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TOTAL FLOW POWER GENERATION FROM GEOTHERMAL RESOURCES USING A HELICAL SCREW EXPANDER

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ABSTRACT

The Helical Screw Expander, a total flow wellhead generator, was tested by the Ministry of Works & Development as part of an International Energy Agency Programme of research, development and demonstration of geothermal equipment. Testing assessed both the performance and the reliability of Helical Screw Expander.

The isentropic efficiency of equipment was observed to be approximately 40% for loads greater than half full load.

The Helical Screw Expander has the potential to extract more power from low enthalpy geothermal fluid than an atmospheric exhaust steam turbine generator set.

Further development work to improve the reliability of the shaft seals must be undertaken.

INTRODUCTION

The concept of total flow power generation using geothermal resources is well over a decade old. On liquid dominated geothermal resources it has the theoretical potential to generate more power per unit mass flow rate of geothermal fluid than conventional flashed steam cycles (Kestin et al). Various types of total flow expansion systems have been tested to characterise their performance and assess their practical potential. This paper specifically considers the Helical Screw Expander (HSE) a Lysholm type rotary screw total flow device.

Lawrence Livermore National Laboratory, University of California, Berkeley, have laboratory tested a modified rotary screw air compressor (Steidel, Weiss and Flower ; Steidel, Pankow and Berger). The Hydrothermal Power Company (HPC) field tested two converted air compressors between 1971 and 1973 at two test sites in the Imperial Valley, California, and also in Mexico at Cerro Prieto (McKay, 1977). Experience from the field trials undertaken by HPC indicated the need to build and test a commercial size unit. The Jet Propulsion Laboratory, California Institute of Technology, solicited funds from the United States Government to enable HPC to design and build a one megawatt HSE. The unit was to be a skid mounted wellhead generator capable of operating on scaling geothermal fluids. The internal rotor to rotor and housing to rotor design clearances were abnormally large for a Lysholm type unit. HPC expected that scale formation would rapidly fill the internal clearances as had occurred during the field trials on the modified air compressors. Details of the desiyn and the construction have been reported by McKay (1982) and by Hydrothermal Power Co Ltd (1980). The HSE, model No 76-1, was built in 1976-77. Testing of the unit was undertaken at Roosevelt Hot Springs, Utah, in 1978-79. Detailed information on the Utah tests has been reported by McKay (1982).

During the Utah tests a research, development and demonstration programme was set up under the auspice of the International Energy Agency (IEA). The IEA programme involved the testing of the HSE, model No. 76-1, in Mexico, Italy and New Zealand.

The testing of the HSE in New Zealand was performed by the Ministry of Works and Development at the Broadlands Geothermal Field from September 1982 to June 1983. Details of the New Zealand test programme which was designed to assess both the performance and the reliability of the HSE are discussed in this paper.

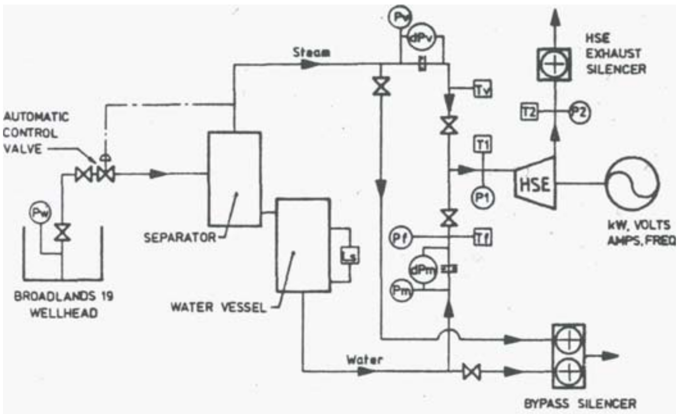
TEST LAYOUT

The New Zealand tests were conducted at well nineteen in the Broadlands Geothermal Field.

The test layout consisted of a two phase line feeding geothermal well fluid to a separation plant, with steam and liquid pipelines going both to the HSE and to waste (figure 1). The steam and liquid flows to the HSE were measured using orifice plates and then recombined prior to admission to the plant. This process layout enabled the mass flow rate, the enthalpy and the fluid quality of geothermal fluid entering the HSE to be determined.

A computer based data acquisition system recorded and analysed process and plant data.

The electrical power generated by the equipment was dissipated in an air cooled resistive load bank.



PROCESS SCHEMATIC

Figure 1

PERFORMANCE TESTS

Performance tests were carried out to define the machines operating characteristics over a wide range of test conditions.

Operating conditions:

Inlet pressure (psia)	100,140,180,220
(bar a)	6.9, 9.7, 12.4, 15.2
Inlet steam quality (%)	0, 10, 25, 50, 100
Exhaust pressure	atmospheric
Electrical load (kW)	to 850
Electrical frequency (hz)	50 ± .4
Male rotor speed (rpm)	2500, 3333

A sample of the data for various inlet qualities at an inlet pressure of 140 psia and a male rotor speed of 3333 rpm is tabulated in table 1.

PERFORMANCE RESULTS

It was found that stable operation of the HSE could not be maintained at an inlet pressure greater than 210 to 220 psia. Stable operation was achieved on all liquid but not on all steam at these inlet pressures. Consequently the maximum safe working pressure for the HSE, model No. 76-1, is considered to be 195 to 200 psia.

The following observations were made from the data:

(1) For a steam fraction of 10% or greater the isentropic efficiency of the HSE:

(a) Increases with increasing shaft power for a given rotational speed and inlet pressure.

(b) Decreases with increasing inlet pressure for a constant load and rotation speed.

(2) For the all liquid case the isentropic efficiency is observed to peak and then decline with increasing load for a fixed rotational speed and inlet pressure.

(3) For a fixed load and inlet pressure the isentropic efficiency increases with increasing inlet steam quality between 0% and 10% and then decreases as the inlet steam quality further increases from 25% to 100%.

(4) A general trend observed is that the 2500 rpm speed has a higher isentropic efficiency than the 3333 rpm for loads less than 400 kW. With the reverse being true for loads greater than 400 kW.

(5) A least squares quadratic curve fitted to all the New Zealand performance data defined the isentropic efficiency of the HSE to be about 40% for loads greater than 400 kW. The data for loads greater than 400 kW spans a range from 28.6% to 44.3%.

Figures 2 and 3 illustrate the trends.

ENDURANCE TEST

An endurance test was run from February 24 to May 3 1983 to assess the reliability and maintenance requirements of the HSE. The plant operating conditions were selected to ensure stable governor speed control could be maintained in the event of electrical load or inlet pressure variations.

operating Conditions:

Inlet pressure (psia)	177 to 182
(bar a)	12.2 to 12.5
Inlet quality (%)	25 to 27.3
Exhaust pressure	atmospheric
Electrical load (kW)	802 to 812
Throttle position (%)	47 to 61
Isentropic efficiency (%) (calculated)	43 to 46.5

The HSE was designed as a wellhead generating unit. Under these conditions the plant must be capable of running unattended. Consequently the endurance test was set up to run with a minimum of operator supervision. Plant checks were performed hourly for the first three days of the test. The interval between checks was then increased until checks were performed at 800 and 1400 hours during the working week and once every 24 hours on weekends and holidays. A plant check once every 24 hours is considered adequate for this unit.

1.3 giga-watt hours of electrical energy was generated from 1632.7 hours of operation. The plant automatically shut down on March 4 when the safety shutdown circuitry malfunctioned. During the endurance test 1534 hours were run without interruption.

The test was terminated on May 3 because of excessive shaft seal oil leakage. At the start of the endurance test the oil consumption for the four seals was monitored at 35 litres per day. The oil consumption steadily increased to 100 litres of oil per day by the end of the test. The maximum length of time the HSE has currently run without developing a shaft seal problem is about 1750 hours. Further development work to improve the reliability and to extend the life of the shaft seals is required.

Routine maintenance performed on the plant consisted of cleaning a centrifuge and changing filter cartridges. The main oil filter elements required changing more frequently than expected by HPC.

A 3.5% increase in the isentropic efficiency of the HSE was observed during the endurance test. This improvement was attributed to scale depositing on the rotors and the housing, partially filling the internal clearances.

POWER OUTPUT COMPARISON

Analysis was undertaken to compare the power generating potential of an HSE and a single admission pressure steam turbine system. Both systems were to be wellhead units exhausting to the atmosphere. Data obtained from the New Zealand tests was used in the comparison. Five fluid enthalpies characteristic of liquid dominated geothermal resources were analysed.

Assumptions:

1. Isentropic efficiency:

   (a) 1 MWe HSE 45% (observed during the endurance test).

   (b) 1 MWe Steam Turbine 60%.

2. Exhaust pressure 14.5 psia.

3. Maximum Stable operating pressure of the HSE was taken to be 195 psia.

4. Pipeline friction and energy losses were neglected.

5. The analysis was based on a unit mass flow rate of geothermal well fluid.

The optimum power output using the HSE occurs at the maximum stable operating pressure. This corresponds to the greatest available isentropic enthalpy drop at which stable operation can be maintained.

The steam turbine optimum occurs as the maximum product of the steam mass flow rate determined by isentropic flash conditions and the corresponding isentropic drop from the flash pressure.

A 1 MWe HSE operating at the optimum conditions requires a smaller mass flow rate of geothermal fluid than required by a steam turbine when operating on a geothermal resource with an enthalpy of 1200 J/g (516 Btu/lb) or less. The analysis assumes that the mass flow rate of geothermal fluid required for one megawatt of electrical power output can be sustained at the optimised inlet pressures. For geothermal wells where this is not valid the mass flow rate variation with wellhead pressure has to be considered.

Figure 4 is a graph of the generated data. The optimum conditions are tabulated in table 2.

CONCLUSIONS

The least squares quadratic equations generated from the New Zealand test data defined the isentropic efficiency of the HSE to be approximately 40% for loads greater than half full load.

The design philosophy of providing abnormally large internal clearances within the HSE to. accommodate scaling was not conclusively tested because of the low scaling potential of the Broadlands geothermal fluid. Trends observed during the endurance test indicate that the efficiency of HSE does increase with adherant internal scale formation.

Plant reliability is of the utmost importance in selection of small geothermal wellhead generators. The shaft sealing on the HSE, model 76-1, needs to be improved to increase the life of the shaft seals. Time periods between overhaul should be similar to or better than achieved by small steam turbines.

For an atmospheric exhaust generating plant the HSE, model 76-1, has the potential to produce more power per unit mass flow rate of geothermal fluid than a flashed steam cycle operating on a liquid dominated geothermal resource with an enthalpy of 1200 J/g or less. The economics of installing a HSE, assuming the shaft seal life can be improved, needs to be carefully assessed. A budget price, supplied by HPC, for a 1 MWe skid mounted unit was $US 1,000,000 in March 1983.

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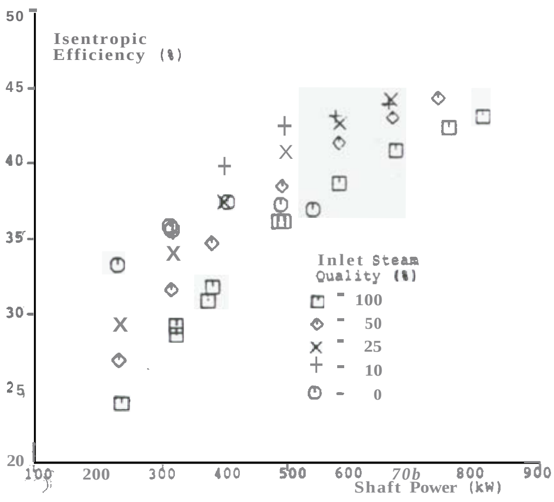

FIGURE 2

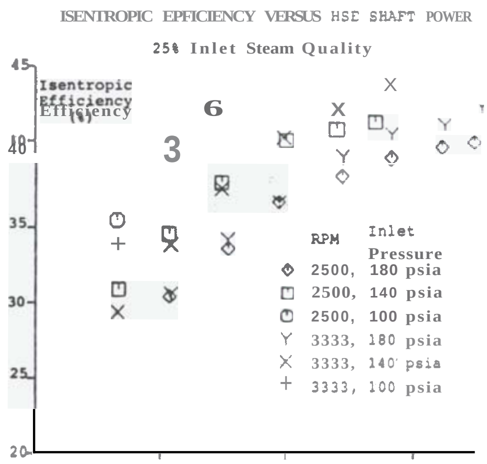

FIGURE 3

Carey

HELICAL SCREW EXPANDER

BROADLANDS 19 PERFORMANCE TEST RESULTS

Inlet Pressure 140 psia

Male Rotor Speed 3333 rpm

Inlet steam Quality 100%

Date	Time	P1 psia	T1 oF	Q1 %	H btu/lb	M1 klb/h	P2 psia	T2 oF	Tr %	KWe KW	KWM KW	Freq Hz	Eff %
28/10/82	16:26:45	140.6	352.6	100.1	1193.6	20.0	14.2	209.9	16	201.0	235.6	50.0	24.0
27/10/82	13:44:52	140.7	352.8	100.1	1193.6	22.4	14.0	209.1	20	284.9	320.9	50.0	29.2
28/10/82	16:09:40	140.3	352.4	100.1	1193.7	23.0	14.2	209.7	20	285.5	321.5	50.0	28.6
28/10/82	15:53:28	140.2	352.4	100.1	1193.8	24.6	14.2	209.7	23	335.1	371.9	50.0	30.9
27/10/82	14:13:44	140.0	352.1	100.1	1193.6	24.3	14.0	209.2	23	342.6	379.6	50.0	31.8
28/10/82	15:32;38	140.6	352.1	100.1	1194.0	28.3	14.2	209.7	30	445.5	484.3	50.3	35.0
27/10/82	14:37:22	139.2	351.4	100.1	1193.6	27.8	14.0	209.1	31	453.3	492.2	50.0	36.1
27/10/82	15:03:12	139.6	351.4	100.1	1193.8	30.6	14.1	208.9	38	538.3	578.9	50.1	38.6
27/10/82	15:34:40	138.4	350.2	100.1	1193.8	33.6	14.1	208.9	49	626.6	669.1	49.9	40.8
27/10/82	15:52:39	139.7	350.7	100.1	1194.1	36.5	14.1	208.9	63	710.3	754.8	49.9	42.3
27/10/82	16:10:53	139.9	350.4	100.1	1194.2	38.3	14.1	208.9	75	762.8	808.6	50.0	43.1

Inlet Steam Quality 50%

Date	Time	P1 psia	T1 oF	Q1 %	H btu/lb	M1 klb/h	P2 psia	T2 oF	Tr %	KWe KW	KWM KW	Freq Hz	Eff %
2/11/82	16:12:10	139.7	352.4	48.3	744.1	33.7	14.4	210.6	18	197.9	232.4	50.0	26.9
2/11/82	15:36:59	139.9	352.1	50.3	761.4	37.4	14.3	210.5	23	277.4	313.2	49.8	31.6
2/11/82	15:07:11	140.9	352.6	48.7	747.9	42.0	14.4	210.5	28	340.4	377.5	50.0	34.7
2/11/82	14:47:26	142.1	352.7	50.3	762.3	47.7	14.4	210.5	36	450.0	488.9	50.0	38.4
8/11/82	17:17:28	141.1	351.7	49.3	753.3	53.6	14.4	210.4	45	537.7	578.4	49.8	41.3
8/11/82	17:29:12	140.5	350.8	50.0	759.1	58.3	14.3	210.9	59	621.3	663.9	50.0	43.0
8/11/82	17:46:59	140.9	350.7	51.0	768.3	61.7	14.3	210.5	72	692.7	737.1	50.1	44.3

Inlet Steam Quality 25%

Date	Time	P1 psia	T1 oF	Q1 %	H btu/lb	M1 klb/h	P2 psia	T2 oF	Tr %	KWe KW	KWM KW	Freq Hz	Eff %
8/11/82	13:52:18	139.1	351.9	24.8	539.9	52.5	14.3	210.6	21	198.9.	233.5	49.9	29.3
8/11/82	14:24:29	139.0	351.4	2S.3	543.8	60.6	14.2	210.6	28	280.7	316.6	49.9	34.0
8/11/82	14:41:30	140.6	352.1	25.9	550.1	67.5	14.3	210.7	34	359.8	397.3	50.1	37.4
8/11/82	15:06:13	138.9	350.5	24.4	536.3	81.4	14.3	210.8	47	456.3	495.3	49.9	40.7
8/11/82	15:26:15	139.4	350.3	25.7	547.5	87.7	14.4	210.8	58	539.0	579.8	50.1	42.6
8/11/82	15:53:08	140.4	350.1	25.8	548.6	96.0	14.4	210.9	73	618.7	661.2	49.9	44.2

Inlet Steam Quality 10%

Date	Time	P1 psia	T1 oF	Q1 %	H btu/lb	M1 klb/h	P2 psia	T2 oF	Tr %	KWe KW	KWM KW	Freq Hz	Eff %
10/11/82	13:12:38	138.7	351.8	9.2	403.7	109.0	14.3	211.0	33	279.2	314.9	50.1	35.4
10/11/82	13:31:05	139.3	351.6	10.0	411.5	117.4	14.4	211.1	42	358.4	395.6	50.0	39.4
10/11/82	13:44:26	142.1	351.9	9.7	410.0	137.4	14.5	211.4	55	450.7	489.6	50.0	42.0
10/11/82	14:02:13	139.0	350.2	10.8	417.9	151.4	14.7	212.0	71	53.2.2	572.8	49.8	43.1
10/11/82	14 24:38	139.5	349.8	10.6	416.5	172.1	14.8	212.7	90	614.9	657.4	49.9	43.9

Inlet Steam Quality 0%

Date	Time	P1 psia	T1 oF	Q1 %	H btu/lb	M1 klb/h	P2 psia	T2 oF	Tr %	KWe KW	KWM KW	Freq Hz	Eff %
20/10/82	16:43:13	142.6	352.6	0.0	324.3	166.6	14.2	210.9	9	194.6	228.9	49.9	33.3
20/10/82	15:05:14	141.0	352.9	0.0	324.7	212.4	14.5	211.9	15	274.9	310.6	49.9	35.8
20/10/82	16:24:28	141.4	353.3	0.0	325.1	214.8	14.5	211.8	16	278.9	314.6	50.0	35.6
20/10/82	15:22:07	139.4	352.3	0.1	325.2	264.8	14.8	212.7	36	365.2	402.4	50.0	37.4
20/10/82	15:44:47	141.5	353.0	0.3	327.9	316.5	15.1	214.1	58	448.4	487.3	49.9	37.2
20/10/82	15:57:26	138.9	350.5	0.5	328.1	358.6	15.5	215.3	83	490.2	538.1	50.1	36.9

P1	Inlet pressure	T2	Exhaust temperature
T1	Inlet temperature	Tr	Throttle
Q1	Inlet Quality	KWe	Electrical Power
H	Inlet Enthalpy	KWM	HSE Shaft Power
M1	Mass Flow rate	Freq	Electrical Frequency
P2	Exhaust pressure	Eff	Isentropic Efficiency

T A B L E -1-

HELICAL SCREW EXPANDER/STEAM TURBINE POWER OUTPUT COMPARISON

OPTIMUM CONDITIONS

Fluid Enthalpy		HELICAL SCREW EXPANDER Inlet Pressure		Power		STEAM TURBINE Inlet Pressure		Power	
(J/g)	(Btu/lb)	(bar a)	(psia)	(kW/kg/s)	(kW/lb/s)	(bar a)	(psia)	(kW/kg/s)	(kW/lb/s)
900	387	13.5	195	27.3	12.4	5.5	79	20.3	9.2
1000	430	13.5	195	36.4	16.5	6.9	101	29.1	13.2
1100	473	13.5	195	45.4	20.6	8.9	130	39.2	17.8
1200	516	13.5	195	54.5	24.7	11.5	166	52.0	23.6
1300	559	13.5	195	63.5	28.8	14.0	203	64.1	29.1

T A B L E -2-

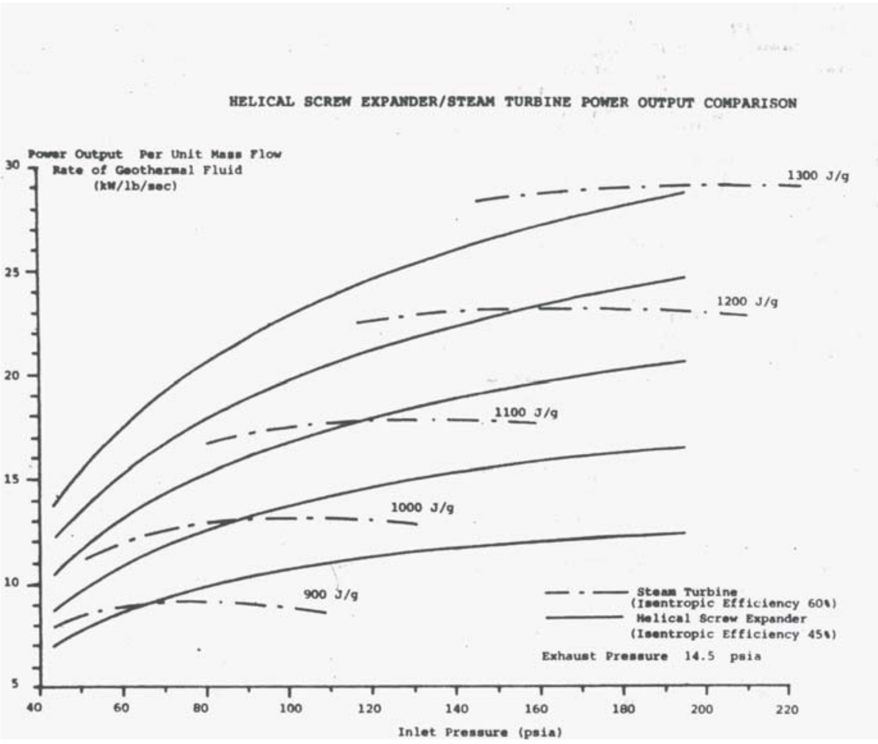

FIGURE 4