Katarína KADUCHOVÁ
Richard LENHARD
Milan MALCHO
University of Zilina, Slovakia

CONCENTRATION OPTIMALIZATION OF ETHYLENE GLYCOL IN THE GROUND HEAT EXCHANGER HEAT PUMP

Introduction

At present, particular attention is paid to the diversification of heat sources, to the efficient use of energy and to the ecological aspects of the use of primary energies, especially in the EU and within the Slovak republic. A very good way to achieve the use of renewable energy sources. Slovak republic has a real renewable energy potential mainly in biomass, geothermal energy, solar energy and hydroponics of rivers. Every kind of renewable energy has its own specifics. In the Slovak republic water energy and biomass are currently used. In Slovak republic there are suitable conditions for use of geothermal energy due to its suitable placement on breaks in the Carpathian arc.

The average geothermal gradient for the SR is 33 K/km, with some locations up to 50 K/km, while the average is 30 K/km in the world. Hydrological research has been focused on prospective geothermal waters with temperatures ranging from 25°C to 150°C with a total usable potential of more than 5 500 MW. The problem of using geothermal water is its potential (water temperature) and mineralization causing the incrustation of pipelines and other system facilities. While geothermal resources with a water temperature above 25°C are closely linked to certain locations, the country's low-potential energy is above average in the whole of Slovak republic. Geothermal heat from the ground is most commonly obtained through horizontal ground/water type heat exchanger (about 40 W/m) or through vertical exchanger embedded in deep boreholes of approximately 100-150 m (40-60 W/m) [4].

Evaluation of the use of low-potential heat sources

Water/water system

As a source of low-potential heat – surface water it is possible to use water from water streams, various natural and artificial water reservoirs, dams and so on. However, this resource, with sufficient expense, is not available for most locations. If it is available, it is often heavily polluted. Surface water temperature fluctuates throughout the year, resulting in an unstable heating factor. For these reasons, the surface water system is not very widespread, but rather for specific local uses. The source of groundwater is generally drilled wells, specific cases are dug wells or deep boreholes. For heat source stability, a sufficient and steady supply of groundwater with low mineralization is required. If the water is strongly mineralized, it is usually pumped from the well to the pre-heat exchanger. The benefits of groundwater application are high heating factors (4 and above) even in the winter. The installation of the water/water heat pump is only appropriate in areas with excellent hydrogeological conditions which are known in advance and there is no need to invest in hydrogeological surveys that may be negative for the use of water for the heat pump. Suitable areas are not commonly found and are often known in the spa and mineral waters protection zone.

Air/water (air) system

The source of heat is usually the surrounding atmosphere, whose temperature strongly depends on the climate and the season. This is caused by a low annual heating factor and the need for an additional heat source. This system is most easily available due to lower investment costs and simple installation. Air/water (air) application is very well suited to the corresponding climatic conditions (e.g. South Europe) where the air temperature is slightly above 0°C even during the winter. For areas in the north of Slovakia, where the winters are much frost-free, this system cannot provide the necessary heat at acceptable operating costs. The air/water system is only suitable for summer cooling of buildings in this area. A notable disadvantage is noise production and aesthetic impairment of the building's appearance and surroundings [9].

Earth/water system

This system uses two sources of low-potential heat energy:

- soil – soil layer to a depth of about 2 m,
- grounds – deep boreholes.

In the use of soils, the primary heat exchanger of polyethylene pipes is put into excavations on the site. The advantage of this application is relatively low investment costs compared to deep boreholes and a higher heating factor than in the case of air system applications. Suitable soil as a source of low-potential heat is relatively commonly available. The main limiting factor in this application is the size of the land and its deterioration in terms of future building plans and planting possibilities.

The use of grounds as a low-potential source of heat is very widespread throughout the world, particularly in the US, Sweden, Switzerland and Germany. Compared to the above-mentioned low-potential heat sources, the deep-water drilling system is the most versatile because it is not bound to any specific climatic, geological or hydrogeological conditions. The undeniable advantage is the stable heating factor throughout the year and the low land size requirements without its significant deterioration. The disadvantage is that heat pump boreholes can not be implemented where the land is legally protected (e.g. spa areas, water sources for water supply, underground water supply and mining works). The factor that most clearly prevents the expansion of this system in Slovakia is the high initial investment for the drilling.

Heat pumps ground/water are also suitable for larger objects where other systems typically have numerous limitations in terms of:

- natural conditions – the primary source of low potential heat does not meet the required thermal input either due to low source temperatures, low water resource yield, or limited land area,
- technical requirements – unstable heating factor, noise, disturbance of land or building appearance.

From the above-mentioned evaluation of low-potential heat sources for heat pumps, it is clear that for the local climatic conditions, the most prospectous option is the use of deep boreholes. It therefore makes sense to deal with the more efficient use of the substrate as a source of low-potential heat for heating or cooling purposes. At present, the Department of Energy Technology is currently exploring the use of low-potential heat from rocks through deep boreholes. In the area of the University of Žilina there are two 150 m deep boreholes works on the Great Work. At present, a standard vertical earth exchanger with two U-tubes is located in one well, and four heat pipes are located in the other [4, 6, 8].

Vertical ground heat exchanger

Vertical ground heat exchangers are divided according to the geometry of their cross section and the way heat is transferred between the working medium and the borehole. The two basic types of heat exchangers are shown in figure 1 and figure 2.

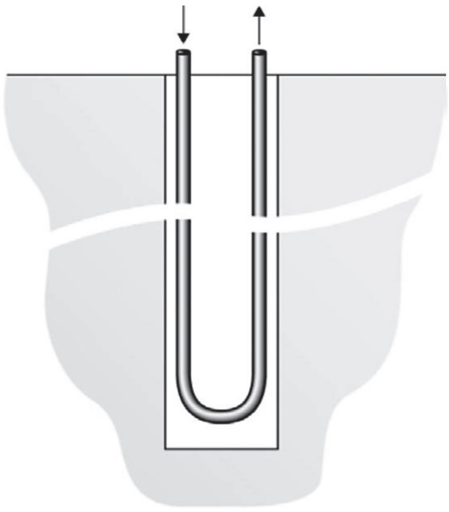

FIGURE 1. *Ground heat exchanger – U [6]*

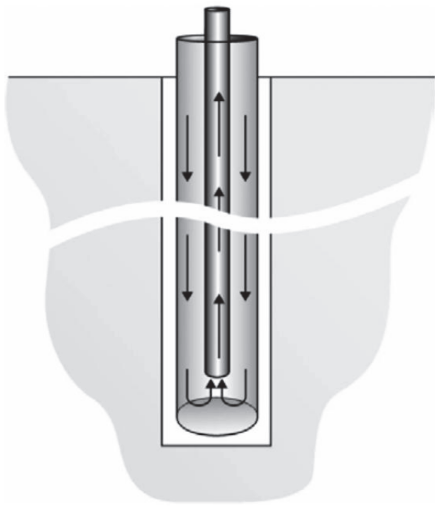

FIGURE 2. *Coaxial ground heat exchanger [6]*

Heat exchanger type U exists with one or more U-tubes. In a U-tube heat exchanger, the heat transfer medium flows through the collector one side and the other out of the heat exchanger. Often a collector with two U-tubes is also used due to lower thermal resistance R_b and pressure drops. In the world, well-filled wells (not injected) are used, but they are not being implemented in Slovak republic [6].

In our conditions a U-exchanger is usually made, usually with two U-tubes, so we only work on this type of work figure 3. The experimental exchanger on which measurements were made is also of this type. The exchanger tubes with two U-tubes can be connected in parallel or in series. In case of serial connection, the heat transfer fluid flows through both pipes and at twice the speed of the parallel connection.

A characteristic feature of coaxial heat exchangers is that heat transfer with the environment occurs in the outer duct, with the flow direction being different for heat delivery and removal. The inner tube is often thermally insulated to minimize heat transfer between the channels. The coaxial exchanger may be designed with or without an outer tube, i.e. a closed or open system [7].

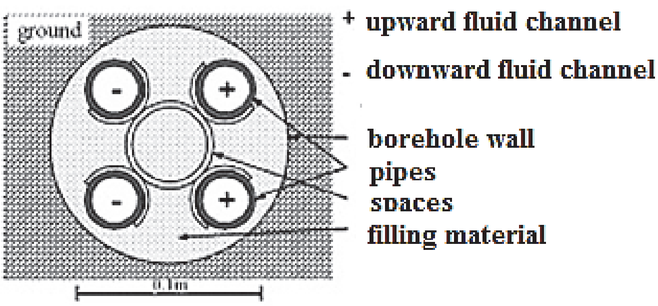

FIGURE 3. *Schematic layout of a typical double U-tube heat exchanger: cross-section of borehole [7]*

Heat transfer medium

The heat transfer medium (fluid) used in the primary circuit of the heat pump also operates at temperatures below 0°C, so it must be ensured that it does not freeze. To protect the heating and cooling systems from frost, different types and concentrations of antifreeze medium are used. Many products are available on the market, some are used as concentration with water, and others are completely free of water. Below is a brief overview of working mediums.

- Ethanol: low corrosivity, high flammability (clean), low toxicity, high thermal capacity, low viscosity, average price.
- Methanol: low corrosivity, high flammability (clean), high toxicity, high thermal capacity, low viscosity, low cost.

- Propylene glycol: low corrosivity, low flammability, low toxicity, low thermal capacity, high viscosity, high price.
- Ethylene glycol: low corrosivity, low flammability, high toxicity, low thermal capacity, high viscosity, high price.

In our case, a solution of ethylene glycol and water is used in experimental ground exchangers, so we do not consider other antifreeze working medium (fluids) [5].

Optimization of the heat transfer media concentration

Pour point is the parameter for determining the required ethylene glycol concentration. The values of the thermodynamic variables vary with temperature, therefore, the density models, the thermal capacity, the thermal conductivity, the dynamic viscosity, and the Prandtl number were used in the calculations. The set values were then used to calculate the amount of heat recovered in the ground U-heat exchanger, the electric power needed to drive the circulator, and the total heat input of the heat pump from the primary circuit. The calculation also considered type of flow and its effect on heat transfer and pressure loss. The parameters of the heat and rock (soil) parameters required for the calculation were selected according to the experimental exchanger at the site of implementation. The temperature and thermal conductivity of the ground as well as the total thermal resistance of the heat exchanger were determined by a Thermal Response Test (TRT). To assess the overall energy balance of the heat exchanger operation, the heat transfer medium flow is decisively affected by the heat exchanger tubes. Increasing flow increases the amount of heat extracted from the rock but only to a certain value, then increases only slightly. On the contrary, the heat exchanger's pressure loss increases quadraticaly over the whole range of the heat transfer media considered. The selection of optimal flow depends on the required heat exchanger design parameters. The results of the optimal solution concentration analysis can be applied to all heat pump heat exchangers working with the ethylene glycol solution.

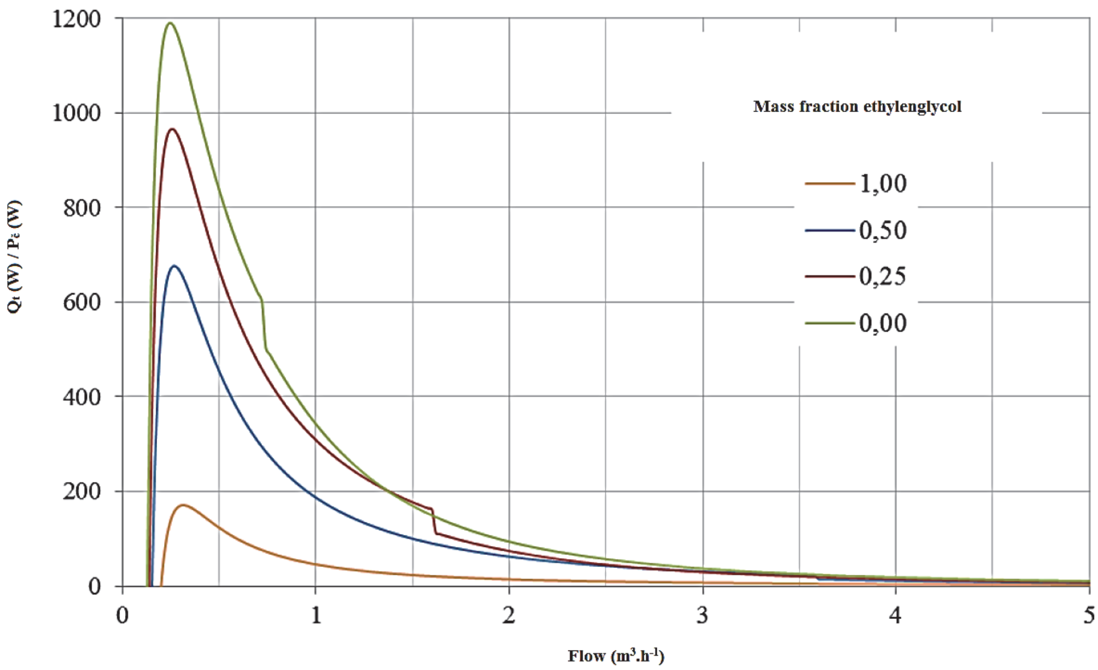

***FIGURE 4.** The specific heat collection when the heat exchanger tubes are connected in parallel*

Conclusion

From the processed dependence of the parameters (density, specific heat capacity, thermal conductivity, dynamic viscosity) with temperature, the increasing concentration of the medium deteriorates the properties of the solution in terms of its use as a heat transfer medium. Emphasizing the most economical operation is to adequately limit the concentration of the solution to what is necessary to protect the system against freezing. In some cases, a 20% concentration of the solution with a freezing point of -7.7°C would be sufficient. The resulting values at 20% and 25% are slightly different, so it is recommended to use a 25% ethylene glycol solution with a freezing point of 10.9°C for the normal operation of the heat pump heat exchanger. The use of a 25% solution at low flow rates has only a small impact on the increase of electricity consumption compared to pure water, up to 10% compared to 20%, providing a certain heat reserve against freezing of the system. The use of a higher concentration solution greatly impacts the efficiency of the use of the electricity used to circulate the heat transfer medium in the ground heat exchanger.

References

[1] Baehr H.D., Stephan K.: *Heat and mass transfer.* Berlin: Springer, 2006, p. 688.

[2] Lenhard R., Malcho M.: *Numerical simulation device for the transport of geothermal heat with forced circulation of media.* Mathematical and Computer Modelling, ISSN 0895-7177, vol. 57, iss. 1-2, (2013), pp. 111-125.

[3] Jakubský M., Lenhard R., Jandačka J.: *Výstavba zariadenia na simuláciu transportu nízkopotenciálneho geotermálneho tepla v laboratóriu*. ALER 2011, Žilina: EDIS Žilina, pp. 88-102.

[4] Lenhard R., Jakubský M., Nemec P.: *Device for simulation of transfer* geothermal *heat with forced and without forced circulation of heat carrier.* Power control and optimization: proceeding of fourth global conference: Kuching, Malaysia, 2010.

[5] Conde M.: *Thermophysical Properties of Brines:* Models. 2011.

[6] Gehlin S.: *Thermal Response Test, Method Development and Evaluation*. Luleá University of Technology, 2002.

[7] Pahud D., Matthey B.: *Comparison of the thermal performance of double U-pipe borehole heat exchangers measured in situ*: výskumná správa. Switzerland: Energy and Building, 2001.

[8] Ryška J.: *Vrty do hornonového masivu - zdroj energie pro tepelná čerpadla* (III): Zdroje tepla 2006.

[9] Srdečný K., Truxa J.: *Tepelné čerpadla.* Brno 2005.

Acknowledgement

This publication is the result of the project implementation: Device for the use of low-potential geothermal heat without forced circulation of the heat carier in deep boreholes, ITMS 26220220057 supported by the Operational Programme Research and development funded by the ERDF.