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HIGH TEMPERATURE HEAT PUMPS CAN ACCELERATE THE USE OF GEOTHERMAL ENERGY

Richard C. Niess

Member ASHRAE

ABSTRACT

The wider spread use of geothermal energy has been limited by the high initial cost of digging deep wells to obtain moderate temperature water for space and industrial process heat applications under 220° F (104° C).

High temperature, industrial water-to-water heat pumps can be used with geothermal sources to lower costs. These heat pumps tap geothermal water in the 60 to 130° F (16 to 54° C) range, normally available from wells less than 3000 ft (0.9 km) deep, and amplify this heat to the 140 to 220° F (60 to 104° C) range usually required in a broad spectrum of processes, space heating and water heating applications.

The industrial heat pump can accelerate geothermal use by either (a) upgrading a geothermal source where the flow and/or temperature is inadequate or (b) obtaining higher temperatures without the expense or problems of drilling much deeper wells.

BACKGROUND

The development of the geothermal energy has been delayed for a number of reasons. Two of the most important reasons are: 1) the economics of recovery, distribution and use in the face of today's relatively low gas and oil costs, and 2) geothermal is not broadly appreciated by many design engineers.

Throughout the United States there are considerable moderate temperature geothermal resources which could be developed and become a significant part of the total energy supply.

This discussion is oriented to the more commonly considered available geothermal sources that have base temperatures below 300° F (149° C); this being the current threshold temperature for economic electrical power generation. Of identified western U.S. natural heat sources, approx. 85 % have base temperatures less than 300° F (149° C). Additionally, the usefulness of extensive geothermal resources in the Atlantic coastal plain is being studied.

WATER TEMPERATURE VS WELL DEPTH

The temperature gradient will vary by location; however, some reasonable assumptions can be made to examine the order of magnitude of the potential geothermal economics. A number of test sites (1) have indicated an average temperature increase of 1° F/100 ft (18° C/km). Test drilling at a Maryland site (2) initially indicated an increase in geothermal temperature of 2½° F/100 ft (46° C/km) of well depth. These two ranges of temperature gradient are plotted in Fig. 1. For purposes of further analysis, a reasonable mean of 1½° F/100 ft (27° C/km) is used and plotted in Fig. 1 using the formula:

$T = 55 + 0.015\ Z$ where T = °F and Z = depth in feet or

$T = 12.8 + 27.4\ Z$ where T = °C and Z = depth in km

USE TEMPERATURE

Most industrial process heat applications and large space heating projects using hot water require water temperatures that range upward from 135° F (57° C). Fig. 1 indicates a well depth requirement in excess of 5000 ft (1524 km) for direct use, or somewhat deeper if an intermediary heat exchanger must be used due to the corrosiveness of the geothermal water.

To provide the 150° F (66° C) hot water extensively used in the food processing and metal fabricating industries, the indicated well depth would be over 6000 ft (1829 km). The cost of drilling wells to these depths could be prohibitive considering the present (and even the 10-yr projected) cost of conventional energy sources to heat process water and to supply space heating.

TEMPERATURE AMPLIFICATION

A potentially attractive alternative to the deeper wells is through temperature amplification of the geothermal source by electric heat pumps. Where the geothermal flow is limited, considerable cooling can be accomplished, thus, extracting many more Btu's from the geothermal water.

R. C. Niess is Manager, Templifier Department, Westinghouse Electric Corporation, Staunton, Virginia.

Using the nonreversible heat pump principle, these industrial heat pumps can recover low grade heat in geothermal water in the temperature range of 60° F (16° C) to 130° F (54° C) and amplify it to higher usable temperature levels. The heat from the geothermal water is absorbed in the heat pump evaporator by the unit's working fluid which is then increased in temperature and pressure by the compressor. From here it goes to the condenser where this heat is transferred to a delivery fluid for providing useful heat at temperatures up to 230° F (110° C), with this upper temperature limit being the current state of the art.

The cycle diagram for such a system is shown in Fig. 2, illustrated with some typical temperatures.

The measure of efficiency, called the coefficient of performance (COP), of one manufacturer's centrifugal compressor heat pump* is shown in Fig. 3. The ratio of the thermal equivalent of the heat pump electrical input to the upgraded heat output (the COP) ranges from roughly three to six. For example, a 165° F (74° C) hot process water stream can be delivered from a 120° F (49° C) geothermal source cooled through a range of 35° F (19° C) with a COP of about 3.6.

Usually temperature amplification is utilized in up to a 80° F (44° C) to 90° F (50° C) range (output hot water minus leaving geothermal water) where a COP of about 3.5 is obtained. A COP of less than 3.0 is not normally used as the economics are not usually sufficiently favorable.

By applying heat pumps to the process, usable water temperatures of 85° F (29° C) to 130° F (54° C) for source heat can be obtained at well depths 2000 ft (0.6 km) to 5000 ft (1.5 km) and the captured heat temperature amplified to the higher use temperature. A previous paper (3) analyzed the economics of a closed loop system using a geothermal heat pump system compared to geothermal only. The results indicated both a lower first cost and lower annual operating cost for the geothermal heat pump. For geothermal systems to achieve widespread application, it will be necessary for such systems to become competitive with conventional fossil-fuel fired systems. By utilizing the combination of geothermal and heat pumps it appears that this can be achieved. An example to illustrate that this can be done has been constructed using mid-1979 costs and a typical industrial plant hot water process heating requirement.

TEMPERATURE AMPLIFIED LOW GRADE HEAT-CLOSED LOOP SYSTEM

The objective in this example is to provide 1800 gpm (114 l/s) of 165° F (74° C) supply hot water to meet an 8.8 million Btu/h (2578 kW) heating load in a closed loop where the return hot water is 155° F (69° C); a closed loop system being one in which the hot water is cooled by the load and then returned for reheating.

If we consider that the corrosive properties of the geothermal water are such that it must be used through a water-to-water heat exchanger to generate 165° F (74° C) freshwater to the load, in a conventional geothermal system the producing well temperature would have to deliver at least 170° F (77° C) at a 1800 gpm (114 l/s) flow rate. From Fig. 1 this would require a well depth at mean gradient of approx. 7700 ft (2.3 km).

A simplified example of the use of the heat pump process is shown in Fig. 4. By the use of an industrial heat pump, a more shallow well of about 5000 ft (1.5 km) in depth could produce 130° F (54° C) water. If we take out 40° F (22° C) of heat, a well flow of only 325 gpm (20.5 l/s) is required to transfer 6.5 million Btu/h (1905 kW) to a 95° F (35° C) freshwater stream to supply the heat pump. Alternatively, if a higher temperature were available, a lower flow would be sufficient, i.e. 215 gpm (13.6 l/s) at a 150° F (66° C) supply temperature. Or, if both higher flow and temperature is available, a larger heating load could be served.

Typically, such a heat pump with 85° F (29.4° C) water leaving the evaporator will produce 165° F (74° C) hot water at a 3.5 COP. Allowing for system losses, this 6.5 million Btu/h (1905 kW) of geothermal source heat will produce the required 8.8 million Btu/h (2578 kW) for the utilization load. The Btu/h difference coming from the 736 kW/hr electrical input to the heat pump.

Thus, a 5000 ft (1.5 km) well delivering 325 gpm (20.5 l/s) of 130° F (54° C) water plus the heat pump will meet a load that would otherwise require a 7700 ft (2.3 km) well producing 1800 gpm (114 l/s) calculated as follows:

$$\frac{8.8 \times 10^6 \text{ Btu/h Load}}{10°\text{F range} \times 8.15 \text{ lb/gal} \times 60 \text{ min/hr}} = 1800\text{gpm}$$

CLOSED LOOP SYSTEM ECONOMICS

Using the geothermal heat pump system shown in Fig. 4, a rough order estimate of the economics compared to a conventional oil-fired hot water boiler system can be made by making several assumptions. For specific situations, these assumptions can be varied to suit and the results recalculated using the format developed here.

The nature of the geologic formation, diameter and depth are all contributors to well

* Westinghouse Templifier (R) Heat Pump

costs. For this analysis we will assume a 5000 ft (1.5 km) well delivering 325 gpm (20.4 l/s) can be completed for $50/ft (4); and that the reinjection well cost (if used) will be identical to the producing well. The complete boiler installation is estimated at $132,000 and the comparable heat pump at $220,000; both including equipment, piping, controls and electrical with the boiler including fuel storage. The installed cost of the geothermal water pump, piping and heat exchanger are estimated at $100,000.

Pumping heads (which will vary according to the way the well is installed, the geologic formation and other such factors plus the available locations of the equipment) were assumed to be:

Well pumping	200 ft (598 kPa)
Piping & Heat Exchanger	150 ft (449 kPa)
Heat Pump Evaporator Loop	100 ft (299 kPa)
Process Hot Water Loop	100 ft (299 kPa)

Further, that industrial sector electric power costs $.03/kWh. (5) Efficiencies of 60 % for pumps and 90 % for driving motors were used. The process heating load is calculated based on 4000 hr/yr -- a typical two-shift industrial plant operation.

The oil-fired hot water boiler operating cost was estimated based on using #2 fuel oil at $.50 per gal, (6) 140000 Btu/gal, (39060 kJ/l) 75 % boiler system efficiency plus $.80/million Btu for oil handling, pumping and evaporation losses to arrive at the "as-fired" energy cost.

The heat pump annual operating cost calculates at $88,300 (= 736 kW x 4000 hr/yr x $.03/kWh). The cost of evaporator pump operation is calculated at $5,400 and other pumps similarly computed.

A capital recovery factor of 0.12 was used in the Table 1 preliminary analysis, representing a 10 % cost of capital over a 20-yr period.

From this data Table 1 is constructed to compare the probable owning and operating costs of the two systems based on today's energy costs. From this table we can conclude that a geothermal heat pump can be competitive with an oil-fired boiler system at mid-1979 costs of energy and deserves further analysis. With all projections indicating that energy costs will continue to rise faster than inflation and many predicting that oil costs will rise faster than industrial electric power costs, plus the various tax incentives that are now applicable to geothermal, a cash flow statement should be constructed to more clearly define the energy savings and determine the discounted cash flow rate of return on the higher investment for the geothermal heat pump. From such information a more informed decision can be made.

CASH FLOW ANALYSIS

For purposes of comparing the systems on a cash flow basis, normally used by businessmen in analyzing investment opportunities, the geothermal system analysis should properly include the applicable tax benefits.

These include investment tax credits, development and depletion allowances. According to the Internal Revenue Service (1), an operator developing geothermal properties may either deduct as expenses or charge to the capital account all intangible drilling and development costs incurred on wells begun after September 1978.

Additionally, geothermal deposits qualify for percentage depletion. The applicable percentage through 1980 is 22 %, decreasing by 2 % yearly through 1983. After that the rate is 15 %.

To simplify calculations, the minimum 15 % depletion allowance was used. Likewise, the well drilling costs have been considered as 70 % expensible and 30 % capitalized. Depreciation in both cases is taken on a 10-yr basis. The applicable 20 % investment tax credit is then taken on the capitalized portion of the geothermal system investment while no credit is now allowed on oil boiler installations.

Table 2 illustrates the first year cost income and cash flow statement for the geothermal system without reinjection compared to a conventional oil boiler system on a zero income basis. It highlights the tax benefits under our interpretation of the current tax laws. Anyone making such a comparison for a project under consideration should consult his tax adviser for his interpretation applicable to that project.

To compute the "value of the heat used," the sum of operating and maintenance costs, depreciation and depletion allowance were taken. The 15 % depletion allowance is at 15 % of this "value of the heat used," considering that the industrial plant boiler house will "sell" the hot water to the manufacturing plant at cost.

Additionally, it is assumed that the company will have income from other sources to take advantage of the favorable tax effect created by the depletion allowance, investment tax credit and the expensed portion of the investment. The favorable tax effect for a company in the maximum 46 % tax bracket equals $245,000 x .46 = $112,700 on the expensed portion of the geothermal investment.

Unfortunately, any energy cost savings are considered as "profit" and thus are taxable. Therefore, in calculating the cash flow comparison over the 10-yr depreciation period, the lower operating cost of the geothermal heat pump system compared to the boiler system creates taxable "profit" which must be considered.

Table 3 illustrates the difference in cash flow taking into account the increased cost of energy and maintenance based on both rising 10 % annually. The tax rate is taken at 46 %; the depletion allowance on geothermal will rise yearly as the "value of heat used" rises based on the escalation of energy and maintenance costs.

From Table 3 it can be seen that the geothermal heat pump system will save $1,469,200 in operating costs compared to an oil boiler system over the 10-yr analysis period. Further, that the added $438,000 first cost will be paid off in operating cost savings in slightly over 4 yr. And, if oil prices rise faster than electric power costs, this payback will be reduced to under 4 yr.

For analyzing cash flow, the time value of money or cost of capital must be taken into account. Therefore, the present value of the net cash flow is calculated using a 10 % cost of capital.

From Table 3 the additional first cost investment of $438,000 in this geothermal heat pump system over the oil boiler system will produce a favorable net cash flow over the analysis period of $798,300 having a present value of $409,400. Using conventional methods, this calculates to be approx. a 45 % return on investment (or internal rate of return) certainly a worthwhile project from a financial viewpoint. Additionally, the cumulative present value of the discounted cost flow becomes positive after the third year. See Table 3.

CONCLUSIONS

For suitable industrial process water heating, space heating and water heating markets, geothermal heat pump systems can offer lower first and operating costs over geothermal-only systems and offer attractive tax benefits, cash flow and return on investment over conventional fossil fired boiler systems.

In addition to the availability of a suitable geothermal resource, a key factor in the economic picture is the utilization factor. The higher the number of hours per year that the geothermal system can be used the more favorable will be the economics.

With the growing need to utilize our geothermal resources to displace imported oil and gas with their rapidly rising costs and decreasing availability, it appears the geothermal heat pump system has an economic application for furnishing up to 230° F (110° C) hot water for process heat, space heat and service hot water in commerce and industry.

REFERENCES

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(6) Wall Street Journal, "Cash Prices," June 6, 1979.

(7) Internal Revenue Service, Publication 553, 1979 edition.

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Table 1
Geothermal Heat Pump vs Oil-Fired Boiler

	$000		
	Geothermal Heat Pump Reinjection Well		Oil-Fired Hot Water Boiler
	Without	With	
Capital Cost Increment			
Producing Well	$250	$250	—
Reinjection Well	—	250	—
Transmission & Extraction	100	100	—
Boiler System Installed	—	—	$132
Heat Pump Installed	220	220	—
Total	$570	$820	$132
Operation, Maintenance Owning Annual Costs			
Geothermal Water Pumping	$ 4.8	$ 7.5	—
Evaporator Water Pumping	5.4	5.4	—
Process Hot Water Pumping	7.5	7.5	7.5
Templifier/Boiler			
Operating	88.3	88.3	195.7
Maintenance	10.0	12.5	5.0
O&M Costs	$116.0	$121.2	$208.2
Memo: $/$10^6$ Btu	$ 3.30	$ 3.44	$ 5.91
Capital Recovery @ .12	68.4	98.4	15.8
Total O,M&O	$184.4	$219.6	$224.0
Memo: $/$10^6$ Btu	$ 5.24	$ 6.24	$ 6.36

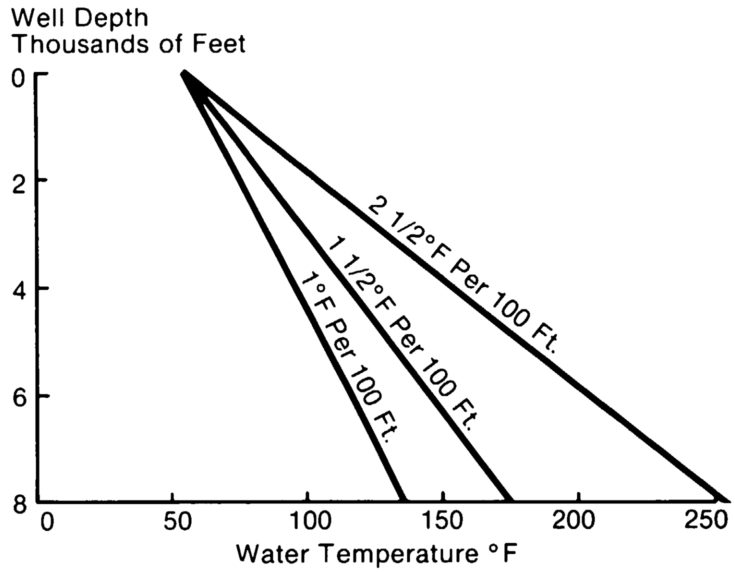
Table 2–
Geothermal Heat Pump vs Oil-Fired Boiler
First Year Cash Flow–Zero Income Basis

First Cost $000	Geothermal Heat Pump	Oil Boiler	Key Differences
Geothermal–Expensed (70%)	$245	—	—
Geothermal–Capitalized (30%)	105	—	—
Heat Pump–Capitalized (100%)	220	—	—
Boiler–Capitalized (100%)	—	$132	—
Subtotal–Capitalized	$325	$132	$193
Total	$570	$132	$438
Income $000			
Tax Sheltered Other Revenue (IBT)	$245.0	0	$245.0
Value of Heat Used	174.7	221.4	—
Less: Operation & Maintenance	– 116.0	– 208.2	92.2
Depletion Allowance	– 26.2	0	—
Depreciation	– 32.5	– 13.2	—
Expensed Costs	– 245.0	0	—
Income	0	0	
Cash Flow $000			
Depletion Addback	$ 26.2	$ 0	$ 26.2
Depreciation Addback	32.5	13.2	19.3
Investment Tax Credit	65.0	0	65.0
Initial Cost	– 570.0	– 132.0	– 438.0
Favorable Tax Effect	112.7	0	112.7
Total Net Cash Flow	–$333.6	–$118.8	

Table 3 –
Cash Flow Analysis – Geothermal Heat Pump vs Oil Boiler System ($000)

	Year 1	2	3	4	5	6	7	8	9	10	Total Project
Energy & Maint. Savings											
Oil Boiler System	208.2	229.0	251.9	277.1	304.8	335.3	368.8	405.7	446.3	490.9	3,318.0
Geothermal Heat Pump	116.0	127.6	140.4	154.4	169.8	186.8	205.5	226.1	248.7	273.5	1,848.8
Savings	92.2	101.4	111.5	122.7	135.0	148.5	163.3	179.6	197.6	217.4	1,469.2
Cash Flow											
O&M Savings	92.2	101.4	111.5	122.7	135.0	148.5	163.3	179.6	197.6	217.4	1,469.2
Deprec. Difference	– 19.3	– 19.3	–19.3	–19.3	–19.3	–19.3	–19.3	–19.3	–19.3	–19.3	–193.0
Depletion Allowance	– 26.2	– 28.3	–30.5	–33.0	–35.7	–38.7	–42.0	–45.6	–49.6	–54.0	–383.6
Income Before Tax	46.7	53.8	61.7	70.4	80.0	90.5	102.0	114.7	128.7	144.1	892.6
Tax @ 46%	21.5	24.7	28.4	32.4	36.8	41.6	46.9	52.8	59.2	66.3	410.6
Income After Tax	25.2	29.1	33.3	38.0	43.2	48.9	55.1	61.9	69.5	77.8	482.0
Deprec. + Deplet. Addback	45.5	47.6	49.8	52.3	55.0	58.0	61.3	64.9	68.9	73.3	576.6
Cash Flow from Operations	70.7	76.7	83.1	90.3	98.2	106.9	116.4	126.8	138.4	151.1	1,058.6
Invest Tax Credit	65.0	0	0	0	0	0	0	0	0	0	65.0
Favorable Tax Effect	112.7	0	0	0	0	0	0	0	0	0	112.7
Initial Cost Diff.	–438.0	0	0	0	0	0	0	0	0	0	–438.0
Net Cash Flow	–189.6	76.7	83.1	90.3	98.2	106.9	116.4	126.8	138.4	151.1	798.3
Present Value of Cash Flow	–189.6	69.8	68.6	67.8	67.1	66.4	65.6	65.0	64.6	64.1	409.4
Cumulative PV of Cash Flow	–189.6	–119.8	–51.2	16.66	83.7	150.1	215.7	280.7	345.3	409.4	

Temperature of Formation Water vs. Well Depth



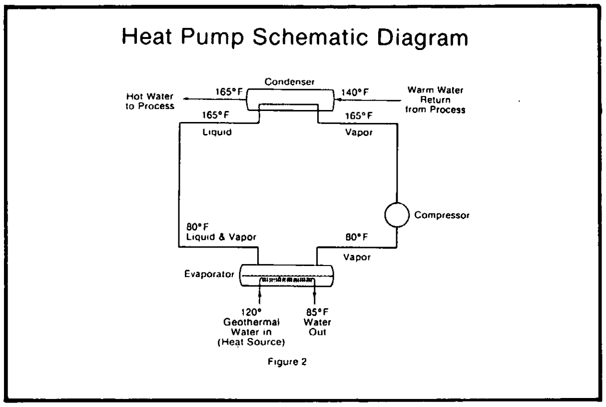


Figure 2

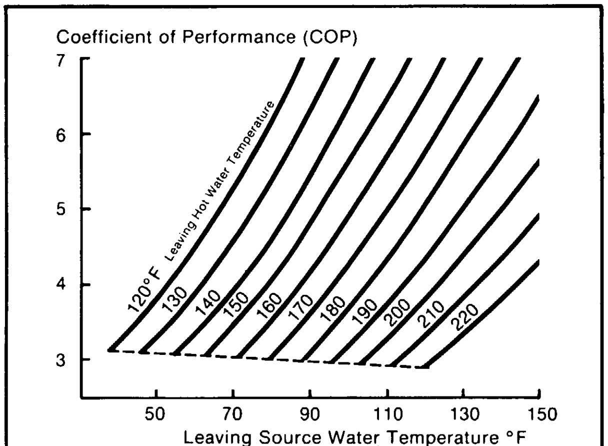


Figure 1