IMPLEMENTATION OF HEAT PUMPS IN GEOTHERMAL INSTALLATIONS UTILISING LOW AND MEDIUM ENTHALPY WATER

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Abstract

Poland has significant resources of geothermal waters with low and medium enthalpy. A solution enabling rational exploitation of these resources is implementation of heat pumps in systems of geothermal power stations. In the paper presented have been general principles of implementation of heat pumps supplemented by a description of geothermal power stations with heat pumps present in Poland.

KEYWORDS

geothermal energy, geothermal water, utilisation of geothermal energy, heating pump

INTRODUCTION

Poland belongs to countries having significant resources of geothermal water with low and medium enthalpy [2,3,4,6]. According to Sokolowski these resources amount to about 6500 km^3 and are evenly distributed in the majority of Polish territory. An important issue of their utilisation is the fact that there is only a small fraction of resources where temperature exceeds 90 ^{0}C. Majority of resources has temperatures, which qualify them to the warm thermal waters (20-35 ^{0}C) or hot thermal waters (35-80 ^{0}C). Due to that fact in the majority of cases it is impossible to utilise them in existing heating installations, where traditionally required is water with temperature 95/70 ^{0}C.

Authors have conducted several analyses regarding utilisation of geothermal energy for heating purposes [7-10]. Performed works regarded utilisation of geothermal waters in various heat receiving installations. The conclusions resulting from there indicate that for example implementation of a low-temperature heating increases the degree of utilisation of geothermal energy, and such influence is greater the greater in the share of such heating in the general amount of received heat [7,8,9,10]. Therefore, one of the ways of improving the effectiveness of operation of geothermal power plant is to utilise low-temperature systems of heat receivers. Such solution gives good results in utilisation of geothermal energy with temperatures from the upper end of hot thermal waters. Applicability of suggested designs decreases with the attempts of utilisation of water geothermal waters (30 – 40 ^{0}C).

UTILISATION OF GEOTHERMAL WATER ENERGY

A basic schematic of a geothermal power plant has been presented in Fig. 1. This is a classical system, where geothermal water from the extraction well is supplied to the counter-current geothermal heat exchanger, where it gives its heat away and subsequently it is pumped back into the water-bearing layer. A supplement to such installation is a peak-time boiler, which is used only then when the heat received by the network water from the geothermal water is insufficient to cover the demand as well as when temperature of network water beyond the heat exchanger is lower than that required by the system control diagrams. Such installation can subsequently be extended to incorporate the heat pump. In case of the heat pump the lower heat source is usually the return network water, which reduces its temperature depending on the applied heat pump and municipal water temperature [2,5,6].

A detailed assessment of the possibility of acquiring heat in geothermal heat exchanger has been extensively described in [6,7]. The amount of heat available is dependent upon the characteristics of the geothermal resource, which can be presented in the form of relevant diagrams, where one in presented in Fig. 2. It results from that diagram that the rate of acquired geothermal energy depends on the volumetric rate of extracted geothermal water, its temperature and the temperature drop in the heat exchanger.

It ought to be stressed that the presented diagram determines only potential possibilities of acquisition of geothermal energy, which is not consistent with its utilisation.

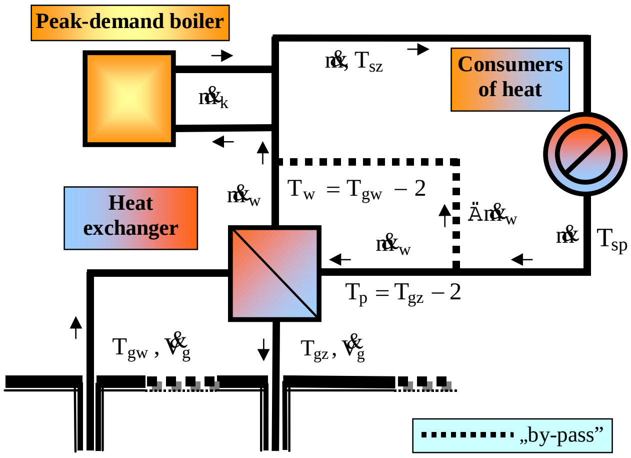

Fig. 1. Schematic of geothermal power plant installation incorporating heat exchanger and peak-time boiler

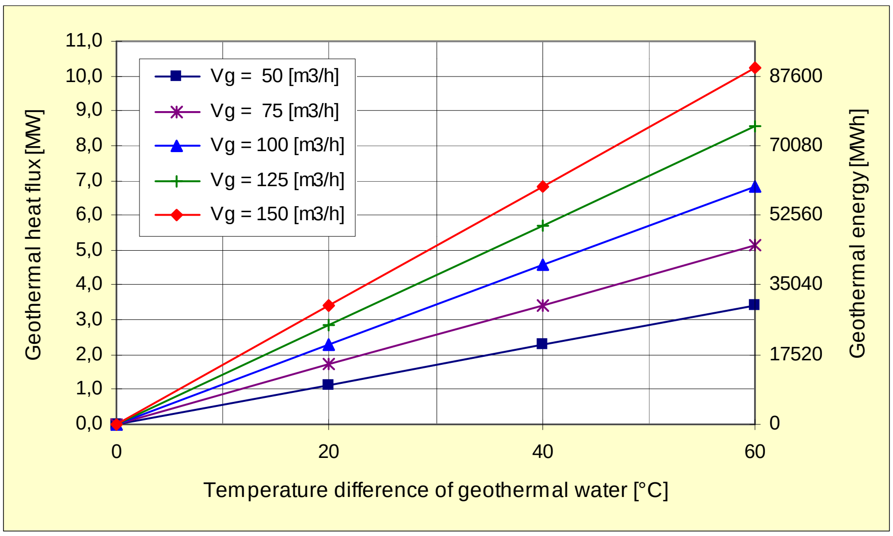

Fig. 2. Potential possibilities of acquisition of geothermal energy from the geothermal resource

The degree of utilisation of geothermal energy, at a given temperature and rate of extracted water, is strongly influenced by the temperatures of supplying and return municipal water, where the latter should be as low as possible.

HEAT PUMPS IN GEOTHERMAL INSTALLATIONS

If extracted geothermal water has a lower temperature or just above from the return municipal water then utilisation of low and medium-temperature thermal waters is impossible or not economically viable. A solution to that problem, enabling exploitation of such resources, is implementation of heat pumps in the system.

The objective of the heat pump is to receive heat from the body with lower temperature and transferring it, together with the driving energy, to the body with higher temperature. Realisation of such process requires supplying to such heat pump of an additional driving energy, for example in the form of electric energy (compressor heat pump) or thermal energy (absorption heat pump) [1,6,11,14]. In geothermal installations utilised are both kinds of heat pumps, which will be presented in the following part of the paper. In practice, in large centralised heat sources better effects are obtained using the absorption heat pumps.

Compressor heat pumps are used in many areas connected to utilisation of low-temperature energy of the ground, subterranean waters, water-courses, etc. as well as waste energy. These are mostly equipment with small and medium power. Principles of operation and applications of such pumps are discussed in a greater detail in [1,6,11,14] and therefore will not be considered here. Knowledge about absorption heat pumps, on the other hand, is scarce and therefore in order to familiarise the reader with that subject presented below will be construction and principle of work of such systems on the example of Sanyo heat pumps.

A schematic of absorption heat pump is presented in Fig. 3 [6]. The heat pump consist of four major elements: absorber, generator sometimes named boiler or desorber, condenser and evaporator. In the generator and condenser attached to it there is pressure more or less equal to atmospheric pressure. Absorber and evaporator are located in the same container, where a very low pressure is present. Between the absorber and generator there circulates the solution of lithium bromide. Water rich solution is heated in the generator to obtain boiling temperature, and subsequently steam leaves the solution to go to the condenser. The driving fluid for the process is hot water (or steam) with temperature of about 160 ^{0}C, which is produced in the high-temperature boiler.

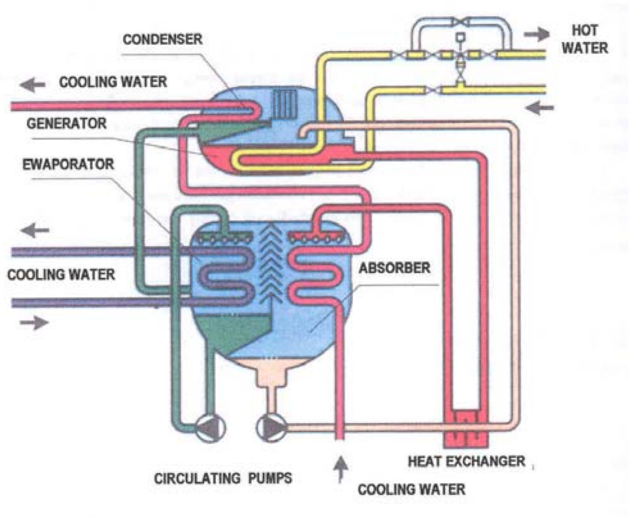

Fig. 3. Schematic of absorption heat pump made by Sanyo [6]

Remaining solution, which is rich in lithium bromide, returns through the heat exchanger to absorber. Steam reaching the condenser condenses on tubes, where inside there is a flow of municipal water. Heat transfer between condensing steam and municipal water renders heating of the latter up to temperature of 80 ^{0}C. The condensate flows down to the evaporator, where by means of the circulation pump, it wets the heat exchanger tubes, where there is geothermal water or the return municipal water. Very low pressure existing in the evaporator renders water evaporation on the external surface of the tubes of the heat exchanger at low temperature and gaining heat from water flowing inside them. The saturated steam produced under such circumstances goes to the neighbouring absorber, where it is being absorbed by the solution of lithium bromide returning from the generator. Diluted solution of lithium bromide is subsequently pumped through the regeneration heat exchanger back to the generator.

If highly mineralised geothermal water is used then the evaporator must be supplied with the treated municipal water instead of aggressive geothermal water. Conducted analyses indicate a high effectiveness of utilisation of absorption heat pumps in geothermal power plants. The coefficient of performance in such heat pumps is equal to 1.7 [15].

HEAT PUMPS IN POLISH GEOTHERMAL POWER PLANTS

In Poland there are six power plants utilising the energy of warm and hot geothermal waters. The majority of them are typical bivalent systems consisting of geothermal heat exchangers and peak-time boilers. Some of them are additionally equipped with heat pumps to improve installation efficiency and enabling to a greater extent utilise the energy of low-temperature thermal waters. A characteristics of thermal power plants equipped with heat pumps is presented below.

Pyrzyce geothermal heating system

In 1996 in Pyrzyce there was commissioned a large combined gas and geothermal power station of 50 MW power, where the power of geothermal side is 13 MW_t [6,12]. The power plant utilises the resources of geothermal water existing at the depth of 1500 - 1650 m which are characterised by the layer average temperature of 60 - 65 ^{0}C and salinity of the order of 120 g/l. Heat obtained in the geothermal power plant serves for heating of buildings and preparation of utility hot water in a specified part of the town. For a more efficient utilisation of geothermal energy incorporated into the system have been absorption heat pumps manufactured by Sanyo o 8 MW power each (Fig. 7), driven by thermal energy produced in high-temperature boilers. A simplified schematic of installation is presented in Fig. 4.

The power plant co-operates with two extracting - pumping dublets. Geothermal water extracted from the well with temperature of 61^{0}C flows through a set of filters and then reaches the counter-current heat exchangers. In the first heat exchanger heat contained in geothermal water is transferred to the return municipal water with temperature of 40 ^{0}C (45 ^{0}C in summer), which heats up to reach temperature of 60 ^{0}C. On the other hand the geothermal water initially cooled to temperature of 44 ^{0}C reaches the second heat exchanger, where it is further cooled down to temperature of 26 ^{0}C, and then after passing through a filter is pumped back to the same water-bearing layer.

In the second geothermal heat exchanger heated is a part of return municipal water, which earlier gave away heat in absorption evaporators of heat pumps and was cooled there from temperature of 40 ^{0}C (45 ^{0}C) down to temperature of 25 ^{0}C. In the present heat exchanger municipal water is heated up to temperature of 41^{0}C.

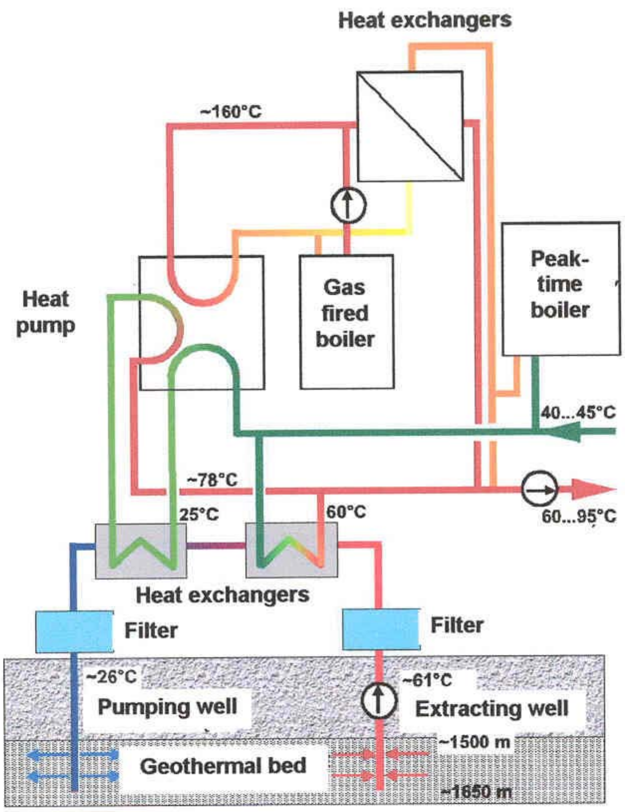

Fig. 4. Simplified schematic of Pyrzyce geothermal power plant [6]

The stream of heated water in the first geothermal heat exchanger is additionally fed with the streams of hot water from absorbers and heat pump condensers, as well as economisers of peak-time and high-temperature boilers. The water stream leaving the first geothermal heat exchanger reaches the auxiliary high-temperature heat exchanger or the peak-time boiler, where it is heated to the required by recipients temperature.

An important element of the whole system is circulation of water supplying the heat pump desorbers. Such water circulates in the cycle consisting of absorption heat pumps, gas-fired high-temperature boilers and, if necessary, high-temperature auxiliary heat exchanger. In specific cases such water can supply the high-temperature heat exchanger, where it heats up to the required temperature the municipal water from the major water main.

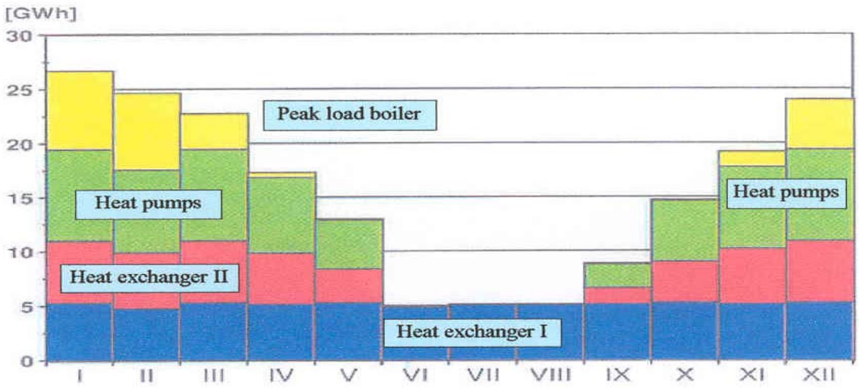

Fig. 5. Structure of heat production in Pyrzyce geothermal power plant [13]

Structure of heat production in the gas-geothermal power plant in Pyrzyce is presented in Fig. 5. Respective shadowed areas denote the amount of heat supplied by the geothermal heat exchangers I and II, absorption heat pumps and gas boiler. The heat exchanger I supplies heat over the period of the whole year. Heat exchanger II is switched into operation together with absorption pumps in the heating period. Peak-time gas boilers operate only in the coldest months of heating period.

Mszczonów geothermal power plant

A simplified schematic of geothermal power plant is presented in Fig. 6. Geothermal water with temperature of about 42°C is extracted from the bed in extraction well Mszczonów IG-1 and is subsequently pumped to the thermal power station in the centre of Mszczonów. Such water is characterised by a very low mineralisation degree (~ 0,5 g/l), which enabled subsequently to use such water as a drinking water and in effect to resign from its pumping back to the water-bearing layer.

In the thermal plant water flows first through the economiser of the high-temperature boiler, where it is heated up to temperature of about 44 ^{0}C, and then through the absorption heat pump (Fig. 8), where it is cooled down to temperature of about 20 – 30 ^{0}C. The source of driving energy for absorption heat pump of the power of 2.7 MW is a high-temperature boiler of the power of 1.9 MW.

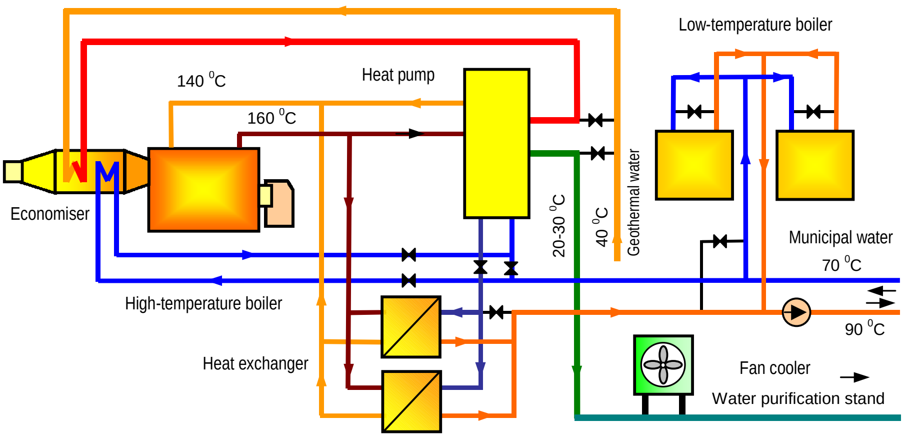

Fig. 6. Schematic of Mszczonów geothermal power plant

Cooled geothermal water is directed to the fan cooler and then to a neighbouring water treatment plant. In the period of low temperatures, in order to cover the peak demand for heat, there are two low-temperature water gas-fired boiler with 2.4MW power each. The peak power of the entire installation is 12 MW_t.

Fig. 7. Absorption heat pumps in Pyrzyce

Fig. 8. Absorption heat pumps in Mszczonów

Geothermal installation at Słomniki near Cracow

A different design of the geothermal power plant operates at Słomniki. In that case utilised are low-temperature thermal waters with temperature of +17 ^{0}C, extracted from the depth of 300 metres by means of three extraction wells. Due to rather low temperatures of extracted geothermal water the thermal plant doe not have a geothermal heat exchanger. Extracted water serves as a lower heat source for compressor heat pumps located in heated objects and the peak-time boiler house. In installation there have been installed total of 13 compressor heat pumps made by Oschner and Secespol-Cetus. The peak-time boiler is equipped with three low-temperature water boilers. Two of them are gas-fired and the other one is oil-fired.

After utilisation geothermal water is dumped to the sewage system. The major objective of the installation is heating and preparation of utility hot water in co-operation with existing heat source. The process of buildings' heating in following: in the case of external temperatures above 0 ^{0}C particular objects are heated by means of heat pumps utilising energy of geothermal water. In the case of external temperatures below 0 ^{0}C switched on are peak-time boilers, which have to ensure required temperatures of municipal water supplied to the specific recipients. The thermal power of the geothermal point is estimated to the about ~ 3,5 MW.

GEOTHERMAL PLANT WITH HEAT PUMP

An example of considerations regarding the improvement of geothermal energy in installations incorporating heat pumps is presented in [11]. Amongst the others analysed has been a system presented in Fig. 9. A single pumping - extracting dublet co-operates with the geothermal heat exchanger. The thermal plant is equipped with absorption heat pump, which aim is to reduce temperature of return municipal water in the geothermal heat exchanger as well as increasing of temperature of water directed to the heating system, which in effect influences the amount of heat removed from the geothermal water. Produced heat is supplied to the recipients equipped with low-temperature floor-heating systems (Q_{comax} = 8000 kW). Existing periodical heat surpluses are used for preliminary heating of technological water.

Extracted from the well geothermal water flows to the heat exchanger, where it transfers heat to the municipal water and then it is pumped to the geothermal bed using the pumping well. Municipal water heated in the geothermal heat exchanger (T_{wsz}, m_{ws}) flows to the absorption heat pump (T_{w1}, m_{wpa}), where it is heated to temperature T_{w2}. From the heat pump water is directed through the mixing point A (T_{wsA}) to the floor-heating installation. The flowrate of water ($\dot{m}_{sp}$) can be additionally heated in the peak-time boiler in order to achieve required temperature (T_{pz}), which results from the installation control diagram.

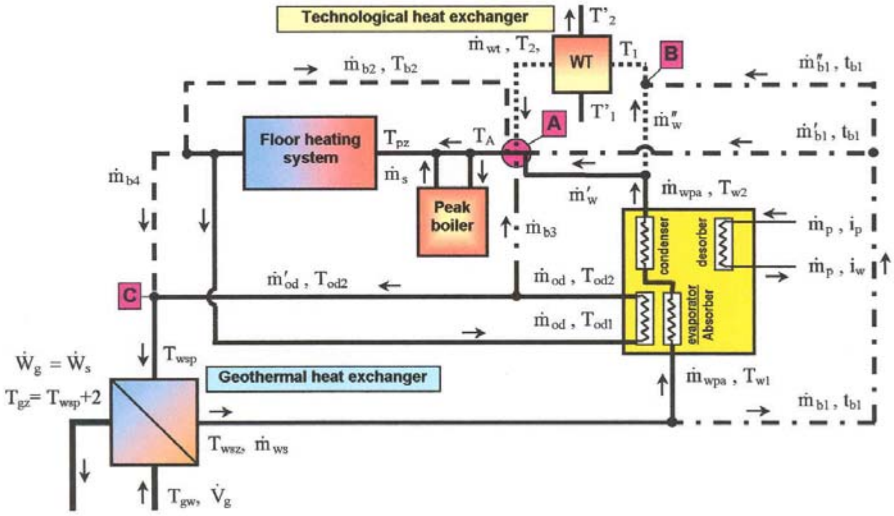

Fig. 9. Schematic of geothermal installation with absorption heat pump

Water leaving the floor-heating installation ($T_{pp} = T_{od1}$) is directed first to the heat pump evaporator, where it reduces its temperature down to (T_{od2}), and then to the geothermal heat exchanger (T_{wsp}). The driving energy for absorption heat pump is a high-temperature gas-fired boiler producing steam (i_p, $\dot{m}_p$), which is supplied to the heat pump desorber.

An important element of the analysis was calculation of a total heat demand for heating purposes Q_c, together with heat supplied in the geothermal heat exchanger Q_g, heat produced in the peak-time boiler Q_k and finally the driving heat for the heat pump Q_{np}. Performed calculations regarded several variants resulting from assumed values of temperatures of geothermal water and analysed (assumed) temperatures of return municipal water leaving the installation of floor-heating. The details have been presented in [11].

Sample calculations regarding only one selected variant performed for the geothermal water ($V_{gmax} = 150\ m^3/h$, $T_{gw} = 42°C$), at assumed constant temperature of return municipal water returning from the floor-heating installation $T_{pp} = 25\ ^0C$ have been presented graphically in Fig. 10.

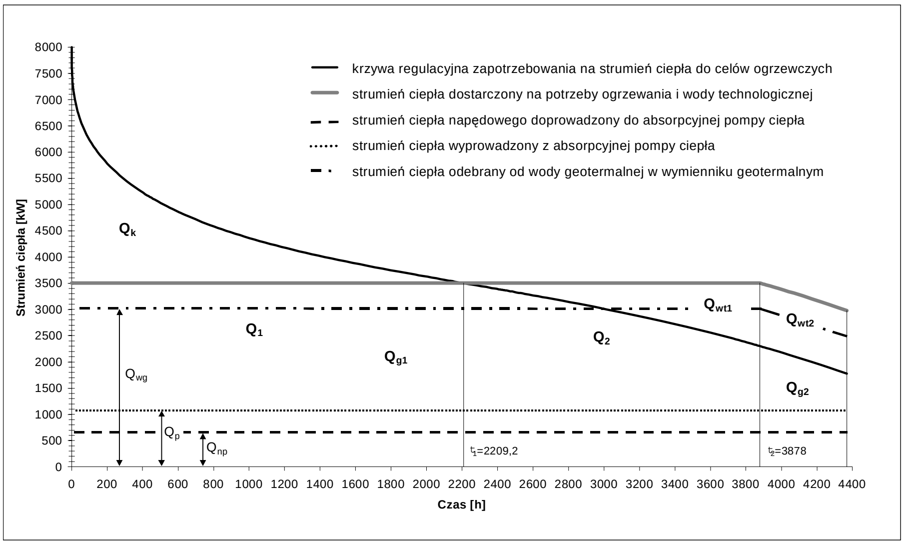

Fig. 11. Demand and utilisation of heat in function of time and temperature: $T_{gw} = 42\ ^0C$, $T_{pp} = 25\ ^0C$

On the basis of obtained results it can be concluded that introduction of heat pump into the system of geothermal power plant contributes, despite relatively low parameters of geothermal water, to obtaining significant amounts of heat from such water.

At the same time, thanks to the heat pump, there are increased the parameters of supply municipal water, which in effect enables more rational utilisation of geothermal heat and reduction of the amount of heat to be introduced in the peak-time boiler.

SUMMARY

Poland has significant resources of geothermal waters with low and medium enthalpy. According to the existing evaluations there are possibilities of utilisation of over 66% of these resources. Analyses conducted by the authors indicate unanimously that even resources with low-temperatures can be used for heating purposes, when these are applied as a low-temperature heat source for heat pumps. To confirm that there are already operating geothermal plants in Poland equipped with heat pumps. These utilise the water temperatures ranging from +17 ^{0}C to + 63 ^{0}C, supplying heat for heating purposes and preparation of utility hot water. More detailed information about these and other thermal plants, both existing and planned in Poland, can be found in the abundant literature on that topic.

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