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THE USE OF GEOTHERMAL ENERGY IN ABSORPTION REFRIGERATION CIRCUITS

ZASTOSOWANIE ENERGII GEOTERMALNEJ DO NAPĘDU ZIĘBIAREK ABSORPCYJNYCH

Abstract

The use of absorption refrigerators to produce cold can definitely reduce energy usage through the use of a heat from the geothermal resources. Absorption refrigerators do not have a negative impact on the natural environment. They are particularly economically attractive when there is a free energy source with a temperature of between 50 and 200°C. This article presents a hybrid absorption-compression refrigerator powered by geothermal energy used for the production of ice slurry for air-conditioning refrigeration.

Keywords: *hybrid absorption/compression refrigerator, water-ammonia absorption refrigerator, geothermal energy*

Streszczenie

Zastosowanie ziębiarek absorpcyjnych do produkcji zimna pozwala zdecydowanie ograniczyć straty energii dzięki wykorzystaniu do ich napędu ciepła pochodzącego ze złóż geotermalnych. Ziębiarki absorpcyjne nie mają negatywnego wpływu na środowisko naturalne. Są one szczególnie atrakcyjne ekonomicznie gdy istnieje darmowe źródło energii o temperaturze 50–200°C. W artykule przedstawiono ziębiarkę hybrydową absorpcyjno-sprężarkową zasilaną energią geotermalną wykorzystywaną do produkcji lodu zawiesinowego do celów ziębienia w klimatyzacji.

Słowa kluczowe: *ziębiarka hybrydowa absorpcyjno/sprężarkowa, ziębiarka absorpcyjna wodno-amoniakalna, energia geotermalna*

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1. Introduction

Due to the dwindling global resources of fossil fuels, and also because of the need to protect the environment from degradation, methods using alternative energy sources are becoming more and more popular. Such a need is enforced by economic considerations regarding escalating resource prices and a policy aimed at the largest possible economic independence from external energy resources. The development of renewable energy is a necessity not only as a result of existing law, international agreements and the Treaty of Accession to the EU, but also in the context of the sustainable energy development of the EU in the agreed energy policy for Europe. By 2020, the following goals are to be achieved: reducing energy consumption by 20%, reducing greenhouse gas consumption by 20% and achieving a 20% share of energy from renewable sources in the overall EU energy consumption [6]. The use of geothermal energy sources leads to a reduction of electricity consumption and to a reduction of the negative influences of refrigeration factors on the natural environment. The use of geothermal energy to drive absorption refrigerators used for air cooling in air conditioning has become increasingly popular, especially when there is a heat source naturally produced by soil. Geothermal energy is produced predominantly by the natural radiation of heat from rocks that make up earth's crust. The reasons why we utilize heat from the earth are as follows: the geothermal energy located beneath our feet is a completely eco-friendly source that does not produce pollutants and it is characterized by a zero GWP factor; it is available all the time and shows little variation due to climatic conditions, time of year or time of day; it is a solid and stable source of energy that is very plentiful as it is always complemented by the absorption of solar radiation. In engineering practice, there are established and proven ways to use geothermal energy in heating and cooling technology. As mentioned above, absorption refrigerators or heat pumps are increasingly used in combined systems – such systems include geothermal heating plants. The basic operational parameters of the geothermal plant in Biały Dunajec, the water from which can be used to power an absorption refrigerator's desorber, are presented below.

T a b l e 1

Parameters characterising the geothermal heat sources in Biały Dunajec

	Bańska–Biały Dunajec	Bańska Niżna–Biały Dunajec
Water temperature in the deposit	86 [°C]	76–80 [°C]
Depth of the deposit	2000–3000 [m]	2500 [m]
Mineralization	39/l	39/l
Flow rate	120 [m³/h]	550 [m³/h]
Total thermal power	9 [MW]	125[MW]

It is expected that in the near future, the number of geothermal power plants will grow for the sake of the economy and because of the need to protect the environment. It should also be noted that Poland has Europe's largest proven reserves of geothermal

energy (the 3 equivalent 25–100 billion tons of oil). The geothermal water capacity stored in sedimentary rocks is estimated at 6000–30 000 km³. Geothermal resources are present below the surface of 80% of the territory of our country [3]. Water temperatures at 4000 m range between 30 and 300°C. In addition to the energy located in the water, geothermal energy is present in salt cavities and hot, dry rocks.

2. The applications of absorption refrigerators

One possible environmentally – friendly use of absorption refrigerators may be their application in place of commonly used compressor refrigerators when it is both possible and advantageous. Instead of electrical energy, energy of the heating or waste factor can then be used to power refrigerator; additionally, substances that are nondestructive to the environment can be used as coolants. These are water or ammonia for which the ODP = 0 and GWP = 0; furthermore, there is the additional benefit of reduced CO_2 emission that would have resulted from the generation of the electrical power that would have otherwise been consumed. The scope of the application of absorption devices covers evaporation temperature values ranging from –60°C to + 10°C and thus from freezing temperatures to temperatures appropriate for air conditioning. The refrigerating capacity of a typical absorption refrigerator can be up to 500 kW in a single stand-alone unit [4]. These devices are used in the chemical, petrochemical and food industries and in construction designed for air-conditioning purposes. The heat source energy used to drive the absorbent circulation does not have to be specially produced but can be used from sources with low parameters, such as the heat from venting steam in power stations, waste heat from processing operations in the form of steam, hot liquids, hot gases, fumes generated from the combustion of natural gas and fuel oil, and geothermal water heat. Absorption refrigeration units are characterised by a slight electricity demand to drive the   liquid solution pumps (within the range of 5–10% of the energy required by a compression refrigerator of a comparable performance). Absorption refrigerators generally have lower efficiency rates than compressor refrigerators and therefore can therefore be used effectively only if there are sufficiently large heat sources present. The operating costs of the absorption refrigerators using waste heat sources are very low; however, investment outlays may sometimes seem high and therefore, their application should preferably only be considered after carrying out a proper analysis. In absorption refrigerators there are used different solutions (usually bicomponent). The most common solutions include aqueous ammonia and the aqueous lithium bromide solution (for temperatures above 0°C). In absorption refrigerators using aqueous ammonia with the same pressures as in compressor refrigerators, there is the possibility to obtain sufficiently low (negative) cooling air temperatures, and at the same time, neither water nor ammonia are considered to be destructive to the ozone layer. Ammonia refrigerators should be equipped with a rectifying column for the proper treatment of ammonia from the water. Therefore, the driving heat consumption of ammonia devices is greater than in bromine--lithium devices.

3. Selection of a priori variables in the absorption circuit calculations

In the calculation algorithm that is used for the absorbent refrigerant circuit, the number of independent variables exceeds the number of equations resulting from the substance and energy conservation laws. Consequently, the known values of the selected process data have been assumed, making it possible to determine the values of other variables – these values are as follows:

− temperature of hot water from the geothermal source powering the desorber: t_{wg} = 80°C
− initial temperature of the cooling water receiving the condensation heat: t_s = 30°C
− initial temperature of the cooling water receiving the absorption heat: t_a = 25°C
− temperature of water on the inlet to the evaporator: t_p = 5°C
− evaporation pressure p_o = 8 bar
− condensation pressure p_k = 13 bar
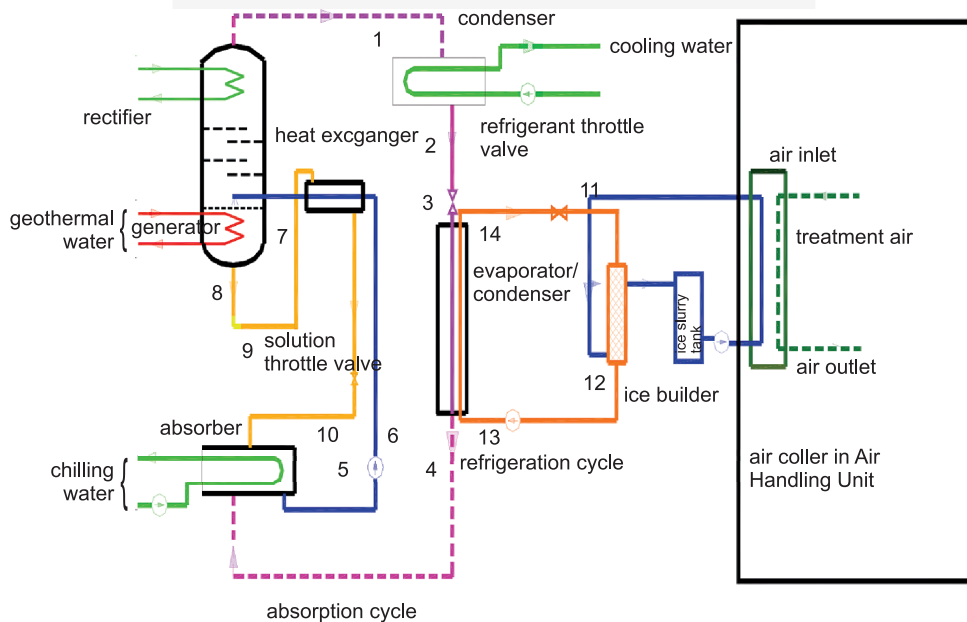− mass flow of geothermal water powering the desorber m_{wg} = 550 m³/h

Fig. 1. Scheme of hybrid absorption-compression refrigerator powered by geothermal energy

4. Hybrid absorption-compression refrigerator powered by geothermal energy

The article analyses the hybrid absorption-compressor circuit which uses water sourced from the geothermal deposit to power the desorber. The system uses the R134a refrigerant in the compressor component, and the ammonia-water solution in the absorption component [2]. The absorption refrigerator desorber is supplied with hot water at a temperature of 80°C. In the compressor system, there is the possibility to produce ice

slurry for air cooling in air conditioning. It is a new promising coolant used in indirect cooling systems. The ice is a mixture of ice crystals, water and glycols, alcohols or salts. The ice crystals in the ice slurry, also called binary ice, are small in size and typically do not exceed 0.5 mm. Thus, the binary ice can be pumped through the pipe system the same as with the liquid phase. Binary ice is now recognised as the best proxy liquid for temperature ranges from –8°C to –2°C and it is used in supermarkets, food processing plants, and for air conditioning in various facilities (hotels, mines, office buildings, airplanes). The use of binary ice as the coolant in indirect cooling systems can bring many benefits, provided that the parameters of the system are properly chosen and its components are properly designed (heat exchangers, piping, pumps) [5]. For this purpose, it is necessary to know the physical and thermodynamic properties of the coolant such as density, viscosity, thermal conductivity, specific heat and specific enthalpy. The possible applications of ice slurry are very numerous and if the costs are relatively low, then this factor can replace the previously used coolants. The hybrid absorption-compressor refrigerator scheme is shown in Fig. 1.

Desorber balance in the absorption circuit of the hybrid refrigerator:
– from the side of the ammonia-water solution

$$Q_{d=m_z}(h_1 + (f-1)h_8 - fh_7) \tag{1}$$

– from the side of the geothermal water powering the desorber

$$Q_{d=m_{wg}}c_{wg}(t_{wg} - (t_d + \Delta t_d) \tag{2}$$

The mass flow of the ammonia water solution can be calculated from the formula shown below. This depends on the mass flow of the geothermal water supplying heat to the desorber and the initial temperature of the geothermal water [1].

$$m_z = \frac{m_{wg}c_{wg}(t_{wg} - (t_d + \Delta t_d)}{(h_1 + (f-1)h_8 - fh_7)} \tag{3}$$

where the number of circulations of the solution is:

$$f = \frac{x_8 - x_1}{x_8 - x_7} \tag{4}$$

The balance of the evaporator in the absorption refrigerator circuit is determined by the relationship:

$$Q_p = m_z(h_4 - h_3) \tag{5}$$

The COP energy efficiency ratio for the absorption component of the system (without the rich solution pump) is expressed by the equation:

$$COP_{abs} = \frac{Q_P}{Q_d} \tag{6}$$

For the compressor component of the hybrid circuit the following equations can be drawn up:
– refrigeration efficiency of the evaporator producing the ice slurry for cooling the water in the radiator of the air handling unit is determined by the relationship:

$$Q_P = m_{R134a}(h_{11} - h_{12}) \qquad (7)$$

– the thermal efficiency of the condenser is represented by the equation:

$$Q_s = m_{R134a}(h_{13} - h_{14}) \qquad (8)$$

– electric compressor drive output power is determined by the relationship:

$$P_e = m_{R134a}\frac{(h_{13} - h_{12})}{\eta_c} \qquad (9)$$

The COP energy efficiency ratio of the compressor part of the hybrid system is therefore defined by the equation:

$$\mathrm{COP}_{R134a} = \frac{Q_P}{P_e} \qquad (10)$$

In the hybrid installation the cooling efficiency of the evaporator of the absorption component is equal to the thermal efficiency of the condenser of the compressor component.

$$Q_{pabs} = Q_{sspr} \qquad (11)$$

Therefore:

$$m_z(h_4 - h_3) = m_{R134a}(h_{13} - h_{14}) \qquad (12)$$

Using the relationship (3), (7) and (12), one can create a new equation for the cooling efficiency of the hybrid installation – this is shown below.

$$Q_P = \frac{(h_4 - h_3)}{(h_{13} - h_{14})}(h_{12} - h_{11})\frac{m_{wg}c_{wg}(t_{wg} - (t_d + \Delta t_d))}{(h_1 + (f-1)h_8 - fh_7)} \qquad (13)$$

In accordance with the above equation, the cooling efficiency of the hybrid system is dependent on the parameters of the geothermal source, i.e. its efficiency and its temperature [1]. One can also formulate a new equation for the driving power of the electric compressor of the hybrid refrigerator.

$$P_e = \frac{(h_4 - h_3)}{(h_{13} - h_{14})}\frac{(h_{13} - h_{12})}{\eta_c}m_{R134a} \qquad (14)$$

From the above formula, we can determine the cooling efficiency and the electric compressor drive of the hybrid unit powered by geothermal heat for each source of geothermal power. For the analysed case the basic values characterising the hybrid absorption-compressor circuit are: thermal efficiency of the desorber Q_d = 5600 kW; energy efficiency ratio of the absorption component COP_{abs} = 0.7; energy efficiency ratio of the compressor component COP_{spr} = 4.5; cooling efficiency of the hybrid refrigerator Q_p = 3890 kW; drive power of the hybrid refrigerator P_e = 880 kW.

5. Conclusions

The conditions of the geothermal deposit in Biały Dunajec allow water from this source at a temperature of 80°C to be used to power the desorber of the absorption refrigerator working in a hybrid system. The use of geothermal energy sources leads to a reduction of electricity consumption and a reduction of the negative impact of the cooling factors on the natural environment. An additional advantage of the geothermal source is the possibility to use it in a hybrid refrigerator for the production of cold air for air conditioning purposes. It is expected that in the near future, the number of geothermal power plants capable of powering absorption refrigerators or hybrid absorption-compressor refrigerators will continue to increase for economic reason and due to the need to protect the natural environment.

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