Simulation of an absorption based solar cooling facility using a geothermal sink for heat rejection

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Abstract

An important issue of solar cooling facilities based on absorption cycles and sometimes not given the necessary attention is the recooling process of the absorber and condenser. This is critical in the overall behaviour of the facility because the condensation and absorption temperatures will affect the COP and cooling capacity of the chiller. Most of the time the recooling process is made by using a wet cooling tower in a closed loop through the absorber and condenser. The use of a wet cooling tower gives good results in terms of cooling capacity and COP, but presents some health risk, like legionella, and its use is restricted to the industrial sector and places where water scarcity is not present. This paper presents the modification of the already validated TRNSYS simulation of a solar cooling facility, implementing a geothermal heat sink instead of the wet cooling tower in order to dissipate the heat generated internally in the absorption chiller. Simulation results shows that a geothermal heat sink composed of 6 boreholes of 100 meters of depth should be sufficient in order to substitute the wet cooling tower, for a typical Spanish single family dwelling.

Keywords: Solar cooling, geothermal heat sink, TRNSYS simulation, Experimental solar plant

1. Introduction

Solar thermal cooling facilities based on absorption cycles, when applied to the domestic sector are being extensively investigated these days because of their great potential on lowering the overload on electricity grids during summer season, but also for their energy and environmental advantages. Most commercially available water fired absorption chillers use the BrLi-H_2O working solution. This solution is widely known and its performance has been well documented by many researchers [1, 2]. These types of chillers commonly need wet cooling towers for recooling, in order to dissipate the heat generated internally in the absorber and condenser, thus limiting their use in both the industrial and residential sector for its cost and bulk but also posing the health risk of legionella . Also the operating cost of a wet cooling tower gets incremented by the need of running the cooling fan, consuming a considerable amount of electric energy, and for replenish the water that gets evaporated and dragged out of the cooling tower. These drawbacks are very impeding for the domestic sector.

There are some commercially available absorption chillers recooled by an air stream, even being fired by hot water [3]. In hot days the ambient temperature result too high for them; as a result their COP and cooling capacity substantially diminishes. This effect is more pronounced when the machine is driven by the limited temperature of hot water produced in solar collectors.

An option for absorption cycles recooled by water is the use of a geothermal heat exchanger, taking advantage of the lower soil temperature. The installation of this kind of heat sink is more complex than installing a wet cooling tower because of the previous excavation of the borehole heat exchangers (BHE). The properties and type of soil underneath will dictate the dimensioning and hence the total cost of the facility, but once installed, its maintenance cost is low. Making use of this type of heat sink could promote the use of these facilities in the more sensitive domestic sector.

The Universidad Carlos III de Madrid (UC3M) counts with an experimental solar thermal cooling facility using a wet cooling tower coupled to an absorption chiller for heat rejection purposes. A numerical simulation using the TRNSYS tool has been accomplished and validated over the current experimental set-up.

This paper presents the modification of the already validated TRNSYS simulation, implementing a geothermal heat sink instead of the wet cooling tower. Different BHE connected in parallel and different borehole depths are analyzed in a trial an error way in order to select the best configuration for supplying the necessary heat rejection rate of the absorption chiller.

2. Experimental Facility

The solar thermal cooling facility installed at Universidad Carlos III de Madrid (UC3M) was first configured to operate with 50 m^2 solar thermal collectors array in the primary loop and a 2 m^3 Thermal Energy Storage (TES) in the secondary loop in order to store and supply hot water as energy input to run the water fired absorption chiller. A complete description of the facility can be found in [4]. But from a recent optimization work done over the facility with the help of the TRNSYS simulation program, it was concluded that working with a lower TES capacity of 0.1 m^3, the daily and seasonal values of COP and SCOP improves from the previous configuration [5]. Even with no TES at all the COP and SCOP increased, pointing out that the design and sizing of the TES in domestic application is of great importance.

In June of 2008 the facility was modified to work with no storage, bypassing the 2 m^3 TES and supplying the hot water coming from the solar thermal collectors directly to the absorption chiller by means of a heat exchanger, see Figure 1. Hot water enters the generator of the absorption chiller earlier than working with TES and achieving higher generator temperatures. This makes the solar facility to start the cold production earlier and with higher cooling rates, but demanding a higher rejection rate to the ambient as well.

2.1. Experimental results

Experimental results for July 9, 2008 are presented in Figures 2, 3 and 4. This day is selected as representative of the season. The absorption chiller installed in the UC3M’s solar cooling facility is a Yazaki pumpless WFC-10 of 35 kW nominal cooling capacity. It incorporates a solution control to work under part load when driven by solar energy.

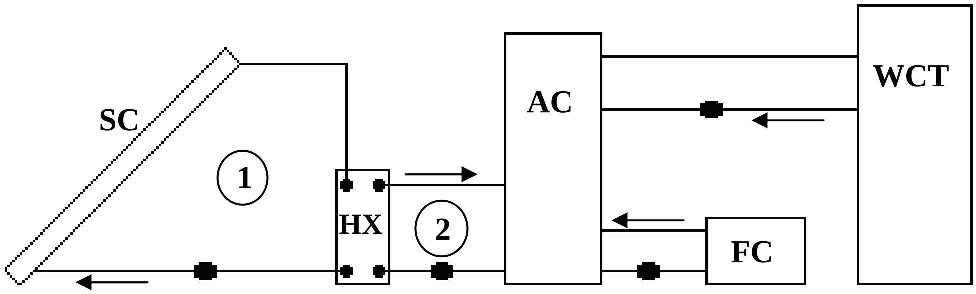

Figure 1. Current configuration of the experimental solar cooling facility at Universidad Carlos III de Madrid. SC: Solar Collectors, HX: Heat eXchanger, AC: Absorption Chiller, FC: Fan-Coil, WTC: Wet Cooling Tower. Numbers in the Figure refers to the facility loops.

In Figure 2 it is shown the behaviour of the solution control marked by circles. This behaviour is more noticeable when high inlet temperatures to the generator are achieved in a relatively short period of time, which is the case of the current facility configuration. The solution control provokes a sudden drop in the cooling rate of the absorption chiller, making the daily COP and SCOP to suffer the same sudden drop as it is shown in Figures 3 and 4. Nevertheless this occurs for a relatively short period of time too. Current operating conditions of the solar cooling facility are presented in Table 1.

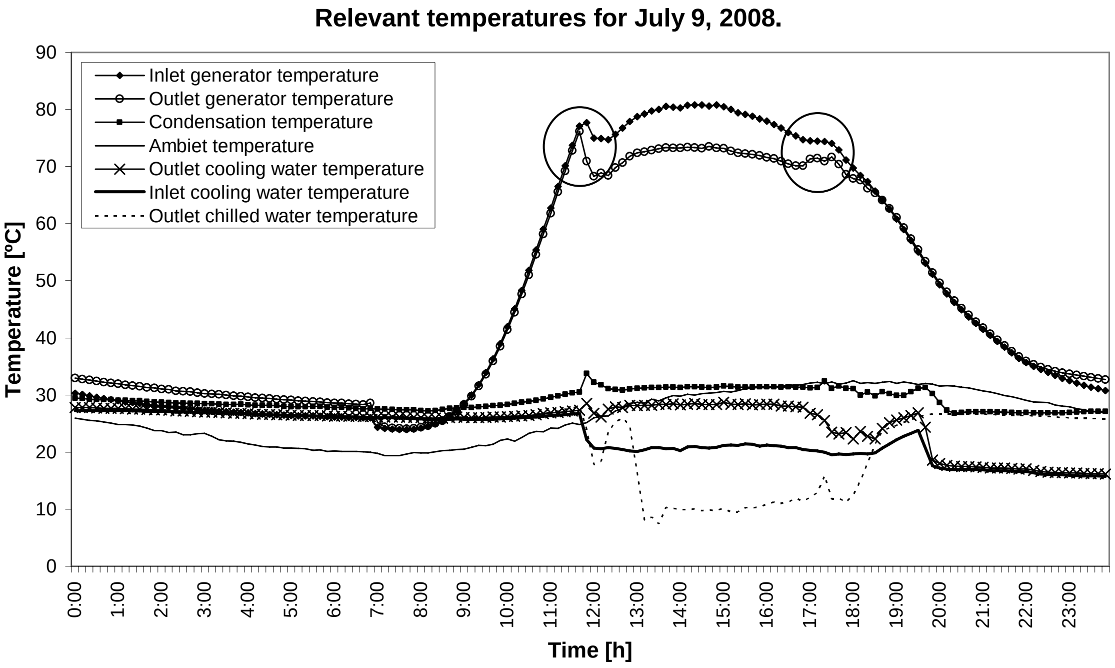

Figure 2. Relevant temperatures of the experimental solar cooling facility, July 9, 2008. Circles in the figure show the behaviour induced by solution control of the absorption chiller.

Table 1. Current operating conditions for UC3M solar cooling facility.

Primary circuit (collectors) fluid	33% propylene glycol mixture
Fluid of the rest of the facility	water
Collector area	50 m^2
Collector slope	40º
Primary circuit (collectors) mass flow rate	0.49 kg/s
Secondary circuit (generator) mass flow rate	0.49 kg/s
Tertiary circuit (load) mass flow rate	0.33 kg/s
Cooling tower mass flow rate	0.77 kg/s
Heat exchanger UA	2400 W/K
Absorption chiller capacity	35 kW
Evaporator set temperature	5 ºC

The parameters presented in Figure 3 have been obtained by means of energy balances in the cooling tower, generator and evaporator loops. The total incident radiation rate has been calculated as the product of the incident radiation on the tilted surface and the total collector area.

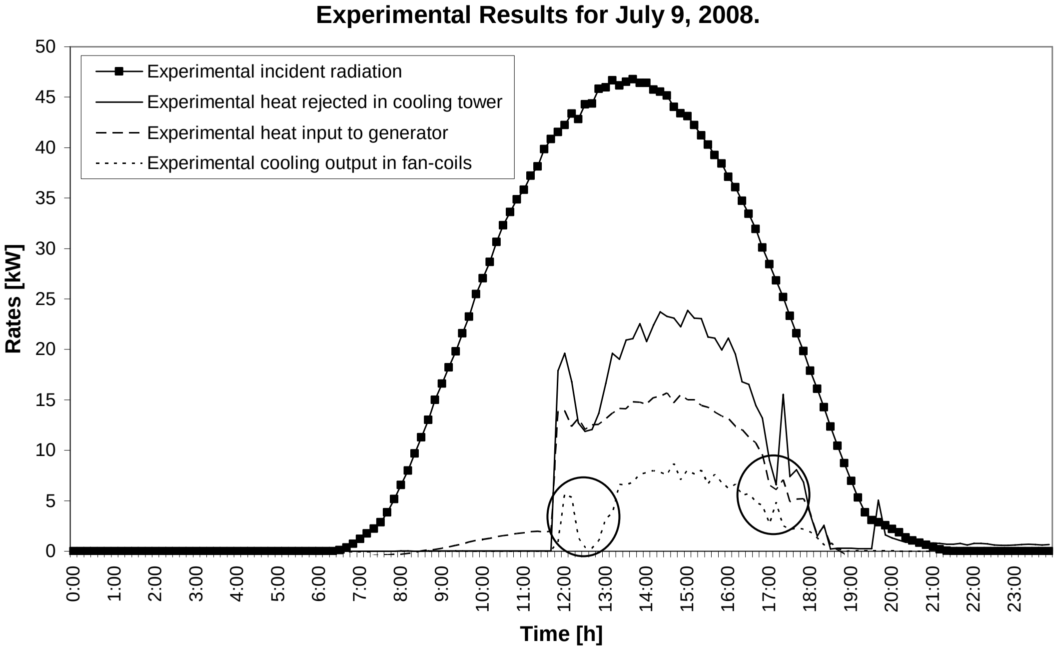

Figure 3. Experimental instantaneous cooling rate, heat input to generator, heat rejected in cooling tower and incident radiation energy for the solar cooling facility, July 9, 2008. Circles in the figure show the behaviour induced by the solution control of the absorption chiller.

$$\dot{Q}_{ct} = \dot{m}_{ct} C_{P,ct} (T_{o,ct} - T_{i,ct}) \tag{1}$$

$$\dot{Q}_{g} = \dot{m}_{g} C_{P,g} (T_{i,g} - T_{o,g}) \tag{2}$$

$$\dot{Q}_{e} = \dot{m}_{e} C_{P,e} (T_{o,e} - T_{i,e}) \tag{3}$$

$$\dot{Q}_{r} = IA \tag{4}$$

The maximum instantaneous heat rejection rate reached 25 kW while the maximum instantaneous heat provided to the generator and the instantaneous cooling rate produced by the facility reached 15.6 kW and 8.67 kW respectively. Integrating the curves the total energy supplied to the generator, the total energy supplied to the evaporator and the total radiating energy can be calculated. The daily COP is calculated by dividing the total energy supplied to the evaporator Q_e by the total energy supplied to the generator Q_g and the SCOP dividing the total energy supplied to the evaporator by the total incident radiation Q_r .

$$COP = \frac{Q_e}{Q_g} \tag{5}$$

$$SCOP = \frac{Q_e}{Q_r} \tag{6}$$

The efficiency of the system in converting the incident radiation energy into useful heat input to the generator is calculated as,

$$\eta_{sys} = \frac{Q_g}{Q_r} \tag{7}$$

Table 2 presents the results summary for the experimental data of July 9, 2008,

Table 2. Results summary for July 9, 2008.

	Q_e [kWh]	Q_g [kWh]	Q_{ct} [kWh]	Q_r [kWh]	COP	SCOP	η_{sys}
Experimental	32,818	81,214	113,861	357,509	0,404	0,092	0,227

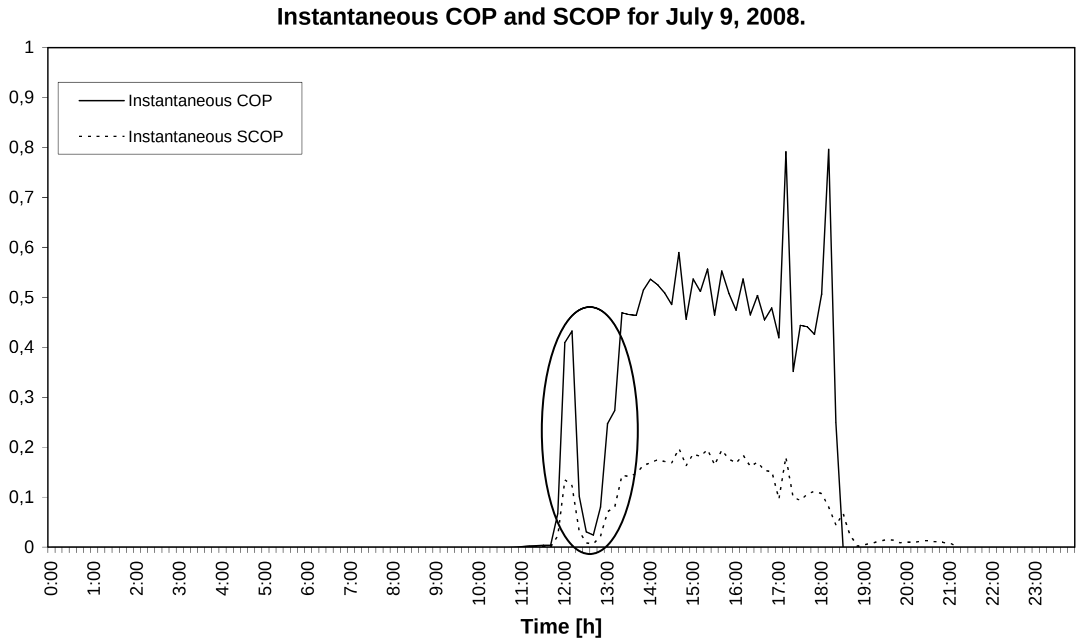

Figure 4. Instantaneous COP and SCOP for the solar cooling facility, July 9, 2008. Circle in the figure show the behaviour induced by the solution control of the absorption chiller.

2.2. Recooling loop

The recooling loop of the absorption chiller incorporates a temperature control and a solenoid valve in order to permit the flow of cooling water when the condensation temperature rises above 30 ºC. This is convenient in order to keep the value of the thermal inertia of the absorption chiller low and to begin the cold production earlier in the morning. This provokes a temperature difference from the inlet and outlet of the recooling loop to stay almost constant during the operation of the absorption chiller in the range of 7-9 ºC. The necessities of instantaneous heat rejection will then fluctuate between maximum values of 24-30 kW using a wet cooling tower in current operating conditions and favourable weather conditions (rel. humidity between 10 and 40 %).

3. TRNSYS simulation

The TRNSYS$^{®}$ interface interacts with the user as a graphic programming tool. It permits to build a virtual facility and easily change from different types of configurations. Using an already validated simulation of solar cooling facilities benchmarked with the UC3M’s experimental solar cooling facility, the model of the wet cooling tower has been substituted by the model of a Ground Heat Exchanger (GHE). This model is the Type 557a from the TESS libraries for TRNSYS 16 and simulates a U-tube GHE. For more information about the TRNSYS simulation program and TESS libraries please refer to [6]. The simulation has been conducted in a trial an error way in order to size the GHE. Different numbers of boreholes connected in parallel have been simulated at different depths until the heat rejected to the ground equals the heat generated in the absorber and condenser.

During this simulation the soil thermal properties are going to be estimated because lack of information about the soil in the Madrid region. Normally, to estimate the thermal properties of the soil a Thermal Response Test has to be performed first in order to be accurate. In the Thermal Response Test a probe is introduced into the ground and a defined heat load is circulated. The temperature difference is recorded and the properties of the soil can be calculated easily. This technique allows the sizing of the GHE to be accurate [7].

Typical market dimensions have been used in order to simulate the GHE. The borehole radius is of 11 cm and the single U-tube in each borehole has an outer radius of 2 cm and an inner radius of 1.6 cm. Different number of boreholes corresponding to 4, 6 and 8 connected in parallel has been simulated at different depths. A summary of the input values for the GHE model is presented in Table 3.

Table 3. Values for the GHE model.

Storage thermal conductivity	2.6 W/m^{2}K
Fill thermal conductivity (Clay)	1.3 W/m^{2}K
Pipe thermal conductivity (Copper)	52 W/m^{2}K
Annual amplitude of air temperature (Madrid)	22 ºC
Annual average air temperature (Madrid)	15.6

3.1. Simulation Results

Simulation of July 9 is conducted in order to compare the behaviour of the simulated facility incorporating the GHE with the current experimental facility. Figure 5 shows the simulation results for July 9.

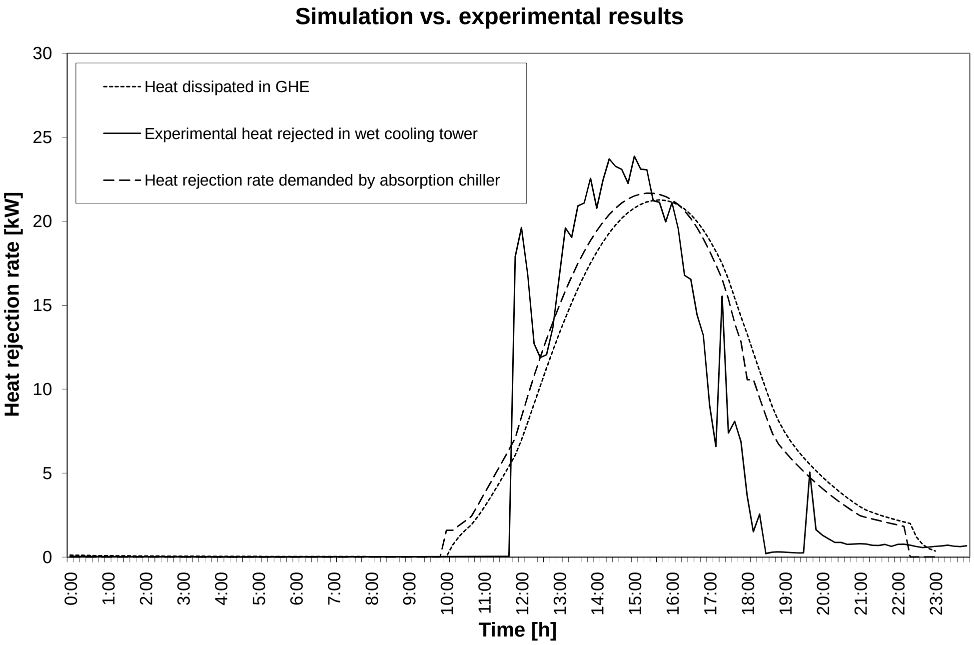

Figure 5. Simulation vs. Experimental results for July 9.

The simulated heat rejection demanded by the absorption chiller reached 135.339 kWh for the day.

Making a trial and error analysis it is found that to dissipate the heat generated in the absorption chiller with 4 boreholes, a depth of 160 meters is necessary. With 6 boreholes, the depth needed for the heat rejection is of 100 meters and with 8 boreholes, a depth of 80 meters is necessary. Estimating a price per borehole of 45-65€ (depending of type of soil) per meter, it is found that the best design should be 6 boreholes of 100 meters deep.

In the Figure it is shown a time delay between the experimental and the simulated heat rejected. This is motivated by the temperature control of the recooling loop. Not circulating water through the condenser when is not needed lowers the thermal inertia of the chiller. Nevertheless, almost the same value of heat rejected is achieved but there is a slight increment in the value of the outlet water temperature from the condenser. Experimental values for July 9, 2008 reached maximum values of 30 ºC while the simulation reached 34 ºC. Nevertheless, the cooling energy produced does not experience major changes. Simulated cooling energy produced reached 36,547, with simulated weather conditions, a slight difference from experimental.

4. Conclusions

Although the wet cooling towers behave well in lowering the water temperature, the GHE seems to be the way to promote the use of solar cooling facilities in the sector.

The simulation conducted shows that a GHE formed by 6 boreholes of 100 meters deep and each containing single U-tubes, connected in parallel could be sufficient to supply the heat rejection rate to cool down the absorption chiller in this kind of facilities.

The construction of this kind of heat sink is more complicated than the installation of a wet cooling tower, but once installed its maintenance cost is low.

Another good characteristic of coupling a GHE to an absorption chiller is that in winter time the facility could operate to supply low temperature heat using the absorption chiller as a heat pump and the cold produced in the evaporator sent to the GHE supplying the load.

A more extensive simulation should be conducted in order to evaluate the thermal depletion of the soil. This could be counteracted by operating the facility during the whole year.

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