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Comparison of LCA results of low temperature heat plant using electric heat pump, absorption heat pump and gas-fired boiler

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ABSTRACT

This study compares the life cycle impacts of three heating plant systems which differ in their source of energy and the type of system. The following heating systems are considered: electric water-water heat pump, absorption water-water heat pump and natural gas fired boiler. The heat source for heat pump systems is low temperature geothermal source with temperature below 20 °C and spontaneous outflow 24 m^3/h. It is assumed that the heat pumps and boiler are working in monovalent system. The analysis was carried out for heat networks temperature characteristic at 50/40 °C which is changing with outdoor temperature during heating season.

The environmental life cycle impact is evaluated within life cycle assessment methodological framework. The method used for life cycle assessment is eco-indicator '99. The functional unit is defined as heating plant system with given amount of heat to be delivered to meet local heat demand in assumed average season. The data describing heating plant system is derived from literature and energy analysis of these systems. The data describing the preceding life cycle phases: extraction of raw materials and fuels, production of heating devices and their transportation is taken from Ecoinvent 2.0 life cycle inventory database.

The results were analyzed on three levels of indicators: single score indicator, damage category indicators and impact category indicator. The indicators were calculated for characterization, normalization and weighting phases as well. SimaPro 7.3.2 is the software used to model the systems' life cycle. The study shows that heating plants using a low temperature geothermal source have lower eco-indicator than a gas boiler unit. In comparison of two heat pumps the absorption heat pump has a lower environmental impact rather than electrical heat pump. However, in spite of high level eco-indicator, gas boiler has the lowest damage to human health.

1. Introduction

Due to growing concern about energy conservation and environmental protection the utilization of renewable energy sources is more and more desirable. For years, high and medium temperature geothermal water was commonly used in district heating systems. The energy and exergy efficiency and environmental issues of geothermal district heating systems were analyzed in many studies [1–5]. In these studies the environmental benefits of deep wells and shallow ground-water systems with temperature higher than 40 °C are assessed. Considered geothermal district systems are mainly based on geothermal water with heat exchangers but often they are supported by peak load boilers based on fossil fuel. Blaga et al. [5] discussed the environmental benefits of shallow geothermal district heating system in Romania. They calculated the CO_2 saving in the case of replacing the wood-based heating system with geothermal district heating system. Kecebas [2] examined the geothermal district heating system in Afyon, Turkey. He complemented exergy analysis with economic and environmental issues, which indicated that geothermal energy is much cheaper than the other energy sources and contributes to reduction of greenhouse gases emissions.

Nowadays, the low and very-low temperature geothermal water heating systems become more interesting due to its good availability and growing markets of heat pumps. The use of low temperature geothermal energy in district heating systems is more attractive due to development of heat pumps efficiency for large scale units. However, it is important to notice, that to utilize the low temperature geothermal sources fossil fuels are needed. Electricity to drive compressor in electrical heat pump comes, in Polish conditions, mainly from coal burning. Also heat driven generator of

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absorption heat pumps frequently comes from gas burning. The comparison of heat pumps with alternative heating sources is subject to many studies [6–9]. Generally, environmental impact assessment and ecological effects of heating or cogeneration systems (CHP) are focused on evaluation of carbon dioxide emission reduction and fossil fuels or primary energy savings [10,11].

In order to evaluate environmental benefits from renewable sources, the analysis should take into account a wide range of environmental effects not only during an exploitation stage but also in all life cycle stages. The life cycle assessment (LCA) method enables to assess an environmental aspects associated with a product over its whole life cycle. The LCA studies are currently common practice to evaluate an environmental impact of investigated product or process [12–21]. In the paper [12] Stanek et al. proposed the combination of LCA and Thermo-Ecological Cost (LC-TEC) methodology to evaluate the energy and environmental benefits of biomass energy conversion in CHP. However, the indicators proposed by authors are developed on non-renewable natural resources savings and reduction of greenhouse gasses emissions. Saner et al. [13] made LCA of shallow geothermal system with the use of ReCiPe indicator. Additionally, they included the comparison of environmental impacts with respect to different variants of electricity mixes. Their findings showed the significance of electricity mix to the LCA results of electric heat pumps. Greening and Azapagic [14] also performed LCA study of different types of heat pumps and referred LCA results to the environmental impacts of gas boiler. The comparison was conducted for the UK and included prospective analysis for different electricity mix scenarios. They underlined the significance of seasonal performance factor on environmental impacts of investigated heat pumps.

2. The concept of low temperature geothermal heating plant

The idea of low temperature geothermal heating system was created for existing borehole located in Silesia region in Poland, to utilize heat of very low temperature geothermal water to supply the neighbouring buildings in heat. At present, the geothermal water spontaneously flows out from unexploited borehole and runs directly into the nearby river without any use. The concept of heating plant assumed that very low temperature geothermal water at 19.5 °C and spontaneous outflow 24 m^3/h is used by heat pump as low-grade heat and then runs into domestic water supply system. To meet the quality regulation of water for domestic use, the heating cycle was separated from domestic water supply system using geothermal heat exchanger. The scheme of the considered district heating system is shown in Fig. 1.

To evaluate the potential benefits of utilization of very low temperature geothermal water in district heating system, the energy and environmental analysis was carried out. The space heating demand of the buildings was calculated for minimal outdoor temperature equal to −20 °C. It was assumed that heating season duration is 210 days with the average ambient temperature of 2.5 °C that correspond to typical heating season for the considered region.

In this study three types of heat source were considered: electric heat pump (EHP) and absorption heat pump (GAHP) using geothermal water and natural gas boiler as a typical heat source based on fossil fuel. The nominal power of heating devices was 400 kW either. It was assumed that both the heat pumps and the gas boiler are working in monovalent system, meeting the space heating demand during the whole heating season. The heat pumps were designed for the particular needs of this low temperature geothermal heating system. Two stage water/water electric heat pump with semi-hermetically sealed compact screw compressor and R134a as a refrigerant was proposed. The seasonal performance factor (SPF) for electric heat pump was equal to 5.5 and it is correlated with electricity consumption during the whole heating season. It also includes the electricity consumption by geothermal water equipment. The high value of heat pump coefficient of performance is connected with the temperature of geothermal water (which is higher than temperature of typical heat source in ground water heat pumps). In the case of gas absorption heat pump an ammonia/water solution was used as a working fluid. The internal gas burner heats the ammonia and water solution, next ammonia gas enters the condenser, where it condenses and releases heat. Gas utilization efficiency (GUE), expressed as amount of received heat to a gas consumption, of gas absorption heat pump was equal to 1.74. To achieve the required heating power of the heat pumps, the particular amount of heat from lower source (i.e. geothermal water) must be supplied into evaporator. In the considered case the electric heat pump needed more heat from geothermal water than the gas absorption heat pump, so the discharge temperature of geothermal water was assumed to be 9 and 13.5 °C for electric and absorption heat pump, respectively. The temperature characteristic of heating network water is 50/40 °C and it is changing with outdoor temperature (quality regulation). To estimate the gas consumption during the heating season, the energy efficiency of condensing gas boiler was assumed to be 0.96 (correspond with HHV).

3. Life-cycle assessment of heating system

The methodology of life cycle assessment is defined by ISO 14044 standard [22] which points at four phases of LCA studies:

- the goal and scope definition phase,
- the inventory analysis phase,
- the impact assessment phase, and
- the interpretation phase.

These basic phases are required in life cycle assessment and were included in this study.

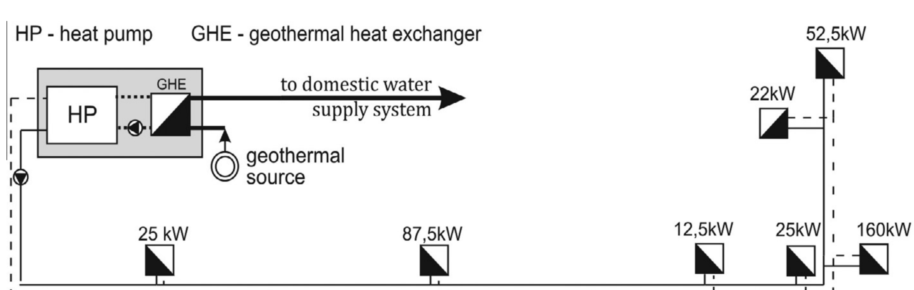

Fig. 1. The concept of low temperature geothermal district heating system.