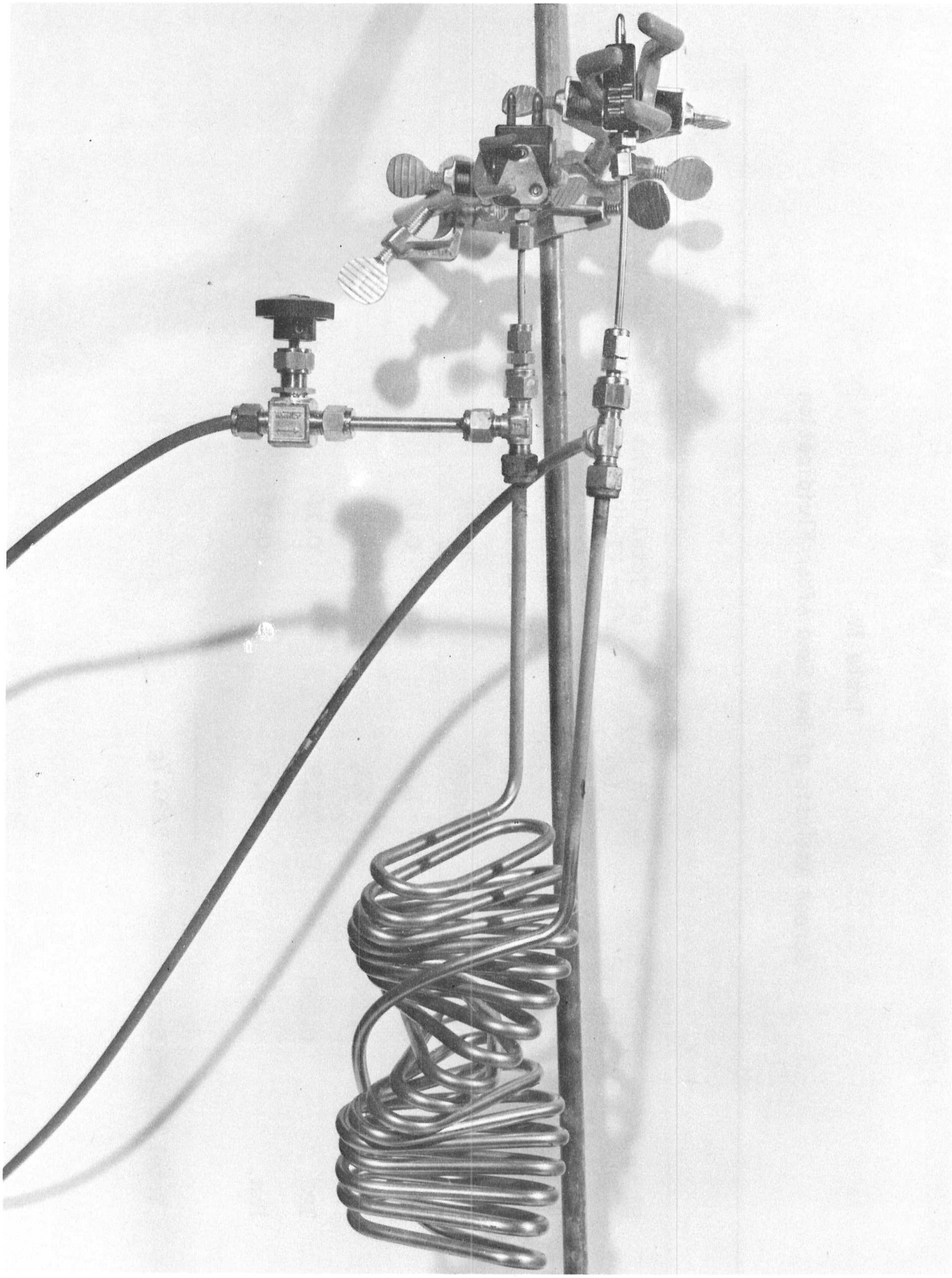


Fig. 33 Cooling Coil Showing Scale Deposition Only Above the Level of the Fluidized Bed

Table IV

Screen Analysis of Bed Sand After Fluidization

Sieve #	Opening Size (mm)	Weight Sand (g)	% of Total Weight Sand After Fluidization	% Weight of Sand Before Fluidization
25	0.710	1.6	0.1%	
35	0.500	1975.6	88.6%	100.0%
45	0.355	242.0	10.8%	
60	0.250	4.9	0.2%	
80	0.180	2.4	0.1%	
120	0.120	1.9	0.1%	
Pan	-	2.3	0.1%	
Total Weight Sand		2230.7g		

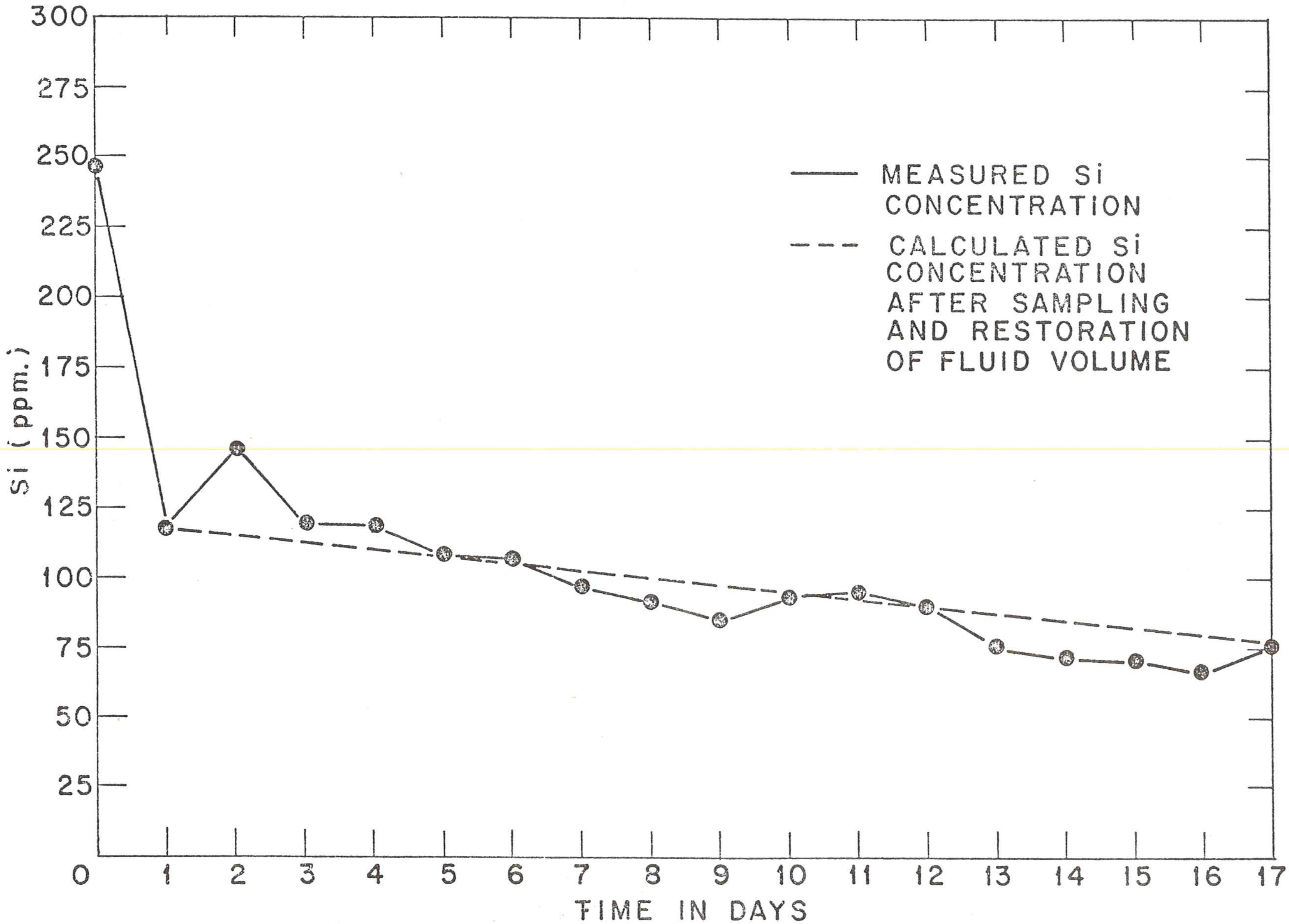


Fig. 34 Silicon Concentration Versus Time - First Sodium Metasilicate Addition

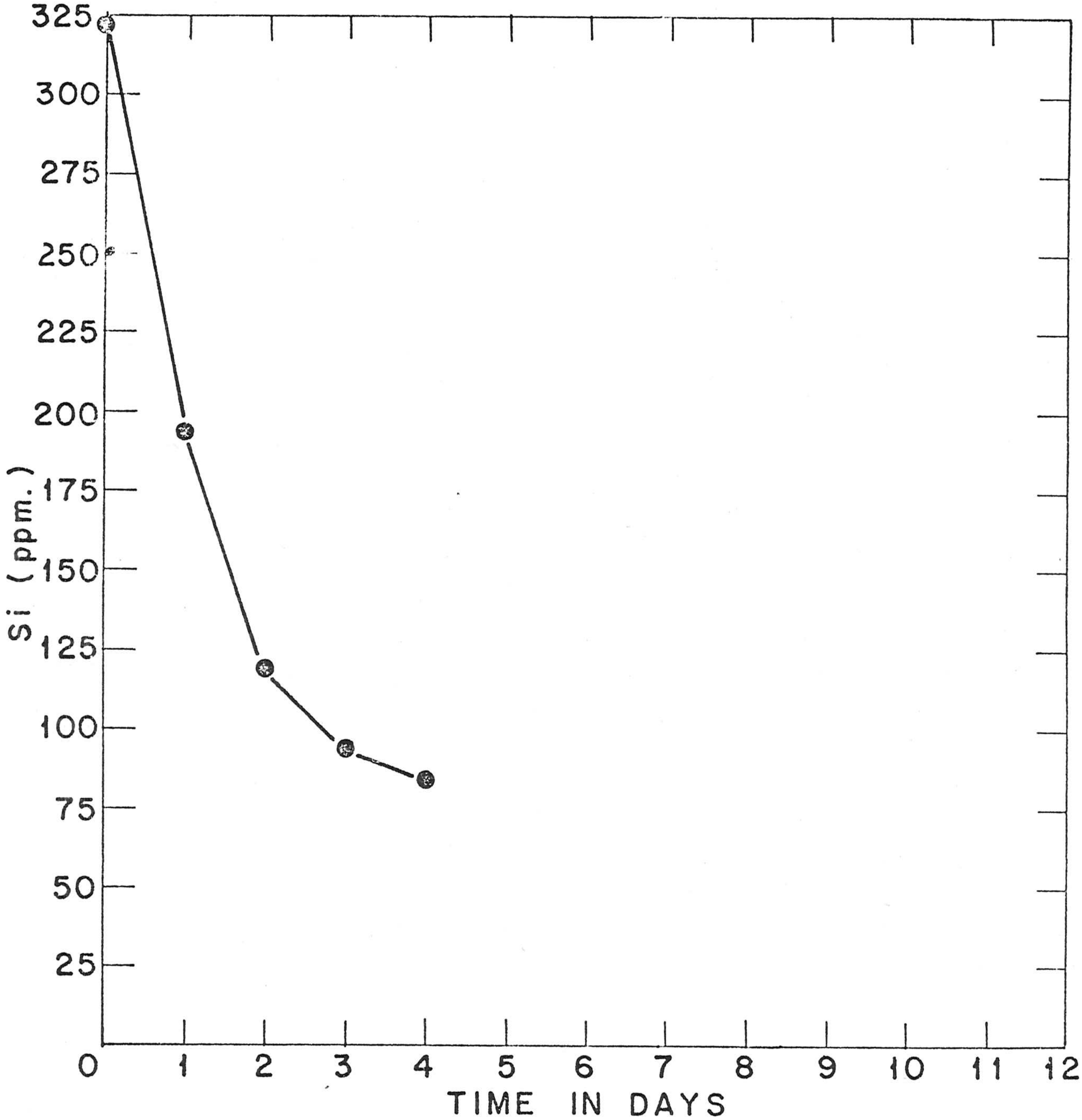


Fig. 35 Silicon Concentration Versus Time - Second Sodium Metasilicate Addition

The outside heat transfer coefficients calculated for the course of the run show considerable variability. However, curve fitting programs indicate that the trend is actually a straight line with a slope of -0.08. This slight decrease in the outside heat transfer coefficient (less than 2 Btu/hr x ^{o}F in 22 days of running time) can be attributed to fouling inside the cooling coil and to scale formation above the fluidized bed level. This slight observed decrease in heat transfer (0.02%/day) is much less than the decrease in the outside heat transfer coefficient observed during the last no-bed $CaCO_3$ deposition experiment (40 Btu/hr x ft^2 x ^{o}F in 9 days of running time or 1.5%/day). A summary of these heat transfer data is shown in Figure 36.

Initial benchscale studies with a liquid fluidized bed heat exchanger indicate that silica and carbonate scale deposition are confined to portions of the system which are not exposed to the fluidized bed. No significant decrease in heat transfer due to scale deposition on the cooling coils was observed. Further experiments are required to define the rate of scale formation away from the fluidized bed area since this affects heat exchanger and power plant design.

A future series of silica deposition experiments are planned. The rate of silica deposition from solutions with various concentrations of $NaSiO_3 \cdot 9H_2O$ will be studied using the benchscale heat exchanger unit. In these studies, a predetermined silica concentration will be maintained by metering in a dilute sodium metasilicate solution. Silica deposition will be measured by coupons in and above the bed.

High temperature, high pressure silica deposition studies will also be conducted using the 1ℓ Parr pressure reactor vessel.

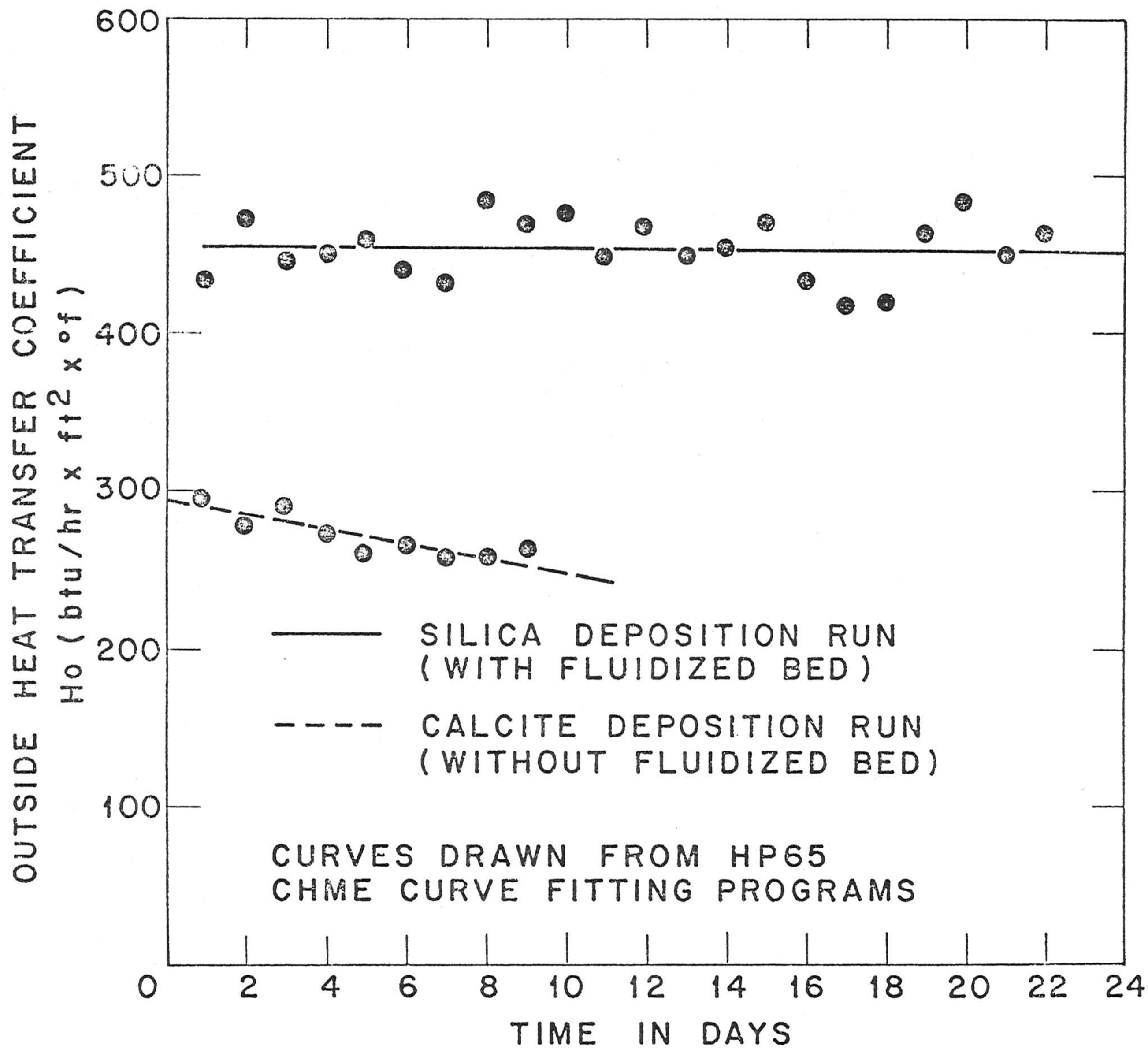


Fig. 36 Liquid Fluidized Bed Heat Transfer From Supersaturated Brines

5.0 NON-ELECTRIC USES OF GEOTHERMAL ENERGY

5.1 Introduction

In the United States, the direct (non-electric) use of geothermal energy has been limited, although rapid expansion of geothermal heating applications has occurred in other parts of the world during the last decade. The non-electric uses that have occurred have centered around space heating with only minor applications to industrial processes. However, geothermal water in the moderate to low temperature range (<150°C) is useable in many process applications and successful demonstrations of such uses should stimulate further development of geothermal resources. A widespread utilization of these resources could release other forms of energy for other critical uses in the nation and help solve the nation's needs for energy independence.

Although the utilization of geothermal energy for non-electric applications is generally coupled to a single industry for a single hot water source, multiple use in the form of industrial parks or integrated industrial activities can make a major impact on our energy usage. Integrated systems take advantage of the latent heat available in the geothermal water as well as the utilization of the waste products from one system as raw materials for an adjoining system. Proper selection of activities will permit a cascading of geothermal users to allow individual processes to "tap into" the proper temperature/pressure for that process.

Current utilization of geothermal energy for non-electric uses appear to be confined to expedient means of satisfying specific needs. Until recently, no systematic technical evaluation and utilization has been undertaken to find ways to maximize use.

Recognizing the need for a scientific evaluation of this energy resource, the Idaho National Engineering Laboratory coordinated the preparation of a national definition study entitled, "National Program Definition Study for Non-Electric Utilization of Geothermal Energy," (ANCR-1214). This study delineated the probable potential of geothermal energy usage throughout the nation and also pointed out what research and development activities might effectively implement extensive usage of the geothermal resource. The intent of this document was to provide a background base upon which the Energy Research and Development Administration could establish a program to perform the necessary research to bring extensive non-electric uses of geothermal energy to the commercial phase.

5.2 Progress During the Reporting Period

5.2.1 Industrial Process Applications for Geothermal Energy at Raft River Demonstration Site

The results of this continuing effort have been encouraging. Several potential industrial participants have shown keen interest in the utilization of low temperature (<300°F) geothermal water. Land and water acquisition problems appear resolvable and no insurmountable system conversion problems have been identified. The project could be accomplished with minimal federal involvement and expenditures while still providing the necessary incentives for participants. The federal government would make available* geothermal water from existing ERDA wells for a trial period and some guarantees on help in establishing new wells at the end of the period. A public meeting was scheduled for the report period to provide background information, then receive public expression of interest, and finally request formal proposals for industrial participation in demonstration projects in the Raft River geothermal area. However, the public meeting was postponed pending related federal action with regard to non-electric geothermal uses.

Several outstanding questions have been identified which must be resolved satisfactorily within ERDA before arrangements with private industry or private groups can be successfully finalized. First is the question of the extent of ERDA involvement. Second, is a geothermal water distribution policy. It is recommended that ERDA provide a header to supply the equivalent of the flow from one existing ERDA well for distribution to the demonstration project for a free water distribution period of several years. This period coincides with the expected construction period of the geothermal power pilot plant or test loop activities at Raft River during which time the full capacity of the existing wells would not be needed. In addition, the ERDA policy should include provision to aid the participants in the demonstration project in establishing new wells at the end of the three to four year period. This federal commitment is considered minor on the scale of the potential benefits to be derived from the project in terms of enhancement of future geothermal utilization practices. A third problem is related to the acquisition of fresh water supply for the project. Resolution of this problem is being pursued with the Idaho Department of Water Resources, which regulates all ground water in the State.

ANCR-1260, "Industrial Process Applications for Geothermal Energy at Raft River Demonstration Site" should be released by the end of the report period. This study presents an encompassing plan for the demonstration of large scale utilization of geothermal heat in an integrated industrial complex with multiplicity of participating industries. The intent of this document is to provide current information and to create awareness pertaining to an integrated, multi-use concept to obtain the maximum and most efficient use of available energy. Emphasis will be directed more to the non-electrical geothermal water utilization for process heat application, instead of (but not excluding) space heating.

Plans were formulated to examine the effects of geothermal water on crop growth rates in a testing activity at Raft River. This activity is directed at using geothermal water beneficially for raising agricultural products. Several environmental questions of geothermal water disposal, buildup of soil contaminants, and the effect on food chains will be addressed by this field verification activity. A test plot of about 12 acres and the necessary tilling and planting operations is being arranged with local farmers. The effect of sprinkling and flood irrigation practices with both fresh and geothermal waters will be examined for crops idigenous

* The details and arrangements by which such water would be made available have been proposed, with several options.

to the area. The University of Utah Agriculture Engineering Department and the Agricultural Extension Service operated by the University of Idaho are providing guidance and consultation.

5.2.2 Process Retrofit Study

A sample case industrial area has been selected to study in detail the specific problems of replacing fossil fuels with geothermal energy. The emphasis is on retrofitting existing process heat applications for food processing and related industries, generally requiring temperatures less than 350°F.

The study will consider specific existing industries and the apparent location of the geothermal resources. The area chosen is presently moderately industrialized, in one of the areas of population concentrations in the Intermountain West. Technical considerations of the retrofit requirements and the delivery of the hot water from the source to the point of use will be examined. More important considerations for study are the financial aspects of making the conversion, as these relate to a variety of institutional factors - tax laws, financing arrangements, return of investment requirements, resource utilization and leasing, etc. The integration of a variety of uses to cover the heat range span, resulting in more complete use of the available heat is an additional consideration. The geographical arrangements for such existing or planned multipurpose uses will be examined.

A single case study of this type will not necessarily provide generalized answers for all situations. But such a case study on retrofitting geothermal into an already industrialized area will help identify the most pressing problems and lead to a more reliable assessment of the ultimate impact nationally from direct heat uses of geothermal energy. There isn't any active work planned for the near future in this particular area.

5.2.3 Small City, Space Heating Evaluation

The program studying the feasibility for conversion of the small community of Butte City, Idaho to total geothermal energy for space heating has continued. Butte City consists of approximately 39 buildings (home units plus several business establishments).

Butte City, has two production wells which were drilled for culinary water use. Both wells produced hot water. The original wells were drilled past the 450-475 ft depth, but were backfilled to that level when it was determined that the influx of hot water was adversely affecting their use for culinary purposes. From 400 to 460 ft, the temperature gradient is approximately 23°F/100 ft. Based on extrapolation, one might anticipate 140°F to 150°F temperatures at as shallow a depth as 700 ft. This temperature is adequate for space heating uses.

Due to the high cost of well drilling and establishing a suitable distribution system, and the small size of the town, the study has shown that the economics of a district space heating system are marginal unless the town was to add more heat load. Such heat load could be some industrial activity.

5.2.4 Geothermal Heat Utilization for Archuleta and Hinsdale Counties

Existing hot water wells are being investigated to evaluate the potential for heating public facility buildings in Joint School District No. 50, Archuleta and Hinsdale Counties, Pagosa Springs, Colorado. Technical expertise and economic evaluation is needed to develop this facility for use as a demonstration heating complex. The institutional complex consists of a high school with a floor space area of approximately 24,300 ft^2, a middle school with 23,800 ft^2, and a library of 1,200 ft^2. Well head temperature at the existing wells is approximately 130^oF with a head pressure of 5 to 10 psi. The last "in use" flow rate was approximately 300 gpm. The wells are presently capped and are not in use. Such luke-warmwarm temperatures are substantially less than normally considered viable for space heating, but attempts are being made to vary the technological considerations sufficiently to make the system economically practical.

5.2.5 Down-Hole Heat Exchangers

A study of down-hole heat exchangers, initiated earlier, was continued through this reporting period. The work is being done in Klamath Falls, Oregon through a research contract to the Oregon Institute of Technology located in Klamath Falls.

As a part of those studies, optimizing determinations are being considered to better understand how a given well in this area can serve more than one dwelling. Mini-district type heating distribution systems were considered as a means of doing this.

Within the downtown area of Klamath Falls, nine churches are located such that their properties either adjoin one another or are separated by only a street or alley. None of the buildings use geothermal heating today. These buildings were selected for study as a prime example of a potential mini-district geothermal heating system. Work has progressed through feasibility studies and design concepts for such a system.

6.0 BOISE DEMONSTRATION GEOTHERMAL SPACE HEATING PROJECT

6.1 Background

A joint federal-state effort was initiated early in 1975 to convert existing heating systems in several state-owned buildings in Boise, Idaho with geothermal water. The State Capitol Building, several other state-owned buildings in the Capitol Mall, in addition to buildings on the Boise State University campus were selected for study and eventual conversion.

The selection of Boise, Idaho as the site to locate a demonstration geothermal space heating project was made on the basis of known geothermal resources, interest on the part of the Idaho governing bodies and the support of the Geology Department at Boise State University. Since 1892, up to 400 homes and businesses located along Warm Springs Avenue in Boise have been heated successfully with geothermal water from two wells and numerous other geothermal wells exist in the immediate vicinity of Boise. The increasing costs of fossil fuel and the availability of geothermal water have added impetus to the interest in Boise.

The aggregate annual expenditure for the ten buildings under consideration is $240,000 (1975 fuel cost). Economic feasibility was analyzed in terms of the cost of retrofitting each of the various buildings, and of installing pipelines capable of supplying not only present needs, but expansion needs as well. In addition to a direct economic benefit, the replacement of fossil fuel-based heating with geothermal space heating will affect a significant long-term conservation of fossil fuel which may be practical in many other localities.

The following principal objectives were established for this research and development effort:

1. To determine if the proposed geothermal resource area is adequate.

2. To determine the costs and practicality of retrofitting existing heating systems for use with low temperature (probably less than 200°F or 93°C) geothermal water.

3. To design the distribution system, the H&V systems (new and conversions) and, in particular, the geothermal waste water discharge system.

4. To determine the impact of the utilization of the geothermal water for heating the buildings on the environment. This will include effects of withdrawal of the water from the aquifer, transportation of the water through the subsurface of the city of Boise, and most importantly, the disposal of the warm waste water. Both preanalysis and post-operational monitoring would be required on environmental aspects of the program.

5. To build and test proposed system to demonstrate the actual costs of construction and operation and to identify the technical difficulties which may arise from long term operation. This fifth phase of the program, if deemed feasible from the results of the first four phases, is expected to be undertaken by the eventual operator and user of the system; i.e., the State of Idaho.

6.2 Progress During this Reporting Period

(A joint effort by Boise State University, Idaho Bureau of Mines and Geology, and the Idaho National Engineering Laboratory.)

A project summary report was made to the Governor of Idaho and presented for consideration by the Idaho State Building Authority and the Permanently Building Fund Advisory Council. This study concluded that no major resource or engineering difficulties exist that would prevent the project from being completed successfully resulting in a significant long term savings in both scarce fossil fuels and total heating costs to the State. For a capital investment of approximately $3 million, the necessary wells, distribution system and discharge system, and the conversion of building heating systems could be accomplished for ten state buildings with potential for expansion to the equivalent of 28 more buildings by using fossil fuel peaking for the coldest days. The significance of this project in size and scope is, that, if fully implemented to the equivalent 38 buildings, it will be similar to:

1. Providing the heat for approximately 4,000 average homes; i.e., a city of 15,000 to 20,000 people,

2. Displacing the equivalent amount of fuel to operate 4,000 typical passenger cars;

3. Providing the equivalent capacity of 40 MW electric power plant, about the size of the installation at the American Falls, Dam.

The major portion of the capital investment (approximately 60%) is the distribution system piping and installation. As presently sized, it can easily provide enough hot water to heat the basic ten state-owned buildings on the coldest winter day. By installing larger pumps and doubling the number of wells, the equivalent of twice as many buildings can be heated on the coldest day, without strain on the distribution system. Reducing the piping size would save little; and likewise installation of even bigger piping to transport more water for still more buildings would add little to the overall cost.

A major factor in computing the overall costs of geothermal heat depends on the average yearly utilization factor. In the temperate Boise climate, the heating season is only eight months long, 5800 degree-days. Boise's average annual temperature is 50^{o}F and the temperature is below 30^{o}F only about 30% of the heating season and below -10^{o}F only a few hours (about 10) each year. The long-accepted design temperature for heating systems in the city is -10^{o}F, but a system designed for 30^{o}F would supply all but about 6% of the total annual heating requirement. For a 30°F design, half as much geothermal water is needed as for -10°F, allowing a given set of wells and the pipeline to serve twice as many buildings and produce notably improved economics.

It was further proposed that the ten-building project itself could be completed in two phases. For about two-thirds the capital investment, the Veteran's Home and the Capital Mall Buildings could be converted to geothermal heating in the first phase. The BSU buildings could be converted in a second phase. The total capital investment of the two phases would still be about $3 million, if the necessary expansion capability is provided during construction of the first phase. The distribution system costed by INEL is suitably sized for this expansion and could also transport geothermal water for heating the equivalent of 38 buildings previously discussed.

The major environmental consideration is the quality of the geothermal fluid and the method of its discharge. In the case of Boise's relatively lukewarm fluid, the dissolved chemicals are minimal (approximately 300 parts per million corresponding to a hardness of about 25 grains) equivalent in concentration to much of the drinking water around the State. The concentration of flourides is, however, generally somewhat higher than the current USPS* and State of Idaho Health and Welfare standards. Fluorides and the temperature of the discharge water are environmental considerations which need further attention with respect to present regulations.

The adequacy of the resource to provide the maximum 5,000 gallons per minute capacity of the distribution system cannot be unequivocably confirmed on the basis of the limited exploratory and "deep" wells recently drilled. However, these wells have encountered the expected resource, and there is no adverse information to suggest that other wells in the area would not be successful. Based on experience to date, wells will typically need to be approximately 1,000 ft deep, where 179°F water will be encountered. A typical well should produce approximately 500 gallons per minute from pumps set to depths of approximately 300 ft.

It was recommended that the State proceed with the outlined project. Full implementation of the proposed system would provide year round heat to the State buildings plus three times as many other buildings at less than 70% of current fossil fuel heating costs.

6.2.1 Exploration Drilling

(See Section 2.2 for more complete details.)

The drilling of Boise Slim Hole 2 (BSH-2) initiated earlier was completed during this reporting period. BSH-3, the Demonstration Well (BHW-1) and an Exploratory Hole (BEH-1) were all initiated and terminated during this reporting period.

1. BSH-2 Drilling

BSH-2 was drilled to a depth of 652 ft at the end of the last reporting period. Basalt was encountered at 630 ft. The basalt encountered at 630 ft appeared to be acting as a cap rock as the

* U.S. Public Health Service Safe Drinking Water Act

temperature gradient doubled over the last 50 ft of hole. The gradient above 600 ft was about 1°F/10 ft and from 600 ft to 650 ft it increased to 2°F/10 ft. The maximum recorded temperature was 132°F at 650 ft. Both BSH-1 and BSH-2 exhibit a similar temperature gradient, as shown in Figure 37.

During the early part of January, 1976, BSH-2 had to be abandoned due to a lost drill rod in the hole. The hole was being cleaned out in preparation for running casing when the tri-cone bit apparently stuck in a basalt crack and the drill rod snapped leaving 135 ft of rod and bit in the hole. Retrieval attempts were unsuccessful. The fishing tool engaged the lost rod but a 15 ton shock pull was not sufficient to jar the bit loose. Perforated casing was subsequently run and set to just above the lost rod to permit the hole to be used for monitoring purposes in the future. See Figure 5 for locations of the drill sites.

2. BSH-3 Drilling

BSH-3 was drilled to a depth of 550 ft and terminated there. This hole encountered consolidated rock formations throughout most of the drilling. Corings and core samples indicated thermally altered sandstone and basalt fairly predominate. The temperature gradient shown in Figure 37 shows the maximum temperature reached here was 94°F at the bottom.

3. BEH-1 Drilling

After BSH-2 was abandoned, due to the unretrievable drill rod, a Nevada Test Site drilling rig (Failing 1500) was moved onto the same site and another larger hole started approximately 15 ft from BSH-2. This new hole was designated BEH-1. Drilling was successfully completed to a depth of 1222 ft. The temperature measured was 164°F at 1050 ft.

4. BHW-1 Drilling

BHW-1 was drilled to intersect one of the lesser faults that intersects the larger Boise Front Fault. This faulted area was reached at 970 ft. The highest measured temperature was 164°F at 890 ft. On March 31, 1976, during pump tests, this well developed a 25-30 gpm artesian flow.

5. Reservoir Testing

Even though the driling to date has been done for strictly exploratory reasons, the success of BEH-1 and BHW-1 offer excellent opportunities to obtain more quantitative data concerning the geothermal reservoir. Due to the exploratory objectives, both holes were left essentially open (BEH-1 is cased to 610 ft and BHW-1 is cased to 200 ft). Sand has now sluffed in to form a sand bridge in BHW-1 that has stopped hot water production.

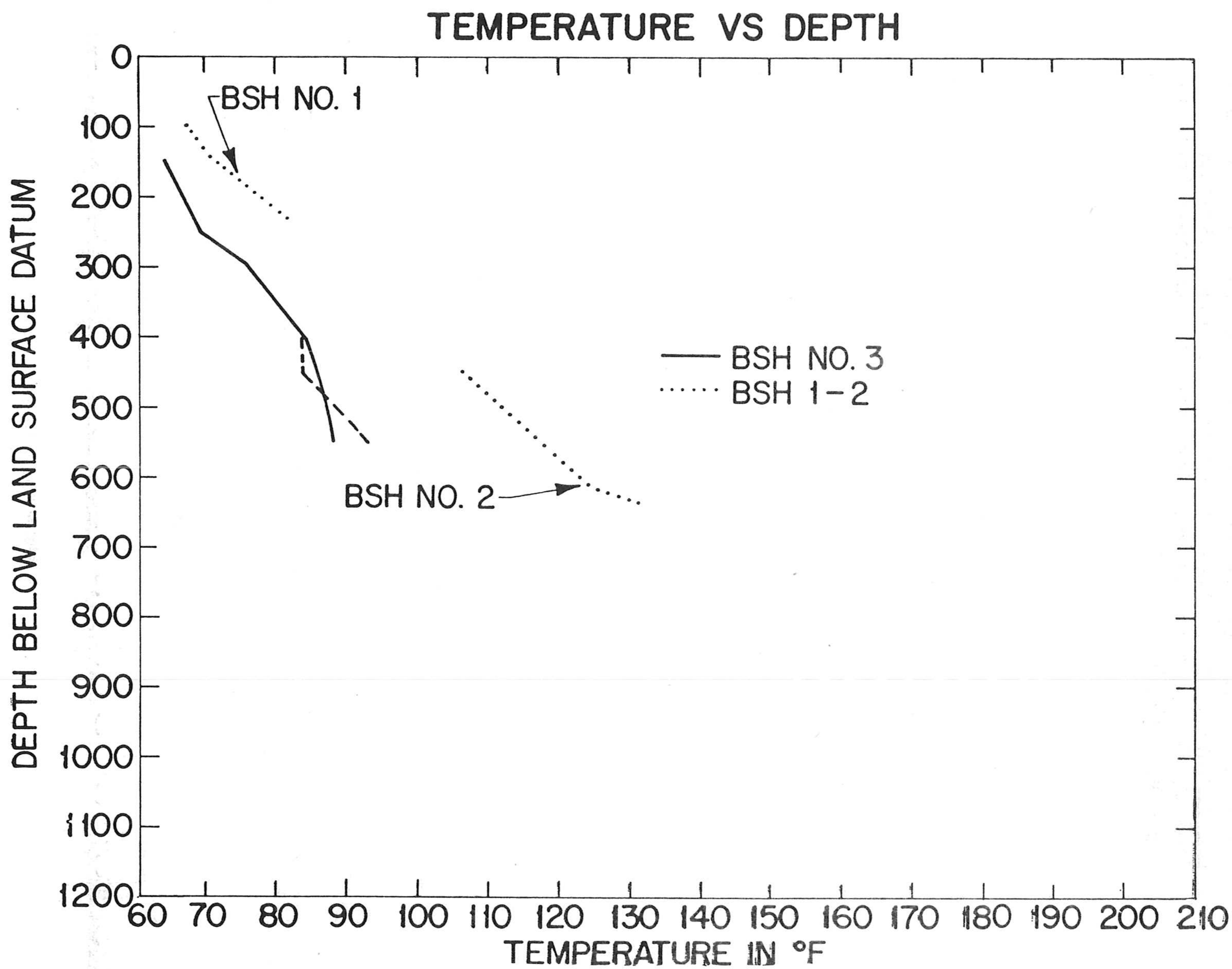


Fig. 37 Boise Geothermal Well Temperature Gradients

The success of downhole pressure measurements of resolution better than 0.01 psi in Raft River has lead INEL to propose both Boise holes be developed, much the same as if for production, and pump tests be performed at both wells to stimulate hot water flow. Measurements will be taken as the pump tests are performed in the hope of defining reservoir parameters from which long range interaction effects with other wells in the area might be predicted.

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