SOLAR COOLING WITH DIFFUSION ABSORPTION PRINCIPLE

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ABSTRACT

A solar powered ammonia-water Diffusion-Absorption Cooling Machine (DACM) was developed, designed for 2.5 kW cooling capacity at temperatures between –10 and +5 °C with indirect heating through CPC (Compound Parabolic Concentrators) vacuum tubes collectors. The indirectly heated, solar powered generator (bubble pump) represents the main new feature of this cooling machine. The first prototype is realized within an European JOULE-CRAFT program at the University of Applied Sciences Stuttgart, Germany. A simplified simulation model has been developed for the cooling machine, which allows the calculation of the coefficient of performance as a function of the fundamental operation parameters, as there are the generator-, the evaporator- and the condenser temperatures as well as heat losses by the rectification and only partial heat recovery. The first measurement results are available since spring 2001 and a second prototype of the DACM is under construction.

INTRODUCTION

At present thermally driven cooling machines and air-conditioning plants experience a renaissance, as both the environmental compatibility of conventional refrigerants and the energy demand of electrically driven compressor plants are critically discussed. For making available cold at low evaporator temperatures for the small and medium cooling performance range between 1 kW and 10 kW cooling capacity there are no thermally driven cooling machines on the market up to now.

A special feature for the development of such cooling machines is the use of the well-known Diffusion-Absorption technique from the Swedish engineers von Platen and Munters (1928). The principle of this technique is based on the pressure equilibration between high and low pressure side through an inert auxiliary gas (in this case helium), so that inside the unit no mechanically moving parts are necessary. Through the thermosyphon operation of the auxiliary gas circuit the pressure losses in the heat exchanger and in the evaporator have to be extremely low. A further special request on this type of cooling machine is the indirect heating through a solar collector field at temperature levels as low as possible. In contrast to a directly heated generator using gas or electricity there are only low heat flux densities available from indirectly heated generators using temperatures between 100 °C and 150 °C which makes the operation of a thermally driven gas bubble pump more difficult.

There also some prototypes of indirectly solar powered Diffusion-Absorption Refrigerators [1,2] with hydrogen as inert gas and a cooling capacity between 50 W and 400 W.

PRINCIPLE OF SOLAR POWERED DACM

The main components of a Diffusion-Absorption Cooling Machine are the generator, condenser, evaporator and absorber (Figure 1). A solution heat exchanger in the solution circuit and a gas heat exchanger in the auxiliary gas circuit are also components of the DACM as well as a dephlegmator for the condensation of the evaporated solvent [3].

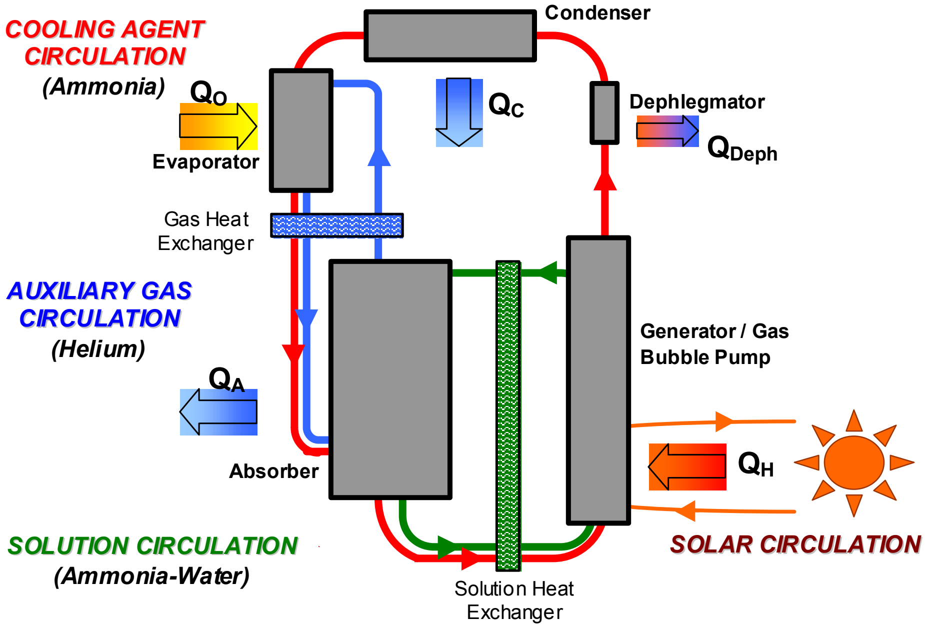

Figure 1: Principle of the solar driven Diffusion-Absorption Cooling Machine.

At a low partial pressure in the evaporator the cooling agent evaporates and in the absorber it will be absorbed again by the weak ammonia-water solution from the generator. In the generator with high heating temperatures the cooling agent will be driven out of the rich ammonia-water solution and so a high cooling agent vapour pressure will be generated which is enough for the condensation of the cooling agent in the condenser. The usual mechanical solution pump of absorption cooling machines is replaced in a DACM by a thermal gas bubble pump. The circulation of the solution between the generator and absorber will be maintained by vapour bubbles which push up a liquid column. The pressure compensation between high and low pressure level is realised by an inert auxiliary gas, helium or hydrogen. The auxiliary gas circulates between evaporator and absorber because of the temperature and density differences. In the whole cooling unit are no mechanically moving components inside and everywhere in the cooling unit is the same total pressure.

DEVELOPMENT OF THE PROTOTYPES

The development of the first prototype of the single-stage solar powered ammonia-water (NH_3-H_2O) Diffusion-Absorption Cooling Machine (DACM) was realized at the University of Applied Sciences Stuttgart. The designed performance range of the cooling machine of 2.5 kW led to the development of a newly constructed generator with indirect heating, an efficient bubble pump as well as new heat exchanger geometries [3].

The standard components condenser, evaporator, gas heat exchanger, absorber and solution heat exchanger were constructed as vertical or horizontal tubular heat exchanger (Figure 2). The condenser and the absorber are water-cooled. A cold brine is used for the refrigeration circle of the evaporator. There are three newly developed, constructed and built generator prototypes all with a different design. By indirectly heating of the generator, the forming of gas bubbles in several lifting tubes is a very complex thermodynamic process. It is necessary to reach good heat transfers, because of the low heat flux densities in the solar heating section.

Figure 2: DACM at the laboratory of the University of Applied Sciences Stuttgart.

The generator prototype No.3 (Figure 2) is built-in the cooling machine and it is investigated and improved during the operation in context with the whole cooling unit. The DACM including the generator prototype No.3 was designed for air-conditioning with the following temperature and heating/cooling capacity parameters (Table 1):

TABLE 1
GENERAL DESIGN CONDITIONS OF THE DACM PILOT PLANT

Design temperatures of the single components:		
	Generator inlet temperature $T_{G,rS}$	+ 101 °C
	Generator outlet temperature $T_{G,wS}$	+ 112 °C
	Condenser temperature T_C	+ 45 °C
	Evaporator temperature T_O	+ 5 °C
	Absorber temperature T_A	+ 45 °C
	Ambient temperature $T_{ambient,air}$	+ 32 °C
	Collector outlet temperature $T_{Coll,out}$	+ 127 °C
	Collector inlet temperature $T_{Coll,in}$	+ 117 °C
Total pressure p (given by condenser temperature)**:**		18,5 bar
Degassing wide in the generator (rich to weak solution)**:**		5 %
	NH_3-concentration rich solution X_{rS}	42 %
	NH_3-concentration weak solution X_{wS}	37 %
Supplied heat:		
	Generator (required heating power) Q_H	5.2 kW
	Evaporator (designed cooling power) Q_o	2.5 kW
Dissipated heat:		
	Condenser (required cooling) Q_C	2.8 kW
	Absorber (required cooling) Q_A	4.0 kW
	dephlegmator (required cooling) Q_{Deph}	0.9 kW

For the investigations of the DACM the pilot plant was filled up with a 38 percent ammonia-water solution and helium as auxiliary gas.

CALCULATION OF THE PERFORMANCE

A simplified stationary simulation model has been used with the MS-EXCEL program for the Diffusion-Absorption Cooling Machine, which allows the calculation of the coefficient of performance (COP) as a function of the fundamental operation parameters, as there are the generator, the evaporator and the absorber-/condenser temperatures as well as heat losses by rectification and heat recovery. The model is based on the energy balances of the Diffusion-Absorption cooling process and does not include materials- and mass balances. Extensive investigations of the performance of the DACM amounted to a COP of 0.53 and with heat recovery of the rectification losses of about 0.72 for the design operating conditions. The coefficients of performance were valid for a 42% ammonia-water solution with a 10% degassing width, an evaporator temperature of +5 °C, absorber/condenser temperatures of +45 °C and a generator temperature of 117 °C [5].

TEST RUNS PROTOTYPE DIFFUSION-ABSORPTION COOLING MACHINE

The generator prototype No.3 with 1,6m height and 19 tubes (∅ 8 mm x 1,5 mm) was installed within the complete pilot plant of the solar powered Diffusion-Absorption Cooling Machine. It is tested together with all other components (dephlegmator, condenser, evaporator, gas heat exchanger, absorber and solution heat exchanger) in the laboratory of the University of Applied Sciences Stuttgart (Figure 2) with an indirect liquid heating system [4].
In the first measurements at generator temperatures of 135 to 145 °C evaporator temperatures down to +10 °C and 0°C could be generated. During these first tests no purpose built dephlegmator was used for rectifying the ammonia vapour out of the generator and no component was heat insulated. However, due to uncontrolled heat losses from the tubing surface section between generator and condenser some rectification took place all the same. The instability of pressure and temperature levels of the Diffusion-Absorption Cooling Machine is problematic but these problems could be reduced by the improvement of secondary fluid circulation. For the first investigations of the DACM the flow through and the inlet temperatures of the secondary cycles were varied to find out the optimal operation point. Without rectification the COP reached values between 0.05 and maximum of 0.25.
After the optimisation of the external system technology of the DACM the flow rates and the inlet temperatures of the secondary cycles were varied to find out the optimal operation point. For the measurements with a stable operation of the DACM generator heating inlet temperatures were set between 150 °C and 170 °C. With this selected generator inlet temperatures investigations without and with rectification of the ammonia vapour were done to reach steady-state temperature and pressure levels (Figure 3). The minimal generator heating inlet temperature for running the Diffusion-Absorption cooling process was determined at 147 °C.

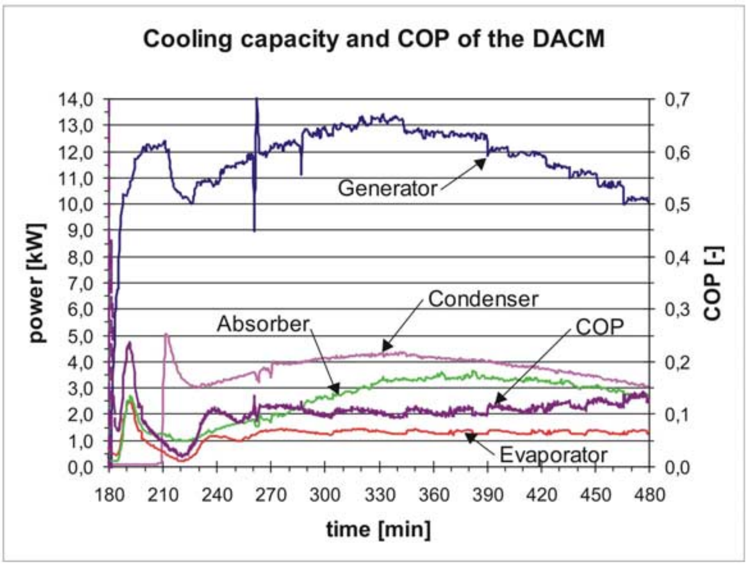

Figure 3: Cooling capacity and COP of the DACM after the optimisations (15.06.2001).

Without rectification the COP reached values between 0.10 and 0.16 (Figure 3). With rectification it was only about 0.10 because of the settings of the condenser cooling circulation and the low condenser cooling capacity. Up to now the best ever reached cooling capacity of the pilot plant amounted to 1.5 kW. However, the results are very difficult to reproduce and a detailed analysis of the process stability and reproducibility has to be done.

CONCLUSION

The developed Diffusion-Absorption Cooling Machine (DACM) is designed for a cooling capacity of 2.5 kW at temperatures between –10 and +5 °C with indirect heating through vacuum tubes collectors. The main new feature of this cooling machine represents the indirectly heated, solar powered generator (bubble pump). The development and the first experience gained in the operation of the indirectly heated DACM at the University of Applied Sciences Stuttgart, Germany represents a extremely promising basis for the further use of this technology. Measurements were done with different evaporator temperature T_o from 0°C up to +25 °C. Up to now the reached COP's are between 0.2 and 0.3 and the best ever reached cooling capacity of the pilot plant amounted to 1.5 kW. Because of the problems with the reached low evaporator cooling power, further theoretical and experimental investigations of the internal fluid cycles are necessary for increasing of the cooling capacity and the COP. A second prototype of the DACM is under construction using partly standard components like plate heat exchangers.

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