

DEVELOPMENT AND EXPERIMENTAL INVESTIGATION OF A NOVEL 10 KW AMMONIA/WATER ABSORPTION CHILLER - CHILLII® PSC - FOR AIR-CONDITIONING AND REFRIGERATION SYSTEMS

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Abstract: The content of the paper is the development, experimental investigation and simulation of the thermally driven single-effect ammonia/water absorption heat pump/chiller for air-conditioning and refrigeration systems for residential, commercial and industrial applications. The novel chillii® PSC has a cooling capacity of 10 kW and compact design. The peculiarities of the chiller are the special design of the membrane pump for the solution circulation, the mechanical solution controller and the vertical falling-film tubular absorber and evaporator, respectively. The experimental investigations at the two test stands of SolarNext and Pink showed that the chiller reaches evaporator outlet temperatures from 15°C down to -5°C at heating temperatures from 65°C to 115°C. The investigated recooling temperatures are between 24°C and 40°C. A TRNSYS simulation of a solar air-conditioning system with a model of the chillii® PSC10 was carried out to analyse the performance behaviour of such system. For Zurich and Madrid the results showed that the system design is sufficient for different climatic conditions and collector as well as heat storage sizes.

Key Words: *heat pump, chiller, absorption, ammonia/water, simulation*

1 INTRODUCTION

Active air-conditioning of buildings is also necessary at European climate conditions, especially in Southern Europe, if high internal and external loads can not be removed by an efficient night ventilation or where alternative low-energy cooling technologies like ground heat exchangers are not available or have not been sufficiently dimensioned and high comfort claims are set on the inside climate during the summer. Usual electrically driven compressor chillers (split-units) have maximal energy consumptions in peak-load period during the summer. Particularly the sale figures of small split-units up to 5 kW are rising rapidly: in Europe the number of sold units has risen about 84% from 4.4 million in 2003 to predicted 8.1 million in 2007 (CCI 2007). In the last few years even in Europe this regularly leads to overloaded electricity grids. The refrigerants that are currently used in the split-units do not have an ozone depletion potential (ODP) anymore, but they have a considerable global warming potential (GWP), because of leakages of the chiller in the area of 5 to 15 % per year.

Therefore a small-scale 10 kW absorption chiller was developed which use ammonia as environmentally friendly refrigerant and has only very low electricity demand. In general the chillii® PSC is available for small-scale solar air-conditioning systems since end of the year 2006. Different other ammonia/water absorption chillers in the small-scale capacity range up to 20 kW are still under development in Europe. A directly air-cooled NH₃/water absorption chiller with 17 kW cooling capacity is driven by pressurized water of a Fresnel collector (Häberle et al. 2007). The chiller is a modified version of Robur's standard gas fired product,

which requires driving temperature of 180 to 200°C. In Portugal also an air-cooled ammonia/water absorber prototype with 6 kW cooling capacity for the South-European market is developed (Pink 2007). The Technical University Graz, Austria just developed a prototype of an ammonia/water absorption heat pump/chiller with 5 kW cooling capacity (Moser and Rieberer 2007). At the ITW Stuttgart in Germany a further NH₃/water absorption chiller prototype with 10 kW cooling capacity is developed (Zetsche et al. 2007). The lifting of the solution to the required high pressure level is achieved by a membrane pump. At driving temperatures of 90°C and re-cooling temperatures of 27/32°C, cold water temperatures of 15°C could be achieved with a cooling capacity of 7.2 kW and a COP of 0.66. Different diffusion absorption chiller prototypes with the working pair ammonia/water and helium as auxiliary gas are developed at the zafh.net of the Stuttgart University of Applied Sciences, Germany (Jakob et al. 2007). The chiller has no mechanical solution pump, but an indirectly driven bubble pump. The latest reached cooling capacity of the third prototype is 3 kW.

2 ABSORPTION CHILLER DEVELOPMENT

The new product is an ammonia/water absorption chiller with 10 kW cooling capacity (Figure 1). The development of the chiller is based on the previous work of Pink and is currently optimised in cooperation with SolarNext.



Figure 1: Ammonia/Water Absorption Chiller (Source: Pink)

The dimensions (width x depth x height) are 0,8 x 0,6 x 2,2 m and the operation weight is approximately 350 kg. For the air-conditioning system the temperature levels are given in the Table 1. Solar energy, district heat or waste heat from CHP units could be used as heat source.

Table 1; Temperature levels for 10 kW cooling capacity and different locations

| Location | Zurich | | Madrid | |
|---|-----------|-----------------|-----------|-----------------|
| | Fan Coils | Cooled Ceilings | Fan Coils | Cooled Ceilings |
| Cold Water Temperature | 12/6°C | 18/15°C | 12/6°C | 18/15°C |
| Heating Temperature | 85/78°C | 75/68°C | 97/90°C | 85/78°C |
| Recooling Temperature (Wet Cooling Tower) | 24/29°C | 24/29°C | 29/35°C | 29/35°C |

2.1 Novel Membrane Solution Pump

Centrifugal pumps according to standard cannot be used in small, continuously working absorption chillers with the working pair ammonia/water, since they have a low efficiency and the seals do not reach the necessary service life. The use of gear pumps is not possible due to the high wear and the large noise generation. Commercially available piston diaphragm pumps fulfil the requirements of these applications but they are large, heavy and cost 30 to 40% of the entire chiller. An appropriate solution pump was developed for this purpose and successfully used in a number of machines. Figure 2 shows the latest generation of the solution pump which is also part of our latest absorption chillers. The diaphragm head with the poppet valves is put on commercially available medium pressure piston pump. The free running diaphragm is moved by oil pad. The driving power transmission takes place via two v-belts from a 0.55 KW asynchronous engine (power consumption approximately 0.25 kW). The intake pressure and the outlet pressure are 2 to 20 bars, respectively.

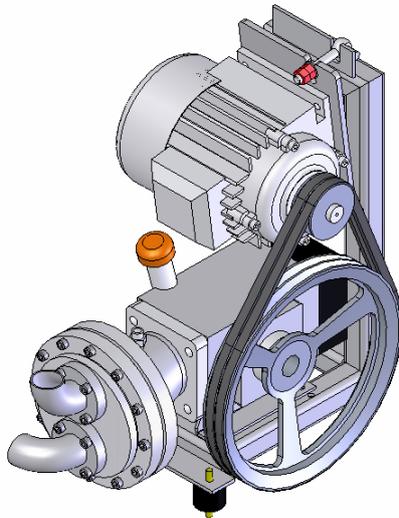


Figure 2: Novel Membrane Solution Pump (Source: Pink)

2.2 Falling Film Absorber and Evaporator

To realize a compact absorber heat exchanger with high efficient mass and heat transfer the absorption chiller is equipped with a self developed falling film tubular absorber. A unique distribution system feeds the inside of the heat exchanger pipes with a certain amount of the poor working solution. To control the speed and the thickness of the falling film it is stabilized by inserts within the pipes. The advantages of the falling film technology are also used for the evaporator of the absorption chiller. The vertical tubular evaporator is supplied from the top by a particularly developed feeding system for a uniform distribution of the refrigerant. Due to this design it is able to work as a dry evaporator. This fact allows an easy handling of the remaining water within the refrigerant without the need of a periodical emptying.

3 EXPERIMENTAL RESULTS

The experimental investigations were carried out at two test stands. One is at SolarNext (Figure 3), which could be used for testing closed absorption or adsorption heat pumps or chillers with cooling capacities up to 20 kW under various controlled conditions. The absorption chiller was implemented and tested since autumn 2007. Therefore inlet temperatures and flow rates of all of the three external circuits passing the chiller can be adjusted independently from each other over a wide range. This provides the possibility of testing the behaviour of chiller or heat pump in any condition. Absolute temperatures, temperature difference between inlet and outlet of every heat exchanger may be varied as well as every state of part load operation can be simulated. The setup facilitates simultaneous testing of recooling components nearly independently from current chiller testing conditions as the circuits are indirectly in contact through a buffer storage but may as well be run almost stand alone. Current recooling devices are one dry cooling tower and alternatively for lower recooling temperatures a hybrid re cooler, all using EC-ventilators. There is data acquisition with direct feedback for the controlled process variables. Data for operation modes like the simulation of solar based heating in the course of day, taking into consideration the effects on recooling and cooling demand corresponding to specific weather data files, may be externally given and all measurement values accordingly recorded. Thus this experimental setup provides a year round testing facility for all kind of small size heat pumps. The ability to simulate all user-defined conditions renders research of the potential of chillers especially within solar cooling systems possible.



Figure 3: Test Stand at SolarNext with the absorption chiller (Source: SolarNext)

The second test stand is at Pink, which was installed in summer 2007 (Figure 4), the performance date of any thermally driven chiller or heat pump up to 40 kW heating capacity and 60 kW recooling capacity can be evaluated. The hydraulic scheme allows having three different circuits for hot water, cooling water and cold water while the cold water circuit is prepared to run with brine as well. This is an important option to be able to simulate even applications using cold water temperatures below 4°C. The complete site is controlled by a programmable logic controller (PLC) connected to a personal computer to allow automatic simulation runs and online data logging.



Figure 4: Test stand for the absorption chiller at Pink (Source: Pink)

During the last months the latest generation of the chillii® PSC10 absorption chiller was installed at the test stand at Pink to generate a complete characteristic diagram for different cold water temperatures. Focused on the cooled ceiling temperature level 18/15°C, the cooling capacity and the COP of the chiller with driving temperatures from 65°C up to 95°C and recoiling temperatures from 24°C up to 40°C were measured (Figure 5). The temperature spread between inlet and outlet was kept constant at 7K in the heating cycle and 5K at the recoiling cycle by controlling the volume flow.

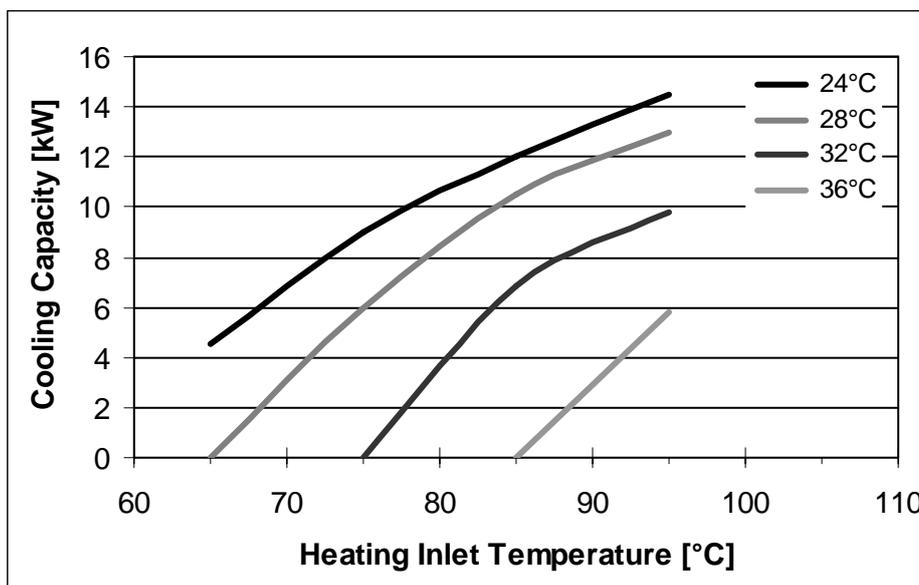


Figure 5: Cooling capacity of the absorption chiller for cooled ceiling temperature level of 18/15°C at different recoiling temperatures versus the heating inlet temperatures

The measurement shows the wide operation range of the absorption chiller. Even at very low driving temperatures the chiller is able to produce cold water for air conditioning usage with good performance.

4 SIMULATION

4.1 Boundary conditions of the system simulation

The solar air-conditioning system which is simulated in TRNSYS consist of the ammonia/water absorption chiller, vacuum tube collectors, a hot water storage with an external heat exchanger and a wet cooling tower. The chiller has a nominal cooling capacity of 10kW, but at high heating inlet temperatures and low re-cooling temperatures the chiller can generate much more cooling capacity. For the system simulation two locations have been investigated with Meteororm meteorological data. For the two locations Madrid (Spain) and Zurich (Switzerland) the size of the solar collector area and the hot water storage is based on the chillii[®] Solar Air-Conditioning Kit of SolarNext (Table 2).

Table 2; Solar Air-Conditioning Kits of the chillii[®] PSC

| Location | Solar Collector Area Size | | Hot Water Storage Size |
|----------|---------------------------|---------------------|------------------------|
| | SAC Kit | Simulation | SAC Kit and Simulation |
| Madrid | 34 m ² | 38.8 m ² | 1,650 m ³ |
| Zurich | 49 m ² | 48.6 m ² | 2,475 m ³ |

The recooling capacity is not limited in the considered model and the recooling input temperature of the chiller depends on the wet bulb temperature of the ambient air with a temperature decline of 5K.

4.2 Absorption chiller model

For the system simulation in TRNSYS a chiller model is developed based on the standard model for a single-effect absorption chiller “type 107”. This model calculates the performance of the machine through internal energy balances. The cold water inlet temperature is 12°C and the outlet temperature of the chiller and evaporator respectively is 6°C.

4.3 Simulation results

Figure 6 shows integrated capacity of the solar collector, the generator of the chiller and the evaporator. Thermal losses of the hydraulic system minimize the available heating capacity of the chiller and the generator respectively at 10%. Because of the warmer ambient air temperatures in Spain more cooling capacity than in Switzerland is necessary. This can be provided in Spain in spite of a smaller solar collector area.

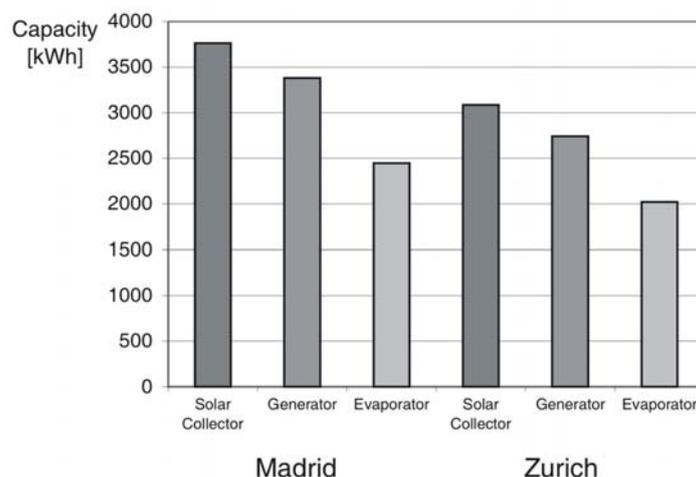


Figure 6: Integrated heating and cooling capacity in July for Madrid and Zurich

Figure 7 and Figure 8 show daily developments of temperatures and capacities of a sample day in July (6th of July) for Zurich and Madrid. A warm day with a high solar radiation to the solar collector area (E_glob_area) was chosen. Despite a lower solar collector area in Madrid almost the same cooling capacity of 15 kW peak load is generated.

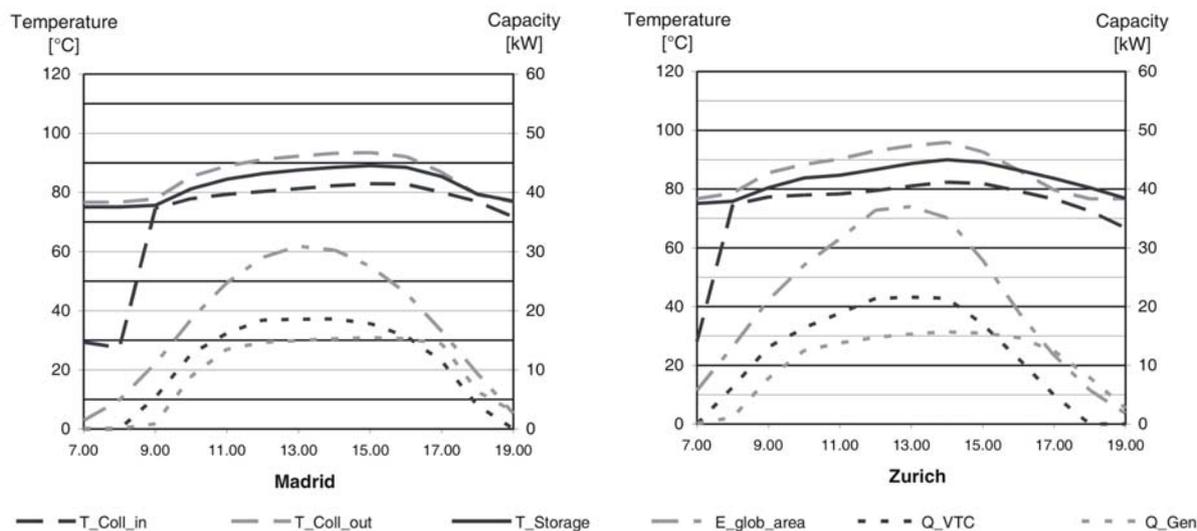


Figure 7: Temperatures and capacities of the hot water side on 6th of July for Madrid and Zurich

The higher the input temperature of the generator, the more cooling capacity can be generated. Through the hot water storage the cooling capacity generation can also be extended until the evening hours.

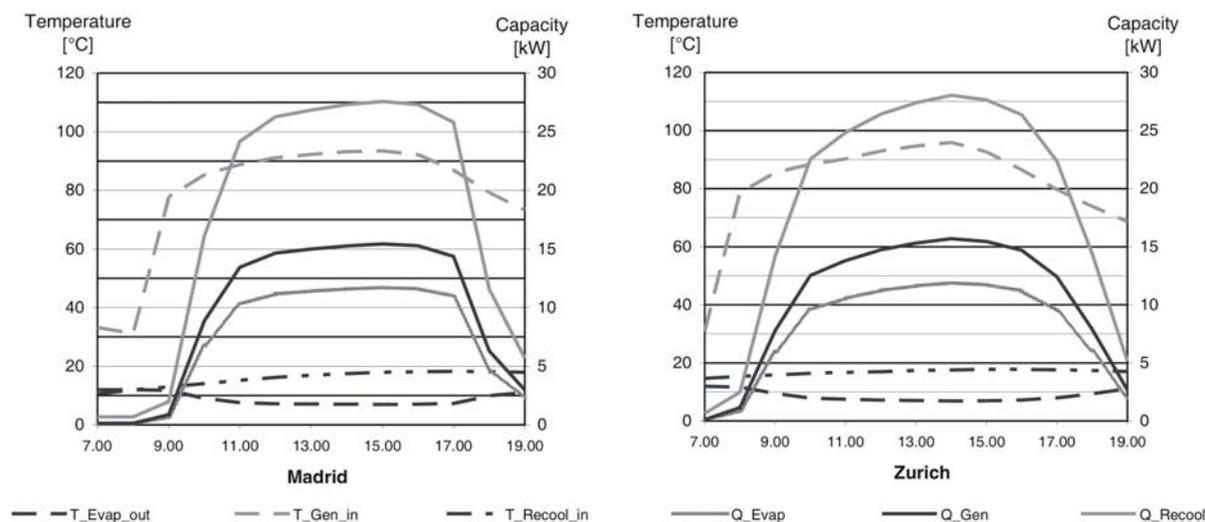


Figure 8: Temperatures and capacities of the absorption chiller on 6th of July for Madrid and Zurich

5 CONCLUSIONS

A small-scale ammonia/water absorption chiller with nominal 10 kW cooling capacity is developed, which could be used for solar air-conditioning systems. Up to now the investigations at the test stands at SolarNext and Pink as well as first experiences of different solar air-conditioning installations showed that the absorption chiller works very well. The lowest logged start heating temperature is 65°C for cold water temperatures of 18/15°C.

The simulation of the absorption chiller and the solar air-conditioning system respectively indicates that solar collector area sizes and storages of chillii® Solar Air-Conditioning Kits are well matched to the climate conditions. As the generated cooling capacity is dependent on different parameters like ambient air temperature, solar radiation etc. a detailed consideration is necessary for an exact dimensioning of the system.

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