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A COST COMPARISON BETWEEN GEOTHERMAL AND COGENERATION SOURCES OF PROCESS HEAT

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ABSTRACT

Industrial process heat can be provided in several different ways. When considering geothermal energy as a source of process heat, the costs of using geothermal fluids are usually compared with the costs of using fossil fuels directly. For the range of process temperatures available to geothermal fluids, many process heat users have a third option. They can burn fossil fuels to generate electricity and then condense the turbine exhaust steam in a heat exchanger to provide the needed heat. For low temperature applications (less than, say, 300°F) this provides the process heat at a cost lower than using fossil fuel directly. In these situations liquid dominated geothermal resources are a correspondingly less attractive source of heat.

COST OF TURBINE EXHAUST HEAT

The simultaneous production of work (or electricity)and usable process heat in integrated facilities is commonly called cogeneration. Recent regulation facilitating the sale of surplus generated electricity makes this option available to large users of low temperature process heat, even when the on-site electrical demand is not in balance with the heat demand.

In a thermal engine, only about one third of the energy in the fuel supply can be converted to mechanical energy. The remaining two thirds, unable to extract more work from them, are communicated as heat to the working fluid and engine coolants. In contrast with conventional power plants, where this heat is dissipated in the environment, cogeneration applications use it as a source of valuable low temperature process heat. The work produced by the engine is used to drive machinery or, most usually, an electric generator.

Almost any thermal engine can be used in a cogeneration mode. For our analysis we will consider the single stage, steam-topping, cogeneration plant, which is the most readily available and proven system for large users of low temperature process heat. The results are,nevertheless, generalizable to other cogeneration systems.

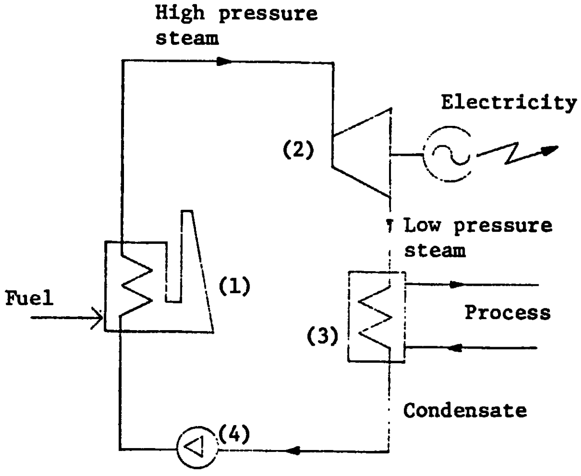

Fig. 1 Diagram of a simple cogeneration steam-topping plant. (1) high pressure boiler, (2) turbo-generator, (3) heat exchanger, (4) pump.

Figure 1 shows a schematic diagram of a single stage, steam-topping cogeneration plant. Fuel burnt in the high pressure boiler produces steam that is expanded in the non-condensing turbine, driving a generator. Electricity is produced and the exhaust steam, cooler and at a lower pressure, is condensed providing process heat.

It can be shown (Meal et al., 1980) that, in the optimal economic operation of these cogeneration systems, only the latent heat of condensation should be used as process heat, and as much latent heat as possible to generate electricity. Thus, ideally, the turbine should be bled and backfed continuously along the temperature trajectory of the process substance. Unfortunately, this is not feasible. For constant temperature processes there is a single well defined condensation pressure and temperature and the difficulty does not arise. In those other applications where the process substance undergoes a large increase in temperature, the best design is frecuently to extract steam from the turbine at several discrete stages. Of course, such optimal designs are taylored to specific cases and finding them can be a difficult, but for our purposes nonilluminating, problem. The single stage system considered here offers results of greater generality and simplicity. The process side can be thought as a constant temperature process or as a stage of a variable temperature one. The important fact to notice is that the condensation temperature of the saturated steam leaving the turbine is determined by the process temperature.

Since both the mechanical energy and the exhaust heat produced by the turbine have value, there is no unambiguous way to determine the "cost" of either separately. We can determine the total cost of providing both, but since the mechanical (or electrical) energy and the thermal energy are by-products or co-products there is no natural way to allocate costs between them.

We may use a common by-product costing technique, however. If the electrical energy produced can be sold, or used internally to avoid buying commercial power, we may take the electrical energy to be the primary product. We then take the opportunity cost of the by-product thermal energy to be all the costs of the power generation and heat supplying which are in excess of the revenues produced by selling (or avoiding buying) electrical energy.

If we build a reasonably large (not gigantic) new fossil fuel power plant we might expect to to produce power at prices reasonably competitive with existing commercial rates for fossil generated electric power. Such a plant will condense the exhaust steam at about 210°F. If we can use heat at that temperature or less (e.g., for space heating) we can obtain that heat with no loss in power output.

If our process is at higher temperature we must increase the temperature, i.e., the pressure, at which the exhaust steam is condensed with a corresponding loss of electric power output. Ignoring the change in turbine efficiency with a smaller pressure drop across the turbine, the electrical energy available from a given amount of steam at temperature T_1 and pressure P_1, in expanding it to temperature T_2 and pressure P_2, is directly proportional to the enthalpy difference h_1-h_2 between the states. T_2 is the temperature at exit from the turbine and also the condenser temperature, dictated by the process we choose to heat.

Suppose the market price of electrical energy is p per kilowatt-hour.The value per hour of the energy generated from a steam flow of $\dot{m}$ pounds per hour is

$$\dot{V}_e = p\,\dot{m}\,E\,(h_1-h_2)$$

where E is the efficiency of the turbogenerator times a conversion factor of Btu to kWh, it de-

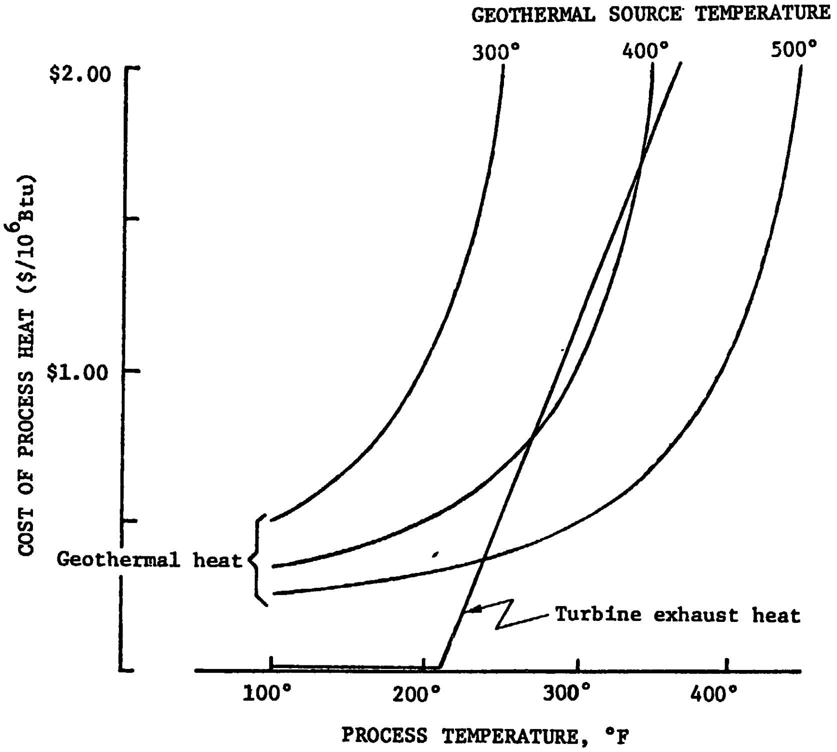

Fig. 2 Cost of process heat from cogeneration and liquid dominated geothermal fluids.

scribes the amount of electricity in kWh actually generated per Btu of energy delivered by the steam in the turbine.

The amount of process heat available per hour, $\dot{Q}$, varies with the condenser (process) temperature,

$$\dot{Q} = \dot{m}\, L_{T_2}$$

where L_{T_2} is the vaporization enthalpy per pound of saturated steam at temperature T_2.

We take the value of the power obtained when the working fluid is expanded to ambient pressure to be equal to the total cost per hour, $\dot{C}$.

$$\dot{C} = p\, \dot{m}\, E\, (h_1 - h_a)$$

where h_a is the enthalpy of saturated steam at ambient pressure. The cost per hour of the by-product process heat, $\dot{C}_t$, is the difference between the total cost per hour $\dot{C}$ and the value of the electric power obtained.

$$\begin{aligned} \dot{C}_t &= \dot{C} - \dot{V}_e \\ &= p\, \dot{m}\, E\, (h_1 - h_a) - p\, \dot{m}\, E\, (h_1 - h_2) \\ &= p\, \dot{m}\, E\, (h_2 - h_a) \end{aligned}$$

The amount of heat obtained is $\dot{Q}$, so the cost per Btu is

$$\frac{\dot{C}_t}{\dot{Q}} = p\, \frac{E}{L_{T_2}}\, (h_2 - h_a)$$

A typical price of electricity is 1.5 ¢/kWh. E is about 0.00025 kWh per Btu. With these values the cost per million Btu is shown in Table 1 and plotted in Figure 2 as a function of the process temperature T_2, taking $T_a = 210°\text{F}$.

COMPARISON WITH LIQUID DOMINATED GEOTHERMAL FLUIDS

The cost of the heat supplied to a process by a liquid dominated geothermal fluid depends on the difference of temperature between the geothermal source and the process. As a first approximation the amount of heat that can be extracted per unit of mass from a given hot liquid is proportional to that difference. Since the cost per pound of geothermal fluid is largely independent of its temperature, the cost per Btu of geothermal process heat is

$$C_g = \frac{p_g}{h_s - h_{2g}}$$

where

C_g = cost per million Btu obtained from geothermal

p_g = cost per million pounds of geothermal fluid

h_s = geothermal source enthalpy

h_{2g} = enthalpy of the geothermal fluid at the process temperature.

This cost is plotted in Figure 2 and shown in Table 1 for nominal geothermal resources at 300°F, 400°F and 500°F providing hot pure water at $100 per million pounds.

Table 1. Cost of process heat from cogeneration and liquid dominated geothermal fluids.

Process Temperature (°F)	Cost of Cogeneration Exhaust Heat ($/10⁶Btu)	Cost of Geothermal Heat ($/10⁶Btu) Source Temperature* 300°F	400°F	500°F
100	0.0	0.50	0.33	0.25
150	0.0	0.67	0.40	0.29
200	0.0	1.00	0.50	0.33
250	0.56	2.00	0.67	0.40
300	1.24	----	1.00	0.50
350	1.81	----	2.00	0.67
400	2.32	----	----	1.00

* The cost of geothermal fluid is assumed to be $100 per million pounds, independent of the source temperature.

CONCLUSIONS

A simple method has been presented for the rational valuation of low temperature liquid dominated geothermal resources. The valuations obtained from it can be of use to developers, users and promoters of geothermal energy.

The results depend on the local costs of electricity and geothermal fluid and, therefore, are sensitive to these costs and case specific. However, with typical current prices liquid dominated geothermal resources below 350°F are an inferior alternative for large users of low temperature process heat.

ACKNOWLEDGMENT

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REFERENCES

Meal, H. C. and Guillamon-Duch, H., 1980. An elementary economic analysis of cogeneration. Unpublished manuscript. Massachusetts Institute of Technology. Cambridge, Mass.