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EXPERIMENTAL INVESTIGATION OF BUBBLE PUMP AND SYSTEM PERFORMANCE FOR A SOLAR DRIVEN 2.5 KW DIFFUSION ABSORPTION COOLING MACHINE

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ABSTRACT

This paper presents the development and experimental investigation of the indirectly heated, solar powered generator with its bubble pump and the 2.5 kW Diffusion Absorption Cooling Machine (DACM) performance. The DACM, which has a combined evaporator-gas heat exchanger-absorber unit, is designed for the application area of air-conditioning as a water chiller as well as for the operation of activated ceilings with an evaporator temperature of 12/6°C or 18/15°C, respectively. The set up of the machine with two different bubble pumps was in October 2005. With a total height of 2.20 m and a weight of 240 kg marketable dimensions were reached. The measurements were carried out at stationary pressure and temperature levels. Heating temperatures of the generator in a range between 100°C and 150°C were obtained. The values of coefficient of performance (COP) were between 0.12 and 0.38, while the continuous evaporator cooling performance was between 0.7 kW and 3.0 kW, depending on cold cycle temperatures (-8 to +18°C). In October 2006, the two bubble pumps were replaced by a single one, which now combines the heat transfer surfaces of the two previous bubble pumps. The latest performance of the machine showed cooling capacities of 2.0 kW and 2.4 kW at evaporator inlet/outlet temperatures of 12/6°C and 18/15°C, respectively. The average COPs are 0.3 at heating inlet temperatures of 125°C. The performance of the investigated bubble pumps shows that they work in a wide operation range at varied heating temperatures as well as external mass flows.

INTRODUCTION

In the last years, the air-conditioning market has been continuously expanding. The units that dominate the market are the small split-units with a cooling capacity of around 2 kW up to 4 kW. Due to the large number of manufactured units, these systems are produced and offered at very low prices; however, such systems increase the adverse effects on local environments by using primary energy such as electricity.

Over the years, some prototypes of commercial absorption refrigerators with indirectly solar powered generators have been experimentally and theoretically investigated. In these studies, COPs of 0.2 to 0.3 and cooling capacities between 16 W and 62 W were reached at heating temperatures between 160°C and 230°C and evaporator temperatures of -6°C down to -18°C (Keizer, 1979; Bourseau et al., 1987; Gutiérrez, 1988; Ajib et al., 1998). One research group used a Diffusion Absorption Heat Pump (DAHP), which is not yet commercially available, and modified it by substituting the direct gas fired generator by an indirectly heated generator (Braun et al., 2002; Stürzebecher et al., 2004). The solar thermal heating capacity of 1.8 kW is provided by vacuum tube collectors. The cooling capacity is approximately 1 kW and the COP is given with 0.59 at a heating temperature of 175°C and an evaporator temperature of 2°C.
Considering the circumstances that no suitable thermally driven cooling machines with small-scale cooling performance (1 kW to 5 kW) are available on the market, the Stuttgart University of Applied Sciences has developed and set up three single-effect ammonia/water DACM (Jakob et al., 2002; Jakob, 2005; Jakob et al., 2005). The design cooling capacity of the machine is 2.5 kW for buildings and residential air-conditioning applications.

PROTOTYPE DESIGN

The well-known diffusion absorption technique which was developed in the 1920s by the Swedish engineers von Platen and Munters (Niebergall, 1981) is based on the principle of pressure equilibration between the high and low ammonia partial pressure sides of the unit through an inert auxiliary gas. A further peculiarity of this type of absorption cooling machine is the use of an indirectly driven bubble pump for the circulation of the solution cycle, instead of the mechanical solution pump, so that inside the cooling machine no mechanically moving parts are necessary.

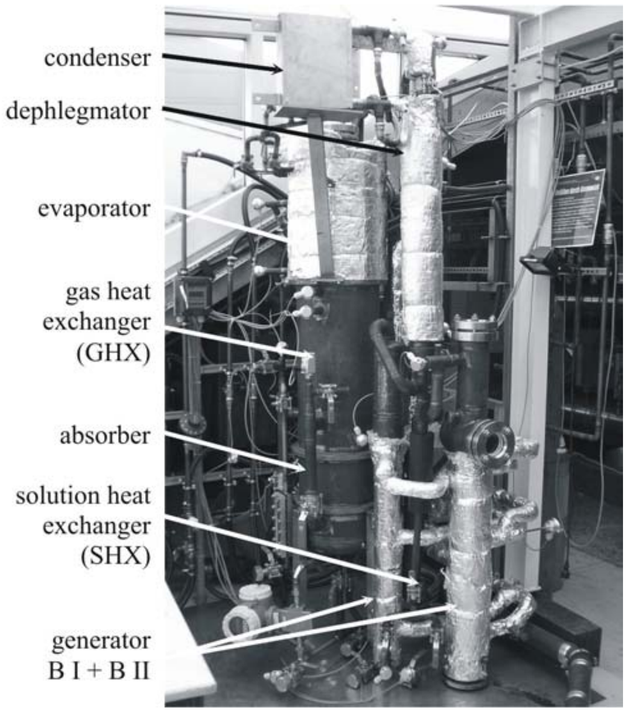

Fig. 1: DACM prototype (photo: zafh.net)

Figure 1 shows the developed DACM, which consists of a generator, a condenser, a combined evaporator-gas heat exchanger (GHX)-absorber unit, a solution heat exchanger (SHX) in the solution circuit as well as a dephlegmator for the condensation of the evaporated solvent. These components are vertical steel tubular heat exchangers or nickel soldered plate and stainless steel coaxial heat exchangers, which are hermetically tight welded. One special feature is the recirculation of the condensed solvent from the dephlegmator into the rich solution before the generator inlet and not as usually into the weak solution at the top of the generator outlet. Simulations have shown (Teußer, 2004), that the runback has a higher ammonia concentration than the rich solution, so that it is better to supply the condensed solvent to the generator inlet instead to the absorber inlet. The constructive solution for this kind of runback is the so-called Jakob-Teußer-bend. The used working pair for the solution circulation is an ammonia/water mixture. The inert auxiliary gas used is helium. The DACM is designed for the application area of air-conditioning as water chiller with an evaporator temperature of 12/6°C as well as for the operation of cooled ceilings with an evaporator temperature of 18/15°C. The third prototype weighs 240 kg and has a total height of 2.20 m.

METHOD OF ANALYSIS

The components of the DACM with its bubble pump were investigated with Pt100 resistance temperature sensors. The volume flow rates of the external heating and cooling cycles were measured by miniature turbine, magnetic inductive and suspended flow meters. Up to now there were no suitable measurement devices for the internal weak or rich solution volume flow available, which could measure very low volume flows inside the tubes and has no high pressure losses. Now with the latest magnetic inductive flow meter the weak solution flow could be measured. The capacities are determined out of the temperature difference from the inlet and outlet as well as from the volume flow measurement. The COP is defined as ratio between the determined evaporator cooling capacity and the generator heating input. For the bubble pump characteristic the ammonia vapour mass flow is determined out of the measured condenser cooling capacity and with that the calculated ammonia condensate, respectively.

EXPERIMENTAL RESULTS

The set up of the machine with two different bubble pumps/generators for comparison measurements (Fig. 1), a small generator (B I) with half of the heat transfer surface of 0.67 m² of the bigger one (B II), was in October 2005. The ducting allows the use one of the generators or both together. The experimental investigations of the third DACM with marketable dimensions are focused on the combined evaporator-GHX-absorber unit and the redesigned generators. The first measurements were carried out at stationary pressure and temperature levels. The investigated heating temperature range of the generator is between 100°C to 150°C. The experimental results show evaporator cooling capacities from 0.7 kW up to 3.0 kW and COPs between 0.12 and 0.38. Figure 2 shows the usually obtained evaporator cooling capacities and COPs at evaporator temperatures of 12/6°C and 18/15°C. The lowest logged external evaporator outlet temperature was –15°C at a generator heating inlet temperature of 135°C.

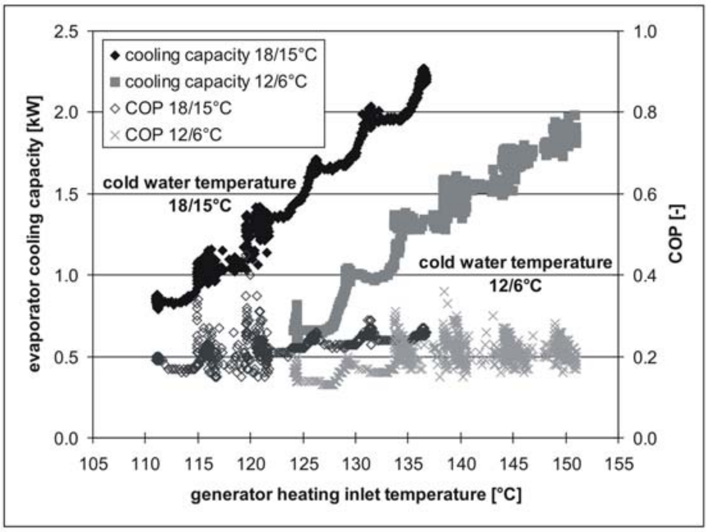

Fig. 2. Measured evaporator cooling capacities and COPs of the DACM versus generator heating inlet temperatures and evaporator temperatures of 18/15°C and 12/6°C, respectively.

In October 2006, the two generators were replaced by a single generator unit, which now combines the heat transfer surfaces of the two previous generators. The latest performance of the machine showed cooling capacities of 2.0 kW and 2.4 kW at evaporator inlet/outlet temperatures of 12/6°C and 18/15°C, respectively. The average COPs are 0.3 at heating inlet temperatures of 125°C.

DISCUSSION BUBBLE PUMP

The directly driven bubble pump of Diffusion Absorption Refrigerators (DAR) usually consists of a single lifting tube where the heat input is restricted to a small heating zone by a heating cartridge or the flame of a gas burner with a high heat flux density. The indirectly driven DACM consists on the other hand, of a bundle of tubes as bubble pump where the heating zone is spread and lower heat flux densities are reached. The developed bubble pumps/generators of the DACM prototype are basically vertical shell-and-tube heat exchangers where the solution flows inside the tubes of small circular cross-section forming slug-flow at best and the heating medium flows through baffled tube bundles on the shell side.

Temperature dependence

In combination with a solar thermal collector plant or if process heat is used the available temperature level for heating the generator is the main restriction. Therefore, measurements were carried out to investigate the performance of the generator depending on the heating temperature. Figure 3 shows the connection between the lifted weak ammonia/water solutions by the generator versus the heating temperature. The curve is characteristic for gas bubble pumps; the temperature range where the maximum lifting is depends on the solution concentration and the pressure. The temperature range between 111°C and 134°C is of relevance, because in this range the lifted amount of solution varies only about 10% so that for higher temperatures the lifting is stable and sufficient.

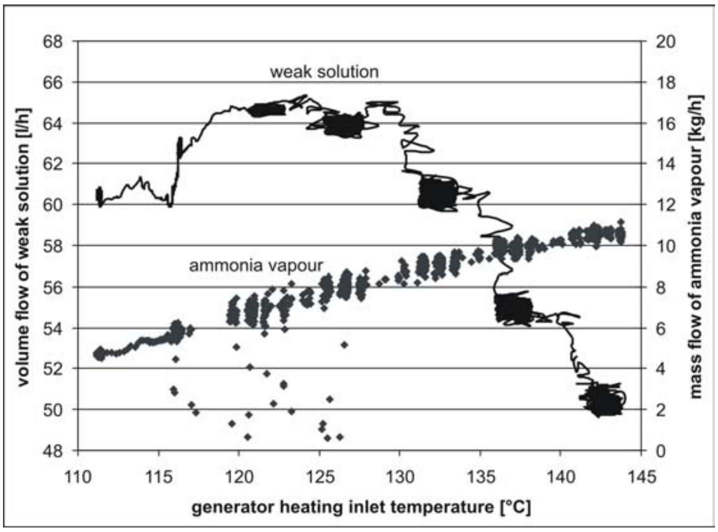

Fig. 3: Measured volume flow of weak solution and mass flow of ammonia vapour versus generator heating inlet temperature (generator B II).

The temperature dependence of the expelled amount of ammonia vapour is nearly linear as Figure 3 shows. The higher amount of ammonia vapour comes only from the higher degassing width. The higher depletion of the solution leads to a higher amount of water in the expelled vapour, because of the equilibrium between the concentration of the weak solution and the vapour purity.

Performance dependence

The essential function of the generator is it to produce ammonia vapour, because it defines the amount of condensate, which is necessary to achieve the cooling capacity of the DACM. One possibility to produce more ammonia vapour is to rise the generator temperature, as shown in Figure 3. Beside the temperature rise, this allows a higher degassing width, the transfer of heating capacity increases if the ammonia concentration of the rich solution increases. This context is shown in Figure 4.

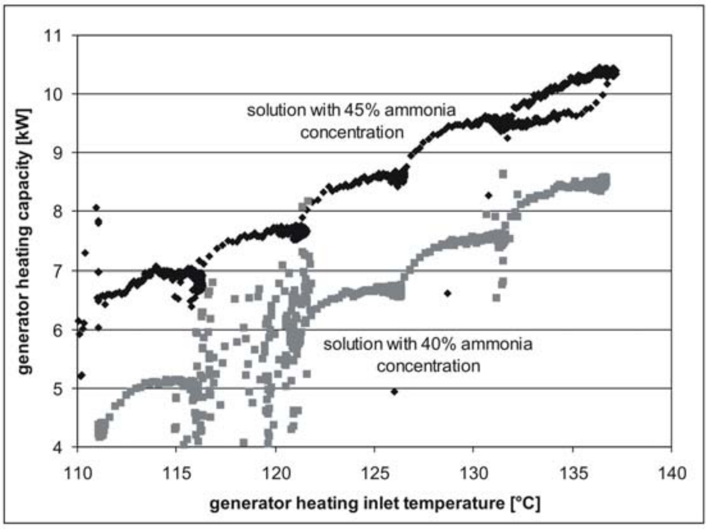

Fig. 4: Measured generator heating capacity versus generator heating inlet temperature (at two different ammonia solution concentrations).

With an equal transferred generator heating input the amount of ammonia is nearly constant in spite of different heating temperatures and external heating volume flows (Fig. 5). This can be explained by the characteristic behaviour of the degassing width potential, which delivers a temperature level, which only can be used, if the required performance can be transferred. With increased generator heat transfer, more ammonia can be expelled at the same temperature level (Fig. 6). Vice versa, the same amount of ammonia vapour is developed at lower temperature if the generator heat transfer increases. The boundary of this optimisation is reached if the degassing potential is exploited. The more amount of ammonia vapour attributes in our case to the use of the big generator (B II) as well as of both generators (B I and B II) which generate higher solution flows.

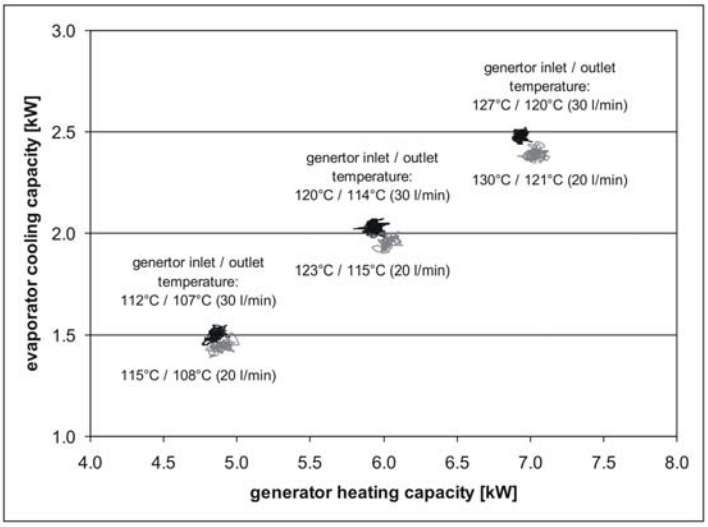

Fig. 5: Measured evaporator cooling capacity versus generator heating capacity (at different external heating volume flows, generator B II).

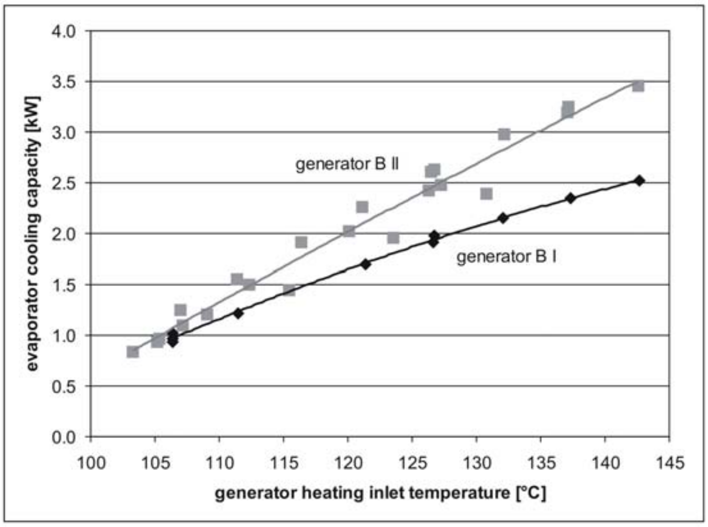

Fig. 6: Measured evaporator cooling capacity versus generator heating inlet temperature (in dependence of the generator heat transfer surfaces).

Even the latest single generator (B III) produces at the same boundaries as temperature, pressure and solution concentration and in spite of a lower lifting capacity the same or even more amount of ammonia vapour as the two generators B I and B II together. The generator B III shown in Figure 7, has the equal heat transfer surface as the generators B I and B II together, but with an improved heat transfer.

Fig. 7: Generator B III after the reconstruction of the DACM (photo: zafh.net).

CONCLUSIONS

The experimental investigation of a 2.5 kW Diffusion Absorption Cooling Machine (DACM) with marketable dimensions based on a combined evaporator-gas heat exchanger-absorber unit is presented. Moreover, the performance of three different indirectly heated, solar powered bubble pumps/generators were investigated and discussed. The system measurements were carried out at stationary pressure and temperature levels. The DACM showed that the values of COP ranged from 0.12 to 0.38, and the evaporator cooling capacity was between 0.7 kW and 3.0 kW. Heating temperatures of the generator in a range between 100°C and 150°C were obtained. After the redesign of the DACM early in October 2006, the latest performance of the machine showed cooling capacities of 2.0 kW and 2.4 kW at evaporator inlet/outlet temperatures of 12/6°C and 18/15°C, respectively. The average COPs are 0.3 at heating inlet temperatures of 125°C. The performance of the investigated bubble pumps/generators shows that they work in a wide operation range at varied heating temperatures as well as external mass flows.

Table 1: Summary of DACM prototypes

prototype	**DACM No.3**	**DACM No.3 rev**
generator/s	B I and B II	B III
evaporator cooling capacity	0.7 - 3.0 kW	2.0 - 2.4 kW
COP	0.12 - 0.38	0.30
weight	240 kg	230 kg
dimensions	0.6 x 0.6 x 2.2 m	0.6 x 0.6 x 2.2 m

ACKNOWLEDGEMENTS

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NOMENCLATURE

COP	coefficient of performance [-]

Abbreviations

B I, II, III	different generator sizes
DACM	Diffusion Absorption Cooling Machine
DAR	Diffusion Absorption Refrigerator
GHX	gas heat exchanger
SHX	solution heat exchanger

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