Evaluation of operation of the geothermal heat plant supplied the mean-enthalpy geothermal water and co-operating with heat receivers connected in series

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Abstract

One of the conditions for rationalisation of geothermal water use is to enable the most efficient heat transfer between geothermal water and municipal water. In district heating networks utilising geothermal heat it is important to bring the return water temperature from the heat installations of recipients to the lowest level, so that it could determine the temperature of injected geothermal water [2,3]. In order to fulfil that condition it is advised to implement predominantly low-temperature heat receivers or at least combination of recipients having high-temperature installations with recipients having low-temperature installations, which enables effective cooling of municipal water [1,5-12].
Authors carried out analyses to determine the influence of parallel and series connection of high-temperature with low-temperature heating installations on improvement the utilisation of geothermal energy in a geothermal heat plant. The main purpose of this work was to evaluate how much the application of the low-temperature heating systems has an effect on the influence on the degree of the geothermal energy in the geothermal heat plant, which supplements the heat distribution network supplying two groups of heat receivers having the distinct shares in a heat consumption. These studies are very interesting because concern the possibility of utilisation the low- and mean-enthalpy geothermal water for heating purposes.
In this work there are presented the results of analysis of utilisation the geothermal energy in a geothermal heat plant supplied the mean-enthalpy geothermal water. This heat plant equipped in geothermal heat exchanger, absorption heat pump and peak load boiler co-operates with low- and high-temperature heating systems connected in series.

Keywords: geothermal energy, low-temperature geothermal water, geothermal heating plant,

Introduction

With respect to the temperature of extracted geothermal water and a value of return temperature of municipal water, independently from the system of geothermal energy extraction, there are two designs of installations on the geothermal water side used in the geothermal power station, namely:

- heat exchangers co-operating with peak-load boilers,
- heat exchangers with absorption heat pump and peak-load boilers.

The first solution is used for higher temperatures of geothermal waters and the second one is used in the case of lower temperatures of extracted water. The applied solution depends also on the temperature of feeding and return municipal water, which directly results from applied design of district heating network, i.e. kind and way of connection of heat receivers [1,2,4,6].

Conducted in the present work considerations will pertain to the problems connected with utilisation of geothermal heat plants equipped solely with a heat exchanger, heat pump and a peak-load boiler. In such installation acquisition of geothermal energy takes place by means of the heat exchanger, which transfers heat from geothermal water to the municipal water with a simultaneous use of a heat pump. A role of a lower reservoir in the heat pump is played by a part of return municipal water, which decreases its temperature with respect to the kind of used heat pump and in relation to the temperature of return municipal water. This water, together with the remaining part of municipal water, is directly flowing into the geothermal heat exchanger, where it is heated up the geothermal water. Supplementary to that installation is a peak-load boiler assuring (in the case of such necessity) heating up of feeding municipal water to the required temperature.

Analysed geothermal heat installation with a heat pump

In order to show the extent of practical capabilities of utilisation the mean-temperature geothermal waters energy in geothermal station installation, an analysis has been conducted of functioning of a selected geothermal systems co-operating with heat pump and a precisely defined heat receivers.
Analysis has been conducted for a two-borehole extracting system of geothermal water. In considerations it has been assumed that a geothermal station supplies heat to recipients having two differentiated types of heating installations. Part of recipients has traditional high-temperature installations with convection radiators and part is equipped with installations for low-temperature heating (floor-heating). The schematic of a geothermal heat plant is presented in Fig. 1.

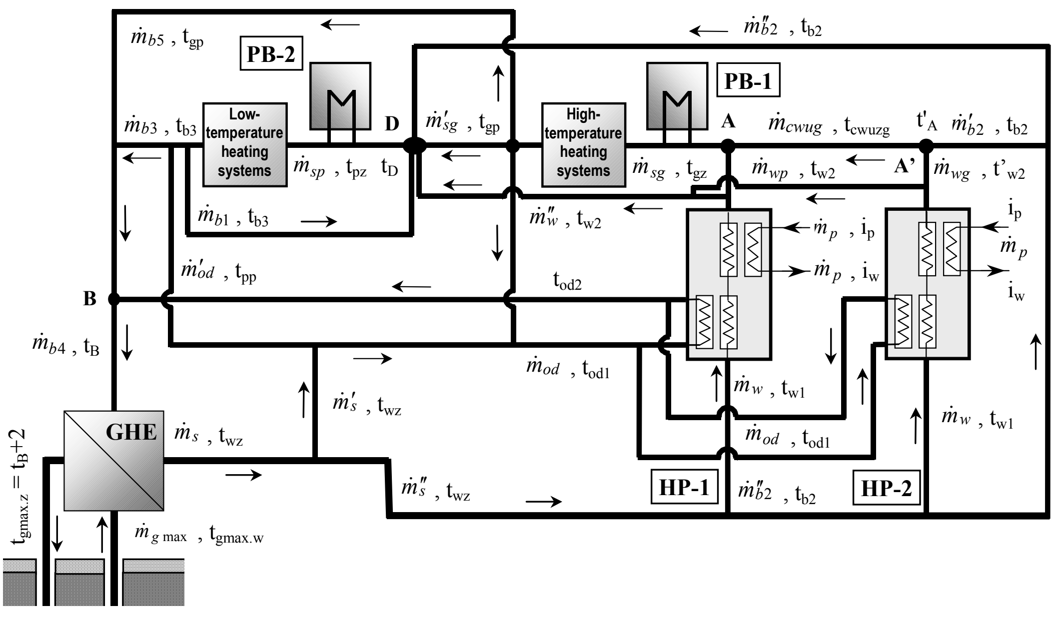


Fig. 1. Schematic of analysed installation of geothermal heat plant with the heat exchanger accompanied by heat pumps and peak-load boilers

The stream of geothermal water $\dot{m}_{g\max}$ with maximum temperature $t_{gmax.w}$ is supplied from the extracting well and then pumped by the heat exchanger GHE, where the heat contained in geothermal water in transferred to the municipal water. A cooled geothermal water with temperature $t_{gmax.z}$ is removed to the geothermal bed by the pumping well. In the analysed system it has been assumed that the temperature of municipal water on return from the heat recipients is lower than temperature of geothermal water.

Part of heated municipal water is directed to the absorption heat pump. In the system applied are two heat pumps HP-1 and HP-2. The first one operates in the heating period whereas the second one in the summer period. The remaining part of municipal water is supplied to, connected in series, high and low temperature (floor heating) heat receivers.

Temperature of municipal water t_{gz} at inlet to the high temperature receiver results from the regulation diagram and varies in accordance to the external temperature t_z . On the other hand the temperature of municipal water leaving the high temperature heating installation is constant and equal to $t_{gp} = 40\ ^{o}\mathrm{C}$.

Low temperature heating installation is fed with water with temperature not lower than $t_{pz} \geq 55\ ^{o}\mathrm{C}$. Water temperature at outlet is constant and in the considered case is equal to t_{pp} = 30 ^{o}C. The level of heat flux received by the floor heating receivers is controlled by the water temperature at inlet to the receiver (a qualitative regulation at $t_{pz} \geq 55\ ^{o}$C), similarly as it was in the case of the high temperature (radiator) heating. If the heat demand for floor heating will decrease so that $t_{pz} = 55\ ^{o}$C, then the system switches from the qualitative regulation to the quantitative regulation. Such transition is reinforced by the fact that at inlet to the floor receivers temperature cannot by lower than 55 ^{o}C, and hence further regulation of the amount of supplied heat takes place by the adjustment of water flow rate flowing through those receivers.

If temperature of water supplied to the heating installation is lower than the required one then there is a possibility of its heating in the peak boilers PB-1, PB-2 to the required temperature.

Part of municipal water leaving the floor and radiator heating installations is directed the heat pump evaporators (lower heat source), where it is cooled by 10 K. In such case the flow rate of municipal water $\dot{m}_{od}$ is constant and its value depends only on the useful power of heat pump (type of the pump). The remaining part of municipal water from the floor heating installation is directed directly to the geothermal heat exchanger. Steam serves as a driving medium for the heat pump.

Assumptions for calculations

Discussed above design of geothermal installation provided grounds for determination of real amounts of geothermal energy produced in the heat exchanger of a geothermal plant and possible for utilisation by heat recipients.

In calculations it has been assumed that a value of a maximum heat flux for heating purposes is $\dot{Q}_{comax}$ = 8000 kW. The heat flux for hot water conditioning is $\dot{Q}_{cwu\max}$ = 1200 kW.

Maximum values of feeding municipal water for a minimum external temperature $t_z = -16\ ^{0}$C, are respectively taking values: for high-temperature heating $t_{gzmax} = 95\ ^{0}$C; for low-temperature heating $t_{pzmax} = 60\ ^{0}$C.

Mean temperatures of return municipal water are constant and in various variants of calculations these were assumed values: for high-temperature heating $t_{gp} = 40\ ^{0}$C; for low-temperature heating $t_{pp} = 30\ ^{0}$C.

Temperature of extracted geothermal water is constant and in the case of different variants it has been assumed the following values t_g = 40, 45, or 55 ^{0}C. Volumetric rate of geothermal water $\dot{V}_g$ = 200 [m^3/h].

Evaluation of the degree of geothermal-energy use was made for two types of heat receivers connected in series, and for five alternative designs (the Variants) represented the different shares of the high- and low-temperature heating, $\dot{Q}_g = \varphi \dot{Q}_c$ and $\dot{Q}_{cp} = (1-\varphi)\dot{Q}_c$ respectively, in the total heat generation $\dot{Q}_c$, namely:

Table 1. Share of the kind of heating in particular installation variants

Share of:	Variant number				
	1	2	3	4	5
- high-temperature heating (φ)	0,0	0,25	0,5	0,75	1,0
- low-temperature heating (1- φ)	1,0	0,75	0,5	0,25	0,0

Results of calculations

From conducted calculations and constructed graphs for particular variants of both systems presented below will only be selected graphs, which present potential and real possibilities of utilisation of geothermal energy in a analysed geothermal plant.
The results of calculations revealing particular heat fluxes for all analysed variants for the installation operating in the heating period are presented in Table 2.

Table 2. Results of calculations of heat fluxes for analysed variants

Variant	$t_{gmax.w}$ [°C]	Q_c [MWh]	Q_{cg} [MWh]	Q_{cp} [MWh]	Q_k [MWh]	Q_{od} [MWh]	Q_{np} [MWh]	$Q_{uż}$ [MWh]	Q_{cwu} [MWh]	Q_g [MWh]
1 A	45	21096,6	0,0	21096,6	4914,1	2297,5	3289,1	5586,6	5241,6	12893,5
1 B	50	21096,6	0,0	21096,6	3467,1	1227,4	1755,9	2983,3	5241,6	15873,9
2 A	45	21096,6	5274,1	15822,5	5757,92	2721,2	3987,9	6709,2	5241,6	11350,9
2 B	50	21096,6	5274,1	15822,5	4437,0	1686,0	2406,7	4092,8	5241,6	14252,9
2 C	55	21096,6	5274,1	15822,5	3741,5	777,5	1083,2	1860,7	5241,6	16271,9
3 A	45	21096,6	10548,3	10548,3	8092,7	2721,2	3987,9	6709,2	5241,6	9015,2
3 B	50	21096,6	10548,3	10548,3	6086,2	2297,5	3289,1	5586,6	5241,6	11721,4
3 C	55	21096,6	10548,3	10548,3	5108,5	1686,0	2406,7	4092,8	5241,6	13581,3
4 A	45	21096,6	15822,5	5274,1	10627,4	2721,2	3987,9	6709,2	5241,6	6481,2
4 B	50	21096,6	15822,5	5274,1	8973,1	2297,5	3289,1	5586,6	5241,6	8834,58
4 C	55	21096,6	15822,5	5274,1	8706,3	1227,4	1755,9	2983,3	5241,6	10634,3
5 A	45	21096,6	21096,6	0,0	8091,1	4450,9	6364,1	6709,2	5241,6	6642,8
5 B	50	21096,6	21096,6	0,0	8542,2	2721,2	3987,9	6709,2	5241,6	8566,4
5 C	55	21096,6	21096,6	0,0	8614,8	1227,4	1755,9	2983,3	5241,6	10725,8

* interpretation of used symbols in the end of the paper

To make the analysis simpler obtained results have also been presented in the form of graphs (Fig. 2 - Fig. 6), where presented is utilisation of geothermal energy as well as the amounts of supplied external energy to the respective variants of installations. Other interesting results of calculations have been presented in [1,2].

Discussion

Obtained results can be considered in a twofold manner, with respect to temperature of extracted geothermal water $t_{gmax.w}$ and with respect to considered variants stemming from a share of particular types of heating in the total heat demand.

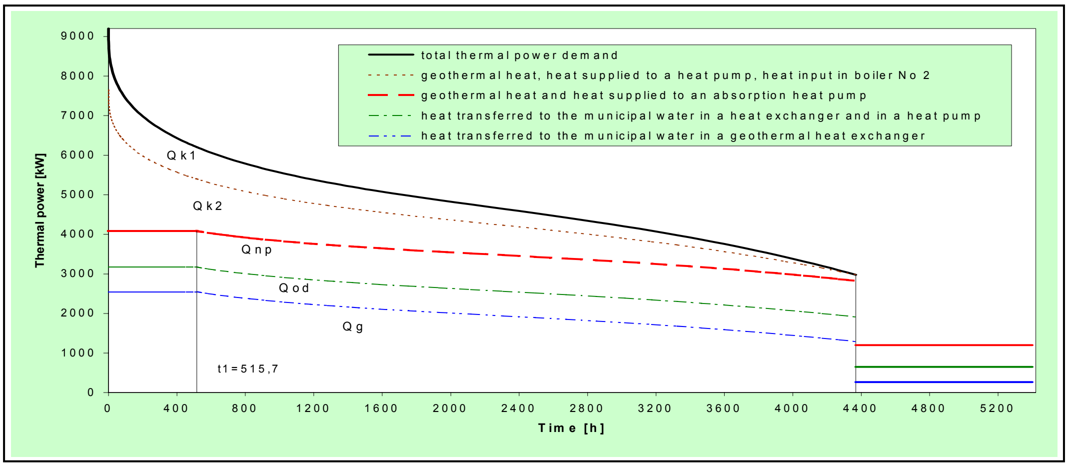


Fig. 2. The diagram of the heat demand and heat utilisation as a function of time (for variant 2A)

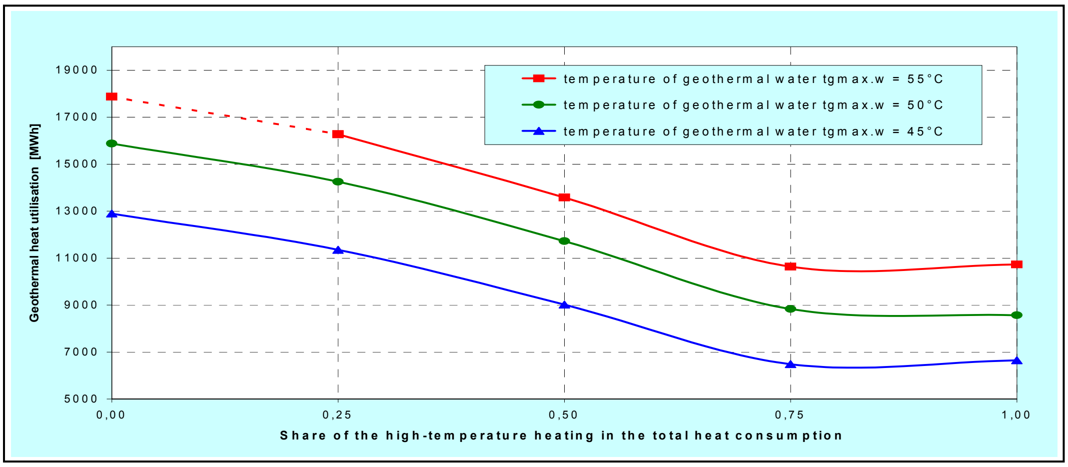
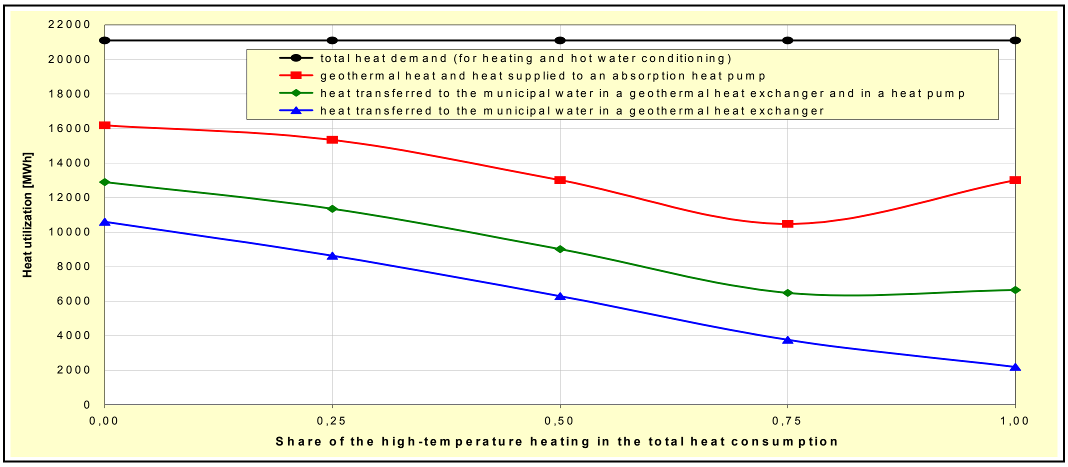
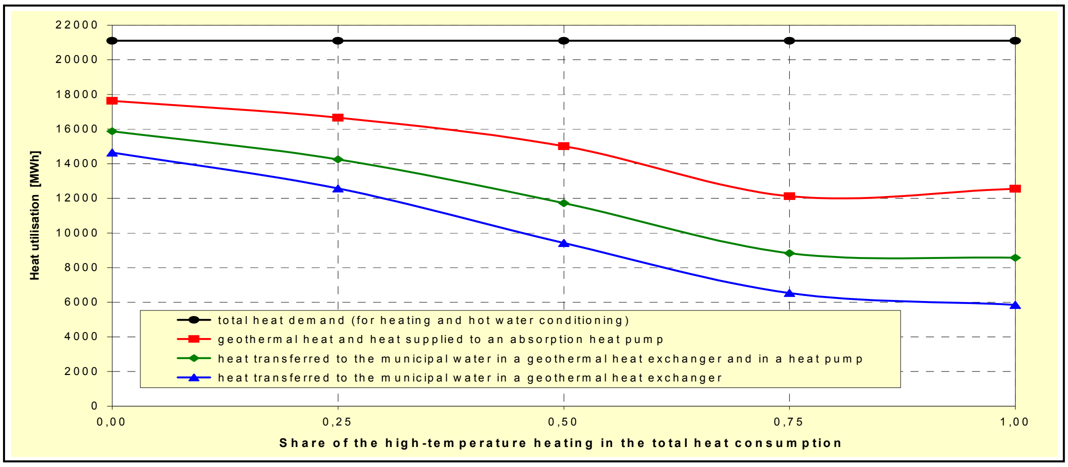


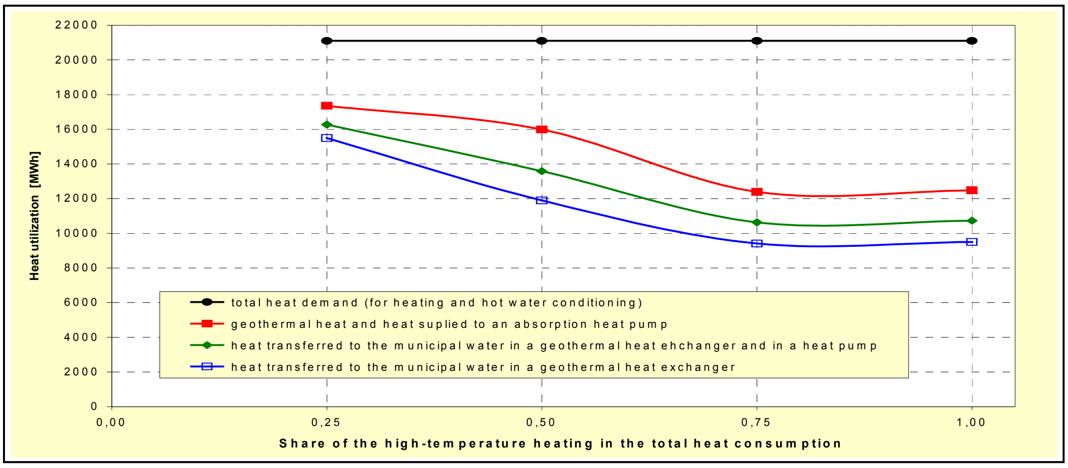
Fig. 3. Geothermal heat utilisation as influenced by the temperature of geothermal water $t_{gmax.w}$, and the share of low-temperature heating in total heat consumption



Rys. 4. The heat utilisation as a function of share of the high-temperature heating system in total heat consumption, for $t_{gmax.w} = 45\,^{0}C$



Rys. 5. The heat utilisation as a function of share of the high-temperature heating system in total heat consumption, for $t_{gmax.w}$ = 50 ^{0}C



Rys. 6. The heat utilisation as a function of share of the high-temperature heating system in total heat consumption, for $t_{gmax.w}$ = 55 ^{0}C

Taking into consideration temperature of geothermal water, then the option when $t_{gmax.w}$ = 55 ^{o}C must be regarded as most beneficial. Then the degree of utilization of geothermal energy is at its outmost. At the same time the extent of energy, which must the supplied in the pear boiler, is reduced as well as the driving energy for the heat pump.

Analysing the results of calculations with respect to the shares of high and low temperature heating in the general heat consumption it can be concluded that for all temperatures of extracted geothermal water the most advantageous can be regarded variant 1 and 2 (maximum share of low-temperature heating). In such variants utilisation of the source of geothermal energy is the outmost and hence the share of supplied energy to the peak boiler and heat pump is the lowest. Taking into account utilisation of geothermal energy the difference between variants 4 and 5 is almost not perceptible and selection on any of any one is of less importance.

Apart from the heating period in all variants and at temperatures $t_{gmax.w}$ = 45 and 50 ^{o}C the demand for the utility hot water is covered by geothermal water and the heat pump. On the other hand at $t_{gmax.w}$ = 55 ^{o}C the demand is covered by the geothermal water and the peak boiler.

From the conducted synthetic analysis of obtained results the following final conclusions can be drawn:

- real amount of geothermal heat which can be removed in a geothermal heat exchanger results from the operational parameters of geothermal installation,
- amount of heat removed in the geothermal heat exchanger increases with increase of temperature of extracted water and reduction of temperature of return municipal water,
- transition from the high-temperature to the low-temperature heating is beneficial, particularly at lower temperatures of geothermal water,

Conclusions

The principal objective of the work was to present the degree of utilisation of energy of geothermal waters of average enthalpy, resulting from operation of a geothermal power plant co-operated with the heat pump and a district heating network feeding differentiated receivers of thermal energy connected in series.
On the basis of conducted calculations we can conclude that from the economical point of view as well as ecological the most appropriate variants are 1, 2 and 3, where utilisation of the sources of geothermal energy are outmost and the quantity of supplied energy for the pump driving and into the peak boiler is the innermost. In the case of variant 4 and 5 utilisation of the geothermal energy source is smallest, particularly at the low temperature of geothermal water. In all variants the lower the temperature of geothermal water $t_{gmax.w}$ the higher the installed heat pump thermal power. Application of heat pump increases the degree of utilisation of geothermal energy and reduces the amount of heat supplied to the peak boiler.
Selection of one of the analysed variants is dependent on the enthalpy of the geothermal source and the needs of specific group of recipients.

Nomenclature

Q_c	- total heat demand
Q_{cg}	- heat demand for high-temperature heating purposes
Q_{cp}	- heat demand for low-temperature heating purposes
Q_k	- heat transferred to municipal water in a boiler
Q_{od}	- heat recuperated in a heat pump
Q_{np}	- heat supplied to a heat pump
$Q_{uż}$	- heat transferred to municipal water in a heat pump
Q_{cwu}	- heat demand for a hot water conditioning
Q_g	- geothermal heat (transferred to municipal water in a geothermal heat exchanger)

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