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MASTER

DISTRICT HEATING WITH GEOTHERMALLY HEATED CULINARY WATER SUPPLY SYSTEMS

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ABSTRACT

An initial feasibility study of using existing culinary water supply systems to provide hot water for space heating and air conditioning to a typical residential community is reported. The Phase I study has centered on methods of using low-to- moderate temperature water for heating purposes including institutional barriers, identification and description of a suitable residential community water system, evaluation of thermal losses in both the main distribution system and the street mains within the residential district, estimation of size and cost of the pumping station main heat exchanger, sizing of individual residential heat exchangers, determination of pumping and power requirements due to increased flow through the residential area mains, and pumping and power requirements from the street mains through a typical residence. All results of the engineering study of Phase I are encouraging.

INTRODUCTION

About 23% or 17 Quads (10^{15} Btu) of current U.S. energy consumption is used each year for space/water heating (Kunze, 1979). The replacement of a significant fraction of this energy use with an alternate source, thereby releasing fossil fuel for other national priorities, is a particularly desirable target for U.S. energy planning.

U.S. Geological Survey Circular 790, Assessment of Geothermal Resources of the United States - 1978 (Muffler, 1978) concludes that an exponential increase in the number of known occurences can be anticipated as the temperature of the resource decreases. This means that the geographic distribution of lower temperature resources is wider and that the possibility of colocation with potential users increases as temperature decreases. In recognition of the value this energy base will have in future U.S. direct heat space/water heating applications, the Department of Energy has sponsored a number of Application Projects (from the Program Opportunity Notice Solicitations) and a number of Project Studies (Engineering and Economic Studies). Many of these projects and studies have involved heating individual structures, schools, etc., along with some cases of district heating. In almost every case the circulation of geothermal water through added piping is assumed.

In addition to these efforts, the Department of Energy's direct applications of geothermal energy planning has included an element of technology development. The feasibility of interchanging heat from a geothermal resource to culinary water and distributing through existing distribution systems as discussed herein is part of this technology development.

Preliminary studies of district heating applications for locations in the United States have indicated that the major supply system from a geothermal resource to a using city can frequently be provided at reasonable cost -- the cost of a distribution system within a city or community, however, is not well known. This latter system cost is dependent upon many factors, including cost of rights-of-way; added construction costs due to existing roads, sidewalks, utilities, and structures; and added costs due to disruption of normal traffic flow, temporary roads, etc.

One approach to distribution of the hot water within a using community is to utilize existing potable water supply distribution systems. Most schemes to accomplish this would involve:

1. Supply of thermal energy from a geothermal fluid via a central heat exchanger to the potable water at a pumping station.
2. Geothermal fluid supply via an insulated pipeline from the resource to the central heat exchanger.
3. Distribution of heated water throughout the using community through the potable supply mains (heated water) with flow as needed to the individual user's heat exchanger and return.
4. Workable systems only in communities with significant water usage rates to maintain sufficiently high water temperature in the distribution lines.
5. Supply of relatively hot water (130°F maximum) to the users and appropriate heat exchangers to provide cooling for consumptive household use.
6. And the use of heat pumps with low temperatures (50°F - 90°F) to supply both heating and air conditioning.

DISCLAIMER

An initial feasibility study (Phase I) of using existing culinary water supply systems to provide hot water for heating purposes to a typical 140-home sub-division was completed. This preliminary study centered on (i) types of municipal water system designs and effects of system design upon heating use; (ii) methods of using low-to-moderate temperature water for heating purposes and institutional barriers; (iii) identification and description of a typical residential community for hot water heating; (iv) evaluation of thermal losses in the uninsulated main distribution system from the pumping station to the sub-division; (v) evaluation of thermal losses in the uninsulated street mains in the sub-division; (vi) estimation of size and cost of the pumping station main heat exchanger; (vii) sizing of individual house heat exchangers; (viii) pumping and power requirements to supply the increased water flow rate through the sub-division; and (ix) pumping and piping requirements to provide heating water flow from the street lines to a typical residence. The results of Phase I were favorable, and Phase II which involves more detailed economic analyses, selection of a target city for analyses (Elko, Nevada) and more detailed analyses on potential options (heat pump use, methods of system hookup, etc.) was begun. The Phase I work is reported herein. Actual implementation of this project is expected in Phase III now being negotiated.

TYPES OF MUNICIPAL WATER SYSTEMS

City water system layouts are of two general types -- a single main line design or a dual main, loop-type design. In general, the dual main or loop system is more readily adaptable to district heating because residential areas and commercial centers are frequently located along cross-connecting sub-mains which provide fire protection loops from either of the dual mains. This type of piping layout readily adapts to through-flow of water which is essential to the residential heating scheme. A single main system has fewer complete loops, and it is more often necessary to add a major return line than with the dual-main system.

The materials used in older public water systems are cast iron and concrete. Both of these are insensitive to the modest temperatures of interest in this study. At the higher temperatures, expansion/contraction may require installation of expansion joints. Some of the newer systems utilize polyvinylchloride piping which may not be suitable at the higher temperatures, but most of the newer systems (installed in the last 10-15 years) use asbestos-cement pipe which should be very suitable.

METHODS OF USE

The hot water resource in the temperature range of this study is suitable for either (i) space heating by direct exchange with simple water-to-air heat exchangers or (ii) space heating with heat pumps. The choice is dictated primarily by the temperature of the fluid at the using point.

Direct Heat Exchange -- In view of the low maximum resource temperature of this study, we considered water-side temperature drops of 15°F, 25°F and 35°F only for direct space heating. These temperature changes control the mass flow rate required for a given residential thermal load, and this in turn is a major variable in determination of the pumping power and temperature degradation in the distribution lines. Most of the pressure loss, pump power and thermal loss parametric studies of this study were undertaken for direct heat exchange space heating.

Heat Pump Space Heating -- An efficient water source system heat pump would provide an economical approach to using warm water in the 50°F to 100°F temperature range. The approximate range of the coefficient of performance of a unit of this type is 3.1 to 3.7 over this temperature range, markedly superior to that for an air-to-air heat pump.

The only institutional barrier that we have considered concerns the return of thermally spent water to the potable water distribution system. We have found no restrictions on this other than the requirement not to inject anything into the water.

For the direct heat exchange space heating application, a two pipe system would be used to supply the hot water from the street main to the heat exchanger(s) in the residence and then pump the used fluid back into the street main. In this case, a magnetic drive pump would be used and the entire system would be sealed with no reason for contamination after the system is put into operation. Any subsequent failure would simply result in water loss with no contamination of the potable water system.

There are possible contamination problems associated with the heat pump space heating approach, since a leak could result in oil and freon contamination of the water supply system. This problem has not been resolved, but we are formulating a conceptual design utilizing a double-jacket water-to-water-to-freon heat exchanger.

TYPICAL RESIDENTIAL COMMUNITY

To "fix" a residential area for study, we chose a real residential sub-division of 140 homes with its existing water supply piping. We believe that the street piping size, lengths and interconnections, as well as the water flow requirements, are typical of small residential areas. This community is served by a dual-loop main city water system, and there is a rather large industrial user of water just downstream resulting in a water through-flow six-to-seven times as large as the consumptive residential flow.

A large percentage of the street distribution lines are 2-inch diameter; this raises the obvious question concerning the cost of pumping sufficient water for house heating through small lines along relatively long streets; street lengths in this community are on the order of 1000 ft. An equally obvious concern is the thermal loss or temperature degradation of the water in these buried, uninsulated pipes. These problems were considered in detail in the study.

For a typical 1800 sq. ft. residence in this community, the 0°F, 15 mph wind design heat load calculated using standard ASHRAE procedures is approximately 28,000 Btu/hr. Based on actual water use records, the average daily consumption of the 140-home community is 34,405 gallons per day. This represents an average household consumptive flow of 246 gallons per day. Assuming a maximum water temperature change of 35°F in a house heat exchanger, this flow rate would supply only about 10% of the design heating load; more precisely about 72,000 Btu/day. Fortunately, the through-flow in the 16-inch sub-main supplying the community is rather steady due to the nature of the downstream industrial use, and this total flow averages 215,000 gallons per day. Dividing this among the 140 houses in the residential sector yields 1536 gallons per house-day. This would provide approximately 18,680 Btu/hr-house, or 2/3 of the design heating requirement.

THERMAL LOSSES BETWEEN PUMPING STATION AND RESIDENTIAL SITE

The residential community is located approximately 16.68 miles from the main water treatment/pumping station. It is between the two main lines of a dual-loop system; the left side main line normally supplies this community through a 16-inch line which inter-connects to the right side main. The main supply system consists of (1) 4.4 mi of 30-inch pipe, (2) 1.0 mi of 24-inch pipe, (3) 3.61 mi of 20-inch pipe, (4) 6.17 mi of 12-inch pipe, and (5) 1.5 mi of 16-inch pipe in the order listed. All piping is cast iron.

The temperature degradation occuring in this 16.68 mile distance depends heavily upon the flow rate which is varying and certainly not precisely known at any point in the system. For simplicity, we modeled the usage upstream of the residential community by a linear decrease with distance expression. Using the mid-point mass flow rate in each size pipe, the temperature drop over each section was calculated by the steady-state conduction shape factor method. For these calculations we used a soil conductivity of 0.62 Btu/hr-ft-°F, a value reported for earth with 42% moisture -- very wet!

This approach yields for a 3-ft buried depth with the pipe surface at 135°F and the ground surface at 0°F, temperature drops of 2.00°F, 0.83°F, 2.89°F, 5.35°F, and 4.74°F in the 30, 24, 20, 12 and 16-inch diameter sections, respectively. The total temperature loss due to conduction to the soil is approximately 15°F for a supply line 16.68 miles long! Note in particular the approximate 5°F temperature loss in the final 1.5 miles of 16-inch pipe; this would be more nearly the situation for a small town.

THERMAL LOSSES IN UNINSULATED SUB-DIVISION STREET DISTRIBUTION LINES

As in the main system distribution line, the temperature losses in the uninsulated sub-division street water lines depend upon pipe depth, pipe diameter, soil conductivity, pipe surface (water) temperature, soil surface temperature, and flow rate. We employed a 4X factor to the flow required for heating the houses along a street so that the thermal degradation due to extraction of energy for house heating will not overly reduce the temperature along a given street; otherwise the end houses along the street would be unable to effectively use the fluid. In addition to the preceding factors affecting the conductive heat transfer rate, the length of street and distance between houses influence the fluid temperature decay by conduction in the uninsulated lines.

Since many of the streets have 2-inch distribution lines, study focused on this size. We chose to examine 3 supply water temperatures -- 135°F, 125°F and 115°F; house lot widths from 80 to 140 ft; a street length of 1000 ft; a single distribution line depth of 3 ft; thermal conductivities from 0.3 to 1.0 Btu/hr-ft-°F; a soil surface temperature of 0°F; a heating load of 18680 Btu/hr-house; and a 4X water flow factor. A parametric study of the water temperature decay due to steady-state, conductive heat transfer was carried out using the shape factor approach and assuming the pipe surface temperature to be the same as the water supply temperature. Typical results are given in Figure 1 which depicts the temperature loss due to conduction to the soil per 1000 ft. of street length as a function of house spacing and soil thermal conductivity with all other parameters fixed.

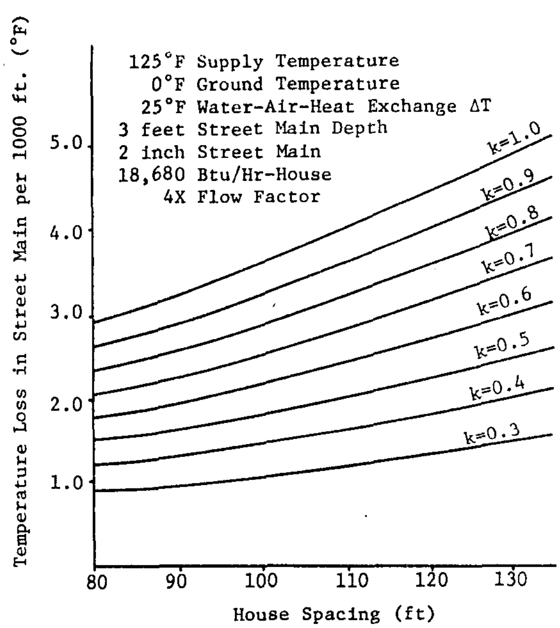

Fig. 1 Temperature Loss in Uninsulated Street Water Lines For 125°F Supply Water Temperature

SIZE AND COST OF MAIN HEAT EXCHANGER

An estimate of the size and cost of the main heat exchanger to supply thermal energy to the drinking water at the water treatment/pumping station is a necessary element for a cost study of the total system. Sizing of this unit is dependent upon configuration-type of heat exchanger, hot-side geothermal fluid temperature, cold-side supply temperature, and cold-side exit temperature (heating fluid for residences).

All of the fluid temperatures are dependent upon local conditions, but to determine ranges of main heat exchanger size and cost, a parametric study was carried out. The basic design was stipulated to be a shell-and-tube unit, which is the most generally used large heat exchanger design. The ranges of parameters studied were:

Geothermal fluid supply temperature--160-200°F
Cold side fluid discharge temperature--115-135°F
Cold side fluid supply temperature--45°F
Overall heat transfer coefficient (Btu/hr-ft^2-°F)--110-170
Shell side fluid passes--one and two
Flow Factor (Potable Water)--4X

Typical parametric results are given in Figure 2.

Cost estimates were obtained for carbon steel heat exchangers. In 1979 dollars, the range of main heat exchanger cost on a per home basis for the 140 home community is from \$320 to \$760.

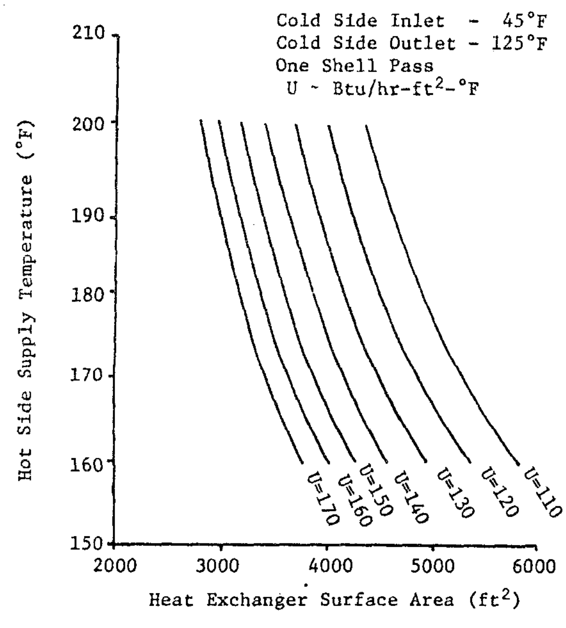

Fig. 2 Main Heat Exchanger Size as a Function of Geothermal Fluid Supply Temperature and U Value

INDIVIDUAL HOUSE HEAT EXCHANGER SIZING

For direct space heating, the simplest house system modification would result when the existing heating unit is a forced hot air, central heating system requiring (i) the addition of a cross-flow finned tube water-to-air heat exchanger in the existing furnace system return air plennum or other suitable ductwork location, and (ii) a modification to increase the blower speed and/or size. Other possible designs would be the installation of baseboard water-to-air free convective units or room-sized forced air wall convectors. A parametric study of the size of forced-flow heat exchanger required for an 18,680 Btu/hr heat load results in a size range of 50 to 200 sq. ft.

PUMPING REQUIREMENTS

In the community considered in this study, the 4X flow factor was applied to a flow rate that had been increased by a factor of 6 above the consumptive flow -- the flow is then about 24 times the normal residential flow rate! The 2-inch lines in the community raises the question of increased pumping power for flow in the street mains. A computer program in Fortran IV was written to calculate this pumping power for the entire community. The total pumping power for the 140 house sub-division under typical conditions is 32.3 hp or approximately 0.231 hp per house, on the average. Assuming a 60 percent pumping efficiency, this pumping power is the equivalent of 5.25% of the thermal energy supplied to each house.

Also, the pumping power for the street main-to-individual residence and return system was calculated for a wide range of design conditions. This power is typically less than 1/20 horsepower per house.

CONCLUSIONS

In summary, all of the engineering analyses conducted for the community chosen are encouraging, and preliminary cost data from the incomplete Phase II study are also indicative that this approach is feasible.

ACKNOWLEDGMENTS

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