COMPARISON OF TWO SIMILAR SOLAR DRIVEN ABSORPTION CHILLERS FOR DIFFERENT VALUES OF SOLAR RADIATIONS

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SUMMARY

Within the Programme Vigoni for cooperation between Italian and German universities, a research work has been carried out between the University of Perugia, Industrial Engineering Department and the Technische Universität Berlin, Institut für Energietechnik on the theoretical analysis and the operational experience of solar cooling plants. The laboratories of the two universities house two similar solar driven absorption plants, with evacuated tubes solar collectors and Water-Lithium Bromide thermosyphon absorption refrigerators of the same manufacturer, but of different cooling capacity. In both plants measurement facilities allow to record in real time all the main operating parameters of internal and external circuits (temperatures, pressures and flow rates). It is known that the main problem for such solar chiller system is to have the highest feeding temperature when the refrigerating load request is greater since many parameters influence their correlation. Therefore, the aim of research has been focusing on the study of feeding temperature variations versus solar radiation and some system parameters, for both absorption chiller, conditions to find the optimal one.

INTRODUCTION

The summer air conditioning demand is growing continuously, not only in the tertiary sector but also in residential applications; the correspondent request of electric power involves frequent crisis of the electrical net, that must cover higher and higher load peaks. Such peaks are mainly satisfied recurring to fossil fuel thermoelectrical plants, with consequent increase of greenhouse effect.

Solar driven absorption chillers produce cooling with negligible requirement of electrical energy and can work using low temperature heat such as waste heat (otherwise lost in the environment, causing a temperature raise), or heat produced by renewable energies, such as solar energy. Therefore, they are discussed frequently for energy-environmental issues and can constitute a valid alternative to compression refrigerating machines, especially for the countries of the Mediterranean area, which are characterized by a growing demand of electrical energy for summer cooling.

In this context, within the Programme Vigoni for cooperation between Italian and German universities, a research work has been carried out by the University of Perugia, Industrial Engineering Department, and the Technische Universität Berlin, Institut für Energietechnik, on the theoretical analysis and the operational experience of solar absorption cooling plants.

The laboratories of the two universities have access to two similar solar driven absorption plants, with Water-Lithium Bromide thermosyphon absorption refrigerators of the same manufacturer, but of different cooling capacity. As a matter of fact, the performance – especially in part-load – of these systems is not as satisfactory as it should be theoretically.

In order to improve this situation and to forward the technology, an analysis of the thermodynamic process was conducted, employing comparable and shared measurement chains. In both plants measurement facilities allow to record in real time all the main operating parameters of internal and external circuits (temperatures, pressures and flow rates). The results of various measurement campaigns are presented, compared, and discussed. The final aim is finding the best working conditions of the plants by analysis and optimization of the external and internal parameters. The results should allow to improve the performance and, consequently, help in disseminating this environment-friendly technology.

2. SYSTEMS DESIGN

2.1 Press and Information Office in Berlin

In Berlin two solar assisted cooling systems (SAC-Systems) are installed at governmental buildings. The first system is located at the Federal Ministry for Traffic, Buildings and Housing (BMVBW) and the second one is located at the Press- and Information Office (BPA). Since all the reported measurements are taken from BPA, especially this system will be explained more in detail. The Press and Information Office is a large building complex in the town centre of Berlin, which consists of four parts: Historic building, Conference centre, Administrative building and a new building part.

Figure 1 shows the new building part of the Press and Information Office, which has been erected in front of the firewall of the adjacent historic building. A small part of the historic building can be seen on the right hand side of Fig. 1.

On the lower left hand side the entrance to the conference centre is located. The administrative building, which is without any air conditioning system, is not shown in Figure 1.

The conference centre and the computer centre in the
The historic building are supplied by a 500 kW absorption chiller with its own chilled water distribution net.

Figure 1 – New building part at the Press and Information Office in Berlin with double glazing facade

Due to the double-glazing facade an energy demand for cooling can be avoided in the standard office area of the new building part by three functions:

- the movable glass blades are used for external sun shading thereby reducing the external loads;
- an automatic control system reduces the internal loads caused by artificial lighting;
- the remaining cooling loads are stored in concrete ceiling and the heavy walls of the adjacent old building. These loads can be removed by natural ventilation during night time (even under thunder storm conditions).

One task of the Press and Information Office is to evaluate the news from TV and radio broadcasts from all over the world during 24 hours. For this purpose special office rooms are needed with a high technical standard. Only for these special offices and the meeting rooms an air-conditioning system is needed, because of the high internal loads from technical equipment and persons, respectively. Although the building is facing to east, cooling load and sun irradiation occur more or less simultaneous due to the possibility of night ventilation and the storage capacity of massive walls and ceilings. Thus it was decided to complement this innovative cooling concept by a solar assisted cooling system (SAC-System) with two absorption chillers from the manufacturer Yazaki, Type WFC-10. In Figure 2 the system layout and the position of temperature and flow meter probes are shown.

2.2 The Perugia Solar plan

At the Laboratory of the Department of Industrial Engineering at the University of Perugia, a Yazaki chiller (Type WFC-5) has been installed in order to investigate its performances under different service conditions [3]. The chiller is a single-stage Water-Lithium Bromide absorption machine and it is driven by solar energy. The plant is integrated with an electric boiler with a thermal input of 30 kW for back-up and experimental reasons. The machine has a nominal chilling power of 17.5 kW which is employed to cool the Laboratories; the system is equipped with an evaporative cooling tower to refrigerate the condenser and absorber [3].

The preliminary tests showed that the chiller is able to work with relatively low temperatures of the supplying water, thus making possible to feed it with solar collectors [2]. The research focused therefore, on design and realization of a solar plant to feed the absorption machine.

The solar plant (Figure 3) is made of 30 m² of CPC-Collector, and a preheating tank (600 l) which is connected to a larger storage tank (1500 l) including an electrical resistance heater of 30 kW capacity (an auxiliary electrical boiler) by a mixing pump. During summer time, the 15 CPC-collectors placed on the laboratory roof (Figure 4) supply the heat for the chiller system, covering about 35% of monthly thermal requirements of machine.
A manual control can set three main parameters to change the working behaviour of the solar system:

**Tp** - working pump temperature: the temperature that the fluid inside preheating tank has to be reach to switch the mixing pump on.

**Tr** - electrical resistor temperature. When the temperature inside the boiler is lower than such parameter the resistors are switched on.

**DT** - differential temperature: if the differential temperature between the collector outlet temperature and the temperature inside preheating tank is lower than a given value, the solar pump is switched off.

Table 1 reports main technical data of Perugia and Berlin solar plants.

### Table 1 Technical data of Perugia and Berlin solar plants.

<table>
<thead>
<tr>
<th>One tank strategy</th>
<th>Perugia</th>
<th>Berlin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector gross area m²</td>
<td>34.2</td>
<td>348</td>
</tr>
<tr>
<td>Collector aperture area m²</td>
<td>30</td>
<td>259</td>
</tr>
<tr>
<td>Intercept efficiency</td>
<td>0.661</td>
<td>0.809</td>
</tr>
<tr>
<td>C₁ coefficient W/(m²ap·K)</td>
<td>0.82</td>
<td>2.22</td>
</tr>
<tr>
<td>C₂ coefficient W/(m²ap·K²)</td>
<td>0.0064</td>
<td>0.0021</td>
</tr>
<tr>
<td>Max collector flow rate m³/h</td>
<td>1.27</td>
<td>20</td>
</tr>
<tr>
<td>Storage volume m³</td>
<td>2100</td>
<td>1600</td>
</tr>
<tr>
<td>Fluid volume pipes m³</td>
<td>160</td>
<td>1500</td>
</tr>
<tr>
<td>Fluid volume collect. m³</td>
<td>24</td>
<td>420</td>
</tr>
<tr>
<td>Yazaki chiller</td>
<td>WFC-05</td>
<td>WFC-10</td>
</tr>
<tr>
<td>N-Cooling capacity kW</td>
<td>17.5 kW</td>
<td>35 kW</td>
</tr>
</tbody>
</table>

## 3. MEASUREMENTS

In Figure 5 typical measured data for the SAC-System at BPA are shown during a sunny summer day in 2005 with a maximum solar irradiation (Htot) of nearly 800 W/m². On this day the system was operated as a solar autonomous system, which means that no conventional energy is used for back-up purposes.

![Figure 5 - Typical day of solar autonomous operation of the SAC system at BPA, Berlin.](image)
a.m. the outlet temperature of the collector field ($t_{K,i}$) is higher than the mean storage temperature ($t_{P}$) and the valve in the collector circuit (VEK, Figure 2) is opened in order to heat up the storage. Since the storage is at a high temperature level from the previous day, the minimum driving temperature for the absorption chiller (which is set to 78°C) is reached near 11:00 a.m. and the solar operation of the chiller AKM-2 is started. This can be seen from the heat input to the generator $Q_{G2}$.

Since the heating capacity of the collector field is higher than the heat used in the generator of chiller number 2 the storage temperature is increased. Thus, at a certain storage temperature (set to 82°C) the second chiller (AKM-1) is switched on. In order to maintain clarity, only averaged values for $Q_{G1}$ and $Q_{G2}$ over 15 minutes are shown, since the high temperature difference during the chiller's start-up period may cause heating capacities higher the 100 kW.

It is also seen from Figure 5 that the collector outlet temperature $t_{K,o}$ is not constant during the operation period of chiller AKM-1 and AKM-2, but varies between 80° and 88°C. Thereby the part load performance of the chillers is influenced by the collector efficiency.

In Perugia, an analogue measurement (mode 3) was carried out at the end of May 2006 under similar values of solar radiation and without using auxiliary energy (electricity).

The first measurements showed that it was not possible to fix the start-up feeding temperature equal to 78°C as in the German system. In fact, if the generator pump was switched on at a temperature of 78°C, the power supply to the generator decreased so quickly that the machine worked only for one hour. Therefore, a start-up feeding temperature of 85°C has been chosen during the following measurement campaign to have longest working time of machine. As an example, Figure 6 shows some data relative to May 18th with start-up temperature of 85°C.

The primary and secondary collector pumps are switched on when the temperature difference DT value is larger than 8 K (approximately at 9:30 a.m., where the solar radiation (Htot) is equal to 500 W/m²).

The solar heat warms up 2100 litres and consequently temperature inside two tanks increases until 85°C (at 14:10 o’clock). At that temperature the generator pump is switched on. Since the collector heating capacity is less than the heat used by the generator of the Yazaki WFC-5, the storage temperature ($t_{P}$) and the generator heat supply ($Q_{G}$) decreased.

The generator pump is switched off when the generator inlet temperature becomes less than 65°C (17:00 o’clock), after 2.5 h of working, when the heat is not sufficient to feed the machine (14 kW). After 15:30, Temperature $T_{Gi}$ decreases more quickly than temperature inside preheating tank because the mixing pump was switched off when such temperature is lower than 75°C. So temperature $T_{Gi}$ is stationary whereas the chiller cools down the second tank (boiler). Results of measurements underline how it would be important to be over 85°C having a significant employment of machine and how it would be better to employ solar heat directly to chiller, between 11:00 and 13:00 o’clock, when collector temperature is over 85°C. Perugia solar plant can send solar heat directly to machine (mode 1). Therefore measurements are carried out to check chiller behaviour in these case. Figure 7 shows how it is possible to supply the chiller directly with solar energy so employing in better way energy ratio around 12:00 o’clock.

Figure 6 – Measurement of solar plant in Perugia in a typical day of May (mode 3).

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Figure 7 – Measurement of solar plant in Perugia in a typical day of May (mode 1).

Also, measurements highlight the chiller needs a start-up temperature over 80°C. Therefore it can not possible to suppose using such way to active processing inside the chiller but only to feed the machine at midday

4. CONTROL STRATEGIES

Since the cooling capacity of a given absorption chiller is determined by all three external temperatures, a certain load (which is characterised by the set values of $Q_{E}$ and $t_{Eo}$) can be supplied by several combinations of hot and cooling water temperatures [4].

The difference between these temperatures is called the external temperature thrust ($\Delta t_{GACi} = t_{Gi} - t_{ACi}$). In addition it has been shown that the refrigerant and solution flow rates of WFC-5 and WFC-10 are determined by the hot and cooling water temperature [3].

Thus the efficiency is highly influenced by the temperature thrust.

Figure 6 – Measurement of solar plant in Perugia in a typical day of May (mode 3).
In Figure 8 this is highlighted for an exemplary load condition for the WFC-10 (e.g. \( Q_E = 35 \text{ kW}, \ t_{Eo} = 8^\circ\text{C} \)), which can be supplied by hot water of 95°C and cooling water of 31°C. But the same cooling capacity and chilled water temperature is available at 88°C hot water temperature, if the cooling water temperature is lowered by approximately 24°C. Thereby a temperature thrust \( \approx 58.5 \) °C COP 0.69 is adjusted, which leads to a high desorber driving temperature at the generator can be compensated by higher driving temperatures at the absorber and/or condenser giving the same cooling capacity.

But for the WFC-10 even the flow rates in the solution circuit (established by the operating conditions for the thermosyphon generator, \( IGi \) and TC(tACi)) are better adjusted to the load condition in the second case. This leads to lower losses in the solution heat exchanger and/or decreases the overflow of refrigerant. Thus the COP of WFC-5 and WFC-10 chillers can be considerably increased, by a simultaneous control of hot and cooling water temperature. In addition the simultaneous control is especially advantageous for the start-up period of SAC-systems in the morning. When the collector outlet temperature is not high enough to cover the full load, low cooling water temperatures can be used without a high electricity demand for the cooling tower. This is illustrated in fig. 8 where the set value for the chilled water outlet temperature is 14°C. According to the momentary load condition (QE) and the available solar driving temperature \( t_{Gi} \) the cooling water temperature \( t_{ACi} \) is controlled in a way to find the maximum value, which is enough to cover the load.

During the starting period of the chiller, where the driving temperature is relatively low \( t_{Gi} \approx 82^\circ\text{C} \) but the load is high (QE) the cooling water temperature is decreased to approximately 24°C. Thereby a temperature thrust \( \approx t_{GACi} \) of nearly 60 K is adjusted, which leads to a high desorber capacity of the thermosyphon generator. Consequently the cooling capacity is high, since no overflow occurs under these conditions (relatively high chilled water temperature). During the day the solar driving temperature is increased up to 88°C and the cooling capacity is waving around 30 kW. Now the cooling water temperature is increased, taking the varying load conditions and the momentary hot water temperature into account.

Simultaneously the chilled water temperature is kept constant at the set value of 14°C.

Despite of relatively high cooling water temperatures (up to 31°C) the COP is normally above 0.7. In addition the energy and water demand for the cooling tower is reduced. Thus the efficiency of the whole SAC-system is increased.

The improvement of energetically efficiency of thermal storage can be a different point of view to increase performances and working time of absorption machine. Therefore a measurement campaign was carried out for different DT values and similar value of solar radiation to determine and compare different efficiency of solar plants. Efficiency is evaluated with equation 1.

\[
E_f = \frac{H_s}{H_i} \quad (1)
\]

Where:
- \( H_i \) = Daily Incident Solar Energy on collector surface;
- \( H_s \) = Daily Solar Energy transferred through the solar heat exchanger into the storage.

The values shown in Table 1 highlight how DT equal to 8°C could be the optimal setting parameter to reach as soon as possible the feeding temperature in Perugia for typical solar radiation at the beginning of summertime.

5. CONCLUSIONS

Solar driven absorption chillers represent an interesting technology to reduce the need of electricity for summer cooling and therefore to reduce greenhouse gases emissions. Among these systems, thermosyphon absorption refrigerators
are especially designed for solar plants, but in some cases their performance is not as satisfactory as expected.

Two similar solar driven absorption plants, located in Perugia (Italy) and Berlin, have been studied by the University of Perugia, Department of Industrial Engineering, and the Technische Universität Berlin, Institut für Energietechnik, within a research programme funded by the Programme Vigoni for cooperation between Italian and German universities. The two plants have Water-Lithium Bromide thermosyphon absorption refrigerators of the same manufacturer, but of different cooling capacity; the comparison of the results is possible thanks to comparable and shared measurement chains. In both plants measurement facilities allow to record in real time all the main operating parameters of internal and external circuits.

The experimental and theoretical analysis focused on upload and on part-load conditions of the machine; the results show how it is possible improve the performance of solar absorption system. In fact, the control of thermal storage parameters can upgrade efficiency of solar plant while the control the solution flow rate and desorber capacity of a thermosyphon generator can optimize energy performance of absorption machine setting the hot and cooling water temperature.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>A</td>
<td>Area, m²</td>
</tr>
<tr>
<td>DT</td>
<td>T_Ko - T_Ps, °C</td>
</tr>
<tr>
<td>E</td>
<td>Evaporator</td>
</tr>
<tr>
<td>Ef</td>
<td>System efficiency</td>
</tr>
<tr>
<td>H</td>
<td>Solar radiation, W/m²</td>
</tr>
<tr>
<td>Q</td>
<td>Heat flow, kW</td>
</tr>
<tr>
<td>t</td>
<td>External temperature, °C</td>
</tr>
<tr>
<td>T</td>
<td>Internal temperature, °C</td>
</tr>
<tr>
<td>TG</td>
<td>Temperature gradient, °C/h</td>
</tr>
<tr>
<td>V</td>
<td>Flow Rate, kg/h</td>
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</tbody>
</table>

Other subscripts:

- A: Absorber;
- G: Generator;
- K: Collector;
- PS: Storage;
- a: Absorbed;
- av: Average;
- C: Condenser;
- i: Inlet;
- o: Outlet.

REFERENCES


