Heat pump enhanced district heating in low-temperature geothermal areas

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***Abstract*— The challenge of scientist and engineers today is to achieve sustainable development of the energy resources, such as geothermal energy. Geothermal energy may be used as multiple integrated energy incorporating heat pumps. This can bring with it a longer reservoir lifespan, a lower specific environmental impact, and greater marketing flexibility and profitability.**

This paper deals with the lowest temperature range of usable geothermal energy, from 10°C to say 40°C, where heat pumps play an important role. A case study from a village in Iceland is described, where the possibility of utilizing low-temperature geothermal water enhanced with heat pump for district heating was investigated.

I. INTRODUCTION

Iceland is endowed with abundant geothermal resources especially in a region of the country reaching from the southwest to the northeast. This is where the Mid-Atlantic ridge divides the island into two halves, one belonging to the North-American tectonic plate and the other to the Eurasian tectonic plate, and stretching it by 1 cm each year, Fig. 1. Outside this region, geothermal heat is limited, and this is where heat pumps can offer an important option for space heating in Iceland.

Geothermal areas are often classified as so-called high-temperarature areas where the source temperature is typically 150 to 350°C, low-temperature areas of 100°C and lower and intermediate temperature, also referred to as boiling low-temperature areas, from 100 to 150°C. The high temperature areas can be harnessed for producing electricity with "conventional" steam turbines, and in wet steam areas for providing hot water for district heating or industry in co-generation with electrical production. The boiling low-temperature areas are typically utilized for electricity production through binary power cycles and hot water for space heating and various industrial use. Typical use of low temperature geothermal water resources is for district heating and greenhouses in the temperature range 70 to 90°C and for balneological use in the temperature range 40 to 60°C. This has been amply demonstrated in the well-known Líndal diagram, Fig. 2.

II. HEAT PUMP FOR VÍK VILLAGE

Vík is the southernmost village in Iceland of 300 inhabitants, set in picturesque surroundings by the coast. The village is located outside the main geothermal zone, but the local authorities decided to investigate possibilities of finding useable geothermal energy for heating. To that end an exploration borehole was drilled in 1977. This proved unsuccessful, but nine years later another well was drilled that produces 2,4 l/s of 46°C hot water with a submersible borehole pump. The well was drilled in a few phases in search for higher temperature, and now the pump draws water from 950 m depth through a special tail pipe. The water from this well has been used for a

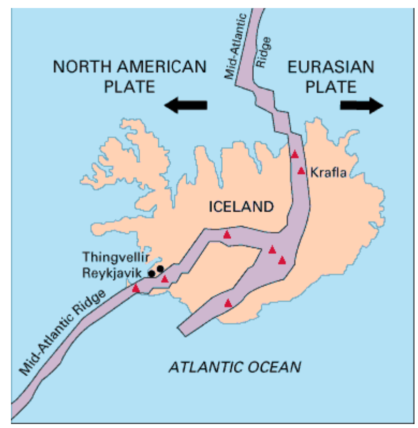

Figure 1. Location of main geothermal active zone in Iceland

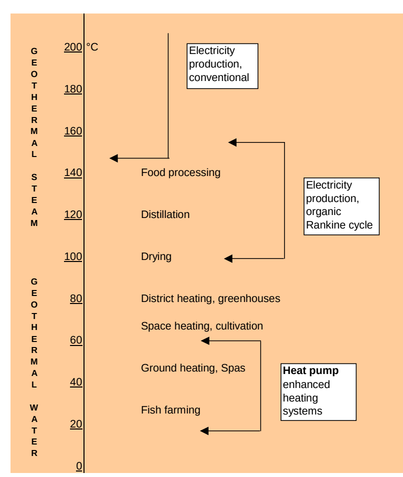

Figure 2 Excerpt from Líndal diagram for geothermal energy

swimming pool and floor heating system in a nearby school. The third well was later drilled six kilometers east of the village to 950 m depth. This well yields 15 l/s of 38°C hot water in artesian flow [1].

The temperature and flow rates available in and near Vík village are similar to what can be found in many low-temperature areas in Central Europe, so the solutions described here can be applied to any area with reasonably accessible geothermal water.

For this study it was decided to investigate the feasibility of a heat pump enhanced district-heating system for the village. The heat source for the heat pump would be on one hand 20°C water from boreholes within the village boundaries and on the other hand 40°C water from boreholes 6 km east of the village. In the light of the previous experience with geothermal water exploration in the area, following main parameters were selected for the study:

Scenario A

To drill 350 m deep borehole(s) in the village assumed to deliver 20 to 30 l/s of 20°C warm water.

Scenario B

To drill 600 m deep borehole(s) 6 km outside the village assumed to deliver 20 to 30 l/s of 40°C warm water.

In both scenarios, the heat pump would be placed in a heat centre in the village. The temperature of the hot water to the consumers, or the water temperature leaving the heat pump, would be 70°C and the return temperature from the house heating systems 35°C.

The cost of these two scenarios is compared with heating with a central hot water electrode boiler system.

III. HEAT PUMP SOLUTIONS

Two solutions are presented for Vík village, one with the heat source within the boundaries of the village, and the other where the heat source lies some 6 km outside the village.

A. Heat source 20°C inside the village

Fig. 3 shows a simplified system diagram for the heat pump and district heating system, omitting a peak load boiler that is required for a few days of the year, Fig. 4. The 20°C water is taken from the borehole(s) to the evaporator of the heat pump. As the temperature of the supply to the district heating system is set at 70°C and the temperature of the heat source is only 20°C, the heat pump will be a two-stage unit. COP is assumed 4.4.

After passing through the evaporator the used geothermal water at 15°C is led to drain (in places where this is not permitted, the return water must be injected back into the ground). The district heating system is a closed-loop system, where the heat is transferred to the homes through heat exchangers in each house.

B. Heat source 40°C outside the village

In this case the heat pump will be a single-stage unit with COP equal to 5.6. The 40°C warm water from the geothermal heat source is brought to the heat centre through a 6 km long transmission pipeline, where it enters

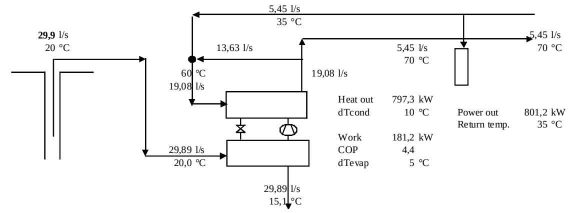

Figure 3. Scenario A – simplified system diagram

the evaporator at estimated 37°C and exits at 32°C. This water still contains useable enthalpy and can be used for e.g. a swimming pool or floor heating panels. Another option that might be worth pursuing if there is abundance of low-temperature water, is to design the district heating system in the village as a single pipe system. This will bring about much saving in network pipelines and heat exchangers in homes, and the homeowner has the opportunity to use the return water from his house for snow melting in pavements, ground heating for cultivation etc. It however calls for larger heat pump and the risk of service interruptions is higher.

IV. OPTIMUM SIZE OF HEAT PUMP

A load duration curve describes heat demand variation of a typical district heating system over a period of one year. For Iceland the heating season spans the whole year, but in central Europe it is common to stop circulation of hot water for space heating from mid April to mid October. Hot domestic water, however, is supplied all year round.

The shape of the load duration curve is characterized by a sharp peak at one end that indicates high power demand but low energy percentage relative to a whole year. This shows that there are short periods each year when heat demand calls for high output (power) of the district heating system. This peak-load is usually supplied from a heat source that is relatively inexpensive to install but may be expensive to run, such as oil or gas fired hot water boiler [2].

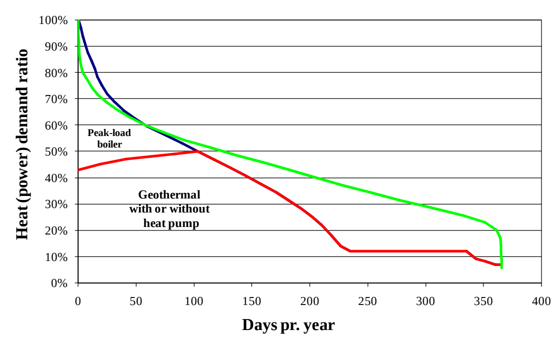

Figure 4. Typical load duration curve for south Iceland (green curve) and central Europe (red and blue curve)

Geothermal energy systems and heat pumps are examples of heating system that are costly to install but inexpensive to run, and are therefore best suited for the base load. Where the optimum installed power ratio of a heat pump system lies, depends on the purchase price of the heat pump and associated equipment and electricity and fuel prices.

In this study for Vík village the optimum size of heat pump proved to be 800 kW of heat output. The peak-demand for heating of the village is 1200 kW, so the peak-power ratio of the installed heat pump is 67%. This is higher than is often referred to in Europe, where the ratio often lies between 50 and 60% [3].

V. Cost comparison

The cost of investment in the heat pump systems using geothermal water as heat source is compared with a 100% hot water electrode boiler solution. When it comes to the operating cost the comparison is done in relation to present cost of heating in Vík village by direct use of electricity.

A. *Investment cost*

For the geothermal side, the investment cost includes cost of drilling, borehole pump and hot water transmission pipeline from the borehole to the heat centre. For the heat pump, the investment cost includes the heat pump assembly installed and ready for operation. For the district heating side the major cost lies with the pipe network and house connections. The remaining cost items comprise the heat centre building, peak-load boiler, and circulation pumps etc, see Table I. Both heat pump alternatives are considerably more expensive than a solution with a central electrode boiler. This ratio will, however, change when the annual cost is analyzed.

B. *Annual cost and cost of produced heat*

The annual cost constitutes the main items shown in Table II and their cost ratio.

TABLE I
Comparison of investment cost (relative)

Option	**Heat pump scenario A**	**Heat pump scenario B**
Geothermal heat source	12%	26%
Heat pump installation	19%	17%
District heating network	53%	48%
Buildings, boiler, pumps etc.	16%	10%
Total investment for heat pump system	100%	100%
Total cost (relative to cost of electrode boiler solution)	145%	162%

TABLE II
Breakdown of annual cost ratio

Cost item	**Heat pump scenario A**	**Heat pump scenario B**	**Electrode boiler**
Financing: Payback and interest	62%	66%	42%
Maintenance	15%	13%	6%
Energy (electricity)	15%	13%	42%
Staff	9%	8%	9%
Total	100%	100%	100%

TABLE III
Comparison of heating cost

Option	**Cost Ratio rel. to present cost**	**Actual energy cost in March 2009 €/MWh**
Heat pump scenario A	86%	42
Heat pump scenario B	89%	44
Electrode boiler	80%	39
Present heating of the village	100%	50

The benefit of the heat pumps can clearly be seen in the low energy cost ratio compared to the electrode boiler. The high investment cost and cost of maintenance of the heat pump solutions is also obvious.

In Table III the cost of the produced heat energy is shown in relation to the present cost of heating in Vík village. This reflects the cost ratio without subsidies and VAT. All solutions will bring cost savings for the homes, from 11 to 20% from the present cost of heating.

In Iceland, the electrical energy from the national grid used for the heat pumps and electrode boiler originates in “green” power plants, hydroelectric or high-temperature geothermal. In countries where electricity is produced mainly from coal and fossil fuels the heat pump alternative is especially important due to its contribution to reducing greenhouse gas emission.

C. *Sensitivity analysis*

The sensitivity analysis demonstrates the sensitivity of the various solutions to changes in either investment cost or cost of electricity to run the heat pump or the electrode boiler.

The effect of investment cost is reflected in higher cost of maintenance and service. This has marked influence on the heat pump alternatives but much less on the electrode boiler, Fig.5.

Effect of changes on electricity price are, however, much more noticeable on the electrode boiler option than the heat pumps, and has drastical influence on the present cost of heating of homes in the village, Fig. 6. The heat pump alternatives are therefore the least sensitive to changes in cost of energy, which is very important especially in the future, when the demand for cleaner and often more expensive energy increases.

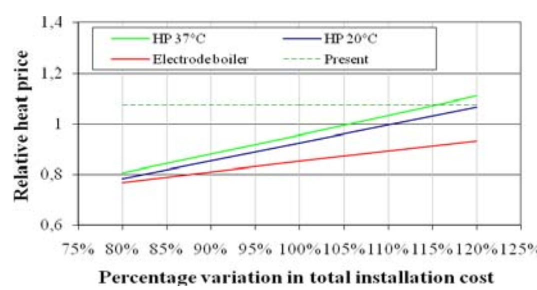

Figure 5. Sensitivity analysis – Installation cost

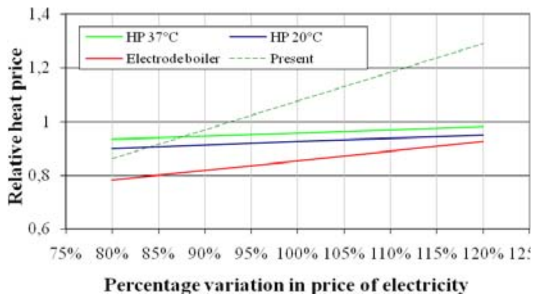

Figure 6. Sensitivity analysis – Operational cost

D. Discussion

In order to decrease cost, EGEC in its Research Agenda for Geothermal Energy Strategy 2008-2030 [4] fixed the research priorities for all geothermal technologies until 2030. For geothermal district heating the goal was set on 5% cost reduction to reach 40 €/MWh$_{th}$, and for geothermal heat pumps by 10% to reach 15 €/MWh$_{th.}$.

To put the Icelandic situation into this context, the current price of a large geothermal district heating system, for example Reykjavík Energy of 800 MW$_{th}$ installed thermal power, the price to the consumer is about 11 €/MWh$_{th.}$ based on exchange rate in March 2009. The heating cost in the small district heating system proposed for Vík village is about 42 €/MWh$_{th.}$. The Vík geothermal district heating system is an example of a new district heating system where density of population and energy demand MW/km^2 is very small. The installation cost of the distribution network amounts to about half of the total investment cost as shown in Table I. If the distribution network had already been available, as in the case where there is a district heating system with a central boiler station, the energy cost would be decreased to 30 €/MWh$_{th.}$.

VI. Conclusion

Heat pumps are a viable option for district heating where there is abundance of low-temperature geothermal water available close to a heating market. Heat pumps can also be part of a multiple integrated energy scheme, such as cascaded use of geothermal water.

As well as providing raised water temperature required for space heating, heat pumps enable maximum effective temperature drop of the geothermal water and minimal fluid extraction from the geothermal reservoir.

Heat pumps are costly compared to conventional hot water boilers, and that cost must be offset by the benefits that a heat pump based solution has to offer. In addition to the benefits already mentioned pertaining to maximum utilization of the geothermal fluid, is the advantage of much lower electricity consumption than by electric boilers or direct use of electricity for heating. This brings with it much less emission of greenhouse gases where electricity is produced from coal or fossil fuels.

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