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AN OPTIMUM FUEL MIX MODEL FOR GEOTHERMAL DISTRICT SPACE HEATING SYSTEMS

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ABSTRACT

Geothermal district space heating systems that are sized to accommodate extreme weather conditions will have excess capacity during the milder portions of the year. By incorporating a lower-capital-cost, higher-fuel-cost system for servicing the peak heating requirements, the excess geothermal capacity, and therefore the total annual cost, may be reduced. A model that approximates the least cost percent of peak demand, for which the geothermal system should be sized, is developed in this paper.

INTRODUCTION

Energy supply systems that face annual time variant demands for heat will encounter portions of the year in which there will be idle system capacity. Geothermal district space heating systems and electric utilities are similar in this respect. Both encounter energy use patterns which are not uniformly distributed throughout the year. Rather the peak demands of the systems are concentrated in some portion of the year. In the production of electricity, minimization of costs to consumers is derived from supplying some base load with a capital intensive, low fuel cost system (see Reference 1). The remainder of the peak heat demands are then supplied with a system which has lower capital costs and higher fuel cost. The determination of the proportions of peak system requirements that will be allocated to different fuel types is called an optimal fuel mix calculation. Accordingly, the objective of this paper is to present a generalized model that approximates an optimal fuel mix for geothermal district space heating systems.

The concept of hybrid energy systems is, of course, well established. Many times a conventional fuel is used to augment the geothermal brine to obtain a higher temperature working fluid (see Reference 3). In a district space heating system, however, the impetus for mixing fuels is somewhat different. As opposed to preheating, the objective here is to minimize the annual costs of supplying space conditioning to a user district.

GENERAL

The geothermal system planner is primarily responsible for ensuring sufficient capacity to service the peak heat demands of the user area while also attempting to minimize the cost of that capacity. The primary source of cost savings to the planner is the inevitable and expensive excess capacity which typifies geothermal district space heating systems (see Reference 5). For a good portion of the year there will exist some idle production well capacity. This is simply a result of the normal temperature fluctuations throughout the year. Additionally, since increments to the capacity of the system are more discrete than continuous, singular use of geothermal heat will require some excess capacity even during peak demand periods. The planners objective might then be thought of as minimizing the cost of natural excess capacity while guaranteeing delivery of heat to all consumers on the coldest day of the year.

A potentially attractive alternative for the planner would be to construct a fossil fuel fired boiler as a peaking heat source for the geothermal system. Though the energy charges for using the boiler may be high there are two benefits which may serve to offset these expenditures. First, because the capital costs of the boiler would be insignificant, it could be sized to serve the entire load in case of an emergency. And secondly, because of the low capital cost, the cost of excess capacity during warmer periods could be minimized.

THE MODEL

For planning purposes assume that the geothermal district space heating system is broken into three capital expenditure components. A geothermal delivery system component, a fossil fuel peaking system component, and a distribution system component. The geothermal delivery system component consists of well-field and transmission expenditures required to bring the geothermal brine to the user district. The fossil fuel peaking system component is simply the cost of the installed boiler at or near the user center. Finally, the distribution system consists of costs for distributing hot water within the user network.

For the present exercise the distribution costs are sunk costs. Irrespective of the relative capacities of the first two components, the distribution system component can be assumed fixed. The planner is then faced with a trade-off between the operating and capital expenditure characteristics of the two heat sources in supplying the peak heating requirements of the distribution network.

The annual cost of the geothermal delivery system component is determined by several factors. Included in the cost of this component are annual costs of production and injection wells, amortization of all pumps required, and the annual cost of the transmission line which connects the geothermal anomaly to the user center. In addition to the annualized capital costs are the annual operating and maintenance cost of these items and electricity cost to run the pumps. Each of these cost items in turn are determined by geophysical, heat demand, and engineering characteristics of the system. The number of production and injection wells are determined by the temperature of the resource, the flow rate, and the peak heat requirements from the geothermal system component. The cost of each of these wells is determined largely by the depth to the resource. The transmission investment is determined by the distance between the geothermal resource and the user center, the peak heat requirements, and the temperature of the resource. The pump cost and its required electricity cost is determined by the depth to the resource (see Reference 2). A previous analysis (see Reference 4) suggests a geothermal delivery system cost equation of the form,

$$GSC = e^{Bo} Xi^{Bi} Xp^{Bp} \quad i = 1 \ldots n \qquad (1)$$

where,

GSC = annual geothermal system cost (operating and capital amortization),

Xi = explanatory variables other than peak heat demand (geophysical and geographical factors), and

Xp = peak heat demand MMBTU/HR.

A general cost function for the peaking system is

$$PSC = P + \alpha A \qquad (2)$$

where,

PSC = annual cost of peaking system (capital amortization and fuel cost),

P = annual amortization of boiler,

α = price per MMBTU conventional fuel, and

A = annual heat required from peaking system, MMBTU/YR.

The total annual cost of the delivery system is then,

$$TSC = e^{Bo} Xi^{Bi} (\lambda Xp)^{Bp} + P + \alpha(1-\phi)A \qquad (3)$$

where,

λ = percent of peak supplied by the geothermal system component, and

ϕ = percent of annual heat demand.

Clearly the planning objective is concentrated in solving for λ in (3) such that the value of the delivery system cost function is minimized. However, one inconsistency appears in (3) which must first be resolved. The geothermal system component is determined by the peak heat requirements. The peaking system, however, is shown to be a function of the annual heat requirements. In order to express the peaking system cost function with peak instead of annual heat demand, the relationship between peak and annual must be determined.

A limited examination of three climatically different cities revealed an expected relationship between these two variables. Using heating degree days per day at peak, and cumulative annual heating degree days, the derived observations were calculated as in (4) and (5):

$$\lambda_i = \frac{H-D_i}{H} \qquad (4)$$

$$\phi_i = \frac{T-C_{D_i}}{T} \qquad (5)$$

where,

λ_i = percent of heating degree days per day at peak,

ϕ_i = percent of total annual heating degree days,

H = heating degree days observed on the coldest annual day,

D_i = degree days on the i th day,

C_{D_i} = cumulative annual heating degree days consistent with the i th degree day observation.

T = total annual heating degree days.

Partial results are given in Table 1 and the general shape of this relationship is illustrated in Figure 1.

Percent Peak λ	Percent Annual Demand Ø		
	Las Cruces, NM.	Denver, CO.	Glaskow, MT
.25	.50	.39	.43
.50	.76	.68	.72
.75	.94	.89	.92

Table 1. Percent of annual demand which could be supplied by systems designed for λ percent of peak demand for three cities.

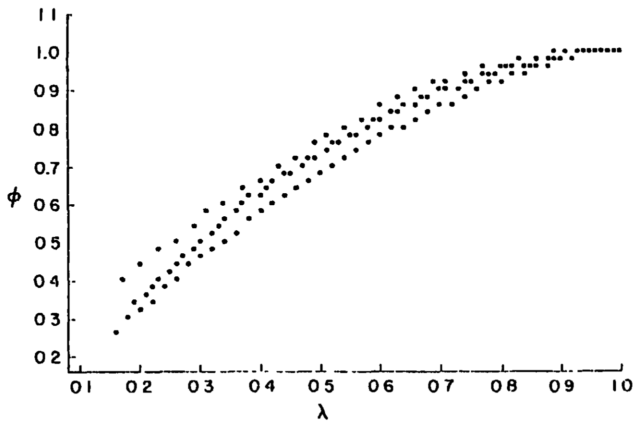

Figure 1. Percent of annual demand which could be supplied with a system designed for λ percent of peak demand.

Two significant conclusions can be drawn from Table 1. As expected, the percent of annual demand which could be supplied increases as the percent of peak demand which could be supplied increases. Moreover, the percent of annual demand which could be supplied varies inversely with the peakiness of the weather pattern. If the ratio of peak to annual heating degree days falls, this indicates a decline in the peakiness of the weather pattern. Naturally, communities which have relatively peakless climates should find that they will be able to supply a greater percent of annual heat demand for a given percent peak.

Relating the data and the observations developed above, we find that

$$\phi = a\lambda^2 + b\lambda + c \quad . \qquad (6)$$

Equation (3) can now be rewritten with consistent variables such that

$$TSC = e^{Bo} X_i^{Bi} (\lambda X_p)^{Bp} + P + (1 - a\lambda^2 - b\lambda - c) A \quad . \qquad (7)$$

Finally, the minimum of (7) can be found where

$$\frac{dTSC}{d\lambda} = Bp\ e^{Bo} Xi^{Bi} (\lambda Xp)^{Bp-1} Xp - \alpha A (2\lambda a + b) = 0 \ . \qquad (8)$$

CONCLUSIONS

A general conclusion is that geothermal district system planners and modelers should consider the inclusion of a fossil fuel fired boiler for meeting the peak requirements of a given system. This is especially true in areas where geothermal capacity charges are expensive and peak demand periods are extreme and shortlived. The model developed above is intended to assist both planners and modelers in calculating the optimum percent of peak demand which the geothermal system should supply.

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