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Comparing different sinks of heat rejection of an existing solar powered absorption cooling system

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Abstract.

Nowadays about 400 [1] solar cooling air-conditioning systems are installed throughout Europe. There are many research papers referring to theoretical studies but the information of experimental studies in this kind of installations is scarce.

This paper describes a solar absorption cooling installation based on the performance of an absorption chiller. The installation is located in the University of Zaragoza (Spain).

The solar cooling system consists mainly of 37,5 m2 of flat plate collector, a 4,5 kW, single effect, LiBr-H2O rotary absorption chiller and a dry cooler tower to cool the absorption cycle. The installation provides cooling to a gymnasium belonging to the sports center of the University. To carry out the installation analyses, the system was continuously monitored.

In the last three years, 2007, 2008 and 2009, several studies have been carried out in order to analyze the full system operation. The measured data results of the installation show the strong influence of the cooling water temperature and the generator driving temperature on the COP.

Due to this experimental evidence of the influence of the cooling water temperature, a geothermal sink for heat rejection system has been installed and studied. The installation with this new configuration started to work this year.

Key words

Solar cooling, absorption, heat rejection, geothermal heat sink, experimental solar plant.

1. Nomenclature

COP	coefficient of performance (-)
I	irradiation on the collector surface (W m-2)
q	flow rate (l min-1)
T	temperature (ºC)
W	power (kW)
η	efficiency (-)

Subscripts

c	cooling
ch	chilling
dbo	dry bulb outdoor
ev	evaporator
g	generator
he	finned tube heat exchanger
well	water well
i	inlet
o	outlet

2. Introduction

Because of the increase of the annual mean temperatures the air-conditioning market has grown in a spectacular way [2]. Unfortunately most of these air conditioning devices are driven with electricity causing overloads in the electrical system and damage to the environment (the most of the electricity is produced by fossil fuels).

The solar cooling facility shows a great potential to mitigate these problems [3]. This cooling technology has a long history in the industrial sector, but lacks still of enough experience in the domestic sector, that would allow understanding exactly its performance in combination with the solar thermal energy. As any thermally driven chiller, it produces heat that has to be rejected. Cooling towers are often employed to reject the heat coming from the absorber and condenser circuits of the chiller [4]. Although these kind of cooling devices are simple to be installed and give good results in terms of cooling capacity, they are mainly limited by posing a health risk of legionella. Moreover, their performance is also limited by the ambient conditions, so the COP of the chiller diminishes substantially. An alternative to palliate this problem is the use of a geothermal sink to re-cool the absorption chiller [5]. This kind of sink is technically more complex than the configurations with cooling towers, but provides a constant low temperature during of the year.

3. Introduction

The installation (Fig. 1) is placed in Zaragoza (Spain), and it is used to cool a gymnasium. This installation was designed as a consequence of the overheating in the existing solar collectors. In summer, the solar field was oversized because solar power was bigger than needed. The solution was to use this additional power in a new refrigeration system [6].

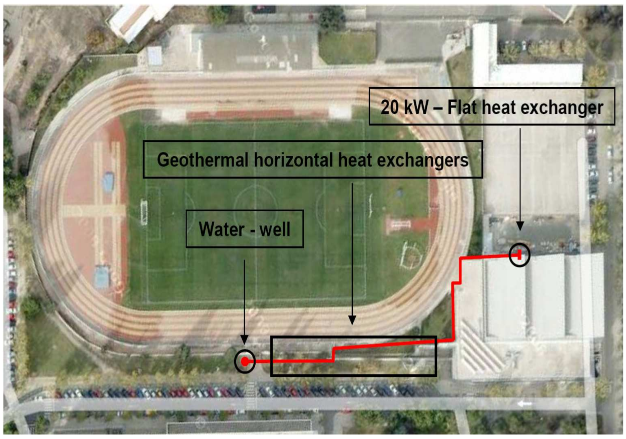

Fig. 1. Situation of the geothermal system

A commercial 4.5 kW air-cooled, single effect, LiBr-H2O absorption chiller has been used (device 5 in Fig. 1). It has a rotary drum in which the single effect absorption cycle is carried out with the drum rotating at 400 rpm. The rotation favours mass and heat transfer. Inside the drum are situated the evaporator and the condenser and instead of a traditional compressor fed with electricity, there is a chemical absorber and a generator which reduce the electricity consumption.

The solar collector field (device 1 in Fig.2) has 37.5 m2 of useful area. Solar radiation is absorbed and transformed in thermal energy to feed the absorption machine. The solar collectors and the solar heat exchanger (device 2 in Fig.2) form the primary circuit. The installation contains a hot water tank (device 3 in Fig. 2) and an auxiliary boiler (device 4 in Fig. 2) but both are not in use. In this way, the absorption chiller will only work when the solar field can provide it enough energy.

Two fan coils (device 7 in Fig. 2) with 6.21 kW of chilling power transfer the chilling power from the evaporator of the absorption machine to the gymnasium air.

Initially, a dry cooling tower was installed to (device 6 in Fig. 2) evacuating the residual heat from the condenser and the absorber of the chiller to the outdoor air.

Over the last three years the performance of the solar powered absorption cooling installation has been monitored and analyzed.

During the first two years, the installation worked with the initial dry cooler tower. After the analysis of the two first years, the conclusion was that there was a strong influence of the cooling temperature on the COP of the chiller, as is also quoted by other authors [7 -10].

Because of this situation several studies to improve the performance of the absorption machine were carried out [11]. In 2009, the cooling system was modified. Close to the gymnasium's building there is a 25 m^3 ground water well, used as watering reservoir for the grass of the sports fields (device 10 in Fig. 2). Due to this use, all the water in the reservoir is watered and renewed, which allows having the same temperature (25ºC) every day before the starting of the chiller.

The new cooling subsystem uses a 20 kW heat exchanger (device 8 in Fig. 2) to reject the absorption heat, and transfers it to the geothermal sink. The length of the buried pipeline between the heat exchanger and the water well is 190.5 meters. The supply pipe of this geothermal network is divided into three horizontal underground heat exchangers of 90.5 meters each one (device 9 in Fig. 2), in order to increase the heat exchange surface.

With this configuration, the rejection of heat can take place in the two sinks of the geothermal system, in series in the water well and in the three ground heat collectors in the supply pipe, and in the dry cooler tower, since the existing air-cooler hasn't been removed from the installation in order to, if it's necessary, use the whole cooling system as a hybrid system.

4. Control and monitoring system

The installation is completely monitored. The procedure of the implementation of the monitoring system was designed in order to carry out the energy balances of the different components of the installation [13]. There is a PLC unit and a web controller which form the controlling and recording values system. In addition to this, there are temperature, humidity, and radiation sensors, flow meters and energy meters (Fig. 2). Moreover seven new sensors were placed in the new geothermal system. In this way, the outdoor and indoor conditions of the installation are well defined.

The monitoring system consists mainly of temperature probes and flow meters located in the three water flows that enter the absorption machine. Two temperature probes (near to the absorber and the condenser of the absorption machine) measure the inlet (T_{ihe}) and outlet (T_{ohe}) temperature of the flow between the absorption chiller and the dry cooling tower (finned tube heat

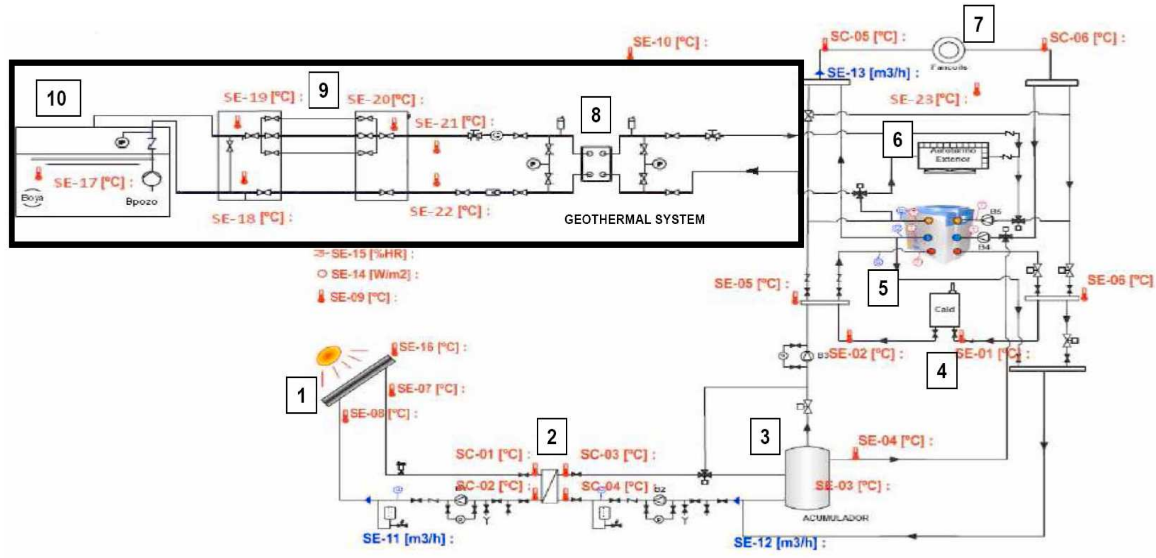

Fig. 2. Scheme of the installation

exchanger). Two temperature probes measure the inlet (T_{iev}) and outlet (T_{oev}) temperature of the flow between the absorption chiller and the fan coils (the measure is taken near the evaporator in the absorption machine).

Two temperature probes measure the inlet (T_{ig}) and outlet (T_{og}) temperature of the flow between the absorption chiller and the heat exchanger (the measure is taken near to the generator in the absorption machine). While the temperature values for the exterior temperature are measured with NTC sensors, the ones located around the absorption chiller are registered with PTC sensors. The accuracy for the PTC sensors reaches ±0.1ºC and ± 1 ºC for the NTC ones.

Furthermore, there is a flow meter in each one of the circuits of the chiller; the water flow that goes to the generator (q_{gen}), the water flow that goes to the fan coils (q_{ref}) and the water flow that goes to the finned tube heat exchanger (q_{dis}).

5. Methodology

Four different types of graphics have been composed in order to compare and relate variables:

'Rank Graphics'. These represent in an independent graphic the evolution versus time of all the days that have been studied of the following variables: the generator circuit flow rate (q_{gen}), the fan coils circuit flow rate (q_{ref}), the finned tube heat exchanger circuit flow rate (q_{dis}), the inlet and outlet temperature at the generator (T_{ig}, T_{og}), the inlet and outlet temperature at the evaporator (T_{iev},T_{oev}), the inlet and outlet temperature in the flow from the finned tube heat exchanger (T_{ihe}, T_{ohe}), the irradiation (I), the coefficient of performance (COP), the power transferred in the generator (W_{gen}), the power transferred in the evaporator (W_{ref}) and the power transferred in the condenser and the absorber (W_c). By analyzing these variables of the installation it is possible to know the whole performance of the rotary absorption system (Fig. 5).

'Phase Graphics'. These are three different graphics for each day. The first one represents T_{ig}, T_{og}, T_{iev}, T_{oev}, T_{ihe}, T_{iha}, I and T_{dbo} evolution versus time, the second one contains q_{dis}, q_{ref}, q_{gen}, development versus time and the third one shows COP, W_{gen}, W_{ref} and W_c evolution versus time. The influence of some variables on the other ones is shown in this type of graphics.

'Stationary Graphics'. To compare the performance of the absorption chiller in different days, it is necessary to define the stationary period, in which the chiller works in a stationary situation. This period of time is defined as an interval of time. For each studied day, the minimum T_{oev} is recognized, and the interval of time of the steady situation defined. The points inside this interval will be those which do not differ more than 5% from the minimum T_{oev} ([$(T_{oev})_{min}$, 1.05*$(T_{oev})_{min}$]). Figure 3 shows the Stationary Graphic of 11/07/2008. In this figure, temporary values (those which are recorded throughout the day) and stationary values (those included in the stationary interval) have been compared for a day (11/07/2008). The stationary interval is the central part of the temporary representation, and the values placed in the stationary period represent a constant behaviour in the performance of the chiller. The stationary values will be the base of the analysis.

'Trend Graphics'. For this type of graphic it is needed to calculate the average values of all the parameters analyzed in the stationary time, of all the days studied. After that, each one of the variables is represented with the other ones, in different graphics. The average values follow the same evolution as the temporary values, and the trend lines are overlapped. Consequently, average values can be considered representative values of the temporary ones. With the average values, an average performance of the installation can be calculated.

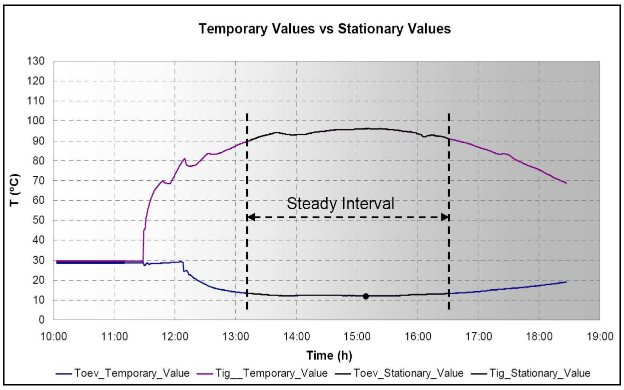

Fig. 3. Temperary Values vs Stationary ones

6. Results

The analysis´ results of the first two years (2007 – 2008) showed the very strong influence of the cooling tower temperature level on the COP (Fig. 4). For this analysis, Trend Graphics have been used.

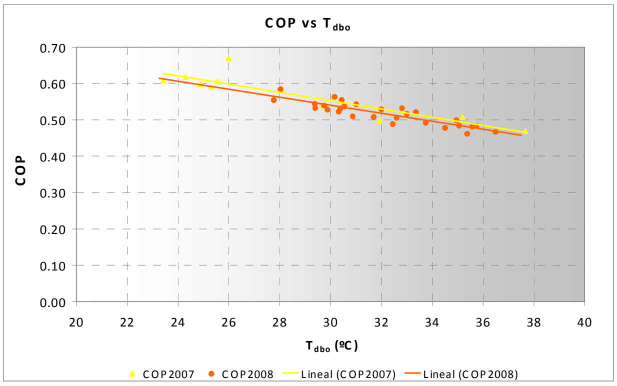

Fig. 4. COP vs T_{dbo}

As shown in the Figure 4, the COP decreases when the sink temperature increases. Both trends have the same slope, although the mean values of the year 2008 are lower because the mean ambient temperature during 2008 was higher, as shown in the table I. This also underlines the temperature influence on the COP.

Table I. - Experimental mean values of the installation in the years 2007 and 2008

Year	W_{ch} (kW)	W_g (kW)	W_c (kW)	COP (-)	T_{dbo} (ºC)
2007	5.8	9.7	15.4	0.56	31.2
2008	4.4	8	12.5	0.51	27.7

Based on these results, several studies have been carried out to improve the performance of the chiller and to eliminate its dependence from the ambient temperature [11, 12]. The conclusions of these studies showed that the water well must be used to reject the heat produced in absorption cycle. With this arrangement the chiller will be cooled with a water loop instead of ambient air. The estimated values of chiller power and COP are driven as function of the potential cooling capacity and the possible temperature of the water well as shown in the Figure 3.

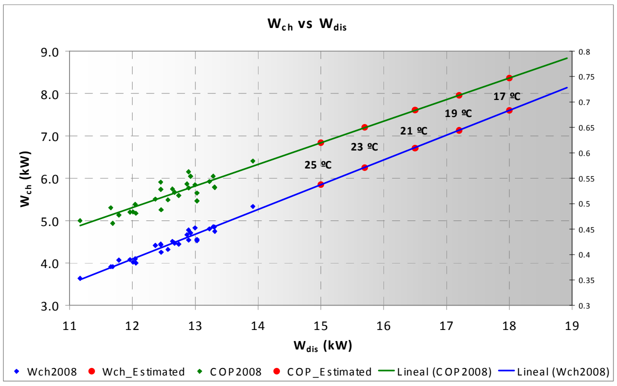

Fig. 5. Chilling power and COP according to cooling capacity and water well temperature

Figure 5 shows the chilling power and the COP as a function of the temperature of the sink and the cooling capacity. In the design phase of the geothermal system, the temperature of the water well was estimated to be 17ºC ± 1ºC, since this value corresponded to the mean temperature of the adjacent wells of the installation. In 2009, during the performance period, the measured temperature of the water sink was 25ºC. Therefore, for this value, the capacity to reject heat achieved is only 15 kW with an estimated chiller power of 5.8 kW and a COP-value of 0.62.

In 2009, the geothermal installation was executed. Different flow rates were used to obtain a wider knowledge of the system (49 l/min and 95 l/min). The obtained results are shown in the Figure 6.

In the Figure 6 are represented the mean values of the stationary steady of the chiller performance working with the dry cooler and with the geothermal sink. As can see on it, the results of the geothermal operation for both flow rates cases, the trend lines of the outlet chilling temperature, inlet generator temperature and the outlet cooling temperature are approximately horizontal.

The chilling capacity and rejected heat power in the new scenario are shown in the figure 7. Just like the previous cases, the chilling capacity and the rejected heat with the geothermal loop show trends more constant than the present one of the air-cooled system. In this aspect, both powers depend no longer directly on the ambient temperature.

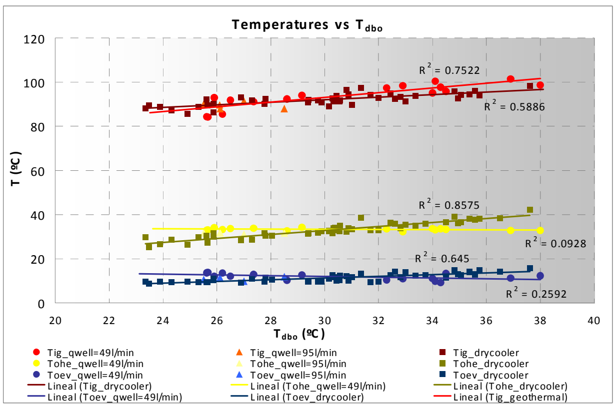

Fig. 6. Obtained results with the dry cooler and the new geothermal sink

In terms of mean values of the obtained experimental capacity, the results have been lower than expected. This is because of an erroneous design of the flat heat exchanger. However, some improvements have been made with the new system. When the system works with the low flow rate (49 l/min) it always presents worse results than the performance with the dry-cooler. If the operation flow rate is set on 95 l/min, the new performance obtains better results than the air cooled scenario when heat is rejected at an ambient temperature above 28ºC. A hybrid condensation system control can be implemented in order to use always the most thermally efficient sink [15].

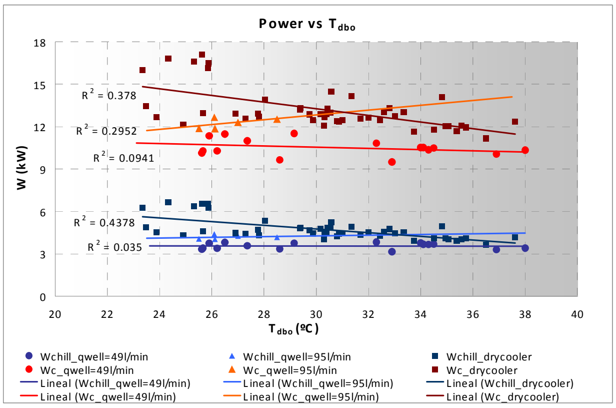

Fig. 7. Chilling capacity and rejected heat power with the dry cooler and the new geothermal sink

The final parameter analyzed related to the ambient temperature is the COP of the chiller. Again its trend holds constant with the increase of the ambient temperature (Figure 8). Therefore, with the water well sink the ambient temperature dependency of the COP has been removed.

Figure 8 indicates clearly that the COP result tendency is similar to the cooling power tendency. For the high flow rate the COP is better in the new case, only when the outside temperature is over 28ºC. This means that a hybrid control system should be taken in account.

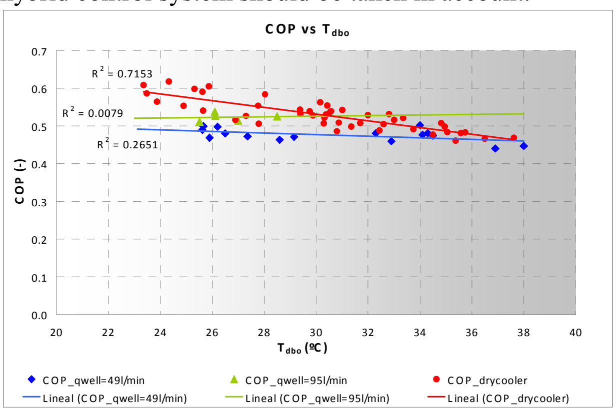

Fig. 8. COP results with the dry cooler and the new geothermal sink

Although only partially satisfactory results have been obtained with the new system, it has been shown that the mean value of the COP measured in 2009 is better than the one measured in 2008 as shown the table II.

Table II. - Experimental mean values of the installation in the year 2009

Flow Rate (l/min)	W_{ch} (kW)	W_g (kW)	W_c (kW)	COP (-)
49	3.5	7.1	10.5	0.47
95	4.2	7.6	12.2	0.52

7. Conclusions

In this paper have been presented the results of the analysis of the performance of a solar powered absorption system. Initially, the chiller used a dry cooler tower to evacuate the absorption cycle heat. The first conclusions showed a great influence of the ambient temperature on the chiller COP. Because of this an open geothermal cycle was designed and installed, allowing for the use of a hybrid heat rejection system.

With the new circuit, this COP dependence is removed, and therefore a constant COP is obtained in function of the ambient temperature.

The study has proved the importance of a good design of the flat heat exchanger placed between the cooling loop of the chiller and the geothermal circuit. Due to differences between the estimated operation conditions and the real operation conditions, the measured performance results are worse than the expected ones. In any case, the mean value of the chiller COP has been improved compared with the mean value of the year 2008. Several studies have been already planned for the next year in order to optimize the geothermal installation, in order to reach the expected results.

Lastly, depending on the planned optimization of the heat exchanger, a condensation hybrid system control must be designed. The possibility of using a hybrid system (air / water cooled) to reject the produced heat in the absorption cycle is another optimization measure to take into account.

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