Systems of simultaneous operation of low- and high-temperature heating installations and the effect on the degree of geothermal energy utilization in a geothermal heating plant

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Abstract

One of the conditions for rationalisation of geothermal water use is to improve the geothermal system load factor. In order to fulfill this condition it is advised to target predominantly low-temperature heat customers, or a combination of customers having high temperature installations with customers having low-temperature installations. This enables more effective cooling of municipal heating water and increasing the geothermal system load factor. The authors carried out analyses to determine the influence the combining of high-temperature and low-temperature installations had on improving the utilisation of geothermal energy in a geothermal heating plant. The main purpose of this work was to evaluate the level of influence the application of low-temperature heating systems has on the degree of the geothermal energy in the geothermal heating plant, which supplements the heat distribution network supplying two groups of heat customers having the distinct shares in a heat consumption. These studies are very interesting as concerns the possibility of modernising the existing heating systems by the application of the geothermal unit in a conventional heating plant.

Keywords: *geothermal energy, geothermal heating plant, geothermal energy utilisation.*

1 Geothermal energy potential in Poland

Poland belongs to the group of countries having a large potential of low or medium enthalpy geothermal waters (Wisniewski, 1997). The temperature and the degree of geothermal water mineralisation usually depend on the depth of rock deposits creating the underground water reservoir heated with energy from the Earth's centre.

Sokolowski, Gorecki and Ney (Ney and Sokolowski, 1987; Gorecki, 1996; Sokolowski, 1997) prepared an evaluation of the Polish energy potential that presented the geological conditions and defined the areas for geothermal water deposits. According to Sokolowski, the Polish geothermal water resources comprise ca. 6500 km^3. This geothermal water resource has the temperature range of 25-120°C, which makes it useful for direct utilisation for heating, hot tap water production as well as technological and medical purposes. The potential is rather equally distributed within the major part of the Polish territory, in separate geothermal basins and subbasins, in defined geothermal provinces and regions. According to the existing evaluations, some 60% of this potential may be used in practice. The most favourable conditions are in Polish Lowlands (Niż Polski), which makes the region a potential geothermal basin. Favourable conditions are also found in Podhale and Sudety (Southern Poland).

1.1 General rules for geothermal water management

Heat demand differs with time. It relies mostly on space heating demand, which varies with outdoor temperature. The ordered chart is the basis for defining the amount of useful heat (Kabat et al., 1999; Nowak et al., 2000; Nowak and Stachel, 1999, 2000b, 2001). While preparing the ordered heat demand chart, it is necessary to take into consideration technological heat consumption for industrial plants, agriculture, handicraft and other customers. The chart is very helpful for deciding the concepts and design of the heat sources structure, especially when choosing systems for energy supply from geothermal water. The systems depend on the geothermal water parameters used for the process and customers demand resulting from an ordered curve. Three sets are possible in this case (Nowak et al., 2000; Sobanski et al., 2000):

- Monovalent set where all the heat is taken from a geothermal installation. The installed capacity is set according to the heat demand, defined for the calculated outdoor temperature. Low value of the annual co-efficient of the power leads to heat cost increase. The set may be used at high geothermal water temperature (ca. 110°C) and/or at cascade utilisation of water enthalpy in various heating- and technological devices.
- Bivalent set where conventional boilers support the geothermal source. In this set, it is possible to use its capacity more completely throughout the whole heating period. A boiler supports the system only during the peak load period. Outside the heating period, the geothermal source supplies energy only for hot tap or technological water production, depending on the demand. The set makes it possible to reach high values for geothermal intake utilisation and it is therefore often used. Existing boilers may be used as peak load heat sources. If it is necessary to build a new peak load energy source, investment costs increase.
- Combined set where a part of customers are supplied by a geothermal installation (low temperature heating) and the remaining part by a conventional boiler (traditional heating). By combining the two systems, it is possible to increase the utilisation value for the geothermal installation, which out of the heating season, is used for hot tap or technological water production for all the customers. Utilisation of nearly full capacity of the geothermal installation may be reached in this case and it causes a decrease of heat production costs.

The generally presented schemes constitute the basic methods for geothermal energy management. Detailed solutions and their technical and operational effects are directly dependent on local geothermal solutions and possibilities of utilisation of periodical surplus geothermal energy heat, occurring mostly out of the heating season (Kabat, 2001).

1.2 Concept of geothermal energy utilisation

Geothermal waters constituting a potential heat source for the economy present within the Polish territory are usually of 100°C temperature. Therefore, it differs from temperatures traditionally used in district heating networks (150/70°C), which are used by fossil fuelled systems. Maximum temperature of heating water used in heating installations in buildings is 95/70°C.

Conventional heat sources supply centralised district heating systems with energy carriers (steam, circulation water) of temperature usually exceeding the temperature of heat required by heat or technological heat customers. On the other hand, geothermal water often has the temperature close or even lower than the temperature required for most district heating installations. This limits the direct utilisation of geothermal waters energy to low temperature heat customers or requires the use of various devices supporting the geothermal energy source. Such constraint results from the kind of heating systems used in Poland, where the supply heating water temperature is 95/70°C, which corresponds to the minimum external calculation temperature of –16°C.

Utilisation of geothermal energy for heating purposes in municipal systems, agriculture, technical processes as support for conventional heating and power plants and as the basic energy carrier in low temperature power plants is the most effective and simplest way of geothermal energy management. When the temperature of a geothermal energy carrier is insufficient for water heating in a heating installation, heat pumps or peak load boilers are introduced into the installation, or the installation has to be improved and changed. Their task is to increase the temperature of the heated water to the required value.

The variety of possible technical solutions and structures of the source devices for heat production from the Earth's centre energy results from the need of adjusting the kind and size of the geothermal intake for the needs and parameters of the heat customer installation taking into consideration local parameters of water and the results of economic analysis (Ney and Sokolowski, 1987; Nowak et al., 2000; Nowak and Stachel, 1999, 2000). The scheme of an example of a geothermal heating plant is presented in Figure 1.

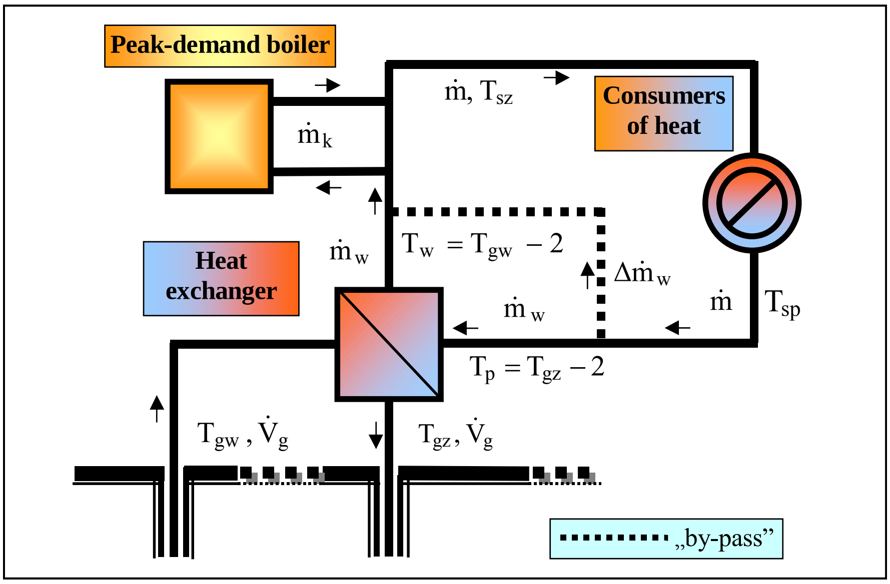

Figure 1: Scheme of a geothermal heating plant with a heat exchanger and a peak boiler.

The concept of producing geothermal energy presented in the figure is based on a two-hole system, in combintion with a conventional heating plant, consisting among others things of:

- counterflow heat exchanger where geothermal water heat is passed to the network circulation water,
- a peak load boiler, used when the heat supplied by the geothermal heat exchanger does not satisfy the demand and if the temperature of the circulation water behind the T_w heat exchanger is lower than the required temperature for the network water at T_{sz} supply.

Heat for heating purposes and for hot tap water production is produced in a central heat source and distributed to customers by a transmission network, consisting of a circulation network of water at the temperature of 95/70°C.

1.3 Evaluation of possibilities of geothermal energy production

The amount of geothermal energy possible for production in a heat exchanger is dependent upon the geothermal deposit- and characteristics of district heating networks.

The characteristics of the resource may be presented in the form of property charts, presenting possibilities of geothermal energy production. The chart presenting the useful energy content of geothermal water taken from the ground, which depends upon the quantity of geothermal water taken from the ground, its temperature and the level of cooling achieved in the heat exchanger (Figure 2). The temperature of the geothermal water taken from the ground determines its quality and is a quantity significant from the point of view of its possibilities for utilisation (Kabat et al., 1999; Nowak and Stachel, 1999, 2001).

Intake system operation time is an important factor deciding on the effectiveness of geothermal energy utilisation and limiting the amount of produced geothermal energy. The maximum heat quantity may be achieved in case of the system operating all year (Kabat et al., 1999; Nowak et al., 2000; Sobanski et al., 2000).

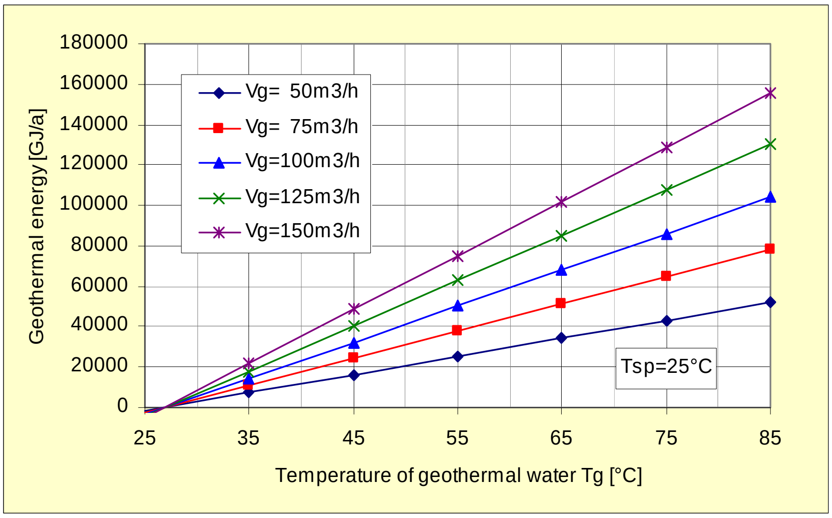

Figure 2: Possibilities of producing geothermal energy from a geothermal deposit.

The quantities presented in Figure 2 only define possibilities of geothermal energy production and are equal to its utilisation in a geothermal heat exchanger. This results mostly from possibilities of its utilisation in heat customers and depends upon their characteristics, which constitute of the thermal demand and temperatures of the energy carrier on the inflow and outflow. On this basis, real possibilities of geothermal energy production for heating purposes in a heat exchanger may be determined (Nowak and Stachel, 1999, 2000a, 2001a; Kabat et al., 1999).

Securing the proper temperature of the energy carrier for heat customers is an important factor for a geothermal heating plant operation. This topic was discussed in many papers (Kabat et al., 1999; Nowak et al., 2000; Nowak and Stachel, 2000b; Sobanski et al., 2000). When the temperature on customer-end-user inlet is supposed to be higher than geothermal water, further water may be heated in a correctly chosen peak load boiler.

In a schema presented in Figure 2 one may clearly see that temperature of the network circulation water (supplying and return water) has a significant influence on the level of geothermal energy utilisation for a certain temperature of geothermal water taken from the ground and for a given quantity of geothermal water. The return water temperature should be as low as possible.

Therefore, under real conditions, one should analyse the possibilities of heat utilisation for heating, hot tap water production and technological purposes taking into consideration possibilities of reducing the pumped geothermal water by decreasing the temperature return water of the district-heating network.

The small temperature difference between district heating water and geothermal water gives a narrow degree of geothermal energy utilisation. If the geothermal water temperature is high enough, parameters of the return district heating water have no influence on the amount of the transferred heat.

2 Possibilities of increasing utilization of geothermal heat

As was shown, the temperature of the pumped geothermal water, limited by the return district heating water, has significant influence on the maximal utilisation of geothermal energy. The district heating return water temperature should be as low as possible. In extreme conditions, conventional heating systems work at water temperatures 95/70°C. High return district heating water temperature significantly limits or eliminates the possibilities of using geothermal heat in water of a similar or lower temperature.

One may suggest that in such a situation, modernisation of the existing heating systems by replacing high temperature installations with low temperature ones would be most appropriate. The solution is, however, most often impossible – for many reasons. Therefore, decrease in temperature of the return water is another solution. Joining high- and low temperature installations is one of the solutions, too. Cascadeing various heat customers, requiring supply of a heat carrier of gradually lower and lower temperature is an example here.

The authors have made a series of analyses aiming at defining the influence of combining high- and low temperature heating installations for improving the degree of geothermal energy utilisation in a heating plant with a bivalent set where the geothermal source is supported by a conventional peak load boiler (Nowak and Stachel, 1999, 2000a, 2000b, 2001a, 2001b). Geothermal energy production is based on a doublet operation pumping system. Geothermal water is pumped through a heat exchanger and its heat is passed to the district heating water. The analyses are interesting because they relate to the possibility of modernisation of the existing, developed high temperature heating systems by implementing a geothermal element and increasing the efficiency due to gradual constructing low temperature installations. The results of the analyses were discussed below, on the example of chosen solutions of geothermal heating plants.

To evaluate the influence of using a low temperature heating element on the degree of geothermal energy utilisation with cascading groups of heat customers, it was assumed here that the heat produced in the central heat source is distributed to the consumers by means of the water main with the hot water circuit, which consists of the network supply-water pipeline as well as the network return-water line. The pipe network links the consumers with diversified heating systems. Some of those consumers have the conventional heating systems (the high-temperature ones) with the unit heaters, while others are connected to the low-temperature heating systems with the floor heating. Three different systems of combination of a geothermal power station with customers have been analysed.

First a scheme of geothermal power station is presented in Figure 3. District heating water heated in the geothermal heat exchanger flows to two parallel groups of heat customers. After giving the heat to the two customers, water is mixed and flows to the geothermal reservoir. A characteristic feature of a described system is that the feeding temperature of both groups of heat customers is the same in both cases and corresponds to the temperature resulting from the regulation graph for radiator-type heating. On the other hand, the heating water temperature at the outlet from both groups of customers is differentiated and independent from external temperature, which occurs in both cases.

The second system of the geothermal power station scheme is presented in Figure 4. This kind of installation can be found predominantly in newly designed and newly developed district heating systems with different, separated feeding of particular groups of low and high-temperature heat customers. In the presented system, heating water with different temperatures is directed to both kinds of heat customers. Temperature of heating water supplied to the radiator-type heating and floor-type heating results from regulation graphs corresponding to particular kind of heating.

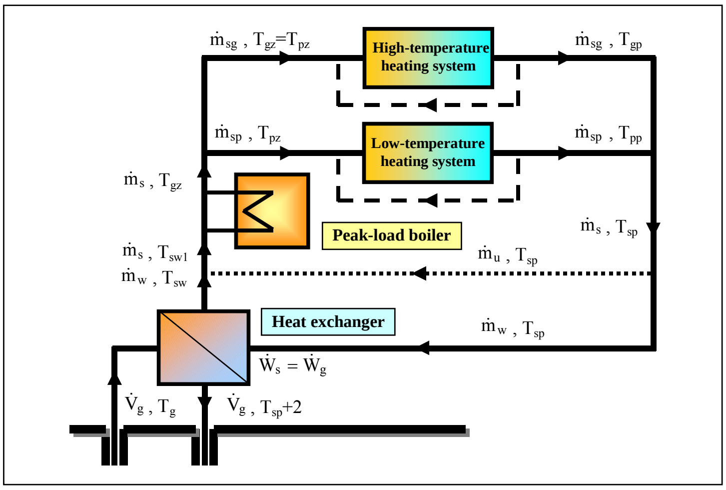

Figure 3: Scheme of a geothermal plant with the network supplying two parallel joint groups of heat customers (variant I).

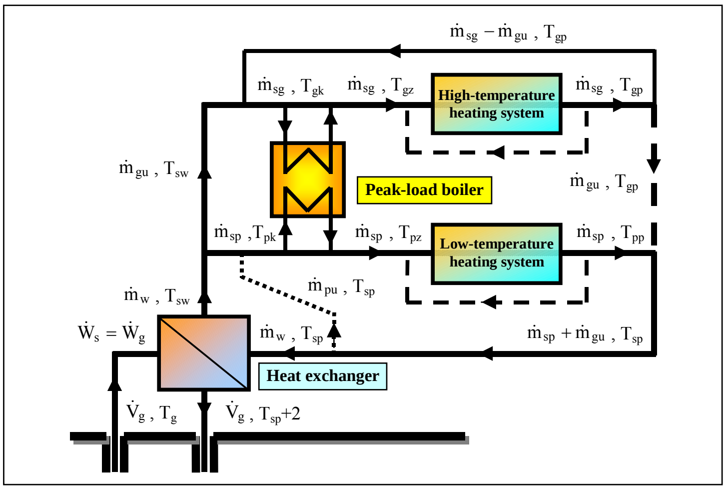

Figure 4: Scheme of a geothermal plant with the network supplying two parallel joint groups of heat customers (variant II).

The third system of the geothermal power station scheme is presented in Figure 5. In the presented system the applicable heat distribution network feeds that network water to the heat customers, connected in series. It is assumed that the network water of the required temperature is first fed to the customers for the high-temperature heating and then to those for the low-temperature heating.

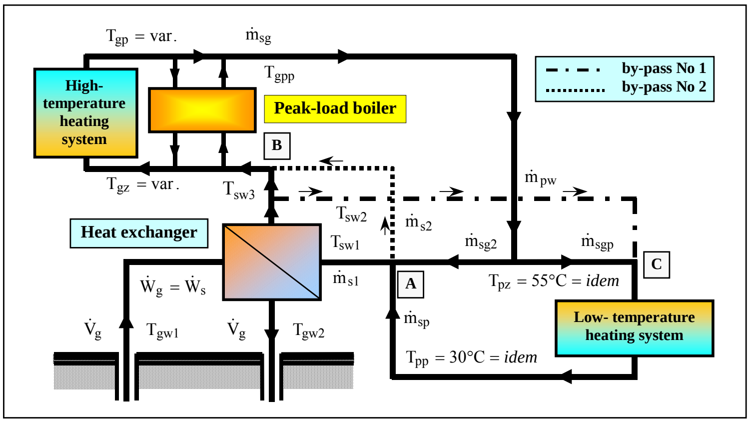

Figure 5: Scheme of geothermal plant operating jointly with a network supplying two groups of customers in a serial.

In all these cases, when the temperature of heating water beyond the heat exchanger is lower than required, which results from the regulation graph for a given kind of heating (i.e. radiator or floor-type), then a peak-load boiler is utilised, where heating water from the radiator-type heating or even floor-type heating attains the required temperature.

3 Results of the analysis

The calculations allowed the preparation of charts presenting the influence of share of low temperature heating on the degree of geothermal heat production for various parameters of geothermal water (Nowak and Stachel, 2000a). A sample chart for an installation with cascaded heating customers is presented in Figure 6. The chart for installations with a parallel connecting of heating customers is presented in Figures 7.

The analysis of the achieved calculation results regarding the influence of the type of heating on the degree of geothermal energy utilisation proved that both serial and parallel connecting of customers with high- and low temperature heating is very reasonable in achieving improved cooling of district heating return water and thus more effective utilisation of geothermal energy. Along with increase in low temperature heating share in the total heat consumption, the degree of geothermal energy utilisation increases. So, variants with floor heating share as high as possible are most favourable.

The influence of the type of heating on the degree of geothermal energy utilisation is more visible at low parameters of geothermal water withdrawal. If the geothermal water parameters (especially temperature) are high, the type of heating is not that significant as regards the amount of geothermal energy produced.

The calculations proved that the maximum amount of geothermal energy might be used in the case of customers equipped only with low temperature heating installations with the assumed maximal temperature of geothermal water and the minimal district heating return water. The lowest utilisation of geothermal energy takes place when geothermal water has low temperature and heat consumption is not effective.

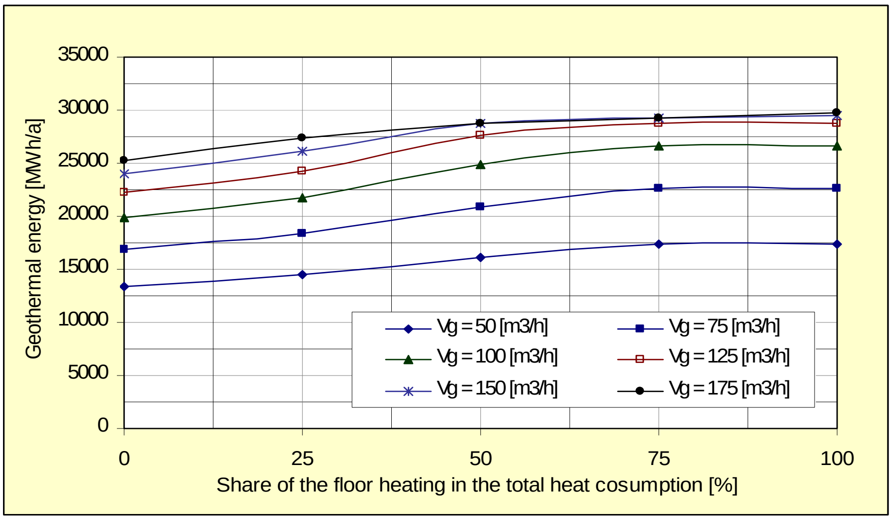

Figure 6: Geothermal heat utilisation as influenced by the volume flow of geothermal water Vg, and the share of floor heating, for high- and low-temperature heating systems connected in series (for temperature of geothermal water T_g = 75°C).

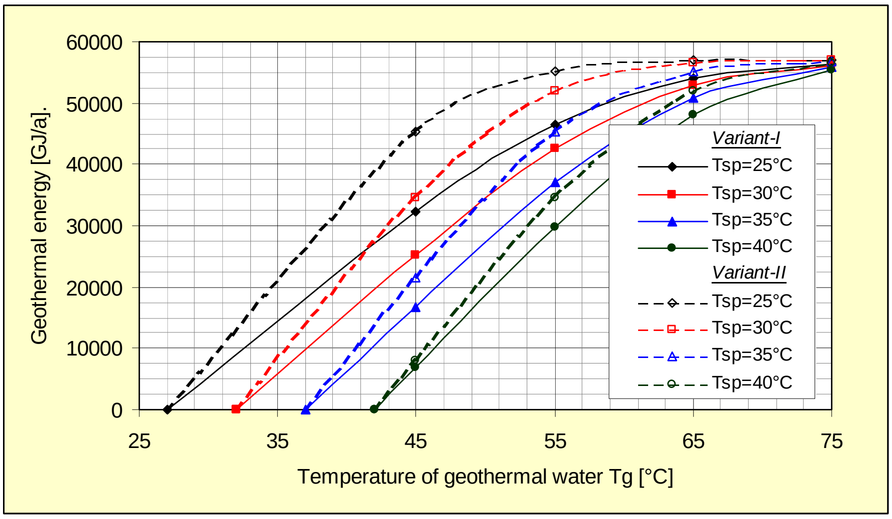

Figure 7: Amount of geothermal energy possible for utilisation in a geothermal plant in function of temperatures: extracted geothermal water (T_g) and return heating water (T_{sp}), for high- and low-temperature heating systems connected in parallel (variant I and II).

In the case of high temperature geothermal water, the influence of the temperature of the district heating return water decreases and, on the contrary, at low temperatures of geothermal water and increase of the temperature of the district heating return water, the amount of energy produced decreases.

4 Conclusions

The paper presents the evaluation possibilities of the utilisation of geothermal energy in geothermal plant co-operating with low- and high-temperature heating installations connected in parallel and in series. On that basis, the following conclusions may be drawn:

- detailed solutions and the effects of geothermal energy utilisation resulting from them, are closely dependent on local geothermal conditions and possibilities of the produced heat management,
- the amount of energy produced in the geothermal heat exchanger increases along with the increase of temperature of the water taken from the ground and the decrease in temperature of the district heating return water,
- in areas of low temperature of geothermal water, heat customers have a significant influence on the amount of energy produced. Small temperature difference between the district heating return water and the geothermal water allows for using the source potential to a very small extent,
- geothermal energy may be used to the largest extent in case of floor heating at maximal temperature of the water taken from the ground and the minimal temperature of the district heating return water. The smallest utilisation of geothermal resources is when geothermal water is of low temperature and heat consumption is not effective (high temperature of the return water),
- replacing high temperature heating with low temperature heating, particularly at lower geothermal water temperatures is a favourable solution,
- analysis of operation efficiency for a geothermal plant supplying two groups of heat customers presents the variant of the biggest possible share of floor heating as the most favourable. Floor heating, owing to the low temperatures of the return water, increases the efficiency of a geothermal plant significantly. But floor heating is maybe the most expensive alternative to increase the cooling of the district heating water. It is good, and pleasant, but expensive.
- a situation when a geothermal plant has a district heating network divided into a low- and high temperature heating system is a favourable solution.

5 Supplement

In Poland low-temperature heating installations are very few. A majority of buildings with remote central heating installations are supplied with heating water with temperature range as high as 95/70°C, where the first value regards the supply water temperature whereas the second one pertains to the return waters from the heat customers. These values correspond to so-called minimum external calculation temperature, which in the case of Szczecin is -18°C. Temperatures of supply heating water as well as the return water vary with external temperature. According to Polish calculation standards traditional heating systems have been designed (and still are) to conform to such extreme parameters of heating water.

In the case of large heating installations, encompassing large numbers of customers of heat supplied by the thermal power stations the heating water delivered to local heat distribution networks, the heating water has temperature of 150/70°C. In such exchange stations there takes place a transfer of heat from the heating water to the water circulating within the building, which has extreme temperature of 95/70°C. In Poland municipal district heating installations are very extensive and for example in Stargard the total length of the transmission networks in over 44,4 km, heat is delivered to about 1000 buildings (customers) and the thermal power station power is 98,9 MW.

A similar situation holds in a majority of towns, where there is a possibility of utilization of geothermal resources for heating purposes. Due to a fact that Polish geothermal resources are characterized by a low or medium enthalpy the possibilities of utilization of their energy in existing heating installations are rather limited. Available for utilization is only that part of energy, which results from the temperature surplus of extracted geothermal water to the return heating water from the heat customers. In the majority of cases concerned with the development of geothermal power plants it would be ideal if a complex modernization of heating installations in buildings (heat customers) was possible as well as transition to the low-temperature heating systems. Due to massive costs of such operation such solution cannot be considered, at least at the present economical situation of Poland. Therefore under Polish conditions the geothermal power can be utilized in a majority of cases as the supplementary source of energy aiding the conventional heat sources. Such status can be improved by implementation of for example heat pumps in power stations. Such situation can also be improved by incorporation of low temperature heating installations (60/30°C) to the existing ones (95/70°C). This leads to a reduction of the return heating water temperature going to the geothermal heat exchanger. Such issues have been discussed in the principal part of that paper.

The described concepts of the improvement of the degree of utilization of the geothermal energy in existing heating installations, stem from the parameters of Polish geothermal waters as well as the specifics of high-temperature heating installations. The problems of operation between the geothermal well and the heat customers are most pronounced on the examples of existing geothermal power plants in Poland. For example, the geothermal power plant in Pyrzyce uses the geothermal water with temperature of 63°C, geothermal power plant in Mszczonow – water with temperature of 41°C, whereas the heating installations in buildings are designed for heating water at 95/70°C. This gives rise to several operational, technical and economical problems (Meyer and Szaflik, 2001). The present paper is an attempt to provide answer to such problems.

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