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TEST PLAN FOR HEAT CYCLE RESEARCH PROGRAM
PHASE I SUPERCRITICAL CYCLE TESTS

Greg L. Mines

Idaho National Engineering Laboratory

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G. L. Mines

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EG&G Idaho, Inc.
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1. INTRODUCTION

The 60 kW Heat Cycle Research Facility (HCRF) provides a means of examining different concepts and components associated with the generation of electrical power from a geothermal resource using a binary power cycle. In this power cycle the heat or energy in a hot geothermal fluid is transferred to a secondary working fluid. This working fluid is vaporized in the heat exchange process and the vapor is in turn expanded through a turbine which drives a generator producing electrical power. The heat or energy in the vapor leaving the turbine is transferred to a circulating cooling water in the condenser where the working fluid is condensed to a liquid which can be pumped back to the heaters, completing the cycle. This waste heat load in the condenser is in turn transferred from the cooling water to the atmosphere in a cooling tower.

The HCRF allows the different components described in the cycle above to be tested as well as the basic cycle itself. This cycle may vary in that the heaters, condenser, cooling system, pumps, etc. may differ in number and type, however the basic cycle does not change significantly. During this sequence of tests, the HCRF will be operated using a supercritical vapor generator and a vertical condenser where the condensation will occur inside of the tubes as opposed to the shell side more commonly used in these applications. In addition to providing the data to be used to evaluate the design of these heat exchangers, these supercritical tests will provide cycle and component performance data with both single component working fluids and working fluids comprised of different mixtures of hydrocarbons. The use of these mixtures promises to improve cycle performance, in terms of watt-hours per pound of geothermal fluid, provided the countercurrent flow paths can be maintained between the fluids in both the condenser and the heaters. The supercritical heaters and the condenser to be used in this series of tests were designed to provide the desired countercurrent flow paths.

The supercritical testing with the HCRF will require that heaters, i.e. the vapor generator, be operated at outlet conditions above the

critical pressure and temperature of the working fluids being used. In this mode of testing the working fluids will not go through a point of discrete phase change such as boiling. Rather the working fluid will undergo a gradual density change as it passes through the preheater and vapor generator where it enters as a high pressure liquid and leaves as a high pressure vapor.

To illustrate typical thermodynamic cycles which will be encountered during the testing, four temperature-entropy diagrams are included as Figures 1-4. Two of these diagrams are for fluids having isobutane as the major constituent (iC_4 and $0.9 iC_4/0.1 C_6$), and two for the propane family (C_3 and $0.9 C_3/0.1 iC_5$).

Isentropic and isenthalpic expansions are shown which "bracket" the power-loop (with turbine) and thermal loop (without turbine) vapor expansion processes for typical supercritical heater-outlet and condenser-inlet pressure conditions. It can be seen that for the isobutane family, superheat increases as the final portion of the turbine expansion process continues, whereas for the propane family superheat decreases during the turbine expansion with the turbine outlet state falling near the saturated vapor line.

This test plan outlines the conditions at which the HCRF will be operated during this series of tests. The purpose of this test plan is not to provide detailed instructions as to how these tests will be conducted. Specifics concerning the operation of the facility will be detailed in operating procedures to the extent that they can be defined. The testing is to be conducted at the Department of Energy Geothermal Test Facility (GTF) in the Imperial Valley of California, beginning in August 1983.

2. PREREQUISITES

The prerequisites for the supercritical cycle tests can be summarized as follows:

- (a) The hydro tests, checkout and S.O. tests have been completed.
- (b) The necessary safety approvals for the operation of the facility have been obtained.
- (c) The calibration is current on the facility instrumentation required for the tests.
- (d) The plant is filled to working fluid liquid levels adequate for operation.
- (e) The plant is in a stand-by condition ready for start-up. There is an adequate supply of geothermal fluid available (at an inlet temperature equal to or greater than 320°F), and the GTF operator (WESTEC) has been contacted requesting that the geofluid be supplied to the piping manifold.
- (f) The working fluid composition is within acceptable limits of the described concentration ($\pm 1/2\%$). For an example if the desired concentration is 95% iC_4 , 5% C_6 then the range of acceptable fluids would be $94-1/2\% iC_4 / 5-1/2\% C_6$ to $95-1/2\% iC_4 / 4-1/2\% C_6$. The fluid chemistry will be verified using the gas chromatograph.

3. TEST DESCRIPTION

Once the necessary prerequisites have been satisfied, the tests will be conducted following the general instructions given here. The operating procedures should be consulted for specific operational instructions. Two families of fluids will be tested during this phase of operation, isobutane and propane. During the first sequence of supercritical tests, isobutane (iC_4) will be the major constituent with different levels of the minor component, hexane (C_6), added. During the next sequence the major component will be propane (C_3) and the minor will be isopentane (iC_5). The isobutane fluids were selected for the startup and initial testing because of the high ambient temperatures at the GTF during the summer months and the higher condensing, and turbine exhaust pressures that will be encountered during this time. The propane fluids will be tested during the winter because of their higher saturation pressures (compared to isobutane) at a given temperature.

In testing each family of fluids, the initial test will be made with a pure or single component working fluid (the major component). Each fluid will be tested at different supercritical boiler pressures (typically two or three) where the geothermal fluid and working fluid flow rates will be varied to provide different heat loads, amount of superheat, etc., to generate performance data for the vapor generator/preheater and condenser over a range of operating conditions. For selected boiler conditions, the cooling water flow rate will also be varied to provide similar performance data. Once the heaters and condenser have been tested over variety of different operating conditions with a single component working fluid, small amounts of the minor component will be added in order to bring the fluid to a desired concentration or chemistry. This new mixed fluid will be tested in a similar process where pressure and flows will be varied to produce data over a range of operating conditions sufficient to allow comparison of the component and cycle performance. Following the completion of testing with this fluid, the concentration of the minor component will be increased until the next desired fluid is obtained and the test process repeated. These tests will proceed toward an increasing concentration of the minor component. Once the fluid chemistry has been set, no more of the minor

component will be added except as necessary to keep the fluid within chemistry tolerances ($\pm 1/2\%$ by mass) until all testing with the fluid has been completed. This procedure will minimize working fluid losses through venting and draining and result in the least time expended. (Continual adjustment of chemistry is a time consuming process.) Both thermal loop and power loop (turbine) tests will be conducted.

Once the testing has been completed with one family of fluids, the facility will be shut down, drained, purged, evacuated and refilled with the major constituent for the next family of fluids. As with the first family of fluids, the initial tests will be made with the single (major) component fluid. The same process of varying pressure, flow rates, amount of superheat, etc. will be followed. Once the pure fluid has been tested, the minor component will be added until it is at the desired concentration. This mixture will then be tested in a similar manner, the concentration adjusted, and the process repeated until all the fluids in this family designated for testing have been used. This procedure will be repeated for each family of fluids.

For a particular fluid and heater pressure, the following general approach will be used to test the fluid and the facility components. The facility will be brought up slowly at relatively low flow rates, i.e. working fluid flow rate between 5 and 10 gpm. The geofluid flow rate will be adjusted to provide the working fluid outlet temperature that would allow for the isentropic expansion of the working fluid to the condenser conditions just outside the two phase region (this is shown graphically in Figures 1 through 4). The cycle will be allowed to stabilize at this point and data will be collected. Flow rates will then be increased in regular intervals (typically a working fluid flow increase of about 5 gpm) with the plant being allowed to stabilize and data collected at each step. When the facility is operating near the working fluid flow rate predicted for operation at this heater pressure, the geothermal fluid flow rate will be increased to provide approximately 1 to 2°F superheat and the plant allowed to stabilize (data also is to be collected). At this point the cycle will be transferred from the thermal loop mode to a power loop mode as the turbine is brought on line. The superheat previously established will be

used to minimize the possibility of turbine expansion in the two phase region. Once the turbine has been brought on line, the geothermal and working fluid flow rates will be adjusted to maintain the outlet working fluid temperature at the lower value set by the single-phase isentropic expansion, the heater pressure, and liquid levels. Data will be collected at this point after which the geofluid will be varied to provide different levels of superheat and data again collected. The flows will be adjusted to return to the baseline condition (defined by isentropic expansion) and the cooling water flow rate will be changed to 75% and 125% of the design value (depending on possible turbine exhaust pressure limits). Data will be collected at each point.

This will complete the turbine testing for the given fluid and heater pressure. At this point the cycle will be returned to the thermal loop mode and the working fluid adjusted to the flow rate that the turbine would take at this pressure. This defines the 100% working fluid flow rate. The geothermal fluid flow rate will be adjusted to repeat the same conditions at which data was collected with the turbine running, i.e. isentropic expansion just outside the two phase region and varying amounts of superheat. The geothermal fluid flow rate will then be returned to the value which produces isentropic expansion just outside the "dome" or the baseline condition, and the cooling water flow rate varied to 125% and 75% of design value. The cooling water flow rate will then be adjusted to the design value and the working fluid flow rate will be adjusted to 125% and 75% of the turbine flow. During this working fluid flow variation, the geothermal fluid flow rate will be varied to maintain the same working fluid to geothermal fluid flow ratio defined by the baseline condition. Data will be collected at each point.

Although these tests are intended to provide performance data on the components and cycle in the supercritical mode, one test run for each fluid will be made with some boiling occurring in the vapor generator. This run will provide data relative to any degradation in performance that might result from boiling in a heat exchanger designed for supercritical operation.

At each test condition the plant should be allowed to stabilize after a flow or pressure change. In the past this stabilization has typically taken about 30 minutes. Usually the last component to reach equilibrium following a change in operating parameters is the condenser. (The heaters have pressure and flow controllers which maintain operating conditions on the heat input side of the cycle.) For each series of tests or data points for a particular fluid and heater pressure, the chemistry of the working fluid is to be checked at the start and end of the test series to verify that the fluid being tested is the desired one.

After a series of tests, the heater pressure will be changed, or if the testing of a particular fluid, has been completed, then the working fluid chemistry will be adjusted to produce the next fluid for testing.

4. TEST CONDITIONS

The anticipated conditions for operation of the facility during the supercritical cycle test Phase I are listed in Tables 1 through 6. The conditions listed provide four test pressures for each fluid over a range of flow conditions. These lists of desired data points may be tempered by schedule and/or budget constraints or by operating limits of the facility components. At this time it is expected that these tests can be conducted within the scheduled test period, however in the event of equipment failure, loss of geothermal fluid, etc. the scope of testing as outlined in these tables may have to be modified. The facility has certain operating limits on its components which may also preclude the completion of some of the tests as outlined. These limits are as follows:

1. Maximum turbine inlet pressure of 750 psig
2. Maximum turbine inlet temperature of 320°F
3. Maximum turbine exhaust pressure of 165 psig.

It should also be noted that the conditions specified in these tables for testing were based on an assumed geothermal fluid inlet temperature of 330°F. If the brine is cooler, some of the tests (particularly with the isobutane mixtures) may have to be modified.

The following notation is used in Tables 1 through 6:

C_3	propane
iC_4	isobutane
iC_5	isopentane
C_6	hexane
$T_{WF \text{ out}}$	outlet working-fluid temperature

$\dot{W}_{WF}$ weight flow of working fluid

$\dot{W}_{GF}$ weight flow of geofluid

$\dot{W}_{CW}$ weight flow of cooling water

FIGURE 1. TEMPERATURE-ENTROPY DIAGRAM FOR AN ISOBUTANE SUPERCRITICAL CYCLE

FIGURE 2. TEMPERATURE-ENTROPY DIAGRAM
FOR A Q9 ISOBUTANE/D1 HEXANE
SUPERCRITICAL CYCLE

FIGURE 3. TEMPERATURE - ENTROPY DIAGRAM
FOR A PROPANE SUPERCRITICAL CYCLE

FIGURE 4. TEMPERATURE-ENTROPY DIAGRAM FOR A
0.9 PROPANE/0.1 ISOPENTANE SUPERCRITICAL
CYCLE

TABLE 1. HCRF TEST CONDITIONS FOR ISOBUTANE WORKING FLUID

Test Number	Fluid	Pressure (psia)	T _{WF out} (°F)	Turbine		$\dot{W}_{WF}/\dot{W}_{GF}$	$\dot{W}_{WF}$ #/hr	$\dot{W}_{CW}$ #/hr
				On	Off			
A-1, -2	iC ₄	470	270	✓	✓	0.99 to 1.03	6400 to 6600	66750
A-3	iC ₄	470	265	--	✓	TBD ^a	6400 to 6600	66750
A-4, -5	iC ₄	470	275	✓	✓	TBD ^a	6400 to 6600	66750
A-6, -7	iC ₄	470	280	✓	✓	TBD ^a	6400 to 6600	66750
A-8, -9	iC ₄	470	270	✓	✓	0.99 to 1.03	6400 to 6600	83500
A-10, 11	iC ₄	470	270	✓	✓	0.99 to 1.03	6400 to 6600	50000
A-12	iC ₄	470	270	--	✓	0.99 to 1.03	8125	66750
A-13	iC ₄	470	270	--	✓	0.99 to 1.03	4875	66750
A-14, -15	iC ₄	500	280	✓	✓	0.97 to 1.01	7000 to 7200	66750
A-16	iC ₄	500	275	--	✓	TBD ^a	7000 to 7200	66750
A-17, -18	iC ₄	500	285	✓	✓	TBD ^a	7000 to 7200	66750
A-19, -20	iC ₄	500	290	✓	✓	TBD ^a	7000 to 7200	66750
A-21, -22	iC ₄	500	280	✓	✓	0.97 to 1.01	7000 to 7200	83500
A-23, -24	iC ₄	500	280	✓	✓	0.97 to 1.01	7000 to 7200	50000
A-25	iC ₄	500	280	--	✓	0.97 to 1.01	8875	66750
A-26	iC ₄	500	280	--	✓	0.97 to 1.01	5325	66750
A-27, -28	iC ₄	550	290	✓	✓	0.95 to 0.99	8000 to 8200	66750
A-29	iC ₄	550	285	--	✓	TBD ^a	8000 to 8200	66750
A-30, -31	iC ₄	550	295	✓	✓	TBD ^a	8000 to 8200	66750
A-32, -33	iC ₄	550	300	✓	✓	TBD ^a	8000 to 8200	66750
A-34, -35	iC ₄	550	290	✓	✓	0.95 to 0.99	8000 to 8200	83500
A-36, -37	iC ₄	550	290	✓	✓	0.95 to 0.99	8000 to 8200	50000
A-38	iC ₄	550	290	--	✓	0.95 to 0.99	10125	66750
A-39	iC ₄	550	290	--	✓	0.95 to 0.99	6075	66750
A-40, -41	iC ₄	600	300	✓	✓	0.92 to 0.96	9000 to 9200	66750
A-42	iC ₄	600	295	--	✓	TBD ^a	9000 to 9200	66750
A-43, -44	iC ₄	600	305	✓	✓	TBD ^a	9000 to 9200	66750
A-45, -46	iC ₄	600	310	✓	✓	TBD ^a	9000 to 9200	66750
A-47, -48	iC ₄	600	300	✓	✓	0.92 to 0.96	9000 to 9200	83500
A-49, -50	iC ₄	600	300	✓	✓	0.92 to 0.96	9000 to 9200	50000
A-51	iC ₄	600	300	--	✓	0.92 to 0.96	11375	66750
A-52	iC ₄	600	300	--	✓	0.92 to 0.96	6825	66750

a. TBD → to be determined--geofluid flow will be adjusted during test to produce desired outlet WF temperature.

TABLE 2. HCRF TEST CONDITIONS FOR 95% ISOBUTANE/5% HEXANE WORKING FLUID

Test Number	Fluid	Pressure (psia)	T _{WF out} (°F)	Turbine		$\dot{W}_{WF}/\dot{W}_{GF}$	$\dot{W}_{WF}$ #/hr	$\dot{W}_{CW}$ #/hr
				On	Off			
B-1, -2	95iC ₄ /5C ₆	470	280	✓	✓	0.86 to 0.90	6500 to 6700	66750
B-3	95iC ₄ /5C ₆	470	275	--	✓	TBD ^a	6500 to 6700	66750
B-4, -5	95iC ₄ /5C ₆	470	285	✓	✓	TBD ^a	6500 to 6700	66750
B-6, -7	95iC ₄ /5C ₆	470	290	✓	✓	TBD ^a	6500 to 6700	66750
B-8, -9	95iC ₄ /5C ₆	470	280	✓	✓	0.86 to 0.90	6500 to 6700	83500
B-10, 11	95iC ₄ /5C ₆	470	280	✓	✓	0.86 to 0.90	6500 to 6700	50000
B-12	95iC ₄ /5C ₆	470	280	--	✓	0.86 to 0.90	8315	66750
B-13	95iC ₄ /5C ₆	470	280	--	✓	0.86 to 0.90	4990	66750
B-14, -15	95iC ₄ /5C ₆	500	288	✓	✓	0.85 to 0.89	7100 to 7300	66750
B-16	95iC ₄ /5C ₆	500	283	--	✓	TBD ^a	7100 to 7300	66750
B-17, -18	95iC ₄ /5C ₆	500	293	✓	✓	TBD ^a	7100 to 7300	66750
B-19, -20	95iC ₄ /5C ₆	500	298	✓	✓	TBD ^a	7100 to 7300	66750
B-21, -22	95iC ₄ /5C ₆	500	288	✓	✓	0.85 to 0.89	7100 to 7300	83500
B-23, -24	95iC ₄ /5C ₆	500	288	✓	✓	0.85 to 0.89	7100 to 7300	50000
B-25	95iC ₄ /5C ₆	500	288	--	✓	0.85 to 0.89	8965	66750
B-26	95iC ₄ /5C ₆	500	288	--	✓	0.85 to 0.89	5380	66750
B-27, -28	95iC ₄ /5C ₆	550	298	✓	✓	0.81 to 0.85	7900 to 8100	66750
B-29	95iC ₄ /5C ₆	550	293	--	✓	TBD ^a	7900 to 8100	66750
B-30, -31	95iC ₄ /5C ₆	550	303	✓	✓	TBD ^a	7900 to 8100	66750
B-32, -33	95iC ₄ /5C ₆	550	308	✓	✓	TBD ^a	7900 to 8100	66750
B-34, -35	95iC ₄ /5C ₆	550	298	✓	✓	0.81 to 0.85	7900 to 8100	83500
B-36, -37	95iC ₄ /5C ₆	550	298	✓	✓	0.81 to 0.85	7900 to 8100	50000
B-38	95iC ₄ /5C ₆	550	298	--	✓	0.81 to 0.85	10025	66750
B-39	95iC ₄ /5C ₆	550	298	--	✓	0.81 to 0.85	6015	66750
B-40, -41	95iC ₄ /5C ₆	600	308	✓	✓	0.76 to 0.80	8800 to 9000	66750
B-42	95iC ₄ /5C ₆	600	303	--	✓	TBD ^a	8800 to 9000	66750
B-43, -44	95iC ₄ /5C ₆	600	313	✓	✓	TBD ^a	8800 to 9000	66750
B-45, -46	95iC ₄ /5C ₆	600	318	✓	✓	TBD ^a	8800 to 9000	66750
B-47, -48	95iC ₄ /5C ₆	600	308	✓	✓	0.76 to 0.80	8800 to 9000	83500
B-49, -50	95iC ₄ /5C ₆	600	308	✓	✓	0.76 to 0.80	8800 to 9000	50000
B-51	95iC ₄ /5C ₆	600	308	--	✓	0.76 to 0.80	11145	66750
B-52	95iC ₄ /5C ₆	600	308	--	✓	0.76 to 0.80	6685	66750

a. TBD = to be determined--geofluid flow will be adjusted during test to produce desired outlet WF temperature.

TABLE 3. HCRF TEST CONDITIONS FOR 90% ISOBUTANE/10% HEXANE WORKING FLUID

Test Number	Fluid	Pressure (psia)	T _{WF} out (°F)	Turbine		$\dot{W}_{WF}/W_{GF}$	$\dot{W}_{WF}$ #/hr	$\dot{W}_{CW}$ #/hr
				On	Off			
C-1, -2	90iC ₄ /10C ₆	470	290	✓	✓	0.74 to 0.78	6600 to 6900	66750
C-3	90iC ₄ /10C ₆	470	285	--	✓	TBD ^a	6600 to 6900	66750
C-4, -5	90iC ₄ /10C ₆	470	295	✓	✓	TBD ^a	6600 to 6900	66750
C-6, -7	90iC ₄ /10C ₆	470	300	✓	✓	TBD ^a	6600 to 6900	66750
C-8, -9	90iC ₄ /10C ₆	470	290	✓	✓	0.74 to 0.78	6600 to 6900	83500
C-10, 11	90iC ₄ /10C ₆	470	290	✓	✓	0.74 to 0.78	6600 to 6900	50000
C-12	90iC ₄ /10C ₆	470	290	--	✓	0.74 to 0.78	8440	66750
C-13	90iC ₄ /10C ₆	470	290	--	✓	0.74 to 0.78	5065	66750
C-14, -15	90iC ₄ /10C ₆	500	297	✓	✓	0.72 to 0.76	7100 to 7300	66750
C-16	90iC ₄ /10C ₆	500	292	--	✓	TBD ^a	7100 to 7300	66750
C-17, -18	90iC ₄ /10C ₆	500	302	✓	✓	TBD ^a	7100 to 7300	66750
C-19, -20	90iC ₄ /10C ₆	500	307	✓	✓	TBD ^a	7100 to 7300	66750
C-21, -22	90iC ₄ /10C ₆	500	297	✓	✓	0.72 to 0.76	7100 to 7300	83500
C-23, -24	90iC ₄ /10C ₆	500	297	✓	✓	0.72 to 0.76	7100 to 7300	50000
C-25	90iC ₄ /10C ₆	500	297	--	✓	0.72 to 0.76	9040	66750
C-26	90iC ₄ /10C ₆	500	297	--	✓	0.72 to 0.76	5420	66750
C-27, -28	90iC ₄ /10C ₆	550	308	✓	✓	0.66 to 0.68	7800 to 8000	66750
C-29	90iC ₄ /10C ₆	550	303	--	✓	TBD ^a	7800 to 8000	66750
C-30, -31	90iC ₄ /10C ₆	550	313	✓	✓	TBD ^a	7800 to 8000	66750
C-32, -33	90iC ₄ /10C ₆	550	318	✓	✓	TBD ^a	7800 to 8000	66750
C-34, -35	90iC ₄ /10C ₆	550	308	✓	✓	0.66 to 0.68	7800 to 8000	83500
C-36, -37	90iC ₄ /10C ₆	550	308	✓	✓	0.66 to 0.68	7800 to 8000	50000
C-38	90iC ₄ /10C ₆	550	308	--	✓	0.66 to 0.68	9910	66750
C-39	90iC ₄ /10C ₆	550	308	--	✓	0.66 to 0.68	5945	66750
C-40, -41	90iC ₄ /10C ₆	600	318	✓	✓	0.59 to 0.63	8700 to 8900	66750
C-42	90iC ₄ /10C ₆	600	313	--	✓	TBD ^a	8700 to 8900	66750
C-43, -44	90iC ₄ /10C ₆	600	320	✓	✓	TBD ^a	8700 to 8900	66750
C-45, -46	90iC ₄ /10C ₆	600	318	✓	✓	0.59 to 0.63	8700 to 8900	83500
C-47, -48	90iC ₄ /10C ₆	600	318	✓	✓	0.59 to 0.63	8700 to 8900	50000
C-49,	90iC ₄ /10C ₆	600	318	✓	✓	0.59 to 0.63	10975	66750
C-50	90iC ₄ /10C ₆	600	318	--	✓	0.59 to 0.63	65805	66750

a. TBD = to be determined--geofluid flow will be adjusted during test to produce desired outlet WF temperature.

TABLE 4. HCRF TEST CONDITIONS FOR PROPANE WORKING FLUID

Test Number	Fluid	Pressure (psia)	T _{WF out} (°F)	Turbine		$\dot{W}_{WF}/\dot{W}_{GF}$	$\dot{W}_{WF}$ #/hr	$\dot{W}_{CW}$ #/hr
				On	Off			
D-1, -2	C ₃	580	216	✓	✓	1.38 to 1.42	7500 to 7700	66750
D-3	C ₃	580	211	--	✓	TBD ^a	7500 to 7700	66750
D-4, -5	C ₃	580	221	✓	✓	TBD ^a	7500 to 7700	66750
D-6, -7	C ₃	580	226	✓	✓	TBD ^a	7500 to 7700	66750
D-8, -9	C ₃	580	216	✓	✓	1.38 to 1.42	7500 to 7700	83500
D-10, 11	C ₃	580	216	✓	✓	1.38 to 1.42	7500 to 7700	50000
D-12	C ₃	580	216	--	✓	1.38 to 1.42	9525	66750
D-13	C ₃	580	216	--	✓	1.38 to 1.42	5715	66750
D-14, -15	C ₃	600	220	✓	✓	1.37 to 1.41	7800 to 8000	66750
D-16	C ₃	600	215	--	✓	TBD ^a	7800 to 8000	66750
D-17, -18	C ₃	600	225	✓	✓	TBD ^a	7800 to 8000	66750
D-19, -20	C ₃	600	230	✓	✓	TBD ^a	7800 to 8000	66750
D-21, -22	C ₃	600	220	✓	✓	1.37 to 1.41	7800 to 8000	83500
D-23, -24	C ₃	600	220	✓	✓	1.37 to 1.41	7800 to 8000	50000
D-25	C ₃	600	220	--	✓	1.37 to 1.41	9875	66750
D-26	C ₃	600	220	--	✓	1.37 to 1.41	5925	66750
D-27, -28	C ₃	650	230	✓	✓	1.35 to 1.39	8500 to 8700	66750
D-29	C ₃	650	225	--	✓	TBD ^a	8500 to 8700	66750
D-30, -31	C ₃	650	235	✓	✓	TBD ^a	8500 to 8700	66750
D-32, -33	C ₃	650	240	✓	✓	TBD ^a	8500 to 8700	66750
D-34, -35	C ₃	650	230	✓	✓	1.35 to 1.39	8500 to 8700	83500
D-36, -37	C ₃	650	230	✓	✓	1.35 to 1.39	8500 to 8700	50000
D-38	C ₃	650	230	--	✓	1.35 to 1.39	10750	66750
D-39	C ₃	650	230	--	✓	1.35 to 1.39	6450	66750
D-40, -41	C ₃	700	239	✓	✓	1.33 to 1.37	9200 to 9400	66750
D-42	C ₃	700	234	--	✓	TBD ^a	9200 to 9400	66750
D-43, -44	C ₃	700	244	✓	✓	TBD ^a	9200 to 9400	66750
D-45, -46	C ₃	700	249	✓	✓	TBD ^a	9200 to 9400	66750
D-47, -48	C ₃	700	239	✓	✓	1.33 to 1.37	9200 to 9400	83500
D-49, -50	C ₃	700	239	✓	✓	1.33 to 1.37	9200 to 9400	50000
D-51	C ₃	700	239	--	✓	1.33 to 1.37	11660	66750
D-52	C ₃	700	239	--	✓	1.33 to 1.37	7000	66750

a. TBD * to be determined--geofluid flow will be adjusted during test to produce desired outlet WF temperature.

TABLE 5. HCRF TEST CONDITIONS FOR 95% PROPANE 5% ISOPENTANE WORKING FLUID

Test Number	Fluid	Pressure (psia)	T _{WF} out (°F)	Turbine		$\dot{W}_{WF}/\dot{W}_{GF}$	$\dot{W}_{WF}$ #/hr	$\dot{W}_{CW}$ #/hr
				On	Off			
E-1, -2	95C ₃ /5iC ₅	570	226	✓	✓	1.30 to 1.32	7300 to 7500	66750
E-3	95C ₃ /5iC ₅	570	221	--	✓	TBD ^a	7300 to 7500	66750
E-4, -5	95C ₃ /5iC ₅	570	231	✓	✓	TBD ^a	7300 to 7500	66750
E-6, -7	95C ₃ /5iC ₅	570	236	✓	✓	TBD ^a	7300 to 7500	66750
E-8, -9	95C ₃ /5iC ₅	570	226	✓	✓	1.30 to 1.32	7300 to 7500	83500
E-10, 11	95C ₃ /5iC ₅	570	226	✓	✓	1.30 to 1.32	7300 to 7500	50000
E-12	95C ₃ /5iC ₅	570	226	--	✓	1.30 to 1.32	9240	66750
E-13	95C ₃ /5iC ₅	570	226	--	✓	1.30 to 1.32	5540	66750
E-14, -15	95C ₃ /5iC ₅	600	231	✓	✓	1.29 to 1.33	7700 to 7900	66750
E-16	95C ₃ /5iC ₅	600	226	--	✓	TBD ^a	7700 to 7900	66750
E-17, -18	95C ₃ /5iC ₅	600	236	✓	✓	TBD ^a	7700 to 7900	66750
E-19, -20	95C ₃ /5iC ₅	600	241	✓	✓	TBD ^a	7700 to 7900	66750
E-21, -22	95C ₃ /5iC ₅	600	231	✓	✓	1.29 to 1.33	7700 to 7900	83500
E-23, -24	95C ₃ /5iC ₅	600	231	✓	✓	1.29 to 1.33	7700 to 7900	50000
E-25	95C ₃ /5iC ₅	600	231	--	✓	1.29 to 1.33	9740	66750
E-26	95C ₃ /5iC ₅	600	231	--	✓	1.29 to 1.33	5840	66750
E-27, -28	95C ₃ /5iC ₅	650	241	✓	✓	1.28 to 1.32	8400 to 8600	66750
E-29	95C ₃ /5iC ₅	650	236	--	✓	TBD ^a	8400 to 8600	66750
E-30, -31	95C ₃ /5iC ₅	650	246	✓	✓	TBD ^a	8400 to 8600	66750
E-32, -33	95C ₃ /5iC ₅	650	251	✓	✓	TBD ^a	8400 to 8600	66750
E-34, -35	95C ₃ /5iC ₅	650	241	✓	✓	1.28 to 1.32	8400 to 8600	83500
E-36, -37	95C ₃ /5iC ₅	650	241	✓	✓	1.28 to 1.32	8400 to 8600	50000
E-38	95C ₃ /5iC ₅	650	241	--	✓	1.28 to 1.32	10625	66750
E-39	95C ₃ /5iC ₅	650	241	--	✓	1.28 to 1.32	6375	66750
E-40, -41	95C ₃ /5iC ₅	700	250	✓	✓	1.26 to 1.30	9100 to 9300	66750
E-42	95C ₃ /5iC ₅	700	245	--	✓	TBD ^a	9100 to 9300	66750
E-43, -44	95C ₃ /5iC ₅	700	255	✓	✓	TBD ^a	9100 to 9300	66750
E-45, -46	95C ₃ /5iC ₅	700	260	✓	✓	TBD ^a	9100 to 9300	66750
E-47, -48	95C ₃ /5iC ₅	700	250	✓	✓	1.26 to 1.30	9100 to 9300	83500
E-49, -50	95C ₃ /5iC ₅	700	250	✓	✓	1.26 to 1.30	9100 to 9300	50000
E-51	95C ₃ /5iC ₅	700	250	--	✓	1.26 to 1.30	11510	66750
E-52	95C ₃ /5iC ₅	700	250	--	✓	1.26 to 1.30	6910	66750

a. TBD = to be determined--geofluid flow will be adjusted during test to produce desired outlet WF temperature.

TABLE 6. HCRF TEST CONDITIONS FOR 90% PROPANE 10% ISOPENTANE WORKING FLUID

Test Number	Fluid	Pressure (psia)	T _{WF out} (°F)	Turbine		$\dot{W}_{WF}/\dot{W}_{GF}$	$\dot{W}_{WF}$ #/hr	$\dot{W}_{CW}$ #/hr
				On	Off			
F-1, -2	90C ₃ /10iC ₅	570	234	✓	✓	1.25 to 1.28	7300 to 7500	66750
F-3	90C ₃ /10iC ₅	570	229	--	✓	TBD ^a	7300 to 7500	66750
F-4, -5	90C ₃ /10iC ₅	570	239	✓	✓	TBD ^a	7300 to 7500	66750
F-6, -7	90C ₃ /10iC ₅	570	244	✓	✓	TBD ^a	7300 to 7500	66750
F-8, -9	90C ₃ /10iC ₅	570	234	✓	✓	1.25 to 1.28	7300 to 7500	83500
F-10, 11	90C ₃ /10iC ₅	570	234	✓	✓	1.25 to 1.28	7300 to 7500	50000
F-12	90C ₃ /10iC ₅	570	234	--	✓	1.25 to 1.28	9225	66750
F-13	90C ₃ /10iC ₅	570	234	--	✓	1.25 to 1.28	5535	66750
F-14, -15	90C ₃ /10iC ₅	600	240	✓	✓	1.23 to 1.27	7700 to 7900	66750
F-16	90C ₃ /10iC ₅	600	235	--	✓	TBD ^a	7700 to 7900	66750
F-17, -18	90C ₃ /10iC ₅	600	245	✓	✓	TBD ^a	7700 to 7900	66750
F-19, -20	90C ₃ /10iC ₅	600	250	✓	✓	TBD ^a	7700 to 7900	66750
F-21, -22	90C ₃ /10iC ₅	600	240	✓	✓	1.23 to 1.27	7700 to 7900	83500
F-23, -24	90C ₃ /10iC ₅	600	240	✓	✓	1.23 to 1.27	7700 to 7900	50000
F-25	90C ₃ /10iC ₅	600	240	--	✓	1.23 to 1.27	9725	66750
F-26	90C ₃ /10iC ₅	600	240	--	✓	1.23 to 1.27	5835	66750
F-27, -28	90C ₃ /10iC ₅	650	250	✓	✓	1.22 to 1.26	8400 to 8600	66750
F-29	90C ₃ /10iC ₅	650	245	--	✓	TBD ^a	8400 to 8600	66750
F-30, -31	90C ₃ /10iC ₅	650	255	✓	✓	TBD ^a	8400 to 8600	66750
F-32, -33	90C ₃ /10iC ₅	650	260	✓	✓	TBD ^a	8400 to 8600	66750
F-34, -35	90C ₃ /10iC ₅	650	250	✓	✓	1.22 to 1.26	8400 to 8600	83500
F-36, -37	90C ₃ /10iC ₅	650	250	✓	✓	1.22 to 1.26	8400 to 8600	50000
F-38	90C ₃ /10iC ₅	650	250	--	✓	1.22 to 1.26	10600	66750
F-39	90C ₃ /10iC ₅	650	250	--	✓	1.22 to 1.26	6360	66750
F-40, -41	90C ₃ /10iC ₅	700	259	✓	✓	1.20 to 1.24	9100 to 9300	66750
F-42	90C ₃ /10iC ₅	700	254	--	✓	TBD ^a	9100 to 9300	66750
F-43, -44	90C ₃ /10iC ₅	700	264	✓	✓	TBD ^a	9100 to 9300	66750
F-45, -46	90C ₃ /10iC ₅	700	269	✓	✓	TBD ^a	9100 to 9300	66750
F-47, -48	90C ₃ /10iC ₅	700	259	✓	✓	1.20 to 1.24	9100 to 9300	83500
F-49, -50	90C ₃ /10iC ₅	700	259	✓	✓	1.20 to 1.24	9100 to 9300	50000
F-51	90C ₃ /10iC ₅	700	259	--	✓	1.20 to 1.24	11475	66750
F-52	90C ₃ /10iC ₅	700	259	--	✓	1.20 to 1.24	6885	66750

a. TBD = to be determined--geofluid flow will be adjusted during test to produce desired outlet WF temperature.