Fossil Superheating in Geothermal Steam Power Plants

by

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ABSTRACT

This paper reports the results of thermodynamic studies of geothermal steam power systems incorporating fossil-fired superheaters. One- and two-stage systems are covered. Realistic assumptions have been included to account for losses that may be incurred in actual plants. The systems are evaluated on the basis of a number of appropriate figures of merit. It is found that fossil superheat hybrid geothermal power plants offer a thermodynamic advantage over individual fossil and geothermal plants for a wide range of operating conditions, and deserve consideration whenever fossil and geothermal energy resources are found in reasonable proximity.

INTRODUCTION

The use of natural, geothermal steam for the production of electricity dates from 1904 when Prince Piero Ginori Conti (1)* first operated a small engine at the boric acid works at Larderello in Italy. Until recently only dry or superheated geothermal steam resources were tapped for electric power production owing to the relative simplicity of the energy conversion equipment required. The idea, however, of improving the utilization of geothermal resources by combining them with fossil energy resources has occurred to several people, including P. Caufourier (2) who, in 1924, proposed an elaborate, four-stage, flashed-steam system with a fossil-fired superheater. His proposed hybrid power plant was recently analyzed by one of the authors (3).

C. R. James (4) examined the possibility of adding a fossil superheater to the multiflash geopower plant at Wairakei in New Zealand. F. J. Dan, et al (5) mentioned that fossil superheating of the dry steam at The Geysers in California was considered during the design of that plant. No actual geothermal electric power plant has ever utilized the hybrid fossil-geothermal concept. We note in passing that the only central power station to use a hybrid-fuel cycle is Consolidated Edison's Indian Point Unit 1 nuclear power plant which incorporates a fossil superheater (6).

The objective of this paper is to report the findings of the analysis of a number of power plant arrangements which are characterized by fossil superheating of geothermal steam. The analyses are directed at the thermodynamics of the systems; economic considerations are beyond the scope of the present work. Of the many systems which were analysed, only the most promising ones are discussed in detail. The complete study may be found elsewhere (7).

*Numbers in parentheses designate References at end of paper.

FIGURES OF MERIT FOR HYBRID SYSTEMS

The question of how to assess properly the performance of hybrid fossil-geothermal power plants recently has been described (8). A hybrid plant must be compared with a number of individual state-of-the-art plants, each utilizing one of the sources of energy used by the hybrid plant.

The overall figure of merit F is defined, for the present case, as

$$F = W / (W_f^* + W_g^*) , \quad (1)$$

where W is the work produced by a hybrid plant which consumes a given amount of fossil energy and a given amount of geothermal energy, W_f^* is the maximum work attainable from a state-of-the-art fossil power plant with the same fossil energy input, and W_g^* is the corresponding state-of-the-art work term for a geothermal power plant. All work terms are taken per unit mass of geofluid at the wellhead. A hybrid system for which $F > 1$ will have a thermodynamic advantage over state-of-the-art fossil and geothermal plants operating individually.

The fossil-fuel figure of merit F_f is defined as

$$F_f = (W - W_g^*) / W_f^* , \quad (2)$$

and the geothermal figure of merit F_g is defined as

$$F_g = (W - W_f^*) / W_g^* \quad (3)$$

The first of these, F_f , attributes all the gain of a hybrid plant to an improved utilization of the fossil fuel by debiting the total plant work by the maximum amount that can be assigned to the geothermal energy. The second figure of merit, F_g , credits the geothermal resource with all the gain in a similar fashion. It follows from the definitions of the terms that whenever

any one of the figures of merit is greater than unity, so are the other two.

For the types of hybrid systems reported in this paper, in contrast to those discussed in a companion paper (9), the determination of what constitutes a state-of-the-art geothermal system must be made with care. Fossil superheat hybrid systems are basically geothermal steam systems with a fossil superheater added on. Thus the reference, state-of-the-art geothermal plant is either a one-stage or a two-stage geothermal steam plant, without a fossil superheater, and with the design variables chosen so as to optimize the plant output. The number of stages in the reference plant must be matched to the number of stages selected for the hybrid plant.

ONE-STAGE SYSTEMS

One-stage hybrid fossil-geothermal systems are modifications of the simplest form of geothermal power plant in which natural steam is obtained (i) directly from the reservoir (as at The Geysers, California, Larderello, Italy, or Matsukawa, Japan), (ii) from a separation process at the wellhead for liquid-dominated reservoirs (as at Wairakei, N.Z., Cerro Prieto, Mexico, or Otake, Japan), or (iii) from a flash process of a liquid-dominated reservoir with pumped wells.

Although steam turbines can be designed and built to handle saturated water vapor at the inlet, with wet steam prevailing during most of the expansion process, such turbines suffer a penalty in efficiency compared to turbines in which the expansion takes place with dry or superheated steam. The well-known Baumann rule (10) provides a reasonable estimate of this penalty: the turbine efficiency decreases by one percentage point for each one percent of moisture present at the turbine exhaust. Thus, the addition of superheat to the saturated geothermal steam will result in a significant improvement in the turbine expansion efficiency. Furthermore, the use of fossil fuel to provide high-temperature.

energy to the working fluid will mean a high utilization efficiency for the fossil fuel and may result in an improved overall energy conversion efficiency for the entire system.

A simple flow diagram for one-stage hybrid systems is given in Fig. 1; a thermodynamic state diagram in temperature-entropy coordinates is shown in Fig. 2. The system contains a separator or flash tank (depending on the quality of the geofluid at the wellhead), a regenerator, the fossil-fired superheater, a steam turbine and a desuperheater-condenser, followed by a re-injection pump. The analysis was performed for systems with and without the regenerator since it is neither always thermodynamically possible nor practically feasible to employ a regenerator.

A number of assumptions have been used in the analysis; these are summarized as follows:

1. The geofluid has the properties of pure water.
2. Liquids are taken as saturated at the given temperature.
3. Condenser pressure is 10 kPa at a saturation temperature of 46°C.
4. Condensate pumps have anisentropic efficiency of 80%.
5. Regenerator effectiveness is 80%.
6. Minimum temperature difference in regenerator is 20°C.
7. Pressure loss in superheater is 5% when regenerator is used, otherwise it is 10%; pressure loss on heating side of regenerator is 5%; pressure loss on cooling side of regenerator is 10%; no pressure loss in desuperheater.
8. Thermal efficiency of state-of-the-art fossil-fuel power cycles is 42%, i.e., $\eta_f^* = 0.42$.
9. Dry turbine isentropic efficiency is 85%, i.e., $\eta_d = 0.85$.

10. Wet turbine efficiency is found from a modified Baumann rule (11), i.e., $\eta_w = (1-\alpha y)\eta_d$, with α being the wetness loss coefficient and y the wetness at turbine exhaust. The coefficient α was selected to give agreement with observed wet turbine performance; i.e., we chose $\alpha=1.2$ which yields, for example $\eta_w = 0.75$ when the inlet steam is dry saturated at 130°C.
11. Dry/wet expansion efficiencies are found from a weighted modified Baumann rule, i.e., $\eta_{d/w} = (1-\alpha\bar{y})\eta_d$, where $\bar{y} = y (\Delta h_w / \Delta h_t)$. The total enthalpy drop in the turbine is Δh_t ; the enthalpy drop in the wet region is Δh_w .

A passive-mode, two-parameter optimization study was carried out using a digital computer. The properties of liquid water and steam were obtained from the WASP code (12) which is based on the fundamental equation of state for water substance of J. H. Keenan, et al (13).

In the first phase of the work, the effect of the flash-steam temperature T_2 on the system performance was studied, both for a purely geothermal steam plant and for a fossil-superheat plant. Maximum plant output occurs at a flash temperature which differs only a little from the approximate rule (14) which places the optimum flash temperature mid-way between the geothermal fluid temperature T_g and the condenser temperature T_c . Furthermore, the study revealed that the location of the maximum is quite insensitive to flash temperature in the vicinity of the optimum; e.g., a typical change in flash temperature of $\pm 5^\circ\text{C}$ from the optimum value produces only a $\pm 0.8\%$ loss in output. This result applies to superheated and non-superheated systems, and led to the adoption of the so-called "equal-split" rule for flash temperatures for the remainder of this study.

The second phase of the computational program concerned the effect of the maximum steam temperature T_4 on system performance for various flash-steam temperatures T_2 (or equivalently, for various geofluid temperatures T_g since

these are functionally related through the equal-split rule for the constant condenser temperature which was assumed throughout).

The results are presented graphically in Fig. 3, where the figures of merit F , F_f , and F_g are plotted against T_4 for three values of T_2 . It was decided to limit the calculations to include only fully-dry expansion processes; the temperatures T_4^{L1} , T_4^{L2} and T_4^{L3} are those maximum steam temperatures below which the expansion line, 4-5, dips into the two-phase region, for flash-steam temperatures of 150, 175 and 200°C, respectively. Since all of the figures of merit shown in Fig. 3 exceed unity, hybrid systems operating within the ranges of temperature shown are thermodynamically superior to individual, geothermal and fossil, state-of-the-art power plants. In general, the highest advantage occurs when the maximum steam temperature is taken as 540°C, which is the current practical maximum turbine inlet steam temperature for central power stations. Furthermore, the higher the geofluid temperature, the higher are the figures of merit.

The results indicate, for example, that a one-stage hybrid system with geothermal steam at 175°C (approximately that at The Geysers) superheated to 540°C will yield an effective fossil fuel efficiency of 50.4% (since $F_f = 1.20$ and $\eta_f^* = 0.42$), while assuming the highest level of utilization of geothermal energy possible in one-stage systems. On the other hand, the same results may be interpreted as indicating that the hybrid plant produces 14% more output than a state-of-the-art, one-stage geothermal plant, while allowing that the fossil-energy input is used at a level of 42% efficiency (since $F_g = 1.14$).

It is not thermodynamically possible to include a regenerator in the hybrid system for any of the combinations of T_2 and T_4 used in Fig. 3. For a given maximum steam temperature T_4 , and the assumed minimum temperature difference in the regenerator, there is a particular flash-steam temperature T_2 above which regeneration is not possible. When

$T_4 = 540^\circ\text{C}$ and $\Delta T_{\min} = 20^\circ\text{C}$, this occurs at about $T_2 \approx 143^\circ\text{C}$. The behavior of the fossil and geothermal figures of merit F_f and F_g in the lower-temperature regime is shown in Fig. 4 for $T_4 = 540^\circ\text{C}$. The addition of the regenerator improves the system performance, especially for the lowest flash-steam temperatures. For $T_2 > 130^\circ\text{C}$, either hybrid system is superior to two individual plants; below this temperature, only hybrid systems with a regenerator hold an advantage over the separate plants.

TWO-STAGE SYSTEMS

It is becoming common to install two-stage geothermal steam power plants in liquid-dominated fields. Plants of this type are in operation at Hatchobaru, Japan (15, 16) and Krafla, Iceland (17), and are planned for Unit 3 at Ahuachapán, El Salvador (16) and for the Los Baños and Tiwi fields in the Philippines (16). Such systems constitute the cutting edge in the technology of geothermal steam plants. The objective of this portion of the study was to see whether such systems could be improved thermodynamically by the addition of a fossil superheater.

A large number of possible hybrid arrangements were devised and analyzed (7); the most promising one is shown schematically in Fig. 5. The arrangement is similar to the one-stage system shown in Fig. 1 except that two flash tanks (or a separator and a flash tank) are used together with a tandem-compound turbine. The exhaust from the first turbine, ST_1 , is used to supply a portion of the superheat to the steam obtained from the first flash tank. The cooled steam mixes with the steam obtained from the second flash tank before being expanded in the second turbine, ST_2 . A temperature-entropy diagram for the operation is shown in Fig. 6.

In accordance with the conclusions from the one-stage studies, the maximum steam temperature was taken at the metallurgical limit, i.e., $T_4 = 540^\circ\text{C}$,

and the equal-split rule for flash temperatures was applied for all analyses of two-stage hybrid systems. A few check calculations were performed to validate these assumptions.

The calculated figures of merit are shown in Fig.7 as a function of the geothermal fluid temperature. The results show, for example, that a two-stage hybrid plant of the proposed design and using a geofluid at a temperature of 225°C (which will be flashed at 165 and 105°C, typical of Hatchobaru (16)) will operate with an effective fossil fuel efficiency of 54.6%, or produce 9% more output than a state-of-the-art, double-flash geothermal plant. The hybrid plant will produce 7% more work output than the sum of the outputs from the state-of-the-art geothermal plant and a fossil plant converting the required fossil energy at an efficiency of 42%.

DESIGN CONSIDERATIONS

One of the main advantages of the proposed hybrid systems is that the components utilize established technologies that exist in the geothermal, steam turbine and gas turbine industries. The turbines that would be required for the hybrid plants would be nearly identical to the low-pressure turbines used in conventional steam power plants; in fact, both the inlet conditions and the expansion ratios would be essentially the same for the two types of systems. Indeed, the turbines for the hybrid systems would be simpler in design than those now being used in geothermal steam plants owing to the dryness of the steam during the expansion process. The steam-steam regenerator of the hybrid plant would be similar to, although different in some detail from gas-gas regenerators for large stationary gas turbine power plants.

The main obstacle standing in the way of hybrid fossil-geothermal plants is the problem of co-location of the two energy resources. Geothermal energy

may be considered as a type of "fuel" from which a power plant may extract a portion of useful work. Unlike its fossil fuel counterpart, however, geothermal "fuel" cannot be economically transported over distances greater than about 2 km for use in power plants. This means that the fossil fuel must be transported to the geothermal site. The cost of providing that fossil fuel on site will play a crucial role in deciding the feasibility of a hybrid plant. Some countries with abundant geothermal reserves, such as Iceland and Japan, have very small or nonexistent reserves of fossil fuel. In the case of Japan, which imports essentially all of its fossil fuel, the geothermal sites are located in the rugged, central mountain ranges, making it difficult to use the fossil fuels which are delivered at port cities.

In the United States, where there is an enormous reserve of coal, there are several sites in the western states where coal and geothermal reserves exist in reasonably close proximity. Utah is a prime candidate; cost studies (18) performed for one type of hybrid plant (9) have shown that Roosevelt Hot Springs, near Milford, is an excellent site.

Assuming reasonable co-location of the two resources, the question arises of plant design and site development strategies to utilize best the given reserves of the two "fuels". This matter will be discussed in terms of two factors: (i) the work amplification factor, ψ , and (ii) an overall figure of merit, F_o , which takes into account the relative resource depletion caused by the hybrid plant. The full development of these factors is treated in a companion paper (9), and only the working equations will be quoted here.

The ratio of the work of the hybrid plant to that of the state-of-the-art geothermal plant is called the work amplification factor,

$$\psi = W/W_g^* \quad (4)$$

This factor may be found from the fossil and geothermal figures of merit:

$$\psi = (F_f F_g - 1) / (F_f - 1) \quad (5)$$

The hybrid plant will derive its input from a geothermal resource with a work potential W_G^* over its lifetime and from a fossil resource with a corresponding work potential W_F^* over its lifetime. The ratio of these two quantities is called the resource ratio R :

$$R = W_G^* / W_F^* \quad (6)$$

A hybrid plant of a fixed design will deplete the geothermal and the fossil resources in a fixed ratio r which can be shown to be

$$r = 1 / (\psi - F_g) \quad (7)$$

The ratio r/R will determine which resource the hybrid plant will deplete first. This ratio,

$$\Delta = r/R \quad (8)$$

is called the relative depletion parameter, and when $\Delta > 1$, the geothermal resource will be depleted first. Fossil superheat hybrid systems typically yield $\Delta > 1$. In such a case, it can be shown (8) that an appropriate figure of merit which accounts for the early depletion of the geothermal resource relative to the fossil resource is:

$$F_o (\Delta > 1) = 1 + \{R(F_g - 1) / (R + 1)\} \quad (9)$$

Since the resource ratio R is a time- and site-specific function, known only with a large degree of uncertainty, the results are presented for a wide

range of values of R . The two-stage hybrid system was chosen as an example, using a geofluid temperature of 225°C and a maximum steam temperature of 540°C . The relative depletion parameter Δ and the overall depletion figure of merit F_o may be read from Fig. 8 for any value of R from 0.001 to 1.0. For example, if the ultimate work potential of the fossil fuel dedicated to this hybrid plant exceeds that of the geothermal resource by a factor of ten (i.e., $R = 0.1$), then $\Delta = 33$ and $F_o = 1.008$. This means that there is a thermodynamic advantage of 0.8% in using this hybrid plant until the geothermal resource gives out followed by conversion of the remaining fossil resource in a state-of-the-art plant, in comparison to using two separate state-of-the-art plants, one geothermal and one fossil, to convert each energy resource to depletion.

It should be noted that the thermodynamic advantage reaches a maximum of 6.9% for the case when $\Delta = 1$ (i.e., when both resources give out simultaneously). For the plant cited in the above example, this would require a resource ratio of $R = 3.33$ (not shown in Fig. 8). Furthermore, this percentage gain is figured on the sum total of the work potential of both resources over their full lifetimes and may amount to a huge quantity of energy.

The work amplification factor ψ dictates the size of the hybrid plant once it has been determined what size conventional geothermal plant the geothermal resource can support. For the example chosen, $\psi = 1.39$; for a site capable of supporting a 50 MW double-flash plant, the hybrid plant with fossil superheating must be designed for a capacity of 69.5 MW. Relatively small amplification factors (cf. systems shown in (8)) may be advantageous for those areas in which electrical load growth can be met with a series of installations of new plants of relatively small capacities. Furthermore, plants of this size are commonplace among conventional geothermal plants and have been used successfully to match electrical growth curves in various countries.

CONCLUSION

Fossil superheat hybrid geothermal power plants offer a thermodynamic advantage over individual fossil and geothermal plants for a wide range of operating conditions. Plants of this type deserve to be considered as candidates wherever fossil and geothermal resources occur in reasonable proximity. Economic studies will determine the ultimate feasibility of such plants on a site-by-site basis.

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REFERENCES

1. P. G. Conti, "The Larderello Natural Steam Power Plant ", Soc. Chem. Ind. J., Vol. 43, 1924, p. 739.
2. Anon., "Recent Developments in the Utilization of the Earth's Heat", Mech. Eng., Vol. 46, No. 8, 1924, p. 448.
3. R. DiPippo, "An Analysis of an Early Hybrid Fossil-Geothermal Power Plant Proposal", Geothermal Energy, Vol. 6, No. 3, 1978, pp. 31-36.
4. C. R. James, "Superheating of Geothermal Steam for Power", N. Z. Eng., Vol. 25, No. 12, 1970, p. 325.
5. F. J. Dan, D. E. Hersam, S. K. Kho and L. R. Krumland, "Development of a Typical Generating Unit at The Geysers Geothermal Project - A Case Study", Proc. 2nd U.N. Symp. Dev. Use Geot. Resources, San Francisco, Vol. 3, 1975, p. 1949.
6. Anon., "Indian Point: Consolidated Edison's Thorium Converter", Nucl. Eng., Oct. 1961, p. 413.
7. R. J. Correia, "Optimization of Some Hybrid Fossil-Geothermal Energy Conversion Systems", Sc.M. Thesis, Division of Engineering, Brown University, 1978.
8. H. E. Khalifa, R. DiPippo and J. Kestin, "Hybrid Fossil-Geothermal Power Plants", 5th Energy Technology Conference, Washington, D.C., Feb. 27-Mar. 1, 1978.
9. H. E. Khalifa, R. DiPippo and J. Kestin, "Geothermal Preheating in Fossil-Fired Steam Power Plants", 13th Intersociety Energy Conv. Engrg. Conf., San Diego, Aug. 20-25, 1978.
10. W. J. Kearton, Steam Turbine Theory and Practice, 7th ed., Pitman & Sons, London, 1958.
11. M. J. Moore and C. H. Sieverding, Two-Phase Steam Flow in Turbines and Separators, Hemisphere Pub. Corp./McGraw-Hill, Washington/New York, 1976.
12. R. C. Hendricks, I. C. Peller and A. K. Baron, "WASP - A Flexible Fortran-IV Computer Code for Calculating Water and Steam Properties", NASA TN 0-7391, Nov. 1973.
13. J. H. Keenan, F. G. Keyes, P. G. Hill and J. G. Moore, Steam Tables, John Wiley, New York, 1969.
14. V. K. Jónsson, "Geothermal Power Utilization, Present and Future", in Alternative Energy Sources, J. P. Hartnett, ed., Academic Press, New York, 1976.
15. K. Aikawa and M. Soda, "Advanced Design in Hatchobaru Geothermal Power Station", Proc. 2nd U.N. Symp. Dev. Use Geot. Resources, San Francisco, Vol. 1975, pp. 1881-1888.

16. R. DiPippo, "Geothermal Power Plants of Japan: A Survey of Existing and Planned Installations", Brown Univ. Rep. No. CATMEC/9, March 1978.
17. R. J. Birsic, "A Krafla Visit - Iceland's Major Project", Geothermal Energy, Vol. 5, No. 10, 1977, pp. 8-16.
18. Burbank, City of, "Site-Specific Analysis of Hybrid Geothermal/Fossil Power Plants", June 1977.

FIGURE CAPTIONS

Fig. 1 - One-stage fossil superheat hybrid system.

S/F = Separator/Flasher; R = Regenerator; FSF = Fossil Superheater;
ST = Steam Turbine; G = Generator; DSH/C = Desuperheater/Condenser;
P = Reinjection pump.

Fig. 2 - Temperature-entropy diagram for one-stage hybrid systems (shown with regenerator).

Fig. 3 - Figures of merit for one-stage hybrid systems (dry expansions only).

———— F_f , — — — — — F_g , — — — — F

Fig. 4 - Figures of merit for one-stage hybrid systems (max. temp. = 540°C, metallurgical limit).

Fig. 5 - Two-stage fossil superheat hybrid system.

F1, F2 = Flash tank 1, 2; R = Regenerator; FSH = Fossil Superheater;
ST1, ST2 = Steam turbine 1, 2; G = Generator; C = Condenser;
P = Reinjection pump.

Fig. 6 - Temperature-entropy diagram for two-stage hybrid systems.

Fig. 7 - Figures of merit for two-stage hybrid systems (with regenerator and for max. temp. = 540°C).

Fig. 8 - Overall figure of merit as a function of resource ratio for two-stage, regenerative hybrid system with max. temp. = 540°C.

Fig. 1 - One-stage fossil superheat hybrid system.

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———— F_f , - - - - - F_g , - · - · - F

Fig. 4 - Figures of merit for one-stage hybrid systems (max. temp. = 540°C , metallurgical limit).

Fig. 5 - Two-stage fossil superheat hybrid system.

F1, F2 = Flash tank 1, 2; R = Regenerator; FSH = Fossil Superheater;

ST1, ST2 = Steam, turbine 1, 2; G = Generator; C = Condenser;

P = Reinjection pump.

Fig. 7 - Figures of merit for two-stage hybrid systems (with regenerator and for max. temp. = 540°C).

Fig. 8 - Overall figure of merit as a function of resource ratio for two-stage, regenerative hybrid system with max. temp. = 540°C .