POSSIBILITIES TO USE THE ENERGY OF GEOTHERMAL WATER IN A CENTRALIZED HEATING SYSTEM

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The paper analyzes the possibilities of increasing energy efficiency of an existent centralized heating system from Calimanesti City, Valcea County, which uses geothermal water. The analysis of the utilization a heat pump to recover the heat from the hot waste geothermal water, with a temperature over 50°C, it is highlights a rising of the heat system efficiency with 133%, in relation to current mode of exploitation. Also, it was analyzed the use of the associated combustible gases to acting a micro gas turbine cogeneration unit to enlarge the capacity of the system. It was highlighted the possibility of an independent functioning of the heating system, without any fuel consumption from another sources.

Keywords: geothermal water; cogeneration; micro gas turbine cogeneration unit

1. Introduction

In our country was discovered many geothermal resources, in particular in the Western Zone, on the Olt Valley and in the Capital Area. Based on the boreholes existing in operation, in literature is mentioned a thermal energy available annually over $2\cdot10^6$ MWh, equivalent with $1{,}7\cdot10^5$ toe [1], [2], [3]. This energy is utilised in particular in the Western Zone for preparing thermal agent used in urban district heating systems, for direct heating of the individual houses and for thermal baths in the hotels and balnear units. The thermal waters from the Romanian subsoil, having temperatures between 60 and 100 °C, constitute medium and low enthalpy resources, being unprofitable for electricity production.

In the South Zone of country, excepting local uses, a notable utilization of geothermal resources is finding on the Olt Valley, where the City of Calimanesti is heated utilizing the hot water from a borehole situated on the right bank of the Olt River. Because the energetically potential of this hot water is only partially utilized, this work proposes some solutions of complete capitalization of this thermal potential, solutions wich can enlarging the capacity of the centralized heating system of the town. The geothermal water coming from the drilling nr.1009 located in vicinity of Calimanesti City contines a large amount of methan,

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gas wich currently is separated and unused. The urban district heating system of the town, has been operated since 2010 with the hot water extracted through the drilling 1009, having the exit temperature in range of 93...98 ^oC.

2. The current mode of geothermal water use.

The geothermal water coming from geothermal deposit near Calimanesti Town has an available constant volume water flow of 18 l/s. The maximum thermal power obtained from this hot water is about of 4.5 MW, assuming that the water is cooled until a temperature of 30 ^oC. The combustible gases separated from hot water have a methane content over 88% and a Low Heating Value (LHV) of 8.9 kWh/m^3_N, the gas content from water being 2...2.4 m^3_N/m^3 of hot water [2]. From this available volume of water, about 45% (8 l/s) is locally utilized for heat supply of a hotel and a balneal unit. The volume flow of 10 l/s (about 55%) is available to be utilized for preparing the thermal agent used in centralized heating system of Calimanesti Town. The locality has about 8500 permanent habitants, 20% living in apartments heated and supplied with domestic hot water (DHW) from the district heated system, operating with geothermal water. In the winter period of 2019-2020, 520 consumers (apartments, individual houses, public institutions and economic operators) were connected to this system [4]. Initially, the district heating system of Calimanesti Town had three neighborhood thermal plants that produced thermal agent for heating and DHW from oil fired boilers.

The transition to the geothermal water heating system was started yet from 2002. The project to create such a geothermal system was supported by the Austrian Chancellery and was finished and put in operation in 2010. On the Olt Valley there are three geothermal drillings and the original project provided for their connection between them. This idea was later abandoned and was used only the drilling 1009, near the Town of Calimanesti. The hot water from this drilling, supply a geothermal station built near it, which produces primary thermal agent distributed in the district heating system. The station is equipped with two plate heat exchangers, producing at outlet to heating system, hot water having a temperature of 85 ^oC. The thermal agent is returning from heating system having a temperature of 45 ^oC. One of these two heat exchangers, with thermal power of 500 kW, is functioning continuously, producing agent for DHW preparation. The second heat exchanger, with a thermal power of 1320 kW, is functioning only in the cold season, when the district heating system is on. In Fig. 1 is prezented the functioning scheme of the station for preparing the thermal agent distibuted in district heating system. The preparation of DHW and secondary agent for heating, take places in the former thermal power plants, now equiped with plate heat exchangers and accumulation boilers. A view of this thermal station and borehole 1009 is shown in Fig. 2.

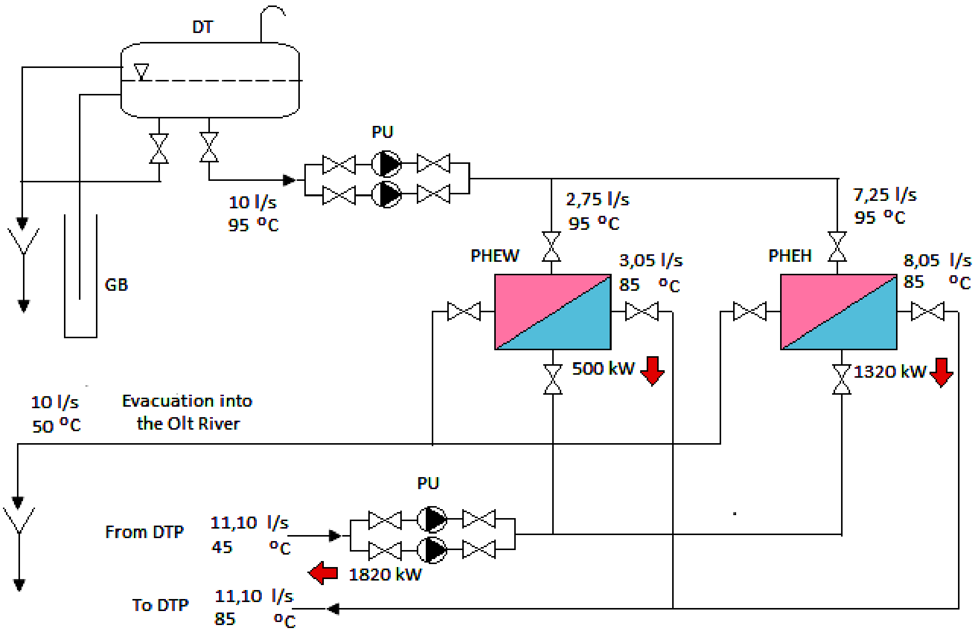

Fig.1. The functioning scheme of the station for preparing primary thermal agent.
GB – Geothermal Borehole; DT – Degassing Tank; PU – Pumping Units; DTP – Distribution Thermal Points; PHEH – Plate heat exchanger for heating; PHEW – Plate Heat Exchanger for DHW

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Because from the three former thermal power plants, now distribution points, the primary agent is returning with a temperature of 45 C, the hot water coming from drilling can be cooled only until the temperature of 50 °C. With this temperature the warm water is discharged then into the Olt River. Thus, the heat content of hot water is incompletly used and a significant heat loss occurs. Even in this situation, the supply of heating system with geothermal water elimitates completly the consumption of liquid fuel needs for hot water boilers to prepare DHW and covers about 1/3 of the heat necesary for heating, considered as peak load. In Fig. 3 are shown the gas fired hot water boilers from Distribution Thermal Point (DTP) no. 2 used to cover the rest of peak thermal load. The use of geothermal energy for funtioning of the district heating sysyem of the Calimanesti Town, leaded in winter season of 2019-2020 to a cost price for thermal energy sold to population, about of 22 €/MWh, while the price of the thermal energy produced in thermal plants equiped only with oil/gas fired hot water boilers was at the level of 60 €/MWh [4], [5], [6].

Fig. 2 The borehole 1009 and geothermal station.

Fig. 3. The gas fired hot water boilers from DTP no. 2.

The efficiency of the heat production in a thermal plant in wich the heat source is reprezented by oil/gas fired boilers can be expressed through the ratio between the maximum thermal power $\dot{\boldsymbol{Q}}$ [kW] which must be realized and the thermal power $\dot{\boldsymbol{Q}}_{\boldsymbol{burn}}$ [kW], obtined from burning process of the fuel. Obviously, this is equal to the efficiency of hot water boilers, $\boldsymbol{\eta}_{\mathbf{HWB}}$:

$$COP_{TP} = \eta_{HWB}\ (\eta_{HWB} = 0.9 \dots 0.92) \qquad (1)$$

In case of the thermal energy produced combined from geothermal water and burning of a fuel, the use of geothermal energy reduces the fuel consumption and as a result the efficiency of the heat production must be related to the actual fuel consumption required for operation. The efficiency of a such mode of heat production can be expressed through the ratio between the maximum thermal power $\dot{\boldsymbol{Q}}$ [kW] which must be realized and the thermal power $\dot{\boldsymbol{Q}}_{\boldsymbol{burn,act}}$ [kW], obtined from burning process of the actual fuel consumed. Noting with $\dot{\boldsymbol{Q}}_{\boldsymbol{HWB}}$[kW], the part of the total thermal power wich cannot be covered by energy obtained from geothermal water and must be produced by burning of a fuel, the efficiency oh the heat production can be expressed in accordance with [7]:

$$COP_{TP} = \frac{\dot{Q}}{\dot{Q}_{HWB}} \eta_{HWB} \qquad (2)$$

The value obtained in this case, calculated in extreme climatic conditions according to current standards (climatic zone III with $t_{ext} = -18$ °C), is $COP_{TP} = 1.65$. This value indicates that the use of the thermal energy from the geothermal water increases the efficiency of the system heat production, reported to primary energy consumption achieved by burning a fuel by about 84%, the geothermal energy being considered as a resource taken from the environment.

3. The possibility to recover the energy of waste geothermal water discharged into Olt River using a water-water heat pump.

The evacuation of the geothermal water used in the heat exchangers, directly into the Olt River with a temperature of 50 ^{o}C, represents a loss about 30% from its total thermal energy content. This heat loss can be recovered by a heat pump that cools the waste geothermal water until a temperature of 30 ^{o}C. The functionning scheme of the thermal station including a heat pump is shown in Fig. 4.

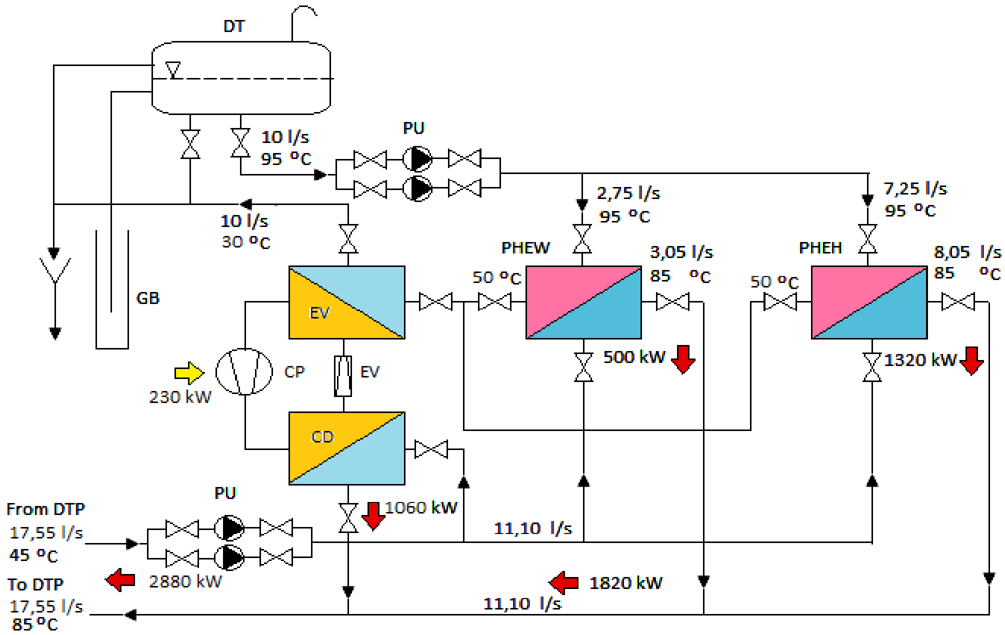

Fig.4. The functioning scheme of the station including a heat pumps.
GB – Geothermal Borehole; DT – Degassing Tank; PU – Pumping Units; DTP – Distribution Thermal Points; PHEH – Plate heat exchanger for heating; PHEW – Plate Heat Exchanger for DHW; CP- Compressor; EV – Expansion Valve; CD – Condenser; EV – Evaporator.

The heat pump is used only in the heating season, when the thermal power required by the consumer exceeds the thermal power that can be obtained only from the use of geothermal water. By vaporizing the working agent in the heat pump evaporator, the waste geothermal water is cooled until a temperature of 30 ^{o}C. At this temperature, the waste warm water can be discharged directly in the Olt River without violation the environmental protection laws and the thermal energy content of water is completly recovered. The thermal agent returned from heating network at 45 ^{o}C, cools the heat pump condenser and taking over heat raises its temperature to 85 ^{o}C. Because the condenser is connected in parallel with the plate heat exchangers of the thermal station, a supplementary mass flow of agent is added to that prepared from geothermal water by this plate heat exchangers. Recovering the heat from the waste geothermal water, the mass flow of agent delivered in system is rising and the available thermal power also is rising, thus about 65 % from peak thermal power required by the system can be covered. The difference till the peak thermal power is possible to be covered burning a fuel in hot water boilers, or using to burning the combustible gases separated from geothermal water. To be able to use the waste water as heat source, the evaporating temperature of the heat pump agent must be about 25 ^{o}C and to be able to produce at condenser hot water with a temperature of 85 ^{o}C, the condensation temperature must be about 90 ^{o}C. Several agents as R123, R245fa and R245fc meet these conditions. The best choice for the refrigerant agent was considered R123. This agent presents the advantage of low pressures into heat pump circuits, low temperature at the end of compression process and reduced compression ratios. Also, this agent is friendly with environment, having a very low ODP (0.02) and a small GWP (120). The simulations made of the authors with EES software shown that the best value of efficiency for one stage heat pump is obtained with refrigerant R123. Similar results have been published [8], [9].

In conditions of the entire available volume flow of the hot geothermal water, the cooling power of evaporator results of 840 kW, and for the heat pump efficiency of 4.7, the thermal power at condenser results at 1060 kW, the electric power for acting the compressor being 230 kW. In this context, considering the current price of electricity of 150 €/MWh, the price of the thermal energy produced by heat pump is about 40 €/MWh, taking in account the cost of maintenance and depreciation rate of investment made in the heat pump. The thermal energy produced by heat pump, eliminates a part of fuel consumption necessary to cover the peak thermal power and its cost is less than the cost of energy produced by hot water boilers. The solution presents interest, being profitable in terms of the price of energy produced.

Using such combined mode to produce thermal agent, from geothermal water and by a heat pump, about 72% of peak thermal power of the heating system can be covered. As result, an important economy of fuel occurs and the amount of carbon dioxide emitted in atmosphere decreases. It should be noted that this estimation was made taking in account extreme climatic conditions for this zone, in accordance with current standards. For this reason, the effect of this solutions is much more important, the probability to realize this conditions in zone being very low.

When using a heat pump, the primary energy consumption is composed by the energy of the fuel burned in the hot water boilers to cover peak thermal power $\dot{Q}_{HWB}^{PC}$ [kW] and the energy of fuel burned at thermo electric plant to produce the electricity necessary to cover the electric power P_C [kW] of the heat pump compressor. The efficiency coefficient of thermal station, related to primary energy consumption can be expressed [7]:

$$COP_{TP}^{PC} = \frac{\dot{Q}}{\frac{\dot{Q}_{HWB}^{PC}}{\eta_{HWB}} + \frac{P_C}{\eta_{EE}}} \quad (2)$$

If the value of the electrical energy production efficiency is considering in range of 30...33%, corresponding to electric energy produced in conventional thermoelectric plants, the value obtained for the efficiency coefficient of thermal station was $COP_{TP}^{PC} = 2.1$. This result has shown a rising of 133% in relation to previous situation without heat pump. In zone, on the Olt River, there are more small hydro power stations and if the electric energy for heat pump acting is obtained on this base, practically the entire heating season can be covered from "clean" energy. The fuel consumption occurs only in eventuality of severe climatic conditions or in case of breakdowns.

4. The possibilty to recover the energy content of the gases separated from geothermal water using a micro gas turbine unit.

The geothermal deposits located on the Olt Valley contain an important number of gaseous hydrocarbons, especially methane. These gases come at surface together with the geothermal water, being separated in degassing tank. There were attempts to use these gases which content over 88% methane, but currently they a not used, being evacuated in atmosphere. Considering his great LHV of about 8.9 kWh/m^3_N and a volume flow in range of 2...2.4 m^3_N/m^3 water, the burning of these gases can produce only from water extracted through the drilling 1009 a thermal power of about 1450 kW.

The most simple and cheap mode to capitalize this available thermal energy is the direct burning of gases in the hot water boilers. A more interesting proposal is the use of these gases to operate a micro cogeneration unit with gas turbine. Due their advantages and lowering the cost price, nowadays there are in operation many micro units of high-speed gas turbine, equipped with high frequency electric generator and convertor for standard frequency of 50 Hz. Their electrically efficiency is in range 28...30% and the thermal efficiency obtained by heat recovery of flue gases, about of 50%. The use of micro gas turbine cogeneration units, leads to possibilities to use a large variety of fuels in conditions of a very low level of environmental pollution. Also, they can operate long time continuously at peak load; have the ability to follow the variable thermal load of the consumers; require maintenance at long intervals and present a high level of automation allowing unattended function [10], [11], [12].

The functioning scheme of the thermal station including a heat pump and a micro gas turbine cogeneration unit is shown in Fig. 5. The combustible gases separated from geothermal water, are collected and cooled to be dehumidified, then being burned in the combustion chamber of the gas turbine. The high air excess coefficient and the high temperature, from the burning zone, lead to a very low level of pollutant emissions. The recovery heat exchanger has a by-pass vane; thus it can be able to follow the variation of thermal load.

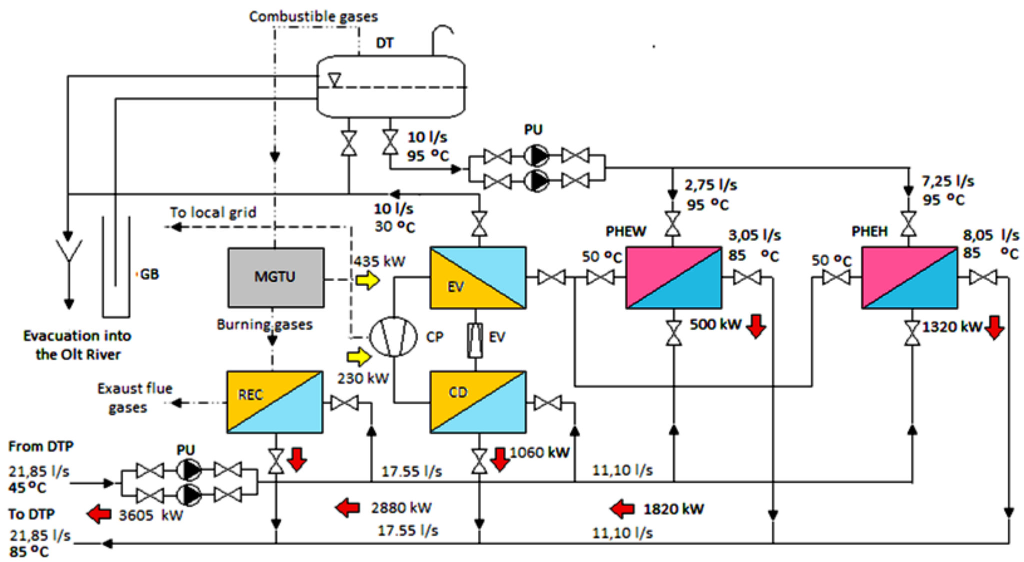

Fig.5. The functioning scheme of the station including a heat pump and micro gas turbine. GB – Geothermal Borehole; DT – Degassing Tank; PU – Pumping Units; DTP – Distribution Thermal Points; PHEH – Plate heat exchanger for heating; PHEW – Plate Heat Exchanger for DHW; CP- Compressor; EV – Expansion Valve; CD – Condenser; EV – Evaporator; REC – Recovery heat exchanger; MGTU - Micro Gas Turbine Unit.

In the same mode as the heat pump, the recovery heat exchanger of the gas turbine is connected in parallel with the heat exchangers functioning with geothermal water and determines the increasing of the mass flow of thermal agent who leaves from thermal station. Considering a value of thermal efficiency of 50%, and a value of electrically efficiency of 30 %, the micro cogeneration unit can generates in conditions of the peak flow of gases a thermal power of 725 kW and an electrically power of 435 kW sufficiently to acting the compressor of the heat pump and the pumping units for thermal agent circulation.

A case study was reported in [13] for a micro gas turbine cogeneration unit of 100 kW, aiming to establish the economic efficiency of the implementation of such a solution similar to the one proposed for recovery of energetic potential of the combustible gases contained in the geothermal water. The obtained result showed a payback time for investment of 7.5 years and an internal rate of return of about 15%. Considering an equipment lifetime of 15 years, the implementation of the micro gas turbine cogeneration unit in system represents a solution of real interest.

5. Conclusions

• The energetic content of the geothermal water estimated at $4.3 \cdot 10^4$ MWh/year, and also of the combustible gases associated with them, estimated at $1.2 \cdot 10^4$ MWh/year, is an important renewable energy reserve of the zone. Using these resources, the centralized heating system of Calimanesti Town can function in an autonomous mode, generating a very low level of environment impact.

• The study of using a heat pump for recovery the thermal potential of hot waste geothermal water, can be covered over 70% of peak heat required in the cold season, generating a rising of energetic efficiency of the system with 133%. The rest of load, considerate in severe climatic conditions, can be covered from hot water boilers, or recovering the energetic content of the combustible gases separated from geothermal water.

• The study of the recovery of the energetic content of the gases associated shown a simple possibilities of use by direct burning, but was highlighted a mode more efficient energetically, by acting a micro gas turbine cogeneration unit or a gas engine.

• It was highlighted that the use of combined functioning scheme including a heat pump and a micro cogeneration unit allows an autonomous mode of functioning, without supplementary fuel consumption, using only renewable energy. Also, the simulation of the heating system [14] functioning shown that in normal climatic conditions of the zone, the thermal load can be covered only from geothermal resources, generating a low cost of thermal energy delivered to population.

• The new used equipment - the heat pump and the micro cogeneration unit - can be designed modularly [15], [16], in the form of several low power units, such conception allowing a great flexibility in following the variation of the thermal load required by the consumers, the conservation of the geothermal deposits and a sustainable development of the zone.

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