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DISCLAIMER

PERFORMANCE TESTING THE PHASE II HDR RESERVOIR

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ABSTRACT

The geothermal energy program at the Los Alamos National Laboratory is directed toward developing the Hot Dry Rock (HDR) technology as an alternate energy source. Positive results have been obtained in previous circulation tests of HDR reservoirs at the Laboratory's test site in Fenton Hill, New Mexico. There still remains however, the need to demonstrate that adequate geothermal energy can be extracted in an efficient manner to support commercial power production. This year, the Laboratory will begin a circulation test of its Phase II reservoir. The objectives of this test are to characterize steady-state power production and long-term reservoir performance.

INTRODUCTION

To date, two circulation tests have been conducted on HDR reservoirs at the Fenton Hill test site. The first was conducted during Phase I of the program. It involved the circulation of fluid through an HDR reservoir at a depth of 9000 feet. The circulation test lasted nine months and produced a fluid temperature of 275°F and nominal thermal power of 3 MW. Throughout the test, the quality of the recirculated water remained good and water loss decreased with time. In addition, there were no detectable environmental effects from operating the test. The test was a convincing demonstration of the technical feasibility to construct and operate a hydraulically fractured, man-made, HDR system.

With the success of the Phase I test, the next step was to produce heat at temperatures and rates to support a commercial-size electrical power plant. To obtain a higher temperature resource, a deeper reservoir was developed during Phase II of the program. The Phase II reservoir is located at a depth of approximately 12,000 feet below the surface in rock temperature of 460°F and is estimated to have a fluid capacity of one million gallons.

In 1986, a 30-day circulation test was conducted to confirm the flow continuity of the Phase II reservoir and to determine its thermal potential. Over this time, a total of 10 million gallons of water at 70°F was injected into the reservoir at a pumping pressure as high as 4700 psi and an injection rate of 285 gpm. Over time, the production rate increased to 235 gpm against a production pressure of 500 psi. Temperature of the produced fluid rose to 375°F and a nominal 10 MW of thermal production was achieved. The reservoir performance was still improving at the end of the test. Water loss initially was very high, in part due to leakage through a damaged casing in the production well. A large part of the water loss was due to storage in fractures that were outside of the circulation paths. This water was recovered later when the system was vented. This short test demonstrated the potential to produce high temperature geothermal water. However, the economics of commercial power plants require higher rates of heat production, reduced water loss rates, and a credible basis for predicting useful lifetime of the heat source. For all these reasons, a much longer test would be needed to demonstrate the reliability and longevity of power production.

The results of the two tests are summarized in Table 1. Unlike the testing of Phase I, the testing of the Phase II reservoir required higher injection pressures and production equipment with the higher temperature ratings. The higher temperatures also required that higher pressure be maintained on the production well to avoid two phase flow. The test also showed other changes from the Phase I testing. Although episodic increases in carbon dioxide production occurred with decreasing frequency during the test, the concentrations were high enough to produce two phase fluid downstream of the heat exchanger. As a result, there were periods when closed-loop operation could not be maintained. In addition, sand and gravel was detected in the production fluid but this was attributed to the damaged casing in the production well.

Table 1. Comparison of Reservoir Characteristics

	Phase I	Phase II
Average Reservoir Depth, feet	9,000	12,000
Average Rock Temperature, °F	374	460
Average Production Rates, gpm	112	225
Production Temperatures, °F	275	375
Nominal Thermal Power Output, MW	3	10

With the experiences of the two circulation tests, preparations are currently underway to conduct another test of the Phase II reservoir. This test, identified as the Long-Term Flow Test (LTFT), will entail the circulation testing of the reservoir for a minimum period of one year. The test is designed to characterize long term reservoir performance in terms of the rate of thermal drawdown, water loss, flow impedance, induced seismicity and geochemical behavior.

TEST PLAN

The testing of the reservoir will consist of five modes of operation. A summary of the operating parameters is outlined in Table 2.

Start-up. The initial phase of the test will involve a start-up period to confirm the operating parameters for use throughout the

Table 2. LTFT Test Plan.

Mode	Operation	Injection Rate (gpm)	Injection Pressure (psi)	Makeup/ Supply Rate (gpm)	Thermal Production (MW)
1.	Start-Up	84	3700	5-10	4
2.	Aseismic	125	3700	7-9	6
3.	Maximum Production	220	4200	<30	11
4.	Stress Unlocking	280	4500	<70	15
5.	Cyclic	400	4500	400	21

remainder of the testing program. Following the 30-day circulation test in 1986, the production well underwent rework to repair the damaged casing. Since the repair, the reservoir has been either in a shut-in state or subjected to pressure cycling experiments. The effects of the repair, time, and pressure cycling may have affected the characteristics of the reservoir as established during the earlier circulation test. This mode of operation will be used to reestablish the relationship between operating pressures and production flow rates by producing at various pressures. The purpose is to establish the highest production pressure to optimize reservoir performance.

Aseismic. During this phase of the test, injection to the reservoir will be limited to a pressure that is below the threshold level for hydraulic fracturing (reservoir extension) to occur. From previous testing, the threshold pressure is estimated to be between 3700 to 3900 psi. The purpose of this test is to circulate the reservoir in the mode that will require the minimum amount of makeup water. During this mode of operation, water loss in the reservoir will be due to diffusion at the boundary of the reservoir. The water loss is estimated to be in the range of 7 to 9 gpm. The production flow rate for this mode of operation is expected to be 125 gpm.

Maximum Production. The primary purpose of this test will be to extract the maximum amount of energy. As a result, it will subject the reservoir to the most demanding test with regards to thermal capacity. To accomplish this test, injection to the reservoir will be at a pressure above the threshold level. Water loss in this mode will be a combination of diffusional loss and volumetric increase of the reservoir. Operating in this mode will require a significant amount of makeup water. Based on previous inflation experiments, water losses could be as high as 60 to 70 gpm at an injection pressure of 4500 psi. The constraint to this test is the finite supply of makeup water. An injection pressure will be established on the basis of a water loss rate that will provide for the maximum period of steady state operation.

The estimated injection pressure is 4200 psi with a flow rate of 220 gpm. This test is expected to provide the bulk of information regarding reservoir thermal capacity and life expectancy.

Stress Unlocking. For the start of this test, the production well will be shut-in and the reservoir pressure will be elevated to the maximum operating limits of the system design (4500 psi). The purpose of this test will be to evaluate the effects of increased pressure on the flow paths in the reservoir.

The maximum production test, as described above, will have cooled the reservoir and created high thermal strains. The pressurization is expected to relax the stresses both within the reservoir and at its boundary, the result being a reduction in the flow impedance of the reservoir. The pressurization will create seismic activity that will be especially prevalent near the boundaries of the cooled region. It will provide a unique opportunity to map the locations of those boundaries.

After pressurization, the reservoir will then be subjected to a circulation test to evaluate the effects of the stress unlocking test and to determine the maximum power production rate.

Cyclic. The final test will be conducted to study the potential of cyclic operation for use in peak-loading power applications. It will entail intermittent flowing of the reservoir. For this test, the reservoir will be inflated to a pressure above the threshold level, then followed by a period of flow production.

SURFACE PLANT

To accomplish the goals of the test plan, a surface plant has been designed to provide the flexibility and control to support the different operating modes. The plant has the following minimum requirements: 1) to develop the required injection pressures and flows to circulate the reservoir, 2) to extract the energy from the hot geothermal fluid, 3) to measure and control the fluid temperature, pressure, and flow, 4) to remove any solids and gases from the production fluid, 5) to allow for open and closed-loop operations, and 6) to provide logging capabilities on both wells.

The process concept of the plant is illustrated in the basic schematic of Figure 1. For closed-loop operation, circulation of the reservoir is created by a pair of positive displacement pumps which deliver water under high pressure to the reservoir through the injection well. After passing through the reservoir and extracting the heat energy, the water is returned to the surface via the production well. At the surface, the hot geothermal water passes through a pressure regulating station then on to a separator where any gas and solids are removed from the process stream. The hot fluid then flows to a heat exchanger where the temperature is reduced and the extracted heat energy is measured. After cooling, the fluid is returned to the injection pumps to complete the cycle. Previous tests have shown that some water loss will occur during the circulation process. To compensate for these losses, the plant includes a makeup water facility. Water will be drawn from a 5 million gallon

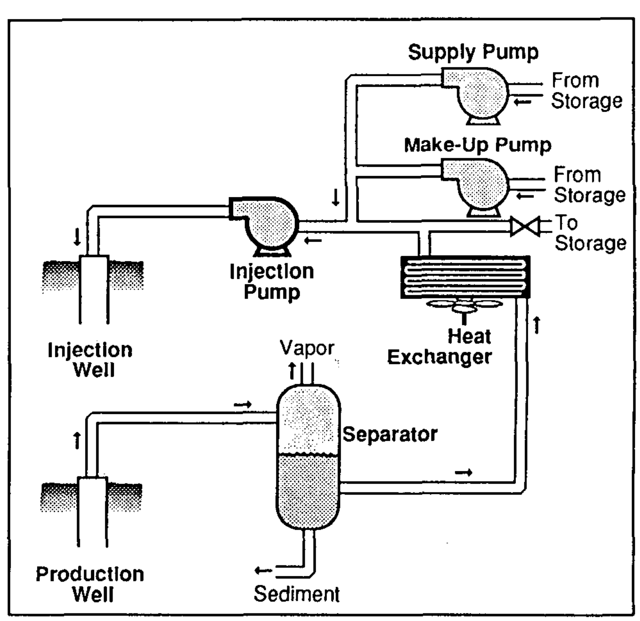

Figure 1. HDR Flow Diagram.

reservoir and pumped into the low pressure side of the plant. The water will be supplied by two centrifugal pumps which will be connected upstream of the suction to the injection pump.

The plant is also designed for open-loop operation. This mode allows for diverting the production fluid downstream of the heat exchanger to surface water storage facilities. Water to the injection pumps is provided by the larger capacity supply pumps. This operating feature provides the capability to flush the reservoir with fresh water. In addition, it will be used in the event of an upset operating condition and to inflate the reservoir.

PLANT DESIGN

From a mechanical design standpoint, the plant can be divided into three sections, namely the production, high pressure and low pressure segments. The production segment consists of the pressure regulating equipment adjacent to the production well that will reduce the fluid pressure to the low pressure side of the plant. This segment has a pressure rating of 4500 psi. The low pressure side of the plant consists of the separator, heat exchanger, makeup pumps and interconnecting piping. This section is designed for a maximum operating pressure of 1100 psi. The high pressure side is comprised of the injection pumps and the piping to the injection well. The components within this portion of the plant are designed for a maximum allowable working pressure of 5000 psi. The operating capacities of the plant are outlined in Table 3.

Table 3. Surface Plant Operating Capacities.

Injection	Rate (gpm)	84 - 336
	Pressure (psi)	3400 - 5000
	Temperature (°F)	40 - 150
Production	Rate (gpm)	0 - 420
	Pressure (psi)	500 - 2400
	Temperature (°F)	40 - 400
Separation	Rate (gpm)	336
	Pressure (psi)	1235
	Temperature (°F)	450
	Vapor (lbs/min.)	350
	Solids (lbs/hr.)	170
Heat Extraction	Rate (gpm)	2000
	Pressure (psi)	2500
	Temperature (°F)	475
	Duty (MW)	97
Makeup Supply	Rate (gpm)	5 - 74
	Pressure (psi)	250 - 1000
	Temperature (°F)	40 - 150
Water Supply	Rate (gpm)	40 - 450
	Pressure (psi)	130 - 160
	Temperature (°F)	40 - 150

DATA ACQUISITION AND PLANT CONTROL

The collection of operating data and plant control will be performed by a high speed (one scan per second) data acquisition and control (DAC) system. The system consists of commercially available software for process automation applications running on an IBM PC computer with modular input/output (I/O) processors. The I/O processors perform local scanning of instrument input, signal conditioning, analog to digital (A/D) and D/A conversion, and signal output for control. The I/O processors are located throughout the site in close proximity to instrumentation and control hardware. Digital communications between the processor and the computer are transmitted at a rate of 19,200 bits per second. Figure 2 shows a schematic diagram of the DAC system.

The control scheme is designed to maintain constant pressure on the production and injection wells. Pressure control of the plant consists of four elements.

Pressure from the production well will be reduced in two stages to obtain the operating pressure on the low pressure side of the plant. Two manually adjustable chokes, installed in parallel in a manifold immediately downstream of the production well, will provide the initial pressure drop. The choke valves will be adjusted to take the brunt of the pressure drop since the wear parts can be economically maintained and are readily serviceable.

The second stage of the pressure drop will be accomplished by two pneumatic control valves, installed in parallel downstream of the manual choke valves. The control valves will serve to maintain a constant wellhead pressure. Operation of the valves will be controlled as a function of the production line pressure upstream of the choke valves by way of proportional, integral, derivative (PID) logic performed by the DAC system. Production line pressure will be measured and transmitted to the DAC system at 1 to 2 second intervals. The measured pressure will become input to the PID loop and compared with the nominal programmed set point. Deviation from set point will be calculated and evaluated, and appropriate adjustments to the control valve output will be made and transmitted one second after data arrival.

There will also be two pneumatic control valves installed in parallel downstream of the heat exchangers. The valves will serve to maintain upstream operating pressure above the flash point of the produced fluid. Control will be performed by the DAC system in the manner described above. The valves would be used predominantly during an open loop operation when it would be necessary to divert the production fluid to either a storage pond or tanks. Flow to either the pond or the tanks would be accomplished by two valves controlled from the DAC system.

Suction pressure to the injections pumps will be maintained by the two make-up pumps. Depending on the demand, the pumps will operate singularly or in parallel to maintain a constant suction pressure to the injection pumps. Control of the makeup pumps will be performed locally and independently of the DAC system as a function of the suction line pressure to the injection pumps. Each pump is equipped with a by-pass line and an orifice in the pump discharge line to allow for safe full-range operation. The local control system will automatically activate and sequence the make-up pumps as needed. When one pump is in operation and the pressure drops below the set point, an indication that the capacity of the first pump has been exceeded, the control system will activate the second pump. The first pump will be shut down when line pressure reaches the high set point. During long periods of steady state operations with one pump in use, the control system will automatically switch pumps periodically to distribute usage and wear.

The output of the injection pumps will be controlled by a manually set speed controller. The pump speed (RPM) will be set manually with the throttle control and automatic transmission.

The design approach for the system automation will allow for extended un-manned operations and, in the event of an unrecoverable upset condition, provide for automatic shutdown in a safe and orderly manner. System re-start or a change in operating modes will be done manually. The control system has been designed to maintain flexibility and to provide for future automation of the control scheme.

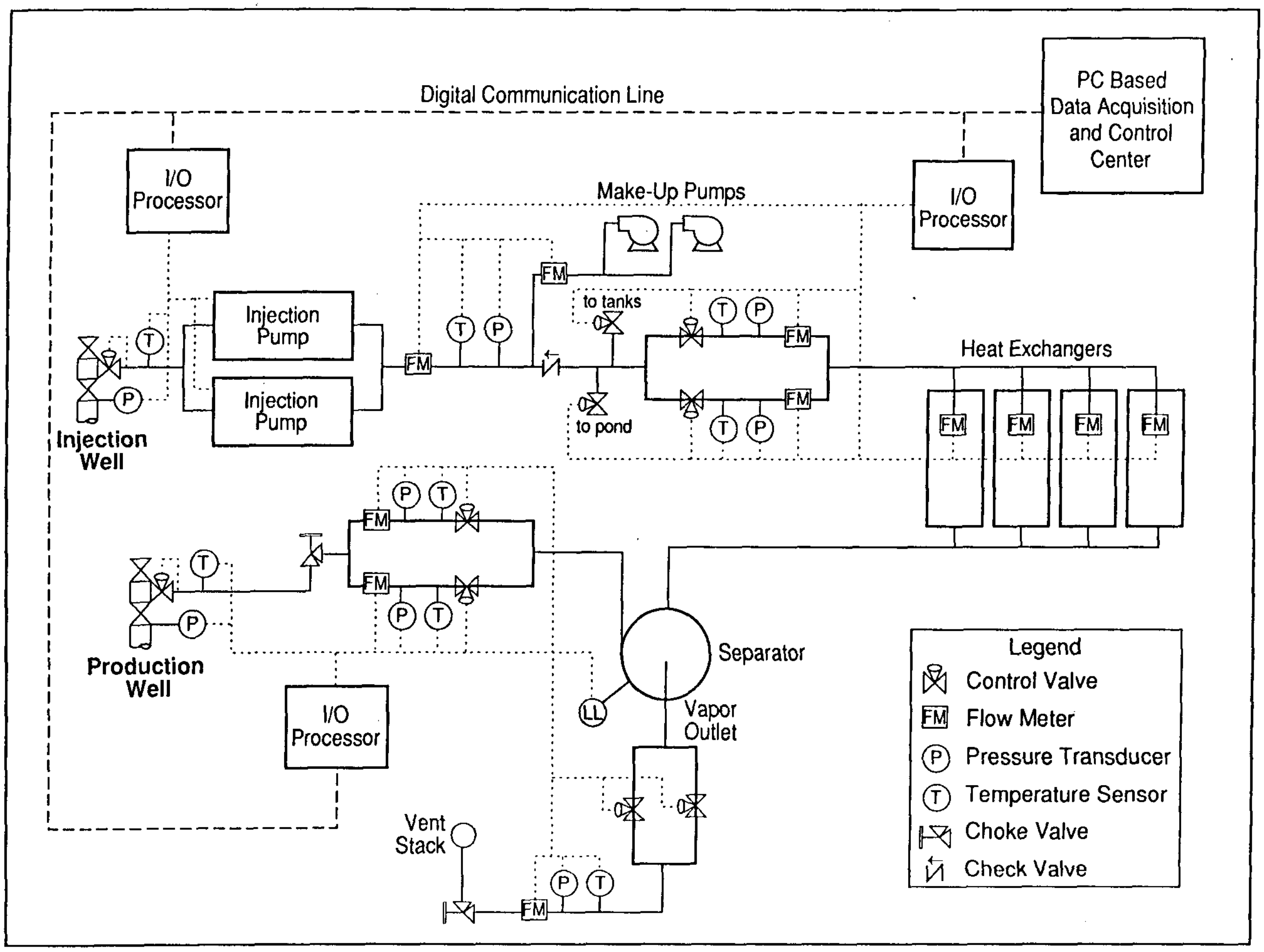

Figure 2. Schematic of LTFT Data Acquisition and Control System

SUMMARY

The LTFT includes a number of operational strategies to characterize the thermal performance of the Phase II reservoir. The test plan provides a number of unique technical challenges with regard to the design, construction and operation of the equipment and facilities. The surface plant has been designed to assure high reliability and safe operation while providing the flexibility and control to support the different operations modes.

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