CHEMICAL ENGINEERING TRANSACTIONS
VOL. 29, 2012
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet
Guest Editors: Petar Sabev Varbanov, Hon Loong Lam, Jiří Jaromír Klemeš

ISBN 978-88-95608-20-4; **ISSN** 1974-9791
DOI: 10.3303/CET1229205

Analysis in a Test Bench for Geothermal Heat Pump with Simultaneous Production of Domestic Hot Water with Heating or Cooling and Efficiency Improvements

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Within the lines of collaboration between the University of Vigo and EnergyLab has been developed the research project of this communication. The main objective of this project has been analyze the energetic operation of a commercial reversible water-water heat pump to residential use in a test bench, with simultaneous production of both heating and domestic hot water (DHW) and cooling and DHW. It has also been studied the adaptation of new components of the heat pump for optimum performance in normal working conditions of geothermal heat pump (GHP) with closed geothermal capture.
This communication describes the detail of design and assembly of a test bench (hydraulic systems, electrical system, control system, data acquisition and processing...) necessary for carrying out the tests on the commercial equipment and on the new developed prototype. Main changes have been the introduction of a new heat exchanger in the cooling circuit between the gas and liquid phases of the R407C coolant besides a bigger thermostatic expansion valves.
Between the project results have been analyzed the trials over the commercial heat pump, the pattern of behavior of this equipment and the realized improvements on this model. The implementation of efficiency improvements in the new prototype and the carrying out of tests has allowed to obtain better results of his coefficients of performance and to assess the optimization of the new prototype.

1. Introduction

As geothermal energy can be used all over the world, both for heating and cooling, geothermal heat pumps (GHP) have attracted increasing interest. Thus, geothermal energy is becoming more competitive energy than fossil fuels, and also environmental benefits associated with this energy source will have that its development will accelerate in the future. Studies have shown that approximately 70 percent of the energy used in a GHP system is renewable energy from the ground (Chua et al., 2010). As a result, it is one of the cleanest technologies available for transferring heat from and to a natural heat source or sink.

Please cite this article as: Álvarez J. T., Pérez F. C., Toimil S. F., Alfaya M. E. V., Fernández–Arroyo J. I. R. and Da Costa E. A., (2012), Analysis in a test bench for geothermal heat pump with simultaneous production of domestic hot water with heating or cooling and efficiency improvements, Chemical Engineering Transactions, 29, 1225-1230

In the case of Spain, Lund et al. (2011) has estimated that, using a coefficient of performance (COP) in the heating mode of 3.5 and 1500 full load heating hours per year, the annual energy use represents approximately 462,92 TJ per year.
GHP is really a water-to-water heat pump operate on an electrically driven vapor-compression cycle. Main elements are the plate heat exchangers (evaporator and condenser), the compressor action by an electrical motor and the expansion valve. The energy is transported by means of a refrigerant fluid.
In the case of HP that can produce heating or cooling, reversible HP has to reverse the cycle of operation interchanging the energy transfer between the thermal focus in the basic heat exchangers. Accordingly, reversible HP has to stop its operation and reverse the cycle by means of a four-way valve to switch between both modes of operation. Besides, some HPs produce domestic hot water (DHW) in the desuperheater where they take advantage of the sensible heat of the exhausted gas from the compressor.
In this way, several works analyze the production of heating/cooling and the DHW by different ways (Hepbsali and Kalinci, 2009; Cui et al., 2008). The production of DHW has also been analyzed through the use of the sensitive heat of refrigerant condensation as overheated gas after the compressor and as of the subcooled liquid after the condenser (Shao et al., 2004; Palm, 2008). It is also possible to study the improvement of the heating capacity of an electric heat pump, using other sources of heat as the recovered heat and the cooling of engine block as exhaust gases (Kim et al., 2009). Other studies have presented the studies carried out to elucidate the influence of the source and sink temperatures on the optimal charge of a propane water-to-water HP (Corberán et al., 2011). Chua et al. (2010) have done a review of the advances in HP systems. These offer economical alternatives of using heat from different sources for use in various industrial, commercial and residential applications. Finally, Lubis et al. (2011) have studied the thermodynamic analysis of a hybrid geothermal heat pump system. There, the components involving the highest exergy destructions are the compressor and the condenser, being the main reasons the friction and the heat transfer.

2. Experimental section

This research is centred in the study of the operation of all of the components of the water-to-water HP. This has a heating power of 7.5 kW at the nominal operating conditions (10 ºC/45 ºC) and a cooling power of 7.3 kW at the nominal operating conditions (30 ºC/7 ºC). The used refrigerant was R407C. This could be the energetic demand of a domestic house.
The layout of the different elements can be consulted in Cerdeira et al., 2011. Mainly, it is composed of a reversible geothermal water-to-water HP, a tank of 732 L, an inertia tank of 283 L, a tank of 250 L and a plate heat exchanger (PHE) through which we can simulate the energy demand.
The design of the installation was made without the use of the energy of the ground, because no drilling has been made. So, the installation was made using the tank of higher size as a heat source/sink, as if it were the Earth. The tank which simulates the wells maintains the conditions desired with the aid of the air-water heat pump situated outside.
The production of DHW is obtained heating the distribution water through the instantaneous production unit of 25 L·min-1. This unit is a heat exchanger in counter flow with a high relation area/length connecting in close circuit with the tank of 250 L.
The installation is integrated by 6 circuits. To do that, it is necessary to control a great quantity of items to study the energy and mass balances. So, the data acquisition is compounded by the following items: 28 temperature sensors, 5 pressure transmitters, 6 flow meters and one electricity meter. A more detail description can be consulted in Cerdeira et al. (2011).
The electricity meter is necessary for counting the electrical consumption of the compressor. With this parameter, it is possible to evaluate the coefficients of performance (COP and EER) completely. All this equipment is controlled by one Omron PLC (CJ1M) and the universal cards.

2.1 Modifications

Figure 1 provides the scheme of the different elements of the geothermal heat pump. This includes several modifications, which were introduced in the internal circuit of the GHP to improve the efficiency of the machine.

It can be cited the possibility of work with different expansion valves (EV) and the heat recovery through a concentric tube heat exchanger (HGL) that interchange heat between the liquid to outlet of the condenser with the gas to inlet in the compressor. Besides, it was introduced a second circulating pump in parallel in the circuit of production of DHW.

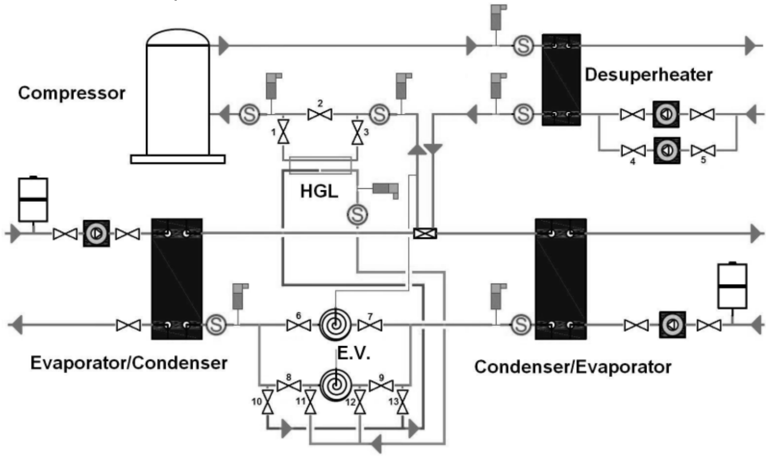

Figure 1: Scheme of the different elements of the geothermal heat pump, include several modifications

3. Results and discussion

When all of the modifications were done, the new data were measured having as a reference the norm UNE-EN 14511 (Air conditioners, liquid chilling packages and heat pumps with electrically driven compressor for space heating and cooling), that defines not only the test conditions but the test methods for different devices and between them it is taken into consideration the water-to-water HP.
The tests were done during a period of 35 min, registering each measuring magnitude each second. The temperatures of in and out in the different circuits of the water-to-water HP were maintained practically constant.
It has been realized 4 types of tests: in heating mode without DHW production, in cooling mode without DHW production, in heating mode with DHW production, in heating mode with DHW production.
In heating mode, the selected inlet temperatures to the geothermal fluid in the GHP were included between 8 – 14 ºC. The outlet temperatures in heating mode were included between 35 – 45 ºC, which are the normal temperatures in a radiant heating systems.
In reversible HP, the changes in surrounding and operating conditions, and in the case of refrigerant mixtures, changes in glide match conditions, affect the heat transfer process in the condenser and evaporator, and the mass flow rate through the compressor causing variation in delivered capacities (Rajapaksha et al., 2003).
In cooling mode, the selected inlet temperatures to the geothermal fluid in the GHP were included between 30 - 35 ºC. The outlet temperatures in cooling mode were included between 10 - 18 ºC, which are the normal temperatures in a air conditioning systems.
Figure 2 show the heating power with nominal operating conditions of 10 ºC / 45 ºC. This heating power is upper to 7.5 kW which is higher than the original BCG.
Figure 3 show the development of Energy Efficiency Ratio (EER) with diferent operating conditions while the GHP was woorking in cooling mode. It is possible to observe that the EER is increase when the temperature of system of production of cold is also increased.
Figure 4 shows the development of COP while it were made two discharges: continuous (35 min) and discontinuous (alternatives discharge of 5 min). It is possible to observe that the COP is better when the discharge is discontinuous.

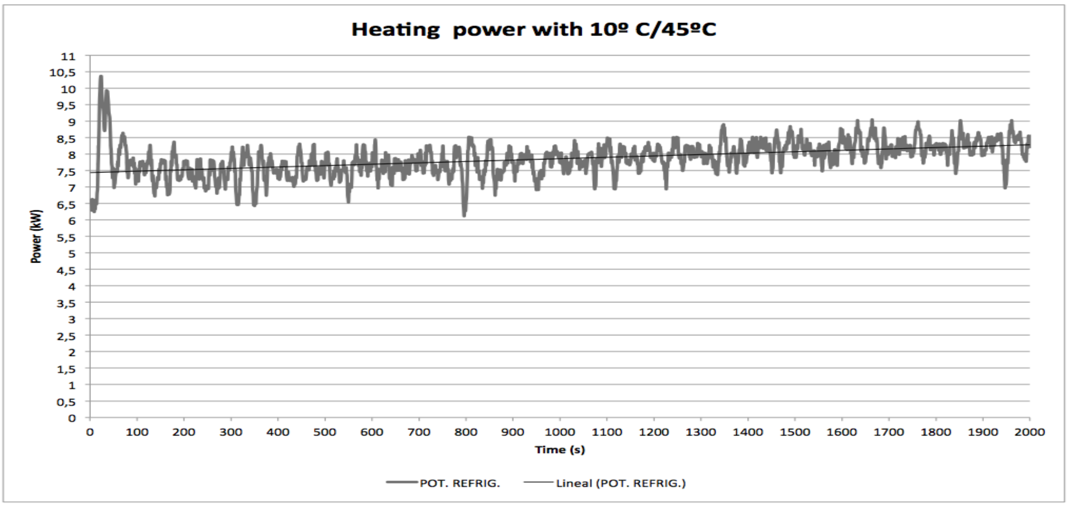

Figure 2: Heating power with nominal operating conditions10 ºC / 45 ºC

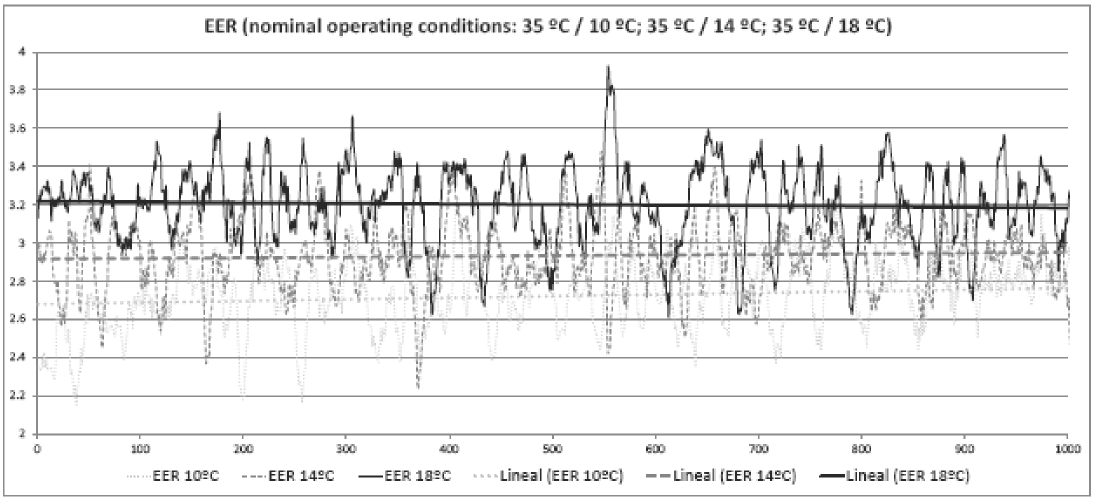

Figure 3: EER while the temperature of dells water is a 35 ºC with three different experiments: the temperature of cooling water was varied to 10, 14 and 18 ºC

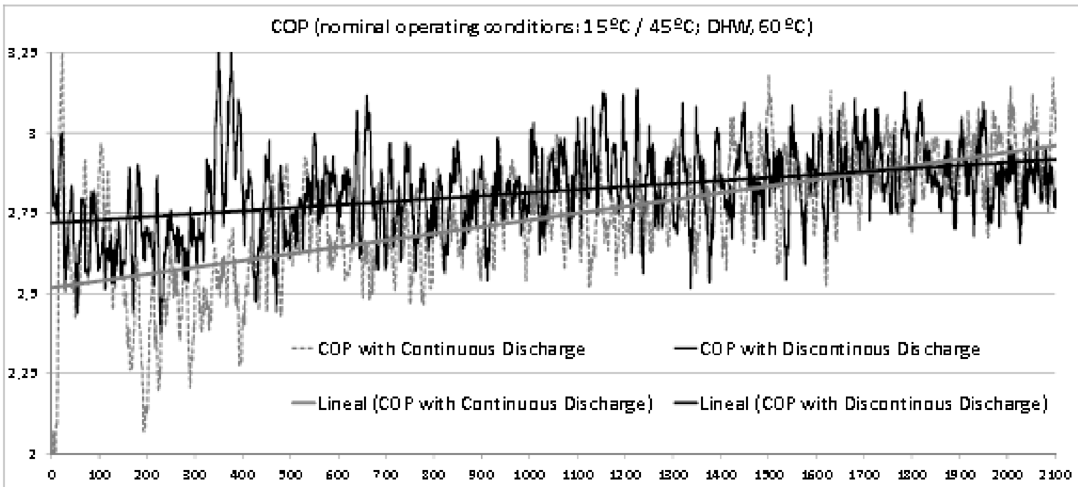

Figure 4: COP obtained while it were made two discharges: continuous (35 min) and discontinuous (alternatives discharge of 5 min)

4. Conclusions

A geothermal installation of water-to-water heat pump of low enthalpy has been designed and totally monitored with temperature and pressure sensors, flow meters and electric energy counters, so it is possible to know the transfer energy in each instant and in each zone.
A system has been designed which allows the reproduction of the thermal conditions of the fluid that circulate through the inside of the drill pipes through a big water tank and an air-to-water heat pump; so them, it is possible to simulate any thermal conditions of the ground.
Both the heating and cooling operation of the geothermal heat pump has been analyzed and also the production of the domestic hot water by means of the sensible heat recuperation of the desuperheater gas from the compressor.
It was possible to deduce that the GHP is not capable to maintain a continuous production of heating when starting the DHW consumption. Hence this indicates that there is a higher previous use of heat in the desuperheater against the heating production in the condenser.
We have checked that the coefficient of performance looks like a bit higher in cooling mode than heating mode. Besides, the heating power is higher than the original BCG.
It is possible to observe that the EER is increase when the temperature of system of production of cold is also increased and the COP is better when the discharge is discontinuous.

Acknowledgement

This study was included in a greater project financed by the Galician Regional Government (Grant: 09REM004CT); it was carried out by EnergyLab and the University of Vigo.

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