TREE-1134

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GEOTHERMAL R&D PROJECT REPORT FOR PERIOD OCTOBER 1, 1976 TO MARCH 31, 1977

EG&G-Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY

Idaho Falls, Idaho 83401

Edited by

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ABSTRACT

This report covers the six month period ending March 1977, of developments in the Geothermal Program at the Idaho National Engineering Laboratory. It features testing and analysis on the three deep geothermal wells in Raft River and the two shallow (1200 ft) wells in Boise, plus the experiments leading to improved technology and lower cost for electricity produced from 300°F wells. Non-electric, direct heat uses of geothermal, to as low as 100°F also receive special attention.

ACKNOWLEDGEMENTS

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

The Raft River Rural Electric Coop.
The U.S. Geological Survey (Menlo Park, Denver, and Boise Offices)
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
Boise State University
Idaho Bureau of Mines and Geology
Lawrence Berkeley Laboratory's Geothermal Energy Division

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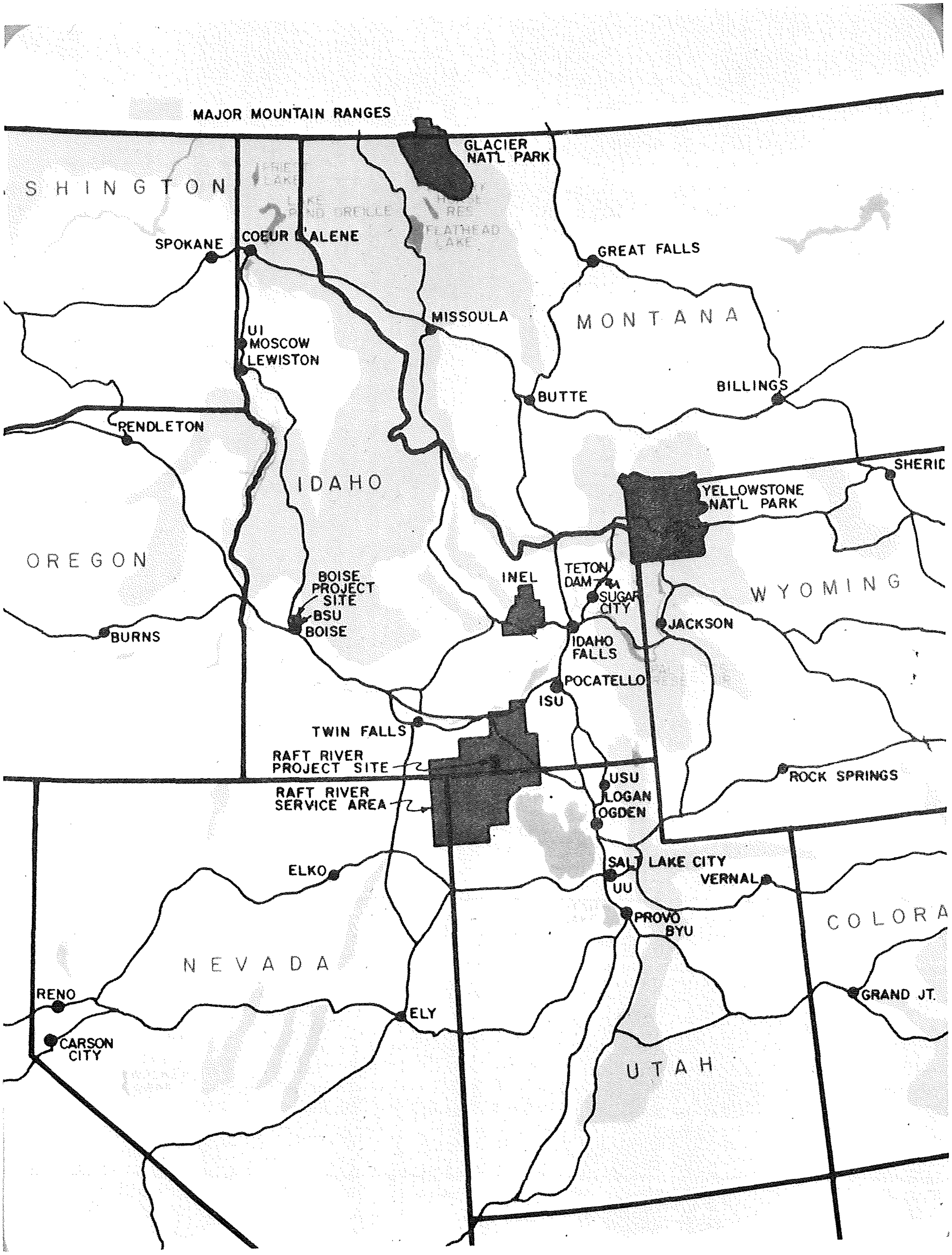


MAJOR MOUNTAIN RANGES
GLACIER NAT'L PARK
SHINGTON
SPOKANE
COEUR D'ALENE
GREAT FALLS
MISSOULA
MONTANA
UI
MOSCOW
LEWISTON
BUTTE
BILLINGS
PENDLETON
SHERID
YELLOWSTONE NAT'L PARK
IDAHO
OREGON
INEL
TETON DAM
SUGAR CITY
WYOMING
BOISE PROJECT SITE
BSU
BOISE
BURNS
JACKSON
IDAHO FALLS
POCATELLO
ISU
TWIN FALLS
RAFT RIVER PROJECT SITE
RAFT RIVER SERVICE AREA
USU
LOGAN
OGDEN
ROCK SPRINGS
ELKO
SALT LAKE CITY
UU
VERNAL
PROVO
BYU
COLORA
NEVADA
RENO
CARSON CITY
ELY
GRAND JT.
UTAH

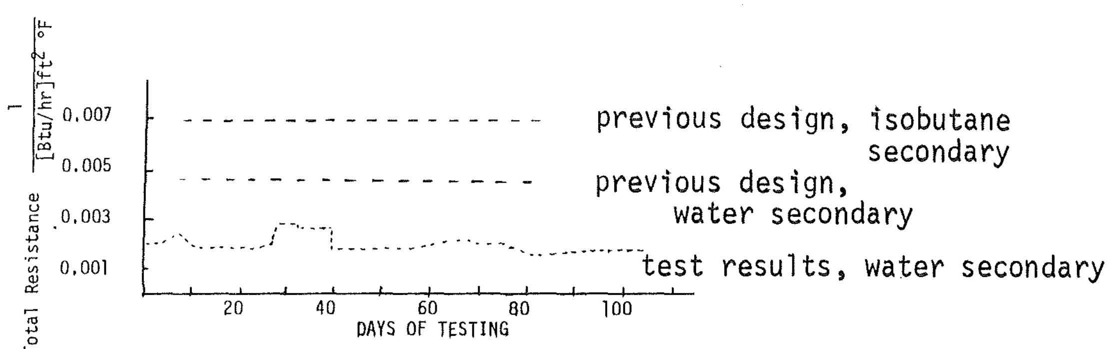
1.0 SUMMARY OF SIGNIFICANT TECHNICAL DEVELOPMENTS IN 1976

The following summarizes the results of experimental work in the field during 1976. Cited are those technical results which should lead to reduced costs of utilizing geothermal energy. In general, most of the developments were not fully anticipated before the experiments began.

1. Development - Deposition on heat exchanger tubing during tests was negligible on both stainless steel and titanium tubing

   Comments - After 2200 hours in controlled experiment with 2000 ppm, longer tests planned, some with 4000 ppm water

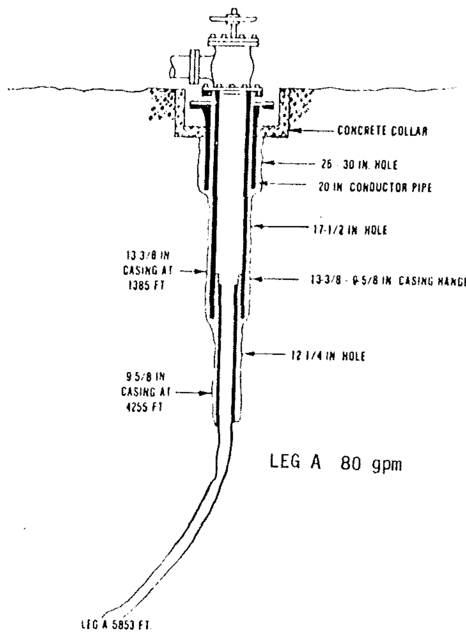
   Significance - Tubing length in heat exchangers can be reduced 20 to 30%

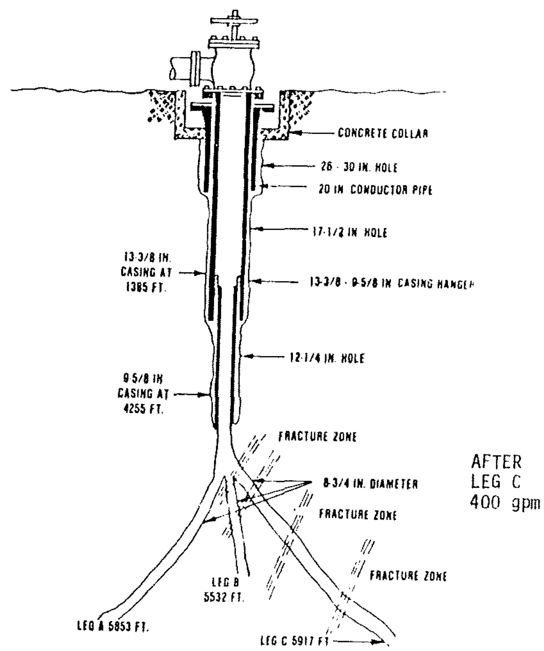


2. Development - Multiple legs in barefoot section of production wells to enhance production at minor increase in cost

Comments - For RRGE-3, production enhanced 3 to 5 times for 20% increase in cost. This is considered an unusually fortunate result, a case in which the first leg encountered few fractures, the other two legs encountered many fractures. For homogeneous permeability, a 50% increase in production for 20% cost increase is the more likely result.

Significance - All future water-dominated production wells should be drilled for multiple legs, if fracture permeability is the predominant source of production.



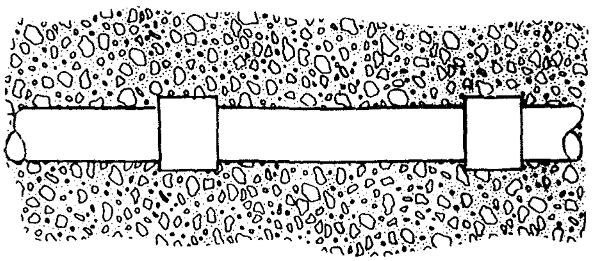


3. Development - Asbestos-cement pipe used successfully at 300°F, at greatly reduced costs compared to steel pipelines

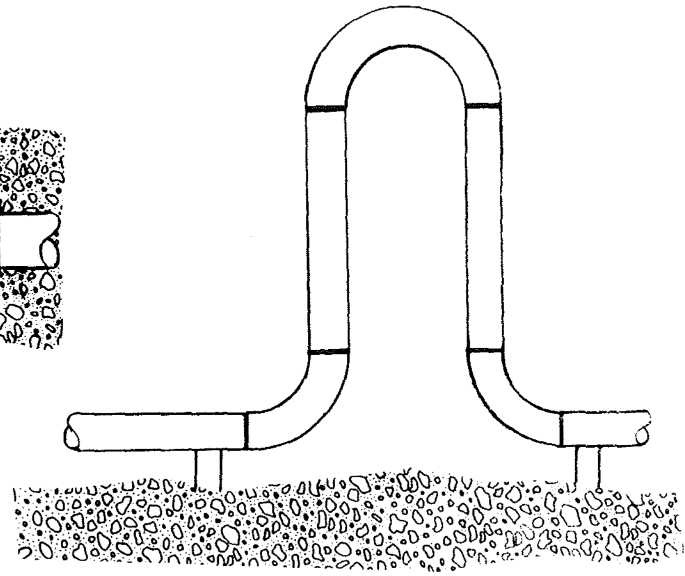
Comments - During early testing, several breaks occurred. These have been attributed to water hammer and extreme thermal shock. Pipeline since has performed well, especially during routine steady state operation. Pipeline should be buried 2 to 2-1/2 ft, and insulated with 1 in. of urethane foam.

Significance - Cost savings of 55% compared to steel pipe. Next size smaller pipe can be used because of reduced pressure loss in asbestos-cement pipe compared to steel pipe.

3. (Cont'd)



TRANSITE PIPE



WELDED STEEL PIPE

4. Development - Agriculture irrigation with geothermal water successful the first year.

   Comments - No difference in mineral uptake compared to control crops. Long term buildup in soil will be monitored for at least three more years.

   Significance - A possible by-product use for irrigation, especially valuable in water poor areas where much of geothermal energy is found.

   12 acres total of grasses, wheat, barley, oats, alfalfa plus some potatoes, beets, spinach, lettuce, and squash

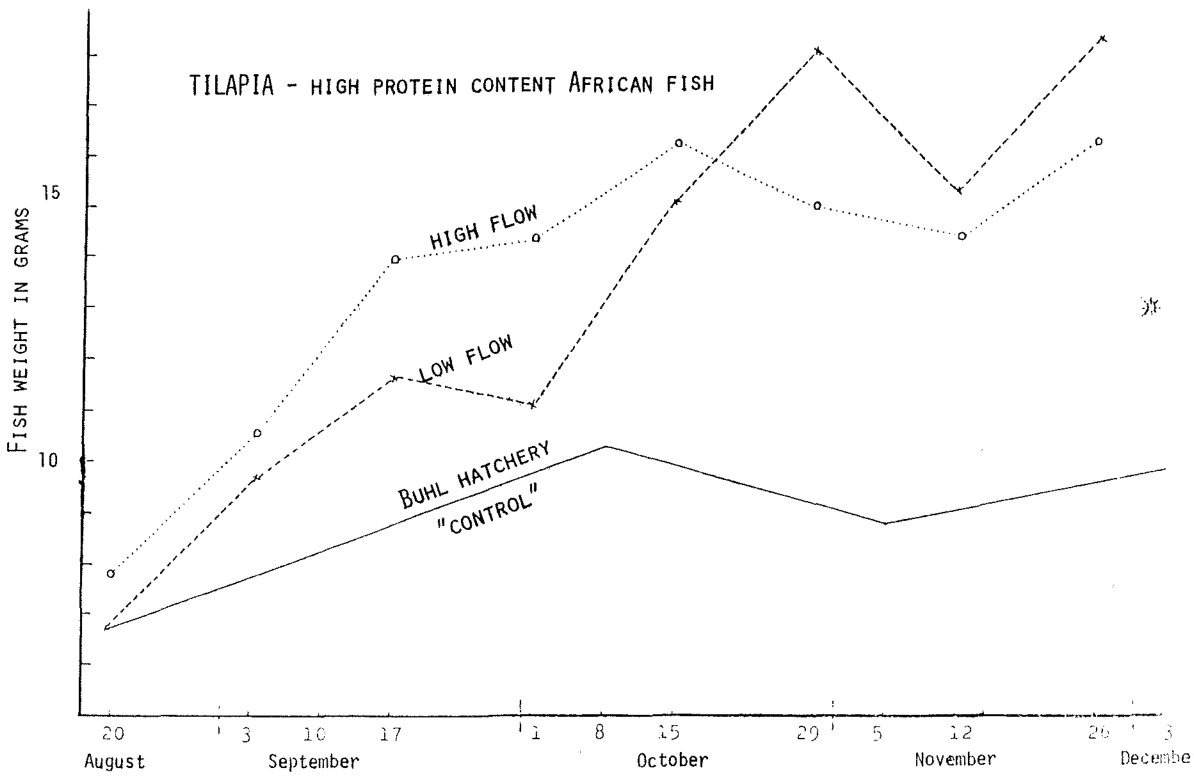
Oats - July 20, 1976

Wheat - July 31, 1976

5. Development - Fish raised were unusually disease resistant.

Comments - Faster growth, virtually zero disease mortality of catfish, perch, and tilapia.

Significance - Geothermal water appears to offer major advantages for fish culture--possible by-product use from power plants.

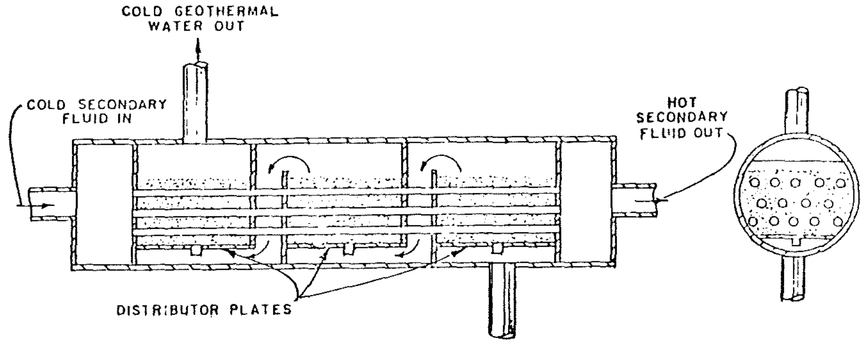


6. Development - Fluidized bed heat exchanger heat transfer coefficient measured to be high and constant, over long periods of exposure to geothermal fluids.

Comments - No fouling on Ti and stainless steel tubes. But experiments to decrease number of stages and size of pressure vessels is continuing. The very high effective heat transfer coefficient through the bed makes it necessary to use several stages for most applications.

Significance - Geothermal application gives 30% less tubing length than standard heat exchanger, probably making overall costs similar. No fouling under most adverse conditions makes the fluidized bed a candidate for all but the most benign geothermal fluids (for which the ordinary heat exchangers will work).

6. (Cont'd)

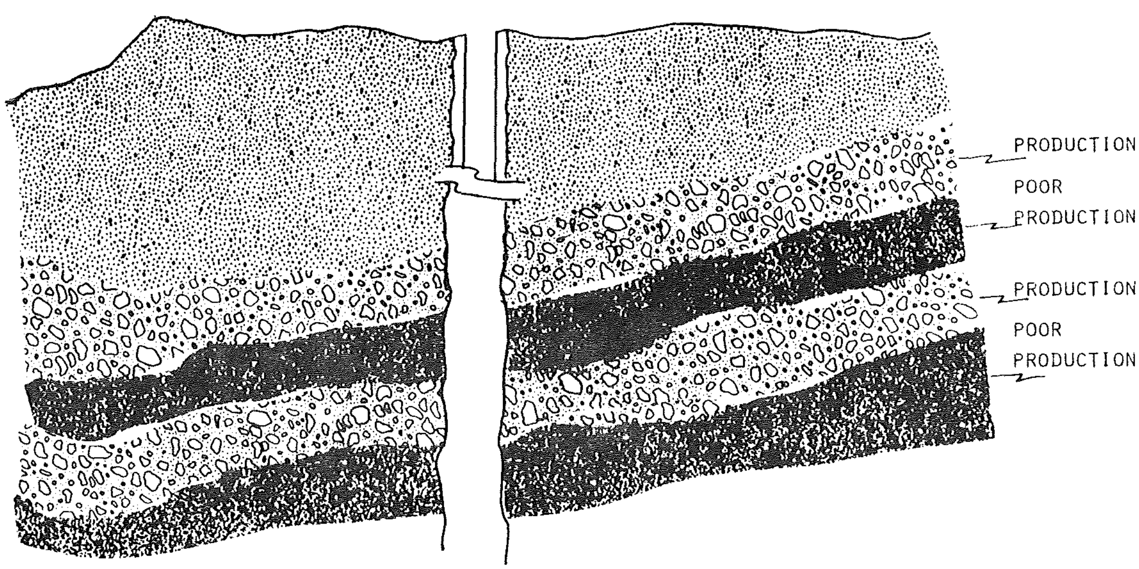


Liquid Fluidized Bed

7. <u>Development</u> - Reinjection experiments in RRGE-2 well gave unexpected <u>information</u> on producing strata, porosity, and thermal cycling.

   <u>Comments</u> - Production zones and stratigraphy of the reservoir were macroscopically "interrogated" by this experiment.

   <u>Significance</u> - Provided a tool for obtaining information on the <u>producing zone</u>. Information previously only very crudely inferred from a variety of standard well logging techniques.

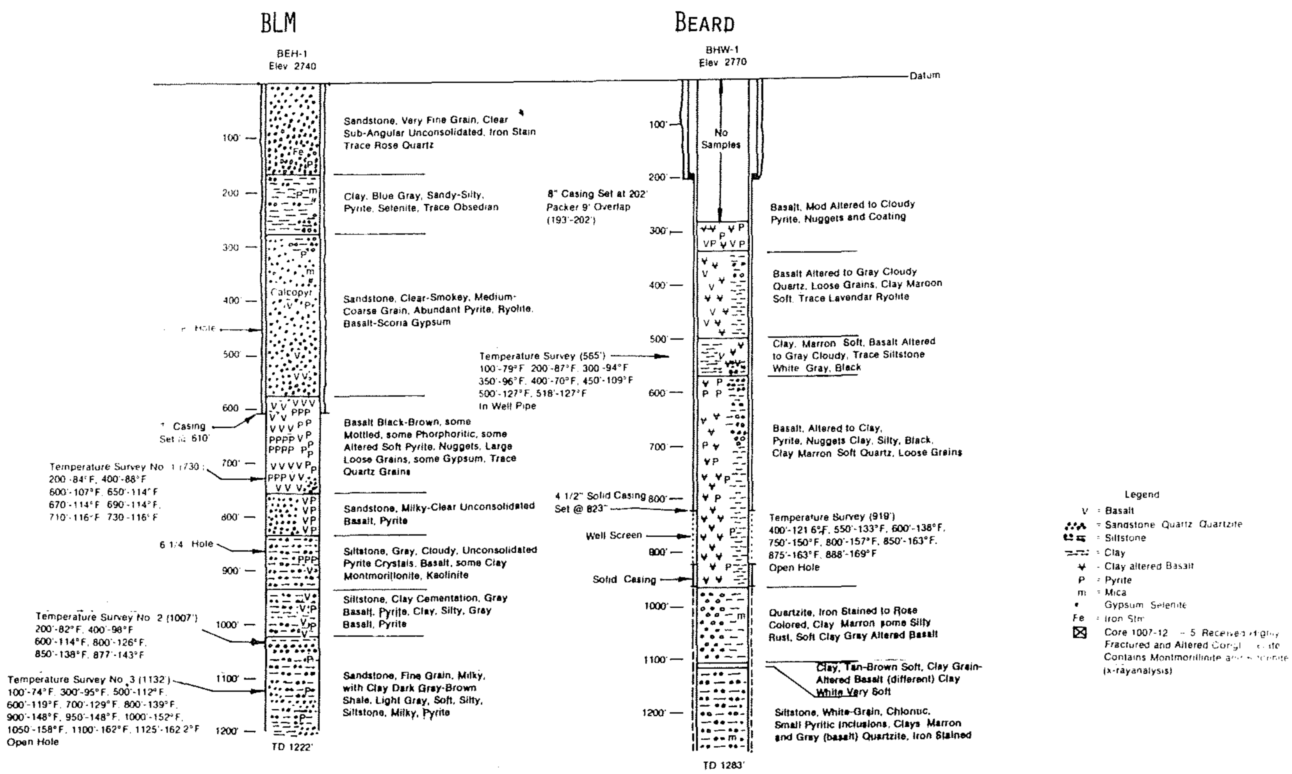


8. Boise Wells

Development - Two out of two were successful. Tapped a reservoir at "shallow" (1000 ft) depth.

Comments - Also drilled with water (instead of mud), making it easier to detect and locate the resource production region.

Significance - Two major successes, drilled only with surface geology information as a guide, at very low cost ($30,000 each).



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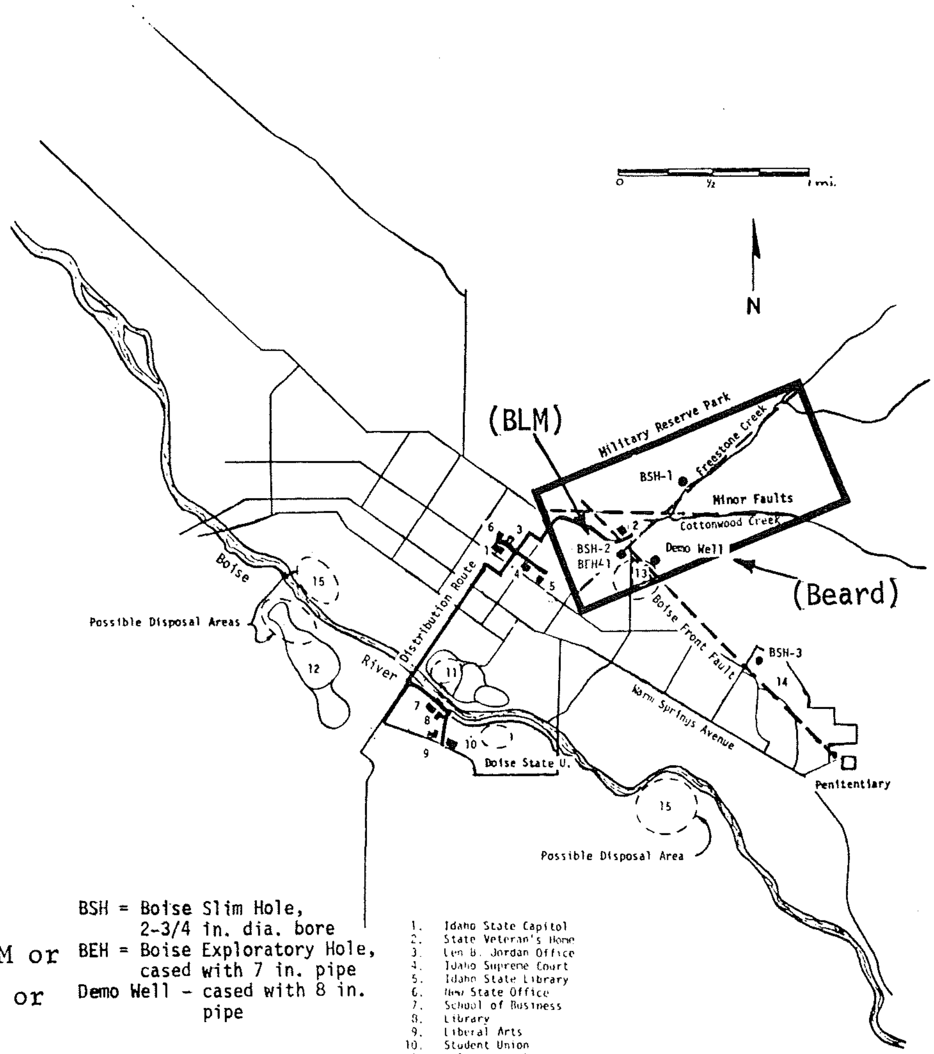


BSH = Boise Slim Hole, 2-3/4 in. dia. bore

BLM or BEH = Boise Exploratory Hole, cased with 7 in. pipe

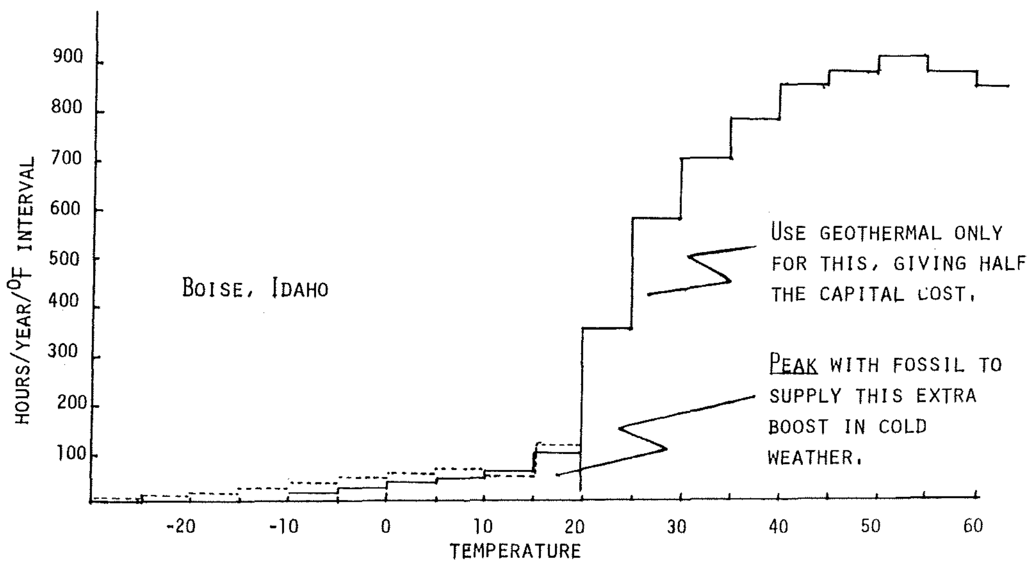
Beard or Demo Well - cased with 8 in. pipe

1. Idaho State Capitol
2. State Veteran's Home
3. Len B. Jordan Office
4. Idaho Supreme Court
5. Idaho State Library
6. New State Office
7. School of Business
8. Library
9. Liberal Arts
10. Student Union
11. Julia Davis Park
12. Ann Morrison Park
13. Revetment Area
14. Morningside Heights Subdivision
15. Old Gravel Pit

9. Development - Economic advantage of fossil peaking for space heating geothermal systems stressed in analysis of Boise and Sugar City designs.

Comments - Designing for twice the load hence to only half the normal design temperature with fossil peaking for the colder days. Leaves fossil supplying only 6% of the energy requirements, cuts geothermal unit capital costs in half.

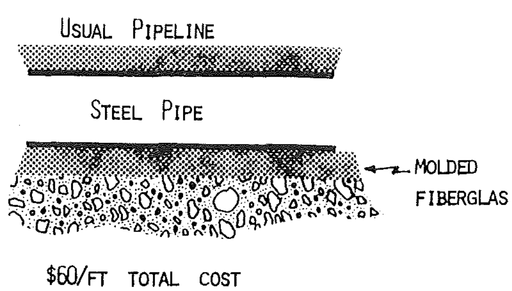
Significance - Overall economics of geothermal heating improved by about 35%.

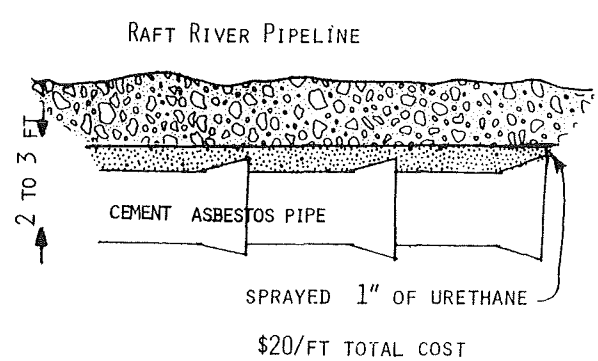


10. Development - Capability and economic savings in use of urethane for 300°F geothermal piping demonstrated.

Comments - Demonstrated at Raft River on 290°F pipes. Considered not practical previously, but adheres well and is fire resistant. Insulation effectiveness is R = 7 per inch of thickness.

Significance - 80% cost savings compared to molded fiberglas. $1000 for 600 ft of pipes and valves insulated with urethane. $8000 for jacketed fiberglas, that is weather resistant.





2.0 EXPERIMENTS AND TESTING AT RAFT RIVER

J. F. Kunze and L. G. Miller

2.1 Wells

Table I summarizes the uses of the three deep geothermal wells over the six month period.

TABLE I

WELL USE - OCTOBER 1976 TO MARCH 1977

Well	Total Flow	Flow Rate Range	Well Head Temperature	Uses
RRGE-1		50 to 200 gpm (continuous use)	275°F	Supplying corrosion-deposition experiments, cooling tower treatment experiment, fluidized bed and direct contact heat exchanger tests, and building space heating for laboratories and offices.
RRGE-2		20 to 500 gpm	272°F	To supply fish tolerance experiment. Conducted step well performance test to evaluate performance parameters. Well is identical to performance in summer of 1975. Freeze prevention at 20 gpm
RRGE-3		20 to 550 gpm	292°F	Well performance testing and freeze prevention (20 gpm)

The basic characteristics of these are summarized in Table II, while Table III summarizes the flow history to date.

TABLE II

THE CHARACTERISTICS OF THE WELLS

RAFT RIVER

RRGE #1 - Completed in March 1975, 5000 ft deep

Solids in water:	1700 mg/liter
Artesian Pressure:	50 psig cold 175 psig hot
Reservoir Temperature:	297°F (147°C)
Flow Experience:	400 gallons per minute for many days with artesian pressure only. 870 gallons per minute for 4 days with a pump, drawing down 375 ft below ground level
Predicted after 10 years of operation:	1100 gallons per minute with 900 ft drawdown below ground level

RRGE #2 - Completed in June 1975, 6500 ft deep

Solids in water:	1800 mg/liter
Artesian Pressure:	60 psig cold 165 psig hot
Reservoir Temperature:	298°F (148°C)
Flow Experience:	400 gallons per minute for several days with artesian pressure only
Predicted after 10 years of operation:	800 gallons per minute with 900 ft drawdown below ground level

RRGE #3 - Completed in June 1976, 5917 ft deep

Solids in Water:	4600 mg/liter
Artesian Pressure:	40 psig cold 140 psig hot
Reservoir Temperature:	301°F (149°C)
Flow Experience:	350 gallons per minute for a day under artesian pressure (291°F at surface)
Predicted after 10 years of operation:	500 gallons per minute with 1000 ft of drawdown below ground level

BOISE

Test Well #1 (Beard) - Completed August 1976, 1283 ft deep

Artesian Pressure:	11 psig hot
Reservoir Temperature:	172°F
Artesian Flow Experience:	195 gallons per minute for 1/2 day

Test Well #2 (BLM) - Completed September 1976, 1222 ft deep

Artesian Pressure:	9 psig hot
Reservoir Temperature:	>164°F
Artesian Flow Experience:	Minimal to date, briefly at 50 gallons per minute

Both Boise wells have dissolved solids of less than 300 mg/liter

TABLE III

RAFT RIVER FLOW OF GEOTHERMAL FLUIDS (GALLONS)

MONTH	RRGE-1	RRGE-2 PRODUCTION	RRGE-2 REINJECTION	RRGE-3
1975				
February	8,000,000	--	--	--
March	1,000,000	--	--	--
April	400,000	--	--	--
May	0	100,000	--	--
June	0	500,000	--	--
July	0	3,400,000	--	--
August	0	1,900,000	--	--
September	0	9,000,000	--	--
October	0	10,000,000	--	--
November	0	3,000,000	--	--
December	1,800,000	1,000,000	2,000,000	--
1976				
January	2,000,000	1,300,000	1,600,000	--
February	5,400,000	1,000,000	4,200,000	--
March	500,000	1,000,000	2,700,000	--
April	0	0	0	--
May	0	0	0	--
June	0	0	0	1,690,000
July	1,300,000	1,000,000	20,000	0
August	12,300,000	5,500,000	0	0
September	8,600,000	7,200,000	0	0
October	7,000,000	1,000,000	0	0
November	6,000,000	1,000,000	16,000	80,000
December	5,000,000	750,000	0	1,240,000
1977				
January	2,600,000	600,000	0	1,240,000
February	3,280,000	1,910,000	0	806,000
March	3,620,000	2,430,000	0	893,000

2.1.1 RRGP-1*

This well was used in continuous service supplying a variety of experiments. These were:

TABLE IV

USE OF RRGE-1 FLOW

Experiment of Test	Flow Rate
Heat exchanger tubing, fouling and corrosion, continuous monitoring of heat transfer coefficient Monel, carbon steel, and stainless steel	17 gallons/minute
Materials deposition, corrosion test loop, coupon samples	48 gallons/minute
Fluidized bed heat exchanger	58 gallons/minute
Cooling tower water treatment	8 gallons/minute
Direct contact heat exchanger	3 gallons/minute
To heat exchangers for geothermal heat to test buildings, labs, and offices	10 gallons/minute

Most of this water was delivered through the pipeline to site No. 2, where it was partially naturally evaporated and in part further distributed to an adjacent alfalfa field.

The behavior of this well has been constant during the last nine months of steady flow. No chemical contact differences or changes in flow vs pressure characteristic have been observed. The latter is shown in Figure 1.

The RRGE-1 site has become the principal test complex for the Raft River Project. The facilities and experiments are shown in the sketch of Figure 2.

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* The fourth letter in the well designation changed as the use of the well changes:

E = exploratory
P = production
I = injection

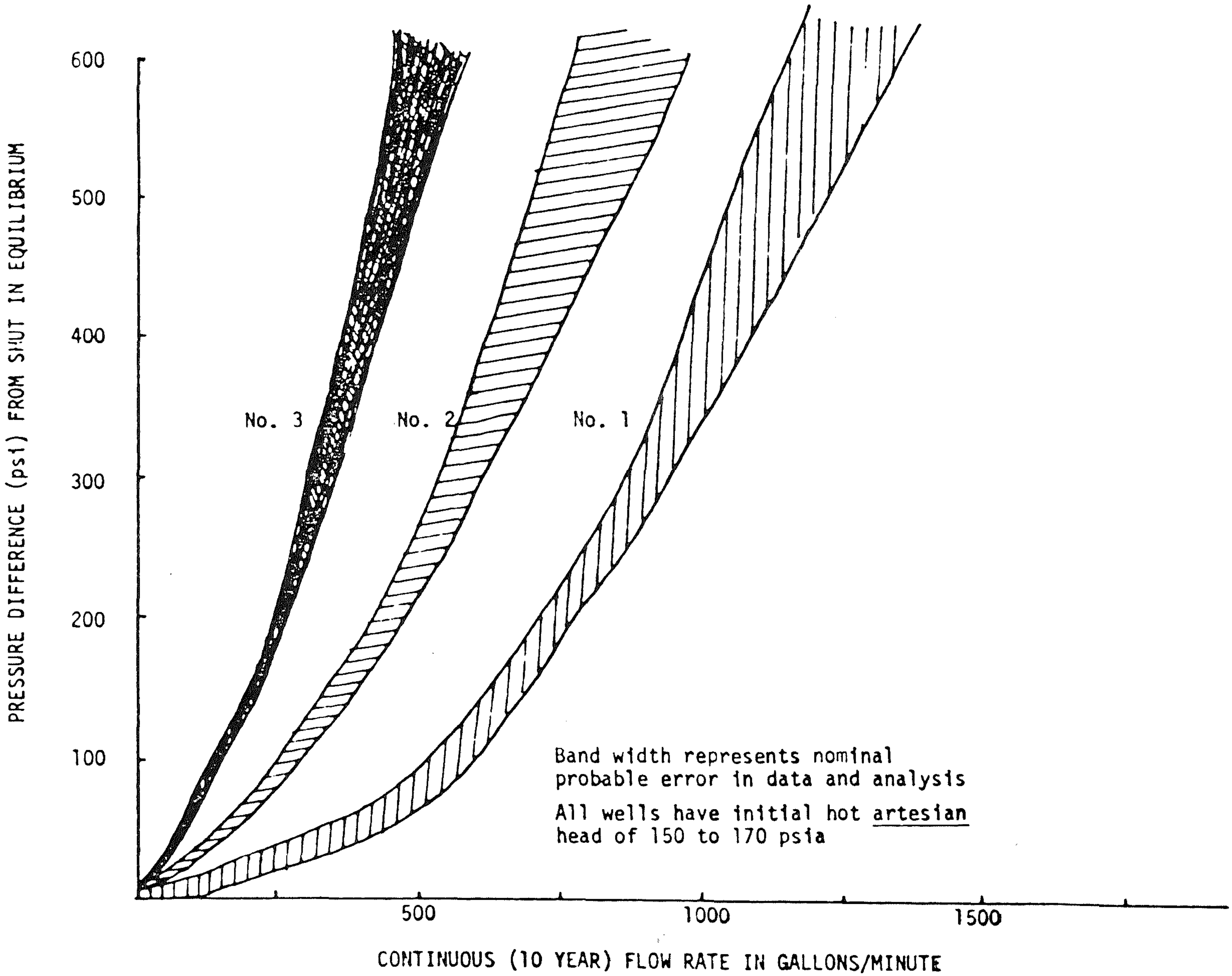

Fig. 1 Raft River Wells Productivity Curves as Extrapolated to 10 years of Continuous Flow

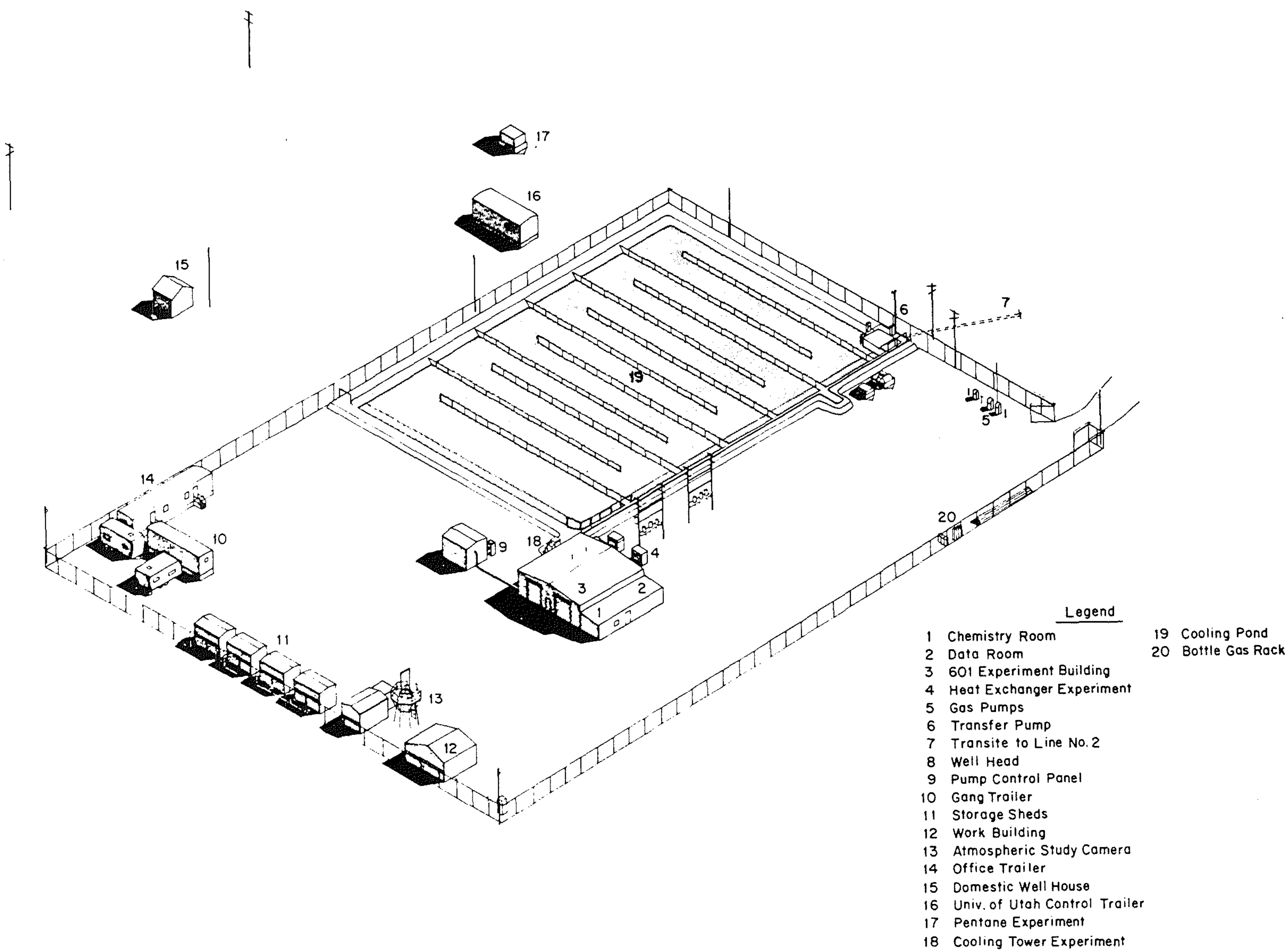

Fig. 2 RRGR Site No. 1

2.1.2 RRGP-2

This well continued to supply the small amount of heat needed for the completion of the first fish tolerance experiment, terminated in early December. The well was then left on small winter flow status, about 20 gpm, to prevent freezing, until February, when a series of step flow production tests were begun. At that time, the nearby farmer could beneficially use the water from these tests, making extensive flow tests possible.

The well site was the second most important test area in the Raft River complex, principally the agriculture, aquaculture, and cooling pond effectiveness test areas. Figure 3 is a sketch of the RRGE-2 Test Facility.

This well had been used for extensive disposal of water during the previous winter. Following that disposal operation, the well demonstrated poor performance. Some concern existed over the chemical blockage potential from reinjection, though preliminary assessment indicated the only effect was from the cooling of the nearby surrounding formation. After reproducing 2.5 times as much water from the well as was previously injected, the formation has still not completely returned to normal. The results of the last of the flow tests in this reporting period compared to a test 1-1/2 years earlier just after the well was drilled is shown in Figure 4. The curves differ for the first 70 minutes because of water column pressure differences as the well heats up. (The one test was measured with the down-hole gauge, the other with a surface gauge.) However, observe the test once it enters the time regime where the logarithmic approximation can be applied to the exponential integral solution of the two-dimensional time-dependent diffusion equation (Thesis Equation). Both pressure drawdown curves are virtually identical. If anything, the well shows a slight improvement with time, but data uncertainty may be the actual reason for this difference.

2.1.3 RRGP-3

The third well has seen little direct use for experiments, since a pipeline connection between it and the test programs at RRGP-1 must first be completed. At the close of this reporting period, this 9000 ft pipeline was completely planned and the asbestos-cement on site ready for installation. One small right-of-way agreement had yet to have negotiations completed before beginning installation. This pipeline will cross the Raft River above the water level, at the location of a new culvert-bridge. (Note: the Raft River at this point is normally only about 15 ft wide, but its spring runoff width can be as much as 100 yards.

RRGP-3 has a dissolved solids content of 4100 ppm, over twice as much as the other wells. Disposal of this fluid to agricultural purposes must await results of small scale tests. It is anticipated that these tests will show that it is difficult to find an acceptable agricultural or other beneficial surface use of the water without undue side effects.

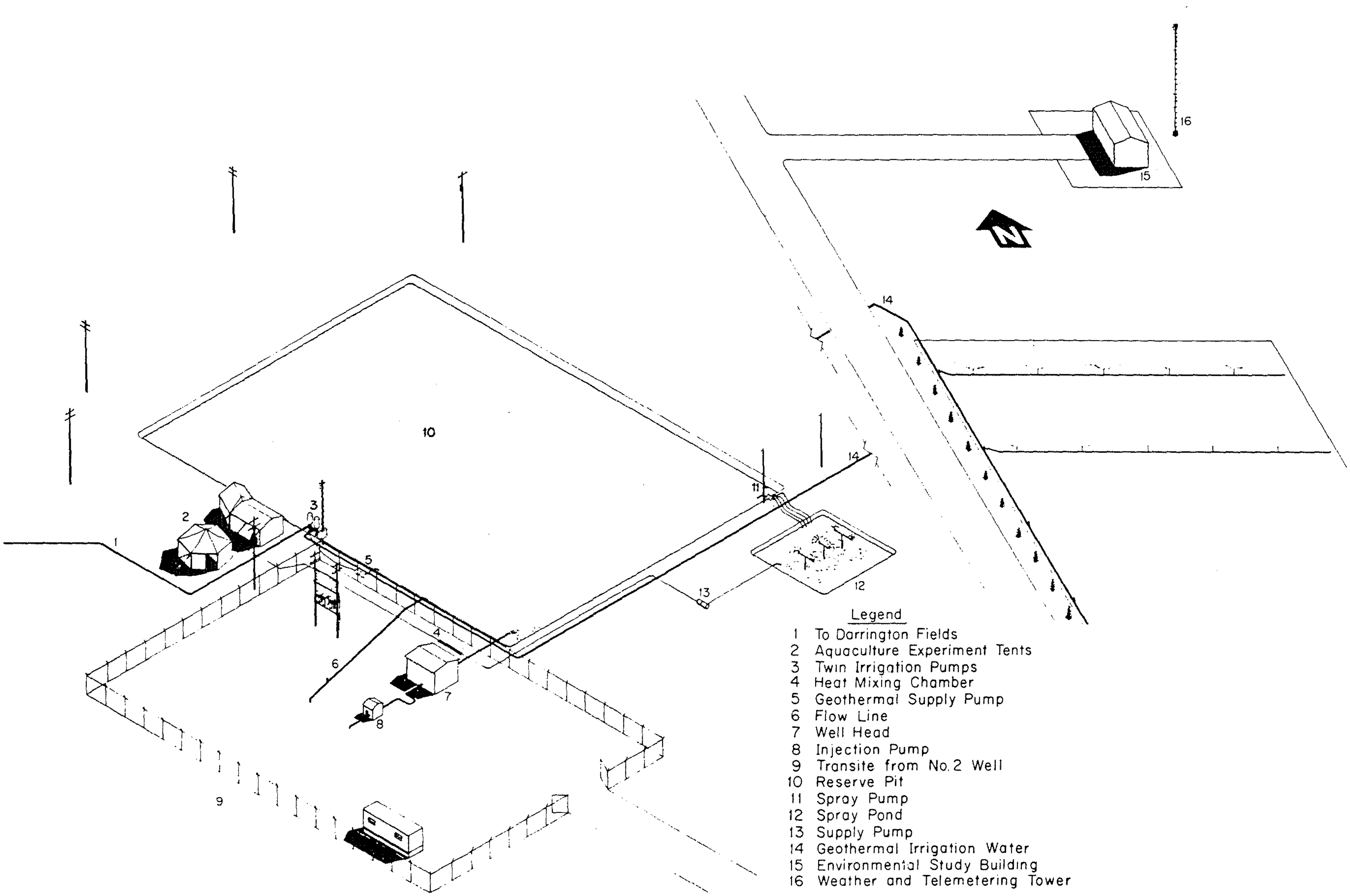

Fig. 3 RRGP Site No. 2

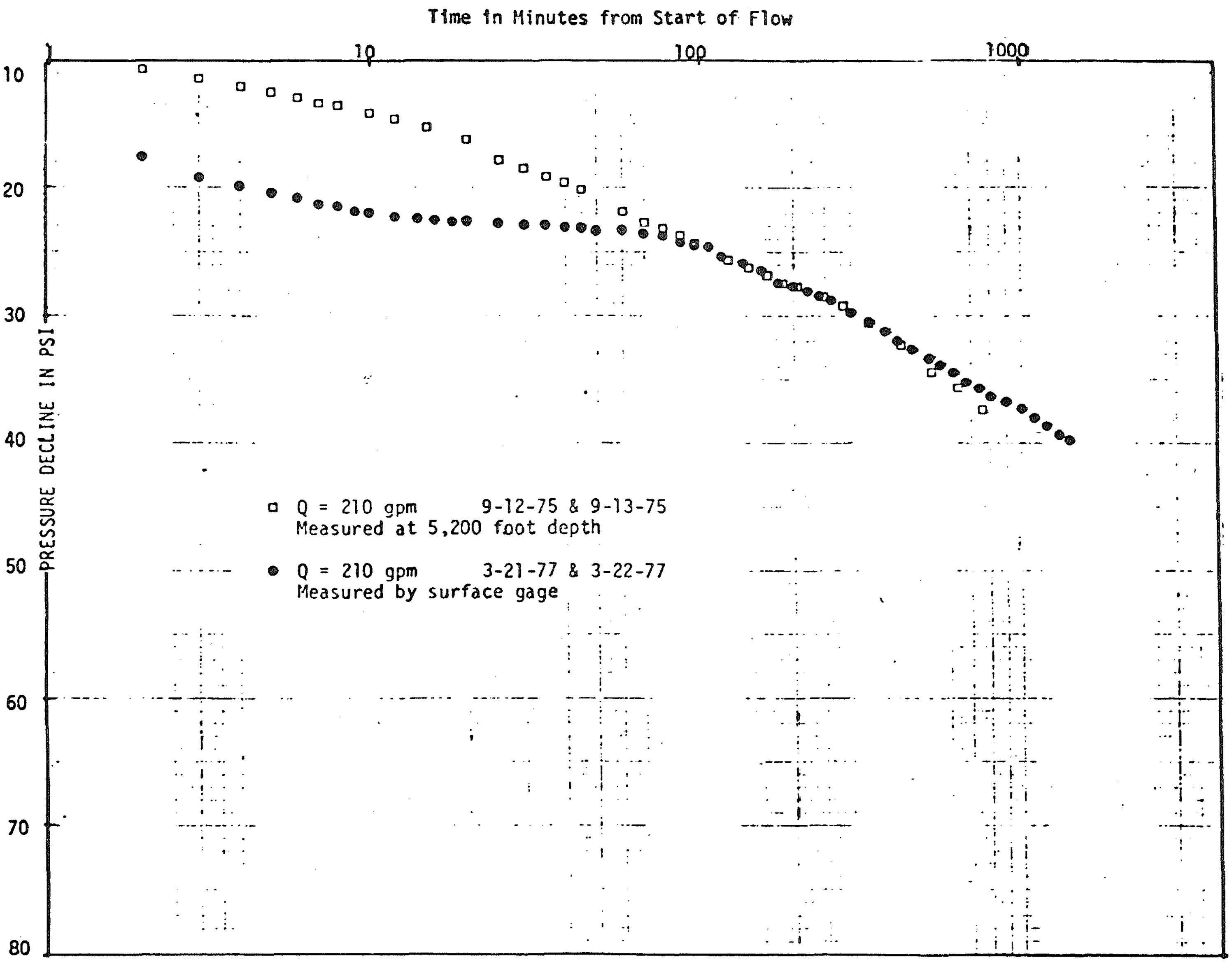

Fig. 4 Flow Tests - RRGP-2

Nevertheless, the large reserve pit capacity did allow the well to be tested in January for its drawdown characteristic. These are discussed in the reservoir engineering section.

The relative locations of the three wells is shown on the map of Figure 5.

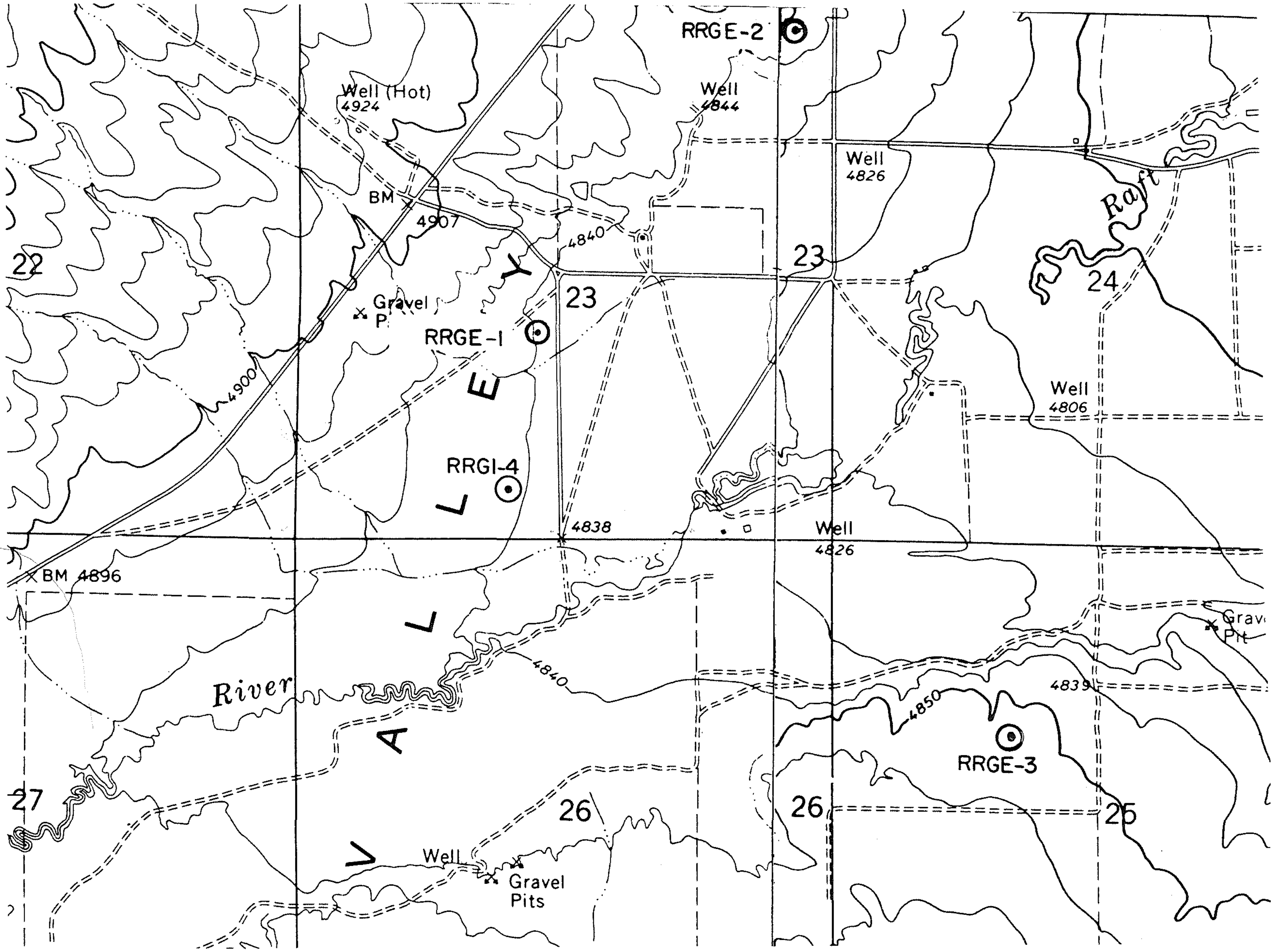

Fig. 5 Raft River Well Location Map

2.2 Site Facilities and Pipelines

The first buried asbestos-cement ("Transite") pipeline used in high temperature (approximately 300°F) service for transport of geothermal fluids was installed in the fall of 1975, and has seen 1-1/2 years of service. The line is 4000 ft long, between the deep geothermal wells No. 1 and No. 2, in the Raft River Valley of Idaho. The experience in using this pipeline has been satisfactory, and methods have been developed for minimizing the thermal expansion/thermal shock breakage problems. The substantially reduced cost (factor of 2) of an asbestos-cement pipeline compared to the conventional steel pipeline, plus the esthetically desirable effect of a buried pipeline dictate adoption of this type as standard practice for moderate temperature geothermal developments. The Raft River Geothermal Project intends to connect all future wells with pipelines of asbestos-cement, insulated with 1 to 2 inches of urethane, and buried between 2 and 3 ft.

The cost effective characteristic is significant. Present costs of a Transite line are about $110,000/mile, while a steel line will cost nominally twice as much. This includes the cost of urethane foam insulation, between 1 and 2 inches thick, and results in a pipeline with loses, less than the equivalent of 20 kW (per mile) of electric power production from the power plant.

For geothermal fluids of higher salinity, the smooth wall asbestos-cement and their resistances to pitting corrosion should make this pipeline even more desirable compared to steel.

The pipeline design from Site 3 to Site 1 is nearing completion. This line will be approximately 8000 ft long. A 1-inch layer of urethane insulation will be used on 10-inch Transite pipe.

The above ground piping at Sites 1 and 2 were sprayed with 1 to 2 inches of urethane foam at a cost reduction, compared to molded fiberglas, of over a factor of eight. Pipe, from temperatures of 20° to 280°F, were insulated with excellent steel-urethane bonding.

Specifications are being prepared for the reinjection well pipeline using 12 inch asbestos-cement between well No. 1 and No. 4.

The pipeline will be completed by October 1, 1977.

2.2.1 Site Facilities

Site No. 3 construction work was completed which included a gravel base and fenced area around the well house to act as a working area for normal well testing and pumping operation, well security, and material storage area, and the new road, which will also provide the right-of-way for the pipeline, and will shorten the distance by four miles.

2.2.2 Site Geothermal Heating System

All of the buildings at Site No. 1, the principal laboratory and office area, have been converted to geothermal space heating. The main laboratory has a separate circuit of two fan-forced air heaters using the geothermal water directly, 4 gpm flow rate, with thermostatic control valves. The other buildings are all heated (with fan-forced heaters) from a clean, demineralized water circuit. This secondary circuit is heated by a tube-in-shell heat exchanger, with 6 gpm geothermal flow. The annual savings of petroleum (butane or fuel oil) will be approximately 400 barrels, or $6000 at delivered oil prices at this time.

2.3 Reservoir Engineering

R. C. Stoker, D. Goldman, J. F. Kunze

2.3.1 Production Testing of No. 2 and No. 3 Wells

Step testing at constant flow, with recovery periods between each step, were conducted on RRGP-2 and RRGP-3, (January through March period). The results are shown in Figures 6 and 7. These results gave relative consistent values of kH (permeability times producing strata thickness), with a slight trend toward quadratic dependence at the higher flow. In each case, the data were obtained with a quartz pressure transducer installed at the surface. Therefore, the early parts of the curves show water column density differences, which become neglible after about 60 minutes of flow.

Table V summarizes the Raft River well tests results in terms of reservoir parameters. The latest results do not imply, necessarily, a change in well conditions, but merely a difference in analysis. These latter results cover a longer test period than those obtained in 1975, and therefore are more likely to be representative of long term conditions including nearby boundary effects.

Note: in Section 2.3.1 above, direct comparison of measured drawdown curves (Figure 4) showed no change (except for possible slight improvement) of No. 2 well over 1-1/2 years of use, both as a production and a reinjection well.

Table VI(a) and VI(b) summarize the measurements made of porosity and permeability on the cores obtained from these wells.

The performance of the wells was discussed in the previous section 2.1, and the well pressure (drawdown) vs flow characteristics given in Figure 1. There is still some uncertainty in how quadratic the well production function might be, indicating a band of turbulence near the well bore. Therefore, pump testing at high flow rates is being planned, once disposal facilities are available. The band of uncertainty in Figure 1 is expected to include the results of the forthcoming pump tests, at 1000 gpm and above.

2.3.2 Geochemistry (R. E. McAtee, C. A. Allen)

The wells have been routinely sampled since being drilled and first flow tested, and elemental and ion chemistry measurement conducted. From these results, geothermometry calculations were conducted. Figure 8 shows these results as a function of time since the wells developed. The trend toward higher indicated reservoir temperatures with time, for No. 1 and No. 3, may have some significance. However, of greater significance is the considerably different chemistry between No. 2 and No. 3 wells, as

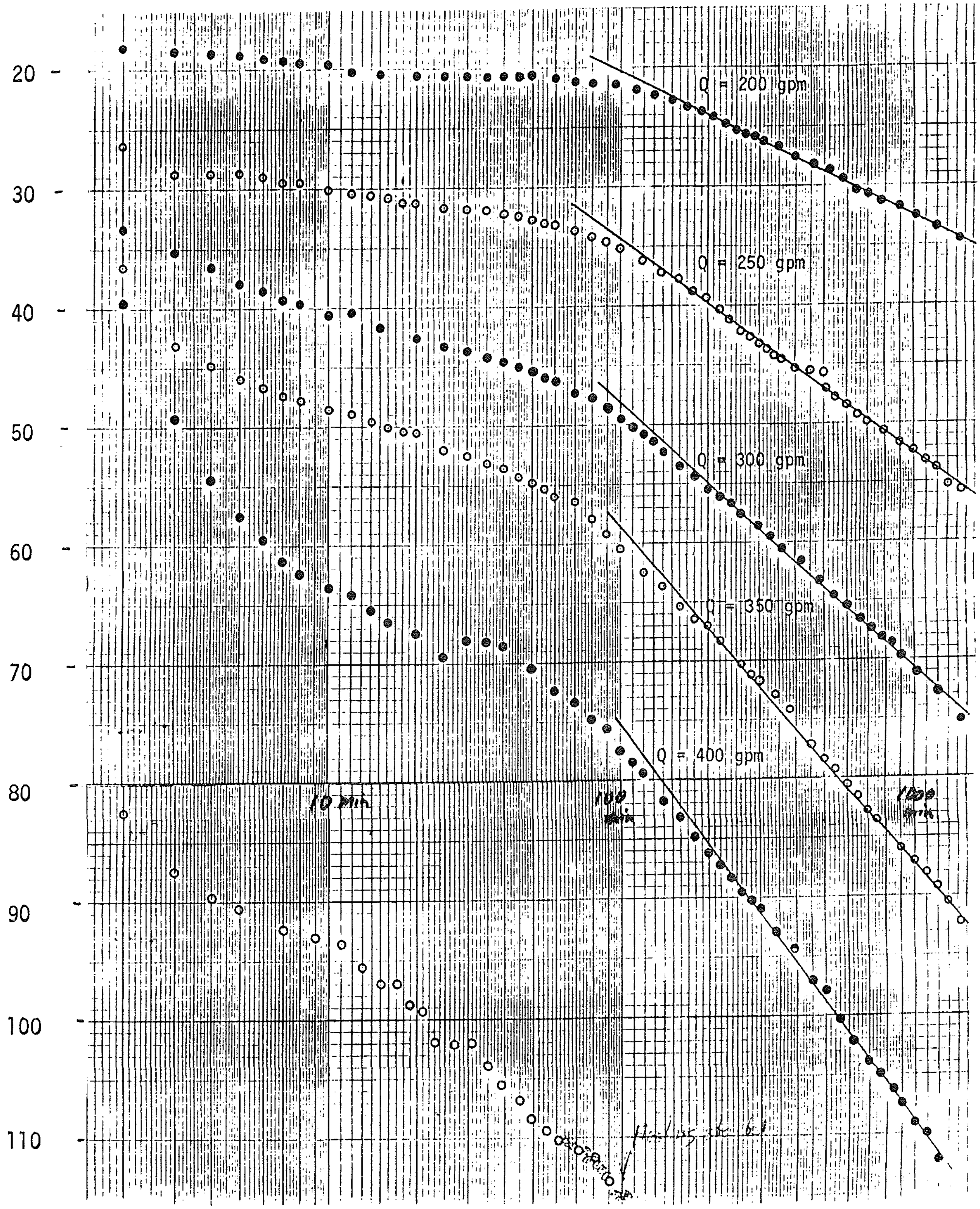

Fig. 6 RRGP-2 Production Test

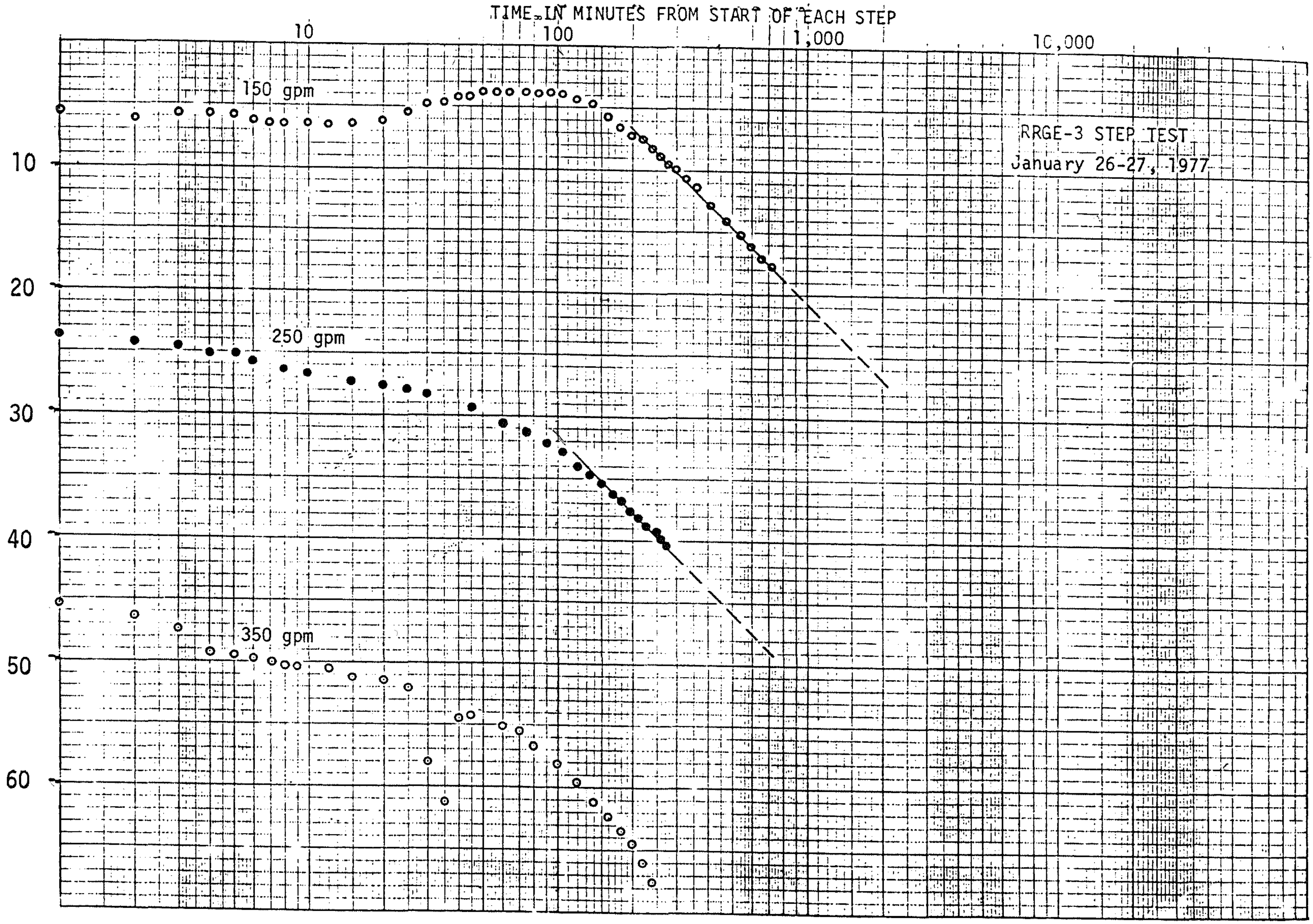

Fig. 7 RRGE-3 Step Test

TABLE V

SUMMARY OF RAFT RIVER WELL TEST RESULTS

Discharging Well & Date	Discharge Rate (gpm)	Duration (hrs)	Data Collected From	Mean kh (md-ft)	Mean T (gpd/ft)	Mean ϕch (ft/psi)	Mean S	Comments
RRGE-2 Sept. 12 - Sept. 13, 1975	210	15	RRGE-2	44,288	4,684	.0276	.0112	
RRGE-2 Sept. 14 - Sept. 17, 1975	800 440	21⅓ 73⅔	RRGE-1	223,000	23,500	.00056	.00022	
RRGE-2 Sept. 20 - Oct. 16, 1975	400	615⅓	RRGE-1	228,000	23,900	.0011	.00043	
RRGE-1 Nov. 5 - Nov. 6, 1975	26	30	RRGE-1	115,000	12,300	.0022	.00081	
RRGE-3 June 8 - June 16, 1976	140	193⅔	RRGE-3 *	6,000	633	.001	.0004	r_w ~30 ft
			RRGE-1	220,000	23,300	.00165	.00065	
			No measurable effect in Well RRGE-2					
RRGE-3 Jan. 26 - Jan. 27, 1977 Step Test	150 250 350	12 4⅓ 4	RRGE-3	8,500	898	.038	.015	r_w ~30 ft
RRGE-2 Feb. 17 - March 25, 1977 Step Test	200 250 300 350 400 500	24 24 24 24 24 2[illegible]	RRGE-2	12,600	1,330	.76	.3	

TABLE VI (a)

RRGE WELL CORE PERMEABILITIES

Well	Depth, KB	Permeability (Millidarcies)	Rock Type
RRGE-1	4,227 ft	.003 - .04 (cap)	Siltstone
RRGE-1	4,506 ft	5.0	Tuffaceous Siltstone
RRGE-2	4,372 ft	0.0022 (cap)	Shale
RRGE-3A	2,807 ft	.25	Sandstone
RRGE-3A	3,365 ft lower	.04	Tuffaceous Siltstone
	3,365 ft upper	>35. (∿100)	Tuffaceous Siltstone
RRGE-3 (A, B, & C)	4,985 ft	.035	Tuffaceous Siltstone
RRGE-3 (A, B, &C)	4,994 ft	.001	Tuffaceous Sandstone
RRGE-3 (A, B, &C)	5,273 ft	.117	Siltstone

NOTE: The best oil producing wells have permeabilities in the order of 1-50 millidarcies.

TABLE VI (b)

SAMPLE	WET BULK DENSITY (gm/cc)	DRY BULK DENSITY (gm/cc)	GRAIN DENSITY (gm/cc)	TOTAL POROSITY (%)	EFF. WATER POROSITY (%)
RRGE-1 4500.5'	--	1.88	2.62	28.8	28.8
4518.0'	--	2.20	2.67	17.6	14.3
4687.0'	--	2.73	2.79	2.2	0.8
RRGE-2 3728.4'	--	2.16	2.66	18.8	13.2
4223.8'	--	2.07	2.66	22.2	15.0
4227.0'	2.29	2.20	2.72	19.3	17.4
4373.0'	--	2.28	2.67	14.5	13.6
6560.0'	--	2.57	2.64	2.7	0.8
RRGE-3A (L) 3365.0'	--	1.74	2.60	33.1	11.3
(U) 3365.0'	--	1.53	2.48	38.3	34.7
RRGE-3C 4994.0'	--	2.31	2.70	14.4	9.1
5273.0'	--	1.97	2.66	25.9	23.0
5550.5'	--	2.64	2.70	2.2	1.2

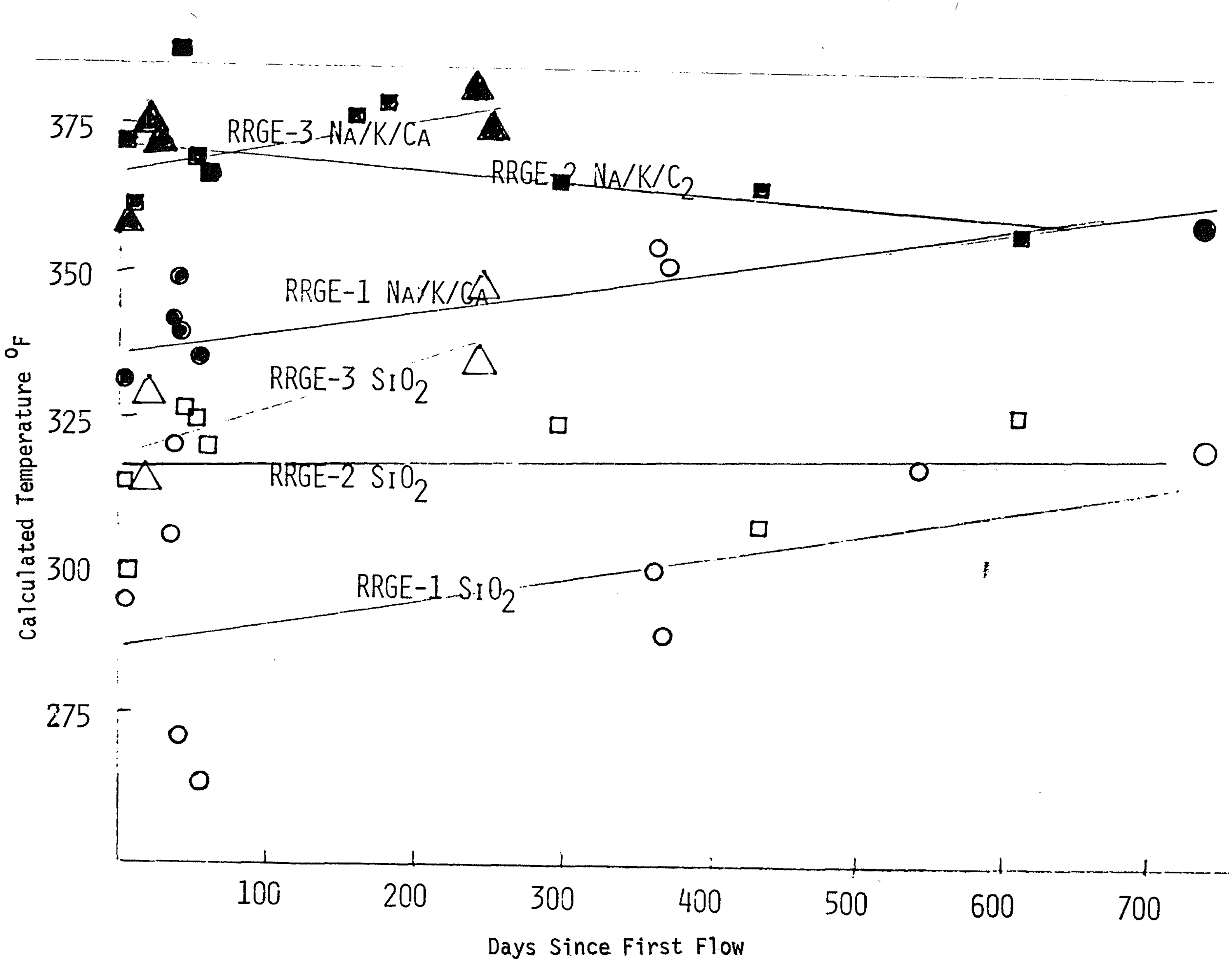

Fig. 8 Raft River Geothermometry

shown briefly in Table VII. At the bottom of the table are best fit values for mixing ratios if one assumes that there are two distinct sources, Resource A characterized by RRGE-2, and B by RRGE-3. The X_m is the fraction of resource A in the particular well water.

The implications, if there are two resources involved, are as follows:

1. If RRGE-1 and the BLM wells are mixtures of resources A and B, then resource A must flow from the north. The fault associated with RRGE-2 runs NE-SW. Since RRGE-1 is SW of RRGE-2, the only way to explain less mixing in RRGE-2 than RRGE-1 is for the water to be moving south along the fault. T This would remove the Narrows as a possible heat source for resource A.

2. The presence of resource B implies a fault which is not obvious at the surface. As seen in Figure 5, the four wells BLM, RRGE-1, Crank, and RRGE-3 are nearly in a straight line. The relationship between RRGE-3 and the Crank well is similar to the relationship between RRGE-1 and the BLM well. This implies a fractured zone connecting the two. Fractured zones are normally associated with faults. The fault associated with resource B could be identified and followed with a surface helium survey.

3. A significant question arises concerning these two resources. Do resources A and B represent two conduits from the same heat source, or are two heat sources involved? If a single heat source is involved, then it must be located to the north. This is because flow between RRGE-2 and RRGE-1 is generally from north to south. If two heat sources are involved, then the heat source for resource B could be to the NE, E, S, or SW. It could not be to the west or north.

It should be cautioned that the above results are deduced primarily from geochemistry. However, at this stage of understanding, geochemistry may be the best definite clue of reservoir source and motion.

2.3.3 Reservoir Modelling

An extensive series of computer runs were made using the reservoir model shown in Figure 9. The area outside of the dotted lines represent lower permeability than inside the dotted lines. Figure 10 shows the results of drawdown within the reservoir with no reinjection after 20 years of 2400 gpm flow, more than necessary for the thermal loop first phase. Figure 11 shows the results with reinjection into an intermediate depth zone, with downward penetration in the area shown.

It is apparent that interferences with the present well spacing is negligible, when one considers that 800 gpm draws down the type RRGE well

TABLE VII
CHEMICAL CONCENTRATIONS AND STANDARD
DEVIATIONS IN μg/mL

Chemical Species	RRGE-1 $\overline{X}$	RRGE-1 S_x	RRGE-2 $\overline{X}$	RRGE-2 S_x	RRGE-3 $\overline{X}$	RRGE-3 S_x	RAFT RIVER $\overline{X}$	RAFT RIVER S_x	BLM WELL $\overline{X}$	BLM WELL S_x	CRANK WELL $\overline{X}$	CRANK WELL S_x
CL^-	776	184	708	70	2170	302	153	70	1139			
F^-	6.32	1.47	8.25	1.06	4.55	0.25	0.65	0.21	5.6		4.11	
Br^-	<1.5		<1.5		<1.5		<1.5		<0.15		<0.15	
I^-	0.036	0.003	0.028	0.019			0.066	0.016	<0.040		<0.040	
*HCO_3^-	63.9	20.8	41.3	11.2	44.4	11.1	172.5	45.0	83			
$SO_4^=$	60.2	6.7	54.1	5.1	53.3	14.6	55.2	28.0	54		54	
NO_3^-	<0.2		<0.2		<0.2		3.8	<0.2				
Total NH_3	1.56	1.19	0.60	0.41			1.0		0.59			
Total P	0.023	0.014	0.020	0.011			0.038	0.028	0.27			
$S^=$			0.256									
$Si(OH)_4$	182	33	201	40	242	21	40.4	21.0	132		142	
Si	56.6	16.7	61.2	14.5	74.0	8.0	18.7	1.5	46		49	
Na	445	99	416	44	1185	52	77	26	550		1074	
K	31.3	7.0	33.4	5.3	97.2	7.3	7.7	0.7	20		34	
Sr	1.56	0.35	1.03	0.32	6.7	0.7	0.52	0.16	1.35		0.36	
Li	1.48	0.40	1.21	0.57	3.1	0.2	0.04	0.01	1.4			
Ca	53.5	9.5	35.3	8.7	193	15	85.3	29.6	55		130	
Mg	2.35	2.09	0.58	0.80	0.60	0.16	23.9	9.8	0.2		0.5	
pH							7.94	0.15				
Total Dissolved Solids	1560		1267		4130	36			1640		3720	
X_m	.898		1		0				.870		.143	
Conductivity	3373		2742		9530	1546						
*Total Gas	33.4	21.9	35.4	22.1					12.9			
H_2	0.10	0.14	0.67	0.69					0.11			
He	0.03	0.01	0.01	0.01					N.D.			
N_2	30.6	20.8	18.8	7.1					12.4			
O_2	0.13	0.17	0.27	0.56					0.05			
Ar	0.49	0.21	0.35	0.12					0.16			
CO_2	1.91	2.48	1.01	0.63					0.15			

*HCO_3^- Concentrations are recorded in μg/mL as $CaCO_3$

*Conductivity is recorded in μmho/cm

$\overline{X}$, Average Value

*Gas Volumes are in Standard cc/liter

S_x Standard Deviation of a Single Value

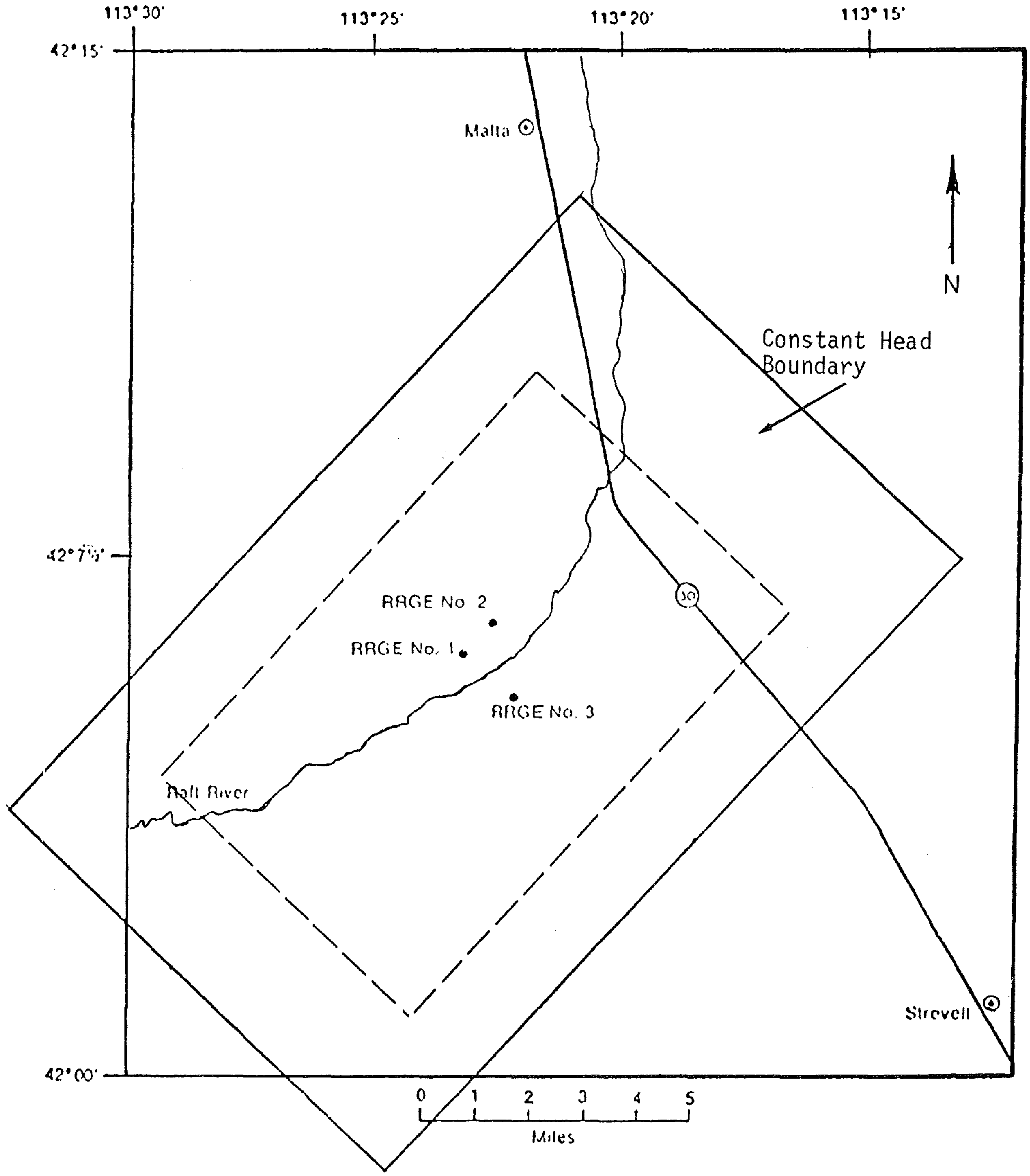

Fig. 9 Computer Modeled Geothermal Reservoir

Computer Projected Pressure Decline

In psi while flowing wells RRGE-1, 2 & 3 at 800 gpm each for 20 years. NW & SE no-flow boundaries and variable permeabilities.

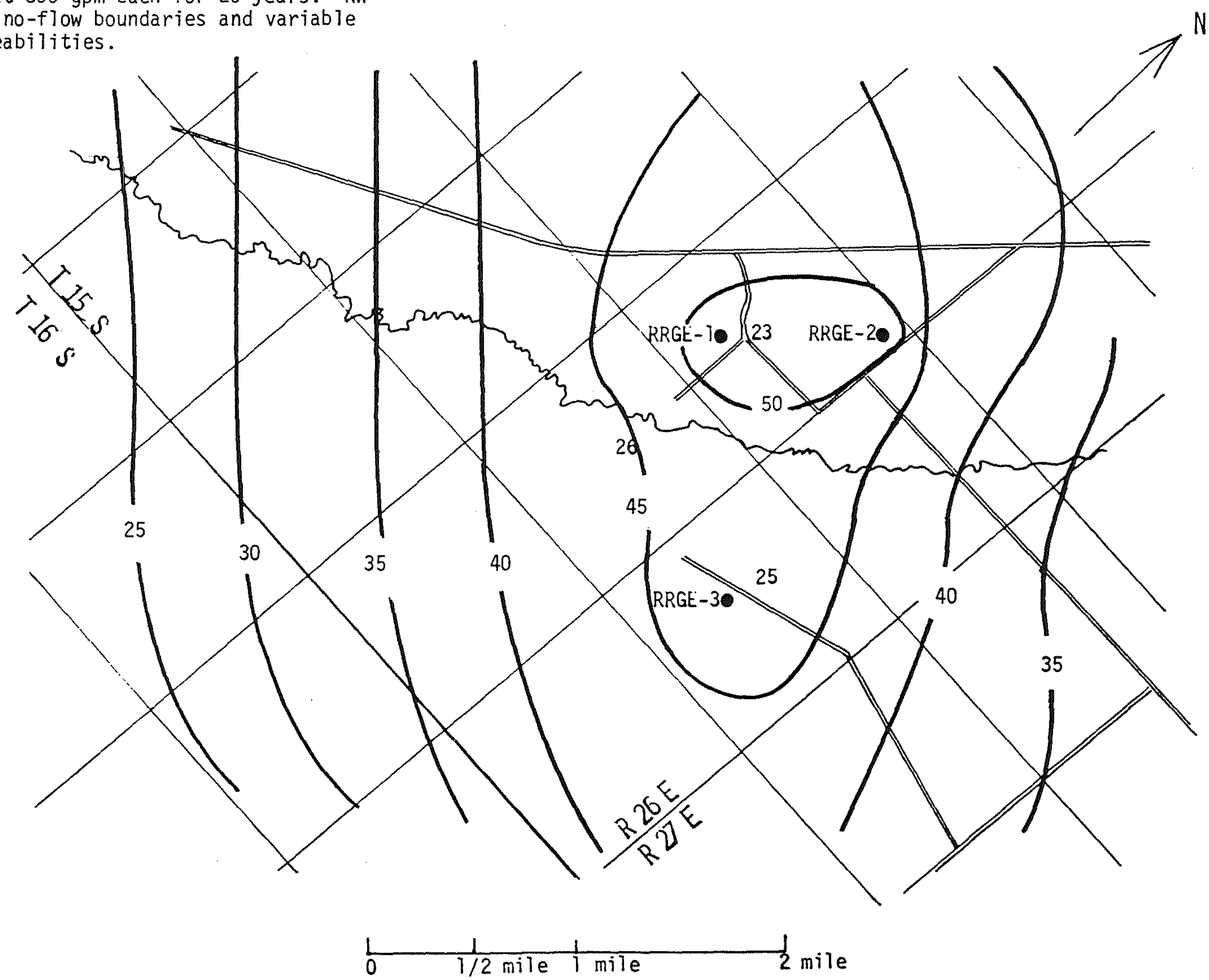

Fig. 10 Computer Projected Pressure Decline - Without Injection

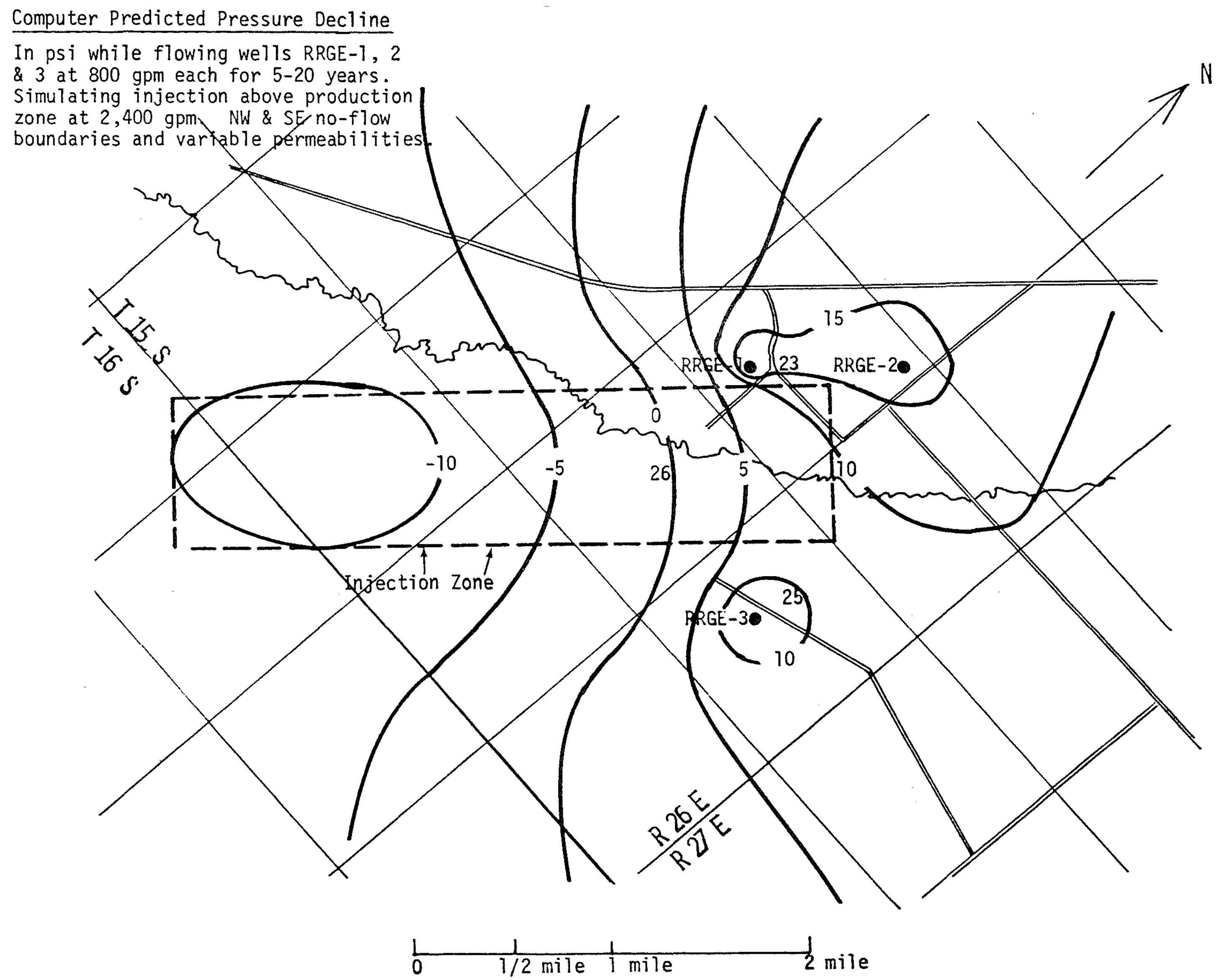

Fig. 11 Computer Predicted Pressure Decline - With Injection

by 500 psi, gross from artesian. Well spacings of 1/2 mile are tolerable, for 20 years operation without reinjection, 1/5 mile with reinjection.

2.3.4 Reservoir Capacity

Of immediate concern to the planned operation of a 40 MW(th) 5 MW(e) "pilot" plant is the adequacy of the present three wells. These must supply 4500 gpm allowing 2000 gpm of 290°F water, preferably 2200 gpm, for contingency. Tables VIII, IX, and X summarize the results as known to date, inferring a reservoir area of only 5 square miles, all within one mile of the present three wells. The reservoir is probably much larger, perhaps an order of magnitude or more. Yet with what is now known over five square miles, the thermal loop could be operated for 100 years or more.

2.3.5 Closed Loop Pump Test

A closed loop reinjection test was run between wells RRGE-1 and RRGE-2. Well RRGE-1 discharged water at an average rate of 340 gpm for 50 minutes. The outlet pump pressure into RRGE-2 was about 260 psi. The quantity of water reinjected was deliberately limited so that for this brief test, no water from the No. 1 well would actually reach the formation within the No. 2 well. The 50 minute test only replaced water in the upper ∿2500 ft of the casing.

2.3.6 Interference Measurements

Monitoring of the artesian flow from wells 155 26E 2366C1 (BLM well) and 15S 26E 23ddc1 (Crank Well) have been routinely conducted, during the periods that the deep geothermal wells were producing significant fluids. Historic data on the BLM well show a flow measurement in 1972 by the Idaho State Department of Water Resources at a rate of 58 gpm. Historic data on the Crank well show the first flow measurement in 1952, by the USGS, at a rate of 26.9 gpm. Current measurements on both wells show similar discharge rates, and have shown only minor variations (presumably due to seasonal changes in artesian reservoir head) over the two years that INEL has monitored the flow rates.

2.3.7 Tritium Analysis of Wells

The tritium concentration in the well water has been of interest, despite the difficulty of making the measurement on such small concentrations. The interest is principally because tritium levels occurring naturally in meteoric (rain) water rose by about a factor of 100 with the start of the H-bomb testing in 1952. Samples were drawn in February from the first and second deep wells, and from the Crank well for analysis of tritium. This had been attempted before, but the laboratory analyses at that time were distorted by background. Two sets of analyses were run, one at a commercially available laboratory, and another sampled by the USGS for analyses in their own laboratory.

TABLE VIII

DEDUCTIONS OF CHARACTERISTICS OF AQUIFER IN AND AROUND PRESENT 3 WELLS

TOTAL "RESERVOIR" THICKNESS = 1200 FT AVERAGE

#1 3700' TO 4600' = 900'

#2 4250' TO 6000' = 1750'

#3 4250' TO 5600' = 1350'

EFFECTIVE PERMEABLE PRODUCING THICKNESS = 600 FT

(VARIOUS ESTIMATES FROM TEMPERATURE LOGGING WOULD GIVE RESULTS FROM 300 TO 800 FT.)

POROSITY IN PERMEABLE REGION = 15% FOR WATER

(TOTAL POROSITY = 20%)

APPARENT EXTENT OF RESERVOIR WITH THESE CONDITIONS IS AT LEAST 3 TO 6 SQ MILES (USE 5 SQ MILES)

TOTAL WATER CONTAINED IN THE RESERVOIR AS DESCRIBED ABOVE IS 288,000 ACRE FT.

TABLE IX

WATER INPUT AND ANNUAL FLOW COMPARISONS

SOUTHERN RAFT RIVER VALLEY
(WITHIN 10 MILES OF PRESENT GEOTHERMAL WELLS)

TOTAL ANNUAL PRECIPITATION	400,000 ACRE-FT
ESTIMATED ANNUAL EVAPOTRANSPIRATION	360,000 ACRE-FT
NOMINAL RAFT RIVER ANNUAL RUN-OFF	40,000 ACRE-FT

NEAR-SURFACE (DOMESTIC-IRRIGATION) AQUIFER CAPACITY (Ø = 0.2)

12 MILLION ACRE FT
(200' TO 500' DEEP)

ESTIMATED CAPACITY BELOW NEAR SURFACE AQUIFER, BUT ABOUT
GEOTHERMAL AQUIFER = 50 MILLION ACRE-FT (MINIMUM) (Ø = 0.1)

INFERRED CAPACITY OF PRESENTLY KNOWN GEOTHERMAL AQUIFER
= 288,000 ACRE-FT

(BASED ON ASSUMPTION OF NO INFORMATION BEYOND
ONE MILE FROM ANY OF PRESENT WELLS.)

TABLE X

RE-INJECTION ZONE

2000 GPM

INTO PREVIOUSLY ASSUMED RESERVOIR (600 FT, 0.15 POROSITY)

3 YEARS, 70% OPERATION, ZONE OF SPREADING IS TO A RADIUS OF 352 FT

140°F WATER INTO SUCH A WELL DROPS TEMPERATURE 42°F, DOWN TO 250°F, AVERAGE IN THE PERMEABLE ZONES, WHILE THE INBETWEEN ZONES ONLY GRADUALLY COOL OFF, SIMULTANEOUSLY HEATING THE PERMEABLE ZONES.

ALLOWING FOR SUCH 50°F COOLING, THE RESERVOIR OVERALL CONTAINS ENOUGH HEAT CAPACITY FOR PHASE I IN 0.045 SQUARE MILES, 29 ACRES - - AND FOR PHASE II IN 0.13 SQUARE MILES, 83 ACRES. (THE LATTER REPRESENTS A RADIUS OF 633 FT, IF FROM A SINGLE WELL.)

The commercial analyses results were:

	Pico Curies/liter
RRGE-1 (after six months flowing at 200 gal/min)	8.3 ± 1.6
	7.5 ± 1.3
RRGE-2 (after all winter at 20 gal/min)	9.9 ± 1.8
	10.0 ± 1.9
Crank Well	11.0 ± 2.2
Site Domestic Well	6.7 ± 1.8

Since the advent of the H-bomb test in 1952, tritium levels in meteoric water have been in the range of 600 to 10,000 pico Curies/liter. The normal levels prior to 1952 were 16 to 50 pico Curies/liter.

Interpreting the meaning of the above results is difficult. Obviously, the water was all of pre-1952 meteoric origin, since only two half lives have elapsed since that time. That is insufficient time for post H-bomb meteoric water to decay to these levels. Yet if these results represent pre-H-bomb levels, the half life of 12.3 years makes it difficult to explain such high results, unless fortuitously all the water was only 30 to 50 years old, and began as 50 pico Curies/liter activity, not the lower 16 pico Curies/liter. This result would indeed be fortuitous, particularly when the same result was obtained for the shallow (200 ft) domestic well. Such a postulate is therefore discarded as being highly unlikely.

The USGS results have been unofficially reported as nominally equal to background in their lab of 0.5 pico Curies/liter. These data would therefore indicate that the water is very old, with negligible residual tritium from its meteoric origin. It is therefore concluded that the magnitude of the commercial lab results are questionable, but it can be concluded that all the water is of pre-1952 origin.

2.4 ENVIRONMENTAL PROGRAM

W. W. Hickman, S. G. Spencer

A draft report of the baseline environmental analysis was completed in March and will be published as a set of environmental reports, about June 1977. The drafts of this report have been sent out for initial review. The main report includes supplementary analysis and data reports from the several universities participating.* These reports address the immediate environmental effects of a 40 MW(th) thermal loop facility. Included are a characterization of the environment, identification of critical areas, the description of the proposed actions, and recommended development strategies.

A socioeconomic study of the Raft River Valley was initiated under a contract to the Battelle Human Affairs Research Center of Seattle in January. Designed to provide input to the environmental reports, this study is also intended to aid planners and developers in the Valley and to contribute to the growing body of research on energy-related social impacts in rural areas. The three major tasks included in this study are: 1) an examination of information on existing conditions; 2) an estimation of the potential impacts within the area; and 3) an identification of alternative planning strategies for the prevention or amelioration of undesirable effects.

In conjunction with Battelle's study, a questionnaire designed to assess attitudes of Valley residents was presented at the Raft River Coop's Annual Meeting. Nearly 140 responses to the questionnaire were received (representing 50% of the families in the Valley). Of those responding, nearly all were in favor of geothermal development in the Valley and felt that the development should proceed without delay.

A series of chemical analyses have been completed, including an extensive set of measurements on harvested crops and soils, to determine the effect of using geothermal water for irrigation. Those results are summarized in Section 2.5. In addition, corroborating on-site measurements of toxic materials including mercury, hydrogen sulfide, ammonia, fluoride, and arsenic were made by the Battelle Pacific Northwest Laboratory. The results of their analyses are shown in Table XI. The mercury, arsenic, hydrogen sulfide and ammonia were quite low--nearly a factor of 100 lower than that found at Cerro Prieto. Battelle's initial conclusion from these results was that fluoride may be the only potentially harmful effluent on site. A similar conclusion was previously reached from INEL data, reported in ANCR-1247, Quarterly Report, April 1 to June 30, 1975.

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* University of Utah Research Institute - Air quality base-line information and plant environment
Idaho State University - Animal baseline studies
Brigham Young University - Insect populations in the area
Utah State University - Soil baseline data plus cattle baseline conditions

TABLE XI

TOXIC MATERIALS* - RAFT RIVER WELLS

DIRECT CONCENTRATIONS MEASURE FROM FLASHED SAMPLES

	Non-Condensible Gas	Steam Condensate	Brine
H_2S	215 ppm	0.66 ppm	0.1 ppm
Hg	39 ng/l	128 ng/l	8; 35 ng/l
As	--	800 ng/l As^{+3} 11,400 ng/l As^{+5}	2,800 ng/l As^{+3} 24,900 ng/l As^{+5}
F^-	--	0.04 ppm	9.8 ppm
NH_4^+	--	1.9 ppm	0.29 ppm

Steam/brine = 1/14 by weight

Non-condensible gas/steam = 0.02% by volume at STP.

* Data obtained by Battelle Northwest Laboratory

Related to fluoride, Utah State University completed a survey of cattle in the Valley that are exposed to high fluoride waters. Some of the animals examined indicated long-term fluoride ingestion of levels damaging to teeth. Because human tolerance to excessive fluoride ingestion is generally believed to be much lower than that of domestic or wild animals, it was recommended that a survey of the Valley residents and culinary water supplies in the area be undertaken. Recommendations on best water sources, fluoride effects, and fluoride intake alleviation procedures would follow such a survey. This work is considered baseline since the fluoride levels to date in the Valley have no relations to the recent man-made geothermal activity.

The University of Utah Research Institute operated an air quality monitoring trailer downwind of RRGE-1 and RRGE-2 for two weeks in December. The intent was to measure "pollutants" from the steam plumes and reserve pits. The results, shown in Table XII, indicate relatively low concentrations of the constituents monitored--concentrations that would be expected in background measurements. Only the hydrogen sulfide and sulfur dioxide measurements may have been influenced by the proximity of the geothermal wells, but these values are still well below guideline levels. (Note: only occasionally can the smell of H_2S be detected by the site work force, usually right at the edge of a reserve pit, or when fresh geothermal water is released into an enclosed laboratory. The integrating nephelometer observations shown in Table XIII suggest that the prevailing visibility in the area was restrictive to less than 32 km (20 miles). This could be accounted for by locally restrictive steam and fog from the wells. Results from an automatic camera located at RRGE-1 have been analyzed. Initial results from companion nuclepore filters indicate that at times when landmarks were only partly visible or obscured with haze, there were substantially increased concentrations of sulfate particles. This adds credence to the hypothesis that pollutants from the Wasatch Front (100 miles southeast) were moving into the Valley through Kelton Pass, and that this source, not the geothermal wells, is the main source of airborne pollution in winter. (During the summer, wind-blown dust from farming activity becomes the main airborne pollutant source).

The microseismic telemetry system is now operating at the environmental station. Three locations were established for the microseismic systems and the geophones temporarily set at a depth of 3 meters (10 ft). Results from an initial monitoring period will determine where the fourth station will go and how deep the geophones should be permanently set to reduce surface "noise" effects.

The biological baseline surveys conducted by Idaho State University, University of Utah Research Institute, Brigham Young University, Utah State University, and private consultants have been completed. The surveys indicate that, in general, geothermal development will not effect critical habitat areas in the Valley. The U.S. Fish and Wildlife Service has recommended buffer zones around these critical habitats, including that of the Ferruginous Hawk. These recommendations will be taken into account in locating future development in the area. The results of the biological surveys have been summarized in the environmental reports. The detailed biological reports are on file with the Geothermal Programs office and are available on request.

TABLE XII

24-HOUR AVERAGE CONCENTRATION OF VARIOUS ENVIRONMENTAL POLLUTANTS NEAR GEOTHERMAL WELL NO. 2 AT RAFT RIVER, IDAHO

Dates	Sulfur Species ug/m3	Sulfur Spe (-) SO_2 ug/m3	H_2S* ug/m3	SO_2 ug/m3	Am. Sulfate ug/m3	Am. Sulf. Converted to SO_2 ug/m3	NO_2 ug/m3	NO ug/m3	NO_x ug/m3	O_3 ug/m3	Nephelometer Visibility Miles
12(17-18)76	49.40	36.30	19.25	12.48	1.25	.605	3.23	.25	3.48	58.9	13.4
12(22-23)76	36.40	22.50	11.94	13.52	.74	.358	6.08	0	6.08	61.9	11.2
12(29-30)76	14.30	6.24	3.30	7.80	.54	.261	3.61	.75	4.36	37.9	13.2
11(3 - 4)77	16.90	14.67	7.77	2.08	.32	.155	3.04	.13	3.17	66.4	16.4

* = Sulfur Species (-) SO_2 mathematically converted to H_2S

1. Sulfur Species was monitored by Meloy sulfur dioxide analyzer Model SA 160-2.
2. Ozone was monitored by Meloy ozone analyzer Model OA 350-2R.
3. Visibility was measured by Meleorology Research, Inc. (MRI) Nephelometer, Model 1550.
4. Sulfur dioxide was measured colorometrically by the modified West Gaeke (pararosaniline) method of Scaringelli et al. Analyt. Chem. (1967) 39, 1709-19.
5. Oxides of nitrogen was measured by colorometric method of NASH. Atmos Environ., (1970), 4, 661-6.

Table Prepared by: W. O. Ursenbach, W. H. Edwards, A. Soleimani - University of Utah Research Institute

TABLE XIII

MEASURE AIRBORNE POLLUTANTS NEAR RRGE-2

(24 hours average concentration of various environmental pollutants near geothermal well No. 2 at Raft River, Idaho

Dates	Sulfur Species ug/m^3	Sulfur Spe (-) SO_2 ug/m^3	H_2S* ug/m^3	SO_2 ug/m^3	Am. Sulfate ug/m^3	Am. Sulf. Converted to SO_2 ug/m^3	NO_2 ug/m^3	NO ug/m^3	NO_x ug/m^3	O_3 ug/m^3	Nephelomet Visibility Miles
12(17-18)76	49.40	36.30	19.25	12.48	1.25	.605	3.23	.25	3.48	58.9	13.4
12(22-23)76	36.40	22.50	11.94	13.52	.74	.358	6.08	0	6.08	61.9	11.2
12(29-30)76	14.30	6.24	3.30	7.80	.54	.261	3.61	.75	4.36	37.9	13.2
11(3 - 4)77	16.90	14.67	7.77	2.08	.32	.155	3.04	.13	3.17	66.4	16.4

* = Sulfur Species (-) SO_2 mathematically converted to H_2S

1. Sulfur Species was monitored by Meloy sulfur dioxide analyzer Model SA 160-2.
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Table prepared by: W. O. Ursenbach, W. H. Edwards, A. Soleimani, University of Utah Research Institute

2.5 Water Use Considerations

J. F. Kunze, C. S. Yrene, J. H. Lofthouse

An issue of major importance in geothermal development concerns net water consumption, especially when considering the rejection of 85% to 90% of the heat from electric power production plants. Moderate temperature geothermal is particularly handicapped compared to fossil or nuclear power plants. The following table shows the magnitude of the concern.

Electric Power Plant Type	Ratio of $\frac{\text{Discharge Heat}}{\text{Gross Output of Electrical Energy}}$
Coal fired (modern)	1.5
Nuclear, light water reactor	2.0
Geysers Power Plant in Sonoma County, California	4.0
Raft River 290°F binary cycle plant	7.0

The conventional method of rejecting waste heat is with wet cooling towers, particularly efficient in their operation in the dry climate of the West. However, when this use of water must compete with agriculture for precious water supplies, a major factor in the future for power plant cycle selection by utilities may be "thermal efficiency." Unless a alternative method of cooling geothermal plants is developed, a method that would not be practical for coal or nuclear, then geothermal electric will indeed face a difficult environmental problem.

Two such alternatives would seem to exist, based on the criteria that geothermal plants are most economically built in modules of 20 to 50 MW in size. Cooling ponds and soil cooling both require substantial areas of land, per MW of rejected heat, typically 2 to 20 acres per MW of heat, depending on the ambient conditions and the desired rejection temperature. In the case of a large coal or nuclear plant, one that rejects 1500 to 2200 MW of heat, land areas become excessive if not impractical. Yet, the optimum economical geothermal plant module, rejecting 100 to 300 MW of heat, would need far less area surrounding the plant.

Table XIV shows a comparison between the conventional wet cooling towers and three non-conventional cooling methods. Either in cost or in power output consumed, pond or soil cooling appears superior to the dry cooling tower method, though more expensive compared to wet cooling towers. However, the alternate methods of cooling were proposed for reducing (or eliminating) "non-producive" consumption of water. A crop such as hay or

TABLE XIV

COMPARISON OF COOLING METHODS

	Cost Fraction of Total, Wells Included	Fraction of Power Output Required To Operate	Nominal Cooling Capability: Summer Days	Nominal Cooling Capability: Winter Evenings
Wet Cooling Towers	8%	6%	$80^{o}F$	$40^{o}F$
Dry Cooling Towers	23%	20%	$120^{o}F$	$30^{o}F$
Cooling Ponds	15%	5%	$80^{o}F$	$35^{o}F$
Soil Cooling	22%	10%	$80^{o}F$	$35^{o}F$

sugar beets will consume the normal amount of water needed for such a crop, whether or not soil heating is used. Soil heating may require somewhat more water, but the amount needs to be determined by actual experiments. The consumption from cooling ponds, annually, also needs to be determined by actual experiment.

Rejection of 300 MW of heat through soil cooling is expected to require approximately 2100 acres. A crop of hay or sugar beets on this acreage will consume nominally 1.5 billion gallons per year. Wet cooling towers, however, will consume 2.5 billion gallons per year (evaporation, wind loss, and blowdown), with no secondary beneficial effects, such as crop production. The crops produced on the 2100 acres of heated soil could have a gross value of 0.6 to 1.0 million dollars, nearly equal to the wholesale value of the electric power output from the 40 to 45 MW power plant that this cooling acreage would serve.

The discharge of waste heat to the soil does appear to offer an excellent symbiotic application of energy--the discharge from a power plant produces enhancement to agricultural applications, both with equivalent dollar value. Consequently, experiments are being set up to evaluate the effectiveness of soil cooling, the temperatures that can be achieved in the cooling circuit, and the effect on crops (sugar beets, hay, and beets) grown on the heated soil. Concurrently, evaluation of cooling ponds will be conducted experimentally. Both experiments will run for a full year period minimum. Soil heating will occupy 1-1/3 acres, the experimental cooling ponds will be several, and occupy a total of three acres.

3.0 ELECTRIC CONVERSION AND PILOT/THERMAL LOOP

J. F. Whitbeck

3.1 Raft River Thermal Loop Facility

R. R. Piscitella

An architect engineer (A-E) was selected for Title I and Title II design work during the first week in October and work on Title I was begun. A Definitive Design Study, which established a firm basis for the remainder of Title I and II, was completed on December 10, 1976. This study was reviewed by EG&G, ERDA, and private utility personnel, and comments were transmitted to the A-E during meetings held December 16 and 17, 1976. Presented as part of the definitive design study was a project schedule. (This schedule is included as Figure 12 of this report.) A brief listing of major milestones is given below:

Completion of Title I Design	April 1977
Completion of Title II Design	January 1978
Begin Title III	January 1978
Begin Construction	March 1978
Complete Construction	July 1979
SO Testing Start	October 1979
System Ready for Operation	January 1980

The study indicated that the A-E has a good basic understanding of proposed facility and a good working relationship was established.

The plant configuration presented in the Definitive Design Study was basically the same as that presented in the system specification completed by EG&G. However, substantial additional work was completed in optimizing the condensing end of the system; design of the main office, control, and shop building; and design of all major process systems. The A-E's cost estimate for the facility was $7,690,055 which compares favorably with $8,000,000 estimated by EG&G.

3.2 Geothermal Systems Analysis

The thermal loop/pilot plant at Raft River is being designed for 290^{o}F inlet temperatures to the power plant. The operation and test results from this plant will represent a specific data point on the experience of a moderate temperature development. A second need will be to extrapolate this experience to what might be expected at higher or lower temperatures.

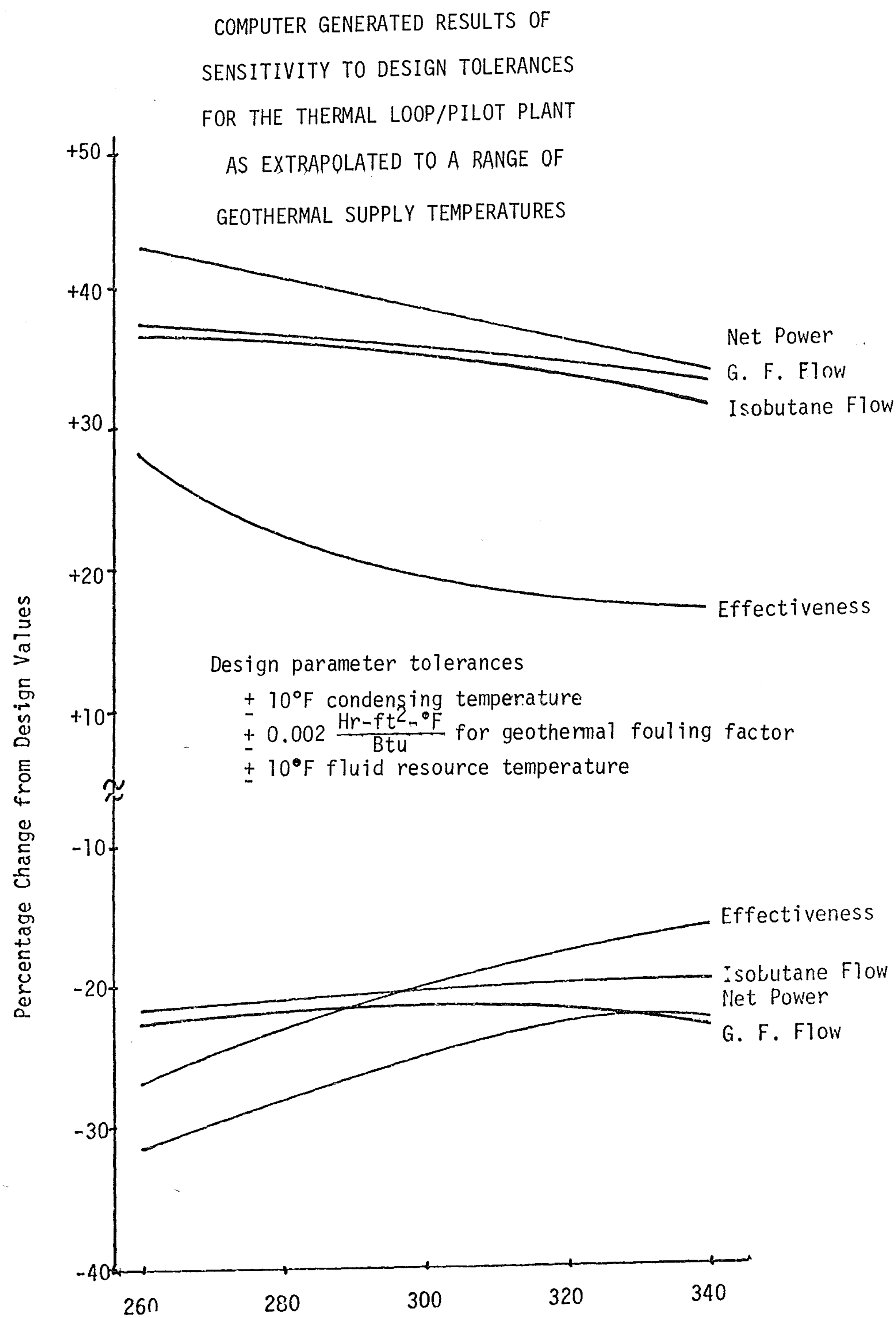

Fig. 12 Geothermal Fluid (G.F.) Temperature (°F)

Two computer codes are being used to evaluate this extrapolation so that the Raft River experiment will have a meaning over a larger variety of geothermal reservoir conditions. The code is an adaptation of a similar geothermal power plant code developed earlier by Green; et al at Lawrence Berkeley Laboratory.

A typical application to date of this code has been to study the sensitivity of the present pilot plant/thermal loop design to uncertainties in specific design parameters. A summary of these results is given in Figure 12 which shows that design parameter tolerances become less critical as the geothermal supply temperature rises. In other words, for lower temperature reservoirs, parameters such as fouling factor, condensing temperature, and shifts in wellhead temperature will be extremely critical. Though this is an obvious intuitive result, the computer analysis gives the magnitude of the effect.

3.3 Testing Related to Pilot Plant Facility

R. L. Miller, G. L. Mines

Testing activities during this reporting period consisted of scoping heat exchanger fouling tests, evaluation of a 70 day preliminary corrosion test and completion of a 100 day sequential corrosion test. Preliminary results of these tests are given in this section. In addition to this work, a small wet tower test system was prepared for testing material compatability when geothermal water is used for cooling tower makeup and the first preliminary testing on this unit is completed.

3.3.1 Heat Exchanger Testing

The initial heat exchanger tests with the Mobile Components Test Trailer at Raft River were started September 15, 1976. The purpose of this test was to first determine the fouling of the heat exchanger tubes due to mineral deposition from the geothermal fluid and second to operate the test system, determine problem areas, and correct where possible.

In order to determine the tube fouling due to brine mineral deposition, the tubes for this test were fabricated from titanium and 304 stainless steel materials. These materials were the most resistant to corrosion processes of the available materials; thus, fouling of the tube surface would be primarily due to minerals precipitating from the geothermal fluid rather than some corrosion process on the tube surface. The geothermal and cooling water flow through the loop was arranged so that flow through the four tubes would be counterflow and in series. The tubes and flow arrangements are shown in Figure 13. The geothermal fluid velocity was set at 5 sps (a typical brine velocity in the thermal loop design) and the cooling water flow was established at a value that would simulate the brine differential temperature in the thermal loop design.

Prior to starting the test, the cooling water system was cleaned with a detergent solution and flushed with clean water. The system was then filled with demineralized water treated with 200 ppm chromate. It

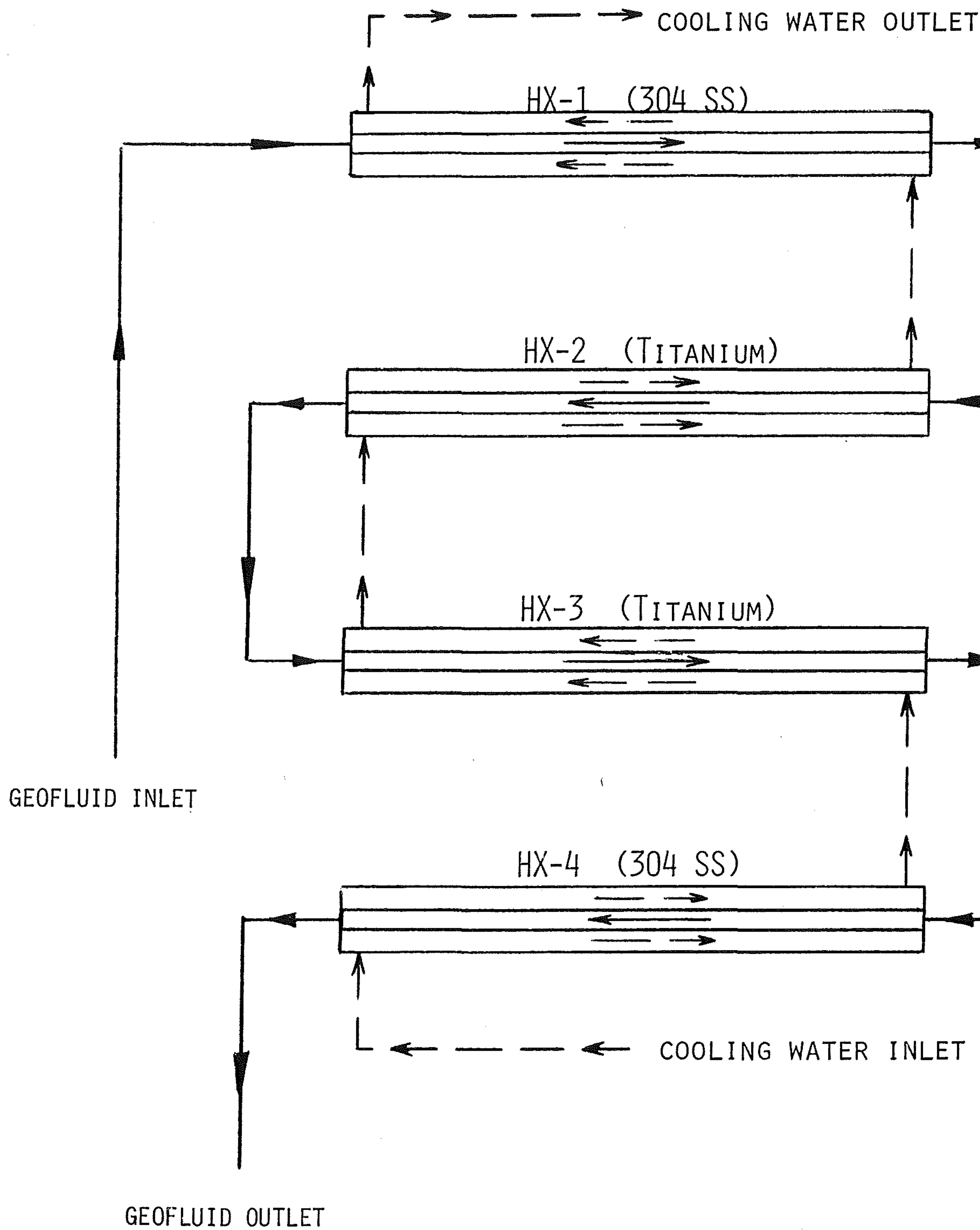

Fig. 13 Flow Arrangement for Initial Heat Exchanger Testing

was hoped that the cleaning and treated demineralized water would minimize the corrosion and scaling of the cooling water system and outer tube surfaces. Any indication of fouling from the test data could then be primarily attributed to fouling on the inner tube surface.

Initial test data indicated that the heat exchanger tubes were being fouled, however, when the test loop was shutdown and the outer tube surface wiped clean, the overall heat transfer coefficients returned to approximately the unfouled, initial conditions. This wiping procedure was performed twice during the test (after one week and 12 weeks) and each time the overall heat transfer coefficient returned to within 1 to 2% of the initial test value. These results imply that the fouling indicated by the test data was primarily on the outside of the tube (cooling water side) and that very little fouling was present on the inside of the tube which was exposed to geothermal flow. Visual examination of tube surfaces during the wiping supported these observations. After 12 weeks of testing, no scale could be seen or scraped from the inside end of the tube. No difference or change in the scale was visually apparent between 1 and 12 weeks of exposure.

This initial heat exchanger test is continuing until the next set of heat exchanger tubes can be fabricated and inserted into the loop. Data reduction is continuing which will attempt to separate the inside and outside fouling rates and account for varying cooling water conditions.

Test results so far seem to indicate that fouling present so far in the titanium and 304 stainless steel heat exchanger tubes is primarily due to corrosion processes and very little, if any, is due to mineral deposition from the geothermal brine.

3.3.2 Materials Evaluation Tests

Materials tests are in progress, and consist of exposure in closed loops of coupons of selected materials to the geothermal fluid at a temperature of approximately 275°F. The exposure phase of the tests are complete and the coupons have been examined for visual evidence of corrosion and scaling. After the coupons are cleaned, a weight loss will be determined to obtain an average corrosion rate for each material tested.

A test to study the corrosion/deposition effects in the condenser cooling circuit was begun. This consisted of a small cooling tower test of potential materials for condenser fabrication, for which the cooling water makeup would come from two sources:

1. Geothermal water as makeup

2. RRGE-1 domestic water as makeup

Tests were begun on the geothermal water makeup, since at this time it would seem to be the only viable alternative considering the Western drought situation that is predicted to last several years.

A third test has been initiated involving coupon samples subject to fluidized bed corrosion and erosion.

1. Controlled velocity corrosion and erosion

2. Atmospheric exposure tests of building materials

3. Direct contact heat exchanger

4. Long term evaluation tests of boiler and preheater materials

Test plans and specifications will be prepared for each test sequence.

In the materials test loop, now in operation nearly nine months, the coupons are mounted on a long stainless steel rod, 0.6 x 25 x 120 cm (0.25 x 1 x 47 in.), in such a manner that the flow of the geothermal fluid is parallel to the faces of the coupons. Two or more coupons are mounted at each position with the coupons separated from each other by polytetrafluoroethylene (PTFE) plastic washers. The mounting screw is covered with a PTFE sleeve. This mounting arrangement effectively insulated coupons from each other so that galvanic corrosion would not be a factor to be evaluated in these tests. The PTFE washer was beveled on one edge (10^{o}) to provide a site for crevice corrosion to initiate and propagate. A similar configuration will be employed in most of the other tests. Figure 14 shows the corrosion test trailer at Raft River Site No. 1.

The purpose of the first test series was to provide data on a wide variety of materials and was of a scoping nature and did not have the control other planned interval 100 day test. The results of the planned interval test will be used to select materials for the thermal loop. The results given here for both tests are preliminary and the result of visual inspection of the test coupons. More quantitative results will be available during the next report period.

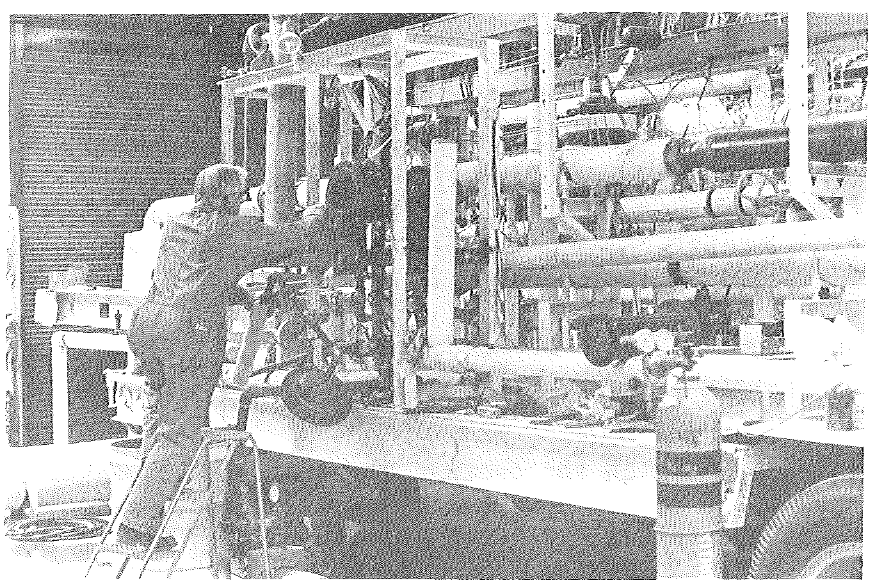

Fig. 14 Corrosion Test Trailer located at RRGE-1 Site

3.3.2.1 Ten Week Test

The configuration of the test loops was simple, consisting of two 3 in. pipes, in parallel, directly off of the wellhead valve system. Entrance to each pipe was made by means of a tee with one leg fitted with a blind flange. The flange was equipped with fixtures for holding and retrieval of the spool on which the coupons were mounted.

The results of visual examination of the corrosion coupons from the scoping test are summarized in Table XV. Aluminum alloys have been touted for use in brine desalinization systems. However, due to severe degradation of the aluminum alloys tested, aluminum has been eliminated from further consideration in the boilers and preheaters of the Thermal Loop Facility.

Copper and nickel based alloys are widely used in marine condensers where seawater is the coolant and have been recommended for water desalinization service. In these scoping tests, the 90/10 and 70/30 copper nickel alloys and Monel 400 did not perform as well as had been hoped. This is thought to be a result of their reaction with the trace amounts of hydrogen sulfide (0.1 mg H_2S/1) present in the geothermal fluid. Selected coupons will be given further testing to more clearly define their probable role in construction of power plant involving medium temperature geothermal fluids.

3.3.2.2 100 Day Test

In the second series of tests, coupons of selected materials were exposed to the geothermal fluid for up to 100 days. The coupons were mounted on spools contained in a series of 48 in. test sections fabricated from 4 in. Schedule 40 pipe. This test was planned to provide a better definition of corrosion characteristics of the subject materials in the geothermal fluid environment the "planned interval test" sequence developed by Wachter and Treseder and recommended by the National Association of Corrosion Engineers. One of the advantages of the planned interval test is the information that may derive relative to changes in the environment and the resistance of the materials to the environment in addition to the corrosion rate.

The results of visual examinations of the corrosion coupons are summarized in Table XVI. From the visual examinations, it appears that the geothermal fluid became less aggressive as the test progressed. However, this will have to be evaluated when weight change measurements are completed.

TABLE XV

RESULTS OF VISUAL EXAMINATION OF CORROSION COUPONS FROM SHORT TERM SCOPING TESTS IN 3 IN. LOOP

Material	Acceptability*	Observations
Low Carbon Steel	5	Thin black scale at 2 weeks, black scale over yellowish scale at longer times. Numerous small pits filled with corrosion product. Corrosion increases with time with the formation of rust-red tubercles and broad, shallow pits. Crevice corrosion developed at edge of PTFE washer, no evidence of crevice corrosion under washer.
ASTM A515	5	Thin black scale at 2 weeks. At longer times the scale thickens with the black scale overlying a yellowish deposit. Numerous small greenish dots at 2 weeks that may be pit nuclei. At longer times there are small rust-red tubercles overlying pits and surrounded by a halo of relatively unattacked metal. The halo is probably a cathodic region with the pit being the attendant anodic zone. A relatively large amount of chloride accumulated in the pits as evidences by scanning electron microscopy and non-dispersive x-ray analysis.
Gray Cast Iron	1-2	Gray-black scale at 2 weeks, thickens with time to become a black scale overlying a yellowish deposit. Corrosion is significantly less than in low carbon steels. No pitting noted at 2 weeks, at 6 and 10 weeks pitting was observed with very small rust-red tubercles overlying shallow, broad localized corrosion.
9% Cr-Steel	4-5	Purple-brown discoloration at 2 weeks, color deepens with time but does not become thick as in low carbon steels. No pitting at 2 weeks, however, there is some evidence of crevice corrosion at this time. At 6 and 10 weeks numerous pits were observed as well as some greenish scale.
Cor-Ten (high strength low alloy steel)	5	Thin black scale, yellowish when scraped, at 2 weeks. Scale thickened with time to yield black-green deposit with areas of yellow-green scale. Numerous small, shallow, broad pits. Some halo-like areas around some pits, absent in others. Some crevice corrosion under and around PTFE washer.
AISI 4140 (low alloy steel)	5	General black discoloration at 2 weeks, yellowish when scraped. Scale thickened with time. Numerous very small pit nuclei at 2 weeks. Pitting increased with time with rust-red tubercles overlying pits. Pits generally surrounded by halo-like areas of immunity. Some crevice corrosion under beveled area of PTFE washer and under washer.
Haynes 6B	1	Thin deposit of yellow-gray material, may not be corrosion product from base material. Corrosion, if any, is of the same magnitude as the surface roughness.

TABLE XV (Continued)

Material	Acceptability*	Observations
Hastelloy-G	1	Deposit of water borne mica, no other discoloration or scale noted. No evidence of corrosion.
Inconel 625	1	Dense black scale overlying brittle gray scale. No evidence of pitting or crevice corrosion.
Monel 400	3	Thin, tightly adherent scale at 2 weeks. Scale thickens with time and becomes black-purple in color with patches of yellow-green scale. Corrosion is not extensive, however, machining or rolling marks are deepened and broadened at 6 and 10 weeks. Some deposition of small calcine crystals in the occluded region between the PTFE washer and insulating tube.
70/30 Copper/ Nickel	3	Gray to purple or black film at 2 weeks. At longer times the scale became massive and purple to black in color. Machining or rolling marks widened and deepened, especially under beveled edge of PTFE washer. Some slight frooving around washer.
90/10 Copper/ Nickel	3-4	Gray to purple to black scale formed at 2 weeks. Scale is formed from well faceted, hexagonal, tabular crystals. Scale thickened with time. Corrosion along machining or rolling marks is more pronounced that for 70/30 copper/nickel alloy. Grooving around beveled edge of PTFE washer is evidence of crevidence corrosion.
Ampco 8 (Aluminum Bronze)	2-3	Thin blue-purple film at 2 weeks. Thickens with time to form dense black scale overlying a thin yellow deposit. No evidence of pitting or crevice corrosion at 2 weeks. At longer time, the machining or rolling marks are deepened and broadened. Some minor selective leaching under PTFE washer.
Ampco 12 (Aluminum Bronze)	2	Thin blue-purple scale at 2 to 6 weeks, becomes black and tightly adherent at 10 weeks. Some indication of nucleation of localized corrosion but no good evidence of corrosion at 10 weeks.
Muntz Metal	2	Discolored to brown at 2 weeks, some areas of black and green scale at 10 weeks. Some selective leaching under PTFE washer at all times observed. Machining or rolling marks deepened and widened with time. Some small whitish tubercles overlying small pits along machining or rolling marks, selective leaching in pits.

TABLE XV (Continued)

Material	Acceptability*	Observations
1100 Aluminum	5	Light yellow to brown scale more-or-less uniformally distributed over surface of coupons at 2 weeks. Scale becomes thicker and friable with time. Areas of light brown and areas of dark gray-brown scale. Evidence of erosion at 2 weeks, increases at 6 and 10 weeks. At 10 weeks one coupon had lost more than 25% of metal, in another coupon an impingement pit had only 0.15 mm (0.005 in.) of metal remaining. Original thickness was 1.6 mm (0.062 in.) a loss of about 90% of its cross section.
5052 Aluminum	5	Thin, friable scale, yellow to brown and gray with small areas of black deposit in more corroded areas, at 2 weeks. At longer times, a black scale overlies yellow-gray scale. Deposition of calcity in corroded areas that are protected by overlying scale, may have siliceous deposit also. Erosion significantly less than in 1100 alloy. Corrosion more general than for 1100 alloy with small pedestals of relatively unattached material. Older scales extend from these pedestals to form occluded areas for calcity deposition.
6061 Aluminum	5	Gray scale, not flaky, at 2 weeks. At 6 weeks the gray scale overlies a light green-gray deposit. Gray scale becomes black at 10 weeks. Deposition of calcity in occluded region under scale, may also have some siliceous materials associated with calcity. Little evidence of erosion, however, corrosion was extensive. Some pitting at 2 weeks, at longer times pitting is worse and large areas of general corrosion were seen. Some pedestals of relatively unattacked materials with older scales extending from these pedestals to form occluded areas for calcity deposition. There was no evidence of crevice corrosion.

*Class 1 - Those materials having best corrosion resistance.
Class 2 - Those materials having satisfactory corrosion resistance.
Class 3 - Those materials that will undergo severe selective corrosion attack.
Class 4 - Alloys having high corrosion rates.
Class 5 - Those materials having low corrosion-resistance to the environment.

TABLE XVI

RESULTS OF VISUAL EXAMINATION OF CORROSION COUPONS 100 DAY TEST

Material	Acceptability*	Observations
Low Carbon Steel	5	Areas of non-adherent yellow and black scale overlying tight black scale in first 32 days. In second 32 days there were areas of iridescent brown and black scale. Scale did not effervese with dilute HCl. At 66 days one side of coupons have scale that are predominatly yellow, other side is predominatly black. At 100 days the differentiation between sides is not as great as at 66 days, areas of yellow, green, black and rust-red scales overlying a gray scale. There is general pitting, shallow and broad, underlying the scales. Some halo-like areas of immunity at 32 days, less apparent at longer times. Some very small tubercles in the halos, overlying pits at 32 days. Slight crevice corrosion.
ASTM A 515 Low Carbon Steel	5	Areas of blue iridescent film and thin black scale, many small yellow spots, at end of both 32 day test periods. At 66 days areas of yellow and black scales are apparent with rust-red tubercles, At 100 days there are areas of green scale in addition to the yellow and black scales. Areas of shallow, broad localized corrosion at end of first 32 day test period. Small pits underlying rust-red tubercles at longer time. No evidence of crevice corrosion.
Gray Cast Iron	1-2	At end of first 32 day test period, there was a yellow scale overlying a non-adherent gray scale. At end of last 32 day test period, there were areas of black and brown scale, black scale appears to be thicker than the brown scale. No extensive corrosion at end of first 32 days of exposure, at end of last 32 day period there are small areas of yellow scale overlying pits. Pitting is more general at end of 66 and 100 day test periods. Corrosion is not severe.
9% Cr Steel	5	Black doscoloration at end of 32 days, some areas of iridescent purple film; brown iridescent film at 100 days. Yellow tubercles at 66 days, black and gray tubercles at 100 days. Machining or rolling marks broadened and deepened at all times, deep pits at 66 and 100 days. Deep crevice corrosion at 66 and 100 days.
Cor-Ten (High-Strength, Low-alloy Steel)	5	Areas of iridescent blue-purple and black films at end of first and last 32 day test periods, also some loose yellow scale and areas of rust-red scale. At end of 66 days the reverse side had yellow-to green- to gray deposit, obverse side had black deposit, difference in sides less pronounced at 100 days. Numerous small pits underlying scales, some with small black tubercles.

TABLE XVI (Cont'd)

Material	Acceptability*	Observations
AISI 4140 (Low Alloy Steel)	5	At 32 days there were areas of iridescent blue-purple to black films. Crusts of white-brown material overlying pits and general corrosion. Some halo-like areas surrounding pits. At longer times green-gray deposits and green-yellow deposits, numerous tubercles overlying pits of varying depth and breadth.
AISI 410 SS	5	Thin iridescent brown film over total surface at 32 days. Numerous gray and yellow-brown tubercles overlying pits. Pits are narrow and deep -- to 0.4 mm (0.01 in.). Severe crevice corrosion near beveled edge of PTFR washer.
AISI 440 SS	5	Iridescent blue and brown films at end of 32 day test periods, films darken to black with time. Scattered deep pits with corrosion products in and around pits. Pits tend to extend in direction of machining or rolling marks. Severe crevice corrosion at end of first 32 days but not at end of last 32 day test period. Crevice corrosion is severe at 66 and 100 days.
AISI 304 SS	4	Overall yellow discoloration on unprotected areas at end of 32 day test period, yellow-green at 66 days and yellow to brown to gray at 100 days. Numerous halo-like areas with tubercles overlying pits in the halos. Crevice corrosion near beveled edge of PTFE washer and under washer.
AISI 316 SS	3	Slight yellow tarnish at 32 days, became yellow-gray in 100 days. Halo-like areas of corrosion products around small tubercles. Tubercles overlay small pits. Pitting is significantly less than for 304 SS. Some crevice corrosion seen in last 32 day test period with one large pit found near beveled edge of PTFE washer.
Allegheny-Ladlum 216 SS	1-2	Very slight tarnish at 32 days, becoming greenish-gray at 66 days and yellow-brown-gray at 100 days. Scattered halos of corrosion products with pitting of the order of the surface roughness of the material at 32 days. At longer times the pits are deepened. One pit under the beveled edge of the PTFE washer suggests crevice corrosion but may be due to pitting.
Allegheny-Ludlum 6X	1-2	Very thin loose yellow to gray film at 32 days, darkens with time to become yellow-green to brown at 66 days and more gray at 100 days. Scattered halo-like areas may be indications of pit nucleation. One pit identified at end of last 32 day test period with pit being slightly deeper than surface roughness. Other pits, if any, are of the magnitude of the surface roughness.

TABLE XVI (Cont'd)

Material	Acceptability*	Observations
Allegheny-Ludlum 29-4 SS	1	General yellow to gray discoloration at 32 days, becomes darker with time. Scattered black tubercle-like deposits at 66 days. Pitting and general corrosion, if any, is of the same magnitude as the surface roughness. Some minor indication of crevice corrosion under beveled edge of PTFE washer at 100 days.
Allegheny-Ludlum 29-4-2 SS	1	Yellowish to light gray discoloration at 32 days. Becomes a gray-green color at 100 days. Few scattered black tubercle-like deposits at 66 days. No evidence of corrosion.
Hastelloy-G	3	Very light yellow discoloration at 32 days, becomes light gray at 100 days. No corrosion observed in first 32 day period, one small pit observed at end of last 32 day test period. A few scattered pits were identified at 66 day, one somewhat deeper than others.
Inconel 625	1	Very light yellow film observed at 32 days, darkens to gray at 100 days. Scale is variable in thickness but easily scrapped off. Halo-like areas of possible corrosion products observed at 66 days, some with small black tubercles in center. Pitting, if any, is of same magnitude as surface roughness.
Haynes 6B	1	Very light gray discoloration at 32 days, becomes gray-green at 100 days. Several halo-like areas may be indications of localized corrosion. Corrosion, including pitting, if any, is of same magnitude as surface roughness.
Titanium	1	Light yellow to gray-brown scaling at 32 days, darkens with time. A few scattered black tubercles observed at 66 days. Very shallow pitting under tubercles, no crevice corrosion observed.
AMPCO 8 (Aluminum Bronze)	2	Purple-black deposit at end of first 32 days. At 100 days scales appear to be dense and non-adherent. There are stacks of hexagonal, tabular crystals. Purple and green scales and scattered white deposits at end of last 32 day test period. Some calcite deposits noted under beveled edge of PTFE washer and in occluded region between washer and PTFE tube. Selective leaching under washer, except for black corrosion products there is little evidence of corrosion.

TABLE XVI (Cont'd)

Material	Acceptability*	Observations
AMPCO 12 (Aluminum Bronze)	3	Purple-black scale at end of first 32 day test period, scale is generally dense and black at 100 days. At end of last 32 days scale was generally purple with areas of green scale and small yellow crust-like spots. Small, broad pits under crust. Slight localized corrosion under black scale. Slight selective leaching under PTFE washer.
AMPCO 483 (Aluminum Bronze)	3	Areas of black, purple and yellow scales at 32 days, black scale under lies yellow areas. Black scale is generally tightly adherent and overlies localized corrosion. Scattered calcite crystals under beveled edge of PTFE washer. Slight selective leaching under PTFE washer, also some pitting observed under washer.

* Class 1 - Those materials having best corrosion resistance.

Class 2 - Those materials having satisfactory corrosion resistance.

Class 3 - Those materials that will undergo severe selective corrosion attack.

Class 4 - Alloys having high corrosion rates.

Class 5 - Those materials having low corrosion-resistance to the environment.

4.0 ADVANCED HEAT EXCHANGERS

4.1 Liquid Fluidized Bed Heat Exchanger

C. A. Allen, A. F. Fanous, S. Fukuda, R. E. McAtee
Allied Chemical Corp., Idaho National Engineering Laboratory

The fluidized bed concept is being applied to prevent fouling on heat transfer surfaces when heat is transferred from geothermal fluids to working fluids such as clean water, fluorocarbons or isobutane. In this exchanger, geothermal water passes through the shell side and the working fluid through the tubes. The tubes are surrounded by a bed of particles, which is typically silica sand. The velocity of the geothermal agitates the particles which causes them to fluidize and the particle motion scrubs the heat transfer surfaces. This concept has been shown to prevent fouling and increases the heat transfer coefficient by approximately a factor or two.

4.1.1 Horizontal Configuration

Early experiments were conducted in vertical vessels. A horizontal unit was conceived which is simpler to build and with features more like conventional tube and shell units. In this case, the geothermal fluid flows vertically through the shell and the working fluid horizontally through the tubes, so the exchanger is of cross-flow design, from stage to stage (see Figures 15a and 15b).

A single stage test vessel unit and tube bundle were constructed of carbon steel. The vessel is 8 in. in diameter and 18 in. long. The tube bundle contains 49 tubes and is 15-1/2 in. long. A more detailed description appears in the previous report (TREE-1030, July 1 to September 30, 1976).

This vessel was installed on the Raft River test loop trailer and hydraulically tested to 150 psi. Problems were ecountered with the O-ring seal between the back tube sheet and the vessel. This was corrected by going to harder O-ring material. Several types of distributors were considered. The best result was obtained with a sandwich structure. The lower plate has 3/8 in. holes on 1 in. centers with a triangular pitch. The upper plate supports the bed and has 1/32 in. holes with 30% free area. A plume of bed material occurred in the center of the bed due to the outlet flow. This is created by uneven flow and results in non-uniform heat transfer and increases the probability of bed elutriation. This plume is associated with the outlet, since there are three inlets longitudinally along the bottom of the vessel, but the plume only appears under the single outlet. A retaining screen was mounted above the bed to keep the bed from slowly elutriating. The modifications are shown in Figure 15b.

Flow rate tests were run where the cooling water flow was held constant at 50 gpm which corresponds to tubeside velocity of 4.6 ft/sec and the geothermal flow rate was varied between 15 and 100 gpm. Bed material is silica sand closely screened to 1 mm in diameter.

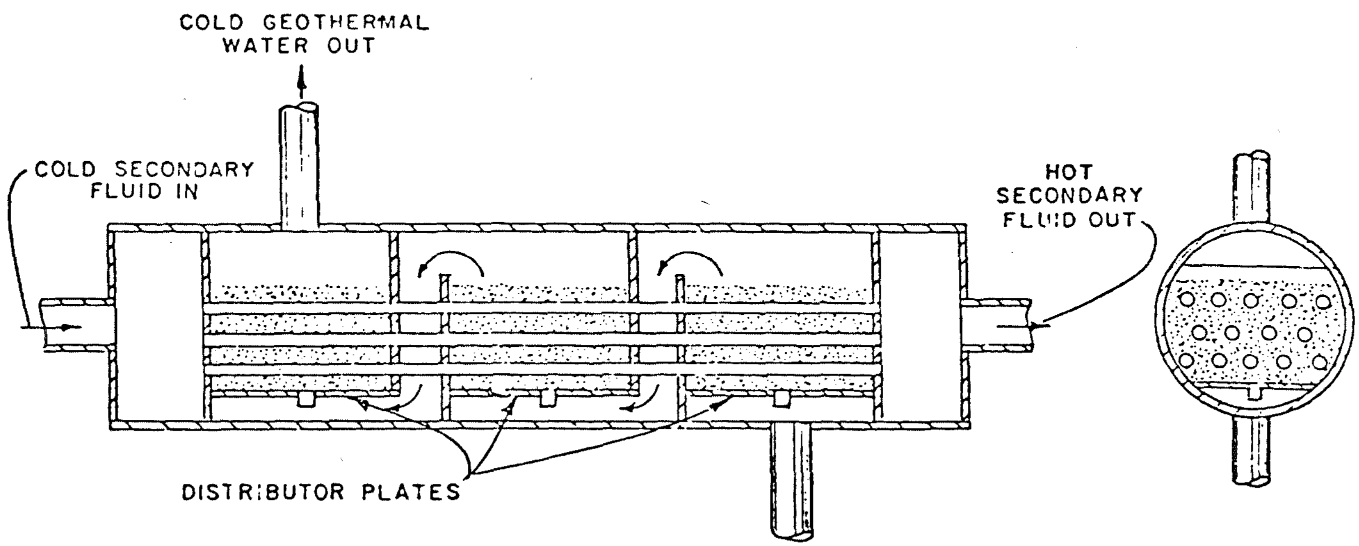

Fig. 15a Horizontal Configuration of Liquid Fluidized Bed

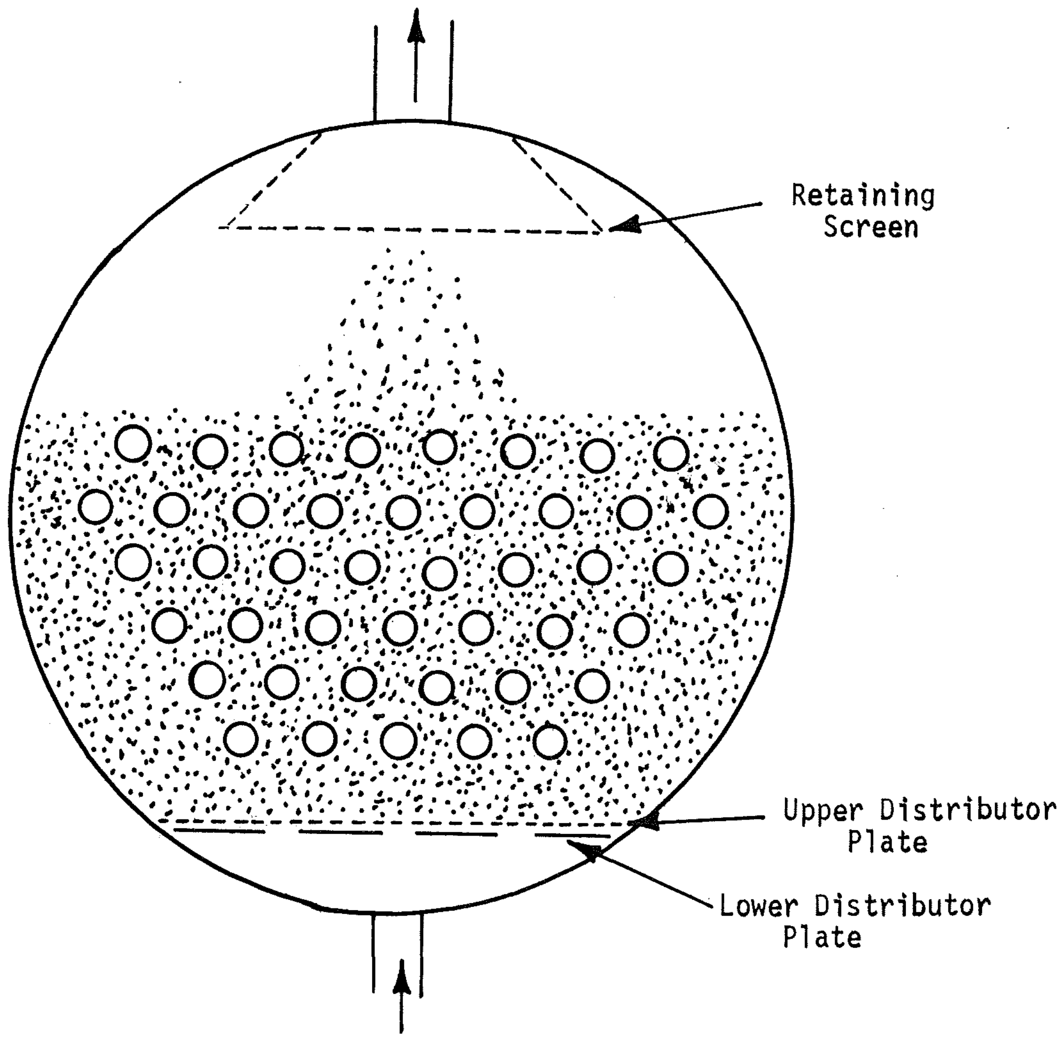

Fig. 15b Cross Section of the Horizontal Vessel Showing Distributor Plates, Retaining Screen, and Outlet Plume

Heat transfer coefficients were calculated and compared with similar experiments from vertical assemblies. (See Figure 16) At low flows, the bed to tube heat transfer coefficients (h_0) is slightly higher in the horizontal configuration. The vertical experiments were not carried to fluidizing velocities as high as the horizontal, but the pattern appears to be continuous.

A six week extended test is being conducted with corrosion coupons mounted above and in the bed. Various alloys are being tested including several stainless steels, a hastalloy and carbon steel. This experiment was terminated February, 1977, and results of the corrosion effects are now being compiled.

The vessel with an improved tube bundle was transported to the Geothermal Component Test Facility at East Mesa, Imperial County, California in March for a 90 day scale-control test. Wells in this area have greater scaling potential than the Raft River wells. Testing on this unit is scheduled to begin in early April.

4.1.2 Dimensional Analysis

Previous attempts to correlate liquid fluidized bed heat transfer data with existing correlations have proved fruitless. However, recent publications on liquid fluidized bed heat transfer provide several new equations to be tried. These equations do not pertain to bed to tube heat transfer, but with modifications they appear to approximate the data. They have the general form:

$$Nu = a \, Re_t^{\,b} \, Pr^c \, E^{-d} \, (E-1)^e \, \left(\frac{dp}{dt}\right)^f \qquad (1)$$

where

- Nu = Nussalt Number
- Re_t = Reynolds number at particle terminal velocity (the velocity which entrains the particles)
- Pr = Prandtl number
- E = Porosity
- dp = Particle Diameter
- dt = Distance between nearest neighbor tubes.
- a,b,c,d,e and f are constants.

Applied to data obtained from the horizontal experiments equation (1) becomes

$$Nu = (1.82 \pm 10\%) \left(\frac{dp}{dt}\right)^{0.2} Ret^{0.52} \, Pr^{1/3} \, E^{0.52m} (1-E)^{0.48} \text{ for } 14 < E > .76 \qquad (2)$$

where $m = \frac{8.85}{\log dp}$

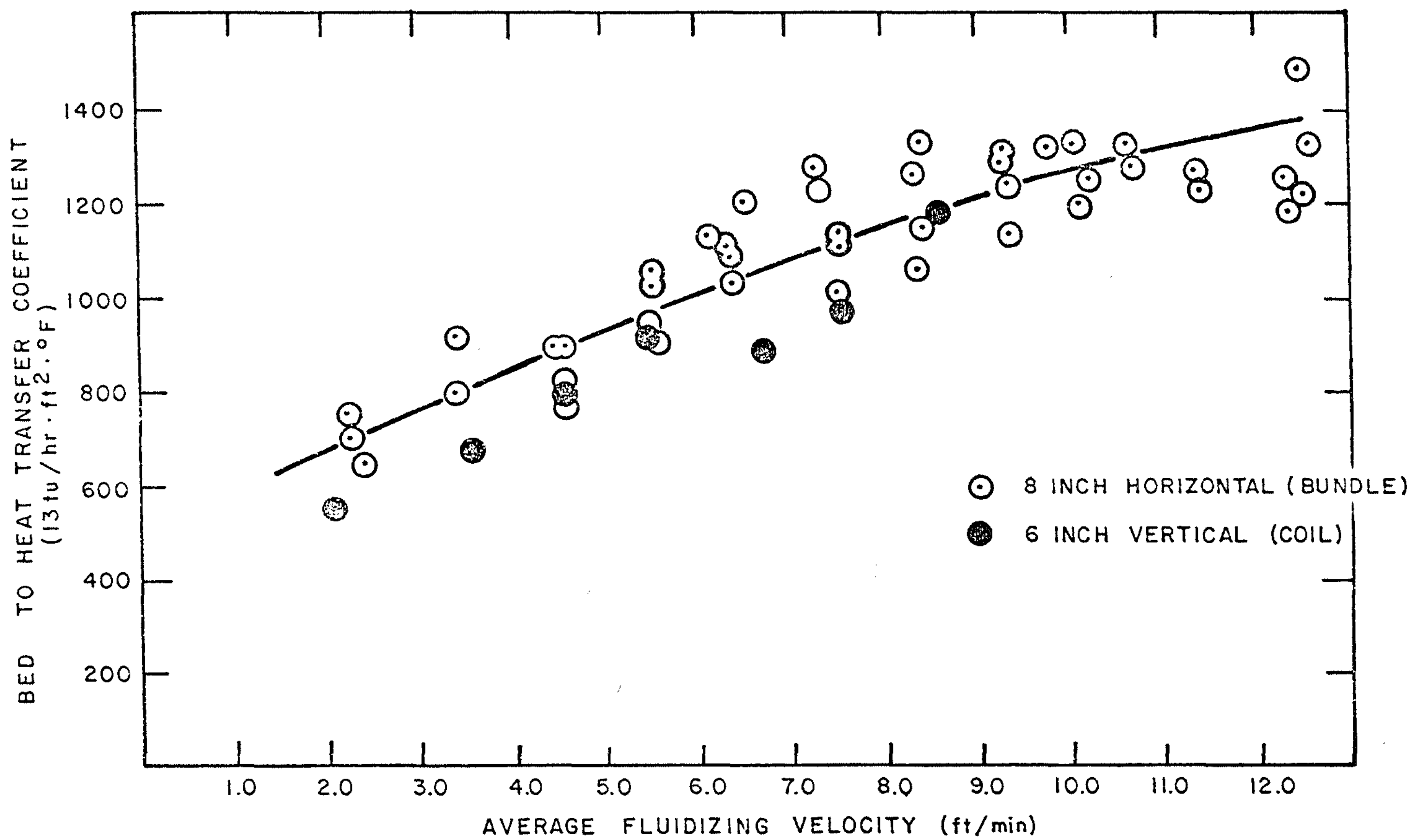

Fig. 16 Liquid Fluidized Bed Heat Transfer Data

There has been observed in all other liquid fluidized bed heat transfer experiments a maximum in the heat transfer coefficient. This has not been seen in these experiments probably because of the scarcity of data above 0.76 void fraction. This information is not readily available since the measurement capability is currently limited to this region. Assuming this system behaves like other liquid fluidized beds then above void fraction = 0.76 equation (1) would become:

$$Nu = (1.87) \left(\frac{dp}{dt}\right)^{1.2} Pr^{1/3} Ret^{0.52} E^{0.48m} (1-E)^{0.52} \quad 0.76<E<1$$

The experimentally determined bed to tube heat transfer coefficients are displayed along with the curves generated from equations (2) and (3) in Figure 17.

4.1.3 Preliminary Size-Cost Analysis

Prior to further development of liquid fluidized bed heat exchangers it was important to determine the cost of a LFB unit relative to conventional tube and shell units. This first cut effort was based on the low pressure preheater intended for installation in the 5MW electric Thermal Loop designed for Raft River. Properties of the fluids are described in Table XVII.

TABLE XVII

Comparison Design Data on Fluidized Bed and Tube-in-Shell Heat Exchangers

	Shell Side	Tube Side
Fluid Circulated	Liquid Geothermal Fluid	Liquid Isobutane
Mass Flow Rate, lb/hr	1,040,000	934,000
Liquid Density, lb/ft^3	60.8	31.3
Liquid Viscosity	0.9047	0.2718
Liquid Specific Heat, btu/lb. deg. F	1.000	0.676
Temperature in, °F	190	105
Temperature out, °F	144	180
Operating Pressure, psia	150	410
Velocity, ft/sec	0.25 (intriasic value)	8
Fouling Resistance, hr. ft^2. deg. F/btu	0	0.001
Heat Exchanger btu/hr	47,200,000	47,200,000

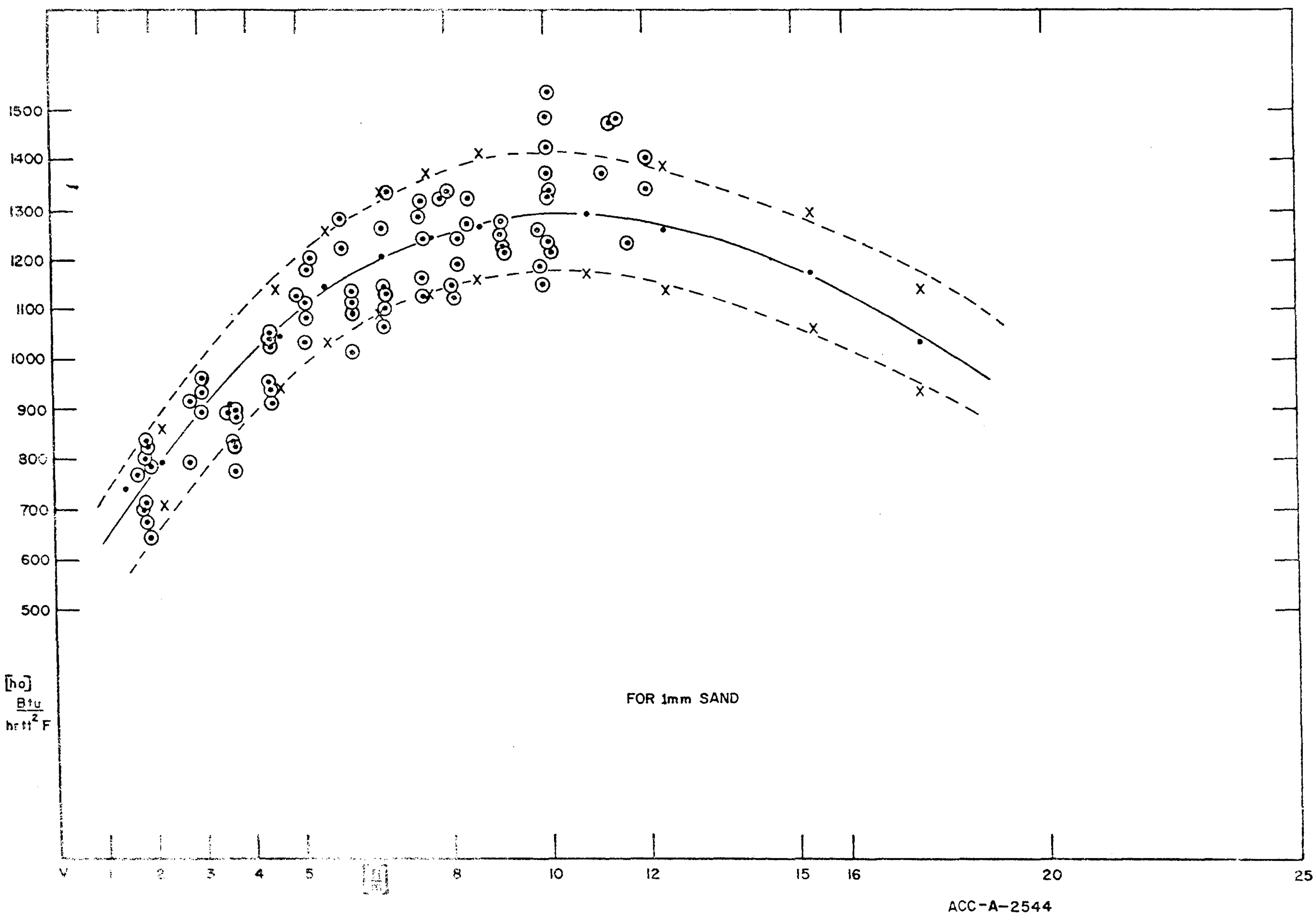

Fig. 17 Experimentally determined bed to tube heat transfer coefficients.

Several assumptions were made for this cost analysis as follows:

1) Average size of sand particles = 3 mm.

2) Number of stages = 6

3) Velocity of liquid isobutane = 8 ft/sec

4) Velocity of geothermal fluid between tubes, at entrance or at exit does not exceed 75% of the terminal velocity.

5) The shell side heat transfer coefficient (h_o) was based on the superficial velocity, defined as:

$$V_S = \frac{\text{Geothermal Fluid Volumetric Flow}}{\text{Shell Longitudinal Cross-Sectional Area at Diameter}}$$

6) Tubeside heat transfer coefficient (h_i) = 250 btu/hr. ft^2. °F

No attempt was made to optimize any of these parameters. All of the assumptions will lead to a conservative cost estimate.

Standard calculations were used to generate values for heat transfer area, shell diameter and length and number of tubes. A standard formula based on the heat transfer area was used to calculate the cost. In this calculation each stage was assumed to be a separate exchanger so the total cost is the sum for six exchangers in the fluidized bed case.

Two parmeters were varied in these calculations. Five tube diameters from 3/8 inch to 3/4 inch were investigated. Pitch to tube diameter was varied between 1.5 and 2.5. This ratio is larger than normally seen in conventional units, because of the requirement that the distance between tubes must be several times greater than the particle diameter. Results of these calculations for fluidized bed exchangers are shown in Table XVIII and a conventional tube and shell unit size and cost is shown in Table XVIX.

Based on these calculations, three conclusions can be drawn, but with the reservation that the liquid fluidized bed unit design is not necessarily optimized for minimum cost.

1) In fluids of low scaling potential like Raft River, the cost of liquid fluidized bed and conventional heat exchangers are comparable.

TABLE XVIII

OVERALL DIMENSIONS AND ESTIMATED COST OF FLUIDIZED BED HEAT EXCHANGER

Tube O.D. Inches	No. of Stages	No. of Tubes	Ratio Pitch Tube O.D.	Overall Heat Transfer coeff. btu/hr ft^2 deg.F	Heat Transfer Area Per Stage ft^2	Effective Length of Tubes Per Stage Feet	Shell I.D. Inches	Estimate Cost Thousand Dollar
			1.50	131	2920	26.7	38	128
			1.75	127	3014	27.6	45	136
3/4	6	557	2.00	124.5	3081	28.2	51	160
			2.25	117	3274	29.9	57	165
			2.50	111	3438	31.4	64	166
			1.50	135	2842	22.9	38	128
			1.75	130	2951	23.6	44	135
5/8	6	775	2.00	125	3065	24.2	50	143
			2.25	119	3230	25.5	57	157
			2.50	116	3308	26.6	63	161
			1.50	143	2685	18.8	35	128
			1.75	139	2766	19.4	41	132
1/2	6	1028	2.00	135	2847	19.9	46	136
			2.25	128	2990	20.9	52	143
			2.50	120	3198	22.6	58	154
			1.50	145	2646	14.7	35	127
			1.75	141	2741	14.3	41	128
3/8	6	1867	2.00	135	2843	15.6	47	136
			2.25	131	2952	15.9	53	136
			2.50	125	3069	17.3	58	143

(Average sand particle size = 3 mms)

TABLE XVIX

OVERALL DIMENSIONS AND ESTIMATED COST OF CONVENTIONAL HEAT EXCHANGER

(For Comparison)

Tube O.D. Inches	No. of Stages	No. of Tubes	Ratio Pitch Tube O.D.	Overall Heat Transfer coeff. btu/hr ft^2 deg.F	Heat Transfer Area ft^2	Effective Length of Tubes Feet	Shell I.D. Inches	Estimated Cost Thousand Dollars
3/4	1	1634 (two tube passes)	1.25	51.8	42779	54 (two tube Passes)	50 (two shell passes)	133
		817 (theoretical single pass)				108 (theoretical single pass)	36 (theoretical single pass)	

2) Shell size of a liquid fluidized bed unit will be nominally 50% larger than the conventional unit.

3) Liquid fluidized bed heat exchangers require nominally less than half the heat transfer tube surface of conventional tube and shell exchangers.

4.2 Direct Contact Heat Exchangers

R. J. Boehm and H. R. Jacobs - University of Utah

The work on direct contact heat exchangers and condensers involved activity at the University of Utah, at the Raft River Geothermal Site, and at the University of Strathclyde where Professor Boehm is in temporary residence.

4.2.1 Boiler Testing at the Raft River Site

Construction of an ASME coded vessel for the large scale direct contact boiler testing was initiated and completed during the reporting period. While the new vessel was being constructed the remainder of the remotely-controlled direct contact loop was installed at the Raft River Test Site and operated at low pressures (using another boiler vessel) using R-113 as the working fluid.

The remote control and sensing systems proved to work very satisfactorily. Operation of the system is extremely smooth and stable and requires a minimum of operator monitoring. The new system has been in operation for four weeks without any significant problems.

The tests with R-113 as a working fluid had two major objectives: checkout and debugging of the new apparatus and an investigation of the residence time required in a surface boiler tray to effect complete boiling of the working fluid. As already mentioned, the system works well and is ready for use with pentane as soon as the coded vessel is installed. The residence time study was performed with a rectangular tray which permitted independent variation of the brine flow rate and residence time. With a constant depth of brine in the tray, the brine flow rate was adjusted until boiling of the maximum allowed (from an energy balance, see the previous quarterly report) quantity of R-113 was achieved just before the brine passed over the weir of the tray. The residence time required to permit boiling of the minimum allowable brine/fluid mass ratio was then used to design a circular tray using a radial "source flow" pattern for the brine. This tray operation exceeded the design specifications in that it achieved complete boiling of the R-113 at higher mass flow rates than expected. These residence time requirements for R-113 boiling will be compared with those for pentane when the new boiler is installed.

The new 600 psi coded pressure vessel has been delivered to the Raft River site and is currently being installed. The new system will be operated using pentane as the working fluid as soon as the safety engineers approve the final review. Testing of the pentane loop in Idaho will be directed at determining the boiling characteristics of the lighter-than-water fluid (for comparison with R-113) and completing system checkout before moving the equipment to the East Mesa site in California during the summer.

A direct contact preheater for use with pentane in the Imperial Valley experiments has also been designed in the past quarter. The preheater is a direct contact column using rotating disc and baffle plate internals. A drawing of the preheater is shown in Figure 18. The unit is currently under construction in the College of Engineering machine shop.

4.2.2 Direct Contact Condensers

With the utilization of direct contact devices for the preheating and boiling functions of the binary cycle, the conventional shell and tube condenser becomes the single largest piece of capital equipment in a plant. Consideration is thus being given to the use of direct contact condensers. Uncertainties regarding this application can be grouped in three categories:

1. Possible increase or decrease in heat transfer efficiency

2. Possible decrease or increase in capital investment

3. Possible penalties for use of closed cooling towers

During this quarter, work has begun on defining item 1.

While at the University of Strathclyde, H. R. Jacobs has evaluated the various direct contact condenser schemes reported in the literature. Although little work directed toward the present application (hydrocarbon being condensed by water) has appeared, he has written a review paper (Jacobs, 1977) on the related work that is reported. Three aspects are evaluated:

1. Types of equipment that might be used for a binary cycle direct contact condenser

2. Design methods for direct contact condensers

3. Research needs

Jacob's survey covered the three basic mechanisms for direct contact condensation: condensation on a film, condensation on a drop and condensation of a bubble in a bulk fluid. Two concepts were singled out for offering the most potential. These are the bubble type direct contact condensers and the packed bed direct contact condensers. The first concept involves the injection of the working fluid vapor in a column of water and this is being tested in benchscale tests at the University of Strathclyde. In the second concept water flows downward over a packed bed while the vapor flows upward through the bed. Benchscale experiments are being planned on this latter configuration for the University of Utah. Laboratory data, design methods and economic feasibility will be evaluated for the two types of devices and relative comparisons will be made.

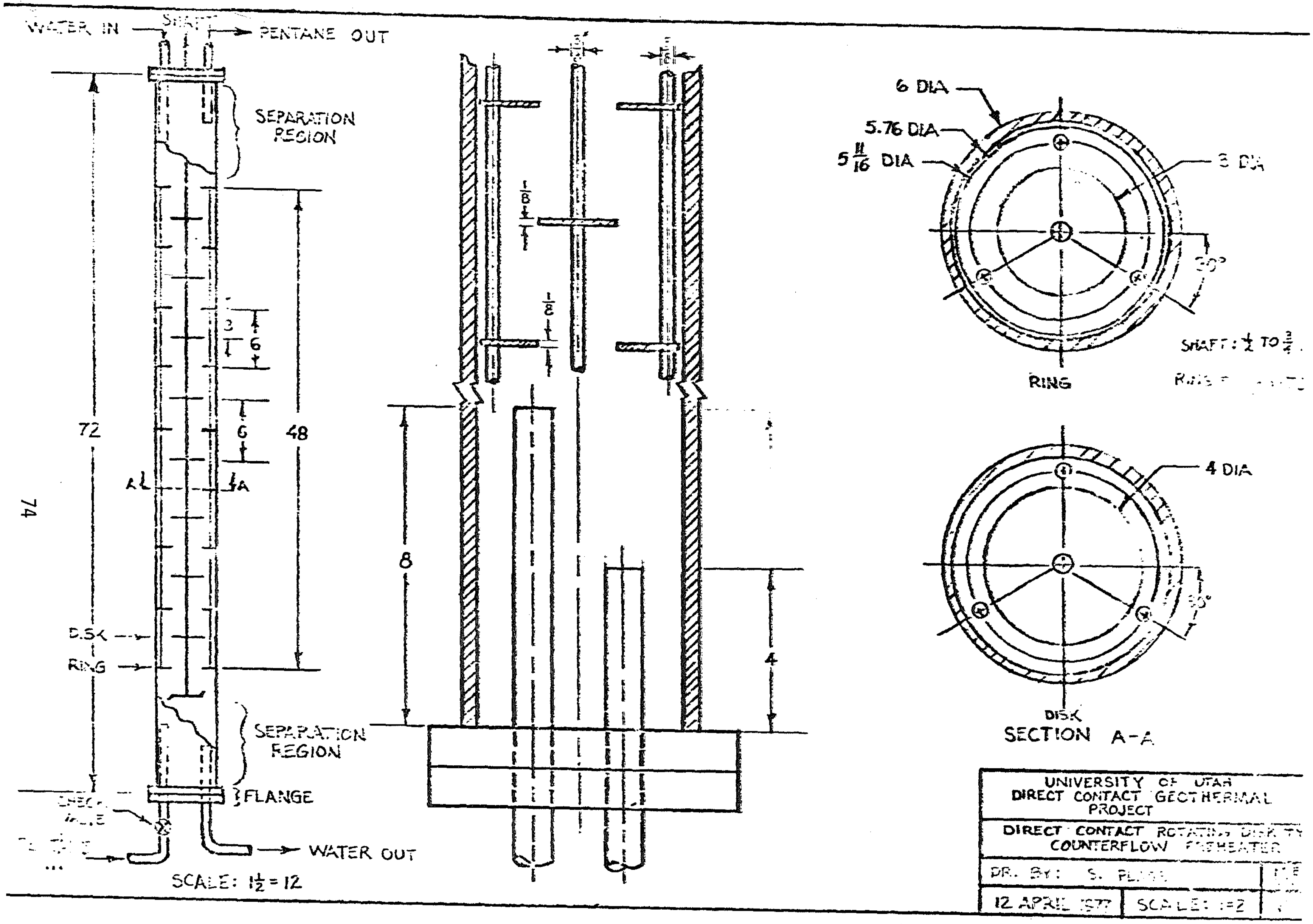

Fig. 18 Rotating disc type direct contact preheater

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4.2.3 Systems Analysis

Systems analysis has proceeded on two fronts. Cycle thermodynamic performance has been calculated for a wide variety of conditions for sensitivity studies. More important, an economic analysis and engineering design of a net 50 MWe demonstration plant for both direct contact and tube-and-shell heat exchangers has been performed. The study was performed by Ford, Bacon and Davis, Utah, Inc., in cooperation with the University of Utah (Harris, et al., 1977).

Some results of the cycle analyses are shown in Figures 19 and 20. Figure 19 shows the optimum Thermodynamic Figure of Merit* that can be achieved in cycles using n-Pentane, Isobutane and R-113 as the working fluids. It can be seen that at relatively low geothermal source temperatures the three fluids all yield the same thermodynamic performance. As the source temperature increases, isobutane shows slightly higher efficiency and R-113 shows poorer efficiency than n-Pentane. Of course, cycle efficiency cannot be the sole consideration in fluid selection. Figure 20 shows the importance of condenser temperature to operating an efficient cycle. As the condenser temperature rises the thermodynamic efficiency of the cycle decreases markedly.

The flowsheet for the demonstration direct contact plant analyzed by Ford, Bacon and Davis is shown in Figure 21. The results of the economic analysis indicate the direct contact system is more economical than a conventional shell-and-tube system on an installed capital basis but that total power costs are about equal for both systems. The cycles using isobutane as the working fluid and assumed a 149°C (300°F) source temperature. Optimum cycle conditions were determined by the University of Utah using the computer program DIRGEO.

The high operating costs for the direct contact cycle were a direct result of isobutane loss due to solubility. The analysis assumed fluid losses were the maximum possible as calculated using equilibrium solubility data. These losses, in an actual direct contact cycle, would be significantly reduced because equilibrium solubility levels will probably not be achieved in the brine and because it has been found that application of simple techniques (discussed in more detail in the next section) will recover much of the working fluid from solution. Thus, it appears that a direct contact cycle will be more economical on both installed capital and total power cost bases.

The Ford, Bacon and Davis study also compared the relative costs of an isobutane cycle and a pentane cycle. It was concluded that a pentane cycle has both a $54/kW capital cost and a 2.02 mills/kWh lower operating cost. This is a result of lower operating pressures, lower fluid flow rate, and lower fluid loss rate.

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* Thermodynamic Figure of Merit is a dimensionaless measure of net power output divided by the brine flow rate.

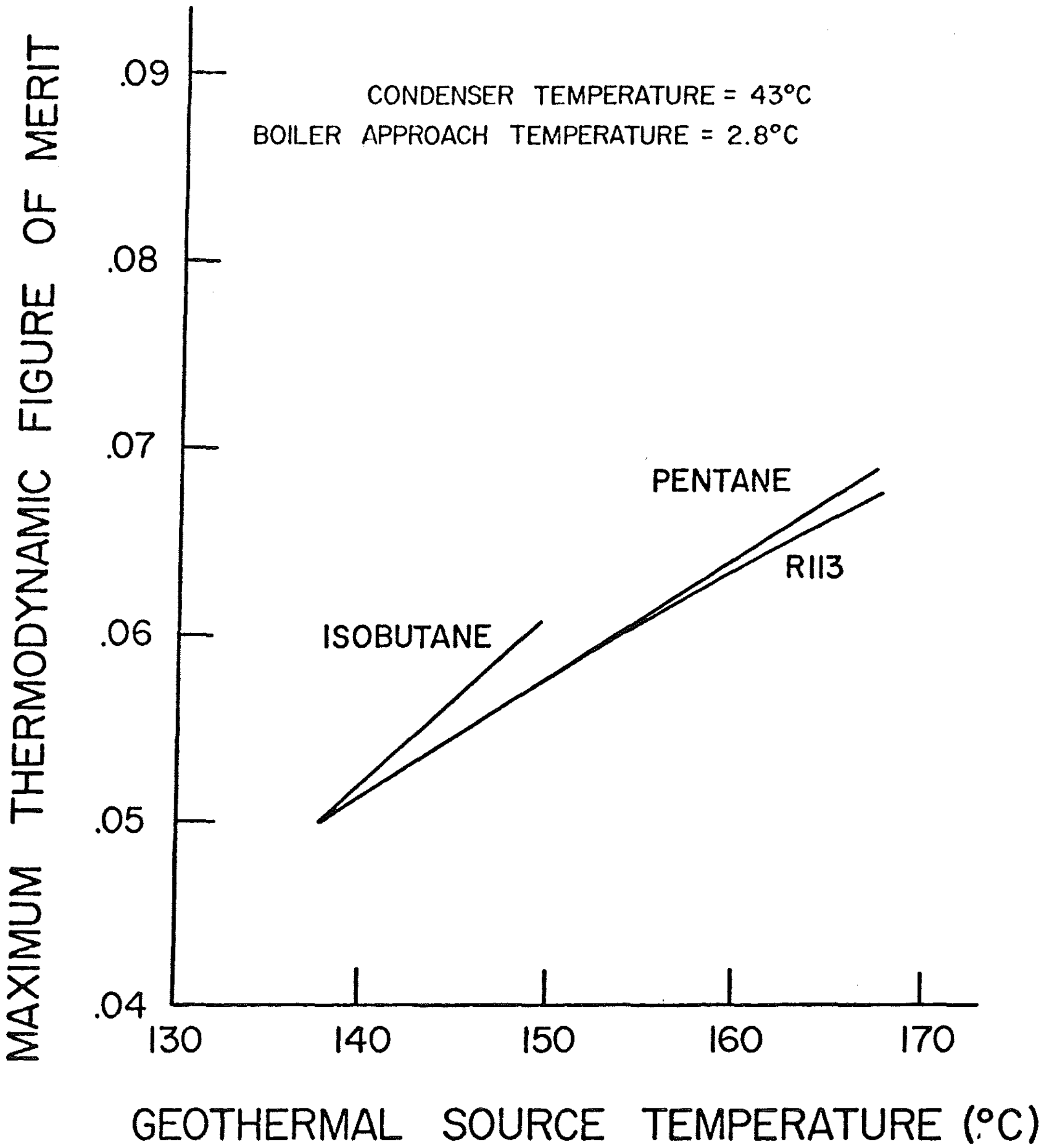


Fig. 19 Optimum Thermodynamic Figure of Merit as a function of geothermal source temperature for three different working fluids.

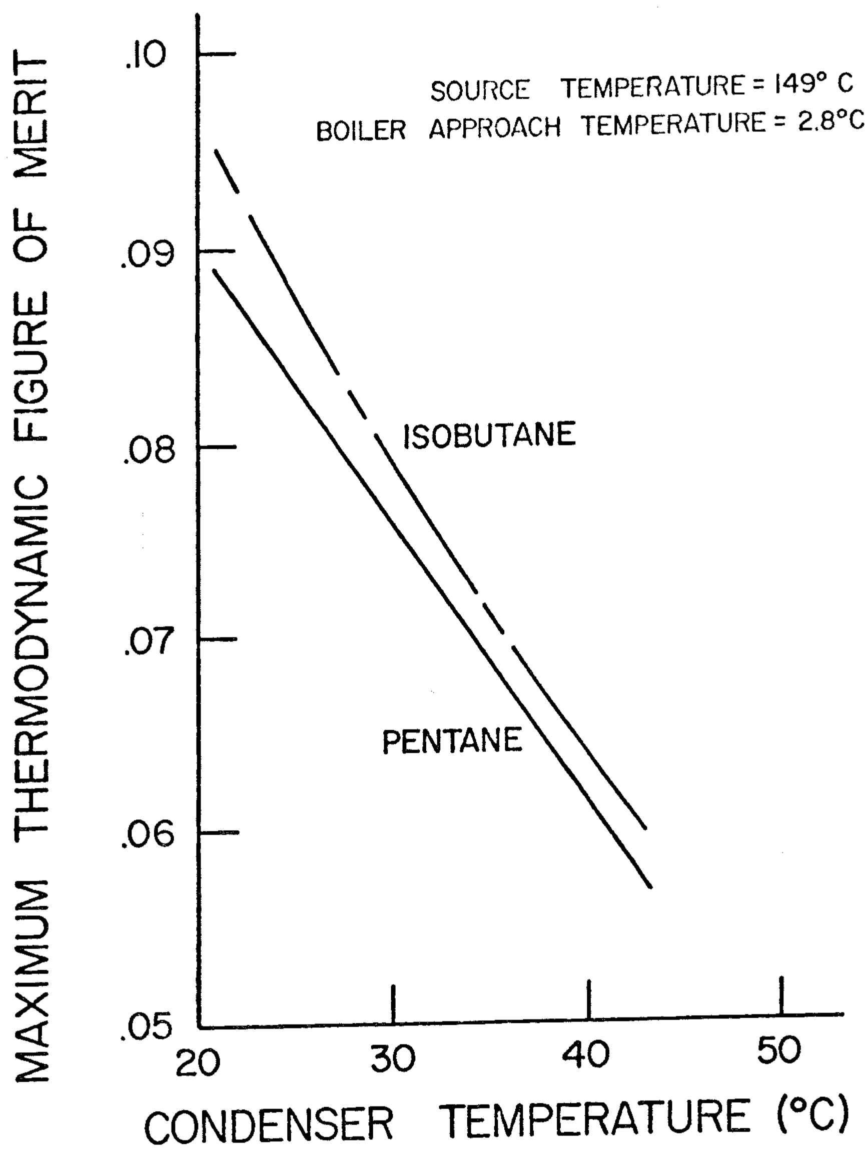
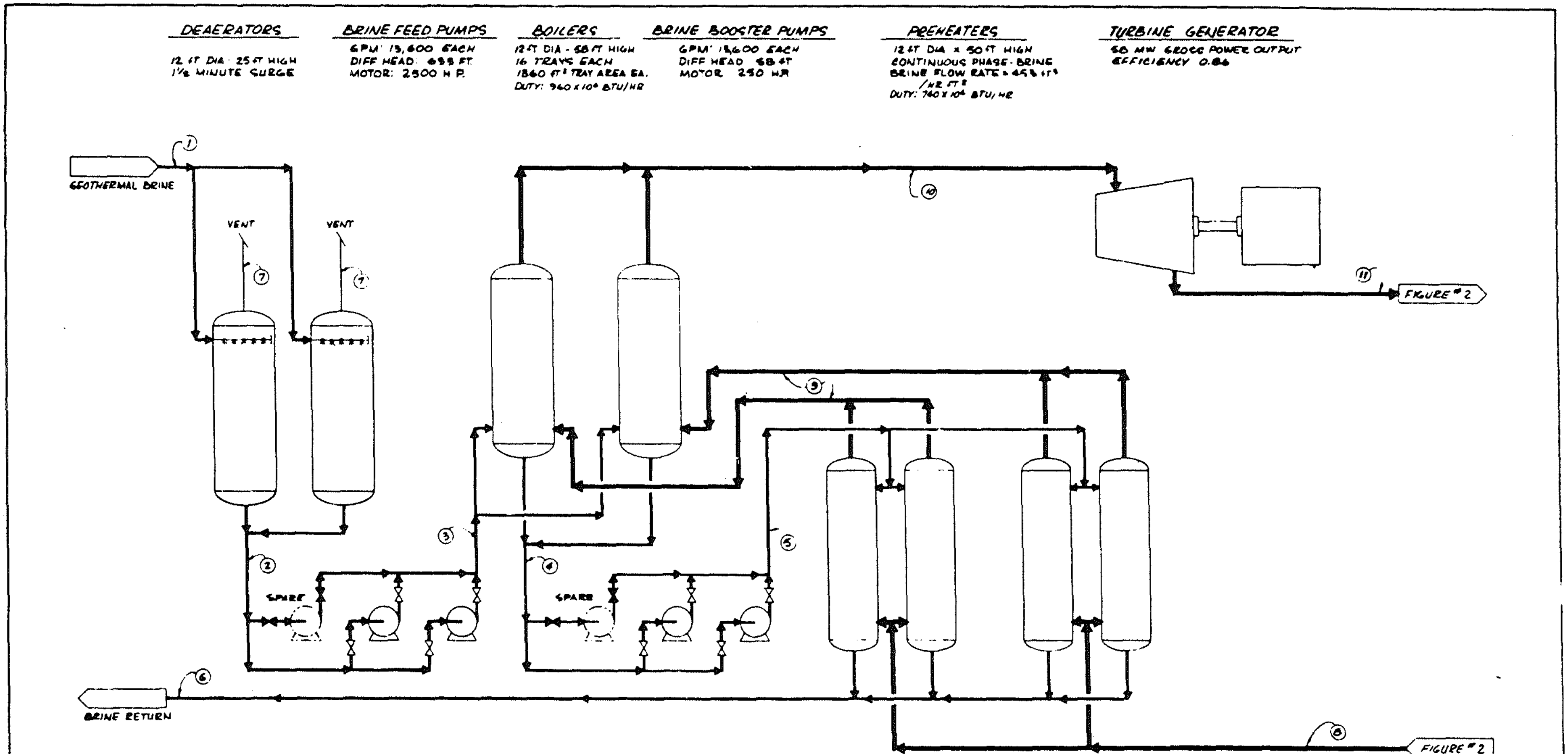


Fig. 20 Effect of condensing temperature on direct contact binary cycle performance.

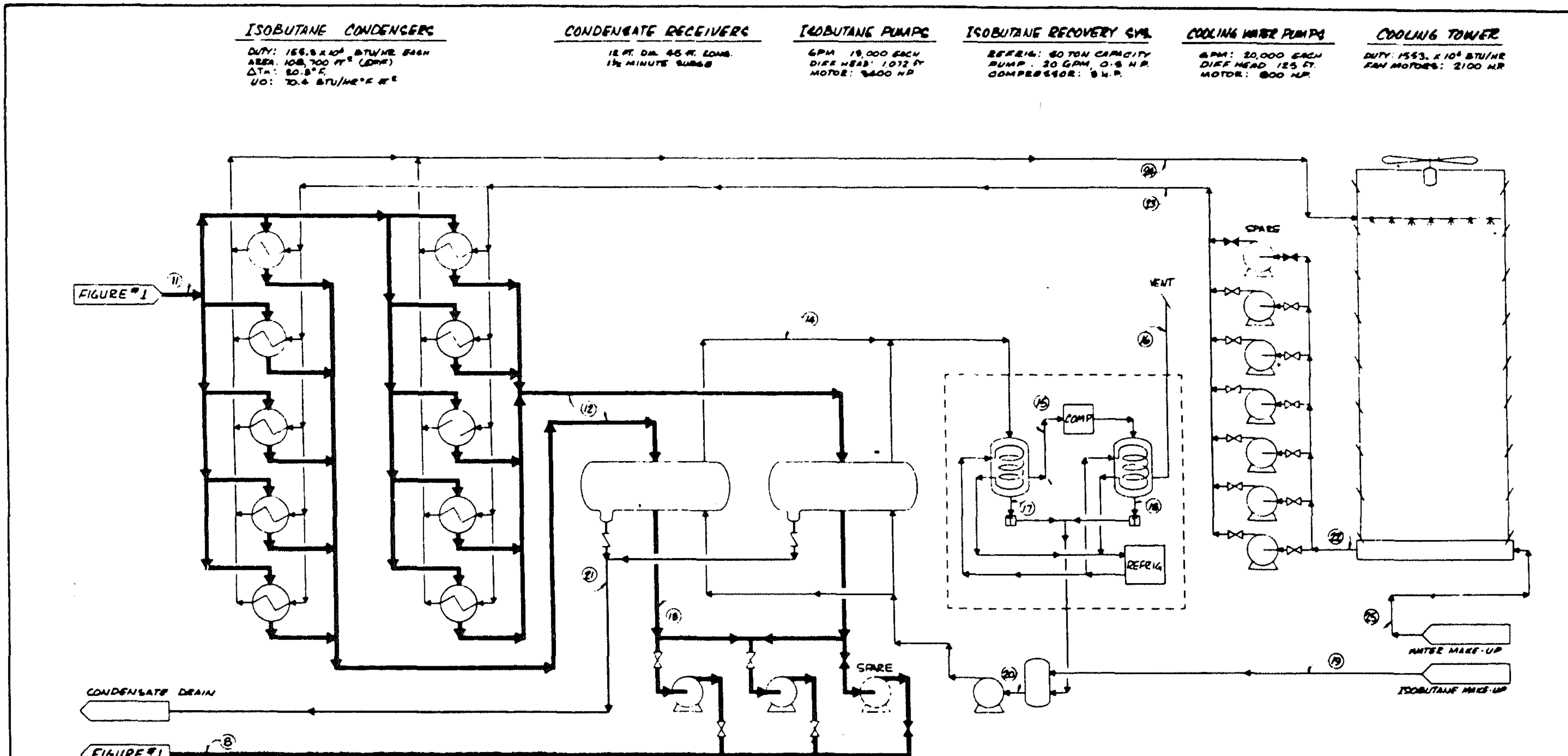


STREAM NO	1	2	3	4	5	6	7	8	9	10	11
TEMPERATURE °F	302	300	300	220	220	160	300	106	214	215	157
PRESSURE PSIA	100	72	340	325	343	315	65	335	320	317	85
GEOTHERMAL BRINE #/HR.	12.49 x 10⁶	12.46 x 10⁶	12.46 x 10⁶	12.35 x 10⁶	12.35 x 10⁶	12.35 x 10⁶	.027 x 10⁶	—	—	.108 x 10⁶	.108 x 10⁶
ISOBUTANE #/HR.	—	—	—	3900	3900	2800	—	9.98 x 10⁶	9.98 x 10⁶	9.98 x 10⁶	9.98 x 10⁶
NON-CONDENSABLES #/HR.	?	125	125	—	—	—	?	—	—	125	125
TOTAL #/HR.	12.49 x 10⁶	12.46 x 10⁶	12.46 x 10⁶	12.35 x 10⁶	12.35 x 10⁶	12.35 x 10⁶	.027 x 10⁶	9.98 x 10⁶	9.98 x 10⁶	10.008 x 10⁶	10.008 x 10⁶
GPM @ TEMP & PRESSURE	27,175	27,100	27,110	25,790	25,790	25,240	GAS	37,700	46,600	GAS	GAS (10,420)

FIGURE # 1

PROCESS FLOW SHEET
41.2 MW GEOTHERMAL POWER GENERATING UNIT
DIRECT CONTACT HEAT EXCHANGE - BINARY CYCLE

Fig. 21 Flowsheet for cycle economic analysis.



STREAM NO.	8	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
TEMPERATURE °F	106	137	106	106	110	35	35	35	35		35	106	74	74	100	—
PRESSURE PSIA	335	85	85	90	85	75	200	75	200		65		15	70	—	—
GEOTHERMAL BRINE #/HR	—	.108 x 10⁶	.108 x 10⁶	—	—	—	—	—	—	—	—	.108 x 10⁶	—	—	—	—
ISOBUTANE #/HR	9.98 x 10⁶	9.98 x 10⁶	9.98 x 10⁶	9.98 x 10⁶	2190	85	25	2105	60	525	2690	2	—	—	—	—
NON-CONDENSABLES #/HR	—	125	125	—	125	125	125	—	—	—	—	—	—	—	—	—
TOTAL #/HR	9.98 x 10⁶	10.088 x 10⁶	10.88 x 10⁶	9.98 x 10⁶	2,315	210	150	2105	60	525	2690	.108 x 10⁶	59.7 x 10⁶	59.7 x 10⁶	59.7 x 10⁶	1.85 x 10⁶
GPM @ TEMP & PRESSURE	37,700	GAS & LIQ H₂O	37,900	37,700	GAS	GAS	GAS	7.5	0.2	1.9	9.6	216	119,400	119,400	119,400	3,700

REVISIONS | DATE | BY | CH'D | APP'D | NO | REVISIONS | DATE | BY | CH'D | APP'D | DRAWING NO | REFERENCE DRAWINGS | ISSUE RECORD | ENGR RECORD

FIGURE #2

Ford, Bacon & Davis Utah Inc
ENGINEERS · CONSTRUCTORS
SALT LAKE CITY, UTAH

PROCESS FLOW SHEET
412 MW GEOTHERMAL POWER GENERATING UNIT
DIRECT CONTACT HEAT EXCHANGE-BINARY CYCLE

Fig. 21 (continued)

4.2.4 Working Fluid Loss Considerations

Studies have been underway to determine the feasibility of recovery of working fluid from solution in the spent brine. Sparging techniques have been investigated experimentally and flash expansion recovery techniques have been investigated theoretically.

The effectiveness of CO_2 sparging has been examined using the same gas chromatograph techniques used earlier to determine equilibrium solubility levels of working fluids in salt solutions. Preliminary results indicate that bubbling a volume of CO_2 (of the same order as the volume of brine) through a brine-pentane solution will reduce the amount of pentane in solution from the equilibrium value to a value too small to be detected. Thus it appears that gas sparging shows promise and warrants further investigation. Measurements of pentane concentration in aqueous solution as a function of time for various CO_2 flow rates are continuing.

Calculations have been performed that demonstrate the feasibility of using flash expansion to recover working fluid from the spent brine. These calculations are detailed, together with previous solubility measurements, in a paper accepted for presentation at the Geothermal Resources Council meeting in May (Boehm et al., 1977). It has been found that expanding the spent brine to the condenser pressure will recover a high proportion of the working fluid. Figure 22 shows working fluid solubilities as a function of brine outlet temperature for four candidate working fluids. Pentane shows the lowest fluid solubility and hence, from a fluid loss standpoint, is the most desirable working fluid.

Working fluid is also lost when non-condensible gases are vented from the condenser. The Ford, Bacon and Davis study determined that this loss can be reduced to a very acceptable level by incorporating two additional features in the power cycle. First, the brine entering the plant must be flashed to one or two psi below its saturation pressure to strip the bulk of the non-condensibles from the brine. The bases remaining in the brine will come out of solution in the boiler and collect in the condenser. Thus, the second step is to put a gas recompression and refrigeration unit on the condenser vent to recover working fluid vapor that is vented with the non-condensibles. These two simple procedures result in little cycle penalty and reduce a major source of fluid loss to an insignificant level.

4.2.5 Preheater Analysis

Prior to September 1976, the only preheater routines developed and included within the system analyses were for the parallel flow stratified liquid heat exchanger. During the period October-December 1976, design techniques for spray towers, sieve plate towers, baffle towers, mechanically agitated towers, wetted wall towers and turbulent pipe mixers were investigated. The subroutines for all of these various types of heat exchangers are now being written. A paper based on this work was prepared and has been submitted to the 1977 National Heat Transfer Conference. (A

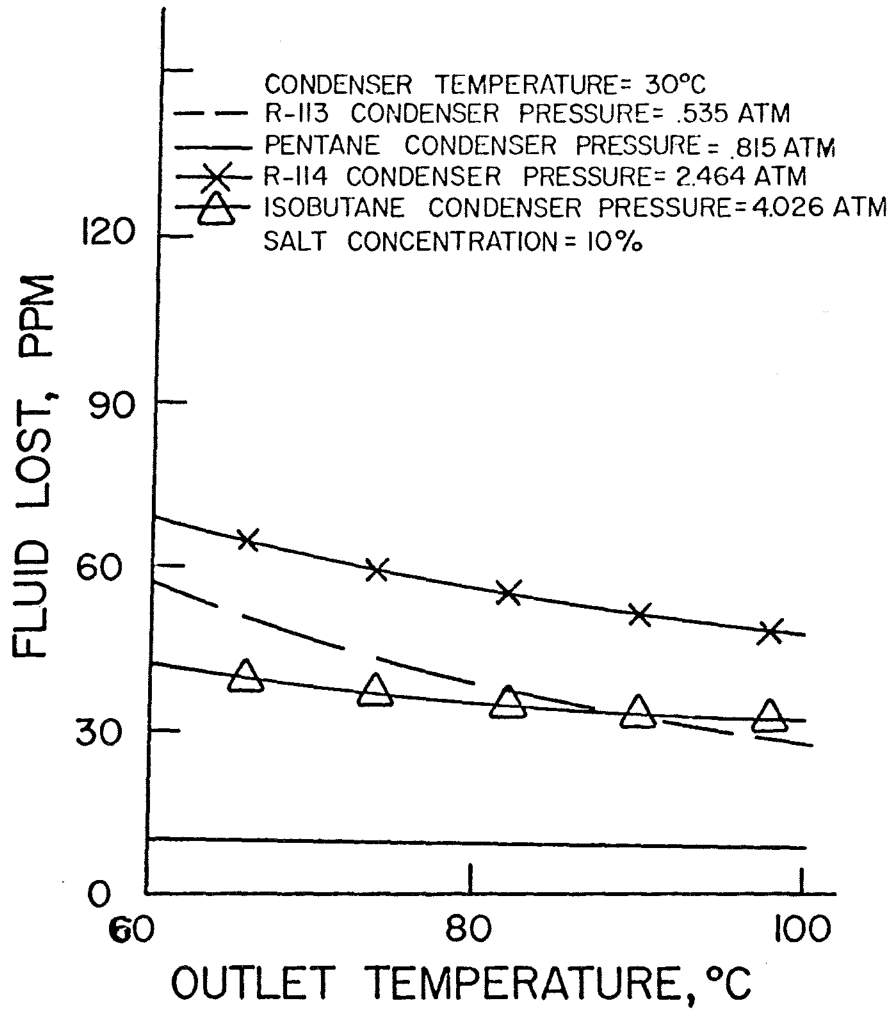


Fig. 22 Working fluid solubilities in 10% NaCl solution.

copy is attached as Appendix A) The results of the study indicate that baffle towers and mechanically agitated towers appear best suited for highly fouling brines. Sieve towers appear reasonable for low fouling brines. Spray towers appear reasonable for large height to diameter ratios; however, single units for a typical power plant would specify a small height to diameter ratio and thus be susceptable to considerable back mixing. This could be partly avoided by the inclusion of longitudinal baffles.

4.2.6 Condensers

The computer search of the literature on direct contact condensers in Britain has been completed. The results indicate that little work has been published for fluid systems other than steam-water. Primarily, the work published has dealt with barometric type condensers although work utilizing a packed bed has been carried out at the University of California for condensing Aeroclor with water. The literature on the packed bed indicates volumetric heat transfer coefficients as large as 60,000-100,000 Btu/hrft^3 ^{o}F have been obtained, but little of the exact flow conditions was cited. Sideman and others have indicated that the best performance ought to be obtained by injecting the vapor into a liquid. This should reduce the volume several times as compared to a barometric condenser for the same heat duty. Based on this, Mr. Heimer Fannar has constructed a "spray type" tower for determining bubble heat transfer rates during condensing. This work should yield correlation information on bubbles condensing in liquids. Mr. Fannar's work is utilizing pentane.

H. R. Jacobs has started some preliminary calculations of condenser sizes for barometric condensers and packed columns so that comparisons can be made with these systems and the work of Fannar at a later date. His work is based on some simple theoretical models. These models indicate that for vapor condensing on drops a high conductivity, high specific heat material should be used for the spray. Thus, the direct contact "barometric" condenser is being designed for the working fluid condensing on water drops. Calculations will be made for R-113, isobutane and isopentane.

4.2.7 Pentane Loop

The field work is now directed towards the construction and operation of a direct contact heat exchanger utilizing pentane as the secondary fluid. A flow diagram of the system for use at Raft River is shown in Figure 23.

The main components of the loop are as follows: a boiler, a brine booster pump, a pentane booster pump, an air-cooled condenser, a gravity type separator, a liquid pentane transfer pump, a transfer vessel, a preheater and a pentane vapor detection system.

The test element of the hardware is the boiler in which liquid pentane is sprayed directly onto the hot geothermal brine. The brine is contained in a circular tray (Figure 24)* and enters by means of a central orifice fixed to the bottom of the tray. The brine flows out radially from the center of

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* Alternate tray configurations are also available.

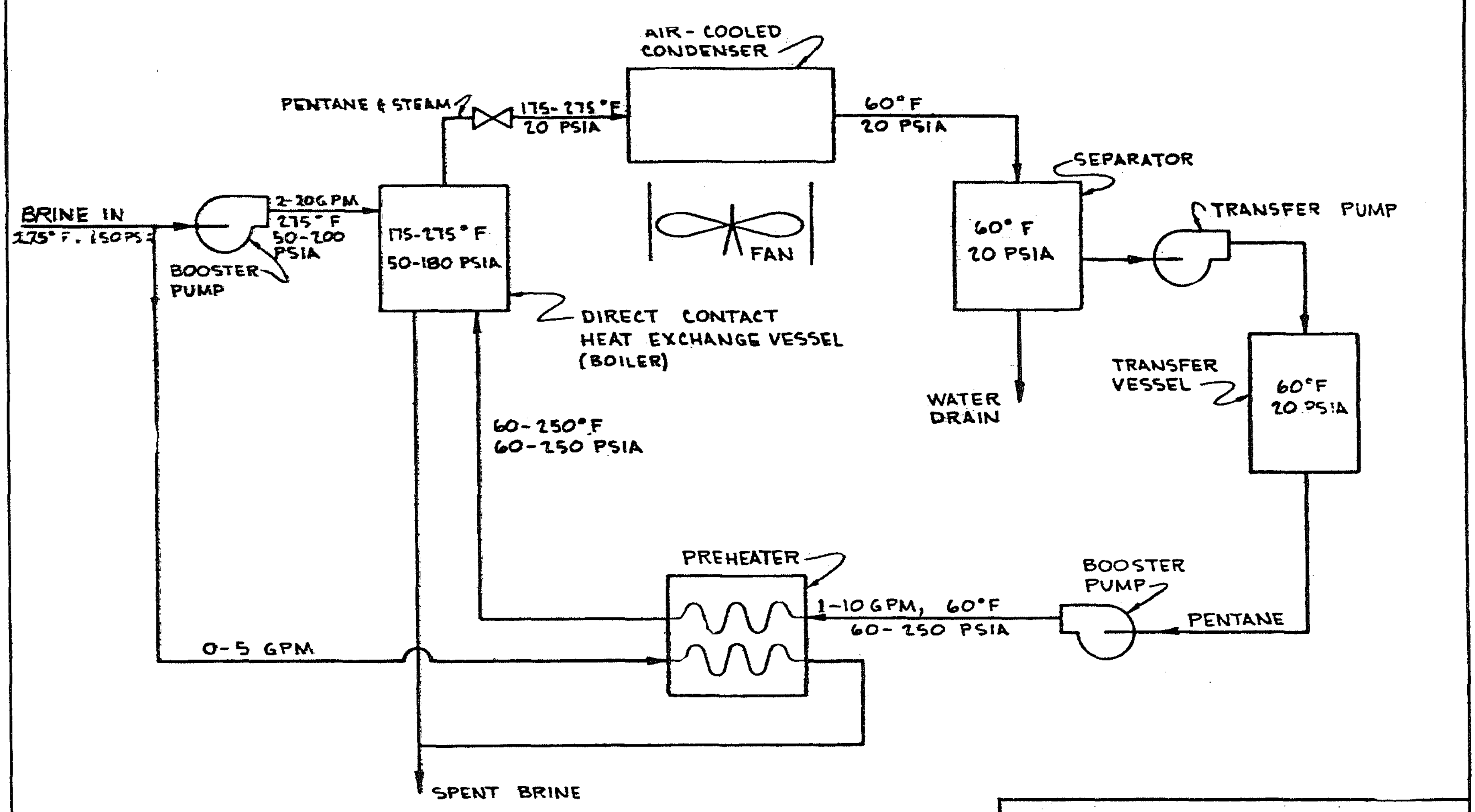
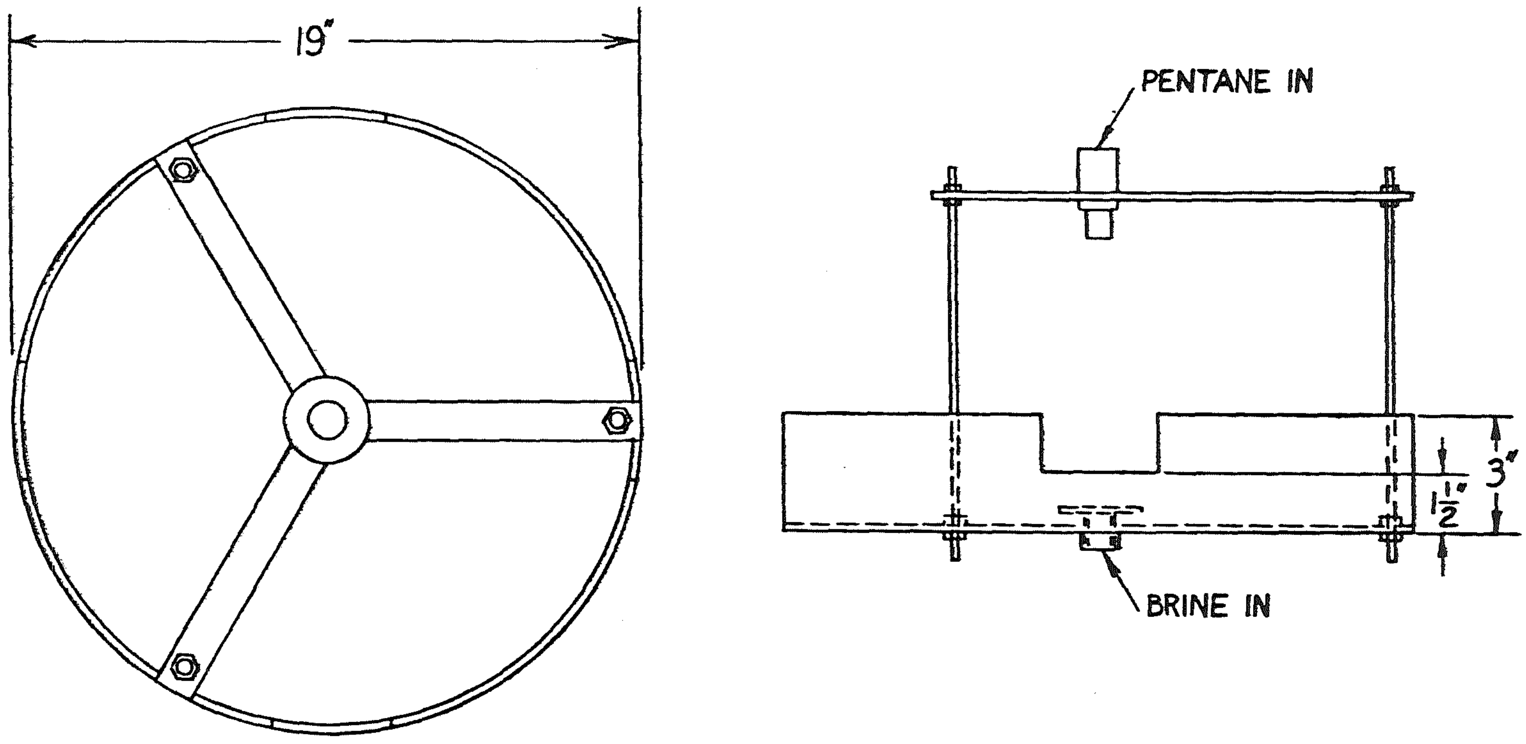


Fig. 23 Direct Contact Heat Exchanger Pentane Loop



ELEVATION

PLAN

UNIVERSITY OF UTAH	
SCALE: NONE DATE: 1-13-77	Cook
DIRECT CONTACT HEAT EXCHANGER PENTANE LOOP	
TRAY "A"	DRAWING: 05

Direct Contact Heat Exchanger Pentane Loop   Fig. 24

the tray and exits over four equally spaced weirs. The pentane is sprayed onto the brine through a centrally suspended hollow cone nozzle. Both the brine and the pentane are brought to the tray by means of flexible hoses connected to fittings welded through the vessel wall and attached to external feed lines. The boiler has four main lines connecting it to the rest of the loop. These are as follows: the brine feed line, the pentane feed line, the spent brine dump line and the pentane vapor/steam exit line.

Brine from the well passes through the brine booster pump whose output pressure is regulated. The flow into the brine feed line is regulated by means of a manual control valve.

Pentane from the transfer vessel passes through the pentane booster pump whose output pressure is regulated by means of a pneumatically operated control valve.

The spent brine collects in the bottom of the boiler vessel after it passes over the weirs and is then dumped through a solenoid valve situated on the bottom of the vessel. From there, it passes through the spent brine dump line out into the holding pond.

The pentane vapor and steam pass through a mist eliminator inside the boiler and exit through a fitting in the top of the boiler, passing through a pneumatically operated control valve before being condensed in the air cooled condenser.

The liquid pentane and steam condensate is gravity fed into the separator where due to its greater density, the water collects in the bottom of this vessel. The water is then removed by an automatic drain similar to the one used to control the level of brine in the boiler.

It is expected the whole arrangement (including trailers A and B) will be moved to Raft River in January. Initial checkouts will be performed with Freon-113. Actual testing will use pentane.

4.2.8 Freon-113 Loop Experiment Results

All of the data taken with the Freon-113 boiler has been re-examined for accuracy and tabulated in summary form. Tables of the more important variables for all of the experiments are presented in Appendix B. Data analysis is continuing with a search for the most suitable and informative means of non-dimensionalizing and presenting the data. Theoretically derived correlation techniques are being explored.

4.2.9 Theoretical Analyses

Theoretical analysis of a complete geothermal power cycle has been continued both at the University of Utah and by Dr. Jacobs at the University of Strathclyde. Dr. Jacobs now has the cycle analysis computer program adapted for use on the University of Strathclyde computer system and is developing relationships between the thermodynamic figure of merit* and

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* Thermodynamic figure of merit is a measure of the new kW-hr/lbm of brine.

the various cycle parameters. At the University of Utah, the cycle analysis program has been corrected and checked for accuracy. Also, the program has been revised to accommodate either the parallel-flow preheaters used in the original program or counter-flow preheaters. The addition of the counter-flow preheat capability adds more flexibility to the program and permits evaluation of a cycle which tentatively appears to be more efficient.

Detailed results of various cycle analyses are not available but one interesting result, that is of immediate importance, is complete. Figure 25 shows the thermodynamic figure of merit plotted against boiler pressure for three fluids. These results were obtained assuming no fluid superheat and 0^{o} approach temperature in the boiler. The isobutane, because of its low boiling point (and high vapor pressure), operates at peak efficiency at much higher pressures than the pentane or Freon-113. The pentane is more efficient than the Freon-113 and is very near its peak efficiency at a boiler pressure equal to the well pressure. It must be emphasized that these results apply to only one brine inlet temperature and well pressure and to parallel-flow preheaters. Also, considerations such as secondary fluid loss and turbine size are not reflected in the thermodynamic figure of merit but may be of major concern.

4.2.10 Minimum Mass Ratio Calculations and Observations

A popular measure of direct-contact boiler performance is the minimum mass ratio which can be achieved while maintaining complete boiling of the working fluid. The mass ratio referred to in this context is the mass flow rate of the brine divided by the mass flow rate of the working fluid. There are two basic requirements that must be met to achieve complete boiling of the working fluid. First, sufficient heat must be given up by the brine to boil the fluid. A simple energy balance in the boiler will establish quantitative criterion which must be met to satisfy this requirement. Second, the fluid must reside in contact with the brine in the boiler for a sufficient time to allow heat transfer and boiling. Consideration of the heat transfer rate between the two liquids in direct contact establishes criterion for the brine residence time and fluid boiling time.

In the past quarter, detailed calculations of the energy balance in the boiler have been completed. The calculations give interesting results regarding the effect of fluid type, boiler pressure, and brine inlet temperature on the minimum mass ratio attainable in <u>any</u> type boiler. Calculations have been initiated to estimate the brine residence time and time required for complete boiling for the surface boiling tray type of boiler. Sufficient information is not available to allow completion of the residence time calculation to the final state the energy balance computations have been carried. Interesting results have been found but are not yet suitable for detailed presentation. Details of the energy balance calculations will be given in the remainder of this section.

4.2.11 The Energy Balance

Energy given up by the brine in the direct contact boiler is transferred to the working fluid for preheating, boiling, superheating of the vapor energy is required for the vaporization of the small amount of water vapor

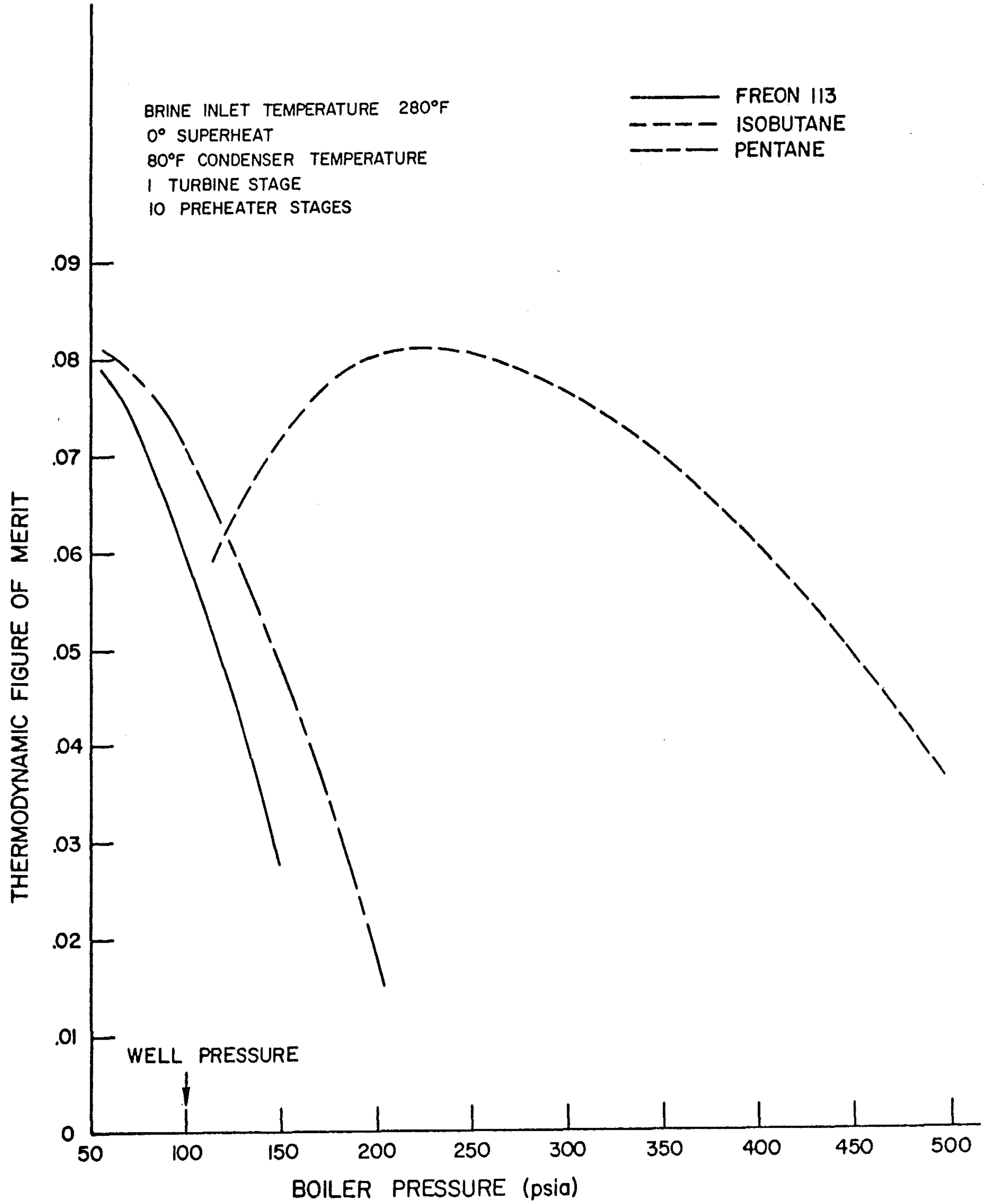


Fig. 25 Thermodynamic figure of merit of a complete binary power cycle for three secondary fluid choices. Cycle has 10 MW gross turbine power output and parallel flow preheaters.

which accompanies the working fluid vapor to the turbine, and energy is lost to the ambient through the boiler walls. Obviously, an increase in the amount of steam or heat losses to the ambient will leave less heat for vaporization of working fluid and the minimum mass ratio will be increased. The amount of heat that can be given up by the brine is determined by the difference between brine inlet temperature, T_1, and the vapor saturation temperature, T_{sat}. The vapor saturation temperature is determined solely by the fluid type, the boiler pressure, and the amount of superheat. Thus, it is apparent that the minimum mass ratio (with complete boiling) achievable in any type of boiler (assuming sufficient residence time to allow boiling) is determined by the fluid type, the boiler pressure, the amount of fluid subcooling and vapor superheat, brine inlet temperature, and heat losses to the environment.

Curves showing the relative importance of these various effects were calculated for three fluids: n-pentane, Freon-113 and isobutane. The energy balance is given by the following equation:

$$\dot{m}_b C_{Pb} \Delta T_b = \dot{m}_f \left[C_{Pl}(T_{sat} - T_{in}) + h_{fg} + C_{Pv}(T_{out} - T_{sat}) \right]_f$$

$$+ \dot{m}_s h_{fg_b} + Q_{LTA}$$

In this equation the following notation is used:

$\dot{m}$ = mass flow rate

ΔT_b = change in brine temperature in the boiler

T = temperature

h_{fg} = heat of vaporization

Q_{LTA} = heat loss to the ambient

subscripts:

b = brine

f = working fluid

s = steam

sat = saturation

l = liquid phase

v = vapor phase

The mass ratio, $R_m = \dot{m}_b/\dot{m}_f$, is given by

$$R_m C_{Pb} \Delta T_b = \left[C_{Pl}(T_{sat} - T_{in}) + h_{fg} + C_{Pv}(T_{out} - T_{sat}) \right]_f$$

$$+ \frac{\dot{m}_s}{\dot{m}_f} h_{fg_b} + \frac{1}{\dot{m}_f} Q_{LTA}$$

Calculations presented in this report were performed with the following conditions in the boiler:

$T_{in_b} = 290°F$

$T_{out_f} = T_{sat}$ (no superheat)

$T_{in_f} = T_{sat} - T_{subcool}$ (variable)

$T_{out_b} = T_{sat} + 5°F$ (5°F approach temperature)

$\frac{Q_{LTA}}{\dot{m}_f}$ was estimated from a curve fit to heat loss data taken in the University of Utah Freon-113 loop experiments.

Figure 26 shows results of calculations of the minimum mass ratio attainable when boiling Freon-113, pentane, or isobutane. It was assumed for these calculations that there was no heat lost to the surroundings. Figure 27 shows results of the same calculations but with heat loss to the ambient equivalent to the heat loss from the University of Utah Freon-113 boiler.

These figures show a very strong dependence of the minimum mass ratio upon the fluid type. The reason isobutane can boil completely at lower mass ratios is as follows: The isobutane has a very low boiling point (11°F at 1 atm). Thus, at a given boiler pressure, the isobutane has a relatively low saturation temperature. Since the minimum possible brine temperature in the boiler (with 0° fluid subcooling) is T_{sat} the isobutane will permit a larger ΔT_b than either the Freon-113 or the pentane. Obviously a high ΔT_b results in a low mass ratio.

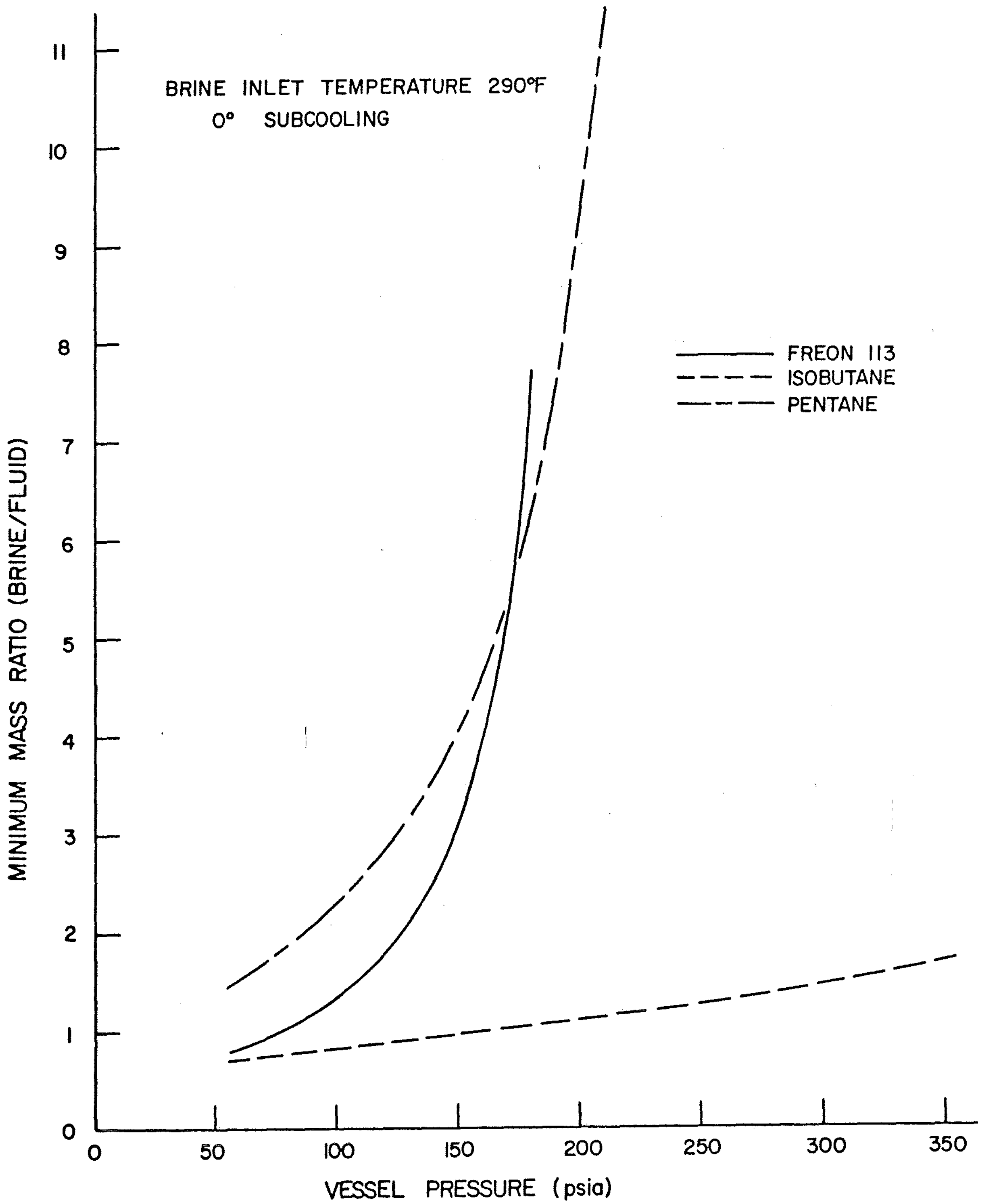


Fig. 26 Minimum mass ratio attainable in any boiler with 5°F approach temperature. Assumes no heat loss to the surroundings.

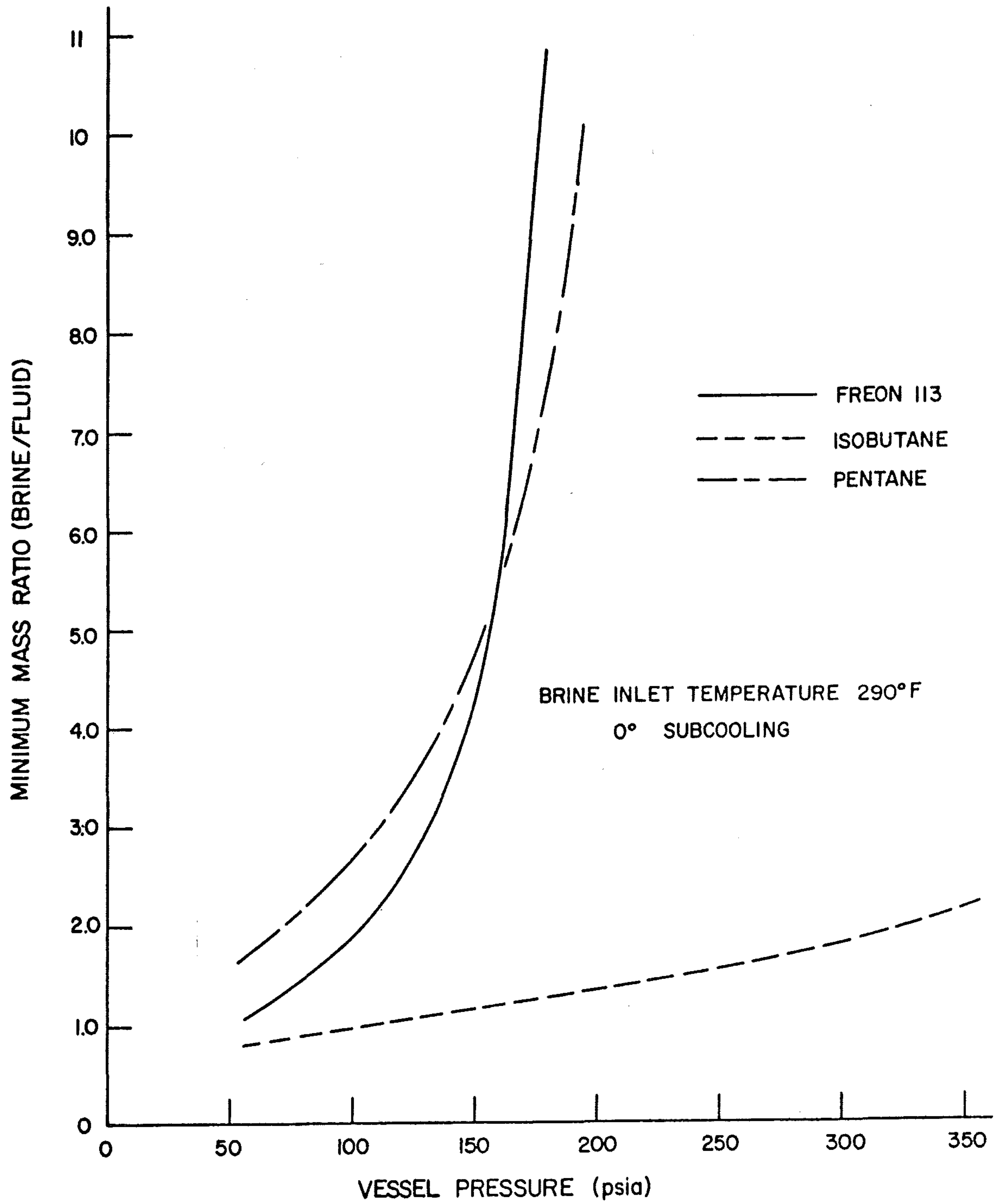


Fig. 27 Minimum mass ratio attainable in any boiler with a 5^{O}F approach temperature. Assumes significant heat loss to the surroundings.

When comparing different boiler designs and performance, it is imperative that the importance of the fluid type in determining the minimum mass ratio be kept in mind. Different boilers using different fluids cannot be compared directly. Rather, the actual minimum mass ratio of any boiler must be compared with the mass ratio attainable as indicated by these calculations.

Comparison of Figure 26 with Figure 25 permits another valuable observation. Notice the thermodynamic figure of merit for a cycle using isobutane as the working fluid peaks at a boiler pressure of approixmately 225 psia. But Figure 26 shows this is not at the minimum mass ratio. This is because the turbine inlet temperature drops with decreasing mass ratio and the pump work increases with decreasing mass ratio. Thus, it is not apparent that the minimum mass ratio is the most desirable mass ratio for all working fluids.

Figures 28 and 29 show the importance of heat transferred to the working fluid, the steam, and the surroundings for isobutane and Freon-113, respectively. Notice the heat transferred to the steam in a Freon-113 boiler is greater than that transferred to the steam in an isobutane boiler. Again this is a result of the high vapor pressure (and hence low steam mass fraction) of the isobutane.

Figures 30 and 31 show the effect of subcooling on the minimum mass ratio for Freon-113 and isobutane. The Freon-113 with its low specific heat, shows little effect of subcooling. This is the reason past measurements have shown little effect of subcooling on mass ratio. Subcooling is more important with pentane or isobutane.

Figures 32 through 34 compare actual mass ratio measurements with the calculations just presented. It can be seen that the three different boiler configurations all achieve the minimum possible mass ratio for the fluid in use. The fact that none of the boilers achieves a mass ratio (without carryunder) less than the minimum predicted is verification of the applicability of the calculations.

In summary, a method has been devised to accurately predict the minimum mass ratio attainable with any given working fluid, brine inlet temperature, and boiler pressure. The method demonstrates that fluid properties strongly influence the minimum mass ratio. It also demonstrates that the boilers currently being evaluated by the University of Utah achieve the minimum mass ratio for the fluids being used. It must be remembered that minimum mass ratio is only one measure of a boiler's performance. A power cycle operating at the minimum mass ratio is not necessarily the optimum cycle.

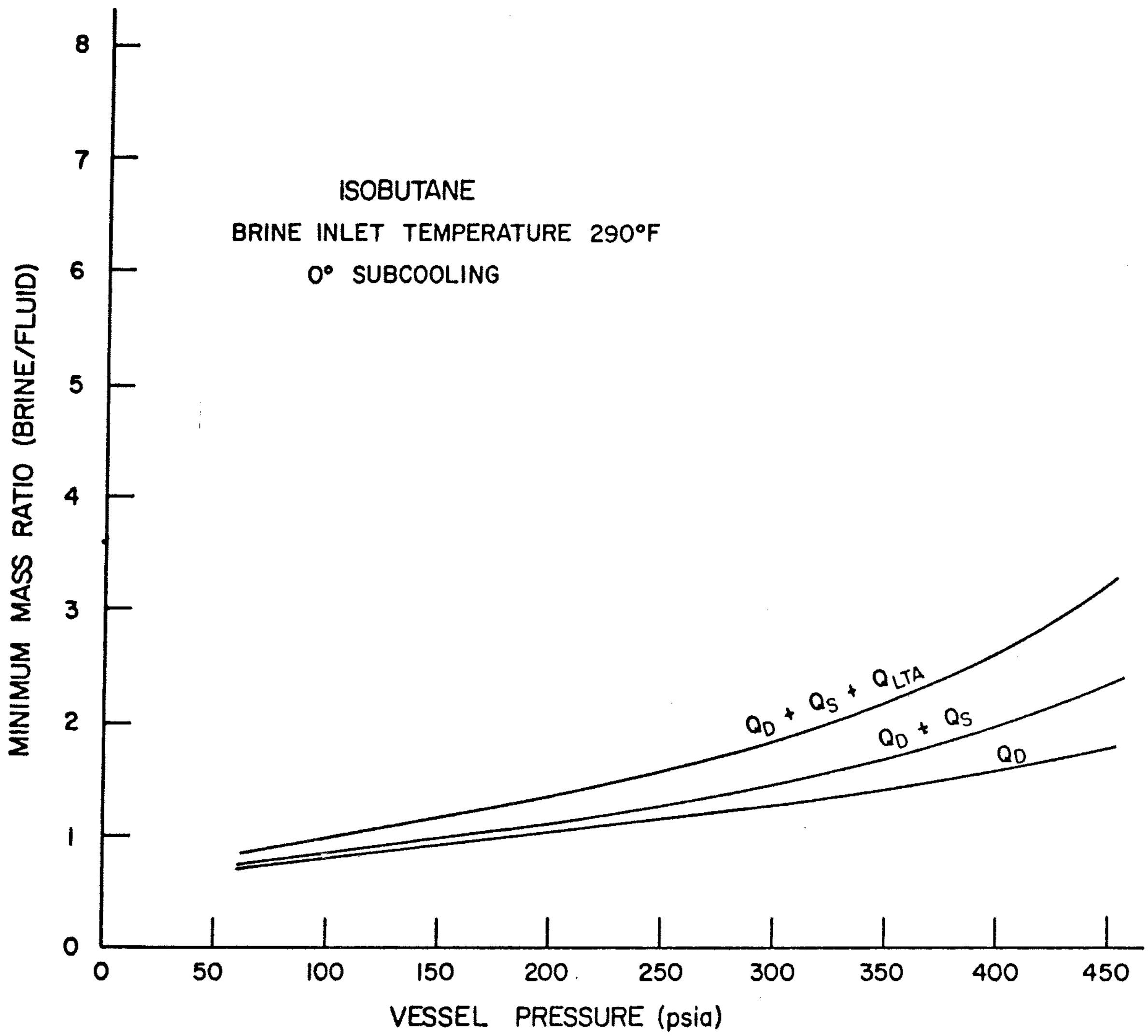


Fig. 28 Contributions of heat transferred to the isobutane disperse phase (Q_D), heat transferred to steam (Q_S), and heat loss to the ambient (Q_{LTA}) to the minimum mass ratio attainable.

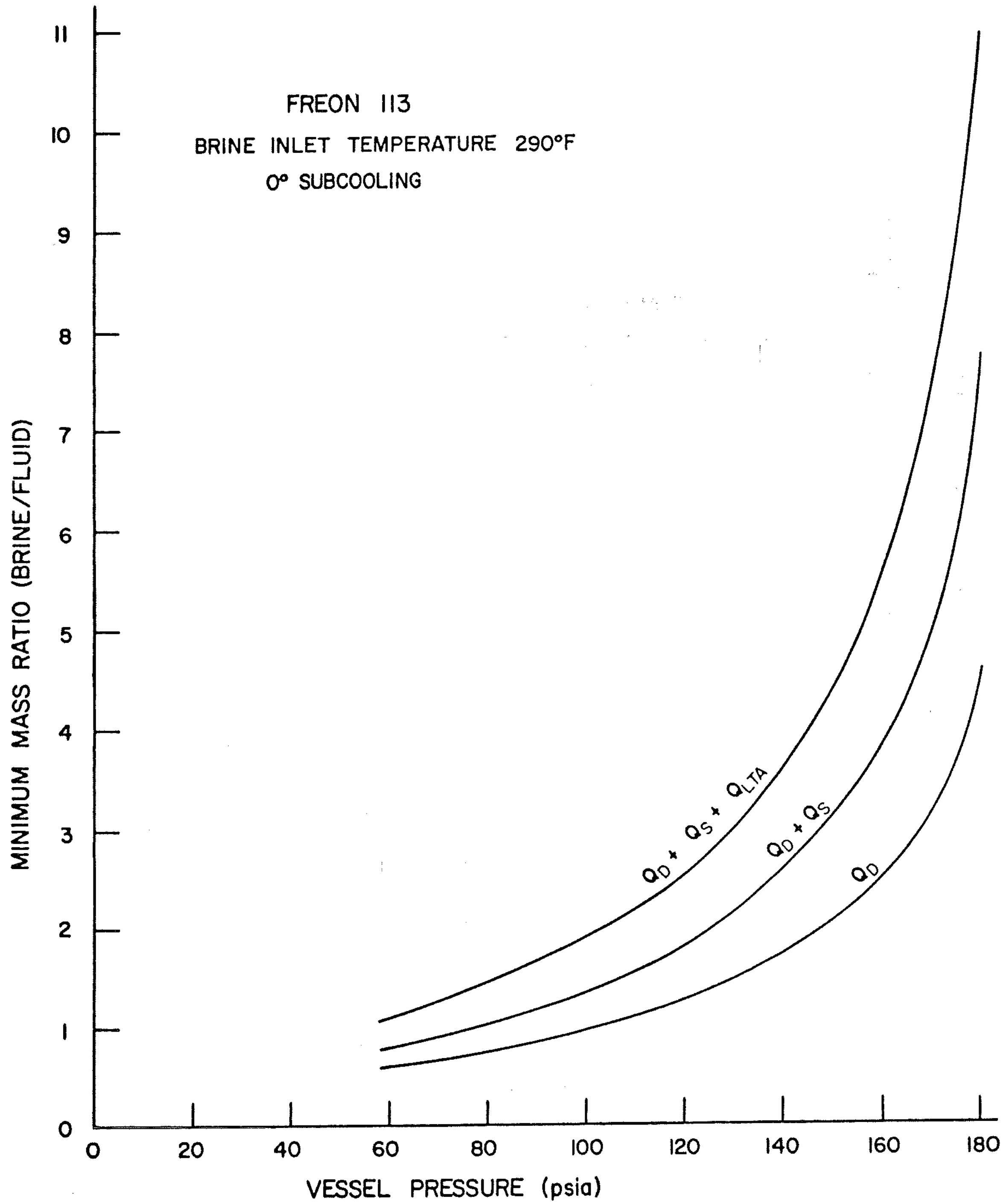


Fig. 29 Contributions of heat transferred to Freon-113 (Q_D), heat transferred to steam (Q_S) and heat lost to the surroundings (Q_{LTA}) to the minimum mass ratio attainable.

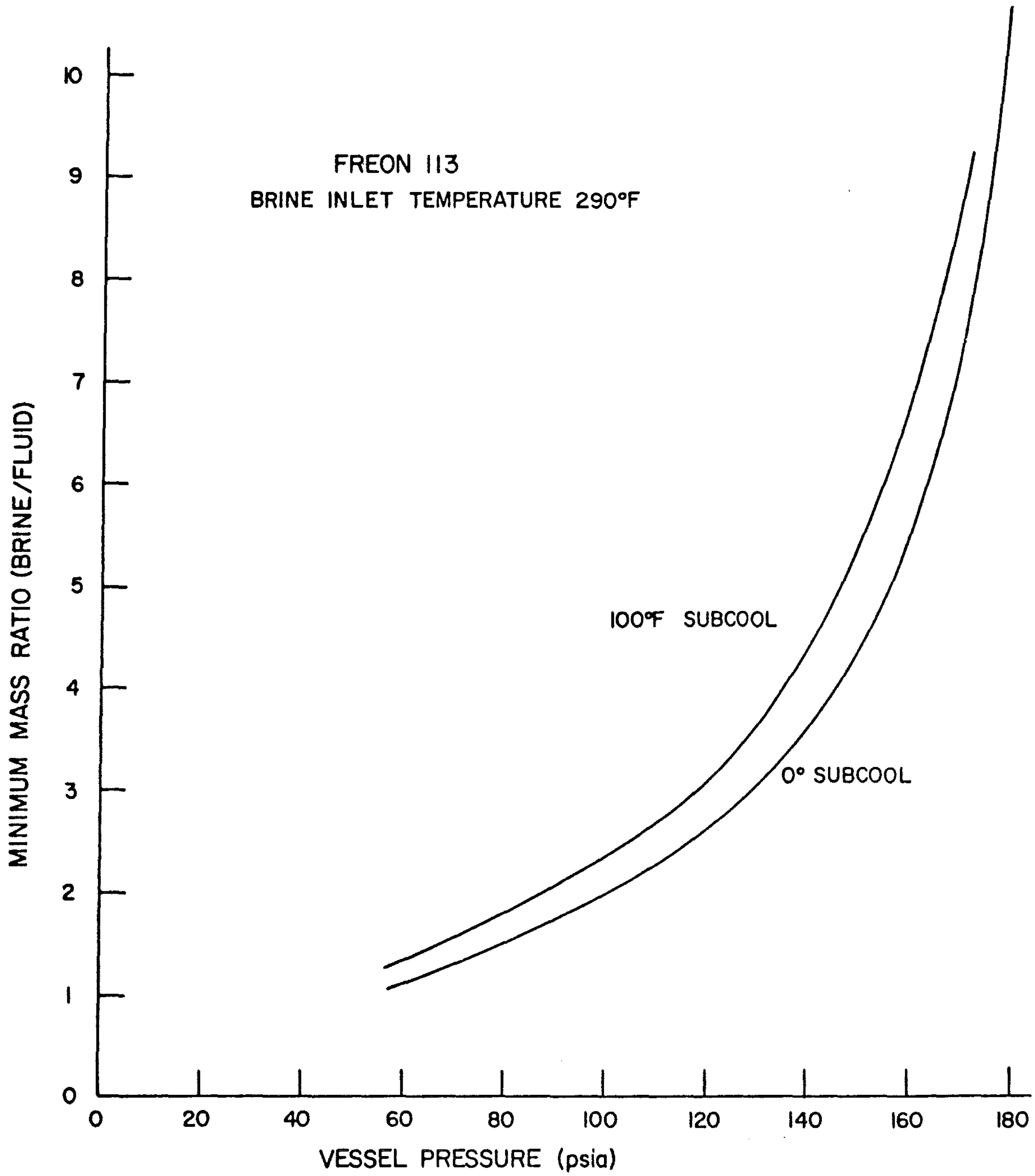


Fig. 30 Effect of subcooling on the minimum brine/Freon-113 mass ratio.

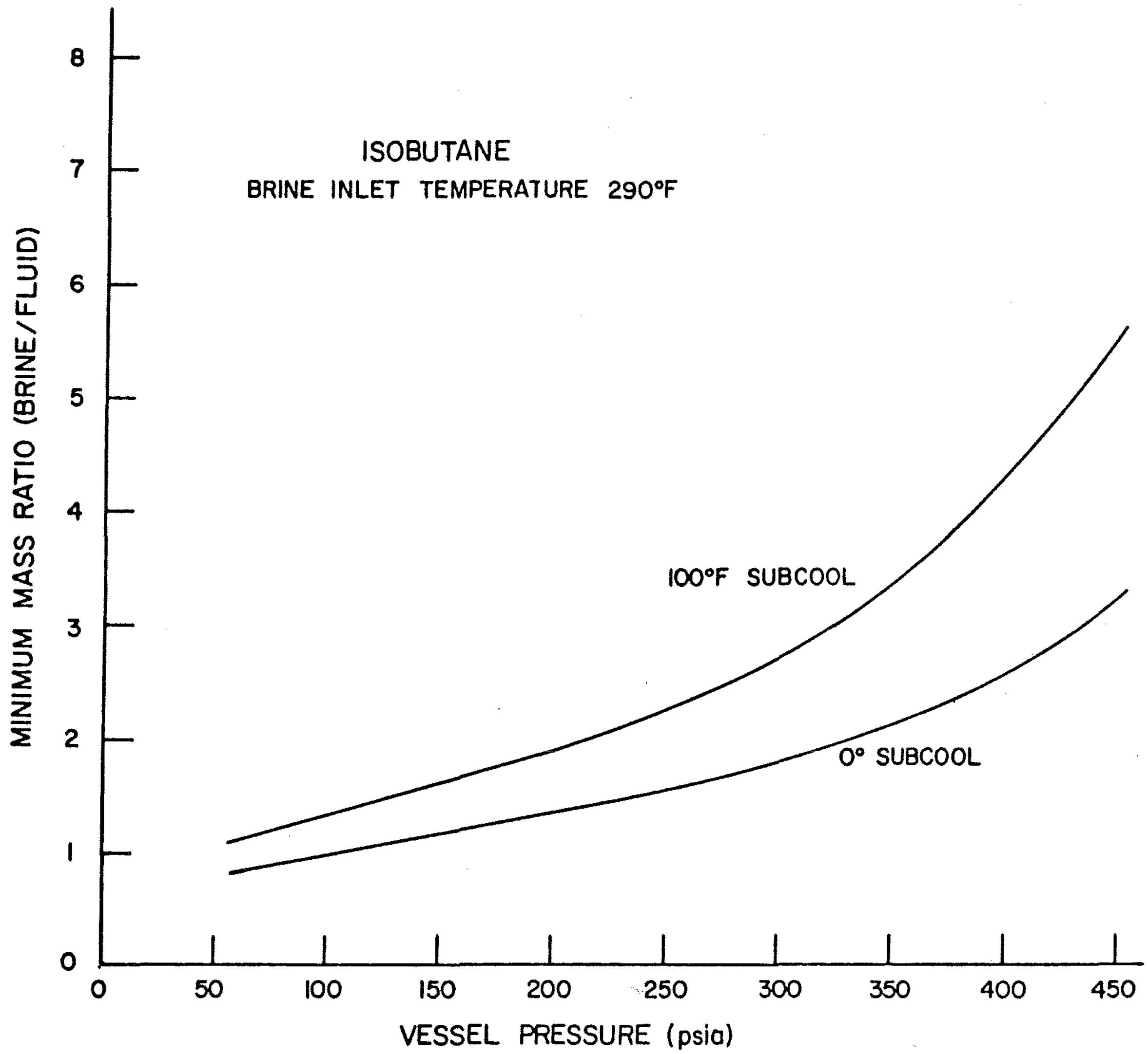


Fig. 31 Effect of subcooling on the minimum brine/isobutane mass ratio.

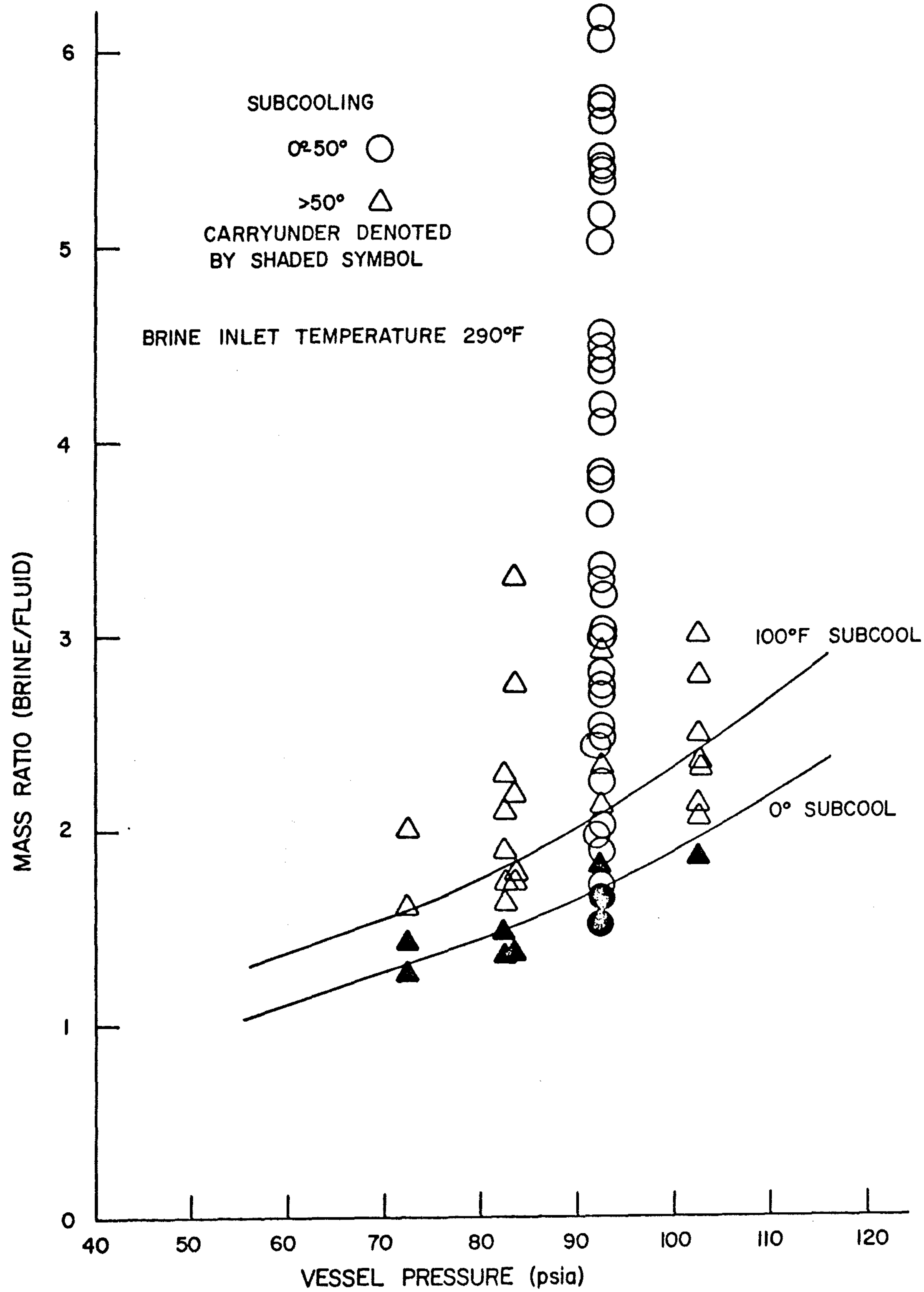


Fig. 32 Comparison of Freon-113 boiler data and the minimum mass ratio calculations. A solid cone spray nozzle was used in the direct contact surface boiler.

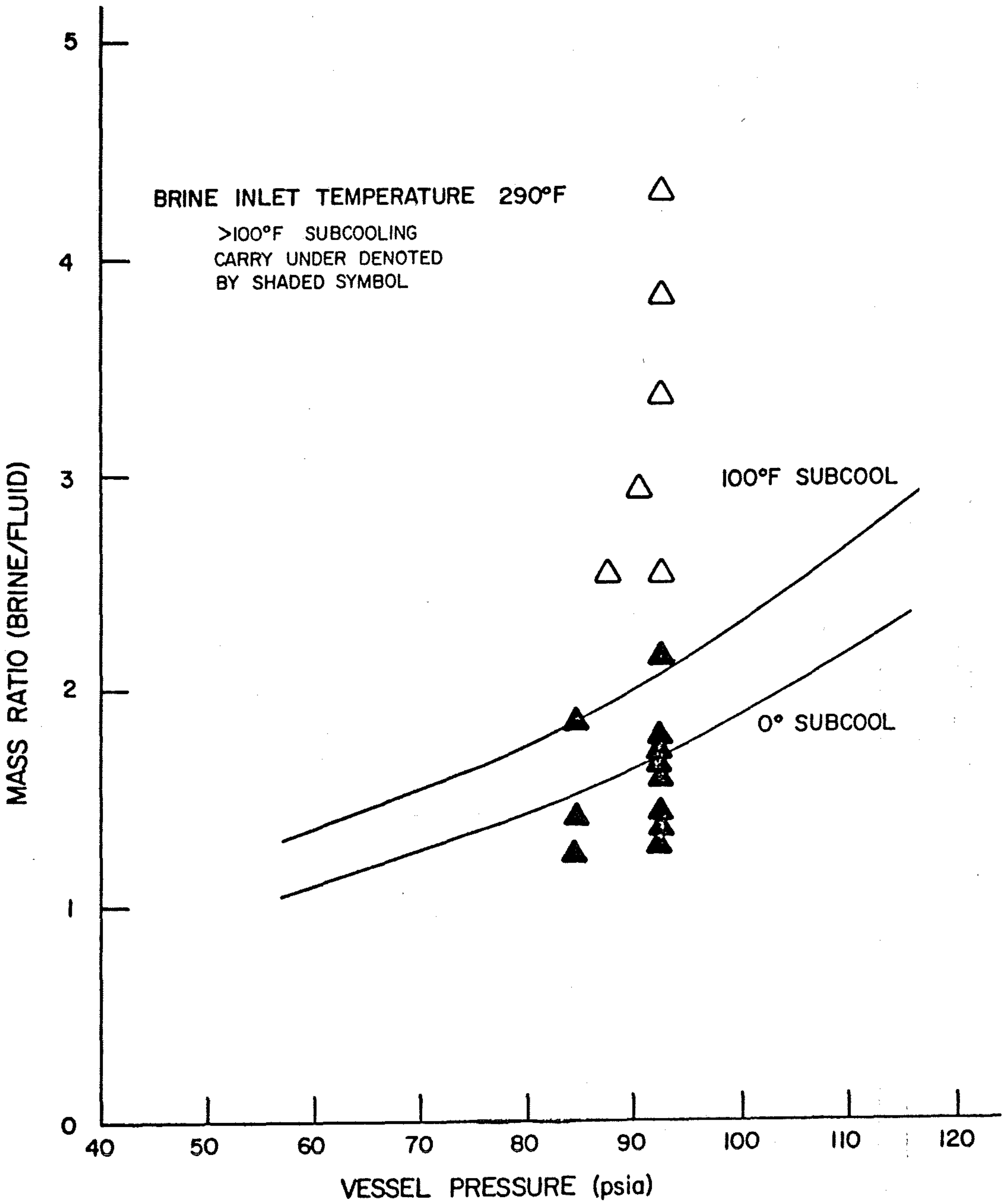


Fig. 33 Comparison of Freon-113 boiler data and the minimum mass ratio calculations. A flat-spray nozzle arrangement was used in the direct contact surface boiler.

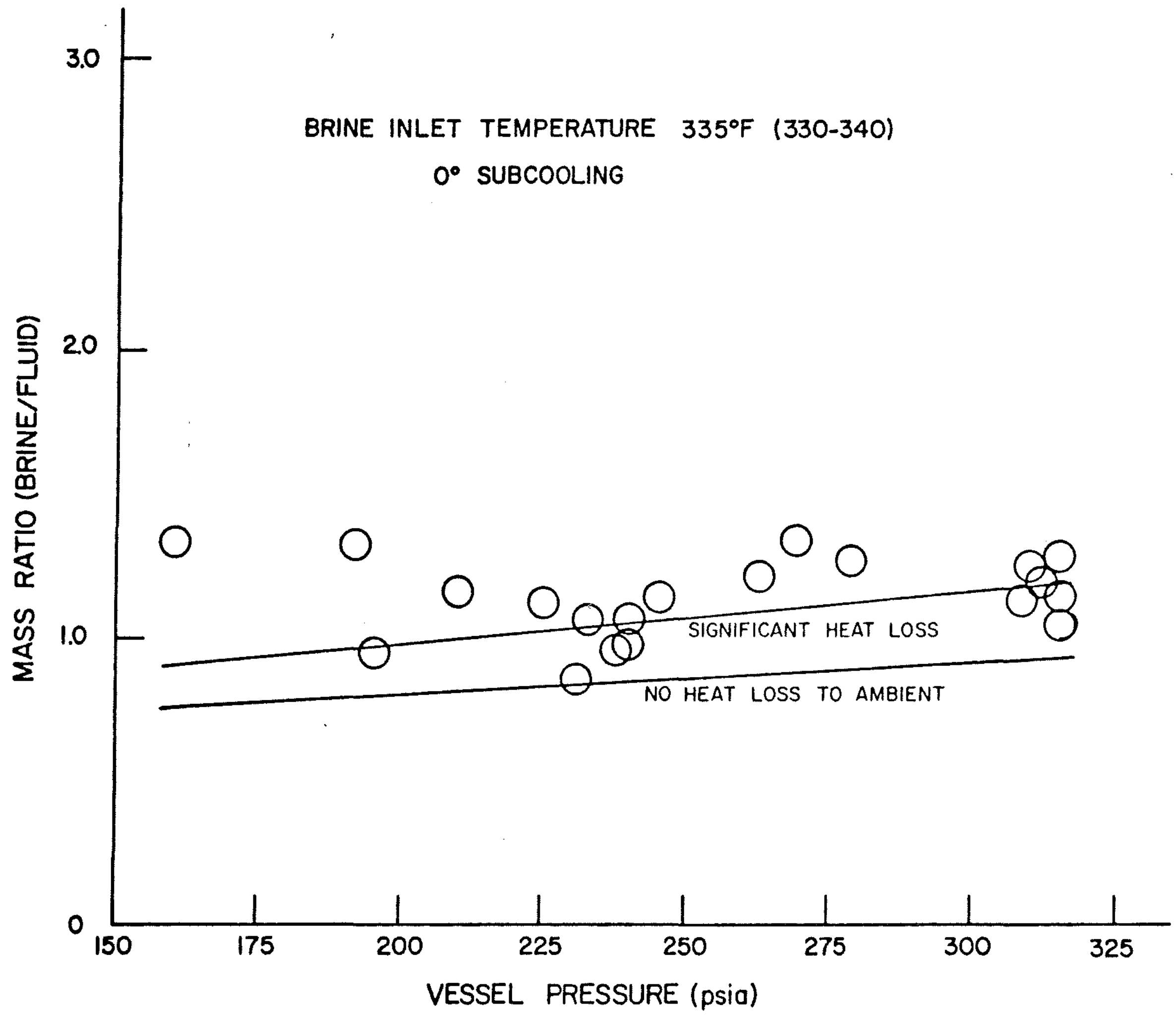


Fig. 34 Comparison of isobutane boiler data and minimum mass ratio calculations. The boiler was of the spray tower type. No carryunder data points were reported.

5.0 LOW TEMPERATURE RESERVOIR ENGINEERING

R. C. Stoker

The low temperature reservoir engineering effort is currently concerned with two areas in Idaho; Boise and Sugar City. Boise represents an area that can support further development and use of geothermal energy for space heating. The two Warm Springs Heating District wells have been in use since 1893 providing space heating for 200 to 400 homes along Warm Springs Avenue. The geological structural controls have been poorly understood and it was to this end that the reservoir engineering effort was directed.

Sugar City represents a potential area for the early use of geothermal energy in the area that exhibit above normal discharge water temperatures although the water has never been put to use for heating purposes. The warmest well in the area was drilled by the town of Newdale to a depth of 385 ft and produces water at 97°F. The water must first be cooled in order to use it for domestic purposes.

5.1 Boise Exploratory Wells and Holes

Five exploratory wells have been drilled in the northeast section of Boise, Idaho. Drilling was accomplished to help define the characteristics and extent of the geothermal resource in that area. Three cored slim (2-7/8 in. diameter) holes (BSH Numbers 1, 2, and 3) and two large diameter test wells (BEH-1, more conveniently designated as BLM since it is with the BLM Compound, and BHW-1, usually known as Beard, the name of the drilling company) have been completed in the area. The slim holes were completed in the first quarter of 1976. The test wells were completed in the third quarter of 1976. (See Figure 35 for well and hole locations)

5.1.1 Boise Hot Water-1 (BHW-1)

BHW-1 was drilled to a total depth of 1283 ft. A maximum downhole temperature of 171.5°F has been measured at the 830 ft depth. The major production zone is located between the 780 and 975 ft level with some production coming from below the 975 ft level. During limited flow tests (up to one day) it has produced 220 gpm under artesian free flowing conditions with a discharge temperature of 166°F at the surface. See Figure 36 for BHW-1 temperature profiles and Figure 37 for well cross section.

5.1.2 Boise Exploratory Hole-1 (BEH-1 or BLM)

BEH-1 (BLM) was drilled to a total depth of 1222 ft. A maximum downhole temperature of 171°F has been measured at the 1090 ft depth. The major production zone is located in the interval from the 1010 ft depth to total depth. The well was cleaned of drilling fluid during last quarter and allowed to flow at a controlled rate of only 50 gpm for a very short time. No further flow tests have been conducted and specific production zones are difficult to determine. See Figure 37 for well cross section and Figure 38 for BEH-1 temperature profiles.

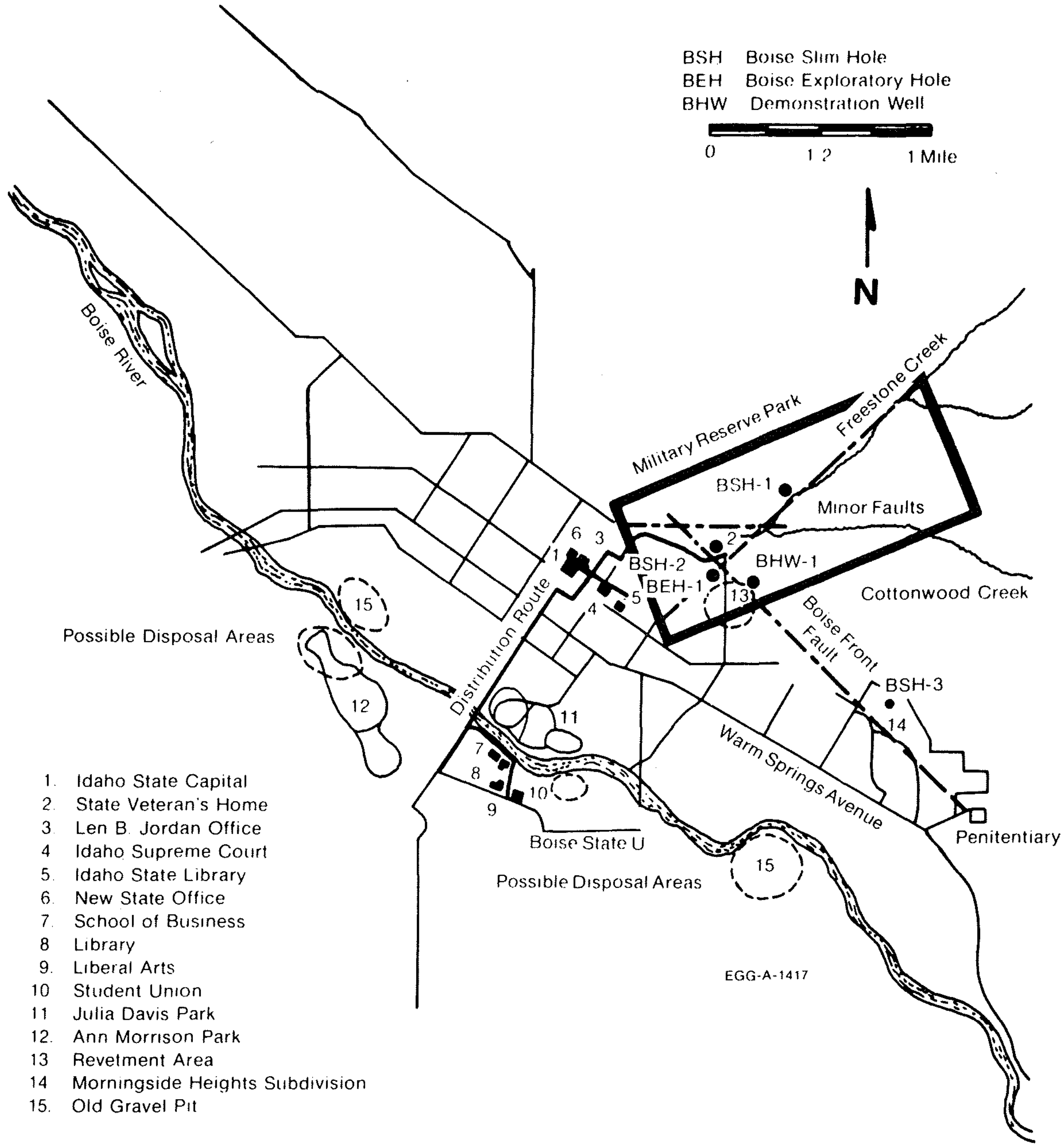


Fig. 35 Map of Boise Exploratory Wells and Holes

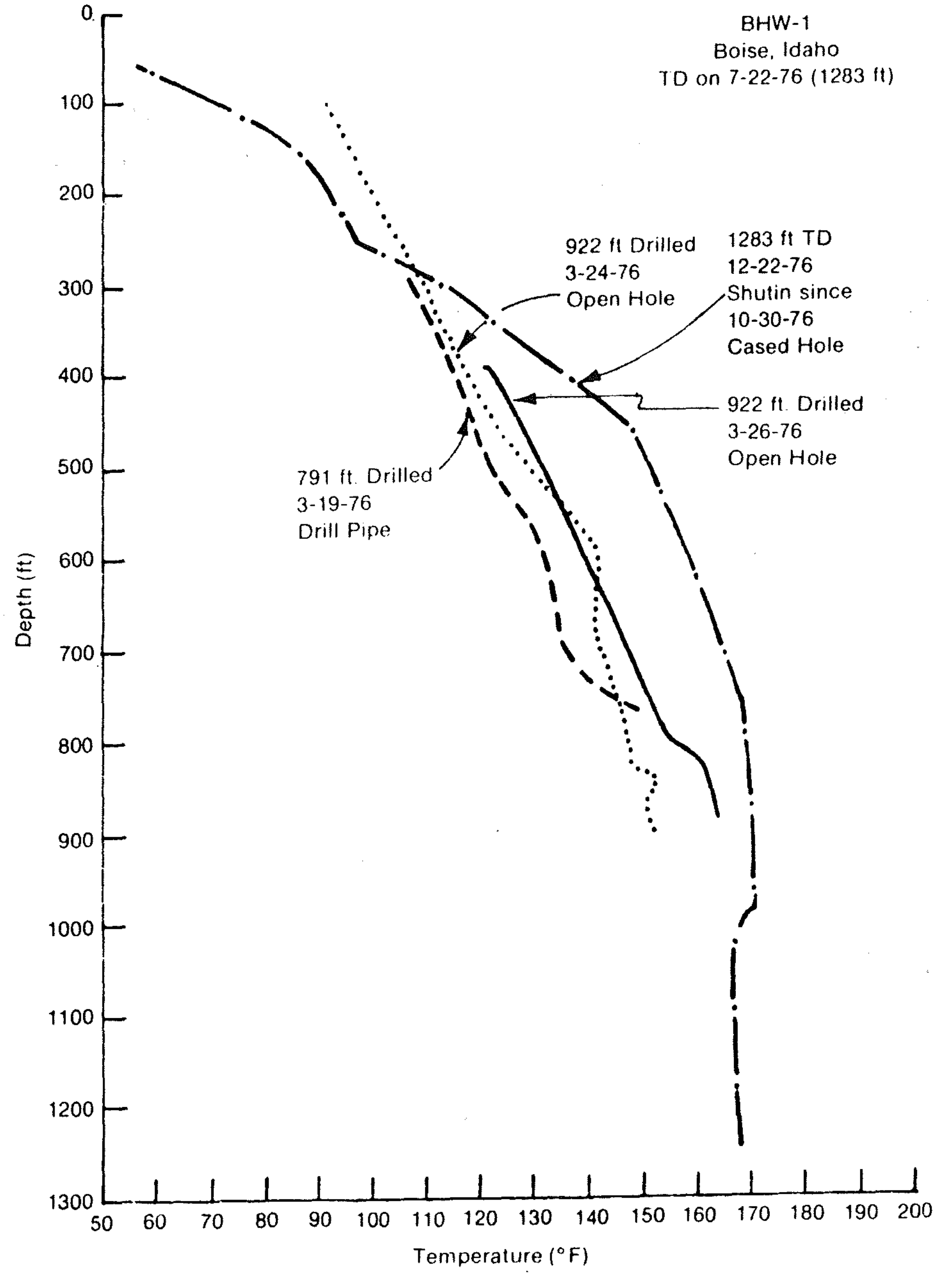


Fig. 36 BHW-1 (Beard Well) Temperature Profiles

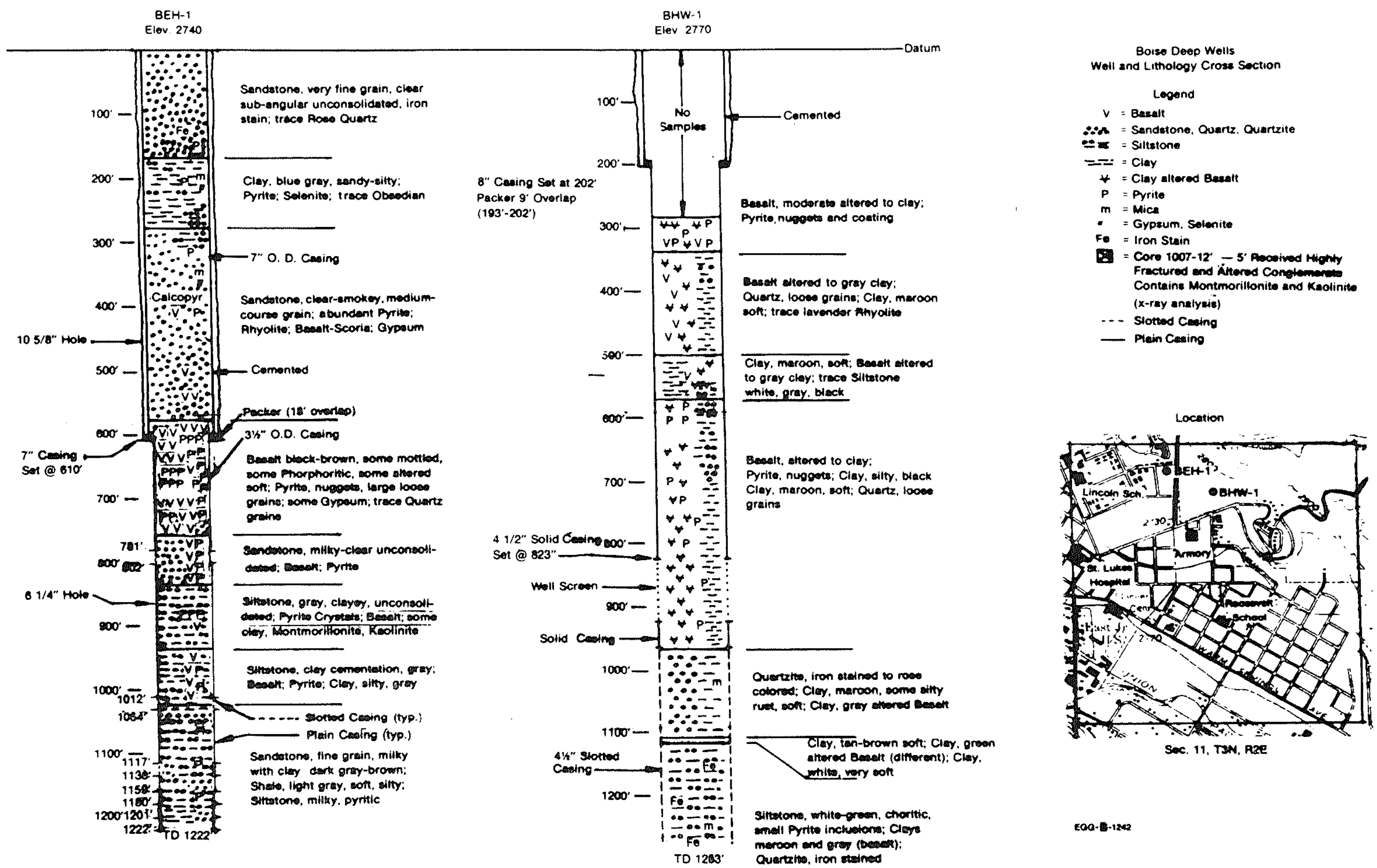


Fig. 37 Boise Deep Wells

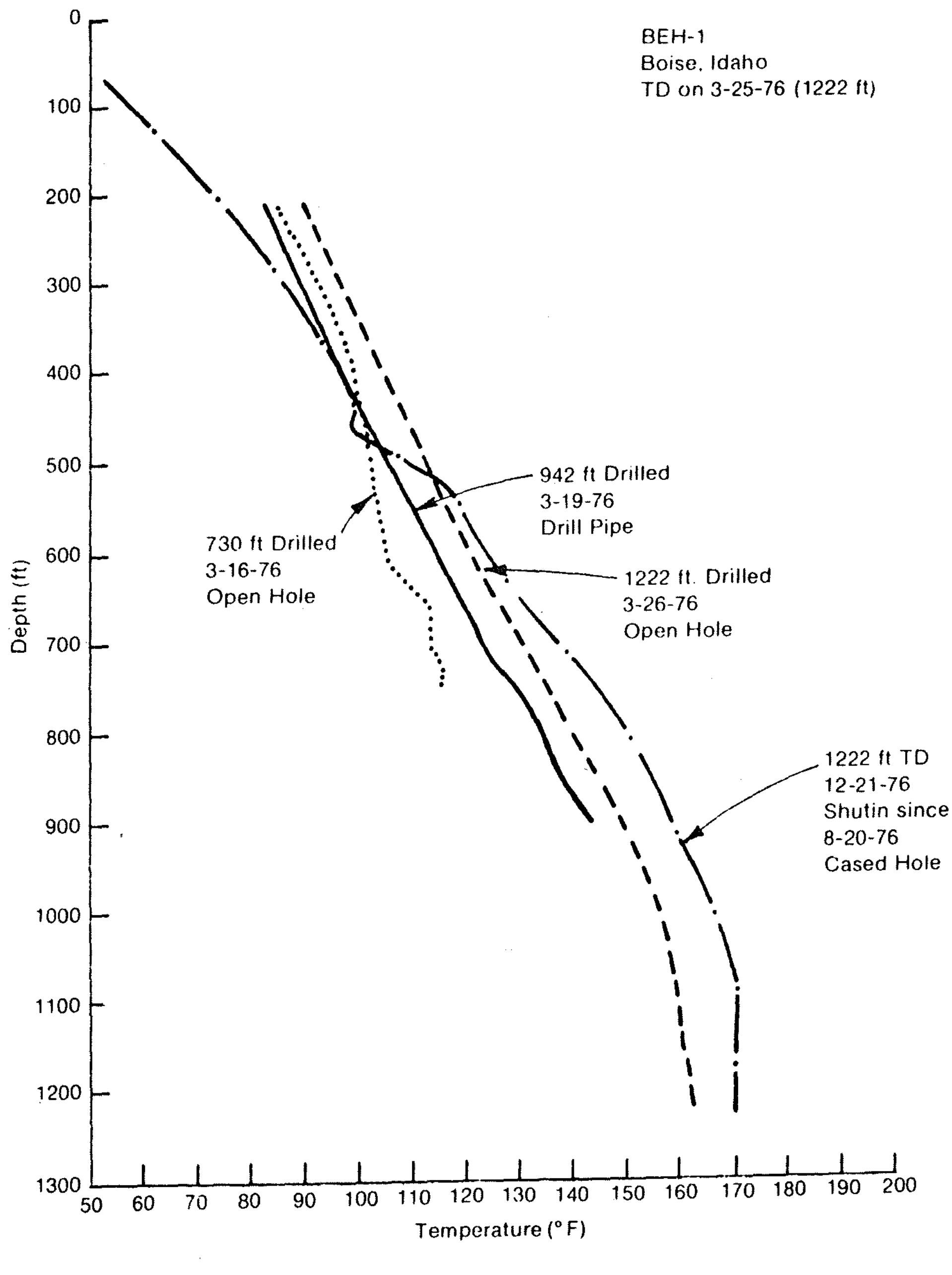


Fig. 38 BEH-1 Temperature Profiles

5.1.3 Well Drilling Summary

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

5.1.4 Boise Well Test Monitoring and Logging

Drawdown/recovery tests were conducted during late October in order to make a preliminary evaluation of the geothermal reservoir. BHW-1 was used as the flowing well with both surface and downhole pressure monitoring devices in operation at the well. BEH-1 was used as a surface pressure monitoring well and is located approximately 1000 ft northwest of BHW-1.

An analysis of the data taken during this short test indicates a large permeable reservoir with little wellbore damage. The Kh calculated from data taken at BHW-1 is 320,000 md-ft and from data taken at the monitoring well (BEH-1) it is 931,000 md-ft. See Figures 39, 40, and 41 for data presentation. The pressure drop that appears on Figure 42 at 1030 hours is unexplained at present.

The surface pressure monitoring system has been left on BEH-1 for baseline data gathering. It is anticipated that the monitoring of this well will continue through the summer of 1977. The results so far, show a cyclic (lunar effects) gradual decline from 21.30 psia (November 1, 1976) to 19.80 psia (December 30, 1976). This gradual uniform decline appears to be a seasonal trend rather than the direct effect of known non-uniform pumping rates from surrounding geothermal wells such as the Warm Springs Heating District wells located approximately 8000 ft away. See Figure 42 and 43 for BEH-1 pressure response.

Both Boise wells (BHW-1 and BEH-1) and the old penitentiary well were logged for temperature profiles in late December by both the INEL and USGS logging trucks. The individual traces from each unit are essentially identical. Figure 44 represents the profile from BEH-1 which has been shutin since August 20, 1976, and is in temperature equilibrium with the country rock. Figure 45 is the profile from BHW-1 which still shows elevated temperatures (especially between the 450 and 780 ft depths) due to the flow testing in October. Figure 46 is the profile from the old penitentiary well which is pumped and used for irrigation purposes most of the year. It shows the uphole elevated temperatures that are typical of any hot water well that is produced over a long period of time. It is a non-artesian well with the water level at a nominal 55 ft below ground surface. This well has also been subjected to a slight uniformly gradual level drop over the last few weeks.

5.1.5 Interference Testing with Warm Springs Avenue

During the entire winter heating season, the BLM well has been monitored using a sensitive quartz crystal pressure transducer. The artesian wellhead pressure initial dropped 2.5 psi in November and early

TABLE XX

BOISE DRILLING SUMMARY AS OF DECEMBER 1976

Hole or Well	Location*	Total Depth (feet)	Maximum Temperature	Casing Depth (feet)	Casing Size I.D. (inches)
BSH-1	Freestone Canyon	259	82°F	150	BW (2-3/8)
BSH-2	BLM Compound	652	132°F	550	NW (3)
BSH-3	Foothills East	552	94°F	130	BW (2-3/8)
BEH-1 (BLM)	BLM Compound	1222	171°F at 1090 ft	1222	3.5
BWH-1** (Beard)	Freestone Canyon	1283	172°F at 830 ft	1283	4.5

* The locations of these exploratory holes and demonstration wells are shown in Figure 35.

** This well developed 194 gpm artesian flow on August 4, 1976, during free flow tests. Outlet temperature reached 167°F after flowing for 12 hours. A flow test on October 28, 1976, resulted in a map. Approximately 220 gpm free flow rate. An outlet temperature of 166°F was recorded after 26 hours of flow at 108 gpm.

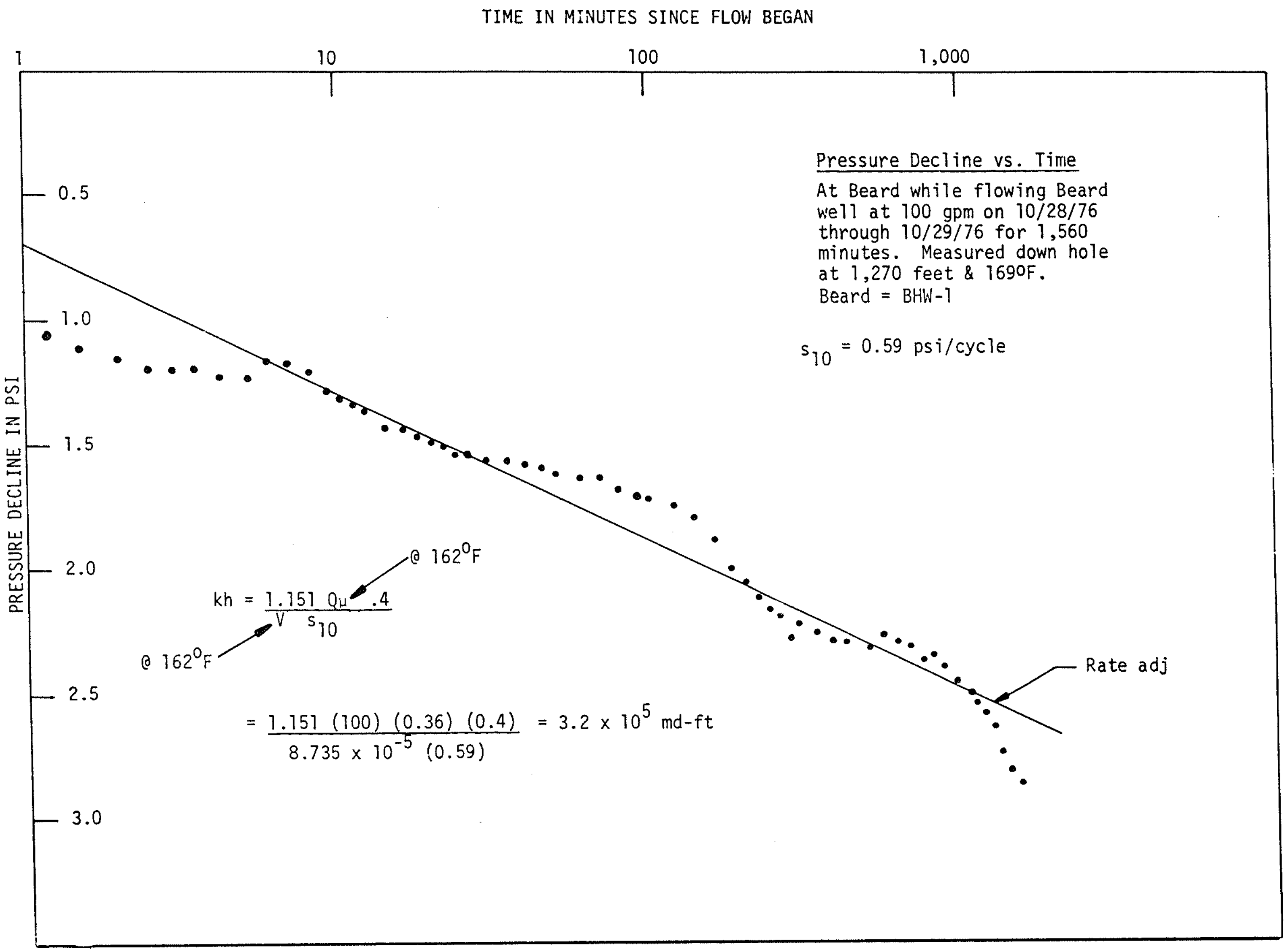


Fig. 39 Pressure Decline vs Time - BHW-1

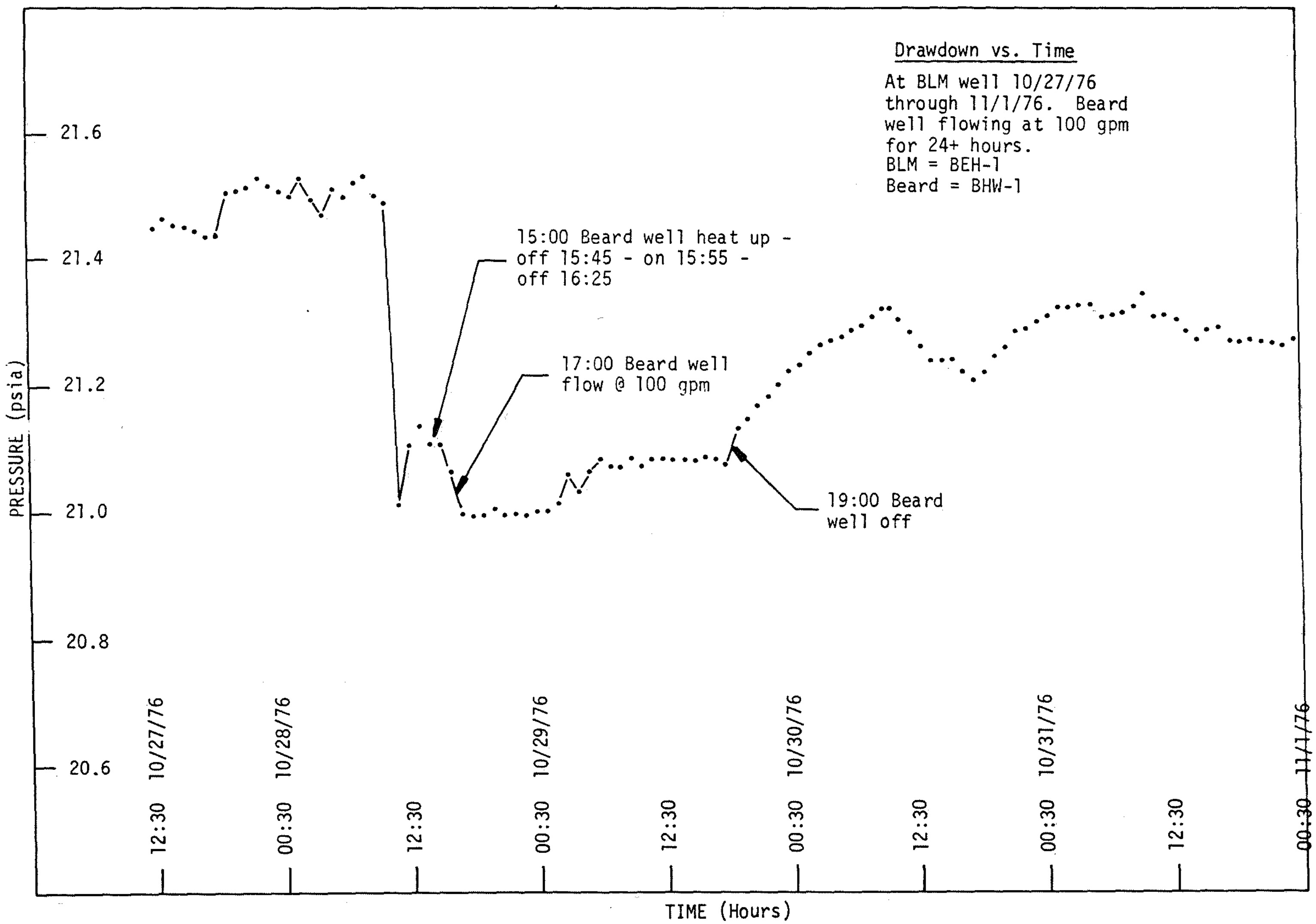


Fig. 40 Drawdown vs Time - BLM and Beard Wells

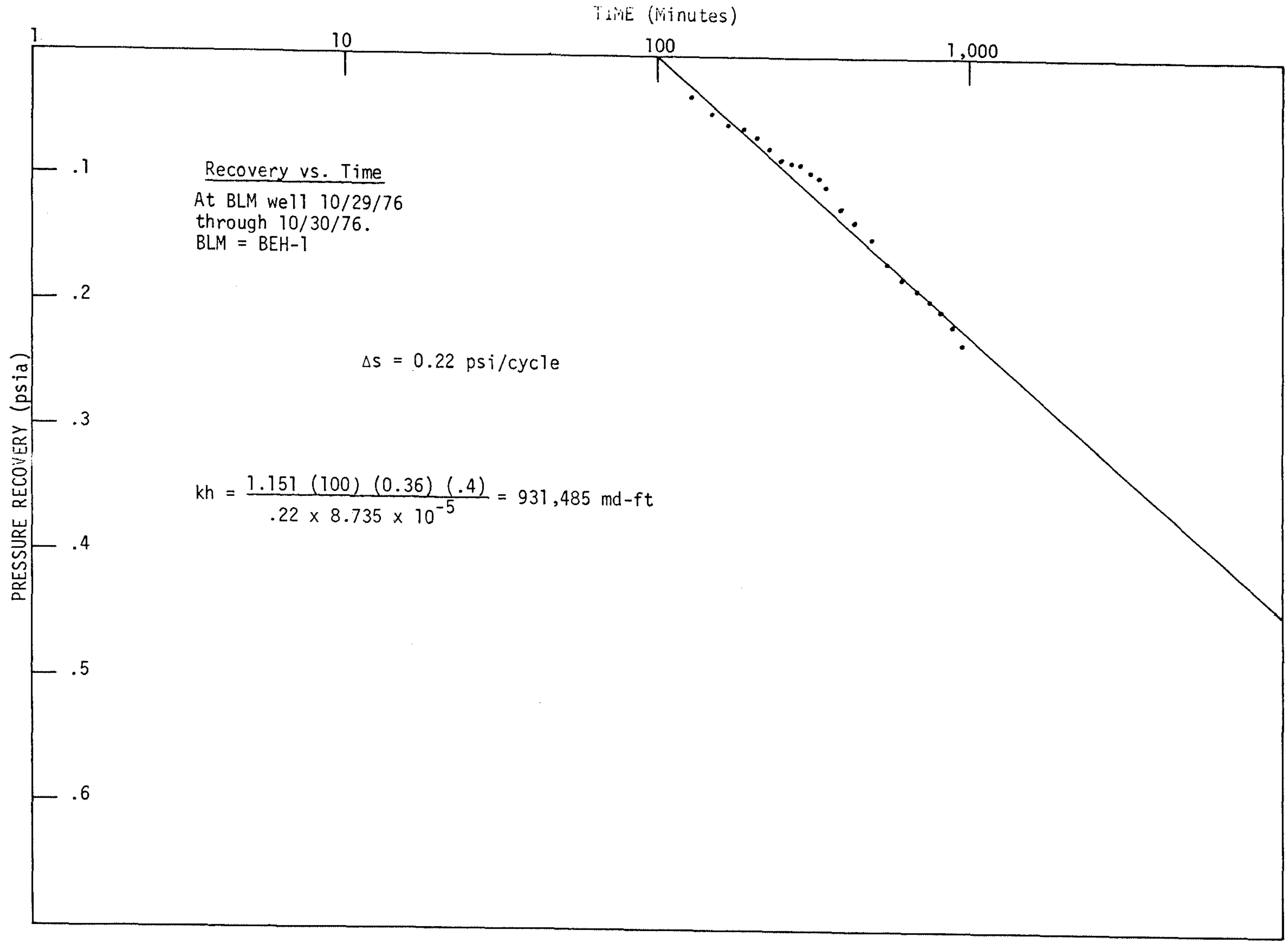


Fig. 41 Recovery vs Time - BLM Well

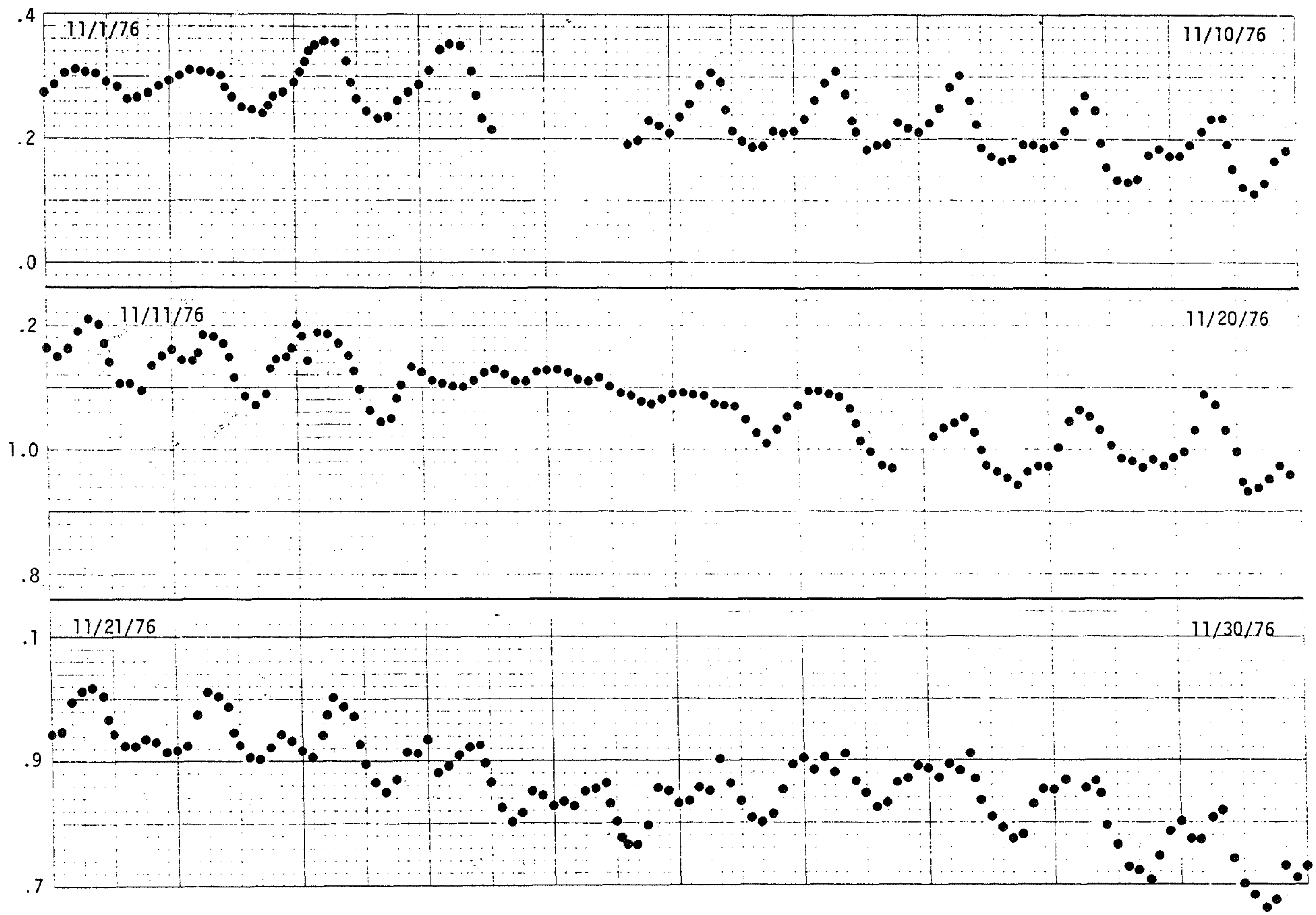
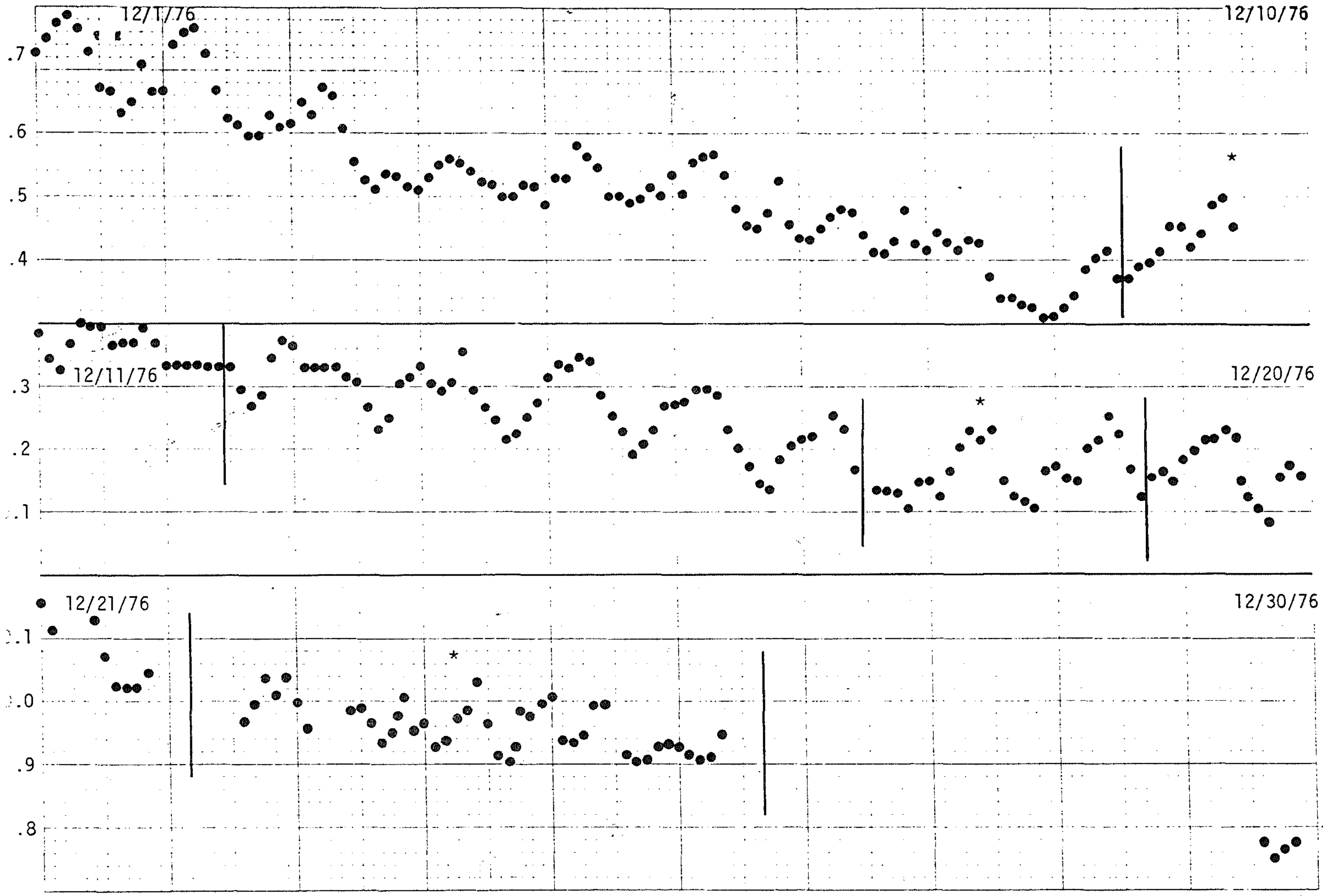


Fig. 42 BEH-1 Pressure Response



*Printer Difficulties - Relative Time

Fig. 43 BEH-1 Pressure Response

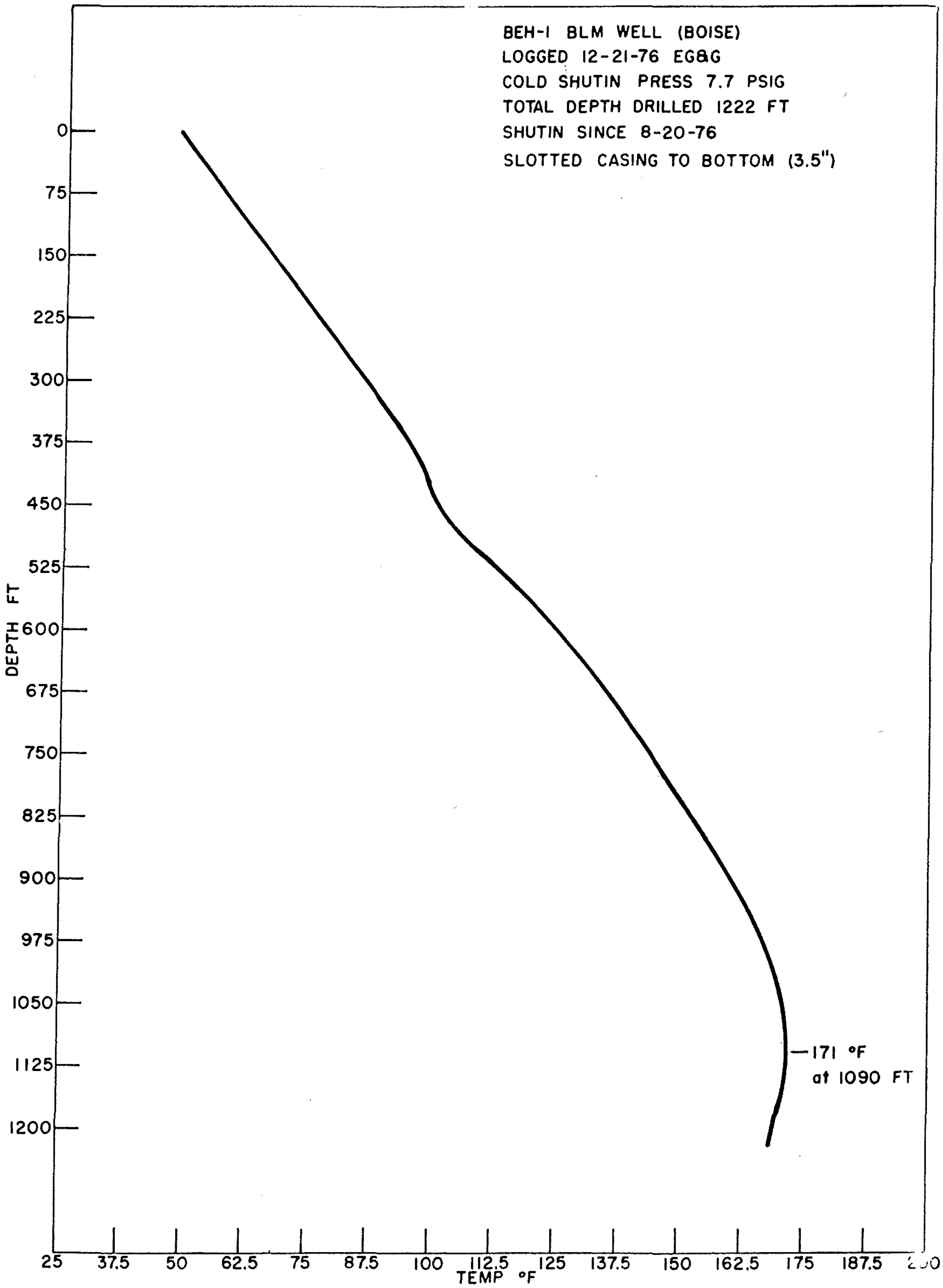


Fig. 44 BEH-1 BLM Well Profile

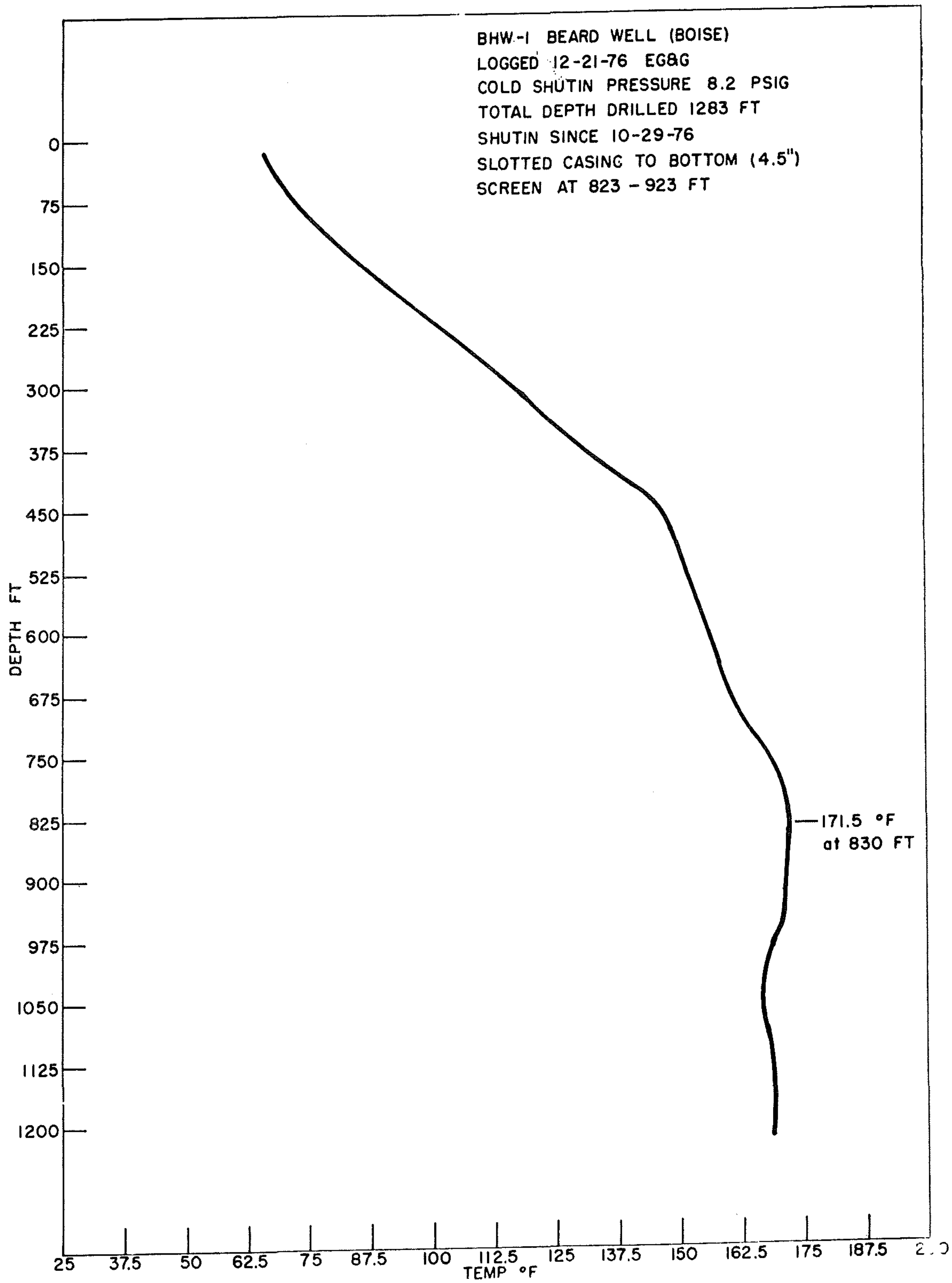


Fig. 45 BHW-1 Beard Well Profile

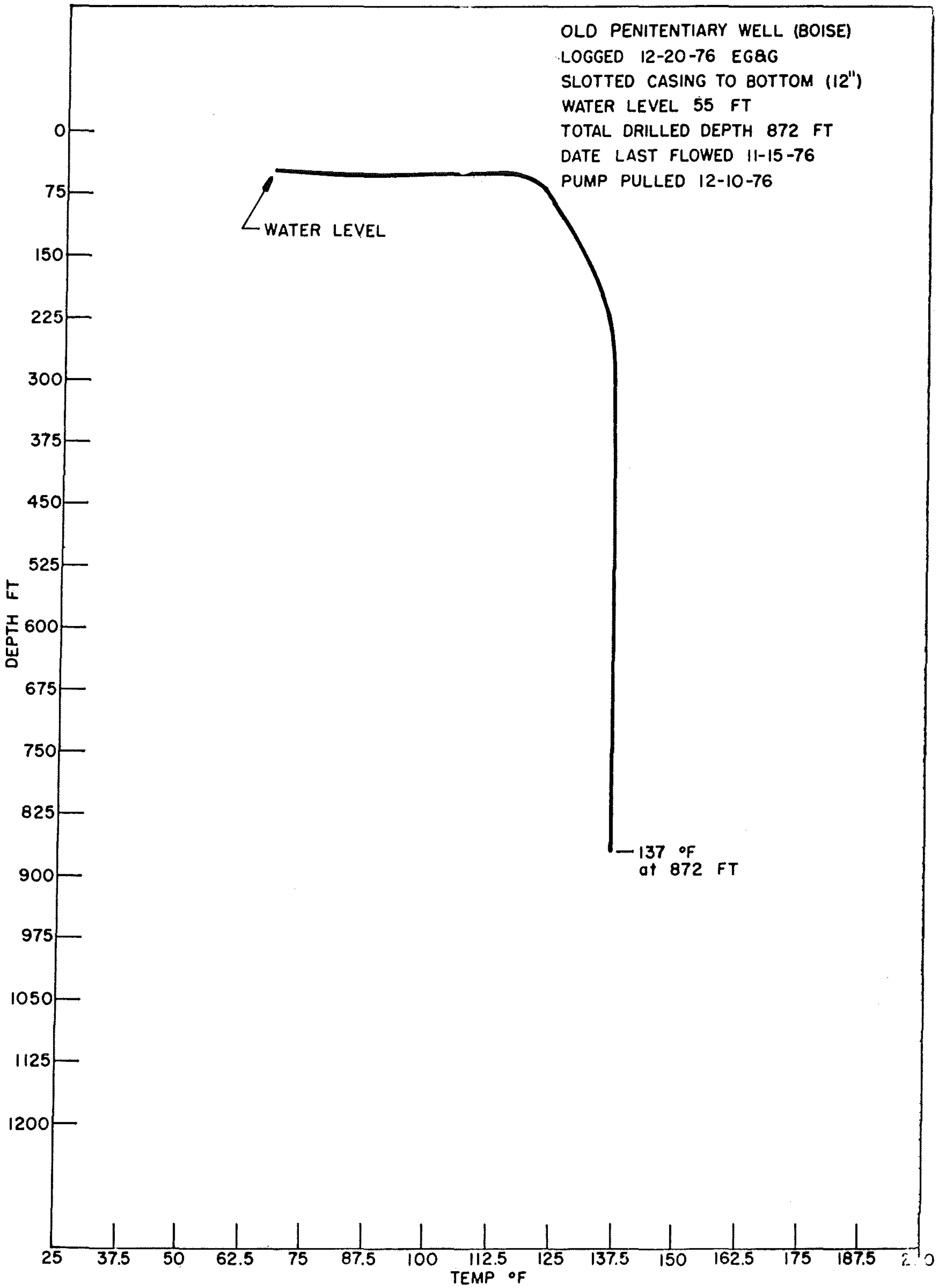


Fig. 46 Old Penitentiary Well Profile

December, both warm months with no precipitation. There has been a rather slow decline since, with a leveling off somewhat in February. Total decline from November through March has been 3.5 psi. The Warm Springs Avenue wells, 1-1/4 miles away saw their maximum demand in January and February. Thus, there appears to be no interference between the two wells, the 3.5 psi drawdown being attributed to seasonal variations in the water table.

5.1.6 Boise Area Geology (P. R. Donaldson, J. K. Applegate, Boise State University)

A hypothetical model of the Boise subsurface has been developed which could account for the Boise hot water as originating merely from typical geothermal gradients for the Western U.S.

If the alluvium is assumed to have a typical thermal conductivity of

$$\sigma_T = 3 \times 10^{-3} \frac{\text{cal}}{\text{sec cm } ^{o}\text{C}}$$

and the basement rock

$$\sigma_T = 7 \times 10^{-3}$$

then a combination of typical heat flow and assumed depths for the alluvium can give reservoir temperature estimates. In particular, if the area has three heat flow unit

$$\text{i.e.,} \quad \frac{dH}{dt} = 3 \times 10^{-6} \frac{\text{cal}}{\text{sec cm}^2}$$

(which is not unusual for the area, just twice world average heat flow) and the alluvium is 2.5 km thick, a reservoir at its base would have a temperature 185°C.

The Boise wells are producing at 77°C, and the chemistry of these wells applied to a standard mixing model (enthalpy and chemical dilution) gives a reservoir temperature of 165°C. The two results are close enough to give support to the theory that the Boise hot water source is merely a reservoir at depth, beneath the sediments of the Snake River Plain.

5.2 Sugar City Evaluation

The report on the initial evaluation of the Sugar City geothermal potential was issued.* A jointly funded study by EDA (Economic Development Agency) and ERDA was initiated, involving the temperature logging of

* "The Potential for Utilizing Geothermal Energy for Space Heating in Reconstructed Sugar City," TREE-1016, EG&G-Idaho, Inc.

40 selected deep irrigation wells, geochemical thermometry measurements on these wells, and eventual recommendations on if and where exploratory drilling for hot water should be conducted. These measurements will be completed in May. The U.S. Geological Survey has tentative plans to pursue further detailed geological mapping and possibly perform some electrical resistivity measurements. These are not expected to be completed until late summer.

6.0 NON-ELECTRIC APPLICATIONS

R. J. Schultz

6.1 Management Assistance Program

S. W. Metzger

In September 1976, ERDA awarded 19 industrial study contracts for non-electric geothermal applications. The INEL was asked to technically monitor and advise on nine of these. During the quarter, post-award contractor meetings were conducted with all nine contractors. Discussions have been held with ERDA-San Francisco Office (which monitors the other ten contracts) and the Geothermal Resources Council concerning arrangements for a Contractor Symposium to be conducted at the conclusion of the contract periods, probably in February 1978. Table XXI lists these nine contracts under stewardship of the INEL.

6.2 Technical Assistance Activities

L. E. Donovan

Assistance during this reporting period was primarily concerned with five geographical locations. A brief summary of these activities by location follow.

6.2.1 White Sulphur Springs, Montana

White Sulphur Springs is a community of approximately 1200 people with what used to be several free flowing hot springs near the center of town. One hot spring is used for space heating 12 motel units, an indoor hot spa and an outdoor swimming pool. The First National Bank of White Sulphur Springs has purchased land directly across the street from the motel for the construction of a new banking facility which they hope to heat geothermally. Land adjoining the motel has a small hospital complex which is in an expansion program. The A&E firm under contract has designed a hot water heating system that can be converted easily to geothermal at a later date.

It was learned this quarter that the hospital complex expansion is well underway and enough warm water was encountered while excavating for foundations to require pumping. Information on recently passed Montana legislation was sent to the First National Bank president. This legislation provides for grants up to approximately $100,000 for alternate energy projects within the state.

6.2.2 St. Mary's Hospital, Pierre, South Dakota

This is a large hospital complex with a central boiler facility supplying heat via steam and hot water circulating systems. The boilers are fired with No. 6 fuel oil and heating bills have been typically $60,000 to $70,000 per year. Oil and gas exploration plus deep irrigation well

TABLE XXI

CONTRACTORS FOR NON-ELECTRIC GEOTHERMAL APPLICATIONS

CONTRACTOR	ORGANIZATION BACKGROUND	NATURE OF CONTRACT
Alaska State Energy Office Anchorage, Alaska	Operates within Alaska's Governor's office in an energy planning, evaluation and administration role.	Survey and select promising Alaskan thermal springs, for siting salmon aquaculture operations, by means of evaluating physical site characteristics, accessibility, engineering, economic, social and environmental considerations.
Coury and Associates Denver, Colorado	Engineering firm which undertakes engineering studies and process development projects in the areas of energy and water resources, and air and water pollution control.	Examine the agribusiness and industrial potential associated with the hydrothermal potential of Colorado's San Luis Valley in conjunction with a geothermal fluid delivery pipeline keyed to an Eastern Range Colorado city.
DSS Engineers Ft. Lauderdale, Florida	Engineering firm engaged in performing contract engineering, process development and conceptual design studies directed toward energy intensive industries.	Investigate product mix that represents favorable Geothermal Energy Industrial Complex potential coupled with an effort that will lead to the design of a specific complex suitable for implementation.
de Laureal Engineers Consortium New Orleans, Louisiana	Architectural and engineering firm specializing in heating, air conditioning, refrigeration, freezing, waste water treatment and piping systems.	Perform specific case studies based upon an inventory of Louisiana's potential geopressured resources found suitable for industrial applications.
The Futures Group Glastonbury, Connecticut	Policy research firm involving forecasting, systems analysis, and technology assessment for private and government organizations.	Following an assessment of geothermal energy food/crop drying opportunities, a dryer design scheme will be undertaken and examined in a cost/benefit and policy analysis framework.

TABLE XXI (Continued)

CONTRACTOR	ORGANIZATION BACKGROUND	NATURE OF CONTRACT
Oregon Institute of Technology Klamath Falls, Oregon	An educational institution offering Associate and Bachelor programs in Engineering Technologies,and incorporating a Geo-Heat Utilization Center.	Study the prospect of introducing geothermal energy to the existing and the potential food processing industry in Oregon's Klamath and Snake River Basins.
Pacific-Sierra Research Santa Monica, California	A research firm specializing in the application of scientific, engineering and system analysis techniques to technological, scientific, policy,national security and doméstic problems.	Identify, in a cost/benefit perspective, potentially attractive uses of geothermal energy for six preselected Alaskan towns.
South Dakota School of Mines and Technology Rapid City, South Dakota	An educational institution offering the Bachelor, Master and Doctor of Philosophy degrees in Science and Engineering.	Evaluate the conditions under which geothermal energy stored in the Madison aquifer in western South Dakota can be utilized by industry, government agencies, or muncipalities.
Terra Tek Salt Lake City, Utah	A research and development firm specializing in natural resource well drilling technology.	Review industrial agribusiness complexes in an environmental, legal, management, social and financial, framework, and conceptually integrate a selected complex into a private enterprise model based at the Raft River site.

drilling around Pierre have produced reliable subsurface geologic information that indicates a source of warm water (approximately 150°F) likely wihtin the first 2000 ft of depth on or near the hospital grounds.

Last quarter, it was reported that an engineering consulting firm was performing an alternate energy study for the hospital. The study was completed this quarter and we were asked to review and comment on their findings. It was concluded in the study report that geothermal water, even in the lower temperature ranges anticipated, would be a viable and economic partial energy alternate. It was interesting to note, also, that solar would not be an economical alternate for this particular conversion. The report further recommended that a test hole be drilled on the hospital grounds. Board of director approval has been obtained to drill this hole and drilling is scheduledfor early spring.

6.2.3 Pagosa Springs, Colorado

Colorado School District No. 50 has a hot water well on the Pagosa Springs school grounds. This well has been used in the past to provide a portion of the buildings heating needs, however, with less than satisfactory results.

As a part of the geothermal feasibility assessment and conceptual design being formulated for the school district, a computer program to aid in future assessments is being prepared.

The computer code GEOTH was developed for the Colorado Energy Research Institute.* GEOTH utilizes a parametric model simulating distribution of geothermal hot water and system economics in comparison with the use of conversion projects and new installation projects as well.

Revisions incorporated by INEL to the present version of GEOTH include provisions for optional costing of piping, pipe insulation, pumps, engineering design, operating labor and taxes. Provisions have been made for the input and utilization of pumping lift, heating system component pressure drop, pipe/insulation material selection and subsequent cost, fuel conversion efficiency of the present system and operating labor rates plus hours assigned for personnel operating costs. Pumping horsepower requirements and costs are calculated for the well or wells, circulation and circulation standby. The calculated electrical operating cost for pumping is computed neglecting any standby requirement.

Based on economic and system input parameters, the program output now consists of main distribution pipe size, maximum flow rate, system pressure drop, thermal pipe losses, pumping requirements and number of required wells. Cost outputs consist of estimated project cost, engineering design cost, system maintenance and operating cost plus a discounted cash flow analysis comparing the economics of the project to the use of

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* Nannen, L. W. et al., "An Investigation of the Technical and Economic Feasibility of Using Low Temperature Geothermal Sources in Colorado," November 1975, Final Report to Colorado Energy Research Institute, Project No. 022-03.

conventional fuels. This analysis also includes the effect of escalating both the electrical rates for operating costs and conventional fuel costs.

6.2.4 Greenhousing, Raft River, Idaho

A small (approximately one acre) private greenhouse installation using geothermal water has been in operation at Raft River for several years. The complete complex is presently in a bad state of repair. Town and Country Gardens, Idaho Falls, Idaho, has just recently purchased the greenhouse and requested INEL's assistance in estimating refurbishment costs for the geothermal heating system. Material recommendations were made along with an estimate and the new owner is proceeding with work to get the greenhouse back in production.

6.2.5 Sun Ranch, Cameron, Montana

This ranch of approximately 30,000 acres, has three free flowing hot springs with the hottest indicating temperature of 140°F. An assessment of present resource potential and preparation of utilization designs in conceptual form are underway.

6.3 Information Disseminationg Activity

The information dissemination activities undertaken during this quarter were presentations to technical and non-technical groups, release of mass media news articles, and transmittal of technical documents and brochures to interested parties upon request.

Information was transmitted to 45 individuals, private companies and institutions at their request. The documentation transmitted included approximately 122 technical reports, paper reprints and brochures.

A brochure entitled, "Rules of Thumb for Direct Geothermal Applications," was published during this quarter.

6.4 Planning Assistance Activity

J. G. Keller

Progress in this area has been in response to a request by ERDA to provide assistance in the collection of data for moderate temperature resource and geothermal reservoir assessment.

The catalog of data will be used for independent evaluation of reservoirs within various Western states. Funding will be channeled to various state agencies to provide baseline studies and preliminary reservoir assessment of the most promising areas. Areas of assessment will be chosen on utilization economics and reservoir potential. The ultimate goal is to stimulate significant interest in the resources for industry involvement in development and utilization for non-electric applications.

Geothermal data is being gathered from Utah, Arizona, Colorado, Oregon, Idaho, New Mexico, Montana, Nevada, and Wyoming. Unfortunately, the majority of the states have prepared few publications on geothermal investigations. There are few states with specific agencies responsible for geothermal investigation or development. The most progressive in that respect is Idaho. Idaho's Department of Water Resources is publishing Water Information Bulletin Number 30, "Geothermal Investigations in Idaho." There are seven parts in print covering geochemistry and geology of selected areas of the state. Utah appears the next prolific. Most of the published information is available through the Utah Geological and Mineral Survey or Department of Water Resources. Within Utah and Nevada, the USGS is conducting statewide geothermal resource investigations, but to date, the data is not in open file or published form.

The majority of the states have completed thermal spring or heat flow investigation either by state agencies or university studies.

The data search has involved contacting the various state agencies, universities and individuals involved in geothermal investigation. The catalog of data acquired will be kept by both ERDA and EG&G's Geothermal Non-Electric Group.

6.5 Case Studies

I. A. Engen

The primary purpose of studies undertaken center upon:

1. Information dissemination
2. Extension of geothermal stimulation efforts
3. To enhance future technical assistance activities
4. Facilitate on-going INEL RD&D projects.

Two studies are underway:

1. Native American Tribal Lands - A U.S. map with overlays illustrating known hot springs or well locations along with all tribal lands was developed. Resource base data has been transferred to magnetic tape for permanent retention.

2. Federal Building Conversion Study - Work is continuing, primarily on a fill-in basis to level work loads, compiling federal building data. When this data is complete, it will be processed with the resource data computed for the Indian lands study.

7.0 RAFT RIVER NON-ELECTRIC APPLICATIONS

The Raft River geothermal Development Program originally had, as its main emphasis, the generation of electricity. However, the thermodynamic efficiency of even an advanced binary cycle power plant operating on 290°F water is not likely to exceed 12 to 15%, meaning over 85% of the useful energy in the geothermal water (herein defined as that above 140°F) will be discharged as very low grade heat (not much above ambient temperature). It quickly became apparent that perhaps a more viable use of the energy would be for direct heat uses, such as space heating and low temperature industrial process heat. Consequently, when the Raft River Geothermal Development Corporation was organized in 1974, as a subsidiary of the Raft River Rural Electric Coop., the bylaws provided the option for that utility to distribute heat and/or electricity.

The problem for direct use applications in Raft River is one of size as it affects economics. Each of the first two geothermal wells are easily capable of supplying 20 to 25 MW of heat, far more than could be used by moderate sized business that one might envision would move into the valley in the near future. Therefore, a complex of several businesses needs to be considered, along with the questions of sociological impact, economic benefit of moving to the energy source, and risks involved with long term use of the resource. In addition, there remain a few technical questions needing answers, principally concerning toxicity or other deliterious effects of the water when used directly to produce a product, and the performance of heat exchangers when a secondary fluid is employed. The latter then lead to questions of cycle performance for a particular system, vs geothermal supply and discharge temperatures.

It was decided that two approaches needed to be pursued:

1. Demonstration projects involving industrial processes, set up and run by the appropriate industries, with ERDA providing an incentive via the distribution of geothermal energy at an attractive cost. Not only the success of the operation, but the essential economic factors were to be evaluated.

2. Experiments and testing to answer the few remaining technical questions.

7.1 Raft River Economics Demonstration

The Raft River Economics Demonstration, involved several proposed process plants to be set up and operated by private industry. This effort is in abeyance pending the results of a business analysis study being conducted by Terra Tek, and the establishment of criteria by ERDA through which the availability and cost of the geothermal water for these projects would be determined.

7.2 Experiments of Raft River Beneficial Uses

7.2.1 Agriculture - R. C. Schmitt

All crops from the 1976 Irrigation Experiment activities were removed by the recipient, the Idaho Youth Ranch. The geothermal water sprinkled and fresh water sprinkled sections of oats on the Udy plot were disced and drilled to winter wheat (October 19, 1976) and geothermal watering of part of the winter wheat commenced on November 7, 1976, with a view to examining the use of geothermal water to extend growing seasons. The dryness of the 1976 fall and early winter seasons dictated the need for sprinkling, as well. A report entitled, "Phase I of the Raft River Irrigation Experiment," EG&G, TREE-1048, has been issued. The report provides a complete description of the experiment along with the results through the end of the period. These results indicate that geothermal waters of the Raft River type can be used effectively for crop raising with no short-range detrimental effect. Some typical grains raised during this experiment are shown in Figures 47 and 48.

Planning for follow-on experiment activities, to examine longer range effects and other aspects of geothermal waters on crops, was initiated during the period. Planting will commence in April on the same 12 acres, plus an additional experiment on sugar beets and barley on a large acreage. The latter are being conducted completely by the local farmer, with ERDA merely making geothermal water available for the experiment. An addendum or data summary to TREE-1048 will be issued by June 30, 1977, accumulating all data and/or analyses from the 1976 crop results.

7.2.2 Aquaculture - D. G. Swink

Phase 1 of the aquaculture operations were completed December 1, 1976. All species were removed from the raceways, weighed, measured, and frozen for analysis. The preliminary report was submitted by December 31, 1976, with some of the flesh residue analyses and the data on length and weight gain. The preliminary results appear favorable from the standpoints of both growth and acceptable flesh residue levels. (See Item 5 in Section I for data on Tilapia species, the type that appeared to thrive most from the warm water.)

Fig. 47 Wheat and Oats Raised on 1976 Irrigation Experiment

Fig. 48 Field of Oats - 1976 Irrigation Experiments

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APPENDIX A

Evaluation and Design Considerations for Liquid-Liquid Direct Contact Heat Exchangers for Geothermal Applications

Evaluation and Design Considerations for Liquid-Liquid Direct Contact Heat Exchangers for Geothermal Applications

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Abstract

Binary fluid subcritical cycles have been recommended for electrical power production from liquid dominated geothermal resources below 200°C. Because these brines can be extremely corrosive or scale forming the use of conventional heat exchangers appears to be impractical; thus, direct contact heat exchangers have been proposed. The heat load using such fluids as isobutane, pentane, R-113 or R-114 is nearly evenly divided between the boiling and the liquid-liquid regimes. This paper discusses the alternate designs of the liquid-liquid heat exchangers and their applicability for use with geothermal brines.

Introduction

It has been estimated that the geothermal resources in the Western United States could have the capability of producing up to 385,000 MW_e by the year 2000 if adequate funds were expended on resource development. However, this estimate is based on development of not only vapor and liquid dominated resources but dry geothermal resources as well. The technology for the vapor dominated resources is well understood and has been demonstrated successfully at the Geysers. Liquid dominated resources are reasonably well understood; however, the corrosive and fouling nature of the brines (up to 300,000 ppm dissolved solids) is such as to make normal heat exchangers inapplicable in many instances. Thus, new heat exchanger technology needs to be developed for dealing with much of the liquid dominated resource. Hot dry rock requires development of new drilling technology as well as energy extractive technology.

Of the known Geothermal resources in the United States, most are liquid dominated. It has been estimated that this resource is at least twenty times more prevalent than vapor dominated systems. Thus, a significant part of the U.S.E.R.D.A.'s Geothermal program has been aimed at developing liquid dominated systems.

Liquid dominated geothermal resources have normally been categorized according to temperature. The categorization has been those above 200°C and those below 200°C. For resources above 200°C it has generally been recommended that they be flashed to obtain steam with the steam expanded through a low pressure turbine as is done with dry steam at the Geysers.[1] More recently I. Sheinbaum[2] has shown that this technique may not be the best means of utilizing the resource due to the possible fouling nature of the residual brine such as in the case of Imperial Valley brines. He has shown that the direct contact cycle shown schematically in Figure 1 could produce less expensive power. This cycle uses a secondary fluid as the working fluid (binary cycle), with the working fluid vaporized in a conventional heat exchanger using flashed steam as the heat source. The residual brine heats the liquid working fluid from its condensing temperature to the boiler temperature by direct contact. This latter accounts for approximately half of the heat load and utilizes a part of the resource that would otherwise be lost. The use of a direct contact heat exchanger is necessitated by the higher solids loading of the residual brine.

For geothermal resources below 200°C binary cycles become the most practical means of extracting the energy. The exact working fluid would change depending upon the characteristics of the resource. However, it would normally be one of the light hydrocarbons or a halogenated refrigerant. All of these fluids have poor thermal transport properties although desirable thermodynamic properties. Thus, the use of conventional heat exchangers would require large surface areas the cost of which has been estimated by Testor and Milora[(1)] to be second only to well drilling as a capital expenditure. Further difficulties are encountered due to the chemical nature of the brine. Although no specific statement can be made as to the dissolved solids loading or its chemistry the general trend is the higher the source temperature, the greater its loading. The dissolved solids are normally chlorine salts and silicon oxides with a preponderance being NaCl. The dissolved gases are normally H_2S and CO_2. Wells, drilled a short distance apart can, as in the case of the Imperial Valley, vary from a few thousand parts up to more than 200 thousant parts per million.

The corrosive and scaling characteristics of geothermal brines led Boehm, Jacobs and Coates [(3)] to suggest direct contact heat exchange as a means of reducing capital costs and maintenance for binary geothermal cycles, particularly for the higher salinity brines. Since then several investigators[(4, 5)] have shown that the direct contact binary process was competitive depending upon heat exchanger performance. Jacobs, Boehm, et al[(6, 7)] have concentrated on the direct contact boiler as the technology for direct contact heat transfer with phase change was limited to the work of Sideman[(8)] Somer [(9)] and Simpson[(10)]

on small scale models aimed at desalinization and numerous single drop studies.

Direct contact heat transfer between liquids has also received sparse attention in the literature. J.R. Fair [11] reports in 1972 that published work on direct contact heat transfer was limited at that time to spray columns and pipeline contactors with the only cited applications as "desalinating water" and hot oil cooling. Geothermal resource development thus furnishes a new impetus to this overlooked problem.

A typical direct contact cycle is shown schematically in Figure 2. It consists of a direct contact boiler, a direct contact heater, a direct contact condenser-separator, a working fluid recovery system made up of a flash tank and vapor compressor, and the turbine. The working fluid recovery system is a penalty that the system must carry due to the direct contact and the fact that all fluids are slightly soluble. Please note also the brine pump which may or may not be necessary depending on the selection of the working fluid and the brine delivery pressure. In many instances a fluid with a high operating pressure, such as isobutane, would be eliminated due to the latter parasitic power requirements in favor of a lower boiling point fluid such as iso-pentane*.

Research at the University of Utah has indicated that high heat transfer rates can be achieved in a direct contact boiler. However, the liquid-liquid heat exchanger which carries approximately thirty per cent of the heat duty, as shown in Figure 3, will by its nature (no phase change) require greater volume. This greater volume normally implies greater cost. The liquid-liquid exchanger is also more susceptable to the perfidities of the working fluid as scaling and precipitation will occur more readily at lower temperatures. This paper thus is directed toward the selection and design of the liquid-liquid exchangers.

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* Both I. Sheinbaum[2, 4] and the University of Utah Geothermal Laboratory favor iso-pentane at this time for moderate temperature resources partly for this reason.

Liquid-Liquid Heat Exchangers

Liquid-liquid heat exchangers for geothermal binary cycle application can be divided several ways. However, as the best utilization of the resource would require counter-current operation this will be noted as the first distinction, i.e. counter-current versus co-current. Other goals consistent with the geothermal application include, low susceptability to fouling and minimization of working fluid loss. All of the above should lead to the lowest system cost.

Counter current devices

"Counter current devices" that could be suggested as heat exchangers are shown in Figure 4. They include spray towers, baffle towers, perforated plate towers, packed towers and wetted wall towers. All of the first four are characterized by acting to disperse one phase as drops within the other. The fifth keeps the phases separated except at a cylindrical interface. The advantages of the former are a higher heat transfer area within the contacting volume, while the advantage of the latter is in maintaining separation and perhaps eliminating or reducing the need for the separation system shown in Figure 2.

Spray Tower

The device which has received the most attention as a direct contact liquid-liquid heat exchanger is the spray tower. As can be seen in Figure 4 it consists of a vertical column, an injection nozzle for each fluid, working fluid and brine, and exit ports. Normal operation would theoretically have the heat transfer taking place between the two inlets with coalescent occurring a small distance above. Coalescence of the dispersed phase is induced by a screen made of an oleophillic or hydrophillic material depending on whether the working fluid or brine is dispersed. Design of a spray tower can be carried out following the outline described by R. Letan[12]. The design method requires only that the Reynolds number for the drops be less than 2300. For Reynolds number greater than 2300 the flow is turbulent and scaling of the size is not possible. The advantages of the system is its simplicity of design. However, it has several drawbacks. A spray tower suffers from strong back mixing. That is, the hydrodynamics for high through put cause considerable back circulation, especially at higher drop Reynolds numbers. At Reynolds numbers below 2300 the heat transfer is strongly affected by an attached wake [13, 14, 15, 16] thus there is poor heat transfer in the central portion of the tower. Typically the net effect is that a spray tower only operates effectively near the dispersion nozzle and the coalescence screen. Thus, the number of transfer units, NTU, is limited to between 1 and 3 [12,13,15,16] depending on holdup and back mixing.* As can be seen from Figure 3 a typical direct contact cycle would require five or more contacts hence requiring two or more spray towers in series and reducing its advantages over a co-current flow device, and significantly increasing its cost.

Baffled Towers

Baffled towers overcome the disadvantage of spray towers in that the baffles limit backmixing to the region between baffle plates. However, the region between plates is nearly isothermal. Thus, it provides any number of theoretical trays depending on the mixing efficiency between plates and the number of plates. Fair[11] indicates that such columns have been used with gas-liquid systems as heat exchangers but no data has been published for liquid-liquid systems. To further complicate the design no mass transfer data on baffle columns has been published; however, as a mass transfer device general observation has shown they are about 50% as efficient as perforated plate towers. They do, however, allow for a greater throughput. General design would utilize the E_h for sieve towers multiplied by 50%. General information on sizing baffle columns is presented by Scheiman[17, 18]. Baffle towers may be used effectively in high fouling situations such as with geothermal brines of high solids loading.

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* Treybal, R.E., "Liquid Extraction"[19] points out that backmixing is a function of height-diameter ratio and increases as the reciprical. Thus Steinmeyer and Woodward[15] for a 3 ft diameter tower were only able to obtain 1.3 to 2 theoretical trays with H/D = 2 while for a 6 inch diameter tower (H/D = 10). Markowity and Bergles[16] recorded 2 to 3.

The primary reason for lower efficiency with baffled towers than with sieve plate towers is the limited redispersion of the "dispersed" phase as compared to the sieve towers in gas-liquid systems. This can be partly overcome by higher continuous phase velocity. For liquid-liquid operation the same is true. In particular, enhanced turbulence between plates or coalescences will improve the efficiency. This may also be obtained perhaps more effectively by mechanical agitation. For the geothermal application Lightnin CM Contactors or Rotating Disk contactors as shown in Figure 5 might be effective. Treybal provides some information on the design of such towers. Strand[20] provides adequate information for the scale up of the rotating disk contactor as a mass transfer device which can be used to size the heat transfer assuming $E_h = E_m$. Mechanically agitated towers for liquid-liquid operation have been built up to ten feet in diameter. As a heat transfer device it must be noted that they introduce a small additional parasitic power requirement and that seals are necessary around the power shaft.

Perforated Plate Towers

Perforated plate towers or sieve towers have been recommended by I. Sheinbaum[2, 4] for use as a liquid-liquid heat exchanger. This device has the highest efficiency for mass transfer of all counter current gravity driven devices. It can be designed as a spray tower with only the high efficiency zones of a spray tower (end effects). Thus, the heat transfer of Steinmeyer and Woodward [15] can be applied as well as the work of Sagar et al [21] and the great amount of mass transfer described by Treybal[19]. Normally the design of the tower is such that the continuous phase wets the plates; however, with the brine as a continuous phase this could lead to fouling of the surfaces; thus, it is preferrable to use a hydrophobic surface which would require the types of perforations shown in Figure 6. The major drawbacks to this device are that the throughput is reduced considerably with less than 26% of the flow area available for the dispersed phase in each plate and the possibility of fouling.

Packed Towers

Packed towers have received more attention as a condenser than as any other heat transfer device. As such, volumetric coefficients as high as 60,000-150,000 Btu/hr ft^3 °F have been obtained.[22] As a liquid-liquid heat exchanger they have the lowest throughput, are subject to fouling and suffer from backmixing although not as severe as with a spray tower.[19] As a liquid-liquid mass transfer device published data is limited to small diameter towers - 3, 4 and 6 inch diameters. [23] When compared with spray towers for the same duty, the HTU were reduced by factors of up to six depending on the packing used. In application to geothermal power production it is recommended that their use be directed toward the direct contact condenser.

Wetted Wall Towers

Wetted wall towers have never been seriously considered for industrial application as mass transfer devices; however, they have received attention in the laboratory since 1934[19]. Basically they are constructed so that one fluid wets the wall of a vertical circular conduit with a central core flowing counter currently. An alternate scheme would utilize an inclined duct with the flow stratified with the heavier fluid flowing along the lower surface and the lighter flowing upward above it. In order to obtain the former flow situation, the walls should be constructed of a material not wettable by the Central flowing fluid. For the case of the geothermal application such an exchanger should be hydrophobic and oleophillic. This would allow the working fluid to flow along the walls and reduce the possibility of fouling. The flow in such a device would be maintained laminar, For the case of a hydrodynamically developed flow the double pipe counter flow heat exchanger analysis of Stein[24] and Blanco, Gill and Nunge[25] should be applicable utilizing the flow rates set by the fully developed flow equations for no intervening wall. As the flow will be laminar the heat transfer coefficient will normally be small and the surface area is restricted to the interfacial area. To overcome these deficiences as compared to all of the heat exchangers previously described, heat exchangers made of multiple tubes as shown in Figure 7 would have to be constructed. The primary advantage of this type of heat exchanger would be the elimination of large volumes necessary for settling and separation as compared to the prior devices.

Co-Current Heat Exchangers

Co-current heat exchangers have as their only advantage over countercurrent devices that they are pressure driven, and thus higher velocities are possible. The primary means of differentiating such devices is in their hydrodynamics. The fluids can be either intimately mixed or stratified. Typical of co-current devices include pipeline contactors wetted wall contactors and stratified contactors. These devices all offer, at best, only one theoretical stage. That is, they can only obtain the mixing cup temperature,

$$T_{mc} = \frac{C_A \, T_{A_{in}} + C_B \, T_{B_{in}}}{C_A + C_B} \qquad (1)$$

and thus multiple devices are necessary to obtain an approach to counterflow heat transfer operation.

Stratified flow can be obtained by having an inclined or horizontal exchanger or one with wettable walls. For co-current stratified flow devices the analysis of Jacobs[26] et al is applicable. Their results indicate that only about 60% of the mixing cup temperature can be obtained with practical lengths for fluids typical of the geothermal application. This is of course limited by the thermal diffusivity of the fluids as well as the non-mixing of the fluids individually among themselves.

As the flow velocities increase, greatly increased heat transfer rates are possible. Grover and Knudsen[27] obtained volumetric heat transfer coefficients of between 6000 and 60,000 Btu/hr ft^3 °F for petroleum solvents and water in a $1\frac{1}{2}$ in diameter pipe. The lower values correspond to a stratification. For considerably higher flow rates Wilke and co-workers [28] obtained volumetric heat transfer coefficients as high as 200,000 Btu/hr ft^3 °F in a 3-inch diameter pipe with water or sea-water and two different petroleum oils. In an application to desalinization Wilke et al[22] studied a variety of settlers and separators and found them to be small cost items; however for geothermal power applications with co-current turbulent pipe contactors the design of efficient compact settlers/separators[29] remain the major deterrent especially when applied to highly fouling brines. For this reason perhaps a combination of a stratified flow and turbulent pipe contactor such as used by Grover and Knudsen[27] is more advantageous, for there the lowest heat transfer rate (6000 Btu/hr ft^3 °F) is greater than that obtained for spray columns which themselves obtain little better than one to two theoretical stages with volumetric heat transfer coefficients of only about 2000-4000 Btu/hr ft^3 °F .

Comparison of Designs

Based upon the above discussions, several different designs are possible for direct contact heat exchangers for use as a preheater in a geothermal direct contact binary cycle. In construction the simplest are the spray tower, the wetted wall tower and the turbulent pipe contactor. However they have additional complications in the fact that the spray tower suffers from back mixing, the wetted wall tower may encounter design difficulties in its inlets and outlets and the turbulent pipe contactor requires separator settlers and several stages if it is to approximate countercurrent flow. The baffle, sieve and RDT require internals of increasing complexity, but offer potentially better performance. An example of the relative size of the preheaters is best illustrated by considering a specific case. Thus, we will look at the preheater for the system of Figure 2. Although it is shown as a baffle tower it could be any of the designs mentioned. The brine enters at 220°F with a flow rate of 967,000 lb/hr and leaves at 150°F. 790,000 lb/hr of isopentane enter at 80°F and leave as a liquid at 210°F. The total heat duty is thus, 62,000,000 Btu/hr. Following the design suggestions from the appropriate references discussed previously, the sizing for the heat transfer zones for six different types of heat exchanger were calculated and are shown in Table 1. Also tabulated are the conditions for holdup, the volumetric heat transfer coefficients attainable for the designs, and an indication of the auxilliary equipment requirements. For the spray tower two different heights are indicated. Based on data obtained from small diameter towers with height to diameter ratios of 10 to 20, volumetric heat transfer coefficient as high as 3150 Btu/hr ft^3 ^oF should be possible; however, for small height to diameter ratios Steinmeyer and Woodward [15] found that the heat transfer was considerably reduced. The value of 2000 Btu/hr ft^3 ^oF is more consistent with their work for towers of height to diameter ratios of two. Thus the larger height of 14.88 feet for the heat transfer zone is more realistic. This may, due to back-mixing, have to be divided into two units with additional volume for separation of the fluids as compared to a single unit.

The volumetric heat transfer coefficient for the baffle tower is very conservative and could be as high as 3150 Btu/hr ft^3 ^oF. The design of the sieve tower is consistant with that of Sheinbaum [4]. The wetted wall tower is shown to require from four to five times the volume for the heat transfer as compared with even a spray tower; however, if simple entrance-exit zones could be designed it might be comparable to the spray tower in actual size but would be expected to be much more costly to manufacture. The RDT tower could well be an off the shelf item; however, its design is based on limited mass transfer data and heat transfer data needs to be acquired.

The turbulent pipe contacter is the only cocurrent device shown in Table 1. It appears quite attractive depending upon the state of the art of settler-separators. Reference 29 indicates that compact settlers can be constructed as small as 1/6th of an empty settler; thus, it is possible that a five stage system as shown in Figure 8 might be constructed and be comparable in cost to the other units considered. The length of the turbulent pipes shown in Table 1 progress from the low temperature end of the system. As shown in Figure 8 it would be possible to reduce cost of settler-separator pressure vessels by inter-stage pumping, although this might not be necessary.

TABLE 1 COMPARISON OF DESIGNS OF VARIOUS LIQUID-LIQUID DIRECT CONTACT HEAT EXCHANGERS

Type	Duty	Diameter	Height Heat Transfer Zone	Holdup	Volumetric Heat Transfer Coefficient	Area Heat Transfer Coefficient Internal Equip.	Auxiliary Equipment
Spray *	62,000,000 Btu/hr	9.2 ft	14.88	26% (90% flooding)	2000 Btu/hr ft^3 °F	-	Coalescence Volumes
			9.5	"	3150	-	
Baffle (Disk-Donut According to Treybal)	"	7.9 ft	16.74 ft	40%	2400 ** (50% Sieve Tower)	18" Spacing Baffles)	Coalescence Volumes
Sieve	"	7.9 ft	8.37	40%	4800	24" Spacing Trays 1/8" D holes ½" square spacing	Coalescence Volumes
RTD	"	7.0 ft	7.0	25% (75% flooding)	8000 ***	Impeller Dia } 3.5' Stator Inner Dia } 4.68' 18" Spacing	Coalescence Volumes 21 HP motor to drive impeller
Wetted Wall Tower	"	102,100 tubes 0.7" diameter (273 ft^2 active area, 347 ft^2 gross area)	8.82	-	646	16.8 Btu/hr ft^2 °F	Manifolds Exit and Entrance
Turbulent Pipe Contactors	"	0.5 ft 5 stages with stages pressure increase	3.96 ft 4.75 ft 6.73 ft 8.3 ft 15.83 ft	-	200,000 (Reynolds Number 6.7×10^6)		5 Settler Separator 5 Brine Pressure Reducers

* For Geometry Reasons Lower Value U_v Probable ** See Discussion on Baffle Towers *** $U_v = 5 U_v$ Stagnant Drops (Fig 11.31 Ref 19)

Conclusions

A wide variety of designs for the preheater in a direct contact bindary cycle are possible. Although at first glance a spray tower would appear attractive its susceptability to backmixing makes it suspect particularly when a low height to diameter ratio is indicated. For low fouling brines a sieve plate tower is attractive as it is indicated to be of a reasonable volume. However, for counter current devices, the baffle tower or mechanically agitated towers look most attractive for a wide range of brine salinities. The power requirement for an RDT tower are low and should not be sufficient to eliminate it from contention. Mass transfer units, both RDT and baffle tower, have been constructed to the size necessary for a preheater.

Parallel flow devices may be attractive if low cost compact settlers can be designed. This type of exchanger settler system has been suggested by Wilke et al [22] for desalination systems.

Final selection of a preheater for a direct contact binary cycle can not be made until further heat transfer design data is made available. However, the design comparison in Table 1 indicates that heat transfer data for baffled tower and mechanically agitated towers should be pursued. Design of compact settler-separators also need further investigation.

Nomenclature

A	Surface area, i.e. Surface of drops
C	m Cp
Cp	Specific heat at constant pressure
HTU	Height for a transfer unit or stage
m	Mass flow rate
NTU	$\frac{m\,Cp}{UA}$ or $\frac{m\,Cp}{U_V V}$
T	Temperature
U	Surface heat transfer coefficient
U_V	Volumetric heat transfer coefficient

Subscripts

A, B	Designation of a fluid
mc	Mixing cup

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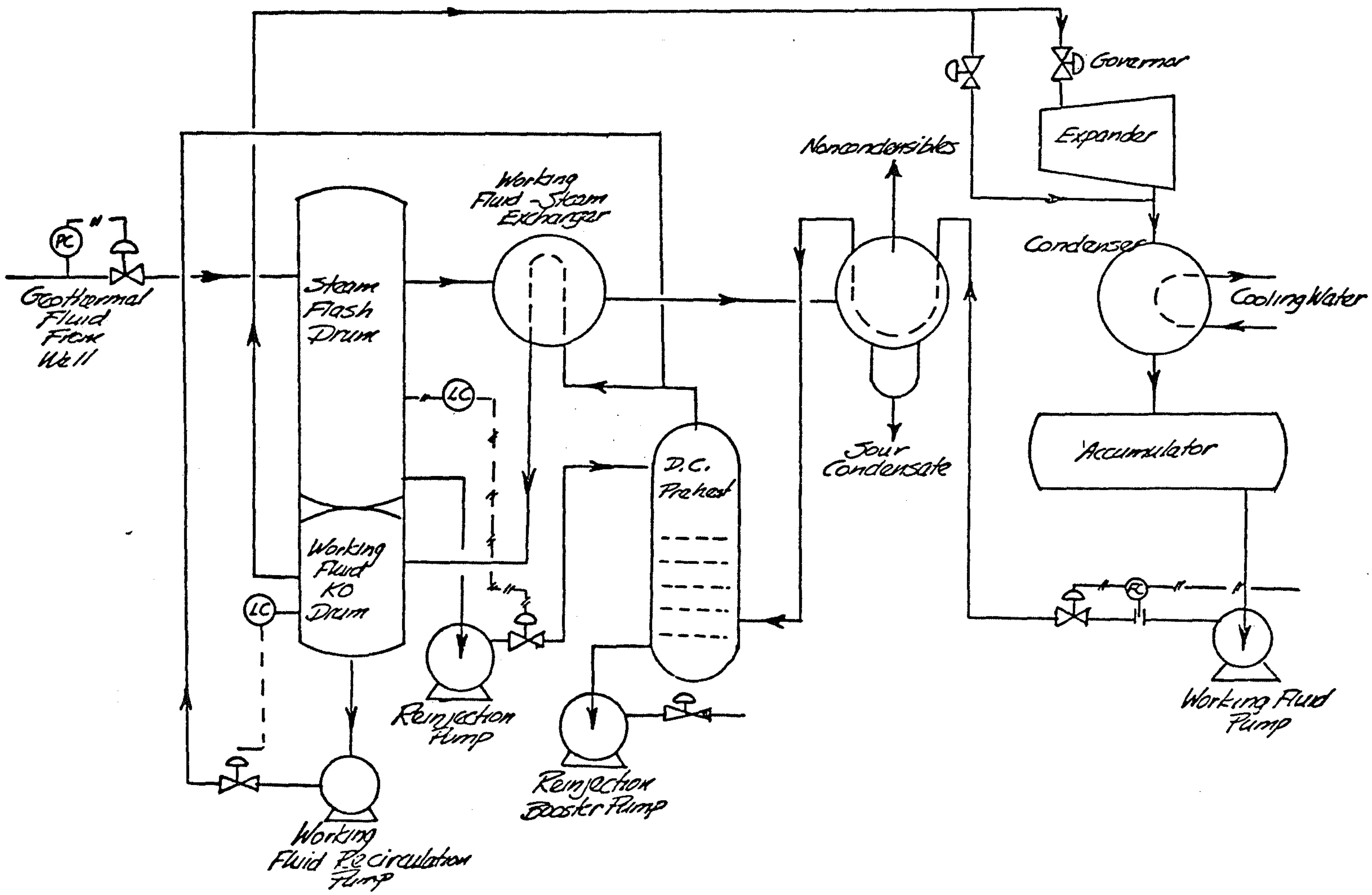

FIGURE 1 HIGH TEMPERATURE DIRECT CONTACT BINARY CYCLE AS PER SHEINBAUM(2)

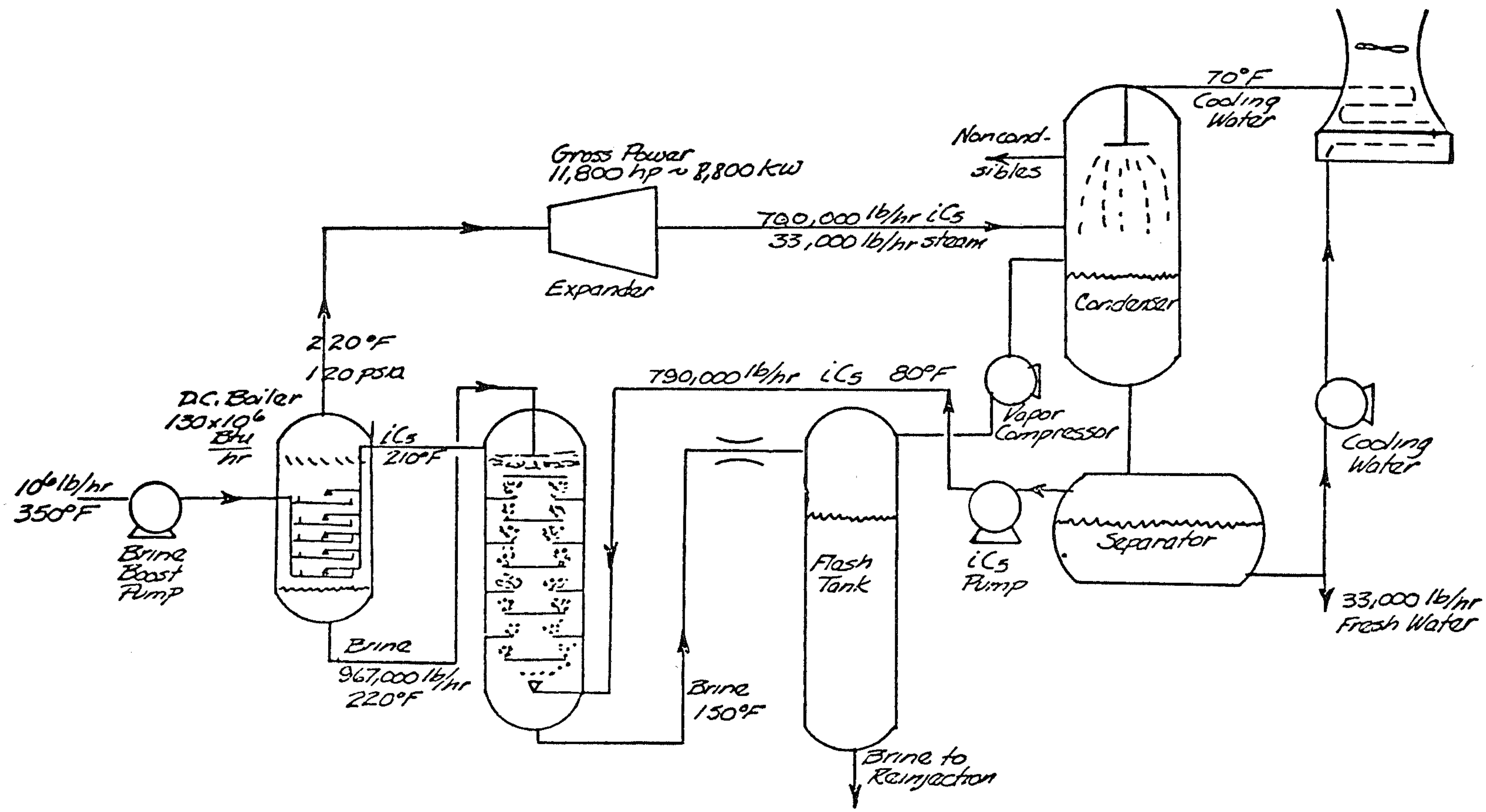

FIGURE 2 DIRECT CONTACT BINARY GEOTHERMAL CYCLE - MODERATE TEMPERATURE

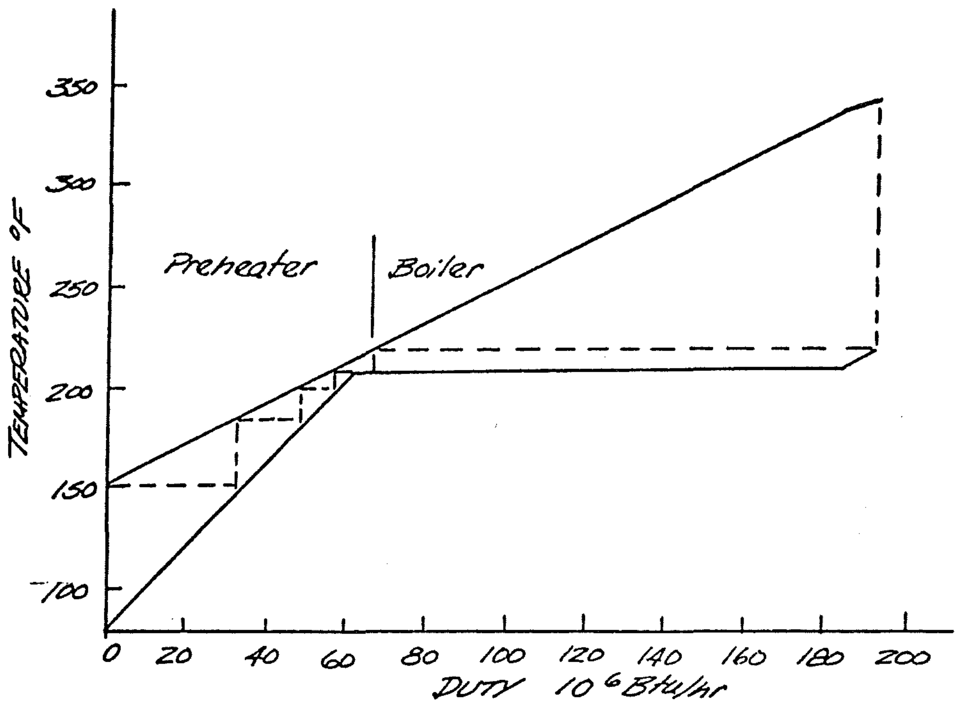

FIGURE 3 TEMPERATURE VS DUTY FOR THE CONTACTORS OF FIGURE 2

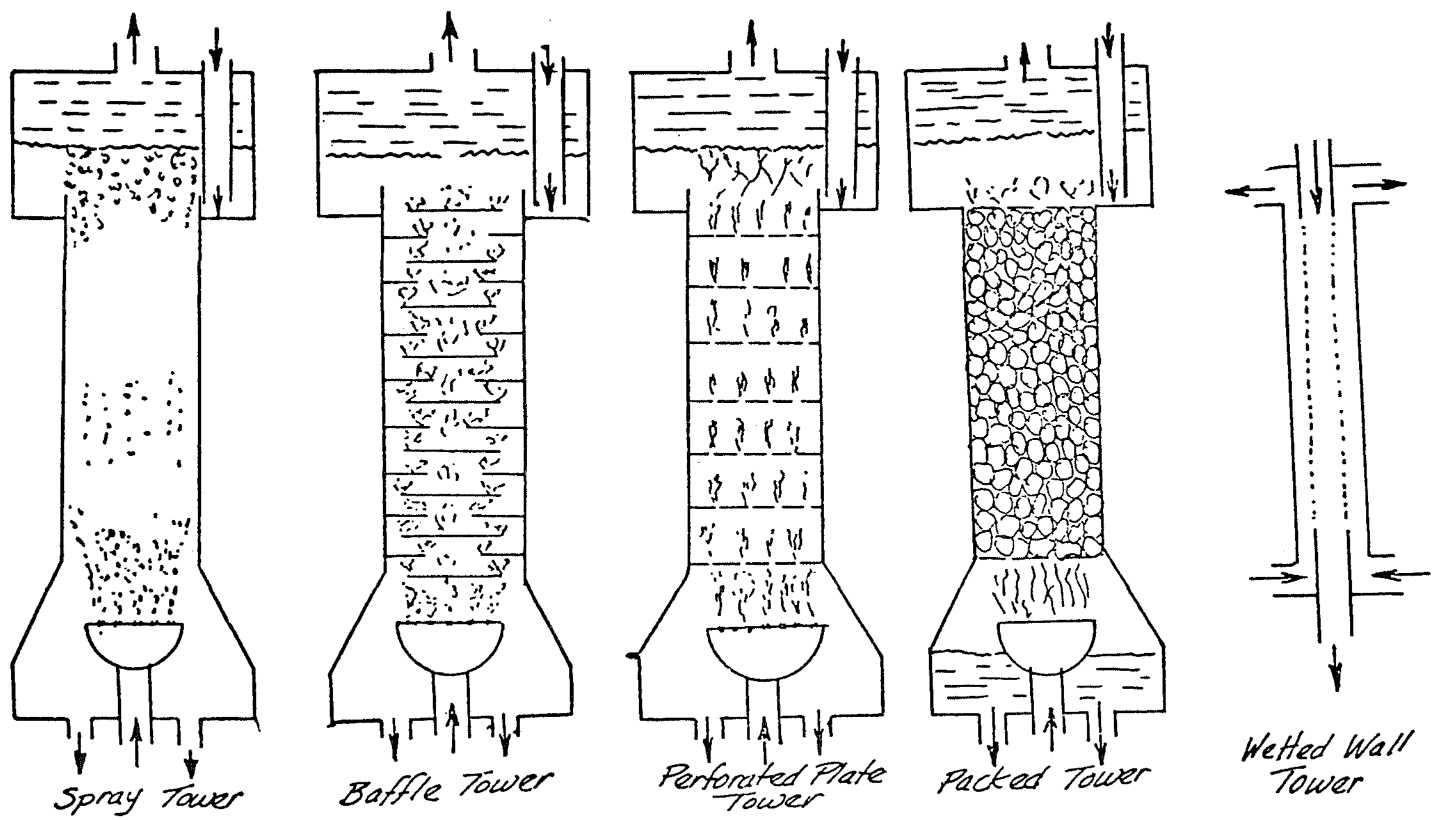

FIGURE 4 SCHEMATIC OF VARIOUS TYPES OF DIRECT CONTACT COUNTER FLOW DEVICES

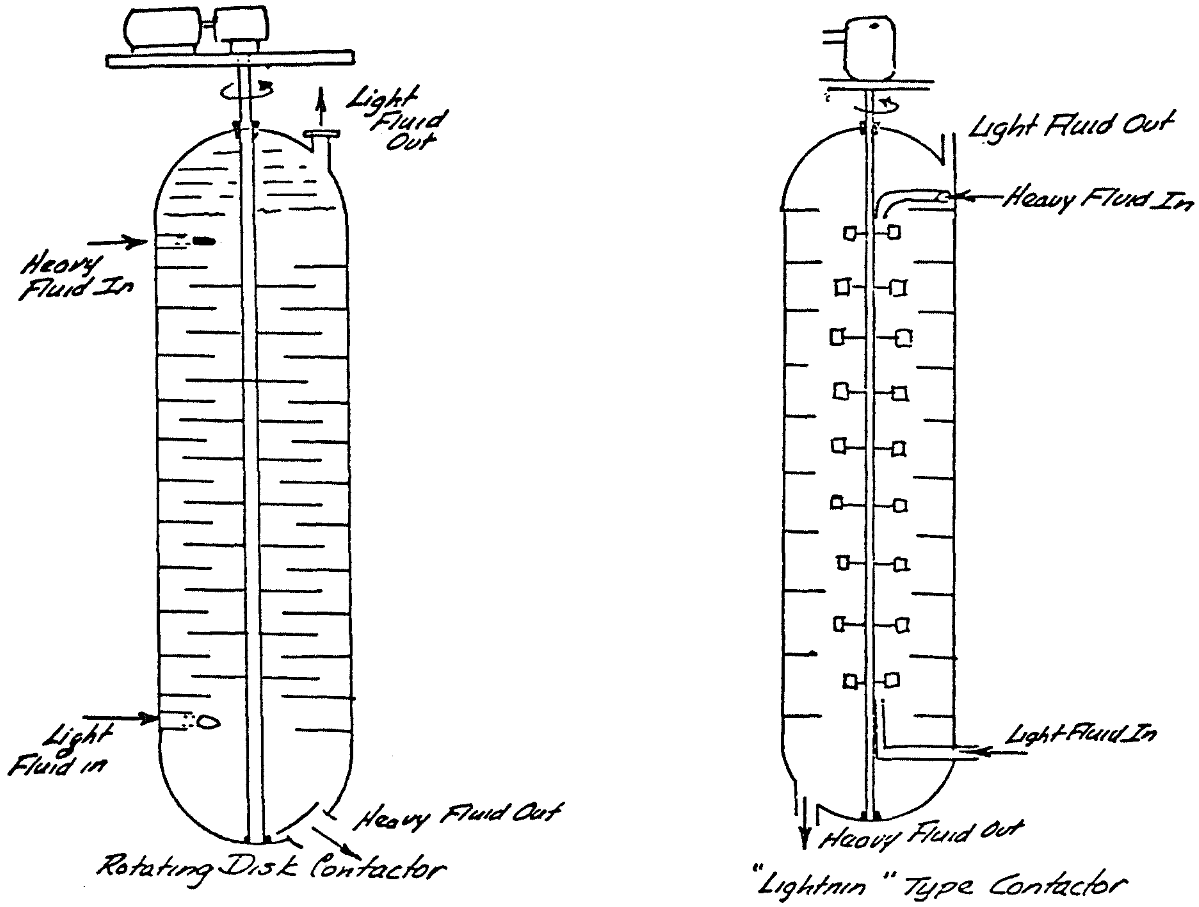

FIGURE 5 MECHANICALLY AGITATED DIRECT CONTACTORS

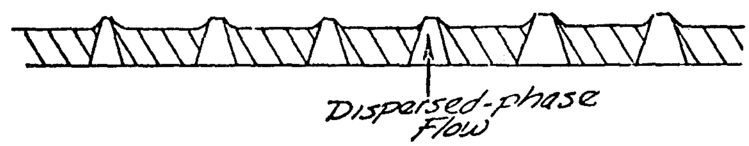

FIGURE 6 DESIGN OF PERFORATIONS FOR FOULING FLUID APPLICATION

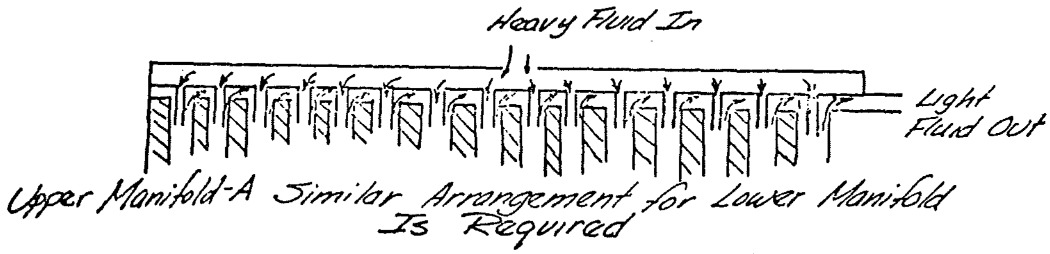

FIGURE 7 TYPICAL MANIFOLD FOR MULTIPLE TUBE WETTED WALL DIRECT CONTACT HEAT EXCHANGER

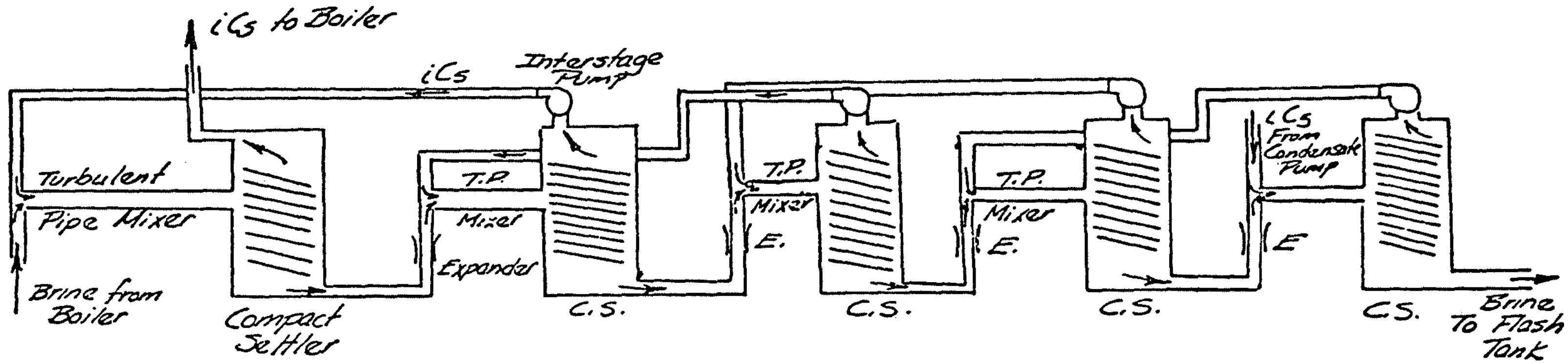

FIGURE 8 FIVE STAGE COCURRENT FLOW (TURBULENT PIPE MIXER) PREHEATER SYSTEM

APPENDIX B

Summary of the Freon-113 Experiment Results

NOMENCLATURE FOR DATA TABULATION

TEMPERATURES

H2O in: brine temperature in (to boiler)

H2O ex: brine temperature out

F in: freon temperature in

F out: freon temperature out

F sat: freon saturation temperature

PRESSURES

Vessel: total vessel pressure, psia

Sat: freon saturation pressure

HEAT TRANSFER

QD: heat transferred to dispersed phase (freon)

UA: overal heat transfer coefficient

MASS RATIO

$$\frac{\text{Mass flow rate brine}}{\text{Mass flow rate working fluid}}$$

CU

Carryunder indicator

0: no carryunder, safe operation

2: $T_{R\text{-}113} - T_{R\text{-}113\ SAT} < 0$

1: detected carryunder

Note: all 1's also satisfy condition 2

STANTON NUMBER

H = PR*JA

H = (Prandtl No.) X (Jacob No.)

FREON NOZZLE 6EW

DATE	TEMPERATURE(F) H2O IN	H2O EX	F IN	F OUT	F SAT	PRESSURES(PSIA) VESSEL	SAT	HEAT TRANSFER QD BTU/HR	UA BTU/HR F	MASS RATIO H2O/FLUID	CU	STANTON NUMBER	H=PR*JA
400													
	291.3	262.1	184.6	247.1	212.0	92.5	64.2	43678.	736.	4.38	0	4.56	3.59
	292.5	271.2	185.2	257.8	204.9	92.5	58.4	44936.	795.	6.57	0	4.93	3.11
	292.4	275.8	183.9	262.4	201.3	92.5	55.6	45734.	826.	8.76	0	5.13	2.94
	290.5	253.6	197.5	237.1	217.4	92.5	68.8	58552.	1069.	3.02	0	4.53	4.15
	286.6	235.7	193.6	221.5	224.0	92.5	74.8	44282.	838.	1.64	1	4.57	5.93
401													
	293.7	265.7	208.2	247.1	212.0	92.5	64.2	62721.	1209.	4.17	0	4.72	3.43
	293.2	270.8	188.0	254.9	207.0	92.5	60.0	71021.	1230.	5.44	0	4.73	3.17
	291.8	267.5	194.0	248.4	211.2	92.5	63.5	83109.	1454.	4.46	0	4.57	3.41
	293.7	263.2	197.8	244.9	213.3	92.5	65.2	75009.	1323.	3.61	0	4.48	3.55
	291.6	251.4	205.2	236.5	217.7	92.5	69.0	69026.	1366.	2.48	0	4.74	4.21
	291.4	243.6	203.5	231.4	220.0	92.5	71.1	84432.	1709.	2.01	0	4.80	4.73
	291.2	259.2	203.5	239.7	216.1	92.5	67.7	86652.	1617.	3.01	0	4.54	3.86
	292.7	266.3	205.0	244.5	213.5	92.5	65.4	87455.	1603.	4.01	0	4.51	3.50
	294.4	267.8	206.8	247.1	212.0	92.5	64.2	87526.	1624.	4.01	0	4.57	3.36
402													
	294.5	263.8	199.8	242.8	214.5	92.5	66.2	98770.	1714.	3.61	0	4.34	3.55
	294.0	256.9	204.0	238.8	216.6	92.5	68.1	92990.	1721.	2.79	0	4.49	3.87
	292.1	242.7	208.2	230.1	220.6	92.5	71.7	88364.	1883.	1.87	0	4.92	4.78
	293.0	239.3	211.1	226.2	222.2	92.5	73.1	96003.	2144.	1.68	0	5.02	5.06
	293.7	254.2	210.5	236.6	217.7	92.5	69.0	99630.	1988.	2.52	0	4.66	4.02
	293.7	264.2	201.2	242.5	214.6	92.5	66.4	105510.	1854.	3.35	0	4.36	3.57
	294.4	261.2	200.8	240.0	216.0	92.5	67.5	117610.	2050.	2.99	0	4.30	3.69
	293.0	252.6	206.6	234.6	218.6	92.5	69.9	113320.	2182.	2.23	0	4.55	4.17
	293.6	237.9	213.1	226.2	222.2	92.5	73.1	106690.	2505.	1.50	1	5.22	5.11
403													
	293.9	267.7	211.3	248.1	211.4	92.5	63.7	66463.	1304.	4.33	0	4.75	3.36
	294.8	268.8	197.3	251.4	209.4	92.5	61.9	70990.	1261.	4.33	0	4.62	3.25
404													
	290.5	257.7	196.3	243.5	214.0	92.4	65.8	43326.	804.	3.19	0	4.73	3.83
	290.0	257.5	199.7	242.3	214.7	92.4	66.4	42591.	810.	3.27	0	4.75	3.89
	289.2	252.3	187.9	240.5	215.6	92.4	67.2	51980.	926.	2.73	0	4.65	4.15
405													
	293.6	275.3	183.6	262.3	201.3	92.4	55.6	43233.	769.	7.72	0	5.06	2.93
	295.3	279.7	174.9	268.4	195.9	92.4	51.7	40691.	710.	10.73	0	5.23	2.72
	291.8	270.5	185.3	258.4	204.3	92.4	57.9	37948.	685.	6.71	0	5.04	3.13
	291.4	264.5	193.6	250.5	209.8	92.4	62.3	36395.	668.	5.14	0	4.83	3.44
406													
	294.9	276.2	186.2	262.3	201.2	92.4	55.6	53937.	954.	7.36	0	4.98	2.89
	293.1	273.1	183.6	259.2	203.6	92.4	57.4	50091.	874.	6.61	0	4.92	3.03
	292.3	268.8	194.9	254.0	207.4	92.4	60.4	47165.	871.	5.31	0	4.89	3.24
	291.4	261.8	210.1	247.9	211.4	92.4	63.6	43315.	912.	4.01	0	5.12	3.57
	294.9	272.7	189.2	259.2	203.6	92.4	57.4	65841.	1171.	6.16	0	4.90	3.01
	292.7	266.6	189.7	251.8	208.9	92.4	61.6	63500.	1114.	5.00	0	4.72	3.33
	293.1	264.5	198.4	247.9	211.4	92.4	63.6	59427.	1081.	4.08	0	4.66	3.46
407													
	295.7	277.5	157.9	265.3	198.8	92.4	53.7	58791.	903.	8.71	0	4.84	2.80
	295.7	277.9	185.8	265.7	198.4	92.4	53.4	53726.	970.	8.70	0	5.15	2.78
	295.3	278.8	181.4	266.2	198.0	92.4	53.2	54523.	964.	8.72	0	5.13	2.77
	294.9	277.9	172.7	266.2	198.0	92.4	53.2	55214.	937.	8.87	0	5.09	2.79
	293.6	274.5	172.1	261.8	201.7	92.4	55.9	55345.	918.	7.52	0	4.92	2.95

	295.3	274.9	162.7	262.7	201.0	92.4	55.4	57417.	892.	7.48	0	4.78	2.90
	294.9	275.3	185.8	263.1	200.6	92.4	55.1	53400.	958.	7.46	0	5.08	2.89
	294.4	271.8	189.2	256.6	205.7	92.4	59.0	51538.	899.	5.62	0	4.77	3.08
	294.9	271.4	181.4	256.6	205.7	92.4	59.0	52126.	862.	5.71	0	4.66	3.08
	294.4	270.1	168.8	256.6	205.7	92.4	59.0	54269.	842.	5.73	0	4.59	3.12
	292.3	261.0	188.4	245.7	212.8	92.4	64.8	49268.	841.	3.82	0	4.52	3.63
	292.3	261.8	198.4	245.7	212.8	92.4	64.8	47726.	875.	3.79	0	4.66	3.60
	291.0	260.5	180.5	245.3	213.0	92.4	65.0	50622.	827.	3.82	0	4.46	3.69
	296.2	274.5	205.3	254.9	206.9	92.4	60.0	77577.	1436.	5.43	0	4.71	3.03
	296.6	275.3	213.6	256.2	206.0	92.4	59.3	75071.	1491.	5.45	0	4.89	2.98
	295.7	274.5	193.1	256.6	205.7	92.4	59.0	81371.	1411.	5.46	0	4.67	3.01
408													
	294.4	270.5	177.5	255.3	206.6	92.4	59.7	76001.	1221.	5.28	0	4.58	3.14
	294.0	271.0	188.8	256.2	206.0	92.4	59.3	72020.	1260.	5.37	0	4.79	3.12
	295.3	271.0	170.5	257.1	205.4	92.4	58.8	77157.	1198.	5.35	0	4.57	3.08
409													
	240.1	227.1	132.8	211.4	165.0	47.4	32.9	45603.	827.	9.58	0	5.65	4.09
	249.2	209.7	130.6	197.5	173.9	48.4	37.5	43224.	671.	2.90	0	4.70	4.89
	251.4	237.5	155.3	223.1	184.9	62.4	44.2	42198.	835.	8.56	0	5.76	4.37
	246.6	227.9	151.0	214.0	189.4	62.4	47.1	41275.	799.	6.22	0	5.59	5.34
	249.7	228.8	177.5	217.9	212.9	81.4	64.9	37506.	921.	4.55	0	6.32	8.81
	251.0	225.3	175.8	215.7	214.9	82.4	66.6	37523.	894.	3.78	0	6.13	9.88
	248.4	217.9	172.3	211.4	216.4	82.4	67.9	38032.	924.	2.94	2	6.34	13.63
410													
	254.9	238.4	182.7	225.3	211.1	82.4	63.4	37602.	912.	6.18	0	6.24	6.57
	249.2	230.1	178.4	219.2	213.6	82.4	65.5	38013.	953.	6.12	0	6.45	8.86
	253.1	229.7	181.8	220.1	213.3	82.4	65.2	37616.	941.	4.89	0	6.35	8.22
	251.0	225.7	176.6	214.9	215.2	82.4	66.9	37363.	884.	3.78	2	6.05	9.90
411													
	289.1	248.1	72.0	231.8	208.2	82.5	61.0	63160.	597.	3.29	0	3.63	3.91
	288.2	234.8	73.9	220.3	214.4	83.5	66.2	92603.	859.	2.18	0	3.45	4.89
	288.5	226.4	76.7	215.6	215.0	82.5	66.7	114510.	1073.	1.77	0	3.42	5.41
	288.3	221.1	82.2	215.0	215.2	82.5	66.9	147170.	1434.	1.36	1	3.50	5.81
412													
	286.9	231.1	69.5	218.0	214.1	82.4	65.9	80559.	741.	2.09	0	3.45	5.13
	287.0	227.0	72.1	217.6	214.2	82.4	66.0	87692.	823.	1.88	0	3.49	5.38
	286.8	222.8	72.0	216.1	214.8	82.4	66.5	104460.	988.	1.61	0	3.50	5.74
	286.2	225.0	71.8	217.3	214.4	82.4	66.1	113450.	1075.	1.48	1	3.52	5.58
413													
	286.5	233.6	65.6	220.5	213.1	82.4	65.0	81281.	745.	2.28	0	3.49	4.93
	286.0	224.3	71.6	217.0	214.4	82.4	66.2	104790.	995.	1.72	0	3.53	5.65
	286.2	223.3	77.0	214.9	215.2	82.4	66.8	128290.	1229.	1.38	1	3.49	5.79
414													
	287.6	242.5	63.3	226.4	222.2	92.5	73.1	63229.	576.	2.90	0	3.51	5.18
	288.1	235.3	67.5	225.2	222.6	92.5	73.5	78390.	733.	2.31	0	3.55	5.68
	287.9	235.5	69.4	225.3	222.6	92.5	73.5	85196.	803.	2.11	0	3.56	5.67
	287.3	235.8	69.8	224.8	222.8	92.5	73.6	99499.	939.	1.81	1	3.56	5.72
	286.1	246.5	77.2	235.1	229.1	102.5	79.7	53436.	542.	3.00	0	3.80	5.79
	292.8	247.7	76.0	235.8	228.8	102.5	79.4	103630.	996.	2.79	0	3.62	5.20
	291.8	243.1	83.6	232.4	230.2	102.5	80.8	110060.	1086.	2.34	0	3.60	5.75
	290.3	242.0	85.8	231.4	230.6	102.5	81.2	107640.	1079.	2.05	0	3.63	6.02
	287.7	237.1	87.4	232.8	230.0	102.5	80.6	107380.	1136.	1.85	1	3.82	6.62
415													
	289.4	227.0	63.9	217.3	202.0	72.5	56.2	91116.	817.	2.00	0	3.45	4.32
	289.3	218.6	69.1	211.8	204.2	72.5	57.9	113470.	1035.	1.60	0	3.41	4.83
	289.4	216.9	74.6	204.6	206.7	72.5	59.8	141420.	1273.	1.25	1	3.27	5.12
	285.4	215.4	80.1	206.5	206.1	72.5	59.3	123030.	1176.	1.42	1	3.42	5.38

FREON SPRAY BOILER, NOZZLE 5PW

DATE	H2O IN	H2O EX	F IN	F OUT	F SAT	VESSEL	SAT	QD BTU/HR	UA BTU/HR F	MASS RATIO H2O/FLUID	CU	STANTON NUMBER	H=PR*JA
	TEMPERATURE(F)					PRESSURES(PSIA)		HEAT TRANSFER					
200													
	264.5	253.6	171.0	224.5	181.0	60.4	41.7	46131.	785.	10.56	0	4.69	3.39
	277.5	264.9	170.5	251.4	211.7	94.4	63.9	28910.	544.	11.83	0	5.44	3.91
	280.5	264.9	135.0	243.1	171.2	62.4	36.0	49241.	663.	11.24	0	4.46	2.70
	278.4	264.5	165.3	251.0	208.3	91.4	61.1	29419.	527.	11.23	0	5.29	3.74
201													
	281.4	267.9	171.0	251.4	197.7	83.5	52.9	40018.	701.	10.69	0	5.11	3.21
	278.8	259.7	157.5	243.6	201.6	92.5	55.9	42143.	670.	6.67	0	4.77	3.50
	274.0	237.5	152.3	224.0	211.7	82.5	63.9	40169.	608.	3.39	0	4.38	5.20
	270.1	224.9	156.6	212.7	214.9	81.5	66.6	39620.	632.	2.49	2	4.43	7.04
	267.1	214.0	169.2	214.9	215.3	82.5	66.9	37940.	784.	1.82	2	5.45	9.07
	274.5	233.6	132.4	215.7	193.1	65.5	49.7	49391.	633.	3.09	0	3.97	4.13
202													
	274.0	220.1	155.3	211.4	214.1	80.5	65.9	42781.	672.	2.76	2	4.37	6.99
	269.7	215.7	155.3	211.4	214.1	80.5	65.9	43356.	731.	1.67	1	4.69	8.06
203													
	282.5	216.4	69.6	210.7	204.6	72.5	58.2	70400.	671.	1.66	0	3.55	5.35
	283.0	213.9	69.9	206.9	206.0	72.5	59.2	78213.	735.	1.48	0	3.46	5.62
	283.7	214.7	70.7	206.1	205.0	71.5	58.4	82143.	765.	1.40	1	3.42	5.42
204													
	283.3	225.7	74.5	212.1	204.2	72.6	57.8	57519.	541.	2.02	0	3.46	4.78
	283.3	217.5	78.4	207.9	205.7	72.6	59.0	68665.	660.	1.68	0	3.46	5.34
	283.6	215.2	80.5	206.0	206.3	72.6	59.5	80804.	780.	1.41	1	3.44	5.53

FREON NOZZLE, FLAT SPRAY

DATE	TEMPERATURE(F) H2O IN	H2O EX	F IN	F OUT	F SAT	PRESSURES(PSIA) VESSEL	SAT	HEAT TRANSFER QD BTU/HR	UA BTU/HR F	MASS RATIO H2O/FLUID	CU	STANTON NUMBER	H=PR*JA.
100													
	271.9	235.2	85.3	212.6	213.8	80.5	65.6	45993.	471.	3.22	2	3.63	5.80
	279.4	256.7	87.9	229.6	209.9	83.0	62.4	52674.	540.	5.84	0	3.74	4.03
	277.4	253.1	89.2	224.9	211.4	82.5	63.6	64215.	656.	4.95	0	3.67	4.33
101													
	257.2	227.0	81.2	205.8	203.9	70.6	57.6	56876.	628.	3.79	0	3.93	6.29
	258.3	226.1	85.7	205.9	206.4	72.6	59.5	55288.	619.	3.81	2	3.93	6.65
	256.6	219.9	89.7	203.9	207.0	72.6	60.1	69708.	814.	2.88	2	4.05	7.60
	257.7	214.9	90.6	204.1	207.0	72.6	60.0	86464.	1029.	2.41	2	4.11	8.10
	257.6	212.6	92.4	205.5	206.5	72.6	59.6	95606.	1174.	2.12	2	4.22	8.32
	257.5	212.1	92.7	205.2	206.6	72.6	59.7	108520.	1335.	1.87	1	4.22	8.44
102													
	299.4	265.5	90.5	247.3	212.0	92.5	64.1	54794.	540.	4.30	0	3.69	3.30
	299.4	251.7	84.6	229.6	220.9	92.5	71.9	92977.	834.	2.52	0	3.27	4.00
	299.5	244.7	89.9	222.0	223.9	92.5	74.7	106750.	955.	2.13	2	3.17	4.57
	298.5	237.9	95.9	221.2	224.2	92.5	75.0	124570.	1171.	1.77	2	3.27	5.00
	298.5	235.8	97.1	221.2	224.2	92.5	75.0	129220.	1230.	1.65	2	3.30	5.12
	300.1	230.6	113.6	221.7	224.0	92.5	74.8	135810.	1409.	1.58	2	3.40	5.33
	301.1	225.1	104.8	221.2	224.2	92.5	75.0	163370.	1655.	1.35	1	3.42	5.66
103													
	288.6	248.7	93.1	229.7	218.6	90.5	69.9	67516.	678.	2.92	0	3.58	4.51
	290.1	244.6	96.3	224.5	217.4	87.5	68.8	70054.	691.	2.54	0	3.45	4.55
	291.0	231.6	95.9	216.0	217.2	84.5	68.6	105110.	1027.	1.85	2	3.37	5.15
	288.2	221.5	99.5	214.9	217.6	84.5	69.0	105730.	1106.	1.41	2	3.57	6.09
	288.3	218.6	97.7	216.4	217.1	84.5	68.5	126480.	1340.	1.24	1	3.63	6.23
104													
	290.2	260.8	76.7	243.1	214.4	92.6	66.2	57467.	572.	3.36	0	3.84	3.76
	289.2	251.3	70.2	229.9	221.9	93.6	72.8	71287.	653.	3.83	0	3.49	4.60
	290.2	239.7	89.2	221.1	224.2	92.6	75.0	105570.	1009.	1.70	2	3.39	5.41
	289.2	232.1	94.5	221.9	224.0	92.6	74.7	124020.	1262.	1.42	2	3.55	6.01
	289.2	224.8	68.1	219.6	224.8	92.6	75.5	157200.	1465.	1.26	1	3.52	6.81
105													
	283.8	230.5	76.0	231.8	209.4	83.5	62.0	53704.	571.	2.75	0	4.03	4.93
	284.6	213.7	75.6	213.5	216.9	83.5	68.4	83117.	824.	1.72	2	3.63	7.06
	283.8	210.4	76.1	212.6	216.1	82.5	67.6	105340.	1059.	1.35	1	3.68	7.36

FREON VOLUME BOILER, *1

DATE	TEMPERATURE(F) H2O IN	H2O EX	F IN	F OUT	F SAT	PRESSURES(PSIA) VESSEL	SAT	HEAT TRANSFER QD BTU/HR	UA BTU/HR F	MASS RATIO H2O/FLUID	CU	STANTON NUMBER	H=PR*JA
300													
	292.3	272.3	100.3	265.7	198.4	92.4	53.4	53061.	682.	8.53	0	4.89	2.94
	293.6	271.8	159.2	267.5	196.8	92.4	52.3	43970.	743.	8.34	0	5.34	2.89
	294.0	272.3	149.0	267.1	201.3	95.4	55.6	43961.	694.	7.73	0	5.15	2.97
301													
	291.4	266.6	158.8	259.2	203.7	92.4	57.5	62696.	1002.	5.46	0	4.94	3.20
	290.5	249.2	159.2	239.2	216.3	92.4	67.8	129300.	1878.	3.01	0	4.23	4.26
	290.1	256.6	157.9	247.9	211.5	92.4	63.7	93864.	1412.	3.81	0	4.52	3.76
	284.5	249.2	172.7	239.2	216.3	92.4	67.8	81794.	1375.	3.00	0	4.65	4.51
	294.0	264.0	169.7	255.3	209.1	94.4	61.7	56857.	911.	4.77	0	4.70	3.37
	292.3	263.6	172.7	254.9	213.8	102.4	70.0	50004.	830.	4.60	0	4.77	3.81
	293.1	264.0	167.9	256.6	192.1	82.4	49.0	61357.	997.	4.97	0	4.87	2.92
	288.3	240.5	185.3	233.6	219.0	92.4	70.2	52370.	818.	2.20	1	4.04	4.94
302													
	266.2	256.6	162.7	253.6	181.0	73.5	41.7	22912.	566.	19.16	0	7.54	3.29
	267.1	254.9	167.5	253.1	179.7	72.5	41.0	23046.	576.	15.29	0	7.50	3.27
	267.1	251.0	168.8	248.4	183.8	72.5	43.5	24311.	567.	11.12	0	6.87	3.48
	264.9	244.9	168.4	241.4	187.5	71.5	45.9	24513.	546.	8.49	0	6.44	3.82
	267.9	249.2	172.7	241.0	190.8	73.5	48.1	64218.	1352.	6.46	0	5.97	3.75
	267.5	247.5	174.0	238.8	190.7	72.5	48.0	64191.	1348.	5.89	0	5.89	3.81
	266.4	243.1	189.7	234.0	195.1	73.5	51.1	59160.	1369.	4.43	0	6.00	4.12
303													
	266.2	254.0	126.6	249.2	183.1	72.5	43.0	31328.	572.	15.67	0	6.25	3.40
	267.9	253.1	126.2	249.2	183.1	72.5	43.0	31202.	552.	12.37	0	6.06	3.38
	267.5	249.2	120.9	244.9	186.5	72.5	45.2	32056.	527.	9.93	0	5.66	3.60
	257.9	240.1	137.2	231.8	195.0	72.5	51.0	29560.	528.	7.51	0	5.63	4.62
	264.5	231.4	167.9	220.1	201.5	73.0	55.7	58313.	1093.	3.04	0	5.10	5.23
	263.6	244.5	125.8	236.2	175.0	61.5	38.2	73635.	1183.	7.36	0	5.39	3.42
	265.7	243.6	127.1	235.3	177.4	62.5	39.5	73065.	1140.	5.92	0	5.19	3.47
	255.3	226.6	145.5	215.3	191.8	64.5	48.8	62743.	1079.	3.60	0	5.07	5.15
304													
	256.6	236.6	88.5	232.3	160.7	52.4	30.8	49182.	717.	8.70	0	5.51	3.32
	254.5	237.9	90.7	232.7	160.3	52.4	30.6	48894.	745.	10.47	0	5.72	3.33
	262.7	239.7	92.9	233.6	161.6	53.4	31.2	48637.	668.	7.30	0	5.13	3.17
	261.8	229.7	119.6	221.0	168.9	52.4	34.9	77469.	1109.	4.19	0	4.76	3.60
	262.7	233.1	110.4	224.9	170.1	54.4	35.6	82065.	1138.	4.82	0	4.79	3.54
	263.1	237.9	94.2	229.2	163.1	52.4	31.9	85139.	1120.	6.08	0	4.84	3.23
	264.9	251.0	106.9	246.6	167.7	62.4	34.3	39644.	651.	12.63	0	6.01	3.08
	261.8	247.1	106.9	241.8	175.8	64.4	38.6	38566.	625.	10.72	0	5.84	3.43
	264.5	245.3	112.2	239.2	174.4	62.4	37.8	37810.	583.	8.57	0	5.44	3.37
	262.3	226.6	189.2	217.5	214.3	82.4	66.1	70038.	1709.	2.56	0	5.95	7.63
	264.0	229.7	184.5	220.1	213.3	82.4	65.2	106830.	2397.	2.68	0	5.64	6.89
	262.7	227.1	186.2	216.6	214.6	82.4	66.3	109030.	2511.	2.24	0	5.68	7.59
	262.3	221.8	187.1	212.3	217.3	83.4	68.7	10919.	260.	2.17	1	.60	9.16
305													
	255.7	241.8	88.0	238.4	150.7	50.5	26.2	44824.	716.	14.54	0	6.15	3.02
	254.9	238.4	89.8	234.0	154.9	50.5	28.1	44246.	680.	11.63	0	5.82	3.18
	252.3	235.3	90.2	229.2	154.7	48.5	28.0	44481.	671.	9.55	0	5.65	3.27
	253.6	231.8	90.7	225.7	153.1	46.5	27.3	44118.	632.	7.64	0	5.33	3.27
	252.3	218.4	107.3	209.2	168.2	48.5	34.5	78733.	1097.	3.95	0	4.71	4.13
	251.4	203.1	133.2	195.8	171.0	46.5	35.9	69226.	1107.	2.30	0	4.78	4.88
	254.9	226.2	101.2	217.5	167.3	50.5	34.1	78476.	1081.	5.12	0	4.84	3.80

FREON VOLUME BOILER, *1

DATE	TEMPERATURE(F) H2O IN	H2O EX	F IN	F OUT	F SAT	PRESSURES(PSIA) VESSEL	SAT	HEAT TRANSFER QD BTU/HR	UA BTU/HR F	MASS RATIO H2O/FLUID	CU	STANTON NUMBER	H=PR*JA
300													
	292.3	272.3	100.3	265.7	198.4	92.4	53.4	53061.	682.	8.53	0	4.89	2.94
	293.6	271.8	159.2	267.5	196.8	92.4	52.3	43970.	743.	8.34	0	5.34	2.89
	294.0	272.3	149.0	267.1	201.3	95.4	55.6	43961.	694.	7.73	0	5.15	2.97
301													
	291.4	266.6	158.8	259.2	203.7	92.4	57.5	62696.	1002.	5.46	0	4.94	3.20
	290.5	249.2	159.2	239.2	216.3	92.4	67.8	129300.	1878.	3.01	0	4.23	4.26
	290.1	256.6	157.9	247.9	211.5	92.4	63.7	93864.	1412.	3.81	0	4.52	3.76
	284.5	249.2	172.7	239.2	216.3	92.4	67.8	81794.	1375.	3.00	0	4.65	4.51
	294.0	264.0	169.7	255.3	209.1	94.4	61.7	56857.	911.	4.77	0	4.70	3.37
	292.3	263.6	172.7	254.9	218.8	102.4	70.0	50004.	830.	4.60	0	4.77	3.81
	293.1	264.0	167.9	256.6	192.1	82.4	49.0	61357.	997.	4.97	0	4.87	2.92
	288.8	240.5	185.3	233.6	219.0	92.4	70.2	52370.	818.	2.20	1	4.04	4.94
302													
	266.2	256.6	162.7	253.6	181.0	73.5	41.7	22912.	566.	19.16	0	7.54	3.29
	267.1	254.9	167.5	253.1	179.7	72.5	41.0	23046.	576.	15.29	0	7.50	3.27
	267.1	251.0	168.8	248.4	183.8	72.5	43.5	24311.	567.	11.12	0	6.87	3.48
	264.9	244.9	168.4	241.4	187.5	71.5	45.9	24513.	546.	8.49	0	6.44	3.82
	267.9	249.2	172.7	241.0	190.8	73.5	48.1	64218.	1352.	6.46	0	5.97	3.75
	267.5	247.5	174.0	238.8	190.7	72.5	48.0	64191.	1348.	5.89	0	5.89	3.81
	266.4	243.1	189.7	234.0	195.1	73.5	51.1	59160.	1369.	4.43	0	6.00	4.12
303													
	266.2	254.0	126.6	249.2	183.1	72.5	43.0	31328.	572.	15.67	0	6.25	3.40
	267.9	253.1	126.2	249.2	183.1	72.5	43.0	31202.	552.	12.37	0	6.06	3.38
	267.5	249.2	120.9	244.9	186.5	72.5	45.2	32056.	527.	9.93	0	5.66	3.60
	257.9	240.1	137.2	231.8	195.0	72.5	51.0	29560.	528.	7.51	0	5.63	4.62
	264.5	231.4	167.9	220.1	201.5	73.0	55.7	58313.	1093.	3.04	0	5.10	5.23
	263.6	244.5	125.8	236.2	175.0	61.5	38.2	73635.	1183.	7.36	0	5.39	3.42
	265.7	243.6	127.1	235.3	177.4	62.5	39.5	73065.	1140.	5.92	0	5.19	3.47
	255.3	226.6	145.5	215.3	191.8	64.5	48.8	62743.	1079.	3.60	0	5.07	5.15
304													
	256.6	236.6	88.5	232.3	160.7	52.4	30.8	49182.	717.	8.70	0	5.51	3.32
	254.5	237.9	90.7	232.7	160.3	52.4	30.6	48894.	745.	10.47	0	5.72	3.33
	262.7	239.7	92.9	233.6	161.6	53.4	31.2	48637.	668.	7.30	0	5.13	3.17
	261.8	229.7	119.6	221.0	168.9	52.4	34.9	77469.	1109.	4.19	0	4.76	3.60
	262.7	233.1	110.4	224.9	170.1	54.4	35.6	82065.	1138.	4.82	0	4.79	3.54
	263.1	237.9	94.2	229.2	163.1	52.4	31.9	85139.	1120.	6.08	0	4.84	3.23
	264.9	251.0	106.9	246.6	167.7	62.4	34.3	39644.	651.	12.63	0	6.01	3.08
	261.8	247.1	106.9	241.8	175.8	64.4	38.6	38566.	625.	10.72	0	5.84	3.43
	264.5	245.3	112.2	239.2	174.4	62.4	37.8	37810.	583.	8.57	0	5.44	3.37
	262.3	226.6	189.2	217.5	214.3	82.4	66.1	70038.	1709.	2.56	0	5.95	7.63
	264.0	229.7	184.5	220.1	213.3	82.4	65.2	106830.	2397.	2.68	0	5.64	6.89
	262.7	227.1	186.2	216.6	214.6	82.4	66.3	109030.	2511.	2.24	0	5.68	7.59
	262.3	221.8	187.1	212.3	217.3	83.4	68.7	10919.	260.	2.17	1	.60	9.16
305													
	255.7	241.8	88.0	238.4	150.7	50.5	26.2	44824.	716.	14.54	0	6.15	3.02
	254.9	238.4	89.8	234.0	154.9	50.5	28.1	44246.	680.	11.63	0	5.82	3.18
	252.3	235.3	90.2	229.2	154.7	48.5	28.0	44481.	671.	9.55	0	5.65	3.27
	253.6	231.8	90.7	225.7	153.1	46.5	27.3	44118.	632.	7.64	0	5.33	3.27
	252.3	218.4	107.3	209.2	168.2	48.5	34.5	78733.	1097.	3.95	0	4.71	4.13
	251.4	203.1	133.2	195.8	171.0	46.5	35.9	69226.	1107.	2.30	0	4.78	4.88
	254.9	226.2	101.2	217.5	167.3	50.5	34.1	78476.	1081.	5.12	0	4.84	3.80

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