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The Use of Compression Heat Pumps for Geothermal Heating Plants in Poland - Analyses of Operating Limitations and Cost-Efficiency

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ABSTRACT

The paper presents the basic technical requirements that have to be met by compression heat pumps in Polish heating installations using geothermal waters. The discussion takes into account the required geothermal installation operating parameters and the energy mix used to produce the electricity that powers the heat pumps.

Taking into consideration the existing limitations, the conditions that have to be fulfilled in order for the use of compression heat pumps to be efficient from the energetic and economic points of view have been determined.

1. INTRODUCTION

1.1. Geothermal Parameters in Poland

Low-temperature geothermal energy resources ranging from 30 to 130°C are the most common in Poland at the depths from which geothermal energy can be sourced and efficiently used (i.e. from 1 to 4 km) (Kepinska 2005, Barbacki et al. 2006, Gorecki et al. 2007a and b). The moderate temperatures and significant depths at which geothermal energy resources can be found suggest that a technique based on the deep cooling of thermal water brought to the surface may be appropriate. This may be effected through promoting cascade uses of geothermal energy and using heat pumps.

1.2. Heat Pumps in Polish Geothermal Installations

High-power heat pumps utilising geothermal energy have operated for several years in geothermal installations in Poland. The largest pumps installed are absorption ones at the Pyrzyce heating plant (two units with a power rating of 10 MW each — Sobański et al. 2000) and at Mszczonów (2.7 MW — Balcer 2001). Both heat plants use heat pumps alongside peak load boilers in order to provide central heating and domestic hot water to customers connected to the municipal heat distribution network. The largest compression heat pump installed in Poland is the one operated at the Bukowina Tatrzańska pool complex (0.5 MW of heating power). Analyses are being conducted into the feasibility of using heat pumps in other geothermal installations. Apart from large pumps that operate in geothermal heat plant installations, many appliances with much lower power ratings are also installed (Bujakowski 2008) The total estimated installed heating power of geothermal heat pumps using cool water with temperatures ranging from 7 to 25°C is around 80 MW (Bujakowski 2008). These data are only an approximation, since pumps installed by individuals are not registered anywhere in Poland. According to some sources (Joniec 2007), the annual sales of such pumps range from 1,000 to 1,500 units. The low power rating (up to 70 kW) pump segment is the largest section of the market (around 50% of pumps sold). Pumps with power ratings in excess of 150 kW account for only 1% of units sold (Joniec 2007).

1.3. Heat Energy Purchasers

Despite the adoption of the European EN 442 standard in 1999 which stipulates that the maximum design temperature for radiator installations supplying is to be 75°C, and the return temperature is to be 65°C, many radiator installations in Poland were designed and constructed earlier, for a supplying temperature of 90°C, and a return temperature of 70°C. Heating mains are often designed for a supply temperature of 130°C, or even 150°C. This limits or prevents the use of geothermal installations, even using heat pumps. Where interoperability can be achieved over a certain range of outdoor temperatures, requirements concerning the high temperature of water in the heat distribution network limit the efficiency of heat pumps (low COP values and low energy output).

1.4. Primary Energy Market

The primary energy sources most widely used in Poland to provide heat are hard coal, high methane content natural gas from the grid, light heating oil, liquid propane-butane and electricity. The market share of liquid propane-butane is marginal. Most propane-butane installations were constructed when this source of energy was cheap, but its current price is not attractive, limiting its use. Estimated current prices of producing heat energy from these sources for retail customers (only taking net fuel purchase prices into account) are as follows (EUR/PLN exchange rate as at 30 April 2009):

- hard coal EUR 5.7/GJ;
- high methane content natural gas from the grid EUR 9.3/GJ;
- light heating oil EUR 16.4/GJ;
- liquid propane-butane EUR 27.3/GJ;
- electricity EUR 33.8/GJ.

The fundamental parameter that makes Poland stand out among other European countries where the heat pump market is developing rapidly is the mix of energy sources used to produce the electricity that powers pump compressors. Based on 2005 figures, the share of hard and brown coal in the overall consumption of energy sources used to produce electricity in Poland can be estimated at around 95% (Energy Regulatory Authority 2009). According to the same figures, the share of hydroelectric power plants and renewable energy sources in overall electricity production does not exceed 3%. Such a mix of primary energy sources used to produce electricity translates into significant differences in the efficiency of using heat pumps between Poland and other countries. This must be taken into account when looking at other countries' data related to the efficiency evaluation of heat pumps.

The factors listed above directly contribute to the still limited popularity of heat pumps in Polish conditions. Low geothermal energy resource temperatures are conducive to the use of heat pumps, but on the other hand, due to the high investment expenditure needed, the required high operating temperatures of customers' heating installations and the dominant share of electricity produced by coal-fired plants, the efficiency of the solutions implemented has to be assessed very cautiously.

2. CUSTOMER PROFILE IMPACT ON THE FEASIBILITY OF USING HEAT PUMPS

Two types of parameter determine whether the use of heat pumps in heating installations is feasible and efficient. The first group are technical parameters, and the second one — economic ones. The most important technical parameters include:

- the profile of the purchaser of the heat energy produced by the pump;
- the origin of the energy used to power the pump;
- the origin, characteristics and availability of the lower source at the location in question;
- the type of source in relation to the heat pump-based installation.

Economic parameters include the following issues:

- the required investment expenditure;
- financial engineering (the sources of funds used to cover the investment expenditure required);
- energy source prices (current prices and future forecasts);
- other parameters affecting investment cost-effectiveness (e.g. the required discount rate, interest on bank loans, tax rates).

Technical requirements concerning the operating parameters of the energy source depend on the customer's requirements. The customer's needs and the characteristics of the heating installation determine the schedule of power requirements, the supply temperature and the required flow of the heating medium. As a result of energy being supplied to the customer's installation, the temperature of the heating medium decreases. The drop in temperature is in proportion to the power required.

The most important technical constraints linked to the use of heat pumps, and in particular compressor heat pumps, include temperature limitations related to the thermodynamic properties of the working medium and compressor design. Thus the maximum temperature of the medium supplied to the heat pump evaporator and the maximum temperature of the medium heated by the heat pump (at the condenser outlet) are limited. The latter parameter is closely related to the type of working medium used (and more precisely, its critical temperature). For standard working media that are currently used in compressor heat pumps, the maximum temperature of the heated medium that can be achieved rarely exceeds 80°C for two-stage compressors, and the standard range is from 55°C to 60°C for single-stage compressors in low power rating pumps. The maximum temperature of the medium supplied to the condenser does not usually exceed 28°C.

Figure 1 presents the operation of a heating installation supplied from a central heating plant located close to the customer. The chart illustrates the typical operation of an energy source supply a customer's heating installation designed for a feed temperature of 90°C and a return temperature of 70°C where both the amount of heating medium and its temperature are controlled. On Figure 1, the possible range within which compression heat pumps equipped with single-stage compressors can supply the customer's installation is shown. The chart demonstrates that peak load boilers have to be used in this case. Additionally, the power rating of the peak load boilers must be equal to the customer's maximum demand for power. This means that heat pumps will not reduce the power installed and ordered with respect to other energy sources.

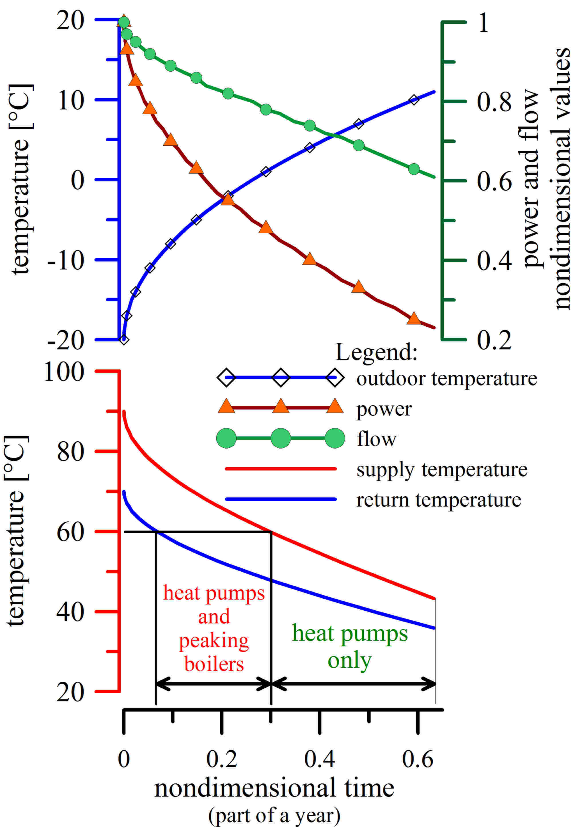

Figure 1 Central energy source control — example diagram. Typical operation of a source supplying a customer's heating installation designed for a supply temperature of 90°C and a return temperature of 70°C (pipe losses excluded). Location: southern Poland (minimum outdoor temperature -20°C)

Heat pumps can operate on their own for over half of the heating season. During less than a quarter of the year (35% of the heating season), heat pumps can work alongside peak load boilers. During the remaining period, pumps cannot operate, since the temperature of the water returning to the heating plant exceeds the maximum temperature attainable using such appliances. A meaningful reduction in installed peak load boiler power along with the amount of the fuel ordered will only become possible when compressor heat pumps are used that enable supply temperatures of around 80°C to be achieved. Obviously, the effects of heat pump operation for high working medium condensation temperatures are not as good as for lower temperatures. Still, favourable economic effects may be achieved owing to a reduction in investment expenditure.

Taking the effects of energy source operation into account, the best solution is to reduce the supply and return temperatures of the customers' heating installations. It should be remembered that the cost-effectiveness of such measures must always be determined on a case-by-case basis. The economic effect is not necessarily favourable, particularly where existing heating installations have to be upgraded in the process (Pajak 2008).

3. INTEROPERABILITY BETWEEN HEAT PUMPS AND OTHER ENERGY SOURCES

The geothermal installations in Poland that use absorption heat pumps operate them in parallel with peak load boilers (Bujakowski 2008, Sobański et al. 2000). Cooled water returning from the heat distribution network is directed to heat pumps, which preheat it. This water is then additionally heated by high-temperature boilers and peak load boilers.

Another possible arrangement consists of installing heat pumps within a separate network. In this case, a group of customers are selected whose heating installations have the desired operating parameters (supply and return temperatures as low as possible) and reasonably constant energy needs during the year. Outdoor leisure and swimming pools fit these requirements well (Pająk and Bujakowski 2005).

4. DETERMINING THE TECHNICAL AND ECONOMIC EFFICIENCY OF HEAT PUMP OPERATION IN HEATING SYSTEMS

The calculation of the cost-effectiveness of using compression heat pumps should take the mix of sources from which electricity is produced into account. Since electricity here is predominantly produced from hard coal, a question may be asked: about what conditions have to be met to reduce the overall consumption of fuel (coal)? In order for heat pump utilisation to be efficient from the point of view of primary energy conservation, the following condition has to be met:

$$COP > n_0/n_{el} \qquad (1)$$

where:

COP — heat pump coefficient of performance;

n_0 – the efficiency with which the primary energy provided by coal can be converted into heat energy for the technology that is being compared to the heat pump;

n_{el} – the efficiency with which the chemical energy released by burning coal can be converted into electricity.

Assuming typical (in Polish conditions) with efficiency levels of n_0=0.7 and n_{el}=0.32 (Szargut 1998), the minimum COP value that ensures that the utilisation of compression heat pumps is efficient can be calculated. This is around 2.2, which is easy to achieve in practice.

The condition concerning the cost-effectiveness of compression heat pumps powered by electricity from the grid is much more difficult to meet, however. A preliminary criterion for assessing the cost-effectiveness of heat pumps may be the comparison between the total operating costs of such devices and the costs associated with technologies using conventional energy sources. Total costs have to include:

- energy purchase costs;
- installation operation costs;
- repair and maintenance costs;
- fixed asset depreciation;
- loan servicing costs;
- other costs (e.g. environmental charges).

In order for the use of heat pumps to be economically justifiable, the total cost should be lower than that for the reference technology. In Polish conditions, COP values at which heat pumps would become cost-effective compared to the following sources of energy for small individual installations (e.g. residential buildings) according to the criterion described above are:

- hard coal COP>7.7;
- high methane content natural gas from the grid COP>5.6;
- light heating oil COP>2;
- grid electricity COP>1.4.

For installations with high power ratings and appropriate heat pump power ratings, the COP values stated above may be expected to fall. They will not, however, decline below the COP values determined when only the cost of purchasing the energy needed to drive the pumps is taken into account. For energy to be produced at a lower cost where only the cost of purchasing the energy that drives the pumps is taken into account, the following must hold:

$$COP > p_{el}\, n_0\, Q_{w0} / p_0 \qquad (2)$$

where:

p_{el} – unit electricity purchase cost [EUR/GJ];

n_0 – as in equation (1);

p_0 - reference energy source unit purchase cost [EUR/kg or EUR/m^3];

Q_{w0} – the calorific value of the reference source of energy [GJ/kg or GJ/m^3].

The minimum COP values calculated according to (2) are as follows:

- hard coal 5;
- high methane content natural gas from the grid 3.3;
- light heating oil 1.7;
- grid electricity 1.

This calculation proves that heat pumps are in fact competitive compared to the direct use of electricity and to heating oil. Measured against natural gas from the grid, they can only be competitive in certain cases. They can virtually never be competitive compared to hard coal.

CONCLUSIONS

Owing to the increase in the share of electricity produced from renewable energy sources and the gradual reduction in operating temperatures of heating installations (according to EN 442 standard requirements), an improvement in the efficiency of heat pumps using geothermal energy may be expected. An additional incentive for the development of the Polish heat pump market will be the probable intensification of competition in the appliance market, which may drive the prices down. A steady increase in the prices of conventional energy sources is also highly probable. The introduction of carbon caps will certainly influence the heat pump market. Currently, the Polish electricity production sector is based primarily on hard coal; carbon caps may lead to a significant increase in the cost of producing electricity, and therefore a drop in the cost-effectiveness of heat pump use. Given the current mix of sources from which electricity is produced, making heat pump use efficient from the point of view of energy is not a problem. When it comes to compression heat pumps, the economic criterion is a much more stringent one. Given the current cost structure of energy sources and the level of required investment expenditure, it may be stated that heat pumps can successfully compete against grid electricity and light heating oil. Competitiveness against natural gas from the grid must be evaluated on a case-by-case basis. Finally, heat pump installations can virtually never be competitive compared to hard coal.

REFERENCES

Balcer M.: Doświadczenia z pierwszego okresu eksploatacji instalacji geotermalnej w Mszczonowie. Materiały konferencyjne Rola Energii Geotermalnej w Zrównoważonym Rozwoju Regionów. MEERI PAS, Kraków. Poland (2001)

Barbacki A.P., Bujakowski W., Pajak L.: Atlas of geothermal reservoirs in Malopolska. MEERI PAS. Krakow (2006)

Bujakowski W: Wody geotermalne i ich wykorzystanie. Materiały konferencyjne Górnictwo Wczoraj i Dziś, Mysłowice. Poland (2008)

Gorecki W. (editor-in-chief):Atlas of geothermal resources of Mesozoic formations in the Polish lowlands. University of Science and Technology in Krakow. Krakow (2006a)

Gorecki W. (editor-in-chief):Atlas of geothermal resources of Paleozoic formations in the Polish lowlands. University of Science and Technology in Krakow. Krakow (2006b)

Joniec W.: Rynek pomp ciepła. Rynek Instalacyjny nr 11/2007, Poland (2007)

Kepinska B.: Geothermal Energy Country Update from Poland, 2000-2004. Proceedings World Geothermal Congress 2005. Turkey (2005)

Pająk L., Bujakowski W.: Problematyka wykorzystania wód geotermalnych w odkrytych kąpieliskach całorocznych w warunkach polskich. Ciepłownictwo Ogrzewnictwo Wentylacja (Heat Engineering and Ventilation) nr 11/2005, Poland (2005)

Pajak L.: Simulation of conditions and effects of the operating of heating systems using cold groundwater by application of compressor heat pumps. Geological Exploration Technology Geothermics, Sustainable Development no 1-2/2008, Poland (2008)

Sobanski R., Kabat M., Malenta Z., Maliszewski N., Grabiec R.: Assessment of thegeothermal heating plant in Pyrzyce based on the operating results from 1999. Proceedings of the Symposium on the Role of Geothermal Energy in the Sustainable Development of the Mazovian and Lodz Regions. Published by Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Cracow, Poland (2000)

Szargut J.: Termodynamika techniczna. Wydawnictwo Naukowe Politechniki Śląskiej, Gliwice. Poland (1998),

URE: Strukturalna charakterystyka rynku (2005 rok). Official Energy Regulatory Authority Web site: http://www.ure.gov.pl/portal/pl/16/1813/Strukturalna_charakterystyka_rynku_2005_rok.html, last access date: 14 January 2009, Poland (2005)