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THE ECONOMICS OF GEOTHERMAL ELECTRICITY GENERATION FROM HYDROTHERMAL RESOURCES USING THE BIPHASE ROTARY-SEPARATOR TURBINE

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ABSTRACT

Geothermal power systems using a Biphase rotary-separator turbine (RST) are compared to flash steam and binary systems. Application to geothermal fluids having temperatures from 280 to 680°F is considered. Brine production costs, capital equipment costs, and competing system efficiencies were taken from published studies. RST performance was extrapolated from field-test results.

Systems incorporating the Biphase RST are projected to produce power at a lower cost than binary or flash-steam systems over temperatures from 360 to 680°F. Below 360°F the binary system was cheaper than the Biphase but by less than 10 percent. Based on economics, the market potential for the Biphase RST was estimated at 18,600 MW compared to 17,350 MW for flash-steam, and 11,550 for binary.

INTRODUCTION

This report compares the engineering, economic, and market potential of the Biphase rotary separator turbine to other technologies for geothermal power production. The evaluation considers reservoir temperatures from 280 to 680°F and different levels of production costs. For temperatures from 280 to 490°F, the Biphase system is compared with binary and flash technology. For temperatures greater than 490°F, the Biphase system is compared only with flash systems.

In conducting this study, the performance of each technology was characterized. Energy-production capabilities at various reservoir conditions were determined. Capital and operating costs were then calculated. For each assumed set of conditions, the technology with the lowest levelized busbar cost was taken to be the market choice. Where busbar costs for two technologies were within 10 percent, both were assumed to have the same market potential.

MARKET BASIS

The Department of Energy (DOE) geothermal projections as reported by Engingh (1979) were used as the market basis. These projections assume continued development of technology, especially for low-temperature and currently uneconomical resources.

Twenty-seven geothermal locations form the basis of this study. "Typical" well characteristics were assembled and reported by Treham (1978). These reservoir temperature and salinity values were used in this study to evaluate the technologies at different resource conditions. The theoretical power available from various temperature geothermal brines (assuming a 122°F condenser temperature) was derived from thermodynamic data.

EVALUATED SYSTEMS

Low-temperature resources, which represent the major portion of known resources, are the most difficult to utilize economically. Prior studies by Holt (EPRI 1976) and Bechtel (DOE 1977) illustrated the economic advantages of high-efficiency binary technology for low-temperature resources and low-capital flash systems on high-temperature resources.

In this evaluation the RST demonstrated higher efficiencies than conventional flash technology (Cerini, 1980) and the potential for lower investment costs than binary and flash systems. The Biphase technology was compared with binary technology at temperatures of 280 to 490°F and with flash processes at 280 to 680°F. For low-temperature cases, both pumped and self-flowing well conditions were evaluated for the RST. All binary cases were evaluated using down-hole pumps and all flash cases assumed self-flowing conditions. The efficiencies and economics of single- and two-stage flash technology are representative of systems being proposed or currently under construction (DiPippo, 1980, and Kestin, 1980).

SYSTEM PERFORMANCE

System efficiency vs. reservoir temperature, curves were established for each process and configuration studied. Efficiency data for the binary system were obtained from publications by Battelle Northwest (Battelle), Ben Holt Co. (EPRI 1976), Bechtel (DOE 1977), and Mitre (Gupta 1978), and discussions with these organizations. While gross binary efficiencies varied in these studies, net efficiencies after considering parasitic losses were similar.

Single-stage flash-system efficiency values were based upon flash at the arithmetic average of the reservoir and condenser temperatures. The optimum for two-stage flash systems was similarly derived.

RST efficiency levels were based upon results from field studies recently completed for EPRI (Cerini, 1980). Data from East Mesa, Roosevelt Hot Springs, and Brawley were extrapolated to allow for the higher turbine efficiencies expected with larger-size RST's and the higher nozzle efficiencies expected with direct wellhead flow. It is believed that the values used are less optimistic than the values used for the other technologies.

Net system efficiency values for each technology were developed by subtracting the parasitic power losses from the available gross work (theoretical work x gross efficiency).

The major parasitic losses are from:

- downwell pumps
- brine-reinjection pumps
- condenser-system pumps
- cooling-tower fans
- working-fluid circulation pumps.

Energy requirements were estimated from Battelle (Battelle), Mitre (Gupta, 1978), Bechtel (DOE, 1977), and Ben Holt (EPRI, 1976) data. The Biphase systems with high efficiency and built-in brine repressurization capability has the least parasitic losses while binary has the most.

Table 1 summarizes system performance at various temperatures in terms of Net Output per million pounds per hour of brine (utilization). The binary system claims the highest utilization levels for low-temperature reservoirs. At about 470°F the RST and the binary exhibit the same utilization level. Above 470°F, binary utilization plateaus and this technology loses its edge compared to the RST and flash technologies.

NET SYSTEM OUTPUT
(MW/10^6 LBS BRINE/HR)

	RESERVOIR TEMPERATURE					
	320°F	HEBER 360°F	ROOSEVELT HOT SPRINGS 450°F	490°F	BRAWLEY 530°F	680°F
SINGLE-STAGE FLASH	2.43	3.66	7.3	9.87	12.6	29.0
TWO-STAGE FLASH	2.90	4.33	8.47	11.3	14.1	29.7
BINARY (PUMPED)	3.73	5.87	10.9	12.4	–	–
RST	2.85	4.79	10.4	13.5	16.0	29.6
RST (PUMPED)	3.24	4.79				

Table 1. Net system output vs. reservoir temperature

PRODUCTION AND REINJECTION WELLS

In this study, for simplicity, we assumed a constant well-production rate of 600,000 lbs of brine per hour for self-flowing and pumped wells and well-production costs ranging from 1/2 to 1-1/2 million dollars. By varying well cost, a family of cost curves ($/lb. brine/hr) were generated, making it possible to evaluate the economic sensitivity of the technologies to brine cost over a range of values.

All cost comparisons were based on a plant of 50 MW net generating capacity. The number of production wells was determined using 600,000 lbs. of brine per hour per well together with appropriate net system output values (Table 1) for each technology and reservoir temperature.

For every two production wells, one reinjection well was assumed. The production and reinjection wells were assumed to have the same costs.

The calculations show that at reservoir temperatures of 490°F and below, the pumped binary and the Biphase technology result in the fewest wells.

INSTALLED CAPITAL AND OPERATION COSTS

Cost curves were developed for the flash, binary, and Biphase RST systems. These curves show the installed cost in $/kW of gross-power production vs. reservoir temperature. Flash and binary data were obtained from Battelle Pacific Northwest Laboratories (Battelle) using their capital cost models (Bloomster, 1976, and EPRI, 1976). The same models were also used for the Biphase RST. To do this, flash-system costs were modified to:

- exclude the flash tanks
- substitute lower-head reinjection pumps
- adjust piping for appropriate flow at differing efficiency levels
- reduce the cost of the central plant to allow for power from the Biphase units
- develop a capital cost for the Biphase turbo-generator/RST since the Battelle model does not include this.

Figure 1 illustrates the relationship of installed capital cost in $/kW vs. reservoir temperature for the three systems. The same ancillaries and indirect cost factors were used for all three systems.

Production plant capital cost is dependent upon reservoir temperature, amount of brine produced and brine-delivery method. The pumped option assumes a downhole pump cost of $120,000 per well. The production plant costs used in this study were estimated from empirical models as follows:

Self-flowing: $/lb. brine production/hr. = 0.93 - 0.00085 (T)

Pumped: $/lb. brine production/hr. = 1.18 - 0.00085 (T)

where T = temperature of brine in °F.

To estimate operating costs, labor and maintenance were estimated as a percentage of initial

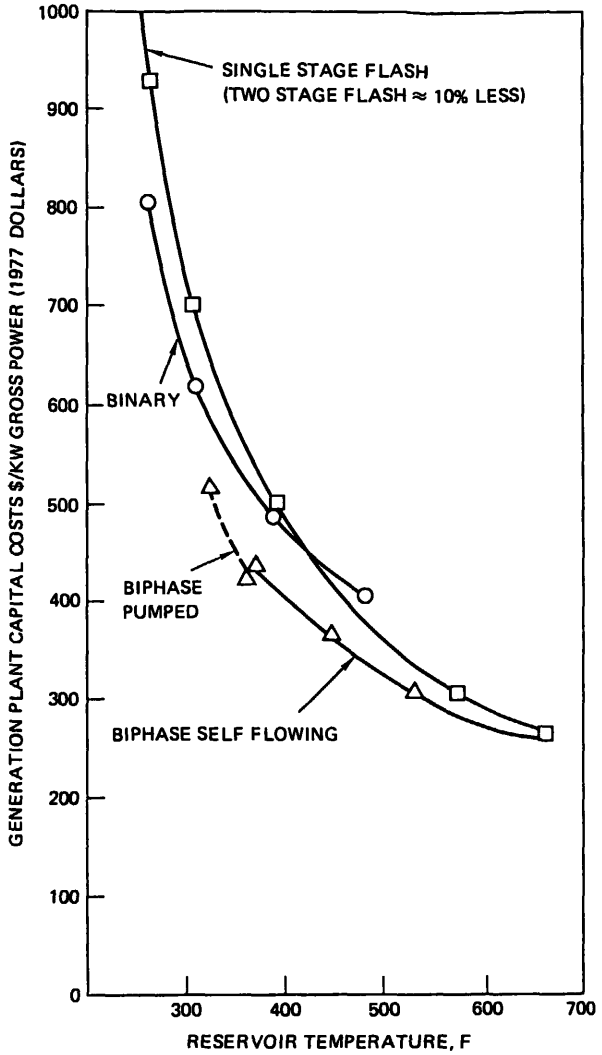

Figure 1. Generating-plant-installed capital cost vs. reservoir temperature.

capital expenditures. Uniform percentages were used except for a higher maintenance factor on binary to allow for heat-exchanger fouling and downhole-pump problems.

STUDY RESULTS

Busbar costs for each technology were calculated over reservoir temperatures ranging from 320 to 680°F using procedures from the EPRI "Technical Assessment Guide" (EPRI, 1978). An example of the detailed calculations is shown in Table 2. All costs are reported in 1977 dollars regardless of the year of start-up. Between 1977 and 1981, plant-construction costs have risen by over 50 percent. These are summarized in Table 3 for three different values of brine-production cost. They indicate that the RST from an economic standpoint is competitive over the whole temperature range of current geothermal activity. In most instances, the RST was the least expensive system.

ASSUMPTION RESERVOIR TEMPERATURE 445°F
WELL COST $500,000
WELL FLOWRATE 600,000 LB/HR
PRODUCTION COST FACTOR $0 83/LB BRINE/HR

	FLASH	TWO-STAGE FLASH	BINARY (PUMPED)	RST
PROD/INJ WELLS, #	14/7	12/6	9/5	10/5
TOTAL BRINE FLOW, 10^6 LB/HR	6 72	5 76	4 32	4 80
GROSS CAPACITY, MW	56 6	56 3	59 6	54 7
NET CAPACITY, MW	49 1	48 8	47 1	49 9
CAPITAL COST, $MILLIONS				
WELLS	12 77	10 95	8 62	9 13
PRODUCER PLANT	4 15	3 55	3 83	2 97
REPLACEMENTS	5 75	4 93	4 16	4 12
TOTAL PRODUCTION CAPITAL COSTS	22 67	19 44	15 61	16 22
GENERATING PLANT	28 72	25 95	30 96	24 29
TOTAL CAPITAL	51 39	45 39	47 47	40 51
O&M COSTS, $ THOUSANDS				
PRODUCTION	389	333	710	278
GENERATION	590	533	929	499
BUSBAR COST, MILLS/kWhr				
LEVELIZED PRODUCTION BUSBAR COST	19 72	17 01	16 47	13 88
LEVELIZED GENERATING	14 63	13 29	17 79	12 17
TOTAL BUSBAR COSTS	34 35	30 30	34 36	26 05

Table 2. Capital cost calculation (1977 dollars), for selected geothermal options.

BRINE PRODUCTION COSTS $/LB BRINE/HR	FLASH			TWO-STAGE FLASH			BINARY			RST		
	0 83	1 67	2.50	0 83	1 67	2 50	0 83	1 67	2 50	0 83	1 67	2 50
RESERVOIR TEMPERATURE												
320°F	88 2	134 0	179 0	8 5	118 3	158 1	77 2	107 1	137 0	75 5	116 2	157 0
360°F	61 5	91 6	122 0	53 2	78.5	103.8	53 9	72 6	91 4	46 6	69 5	92 5
445°F	34 4	49.4	64 5	30 3	43 2	56 1	34 2	44 7	55 1	26 1	36 6	47 2
490°F	25 3	38 4	49 5	24 2	33 9	43 6	30 6	39 4	48 3	21 4	25 5	29 5
530°F	22 2	30 9	39 6	19.9	27 7	35 5	–	–	–	18 7	25 6	32 5
680°F	13 0	17.0	20 9	12.7	15 9	19.7	–	–	–	13 2	17 0	20.8

Table 3. Geothermal power busbar costs (mills/kWhr — 1977 dollars).

As was previously indicated, a system was assumed to have an economic advantage when its annualized cost was at least 10 percent lower than competing systems. The available market for each system was determined by summing up the megawatts for each well condition where a given system demonstrated an economic advantage. The "potential" market measures the gross market in which a given system has an equivalent or preferred position developed solely on the basis of economics. Table 4 summarizes these results. It can be observed that:

- When all three systems compete, the lower cost/higher-efficiency RST is competitive over the complete temperature range. The binary system is competitive at low temperatures but loses its economic edge above 425°F. On the other hand, the single-stage flash system is competitive for high temperatures but has difficulty competing below 500°F. Two-stage flash, however, continues to be competitive down to 390°F.

- In a flash/binary-only market, both systems can complete in the 420-445°F temperature range but the RST exhibits lower costs than either and appears to be the better alternative.

- Since most geothermal resources are less than 400°F (<10,000 MW) the RST and the Binary technologies will be competing for the major geothermal market.

ECONOMIC COMPETITIVE RANGE	TECHNOLOGY			
	RST	SINGLE-STAGE FLASH	TWO-STAGE FLASH	BINARY
CONSIDERING ALL THREE TECHNOLOGIES, °F	284 – 680	500 – 680	380 – 680	284 – 488
CONSIDERING ONLY FLASH/BINARY, °F	NA	420 – 680	380 – 680	284 – 445
MARKET POTENTIAL, MW (BASE ON MITRE MARKET PROJECTION) (1)	18,600	2600	17,350	11,550

Table 4. Potential geothermal market based upon economic criteria.

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