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GEOTHERMAL R&D PROJECT REPORT FOR
PERIOD APRIL 1, 1976, TO JUNE 30, 1976

EG&G Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY
Idaho Falls, Idaho 83401

Edited by

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ABSTRACT

Progress in the second quarter of 1976 is reported on the geothermal energy projects conducted by 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

The authors of the various sections of this report wish to express appreciation to the numerous individuals within the INEL who have made significant contributions to this program within the last three months: in particular, Mr. J. L. Griffith, Director of Geothermal Energy Office, of ERDA-Idaho Operations Office, Ms. R. M. Peterson for assistance in editing the report, and W. W. Hickman and S. D. Gilliard for their contributions to the project.

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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 indiciated 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.

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 reasons 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.[1,2,3]

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

1. The third deep geothermal well, RRGE-3, was drilled approximately 1-1/3 miles away in the southeasterly direction from the other wells. The initial drilling revealed high productivity (>300 gpm) of waters slightly above boiling from the 2,000 to 4,000 ft depth. The well was cased with 9-5/8 in. casing from 1,385 ft to 4,255 ft, in search of hotter water deeper.

   Drilling then proceeded on a slight side-tracked angle westerly to 5,853 ft depth. It was planned from the start of this well to try a multiple side-tracking below the production casing in the hope of significantly enhancing production. After completion of the first leg, however, temperatures were 149°C at the bottom, but production was poor, averaging only 80 gallons/minute, geysering on a 10 minute period under artesian (natural flow) conditions.

Nevertheless, it was decided to attempt the multiple leg side-tracking from below the 4,255 ft casing. Leg B was drilled to the northeast, and almost immediately encountered substantially better productive zones. It reach 5,532 ft, leg C was then drilled NNW to 5,917 ft. Initial flow from all three legs, with a subcooled head, was 800 gpm.

Reservoir testing on the well was conducted for about two weeks. Virtually no communication was seen with the other two wells. Lower permeability appeared to exist compared to the other wells, despite comparable productivity. It is therefore, concluded that the triple side-tracking was essential for making this a useful production well. The well has a dissolved solids content 50% higher than RRGE-1 and RRGE-2 wells.

This experience with the No. 3 well indicates the value of side-tracking, which added only 25% to the cost of the well with only a single leg. Yet the production, in this heterogeneous formation was enhanced approximately a factor of 5 based on artesian flow conditions.

2. Direct contact heat exchanger testing addressed the problem of relative solubilities, since the carry over of organic fluid into the geothermal discharge can significantly affect the economics. Solubilities of organics in highly salty waters are substantially less than in the purer waters, and hence the cost penalty of carryover would be least noticed in the high salinity brines.

3. Design and cost estimating continued on a 40 MW(th) organic-binary heat exchange facility (thermal loop) adaptable to a nominal 5 MW(e) output pilot plant. The facility would have provisions to add a second and third loop of equivalent size at a later date, employing more advanced concepts.

4. A 12 acre test agricultural experiment was set up near RRGE-2 in Raft River. Crops typical of the area are being grown to study the effects of irrigation (both flood and sprinkle) with geothermal water containing 2,000 ppm. The crop was started too late in the spring to take much advantage of heat from the geothermal water, but re-seeding of portions into winter wheat and alfalfa is being considered for late summer to study the heat effect this fall. Half of the test area is being irrigated by river water as a control on the experiment.

5. Reservoir engineering work was devoted to obtaining downhole data from RRGE-3, using logging techniques, drilling sample analysis, and from a number of cores. Though lithologically the well appeared similar to RRGE-2, its performance demonstrated substantial differences.

2.0 RESOURCE DEVELOPMENT AND ENERGY SUPPLY SYSTEMS

L. G. Miller, Field Operations Manager

2.1 Raft River Wells

2.1.1 RRGE-1

The REDA submersible test pump was removed from RRGE-1 and the wellhead reinstalled in May. The pump is to be studied for further design information. A second pump is on order and will be ready for installation in the near future. This pump will incorporate design modifications based on performance of the test pump. The original pump shall be rebuilt for future use and testing of design and application.

Well flow during the quarter was rather limited, supplying the corrosion test loop operation for three weeks in April. Major piping and reserve pit modifications then began, and flow was scheduled to resume on a routine basis in early July.

2.1.2 RRGE-2

With the setting of the Baker plug at the 1,246 ft depth at the termination of the additional drilling to deepen the well, the well was shut in. The wellhead was installed during the first of this quarter. A stinger was set in the Baker plug the first of April, opening the well for flow, temperature, and reservoir testing.

The reinjection pump was installed in its bunker near the well, and tie-in to the well is scheduled for early July.

2.1.3 RRGE-3

The third well was spudded at the end of March. By the first of this quarter, surface casing had been set at 1,383 ft (ground level).*

Two goals were incorporated in the well design: 1) to reduce well costs significantly by utilizing smaller (9-5/8 in.) production casing, since it appears that the fluid friction penalty over the life of the well should be less than the cost savings in completing the well; and 2) attempt well stimulation through directionally drilled side-tracked holes below the production casing. Such side-tracked holes should add little to the total well cost, since most of the investment is in the hole casing, and cement to the production depth. Calculations on wells No. 1 and No. 2 had indicated that a side-tracked leg might add 40% to the production capability of either well, if separation of the two legs would be 300 to 400 ft in the primary production zones.

Following the setting of production casing, three directionally drilled holes were drilled, legs A, B, and C, respectively. (See Table I) Leg A was completed at a total depth of 5,853 ft at a deviated angle of $6\text{-}3/4^{o}$, and was terminated 375 ft west of the vertical hole surface location. Flow testing yielded only 80 to 100 gpm average, on a 10 minute geysering

* Prior quarterly report incorrectly stated that the well was located southwest. Its actual location was approximately 1-1/3 miles away in the southeasterly direction of the other two wells.

Table I

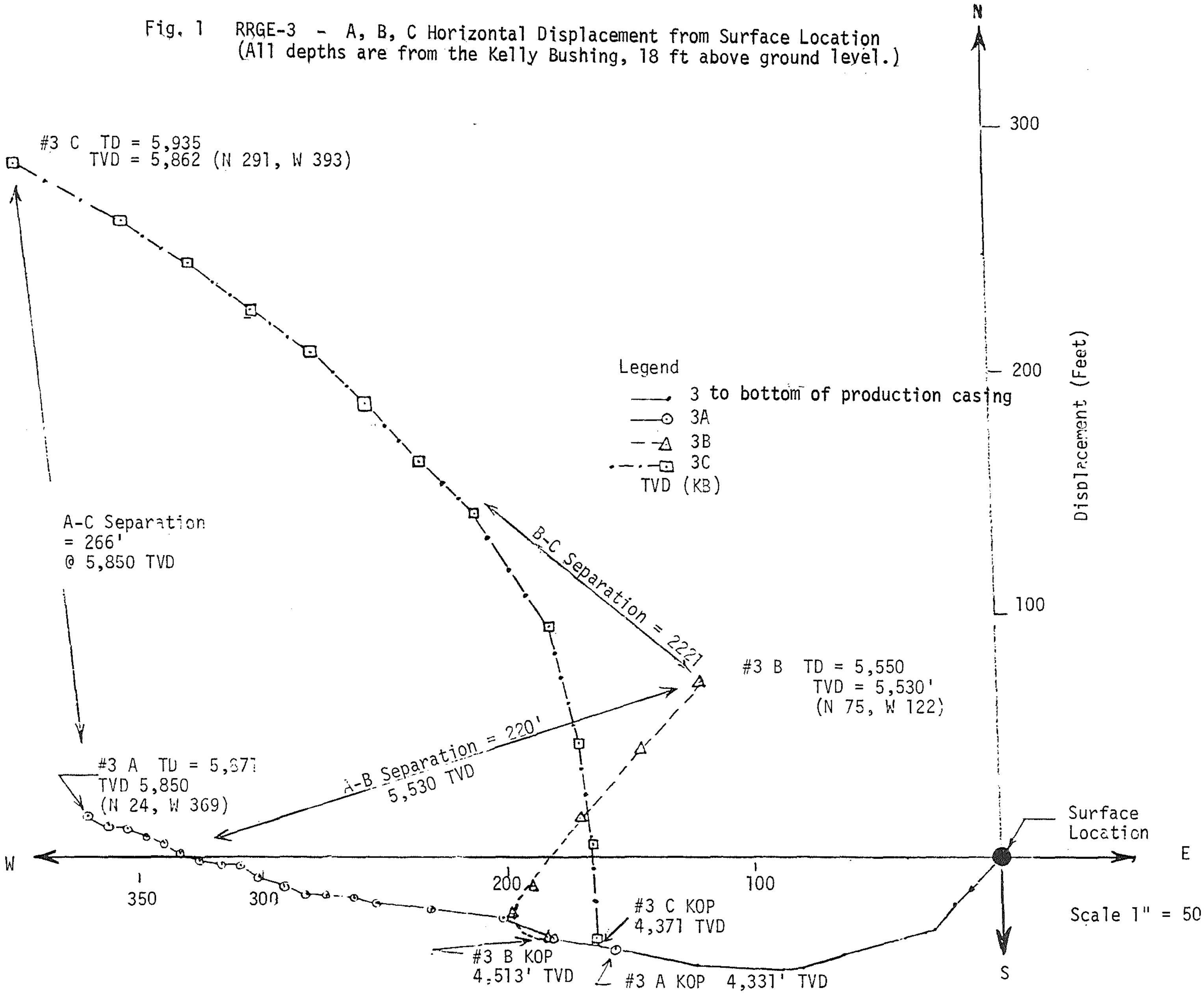
RRGE-3 A, B, C

Directional Drilling Information

Leg	Kick-Off Depth ft	Degree Deviation Achieved	Coordinates from Vertical Surface Location	Direction from Kick-Off	Total Depth ft	GPM	BHT °F
3-A	4331	6-3/4°	N24, W369	N65W	5853	<100 with air lift	295°
3-B	4513	14°	N75, W122	N31E	5532	100	296° WHT flowing
3-C	4371	22-3/4°	N291, W393	N60W	5935	800	298°

Note: BHT = Bottom Hole Temperature
WHT = Well Head Temperature

Fig. 1 RRGE-3 - A, B, C Horizontal Displacement from Surface Location
(All depths are from the Kelly Bushing, 18 ft above ground level.)



period, but with the same high temperatures that had been found in RRGE-1 and RRGE-2. It was decided to still proceed with the planned side-tracking.

Leg B was initiated at a depth of 4,513 ft and drilled northeasterly to 5,532 ft total depth. This leg achieved a deviation angle of 14° and is located 150 ft northwest of vertical hole surface location. Starting in a north direction, leg C kicked-off at 4,331 ft and was drilled to 5,917 ft. Once hole orientation was established with the Dyna-drill, the hole was drilled conventionally. With the rotating drilling string following Dyna-drill removal in leg C at 4,703 ft, the hole drifted to the northwest. The bottom of leg C is located 500 ft northwest of vertical and 260 ft north of leg A. Figure 1 shows a directional trace of these legs on the horizontal projection.

The disappointing flow rate from leg A was unexpected. Though the cores and cuttings showed little fracturing and the "tight" nature of the formations allowed for little permeability, the geological stratigraphy appeared similar to RRGE-2. Leg B and leg C samples and cores were lithologically similar, but appeared more fractured with a significant increase in permeabilities of the few core samples taken. The cuttings also contained more unconsolidated sand. The amount of permeability present in the legs explains the greater flow with the completion of legs B and C.

Air lift testing, coring, reinjection tests and temperature surveys were performed during drilling of the well to evaluate borehole productivity capability. (See Figure 2)

Legs A and C penetrated the Precambrian quartz monzonite intrusive. Based on lack of fractures present below 5,500 ft, leg B was drilled to a shallower depth and terminated in the overlying Elba Quartzite.

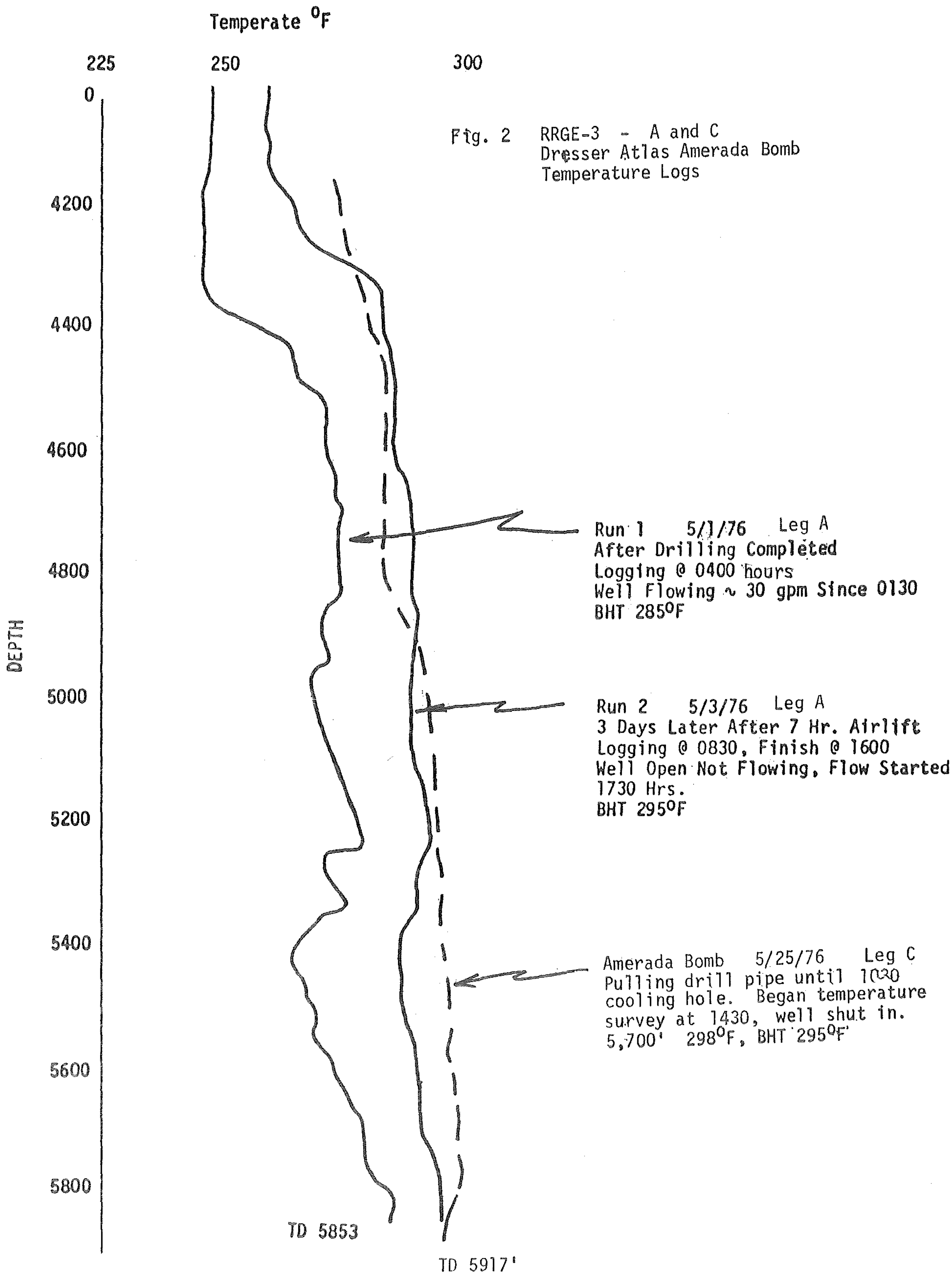
A set of logs were run on leg 3-A from 120 ft to total depth. The techniques included were dual-induction, acoustic, density, caliper gamma ray and self-potential. Porosity deduced from the compensated neutron log ranged from high to moderate above 4,200 ft. Below 4,200 ft through the tuffaceous section porosity was fairly good, approximately 15%. In the basement rock, zones of porosity exist at 5,700 ft to 5,800 ft, 5,350 to 5,470 ft and 5,340 ft. The only significant zone is at 5,750 ft.

Reservoir testing between the three wells was conducted late in June.

2.2 Boise Exploratory Wells and Holes - R. C. Stoker

Five exploratory wells were drilled in the northeast section of Boise, Idaho. Drilling is being accomplished to help define the characteristics and extent of the geothermal resource in that area. Three slim core holes (BSH-1, BSH-2, and BSH-3) were drilled under contract to Boise State University (BSU) using a small Acker core-drilling rig.* A larger diameter

* Owned jointly by Boise State University and the Idaho Bureau of Mines and Geology. It is a 2-7/8 in. diameter, wire-line coring unit.


Temperate °F
225
250
300
0
4200
4400
4600
4800
5000
5200
5400
5600
5800
DEPTH
Fig. 2 RRGE-3 - A and C
Dresser Atlas Amerada Bomb
Temperature Logs
Run 1 5/1/76 Leg A
After Drilling Completed
Logging @ 0400 hours
Well Flowing ~ 30 gpm Since 0130
BHT 285°F
Run 2 5/3/76 Leg A
3 Days Later After 7 Hr. Airlift
Logging @ 0830, Finish @ 1600
Well Open Not Flowing, Flow Started
1730 Hrs.
BHT 295°F
Amerada Bomb 5/25/76 Leg C
Pulling drill pipe until 1030
cooling hole. Began temperature
survey at 1430, well shut in.
5,700' 298°F, BHT 295°F
TD 5853
TD 5917'

8

test well (BEH-1) was drilled using a borrowed drilling rig and drilling supervisor from the Nevada Test Site and drill hands from INEL. A demonstration well (BHW-1) was drilled to 967 ft by Beard Brothers Drilling under contract to INEL. See Figure 3 for the location of the five wells and structural linears in the area.

All five wells were completed in the previous quarter, but short descriptions of each well are presented here as a summary of work completed to date. No further drilling or well testing was conducted during this quarter as the original objective (prove the resource existence) was previously accomplished. The budget was insufficient to fully test and complete the exploratory and test wells. Further work is budgeted for the summer.

2.2.1 Boise Slim Hole - 1 (BSH-1)

This hole was drilled to a depth of 259 ft at which point a core barrel was lost in the hole. The barrel seized in the fractured basalt at this depth and caused a fatigue failure of the drill rod. Retrieval attempts proved unsuccessful and the drill rig was moved to the site for BSH-2. Maximum fluid temperature was 80°F at 250 ft. The hole has been logged and is available for use as a hydrological observation well during future testing.

2.2.2 Boise Slim Hole - 2 (BSH-2)

BSH-2 was drilled to a depth of 652 ft and encountered basalt at 630 ft. The basalt appears to be acting as a cap rock as the temperature gradient doubled over the last 50 ft of hole. The gradient above 600 ft was 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 the similar temperature gradient, as shown in Figure 4.

During the early part of January, 1976, BSH-2 had to be abandoned due to lost drill rod in the hole. The hole was being cleaned out in preparation for running casing when the tri-core 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.

Because of the rapidly increasing temperature gradient below 600 ft, it was determined that a bigger drill rig should be moved in and another hole drilled in the immediate vicinity of BSH-2.

2.2.3 Boise Slim Hole - 3 (BSH-3)

The site for BSH-3 was selected on the basis of the area geology and geophysical data and was designed to act as an observation hole. 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 enclarged hole.

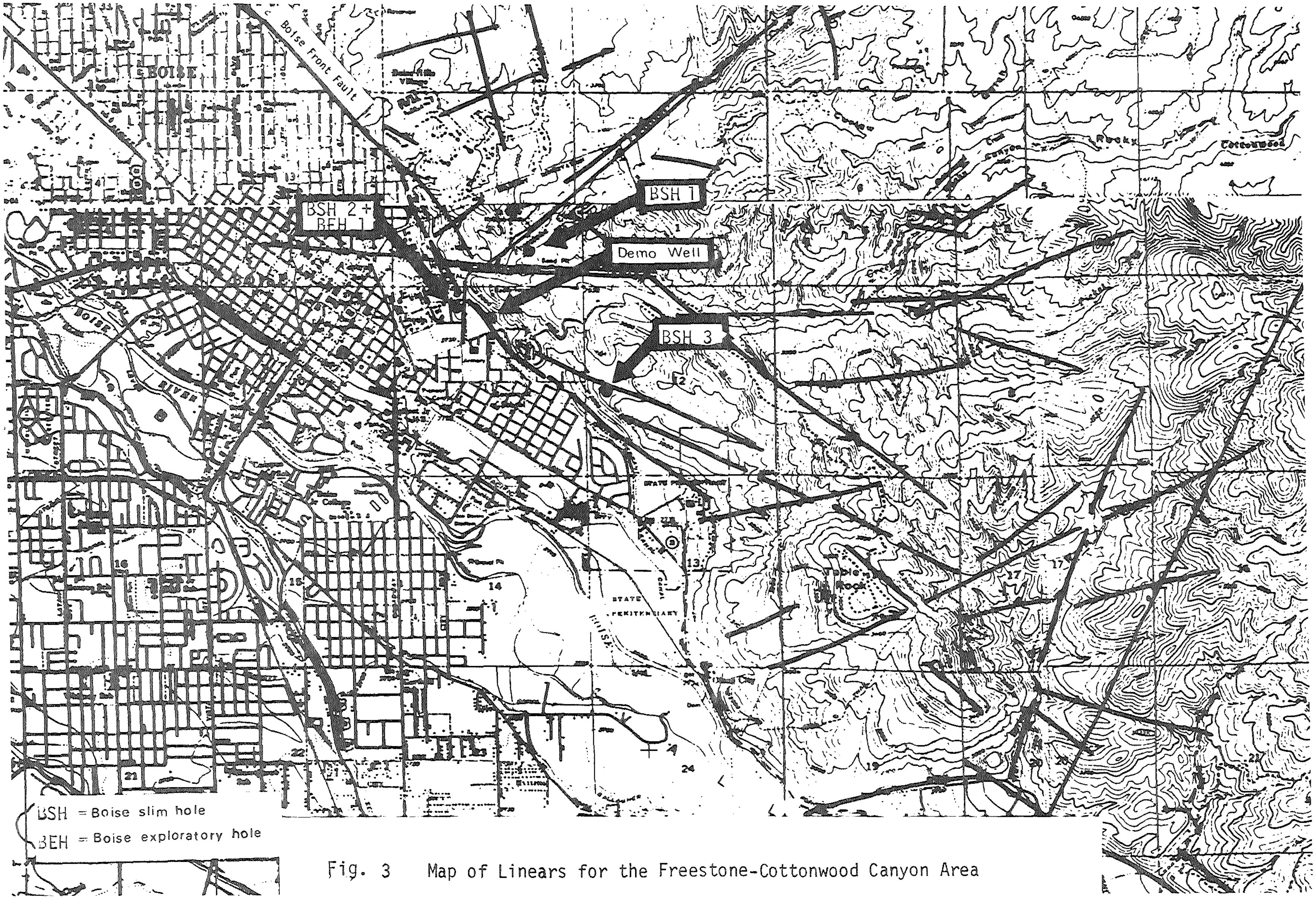


Fig. 3 Map of Linears for the Freestone-Cottonwood Canyon Area

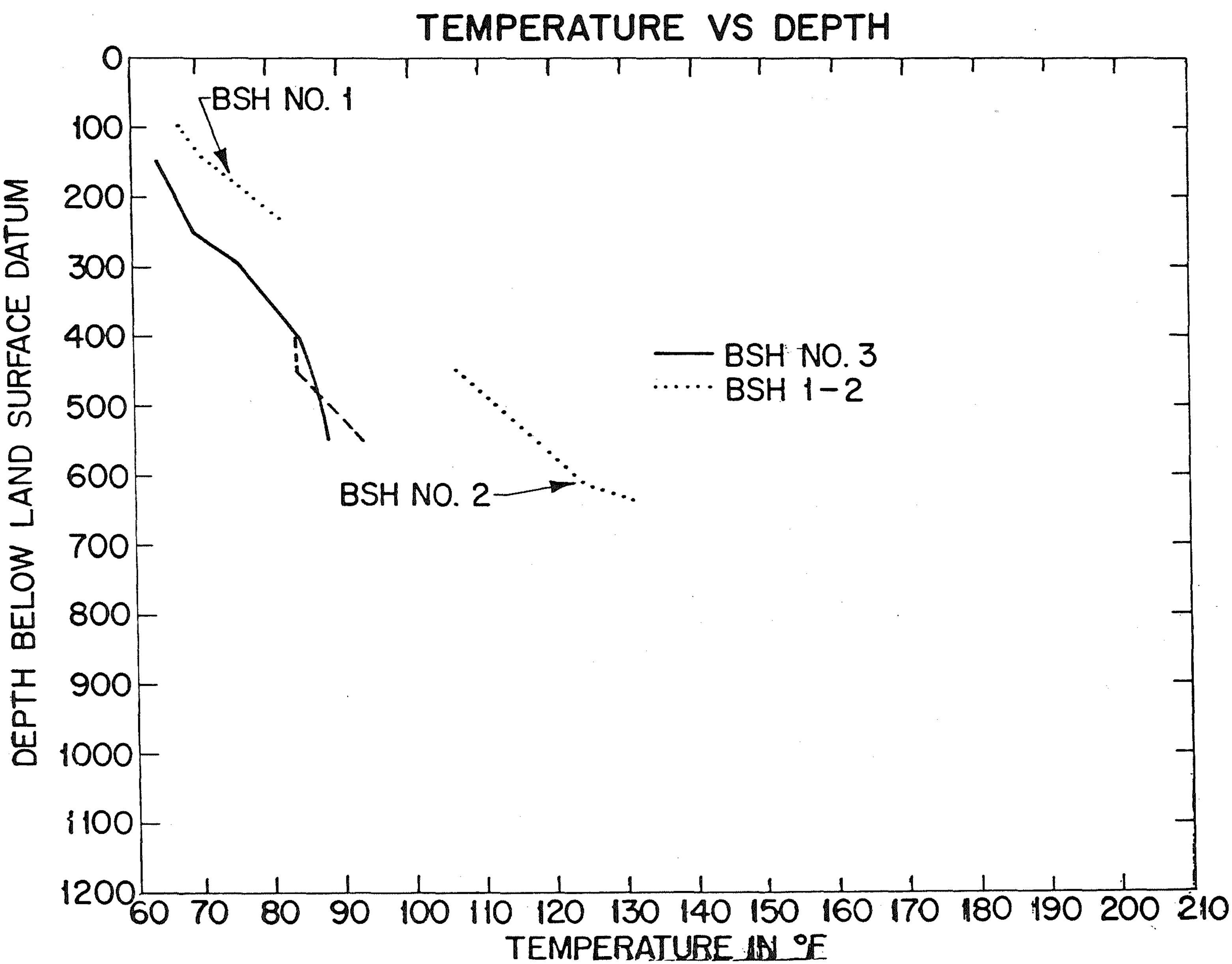


Fig. 4 Boise Geothermal Well Temperature Gradients

Drilling operations progressed smoothly during the early portion except for wet cold weather. The basalt and cemented sandstone show a particularly high degree of alteration in the upper reaches of the hole. 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.

The temperature gradient of BSH-3 is much less than either BSH-1 or BSH-2, as shown in Figure 4. The gradient and maximum temperature of 94^{o}F confirm that it is located above the major source of geothermal water, but will serve as an excellent observation hole during testing of the other wells.

2.2.4 Boise Exploratory Hole - 1 (BEH-1)

BEH-1 was drilled on the same location as the slim hole BSH-2. 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 5 for the stratigraphic section of this well.

BEH-1 was then drilled to a total depth of 1,222 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, the well will flow when the cold drilling fluid is removed. See Figure 6 for the BEH-1 temperature gradient.

Plans have been completed to case the well to total depth and flow test it during the coming quarter in conjunction with BHW-1.

2.2.5 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 7 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 bentonitic 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 Boise Front Fault Zone. A pump was installed for flow evaluation purposes but the well began to free flow at 30 gpm before the pump was 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 the water. The maximum temperature recorded was 164^{o}F at 890 ft as shown in Figure 8.

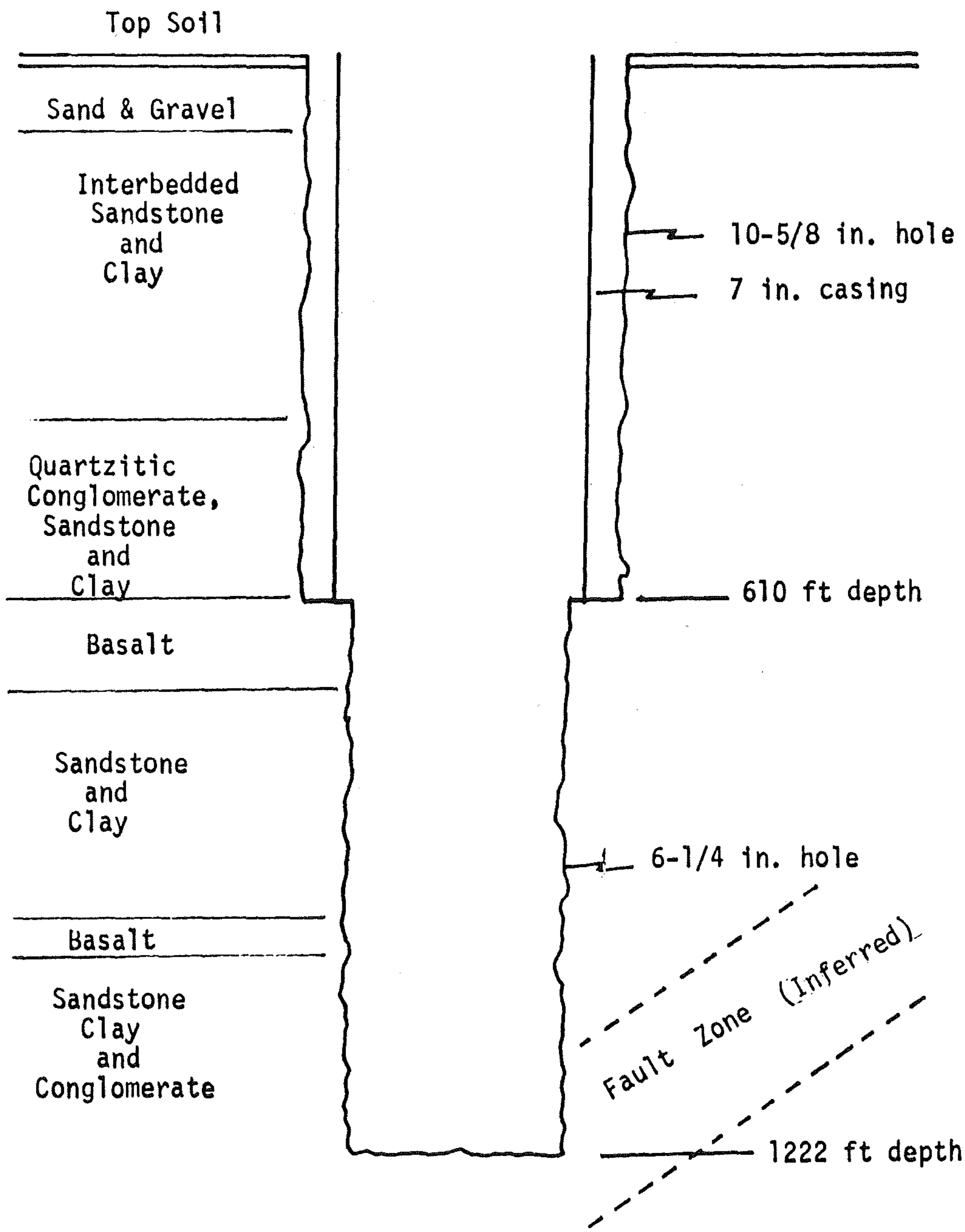


Fig. 5 BEH-1 (Preliminary) well and stratigraphic section

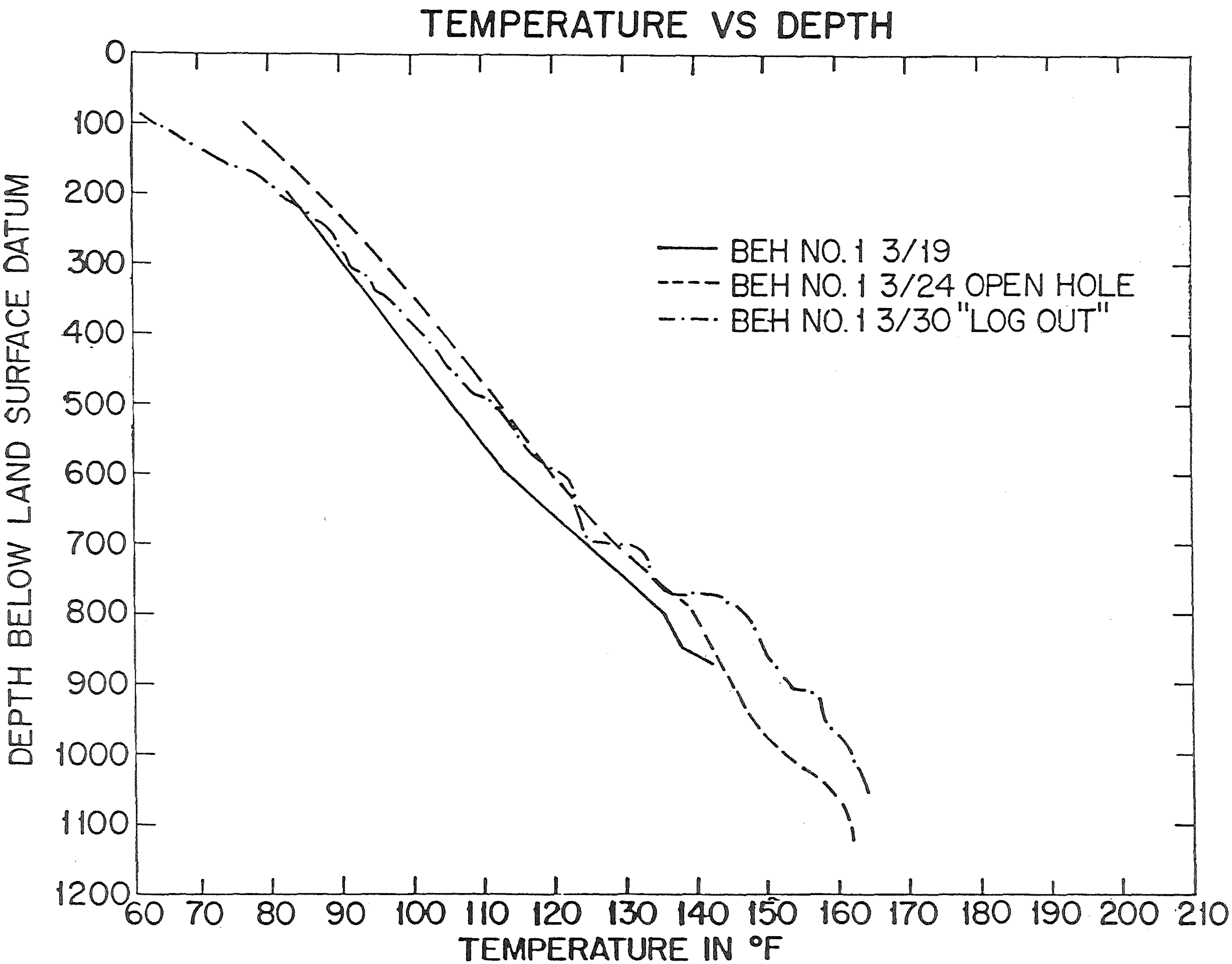


Fig. 6 Boise Geothermal Well Temperature Gradients

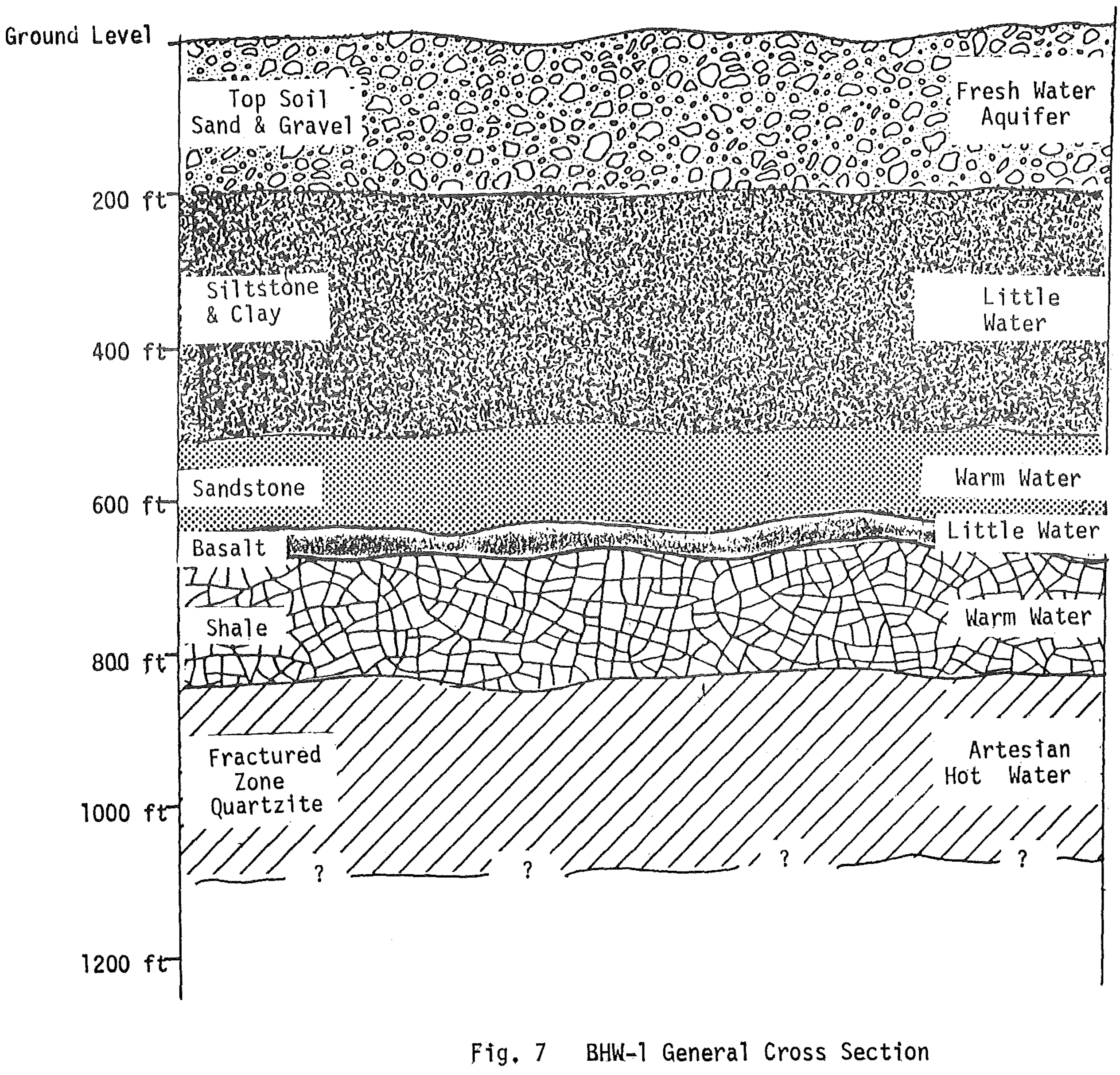


Fig. 7 BHW-1 General Cross Section

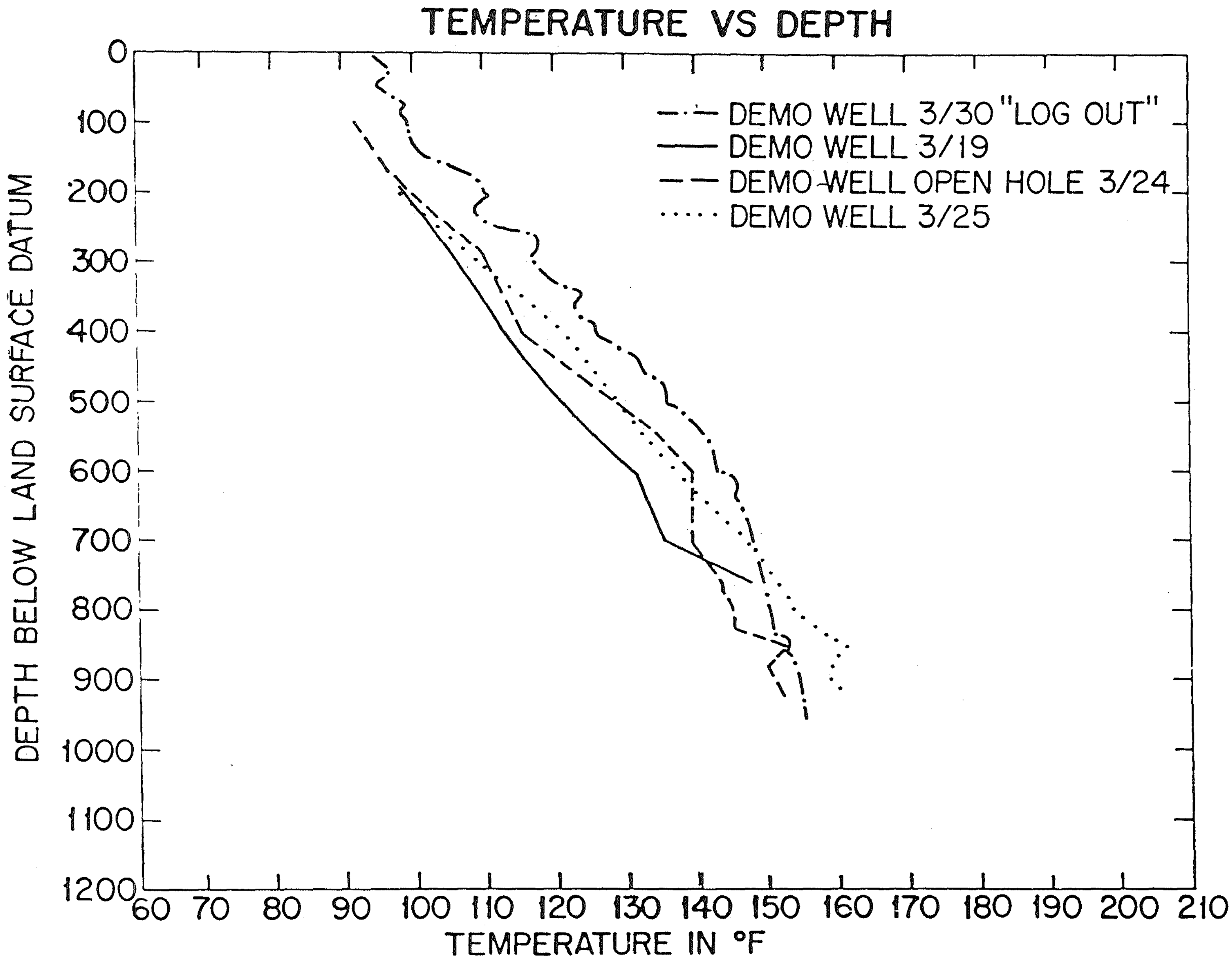


Fig. 8 Boise Geothermal Well Temperature Gradients

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 Beard Brothers Drilling is moving back onto the site at the end of the reporting period.*

2.2.6 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, 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 (of fault zones) that occur in the immediate area of investigation although the Front 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.

2.2.7 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 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 Acker core drilling rig appears to be too small for coring in the fractured basalt environment that exists in this area. Careful consideration of the rock type to be penetrated must be made before committing this rig to a particular job.

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°F plus) are adequate to support the space heating project proposed for the Boise area.

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

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* Editor's Note: In August 1976, both wells in Boise were successfully cased and are flowing artesian geothermal water of 160 to 170°F.

Table II

Boise Drilling Summary
As of June 30, 1976

Hole or Well	Location*	Total Depth (Feet)	Maximum Temperature	Casing Depth
BSH-1	Freestone Canyon	250	82°F	150'
BSH-2	BLM Compound	650	132°F	550'
BSH-3	Foothills East	550	94°F	130'
BEH-1	BLM Compound	1,222	164°F @ 1,050 ft	610'
BHW-1** (Demo. Well)	Freestone Canyon	970	164°F @ 890 ft	202'

* The locations of these exploratory holes and demonstration wells 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.

2.2.8 Future Plans

BHW-1 (Demonstration Well) will be cleaned out and drilled deeper (967 ft to 1,250 to 1,300 ft). Perforated casing will be installed to eliminate the sloughing problem and the well will then be developed to its maximum potential. BEH-1 will also be cleaned out and perforated casing installed. Both wells will then be tested together for maximum data acquisition concerning the reservoir. These objectives are expected to be accomplished by October 1, 1976. A full report will then be issued covering the geology, hydrology, and reservoir characteristics of the geothermal resource by the end of 1976.

2.3 Hydrology and Reservoir Testing - D. Goldman

Monitoring of drilling well RRGE-3 indicated multiple zones of highly porous material between the depths of 1,383 ft and 4,237 ft below land surface. Air lift pumping of these zones produced initially 600-700 gallons per minute (gpm) discharge at about 200°F temperature. The discharge eventually reached over 1,000 gpm at 222°F with a bottom hole temperature of 240°F. See Figure 9, showing several temperature surveys of this zone. The data suggest that there are highly transmissive zones of warm water above the high temperature resource.

Upon completion of drilling leg A of RRGE-3, a short step reinjection test was run. The results shown in Figure 10 suggest that there was no significant borehole damage, such as calcifications of the formation from the circulating drilling fluid. A 9-hour discharge test which followed, utilizing air lift pumping techniques, resulted in the well geysering. The well pulsed on for about 3-1/2 minutes every 9-1/2 minute interval, discharging approximately 780 gallons during each interval. The geysering effect and a low shut-in pressure (approximately 26 lbs hot) suggested either borehole damage or that the reservoir characteristics at this site are different than that at RRGE-1 or RRGE-2. The recovery data, shown in Figure 11, indicate significantly lower transmissivity than RRGE-1 and RRGE-2.

It is assumed that leg B of RRGE-3 encountered fracturing not seen by leg A, as cold shut-in pressure was on the order of 20 psi and the well would flow in excess of 200 gpm at 200°F, during a brief flow test after drilling leg B. Full heat-up was not permitted because of time constraints on the drill rig.

Leg C further enhanced the productivity of well RRGE-3, as suggested by the cold shut-in pressure of 80 psi. The results of a step flow test at the rates given in Table III suggested minimal borehole damage. A 12-hour continuous flow test at about 370 gpm immediately following step testing caused a cummulative downhole pressure change of 116 psi (Figure 12 shows change in well-head pressure over this period of time).

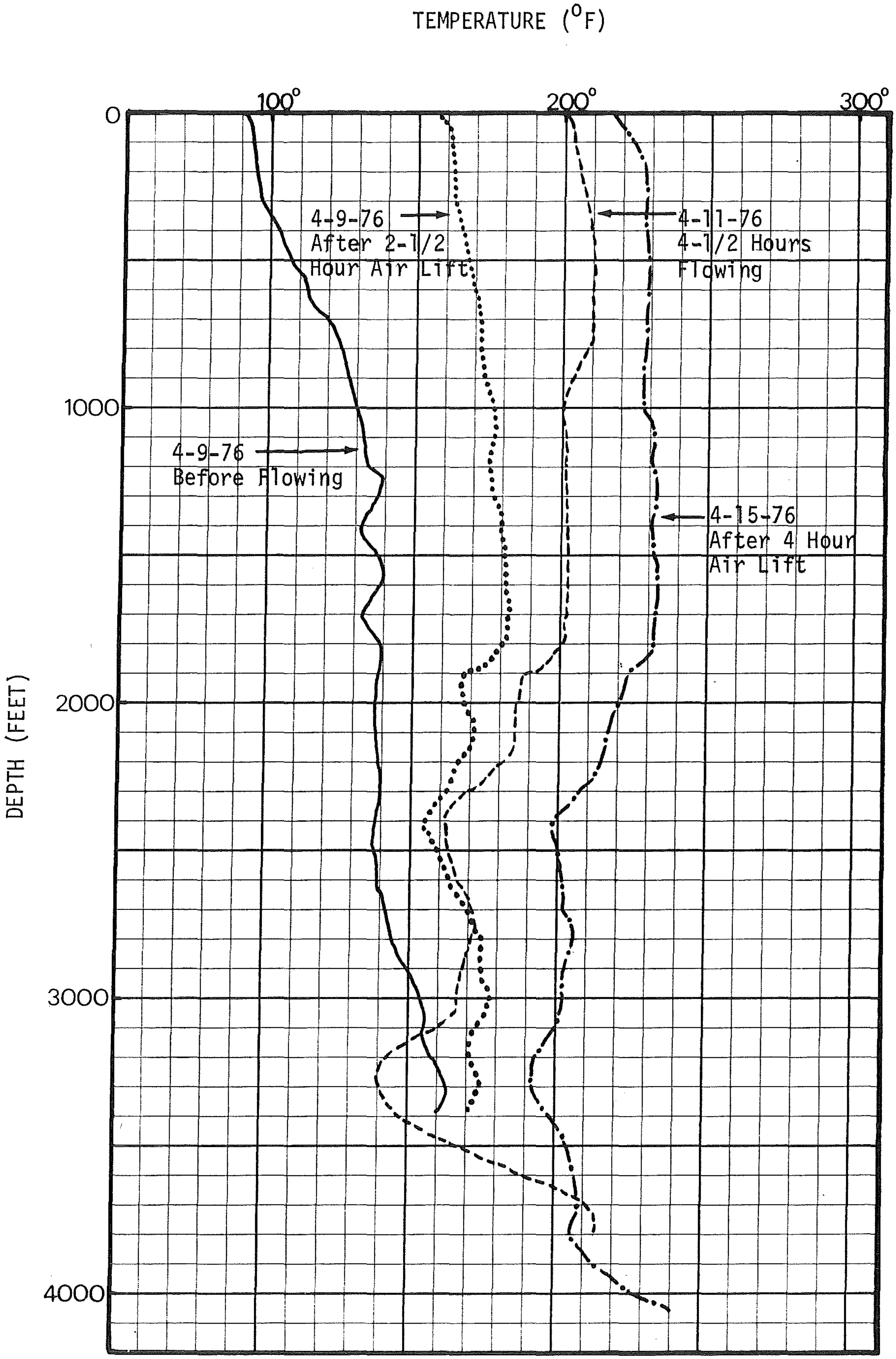


Fig. 9 Temperature profiles in RRGE-3 after completion to a depth of 4,237 ft.

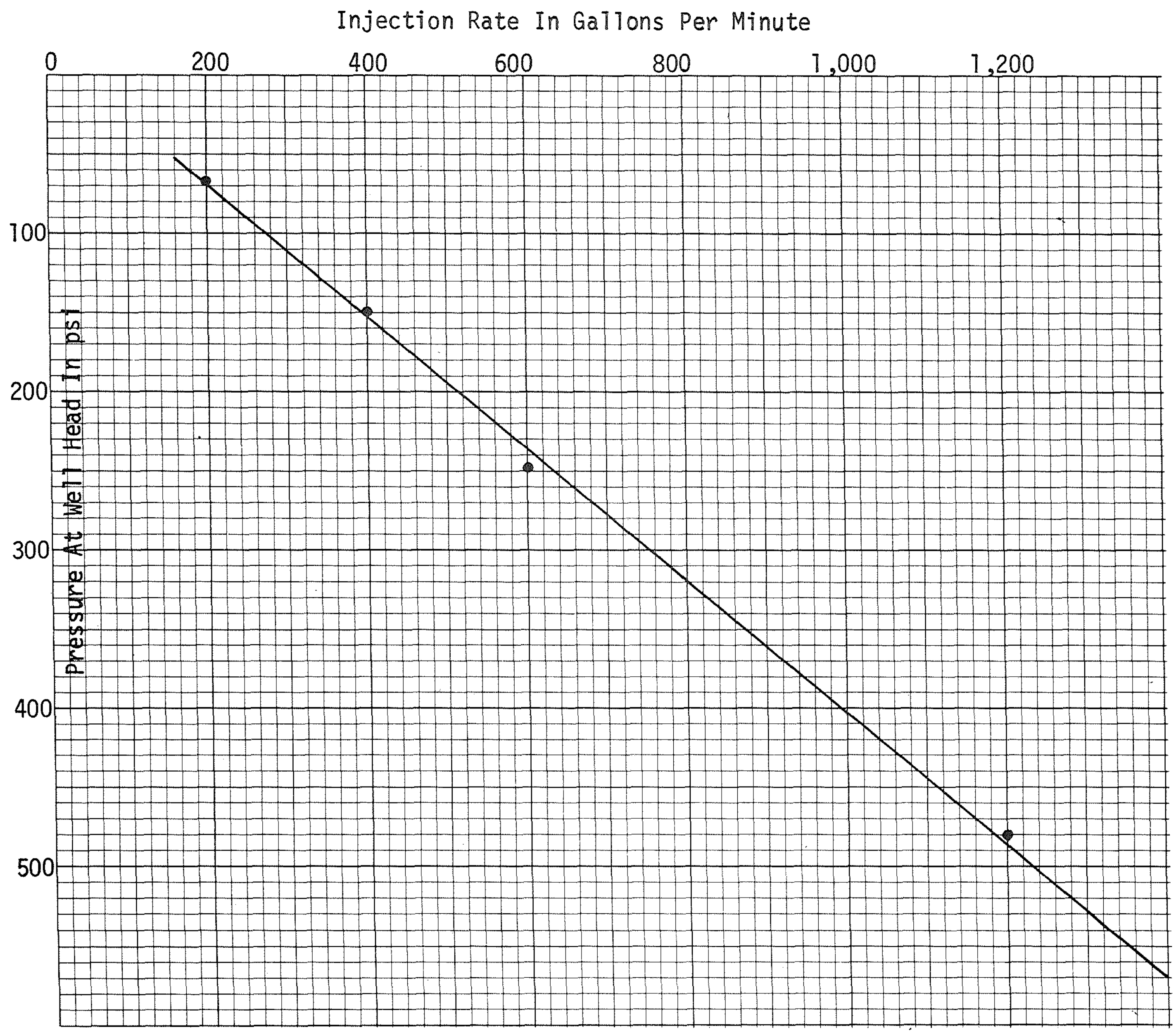


Fig. 10 Reinjection Testing of RRGE-3, Leg A

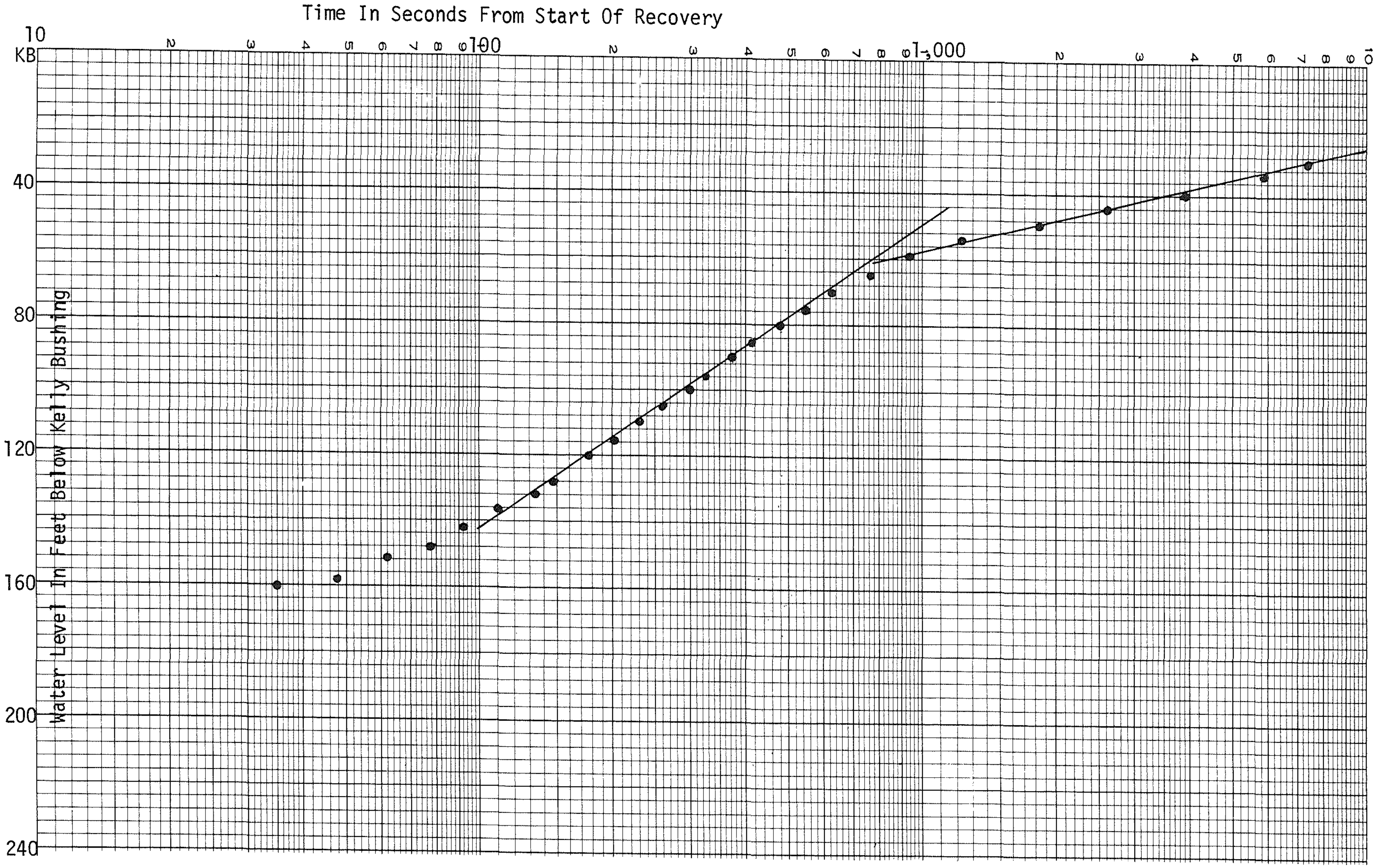


Fig. 11 Water Level Recovery After Several Hours of Air Lifting RRGE-3, Leg A, from a depth of 300 ft.

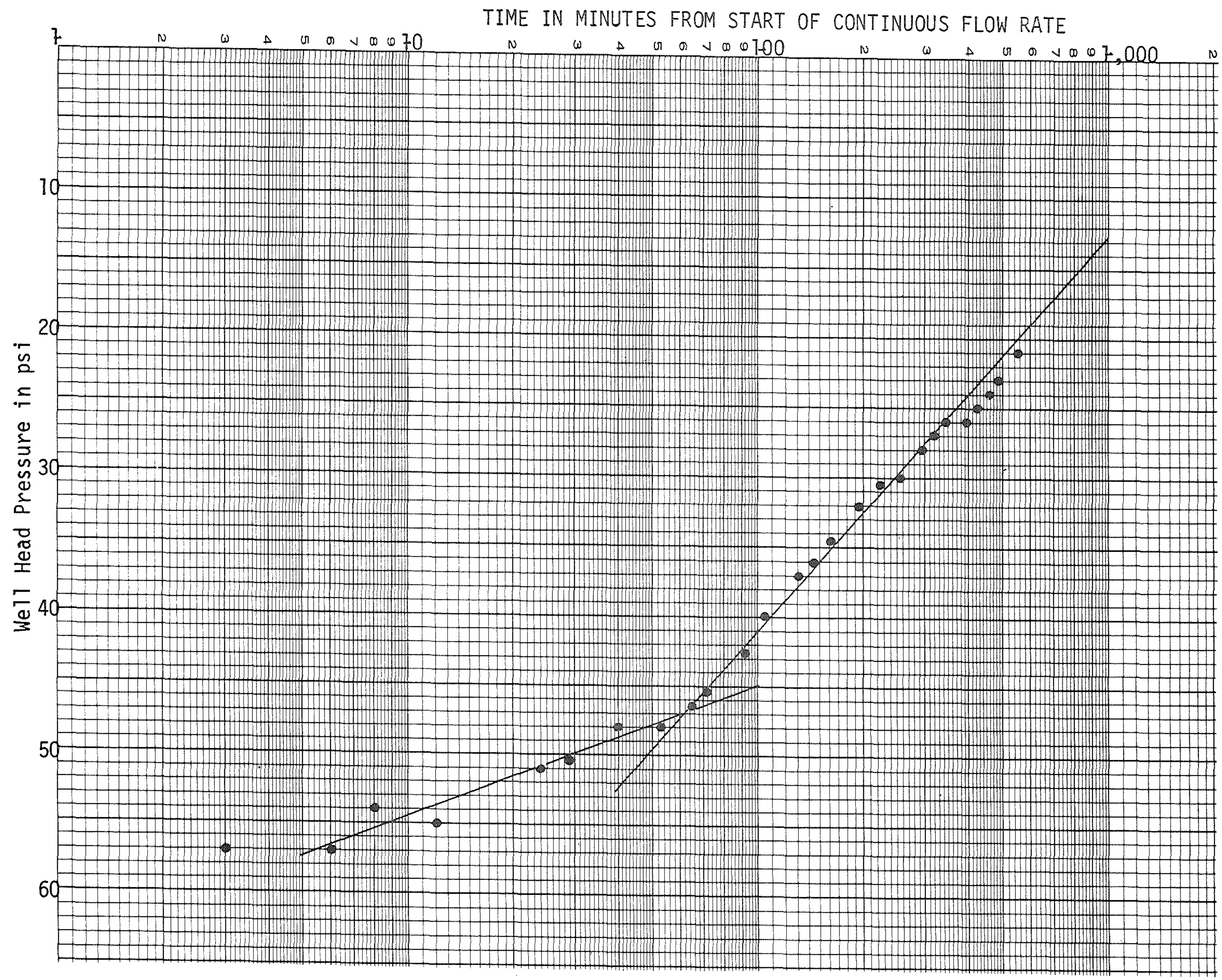


Fig. 12 Change in Well Head Pressure While Flowing at 370 gpm

Table III

Down-Hole Pressure Changes from Stopped Flow Testing in RRGE-3, All Three Legs

Flow Time	Discharge Rate (gpm)	Down-Hole Pressure at End of Period*
Initially	0	2458.00
7 min.	675	2458.00 - 82.55
60 min.	450	2458.00 - 66.75
60 min.	319	2458.00 - 57.41
60 min.	184	2458.00 - 48.23
12 hours	370	2458.00 - 116

* The base condition, arbitrarily assigned double digit decimal accuracy to show change in pressure, which was determined to the second.

An eight day flow test of RRGE-3 was begun on June 8, 1976, at an average discharge rate of 140 gpm. Wells RRGE-1 and RRGE-3 were instrumented with a downhole quartz crystal pressure transducer and a frequency recorder at the surface to record downhole pressure changes. Well RRGE-2 was instrumented with a similar surface pressure transducer. Barometric pressure was recorded at the No. 1 site by a recording microbarograph. Additional water level data was gathered in intermediate depth wells by the U.S. Geological Survey. Recovery data was obtained for six days.

At the beginning of the flow test, the wellhead pressure in RRGE-3 showed an increase of approximately 30 psi due to the wellhead temperature increase, (lighter weight column of water) then a slow decline of about 42 psi at the termination of the flow test. The downhole pressure at 5,800 ft was nominally unaffected by a change in temperature, and showed an apparent maximum decline of 71 psi (see Figure 13 for raw data time-pressure relationship).

The effects of flowing RRGE-3 on wells RRGE-1, a distance of approximately 6,330 ft, and RRGE-2, a distance of approximately 7,320 ft, is difficult to interpret from the raw data due to the effects of barometric pressure changes (for the pressures being measured at the surface) and earth tides (see Figure 14). There appears to be virtually no observable pressure interaction between well No. 3 and either of the other two wells. "Square-wave" testing patterns are planned during the summer to determine the extent of pressure propagation from the No. 3 well to the other two.

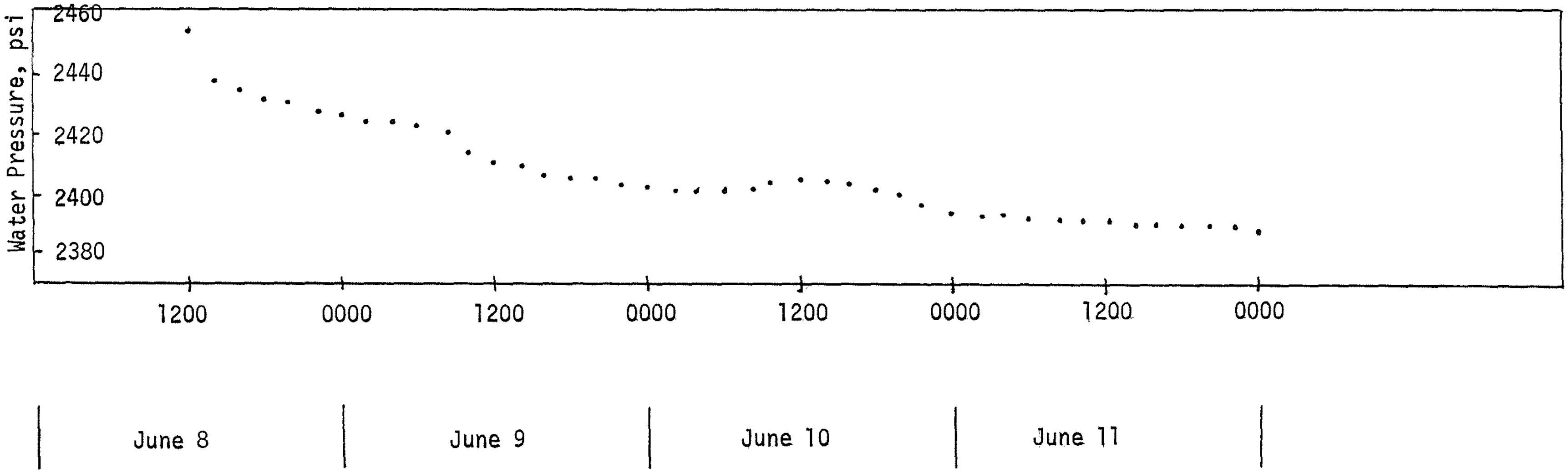
Future reservoir testing is scheduled at the RRGE-1 and RRGE-2 well sites. Long term flow testing and extensive step testing is planned at the RRGE-1 well. Some reinjection testing followed by production testing for heat-up/pressure data is planned at the RRGE-2 well.

2.4 Environmental and Area Impact Considerations - S. G. Spencer

As baseline information, subsidence data over a wide area has been gathered by USGS in addition to the small area detailed survey covering nine square miles on a detailed grid conducted by the Idaho National Engineering Laboratory.

A report[(4)] from the USGS on pre-geothermal development subsidence in the Raft River Valley was received and will be used as background data for determining if ground movement occurs in the valley which can be related to geothermal development. Data in the report was based on the re-leveling of benchmarks in the valley in the fall of 1974. This resurvey brought to light significant elevation changes that have occurred since benchmarks were first leveled 40 years earlier. Two different types of ground movement were suggested by those measured changes: 1) regional differential movement of about 6.4 cm, apparently due to tectonism; and 2) extensive land subsidence of as much as 0.8 m caused by withdrawal of groundwater. Data were too sparse to calculate the areal extent of subsidence; however, tentative lines of equal subsidence suggest that the area affected by subsidence probably exceeds 260 km^2.

Fig. 13 Pressure Change in RRGE-3 While Flowing Well RRGE-3 (all three legs) at about 140 gpm



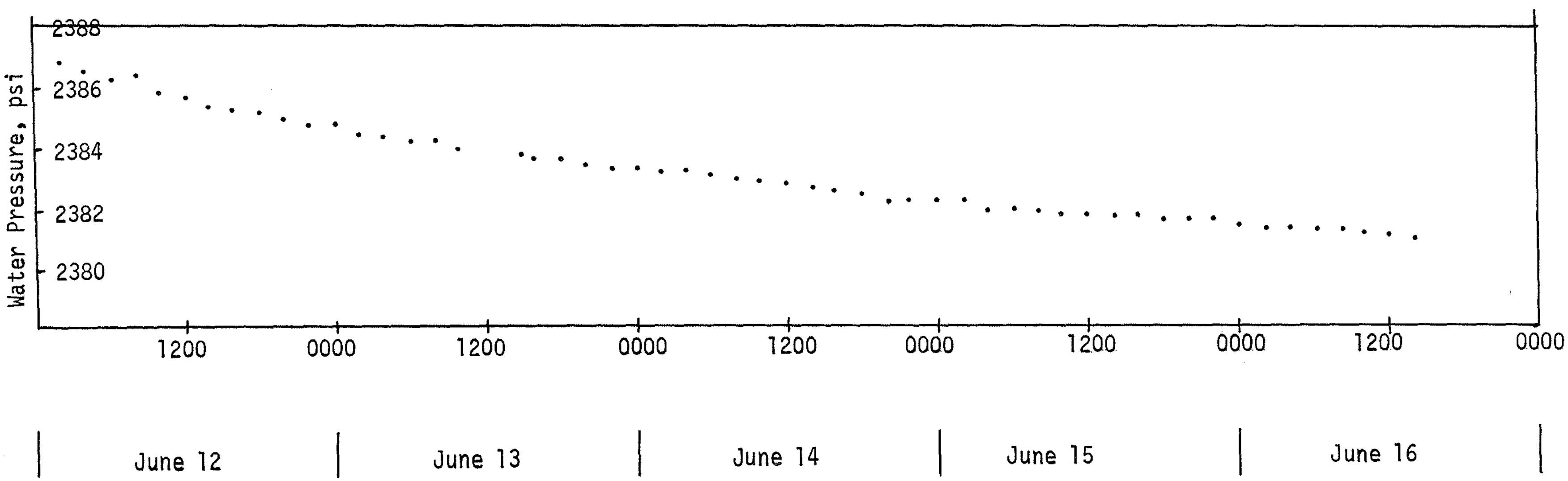
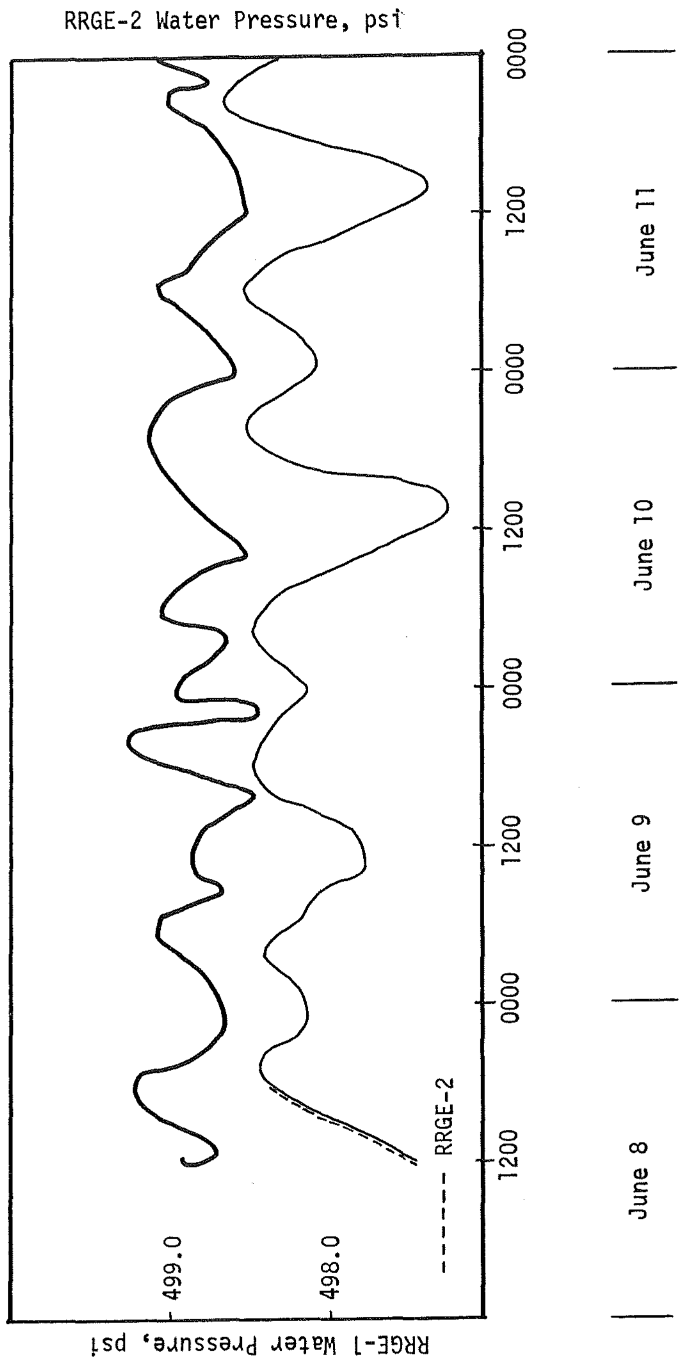
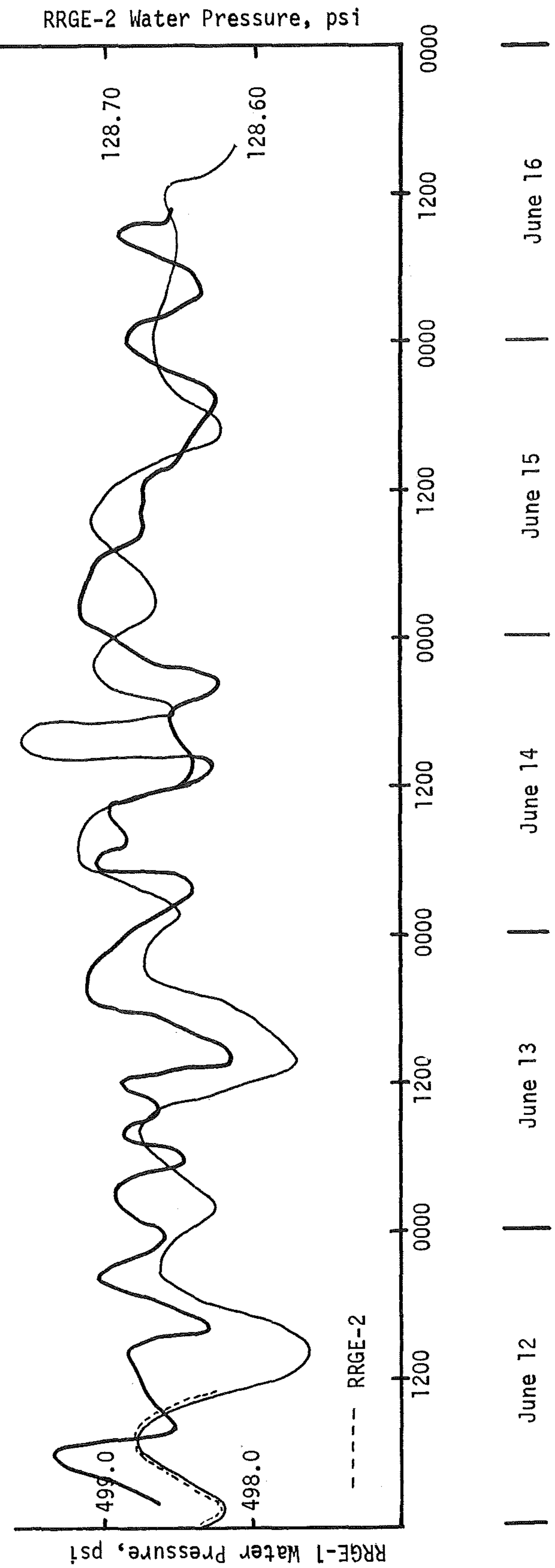


Fig. 14 Pressure Changes in Wells RRGE-1 and RRGE-2 while Flowing Well RRGE-3 at 140 gpm





An extensive sampling program has been established in support of the non-electric geothermal irrigation experiments. Samples of soil, water, and plants will be collected bi-weekly for chemical and neutron activation analyses and the results compared to baseline samples. In a companion program, nearly 2,000 trees have been planted (or potted for planting this fall). These trees, which will be irrigated with both geothermal and fresh water, include a variety of conifer and deciduous species. The objectives of this program, under the direction of the University of Idaho, are: 1) to demonstrate the beneficial use of thermal water in irrigation and ground heating for bio-mass production; and 2) to investigate the feasibility of groundwater cooling as a possible alternative to the cooling tower.

Baseline studies are continuing. The Idaho Department of Water Resource's spring sampling of irrigation wells in the area yielded interesting temperature variations over those recorded last August (most temperatures were significantly lower). Monthly temperature surveys will be taken this summer to determine if these variations are seasonal (normal) or induced.

Additional Hi-Vol and Nuclepore particulate samplers were set up at the east end of Mrs. Crank's greenhouses. Initial data indicate that on at least one day during the sampling period, the particulate concentrations neared the primary ambient air quality standards. Contributions to the particulates came primarily from road and farming operations and particulates propogated from the Salt Lake Valley.

Eleven of an ultimate 18 permanent vegetation plots have been established in radial patterns generally going out in the four compass directions from the triangle formed by the three geothermal well sites. Over half of these plots have stations which will measure long term maximum and minimum air temperatures, rainfall, and soil temperatures.

According to current schedules, the data obtained from these baseline surveys and the accompanying analyses will be submitted to ERDA by March 1977, for inclusion in the environmental impact statement for the thermal loop facility.

3.0 MODERATE TEMPERATURE CONVERSION TO ELECTRIC ENERGY

J. F. Whitbeck, Geothermal Electric Systems Manager

The conversion of fluids from a 150°C (300°F) reservoir represents not so much a challenge in practice as one in economics. The technical developments to improve the efficiency and reduce the cost of equipment for this low temperature conversion are the main thrusts of the electric program effort. Steam as a working fluid flashed directly from the geothermal water and run through a turbine is a practical approach, but an uneconomical one unless the production wells are extremely inexpensive and highly productive. But with projected average production of 1,000 to 1,500 gallons/minute of geothermal fluid per well, and each well costing $500,000, a more efficient approach than steam for the working fluid is needed. An organic working fluid of much higher density below 150°C is the initial approach being pursued; since it virtually represents technology of machinery presently in hand. A future approach is one that would use both the steam and all the geothermal water directly in a prime mover machine. Such machines are largely in the developmental phase, however, and their efficiency, reliability, and the overall performance of such a cycle has yet to be proven.

The immediate approach being pursued with the Raft River 150°C reservoir is to improve the efficiency and reduce the capital cost of the equipment in a heat exchange cycle to an organic working fluid. Isobutane has been selected as the preferred, but not necessarily the only or the most suitable fluid. The thrust of the developmental effort is as follows:

1. Improve the heat exchange cycle by reducing the pinch point (minimum temperature difference between fluids) and the cost of equipment. This effort is discussed in more detail in Section 4.0.

2. Improve overall cycle efficiency by lowering the condenser discharge temperature by taking advantage of the low average ambient temperature conditions characteristic of the mountainous geothermal areas.

3. Find materials of construction that are inexpensive and will perform well in the presence of the likely organic fluids and in the presence of the low salinity geothermal waters characteristic of the recent volcanic regions of the Northwestern United States.

The following sections describe work consisting primarily of thermal loop design, testing, and miscellaneous performance studies.

3.1 Raft River Thermal Loop Facility - R. R. Piscitella

Conceptual design of a 40 MW (thermal) thermal loop facility was completed. This design was documented in a system specification and will be used as a baseline document for the detailed design. The current design utilizes conventional state-of-the-art components in a dual boiling Rankine cycle with isobutane as the working fluid. Tentative plant arrangement drawings, equipment sizes, and a piping and instrument diagram have been completed. System optimization analysis on the 40 MW(t) test loop has been completed and the state-points derived were incorporated into the design as presented by the system specification.

The process of selecting an architect engineer to do the detailed design, and equipment procurement is underway. It is expected that ERDA-Idaho Operations Office will let the design contract in October. Figure 15 represents the proposed schedule for completion of the thermal loop, assuming funding is made available on a consistent schedule.

3.2 Results of Miscellaneous Power Plant Studies - W. W. Madsen

A parametric study was performed to determine the optimum boiler temperature(s), for various brine temperatures based upon brine utilization, for the geothermal isobutane binary cycle. This study was performed using a modified version of GEOSYS[5]. The modifications include a consistent property deck based upon ASHRAE tables and a plotting option to plot major variables in the study.

The parametric study considered the single boiler case and combinations of boiler temperatures and flow splits in the two boiler case for high and medium temperature brine. Brine temperature was varied in 20 degree increments from 360°F to 260°F and included a 290°F case corresponding to brine temperatures encountered at Raft River. For brine temperatures of 300°F to 260°F, several high pressure (HP) boiler temperatures were chosen, and for each of these several low pressure (LP) boiler temperatures were chosen. Then for each combination of boiler temperatures, the flow split was varied from zero (single boiler case) to a value at which the effectiveness reached its peak. For the high temperature brine cases, 360°F to 320°F, supercritical cycles were run in addition to the boiling cycles described above.

Some representative curves of the results are shown in Figures 16 and 17 for isobutane. It is evident from Figure 16 that the reduction in brine temperature greatly reduces the effectiveness of a single boiler cycle. Figure 17 shows that performance of the dual boiling system is quite sensitive to the selection of boiling temperature. The performance of the dual boiling system is about 25% better than that of the single boiler over a large temperature range. A report covering the various optimization studies is currently being prepared.

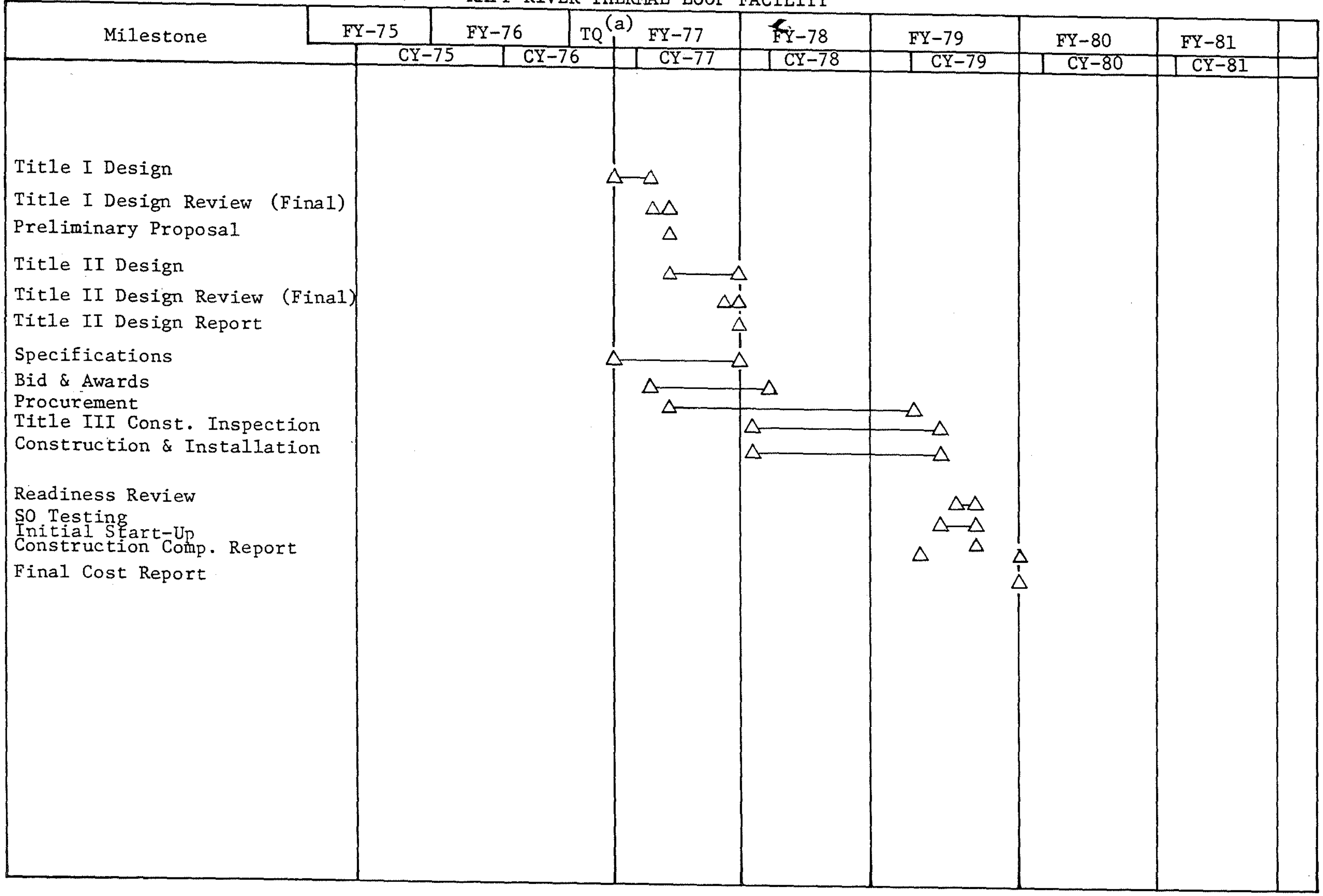
3.3 Testing Related to Pilot Plant Facility - R. L. Miller, G. L. Mines

The component test trailer has been installed in a metal building at Raft River for weather protection. Piping connections have been completed and instrumentation is being installed. These preparations will be completed by mid-summer, and testing on a variety of metallurgical and heat exchanger tubing samples will then begin under controlled conditions.

Fig. 15

MAJOR MILESTONES

RAFT RIVER THERMAL LOOP FACILITY



(a) Transition Quarter End

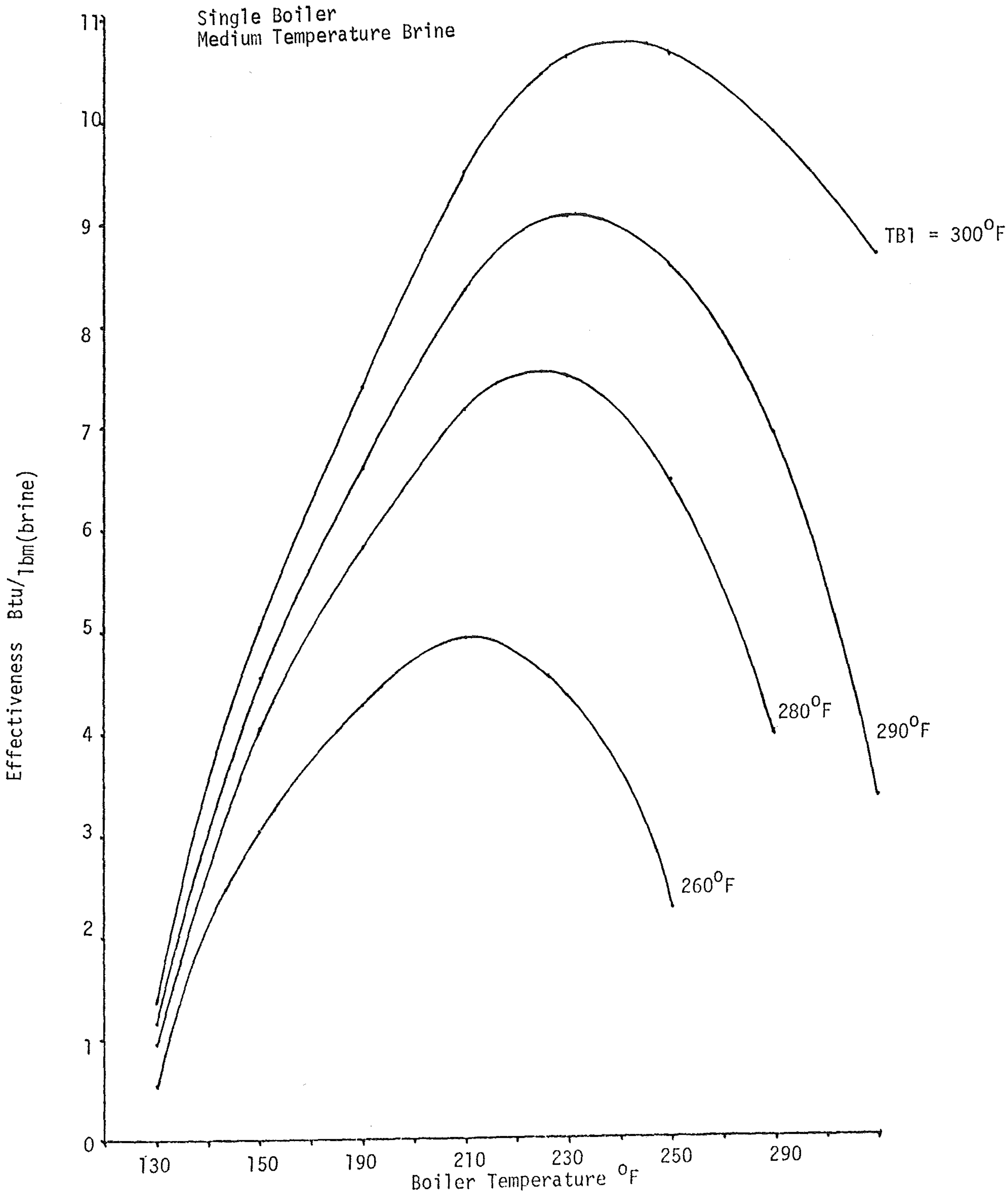


Fig. 16 Effectiveness vs Boiler Temperature for Various Brine Temperatures, Single Boiler Case. NOTE: TB1 means Temperature of Boiler, for single boiler case.

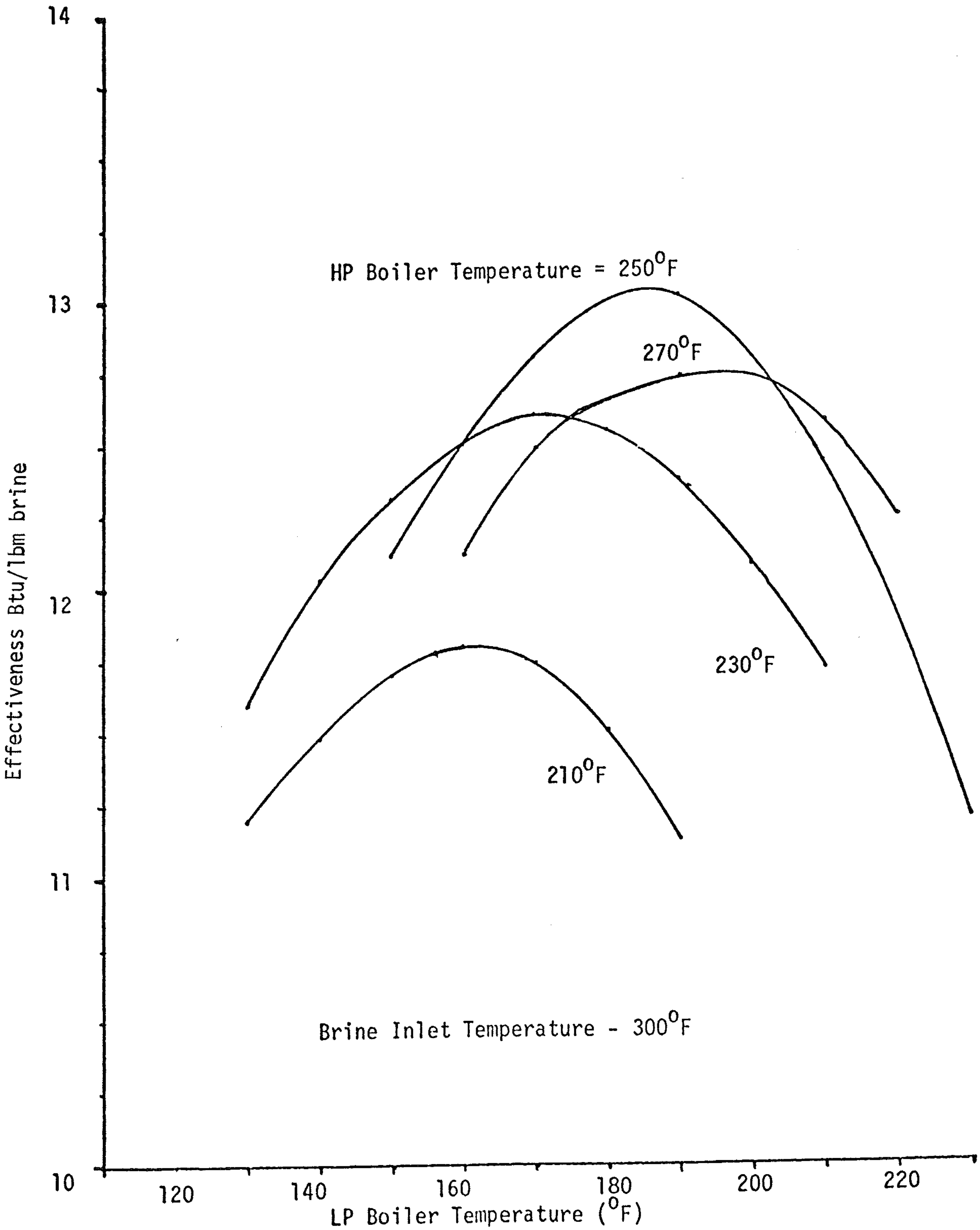


Fig. 17 Effectiveness vs LP boiler Temperature for Various HP Boiler Temperatures (270°F down to 210°F)

4.0 ADVANCED HEAT EXCHANGER DEVELOPMENT

The development of better performance and more economical heat exchangers is considered of prime significance to both the electric and the non-electric applications of geothermal energy. Operating from a 150^{o}C reservoir; a binary, organic working fluid electric power plant has tube-in-shell heat exchangers representing approximately 1/2 of the total cost of the above-ground equipment (heat exchangers plus condensers). Improvements in the heat exchange mechanism can thus have a very significant effect on the cost of electricity from such a plant.

In the case of non-electric applications, many geothermal fluids have too high a solids content to be conveniently used. The economical transfer of their thermal energy to a clean fluid is thus essential to the national finding extensive non-electric geothermal uses.

Two principal approaches to advanced heat exchangers are being pursued:

1. A direct contact process that uses no tubes, but depends on the immiscibility (very low relative solubility) of one fluid into another. This concept shows promise also for the condenser. The principal problem is one of relative solubility, resulting in contamination of and losses from the working fluid.

2. A fluidized bed, with gentle motion of the sand particles in the geothermal bed side. Tubing carries the secondary fluid, but geothermal side heat transfer is enhanced and deposition on the tube walls is prevented. The relative success of the concept in preventing scale is to be noted, along with the need to reduce the size and hence the cost of these units compared to the non-fluidized bed version of the tube-in-shell.

Also to be considered are methods of keeping clean the present, standard tube-in-shell heat exchangers, as well as methods of reducing the cost of manufacture. Since these units have been used in the power industry for nearly a century, it is felt that manufacturing economics have been thoroughly considered and researched by the manufacturers. The methods of keeping the system clean, however, with a minimum of increased cost, is a problem peculiar to the solids laden geothermal waters. A detailed study did begin this report period on such methods, analyzing the effectiveness and cost of the various types of cleaning methods possible.

4.1 Direct Contact Heat Exchanger Development

(Reported by R. F. Boehm and H. R. Jacobs, Department of Mechanical and Industrial Engineering, University of Utah)

The direct contact development work reported in this section includes development testing and correlation of results on two types of boilers designated a surface boiler where the working fluid is sprayed upon the geothermal water system and a volume boiler where the working fluid travels from holes in a tray upward to the geothermal fluid. Since direct contact heat exchangers require special systems (compared to surface type heat exchangers) an evaluation of overall conversion system performance is required. Evaluation of direct contact preheating, condensing, and removal of dissolved working fluid is a part of this program and progress in these areas are reported in this section.

4.1.1 Boiler Heat Transfer Testing and Data Correlation

During the report period, the heat exchanger trailer facility was moved from the Raft River geothermal test site to the University of Utah. The move was precipitated by temporary shutdown of flow from RRGE-1 so as to install permanent piping, valves, and pumps. A large boiler facility at the mechanical engineering laboratory is furnishing the high temperature fluid for these tests. Detailed data has been further accumulated for heat transfer rates for a spray type boiler. Included in the study were the effects of preheating of the binary working fluid. Several long period tests were conducted at fixed conditions to ascertain the stability of the system and the rate of loss of working fluid by dissolution and subsequent flashing of the pseudo-brine. The lost working fluid was accounted for by solubility considerations which could be computed using solubility data and evaporation. It is estimated that if the system were operated with R-113 recovery equipment about 40 ppm of working fluid would be lost in pure water.

Heat transfer results acquired from the direct contact surface type boiler were reduced as per the method of Jacobs, Deeds, and Boehm(6) for entrance conditions of within 30°F of saturation for the working fluid The correlation of the data is shown in Figure 18. The correlation equation for the combined data from Reference 6 and the present results fit the equation:

$$St = 1.85H^{0.6}\left[\frac{\dot{m}_{H_2O}}{\dot{m}_{Disp}}\right]^{0.15}$$

where $H = JaPr$

$$St = \frac{UA}{(\dot{m}\ c_p)_{\text{working fluid}}}$$

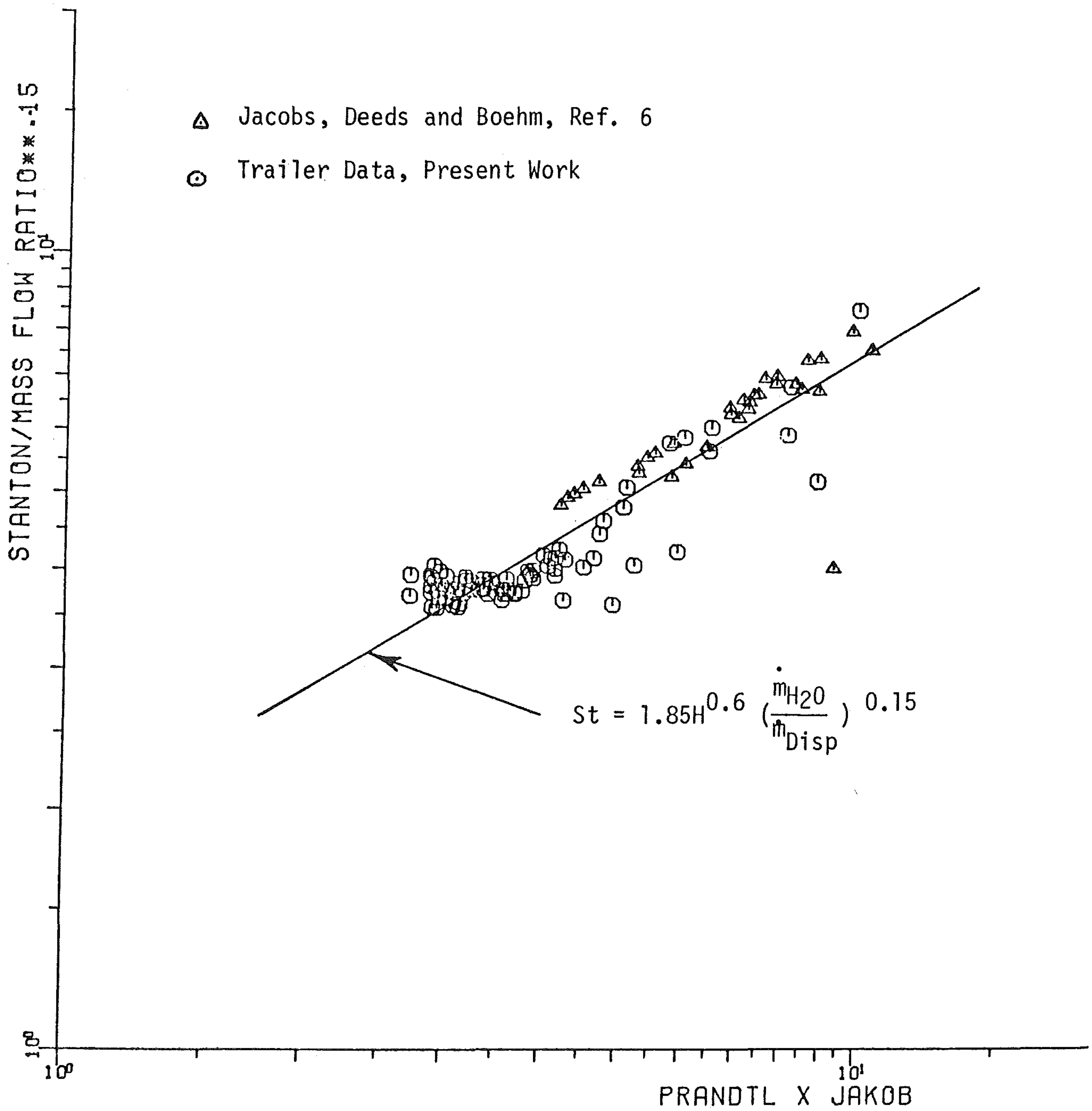


Fig. 18 Surface type direct contact boiler heat transfer with minimum subcooling.

where St = Stanton # defined as above

U = heat transfer coefficient $\left(\frac{E}{\ell^2 \ t \ ^\circ K}\right)$

A = area of boiler (ℓ^2), i.e. spray area

Ja = Jakob's No. $\left(\frac{C_{pf}\ \rho_f\ \Delta T_{sat}}{\Delta h_{fg}\ \rho_g}\right)$

Pr = Prandtl No. $\left(\frac{C_p\ \mu}{k}\right)$

This differs only slightly from the results of Reference 6 which yielded:

$$St = 1.92\ H^{0.625}\left(\frac{\dot{m}_{H_2O}}{\dot{m}_{Disp}}\right)^{0.142}$$

The table top equipment utilized by Blair, Boehm, and Jacobs[7] has been modified for studying volume type boilers with pentane as the working fluid. Preliminary data has been obtained but final reduction has not yet been completed. Additional data will be required.

The study of two fundamental problems concerned with direct contact boilers were initiated during this quarter. They involve the initiation of the evaporation phase of a pure fluid drop in an immiscible second phase, and an integral model to define the heat transfer rate for the evaporation of a jet of fluid in a second immiscible phase. The first problem is still in the pre-formulation stage while the second problem has been formulated and is currently being programmed for computer reduction.

4.1.2 Direct Contact Condensing

A review of possible direct contact condensers for use in a direct contact binary geothermal study has indicated that the only production type direct contact condensers that have been designed are the direct contact barometric and low level condensers. These types of condensers are described as:

1. spray type counterflow
2. spary type parallel flow
3. wire and tray type counterflow
4. ring and disk counterflow

In all of the above condensers, the continuous phase in the heat transfer process is the vapor while the cooling medium is dispersed. The dispersed phase is normally of low loading which requires large volumes and thus large equipment sizes. These types of exchangers have been primarily used for condensing steam with water. Little information is available for other fluids or for basic heat transfer data.

Direct contact condensers where the vapor is bubbled through a continuous second liquid phase have been described in simple laboratory models by Sideman (in Heat Exchangers: Design and Theory Sourcebook, Scripta Book Co., Washington, D.C.), however, basic heat transfer data is minimal and no large scale designs have been suggested. However, a sieve-type extraction tower or similar configuration may work well as there would be no scaling problems as associated with brackish fluids.

Work is continuing on the definition of this problem. Recommended test configurations will be forthcoming.

4.1.3 Direct Contact Preheating (Liquid-Liquid Heat Exchangers)

An experimental apparatus has been constructed to evaluate the heat exchange in direct contact parallel laminar flow of two immiscible liquids (see Figure 19), as would apply in a preheater section of a power plant. This experimental work is being carried out to verify the analysis of Reference 6 which was carried out under this grant. It is expected that the study will define the operating limits in terms of Reynolds number where the analytical results are valid and will provide additional information on the stability of the interface between two immiscible liquids.

Work was initiated to look at standard extraction columns as possible liquid-liquid heat exchangers. Equipment in the Chemical Engineering Department is being instrumented for this work. Initial experiments will be conducted with a pulsed sieve plate extractor, Mixco Lightnin CM contractor.

4.1.4 Solubility of Working Fluid in Brines

The principal concern about the practical utility of direct contact heat exchangers in geothermal applications is the relative solubility of the working fluid in the geothermal, and the resulting economic impact of the needed makeup. During this period, the solubility measurement techniques for low pressure measurements were perfected. The experimental technique used was gas chromatography. The technique allows for the direct injection of samples upon the gas chromatographic column, without stripping of the water as had been done by previous investigators. During the reporting period, data was obtained and reduced for two fluids, pentane and refrigerant 113 over the temperature range of 25 to 100^{o}C, and for concentrations of sodium chloride up to 25 st. percent.

The solubilities of each fluid were correlated by the equation,

$$\ln(H) = A + 1000\ B/T + C\text{-}\ln\ (T/1000) = W\ (D + 1000\ E/T + F\text{-}\ln\ (T/1000)$$

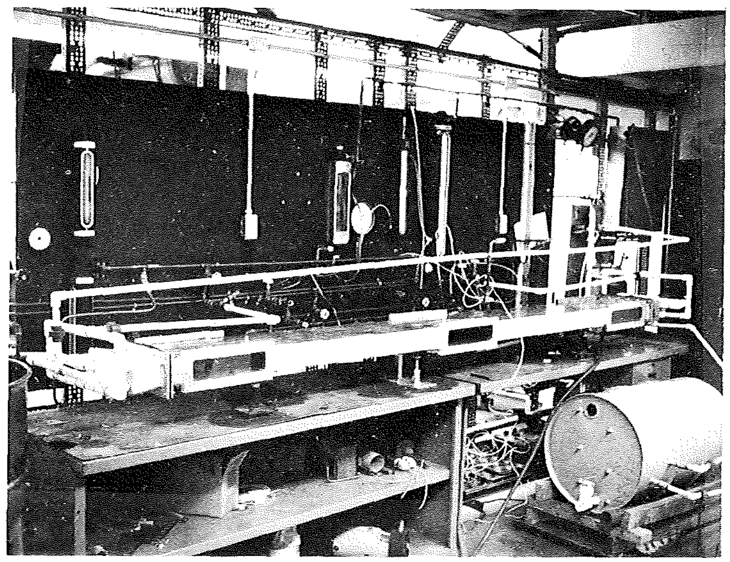


Fig. 19 Liquid-liquid direct contact heat exchanger test apparatus

where:

H is solubility in ppm/atm

T is in ^{o}K

W is weight percent NaCl

and A, B, C, D, E, and F are constants to be determined.

H was determined as the solubility at a given condition divided by the partial pressure of the fluid at that condition.

The coefficients for the above equation are given in Table IV. Plots of the experimental data and the correlations are shown in Figures 20 and 21.

Currently, work is proceeding on refrigerant 114 and isobutane solubilities. It is expected that complete data to $100^{o}C$ will be obtained by August 1, 1976. Data at higher temperatures for the four fluids will be initiated next. Experimental techniques for high pressure sampling are being developed.

4.1.5 Thermodynamic Cycle Analysis

1. Fluid Properties and Systems Analysis Code

   Thermodynamic cycle analyses are being developed both for actual applications on heat exchanger requirements and for generic studies. The work on developing the computer programs has been primarily of generic (general) nature, but it is planned to utilize the developed programs for analyses of actual systems concerned with heat transfer from moderate temperature geothermal systems.

   To date, the thermodynamic properties subroutines have been completed. A report has been released on subroutine WATER (UTEC 76-171) which computes the thermodynamic properties of water. The reports on subroutines CARBON and FREON are currently in final preparation and should be released by August, 1976. These subroutines compute the thermodynamic properties of light hydrocarbons and fluorocarbons, respectively.

   The main cycle analysis program (DIRCON) has been completed and tested on secondary fluids refrigerant 113 and pentane. Further testing for refrigerant 114, isobutane, and n-butane is required. The documentation for DIRCON is currently being written, DIRCON calculates important turbine parameters, secondary fluid losses due to the solubility of the secondary fluid in the brine, liquid-liquid direct contact preheater length, pump work and the required mass flow rates for the brine and secondary fluid in order to produce the necessary power. As details on alternate preheaters and the surface and volume boilers are completed, they will be included so that these heat exchangers may be sized.

Table IV

Coefficients to the Equation

---

ln(H)=A+1000 B/T+0-ln(T/1000)+W(D+1000 E/T+F-ln(T/1000))

Pentane:

A = 2.6780997	
B = 14.158010	Average error from data
C = 38.134244	8.75%
D =-.05511179	Standard deviation of error
E =-.20639692	6.24%
F =-.54299011	

R-113

A =-.82656685	
B = 5.280116	Average error from data
C = 8.8971230	8.45%
D =-.1241473	Standard deviation from error
E =-.07342722	5.79%
F =-.26159543	

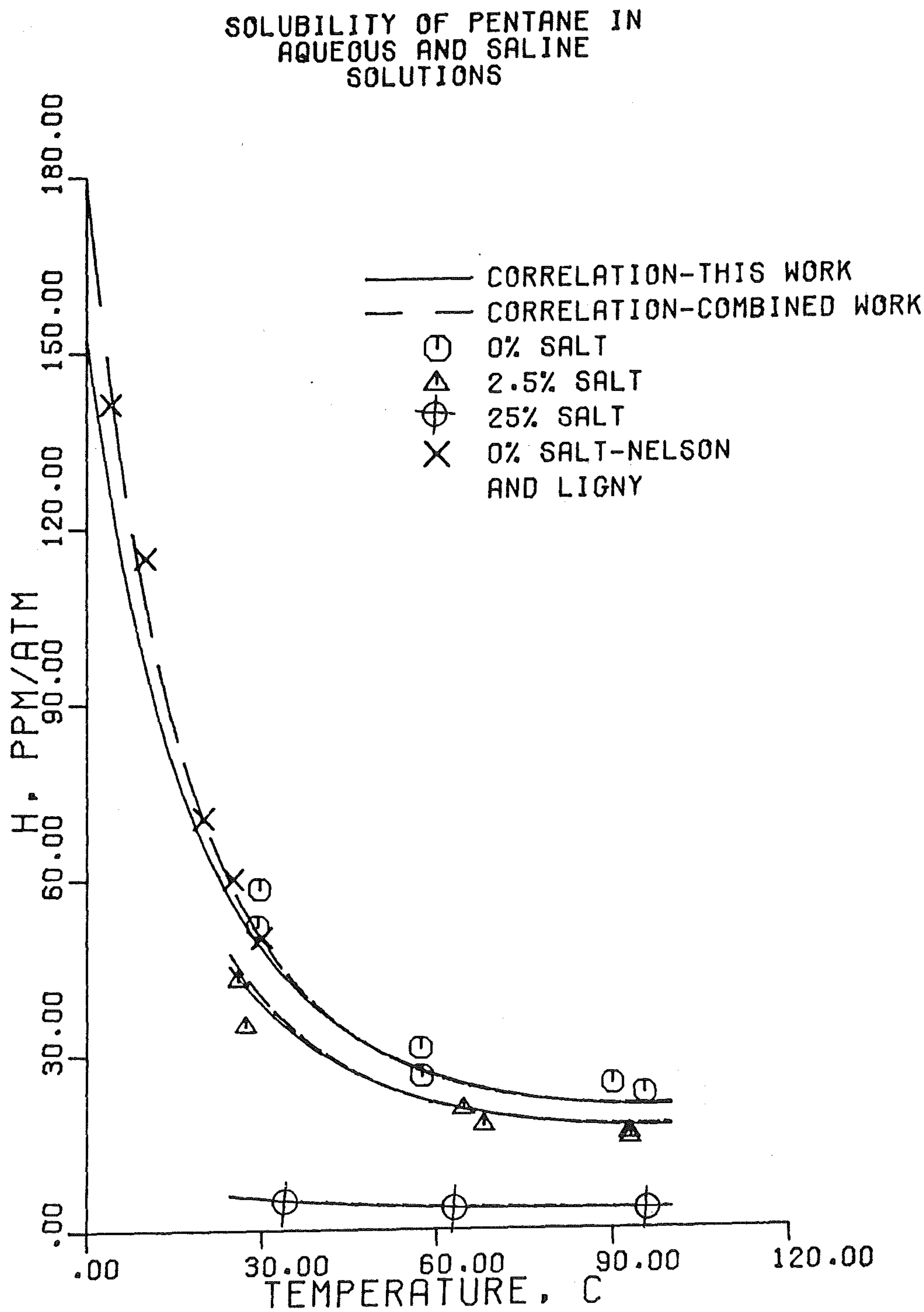


Fig. 20 Solubility of Pentane

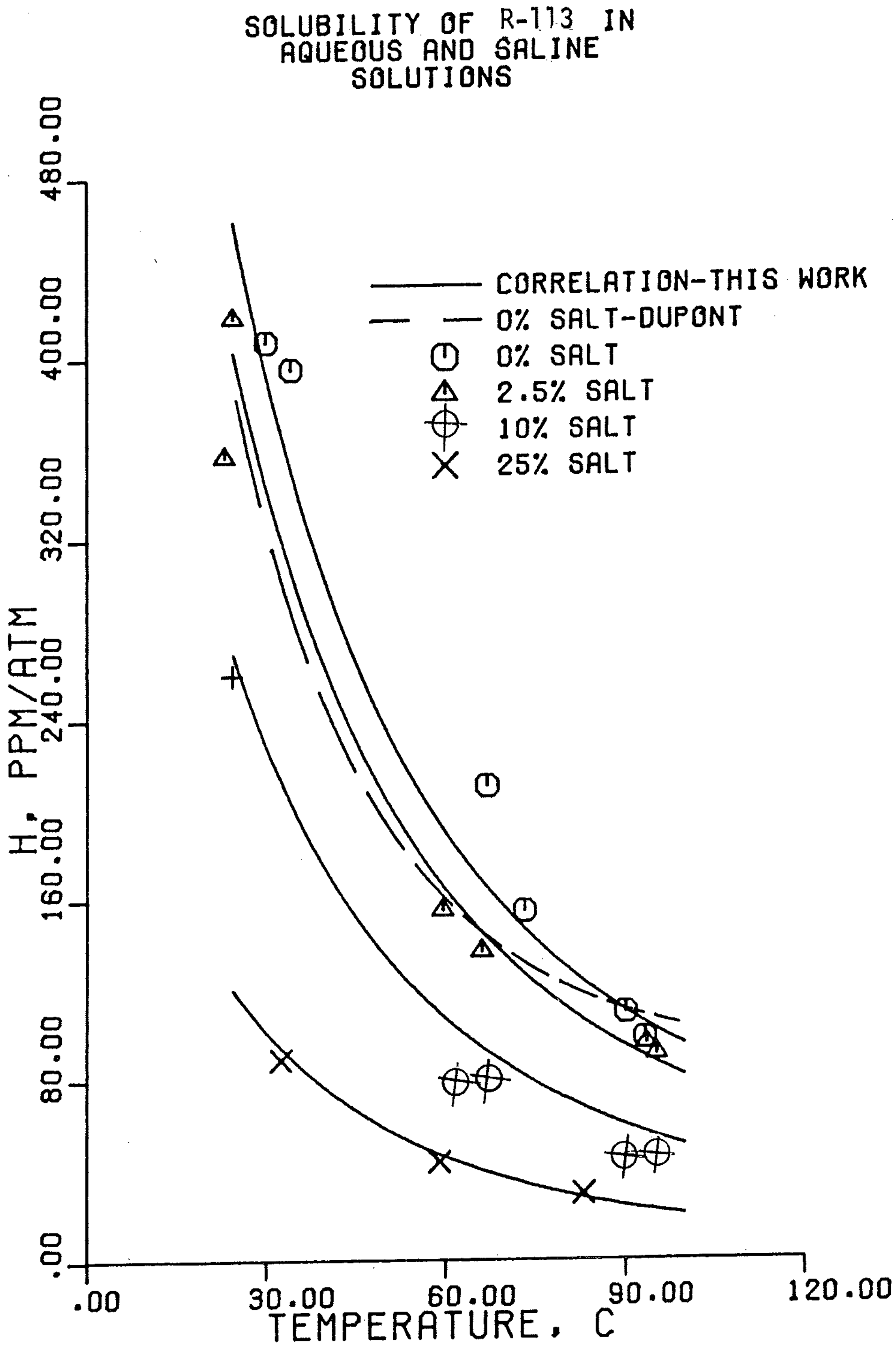


Fig. 21 Solubility of R-113

Sample results from the program are shown in Table V for refrigerant 113. Currently the calculations do not include any equipment to recover the dissolved working fluids other than reduction in brine pressure to 14.7 psia. Thus, these are worst case analyses with respect to working fluid loss.

2. Turbine Size and Cost Analyses

A computer program has been developed to rapidly calculate the ideal and actual exit state (in addition to other parameters) of a turbine using a binary mixture. (This program is being incorporated in the general cycle program.)

An important parameter in minimizing turbine cost or size is the energy density of the fluid used in the turbine. Energy density is herein defined as the isentropic enthalpy difference across the turbine divided by the exit specific volume of the fluid from the turbine. The cost of the turbine will generally have an inverse relationship to the energy density. A correlation of energy density and cost is given in Figure 22. The six fluids evaluated were refrigerant 113, refrigerant 114, isobutane, n-butane, pentane and propane. Refrigerant 113 would require the most expensive turbine while propane and isobutane yield the least expensive and most compact turbine.

For five of the fluids, the evaluation was carried out over a variety of saturation inlet states and condenser temperatures. The remaining fluid propane, is supercritical over most of the inlet temperatures under consideration. To make a valid comparison, the inlet state for propane must be carefully chosen. For a given inlet temperature, which is sufficiently below the critical point, the optimum inlet state is at saturation since superheat decreases the energy density. As the critical point is approached, the optimum inlet state moves from the saturation line to increasing amounts of superheat. This phenomenon gives rise to the idea of an "energy corridor" which extends into the supercritical region. Therefore, a search must be carried out at a given supercritical temperature to find the optimum inlet state.

Figure 23 depicts the effect of superheat on refrigerant 114. The results from propane will be available soon.

Future work planned is to map out the nature of the expansion path for a binary mixture, comparisons to single fluids, and multi-staging.

Table V

UNIVERSITY OF UTAH
DIRECT CONTACT
GEOTHERMAL PROJECT

INPUTS	
POWER (KWATTS)	.10000000+05
SECONDARY FLUID	F113
BOILER EXIT TEMPERATURE	266.00 DEG.F
CONDENSER TEMPERATURE	80.00 DEG.F
PLANT EXIT PRESSURE	14.70 PSIA
INLET BRINE TEMPERATURE	280.000 DEG.F
SALT CONCENTRATION (WT%)	10.00
ΔT OF BRINE IN BOILER	20.000 DEG.F
ΔT SUPERHEAT FOR FLUID BOILER EXIT	.000 DEG.F
TURBINE ADIABATIC EFFICIENCY	.9000
PUMP EFFICIENCY	.8000
RESULTS	
WATER/FLUID VAPOR	.026045 LB/LB
FLUID LOST/HR.	299.11 LBM/HR
BRINE/KWATT	590.4 LB/KWT
BRINE/HR	5904347.4 LBM/HR
FLUID/HR	1476131.1 LBM/HR
MASS RATIO OF BRINE TO FLUID	4.00 : 1
TURBINE EXIT TEMPERATURE	117.56 DEG.F
TURBINE EXIT QUALITY	.9997
TURBINE EXIT WATER QUALITY	.9887
TURBINE SPEED	3958.4 RPM
TURBINE DIAMETER	4.561 FT.
TURBINE COST	142493.54
TURBINE COST/KWATT	14.25
TURBINE ENERGY DENSITY	4.59 BTU/'3
BOILER PRESSURE	161.42 PSIA
CONDENSER PRESSURE	6.9976 PSIA
PREHEATER PRESSURE # 1	80.00 PSIA
PREHEATER EXIT TEMPERATURE # 1	251.56 DEG.F
PLANT EXIT TEMPERATURE	212.03 DEG.F
PUMP WORK	314.1212 HP

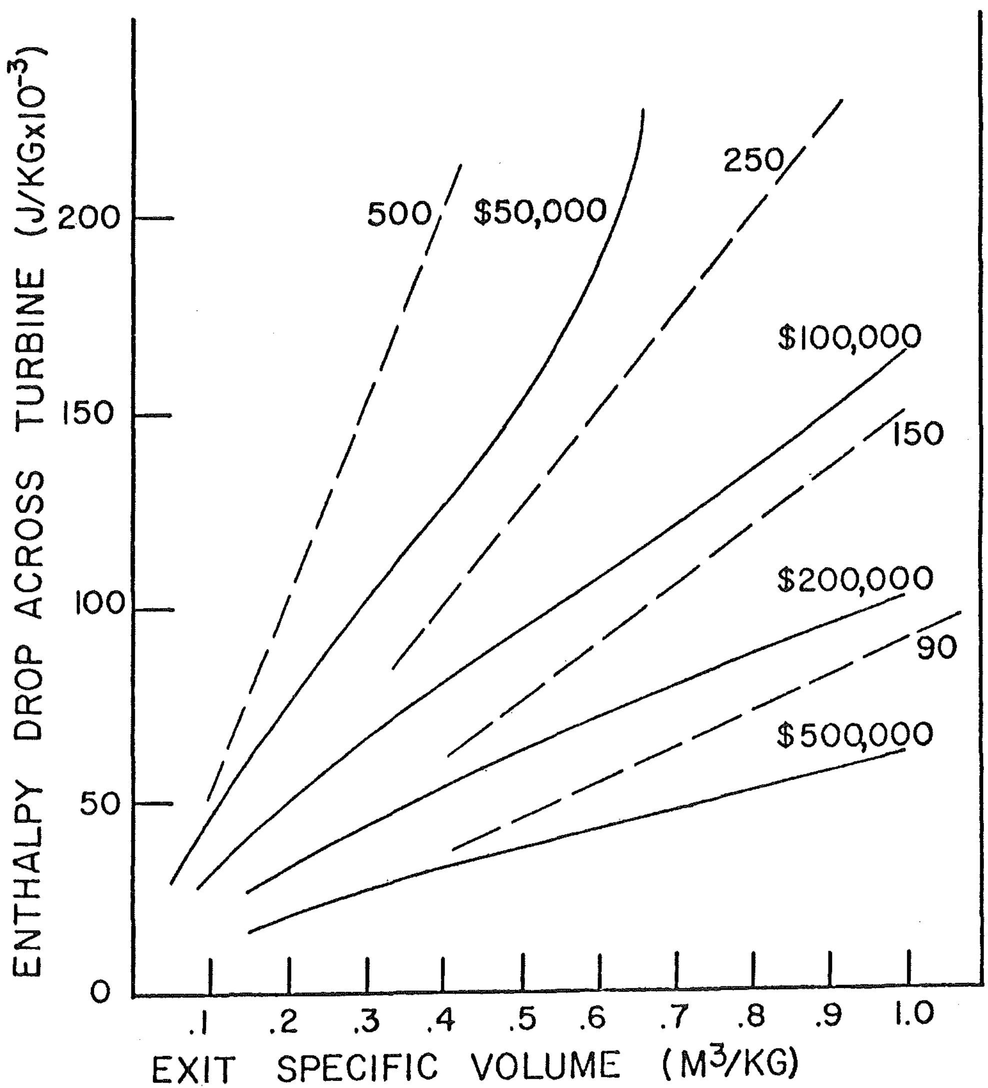


Fig. 22 Comparison of turbine cost and fluid mixture energy density. Energy density, (Joules/cubic meter) x 10^{-3}, of the exit fluid is given by the dashed lines.

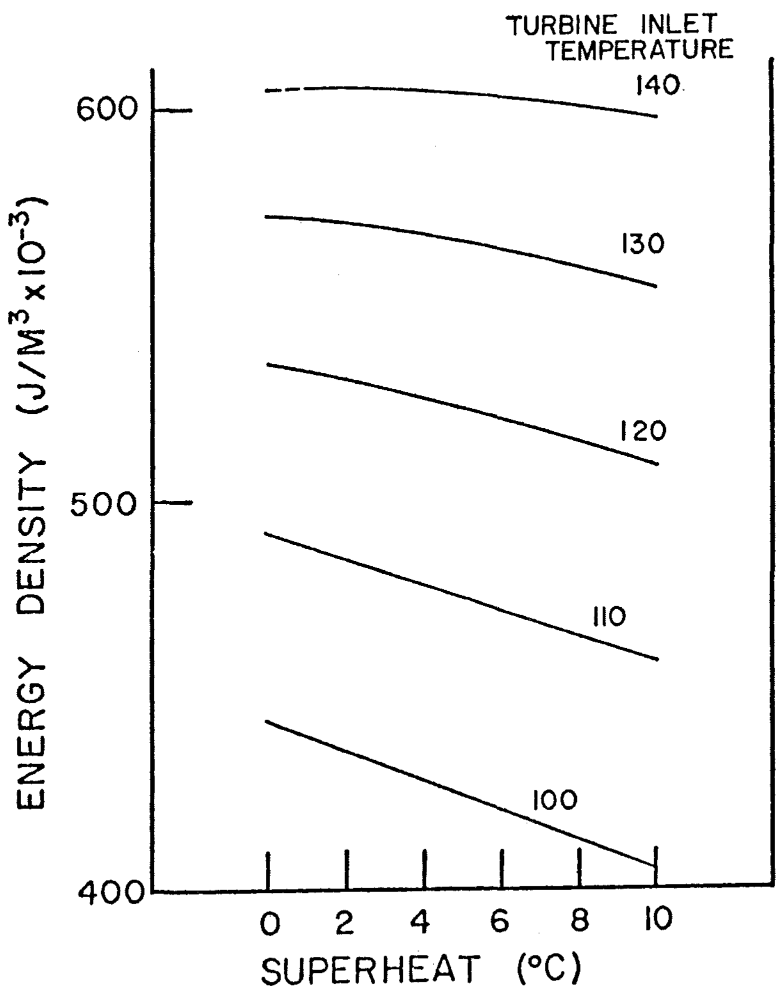


Fig. 23 Effect of superheat on the energy density of freon 114 for various inlet temperatures (°C).

4.2 Liquid Fluidized Bed Heat Exchanger

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

Use of geothermal energy depends on development of techniques to prevent scale on heat transfer surfaces. This provides the primary motivation to develop a liquid fluidized bed heat exchanger. Experiments to date have been performed with synthetic brines and with Raft River geothermal water which contains 2,000 ppm dissolved solids. A bench-scale experiment operating at atmospheric pressure was set up at the Bureau of Reclamation Site near Imperial Valley, California where the geothermal fluid contains 25,000 ppm dissolved solids. The liquid fluidized bed test will run for a minimum of 30 days but long enough to conclusively demonstrate scale control in more concentrated brines. Heat transfer data will be collected and compared with results from Raft River. This experiment will determine if the distributor plate or instrumentation will have to be modified for more elaborate experiments operated at maximum temperatures and pressures, planned to begin during the first quarter of FY-1977.

Liquid fluidized-bed techniques were applied to a horizontal heat exchanger design in a glass bench-scale unit. The heat exchanger is composed of a series of isothermal beds with the fluidizing liquid directed from stage to stage by a series of baffles. (See Figure 24) This concept offers several advantages:

1. It closely resembles standard heat-exchanger design.

2. Greater flow rates can be achieved in the same diameter vessel compared to vertical tower assemblies.

3. Flow is perpendicular to the tube bundle rather than parallel with it.

4. Distributor plate mounting is simpler.

To test this concept with geothermal fluids, an 8-inch, single-stage, pressurized unit was constructed of carbon steel. The tube bundle is 16 in. long and contains forty 3/8-inch tubes. The vessel is completely instrumented for measuring flow rates, pressure drops, and temperatures. Special tubes are being constructed with 0.01-inch thermocouples welded to the inner and outer tube surfaces to provide accurate heat-transfer measurements. This unit was installed at the Raft River site for testing. When the preliminary tests are completed, it will be transported to the Bureau of Reclamation site in Imperial Valley, California, to demonstrate the liquid fluidized-bed scale-control concept in fluid containing up to 25,000 ppm solids. The Imperial Valley test will begin in the summer of 1976.

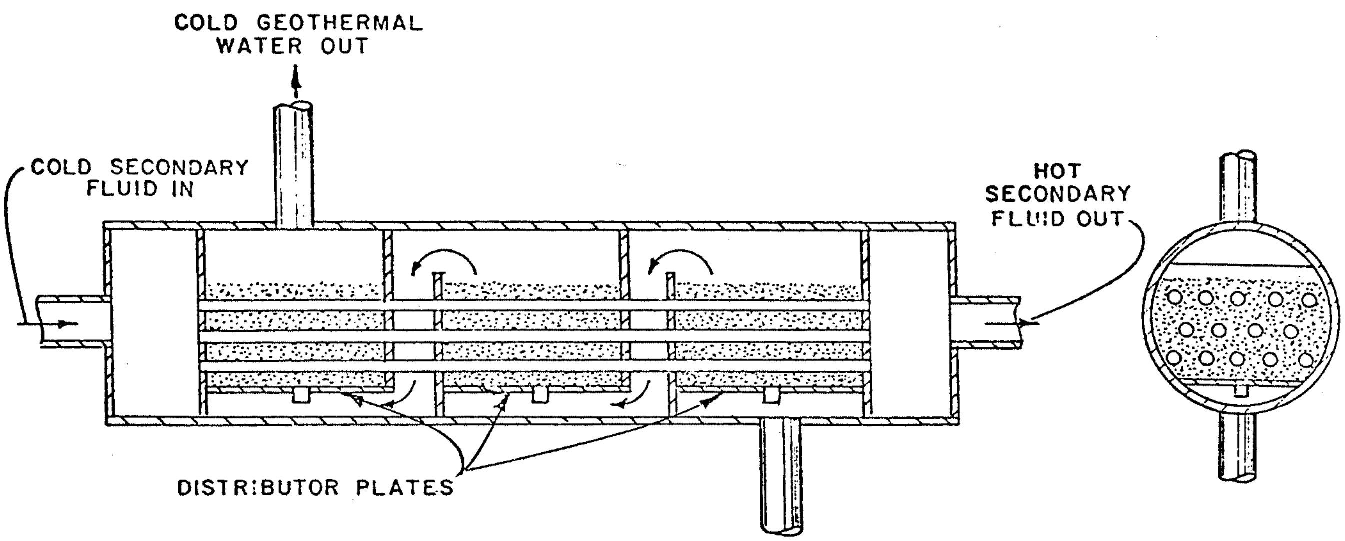


Fig. 24 Liquid Fluidized Bed

5.0 NON-ELECTRIC USES OF GEOTHERMAL ENERGY

R. J. Schultz - Non-Electric Uses of Geothermal Energy Manager

5.1 Introduction

In the United States, the direct (non-electric) use of geothermal energy has been limited, although rapid expansion has occurred in other parts of the world during the last decade. The non-electric uses that have occurred in the U.S. 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 is a more efficient use of the resource. The integration of processes take advantage of the latent heat available in the geothermal water as well as the utilization of the products from one industrial process as raw materials for an adjoining process. Proper selection of activities will permit a cascading of processes progressing from higher to lower temperature/pressure requirements.

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 the 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. In addition, the Idaho National Engineering Laboratory has made preparations for a demonstration project for the direct utilization of geothermal energy at Raft River and taken several steps to explore facets of the beneficial uses of this energy source.

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^{O}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 current plan is for the federal government to make available* geothermal water from existing ERDA wells for a trial period and some guarantee 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 groups can be successfully finalized. First is the question of the extent of ERDA involvement. Second, is a geothermal water distribution policy, which may include low cost hot water supply for a specified trial period. 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 provisions to aid the participants in the demonstration project in establishing new wells at the end of the three to four year trial 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 regard to the possibility of using the geothermal water, suitable treated for this purpose.

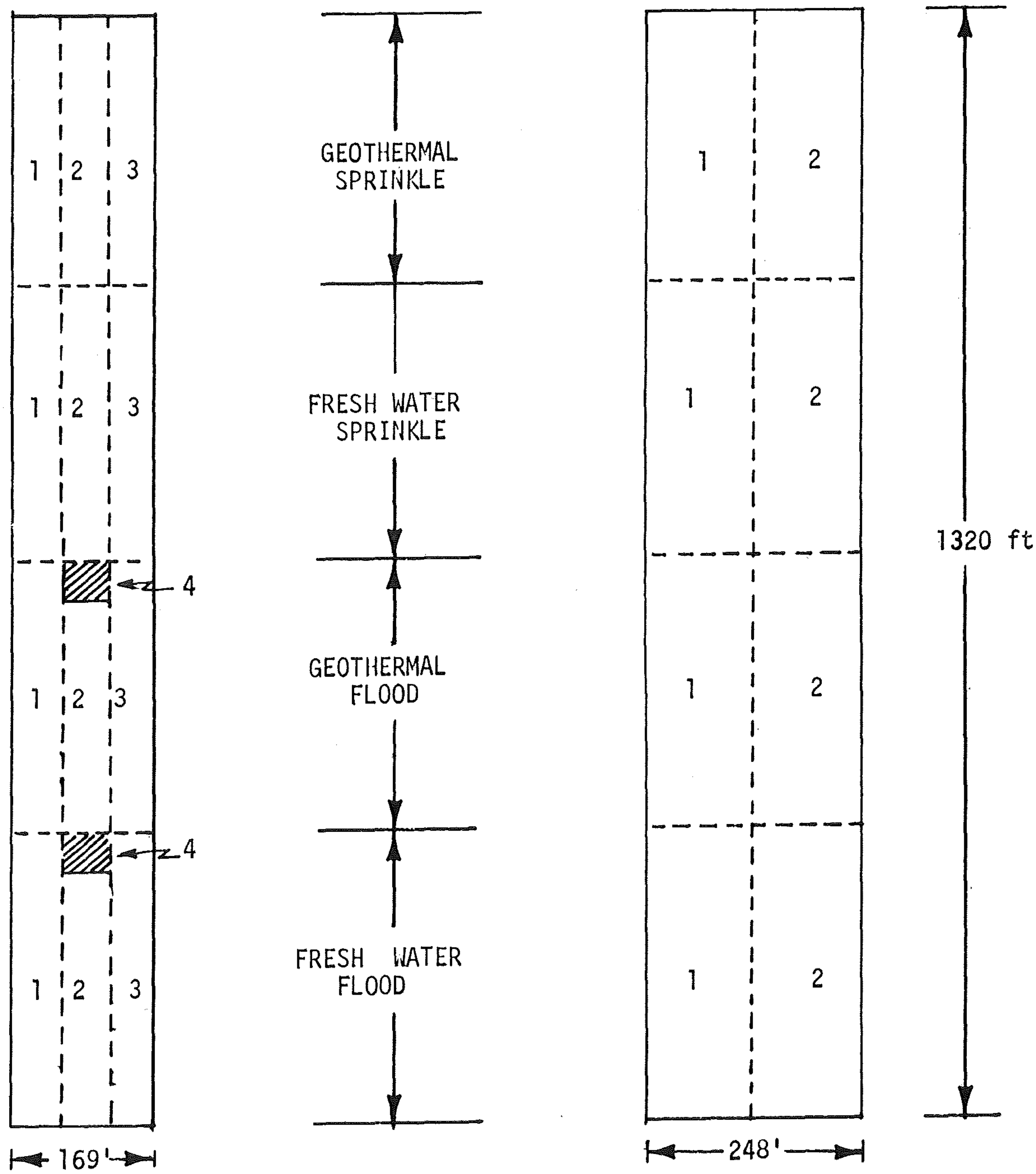
5.2.2 Beneficial Uses of Geothermal Brine

Experimental tasks were established at Raft River to examine the beneficial uses of geothermal brine. These experiments are in part directed to utilizing geothermal brine subsequent to electric power plant utilization. Utilization of brine could offer significant reduction in re-injection costs for example. Both agriculture and aquaculture practices are being examined.

1. Agriculture Experiment - R. C. Schmitt

   Plans were implemented to determine the effects of geothermal water on crops in an irrigation experiment at Raft River. A test plot of about 12.5 acres was established and subdivided into 20 smaller plots for five crop species and a small truck garden. Two water application techniques (flood and sprinkler) are being examined. Data on the water application effects, plant behavior uptake of heavy metals, flouride effects and soil contaminant buildups are expected. A fresh water source is being used as a control. A pictorial layout for the irrigation experiment is shown in Figure 25.

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



PLANT SPECIES

1 Pasture Mix
2 Oats
3 Wheat
4 Garden Vegetables

PLANT SPECIES

1 Barley
2 Alfalfa

Fig. 25 Raft River Irrigation Experiment

2. Aquaculture Experiment - D. G. Swink

An experiment of fish behavior in geothermal waters was planned for implementation and completion during the next reporting period. Growth rates, tolerances, and residues are to be examined for Yellow Perch, Catfish, and Talapia. A layout for this experiment in the beneficial use of geothermal water is shown in Figure 26.

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^{o}F/100 ft. Based on extrapolation, one might anticipate 140^{o}F to 150^{o}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 Down-Hole Heat Exchangers

A study of down-hole heat exchangers was initiated earlier in Klamath Falls, Oregon through a research contract to the Oregon Institute of Technology located there.

Activity this reporting period has been largely that of finalizing calculations and assimilating data for the final report.

Conceptual designs and estimated construction costs have been made for a mini-district heating distribution system to be used in the report. A mini-district geothermal heating system is one method studied in an attempt to optimize the use of the geothermal resource in Klamath Falls. Several alternatives built around different materials of construction have been estimated and conclusions drawn.

Working remaining under this research contract is largely that of arranging the report in final format.

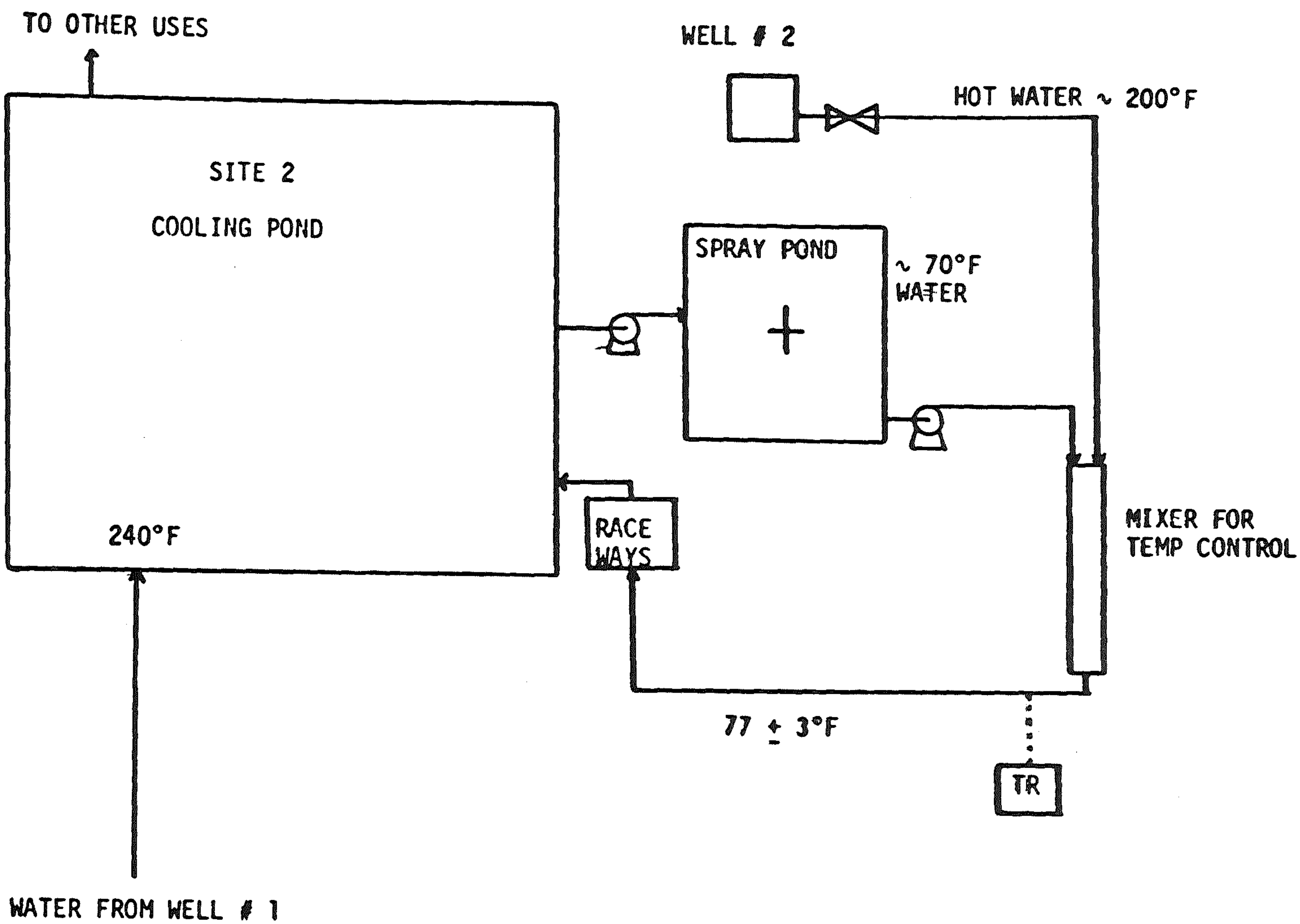


Fig. 26 Aquaculture Water Supply System

6.0 BOISE DEMONSTRATION GEOTHERMAL SPACE HEATING PROJECT

L. E. Donovan - Space Heating Projects Manager

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.)

As reported last quarter, a project summary report was made to the Governor of Idaho and presented for consideration by the Idaho State Building Authority and the Permanent 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.

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 Capitol 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.

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 possil fuel heating costs.

Due largely to the outcome of the Boise Project and the resultant summary report, the State of Idaho is proceeding with plans to implement at least a portion of the geothermal project as early as possible.

The Governor of Idaho has organized and staffed an energy office responsible to him. Funds totalling $355,000 have been requested of the Northwest Regional Commission and approved for expenditure this year. This funding is planned to be used for the drilling of two production wells and to connect two buildings to the Warm Springs geothermal system for this coming heating season. By connecting to the Warm Springs system, it is anticipated many environmental concerns about discharge can be resolved and operating data can be accumulated early. Engineering assistance is being provided by INEL for conceptual designs needed to connect these buildings to the Warm Springs system.

6.2.2 Reservoir Testing

Even though the drilling in Boise was performed for exploratory reasons, the success of BEH-1 and BHW-1 offers excellent opportunities to obtain more quantitative data concerning the geothermal reservoir. Due to the exploratory objectives, both holes were left essentially open (BEH-1 was cased to 610 ft and BHW-1 cased to 200 ft). Sand sluffed in to form a bridge in BHW-1 that stopped hot water production and BEH-1 has not been pumped.*

The success of downhole pressure measurements of resolution better than 0.01 psi in Raft River lead INEL to propose that 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 would be taken as pump tests are performed in the hope of defining reservoir parameters from which long range interaction effects with other wells in the area could be predicted. Additional funding was received for this work and well stabilization activities are now in progress.

6.2.3 Resource Definition

As the Boise Demonstration Geothermal Space Heating Project is being phased down and becoming a state funded implementation project, a completion and summation of work initiated earlier is underway. Resource definition studies performed by the Boise State Geology Department are being completed by obtaining additional electrical resistivity readings along the Boise Front Fault. These readings are necessary to fill in voids in the original data and to round out all the information gathered earlier. Along with the results of the drilling program and reservoir analysis work being performed, this resource definition data can be used to add credence to predictions about the expected extent of this particular resource.

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* Editors Note: During August 1976, both of the wells were completed, cased, and flow tested. Both developed good artesian flow (190 gpm from BHW-1 at 170^{o}F, and 50 gpm briefly from BEH-1 at 160^{o}F). Both are scheduled for further testing in September 1976.

Improvements in the resistivity equipment incorporated by Boise State includes the building and testing of a new signal switching device used in the resistivity field work. Approximately 100 field data points have been collected after completion of the device. The analysis of this data is to be included in a final report that will take into consideration all of the data collected for the studies.

Drilling of the five exploratory holes, geophysical studies, hydrological studies and geological interpretation has led to a preliminary concept of the geothermal resource. The Boise Front Fault zone is a structural control for the geothermal resource but more importantly, is fed by the NE-SW trending linears that intersect it. It would appear that the heated water moves along certain linears from the northeast and spreads out along the Front Fault where the linears intersect it. The Front Fault is not completely impervious and allows leakage of the geothermal waters through it and subsequently out into the valley proper where it mixes with the cool water of the fresh water aquifer thus diluting the geothermal resource temperature in the valley. This flow system is also short-circuited or interrupted when the NE-SW linears are intersected by NW-SE trending linears before they reach the Boise Front Fault. This situation makes the selection of production drill sites only slightly more complex.

The existence of the successful wells, BEH-1 and BHW-1, with temperatures in the range of 165-170^{0}F assure the success of the space heating project provided the production wells are carefully sited to intersect the faults that will produce the necessary temperatures and flow rates. See Section 2.2 Boise Exploratory Wells and Holes for more information on these wells.

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