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MODELLING GEOTHERMAL DISTRICT HEATING SYSTEMS

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ABSTARCT

Mathematical modelling is a useful tool for evaluating or comparing energy supply systems, particularly for aggregations over an extended area, where detailed analysis of each project is not possible. The basic modelling design of geothermal district heating systems is considered, along with suggested estimators for data elements which are not readily available for most applications.

WHY MATHEMATICAL MODELLING?

With alternate energy systems being considered for more and more applications, a need has arisen for a tool to quickly analyze projects for economic viability and cross-project comparison. Detailed analysis of each project under consideration would be the best of all possible courses, but is not practical in most applications. Using a sufficient mathematical model, an analyst could quickly determine whether a project might be economic, or give a rank-ordering to a number of different projects based on any of a variety of factors. For purposes of aggregation, a mathematical model implemented on a computer, could analyze and aggregate a large number of projects in a short time, resulting in either summarized data or a rank-ordering of the projects.

MODELLING A GEOTHERMAL DISTRICT-HEATING SYSTEM

The model described in this paper is a "price solving" model - the bottom line solution is for the price/MMBTU the developer would need to charge the users to result in a break-even cash flow. Other models exist which solve for internal rate-of-return. A price solving model treats the investors expected return on investment as an expense item which must be met for a nonnegative cash flow.

There are four logical components in modelling a basic district heating system:

- User community and associated heat demand
- Well field and geo-heated liquid supply
- Local delivery, distribution and conversion
- Finances and economics

In addition to these four, some projects might involve gas-fired peaking plants to augment the geothermal system, or multi-developer systems. Each of these is worth a paper of its own, and will not be discussed further here. The four basic components will be discussed in detail separately.

USER COMMUNITY

There are two heat demands necessary to typify a user community; average annual energy demand (commonly in BTU/yr) and peak short-term demand (commonly BTU/hr). The average annual demand is used to calculate expected sales, hence income; peak demand is used to design the energy supply system to operate under the most severe expected conditions.

Certain data elements are required to perform a credible analysis. For the user community these are:

Population - number of people in the area
Weather factors - heating deg. days, low temp
Growth rate - expected growth rate per year.

In addition, there are factors which aid in the analysis, but are difficult to find for most applications:

Floor area per capita - average is 365 ft^2 (Housing and Urban Dev., 1974)
Heat loss / home - avg is 0.421 BTU/hr/F^o/ft^2 (Oregon Inst. Tech, 1975).

Using these figures, the annual heat demand may be approximated. In this model, the demand for a residential district is calculated in two parts: space heating demand and hot water demand.

Space heat demand = (population) x (avg space heating demand/capita) x (heating degree days / avg. HDD)

Hot water demand = (population) x (avg hot water demand / capita).

The national average hot water demand per capita in 1975 was 7.5 x 10^6 BTU/yr/capita (American Gas Assoc, 1978). The national average space heating demand for 1975 was 24.7 x 10^6BTU/yr/capita (American Gas Assoc, 1978 and Dept of Housing and Urban Dev., 1974). The average heating degree days is 5530 days-F^o(SERI, 1980).

Peak heat demand for a community would be during the coldest part of winter, early in the morning.

The peak demand for a residential district may be approximated by:

Peak demand = (population)
x (floor area per capita)
x (room temperature - low temperature).

WELL FIELD AND GEO-HEATED LIQUID SUPPLY

As defined here, the well field is made up of the production wells, reinjection wells, down-hole pumps, main transmission pipe, well-site leasing, and heat exchanger. The production wells are assumed to be at the reservoir, the reinjection wells to be just outside the user area.

The information necessary for a credible analysis is:

Drilling depth for production wells
Resource temperature at that depth
Flow rate per well
Distance from resource to user
Draw-down depth (down-hole pump depth).

Other useful but difficult to obtain information:

Required temperature - 140°F is common usage
Leasing costs - usually near $50 per acre
Production to reinjection wells - near 2.5:1.

Using the peak and annual energy demands, and the above information, the well field may be approximated by:

Maximum flow rate = (peak hourly demand) ÷ (temperature drop across primary)

Number of production wells = (maximum flow) ÷ (flow rate per well)

Electricity to run pumps = (3.766×10^{-7})
x (draw-down depth in feet)
x (annual energy demand in BTU/yr)
÷ (0.67 X temp. drop across second.)

Transmission pipe diameter =

$$2 \times \left[\frac{(\text{max flow rate in primary})}{(\pi \times 7560)}\right]^{1/2}$$

Transmission pipe cost per foot approximates:
7.2474 + 4 x pipe diameter

Heat exchanger area = (maximum flow rate) ÷ (200 x log mean temperature diff.)

Log mean temp. diff. =

$$\frac{(\text{primary - secondary temp drops in heat exch.})}{\ln\left[\frac{(\text{primary temp drop in heat exchanger})}{(\text{secondary temp drop in heat exchanger})}\right]}$$

Cost of heat exchanger may be approximated:

$$5.86 \times e^{4.578} \times (\text{plate area of heat exch.})^{0.6471}$$

LOCAL DELIVERY SYSTEM

The distribution, retrofit and hookup costs for a community are the most difficult to model, due solely to the lack of generalized data. Without specific data on the layout of the user area, the type and size of the affected buildings, and the population densities, we must rely on broad approximations. Keith Brown of New Mexico Energy Institute (NMEI) has developed highly specific analyses of distribution, retrofit and hookup costs for model residential communities. These data, show in Table 1, may be used for general approximations in lieu of user-specific information.

The required information for a credible model is:

Average persons per dwelling (average is 2.9)
Breakdown of population by housing type

Useful information that is not usually available:

Operations and maintenance - NMEI uses 2.5% of total investment

Using the above information and data from Table 1, we have:

Number of units = (population) ÷ (persons per dwelling)

Distribution cost = (number of units)
x [(3453 x % single family units)
+ (2410 x % double family units)
+ (2065 x % four family units)]

Retrofit costs = (number of units)
x [(1800 x % single family units)
+ (1600 x % double family units)
+ (1600 x % four family units)]

Hookup costs = (number of units)
x [(1705 x % single family units)
+ (1085 x % double family units)
+ (660 x % four family units)].

FINANCES AND ECONOMICS

Finances for an energy supply project may be considered either investments or annual expenses. Investments are generally made up of two parts, the equity portion that the investor provides and the debt portion that is borrowed. The debt portion is borrowed at the prevalent bond rate, and the equity investor will require a rate of return on his investment. Assuming that all investments have the same proportions of equity and debt, the information we need on each investment is:

Amount of the investment
Year in project life investment is made
Amortization life of debt portion
Depreciation life of investment.

For each investment, the amortized payment per year can be calculated using the debt portion of the investment, the bond rate, and the amortization life. The resulting payment schedule is an annual debit on the cash flow. Principle

Housing Type	Costs per unit Distrib.	Hookup	Retrofit
Single-family units	$ 3453	$ 1800	$ 1785
Double-family units	2410	1600	1085
Four-family units	2065	1600	660

Table 1. Distribution and conversion costs by housing type for a model community

and interest portions of the payments are kept separate for tax purposes. Using the equity portion of the investment, and the expected rate of return, the required return on investment by year can be calculated. This return on investment is another cost that must be covered for a nonnegative cash flow. Depreciation calculations are straight-forward and well documented elsewhere.

Tax credits are in direct proportion to the total investment, though the exact percentage is not the same for all projects. In general, unused tax credits may be rolled forward up to 6 years to offset taxes in those years.

Income by year is the average annual demand times the price of delivered energy. This price is the desired result of the model. Sales tax is calculated as some percentage of this annual income. Federal and state taxes are calculated from the net taxable revenue, which is the total income less annual expenses, interest payments, depreciation, depletion and sales tax. Nonnegative taxable revenue may be rolled back 5 years and forward 7 years to offset negative taxable revenue years.

Book profit is defined as the net taxable revenue less taxes paid. Cash flow is defined as profit plus depreciation and depletion, less principle payments and dividends (return on investments). Even though depreciation and depletion are not hard cash items, they are added back in to cash flow since they were taken out of profit as book items.

The minimum price the developer must charge for geothermal energy is that price which causes the net present cashflow to be zero. Remember that the cashflow contains the investors return on investment.

SUMMARY

Mathematical modelling of geothermal district systems is a fast and inexpensive tool for evaluating particular projects or rank-ordering a number of projects. The major constraint on modelling is the lack of data. Certain cost segments may be approximated using average figures, although this implies a certain lack of confidence in the results. Modelling is not a substitute for a detailed econo-engineering design study, but is useful for order-of-magnitude costs.

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