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Research and development on heat pump systems in Mexico using geothermal energy

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ABSTRACT

Extensive research and development work on heat pumps operating on geothermal and waste energy has been carried out by Instituto de Investigaciones Electricas, Mexico. Systems include (i) mechanical compression; (ii) absorption – one- and two-stage and double absorption; (iii) heat transformers, and (iv) hybrid, heat pump systems. Specific work and results are described on three applications: (a) a mechanical compression heat pump commissioned for brine purification and operating on low-pressure geothermal steam in Los Azufres geothermal field; (b) a cooling and refrigeration ammonia/water absorption heat pump operating on low-enthalpy geothermal energy and tested in Los Azufres and Cerro Prieto geothermal fields, and (c) an absorption heat transformer tested extensively to evaluate the performance of ternary solutions as working fluids.

1. Introduction

Heat pumps (HPs) can be used for cooling and/or heating in almost any part of the world. They extract heat from a low-enthalpy thermal source, like geothermal energy or waste heat from industrial effluents, and require a relatively small amount of mechanical or thermal energy at a relatively high temperature, depending on the HP type, but reduce CO_2 emissions by at least 50% compared with fossil fuel fired boilers. If the electricity needed to drive the HP is generated from a renewable energy source like solar or hydro, then there are no emissions. Heat pumps are classified as mechanical vapor compression MCHP, absorption AHP and heat transformer heat pumps HTHP, also called absorption heat pump type 2 [1,2]. The MCHP is the most common type and has typical COPs of 3–4 whereas, AHPs have COPs less than unity but use thermal energy instead of electricity since it has no compressor.

Worldwide, geothermal heat pumps GHPs or ground-coupled heat pumps GCHPs, both of the MCHP type, are the fastest growing segment in geothermal technology. In 2005, 32 countries used GHPs for heating, cooling and hot water domestic supply. Their installed capacity increased 730% over the last 12 years and the energy use for heating 500%. The main developments are in European countries and the USA [3,4] with about 1.5 million units installed. R&D on GHPs in Mexico was intensive in the 80's and 90's but slowed down and is being reconsidered given its potential contribution to energy savings and mitigation of environmental impact and climate change. Only a brief summary is presented here due to space limitations. Frias et al. [5] commissioned a MCHP in the Los Azufres geothermal field for brine purification purposes. Best et al. [6,7] tested an ammonia/water cooling and refrigeration AHP in Los Azufres and Cerro Prieto geothermal fields. Barragan et al. [8] experimented with different ternary solutions in an absorption HTHP. Rivera et al. [9] evaluated a single-stage HTHP operating on water/carrol. A heat pump-assisted distillation system for geothermal brine purification is described in [2]. A hybrid HTHP/MCHP system was studied by Rivera et al. [10] who designed a mobile pilot-plant to produce steam, and by Ayala et al. [11] who tested an AHP/MCHP system. Sierra et al. [12] studied an AHP system powered by a solar pond. This work deals with a MCHP, an AHP and a HTHP, operating on geothermal energy [5–8]. Work on a GHP for air conditioning and space heating in a school is underway.

2. Experiments

Fig. 1 shows schematically a MCHP. The actual coefficient of performance COP_A is given by the ratio of the heat given out in the condenser Q_{CO} and the work put in by the compressor W:

$$COP_A = \frac{Q_{CO}}{W}. \tag{1}$$

In an AHP, the compressor is replaced by a secondary circuit in which an absorbent liquid is circulated using a pump. In this case, the COP for cooling (see Fig. 2) is defined as the ratio between the cooling capacity of the absorption cooler Q_{EV} and the input of high grade heat energy into the generator Q_{GE}:

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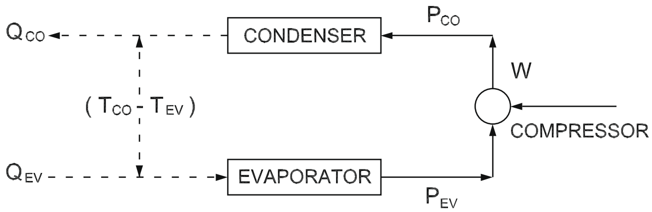

Fig. 1. Schematic representation of a MCHP.

$$COP_A = \frac{Q_{EV}}{Q_{GE}}. \quad (2)$$

For the actual test system employed shown in of Fig. 2, Q_{EV} including the precooler is given by

$$Q_{EV} = m_w(H_{19} - H_{13}), \quad (3)$$

where m_W is the mass flow rate of refrigerant in the primary circuit and h is the enthalpy per unit mass of the refrigerant. The heat into the generator Q_{GE}, including the rectifier, is given by

$$Q_{GE} = m_w H_{10} + m_{GE} H_{11} - m_{AB} H_7, \quad (4)$$

where m_{GE} and m_{AB} are the mass flow rates of solution in the secondary circuit coming from the generator and absorber, respectively.

In a HTHP, heat is supplied at a temperature T_M and a fraction is rejected at a lower temperature T_O, and the remaining energy is upgraded to a higher temperature T_H. Absorption HTHPs recover approximately 50% of low grade heat for use at a higher temperature, using only a small amount of high grade energy, (Fig. 3). The actual coefficient of performance is defined as the ratio between the useful heat delivered by the absorber Q_{AB} and the total heat input (Q_{GE} + Q_{EV}), which is a measure of the efficiency of the process:

$$COP_A = \frac{Q_{AB}}{Q_{GE} + Q_{EV}}. \quad (5)$$

3. Results and discussion

3.1. MCHP

A water-to-water heat pump-assisted geothermal brine purification system operating on R114 was installed at Los Azufres geothermal field. It has two working fluid circuits and was designed to deliver 56 kW at 71 °C with a COP of 4.74 from a source of 52 °C. Two auxiliary heat exchangers were installed, one to heat the salt-free water to be supplied to the evaporator, and another to receive the heat delivered by the heat pump. Fig. 4 shows the schematic layout of the mechanical compression heat pump system. Seventeen runs were carried out with the HP coupled to the geothermal brine purification system. Seven tests utilized water and ten runs used brine in the evaporator of the brine purification system with source temperatures between 35 and 56 °C and boiling temperatures between 60 and 85 °C. Condenser water temperatures were between 45 and 60 °C. Water boiling temperature and distillation velocities of the purification system were determined with the aid of applied vacuum.

Fig. 5 shows a plot of COP_A versus the gross temperature lift GTL, defined as the difference between the condenser and evaporator temperatures ($T_{CO} - T_{EV}$). Also shown in this graph is the variation COP_A against the heat received by the evaporator since the heating capacity of heat pump is also a very important performance indicator. This figure shows that the COP_A decreases as GTL increases and that COP_A increases as the heat delivered to the purification system evaporator increases. It can also be seen that there are two sets of data. The difference between them is due to the boiling temperature of the water and geothermal brine in the purification system. From the experiments it was found that distilled water or brine flow rate increases as the GTL decreases. Distilled brine rates of 0.00777 kg/s were obtained for a COP_A of 3.8 at a temperature of 83 °C with heat pump effectiveness between 0.4 and 0.6.

3.2. Ammonia/water AHP

A 10.5 kW experimental ammonia/water AHP was tested at Los Azufres geothermal field. The condenser and evaporator are commercially available units with nominal capacities of 17.6 and 10.6 kW, respectively. The generator, rectifier and precooler were all of the shell and tube type. A mixture of 49.3 kg of water, 35.7 kg of ammonia and 0.75 kg of sodium chromate as corrosion inhibitor was used as the working fluid for tests in Los Azufres. Steam was fed to the generator for system operation. Fig. 2 shows the diagram of this unit. A cooling capacity of 10.3 kW was obtained at a generator temperature of 91.5 °C and an evaporator

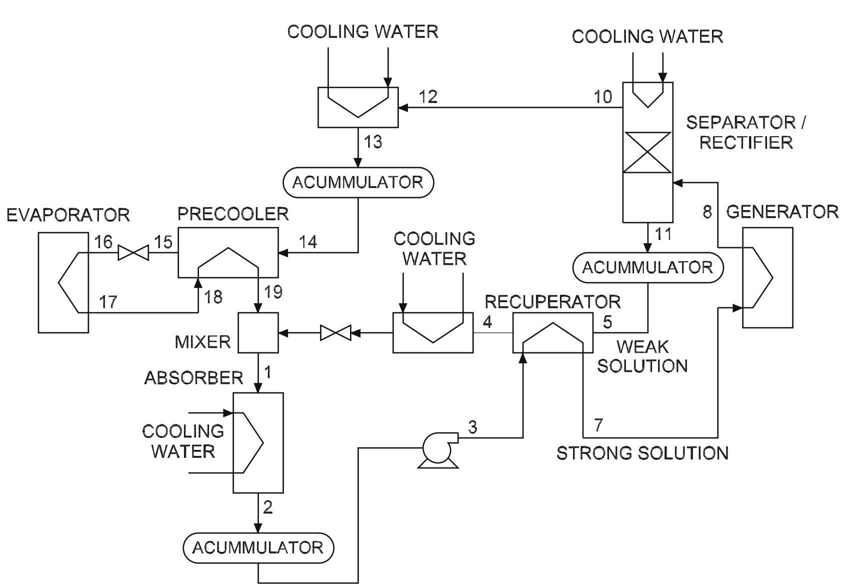

Fig. 2. Ammonia/water cooling AHP tested in Los Azufres and Cerro Prieto geothermal fields [6,7].