A new diffusion-absorption cooling machine powered by solar collectors or waste heat offers a 2.5 kW cooling capacity suitable for houses, offices and hotels. **Uli Jakob**, **Ursula Eicker** and **Ulrich Barth** describe the development and results obtained with a near-market prototype.

Solar cool

Promising results with a new diffusion–absorption cooling machine from Germany

There are currently no thermally driven absorption cooling machines on the market capable of providing the smaller cooling capacity needed for housing, offices or hotel rooms. Air conditioning in these applications typically has a cooling demand of less than 10 kW. The development and testing of an optimized single-stage solar or waste energy heated ammonia–water diffusion–absorption cooling machine (DACM) presents a new challenge. The designed cooling capacity of the machine is 2.5 kW at evaporator temperatures of between –10°C and +15°C with, for example, indirect heating through commercial vacuum tube collectors. The indirectly heated, solar-powered generator/gas bubble pump represents the main new feature of the new cooling machine described in this article.

BACKGROUND

The well known diffusion–absorption technique developed by the two Swedish engineers von Platen and Munters is based on the principle of pressure equilibration between the high and low pressure side through an inert auxiliary gas such as hydrogen or helium. A further special feature on this type of cooling machine is the use of a thermally driven gas bubble pump instead of a mechanical solution pump. This means that no mechanically moving parts are needed inside the cooling machine.

> No mechanically moving parts are needed inside the cooling machine

Conventional gas or electrically driven diffusion-absorption refrigerators (DAR), with their directly powered gas bubble pump, have been available since 1925 and are manufactured, for example, by Dometic AB, Sweden (formerly Electrolux AB). The cooling capacity of these DARs is 40–200 W.

There are three similar developments in Europe based on the von Platen and Munters cycle:

- an indirectly driven cooling machine with an extra loop for lower heating temperatures around 80°C[1]
- a directly driven heat pump with 3.6 kW output heating capacity and required 1.2 kW power input out of the environmental heat through the evaporator (cooling capacity) by a solar air collecotor[2]
- and a further directly driven heat pump with output heating capacities between 2.6 kW to 8 kW, respectively[3].

ADVANTAGES OF SOLAR-POWERED DACMS

Indirectly solar-powered DACMs have a number of advantages compared with conventional compressor cooling machines, including:

- primary energy savings and lower carbon dioxide emissions through the use of, for example, solar thermal energy for the indirect heated generator
- coincidence of the solar irradiation and the cooling requirement
- the working fluid (ammonia–water, with helium as a pressure equalizer) is ozone-friendly and no chlorofluorocarbons (CFCs) are used
- no need for electricity because the DACM has no mechanical solution pump
- no mechanical components such as pumps or valves mean that the cooling unit is maintenance-free
- the silence of the equipment.

Welding of an evaporator tubular heat exchanger for a diffusion-absorption cooling machine ULI JAKOB HFT STUTTGART

THE DACM PROCESS

The main components of a DACM are the generator, condenser, evaporator and absorber (see Figure 1). Additional components include:

- a solution heat exchanger (SHX) in the solution circuit
- a gas heat exchanger in the auxiliary gas circuit
- a dephlegmator for the condensation of the evaporated solvent.

At low partial pressures in the evaporator, the cooling agent evaporates and is absorbed again in the absorber by the weak ammonia–water solution provided by the generator. In the indirectly solar-powered generator with high heating temperatures, the cooling agent is driven out of the rich ammonia-water solution. This generates a high cooling agent vapour pressure, which is sufficient to condense the cooling agent in the condenser.

> Indirectly solar-powered DACMs have a number of advantages compared with conventional compressor cooling machines

The usual mechanical solution pump of an absorption cooling machine is replaced in a DACM by a thermal gas bubble pump. The circulation of the solution between the generator and absorber is maintained by vapour bubbles, which push up a liquid column. The pressure compensation between high and low pressure levels is realized by an inert auxiliary gas – helium or hydrogen. Temperature and density differences cause the auxiliary gas to circulate between the evaporator and the absorber. The cooling unit has no mechanically moving internal components and everywhere in the cooling unit is at the same total pressure.

DESIGN AND DEVELOPMENT

Researchers at the Department of Building Physics at the Stuttgart University of Applied Sciences have been developing, since 1998, a single-effect solar-heated ammonia–water DACM with a 2.5 kW cooling capacity and using helium as the inert gas. Two prototypes have been tested.

The first prototype solar-driven DACM was designed, developed and built in the Building Physics laboratories at the University in October 2000 as part of an EU JOULE-CRAFT programme. The requirement for a performance range of the cooling machine of 2.5 kW led to the development of a new generator with indirect heating, an efficient bubble pump and new heat exchanger geometries.[4]

The same laboratory produced a second optimized near-market prototype in July 2003, based on the experiences and results of the first prototype. To achieve the cooling capacity range of 2.5 kW, an improved indirectly heated bubble pump was developed. The auxiliary gas circuit was also reworked, resulting in a reduction in weight to 240 kg and a height reduction to 2.4 metres – both important for a subsequent commercial unit.[5]

The second prototype DACM was set up using standard commercial components; a nickel-soldered plate heat exchanger for the condenser and a coaxial heat exchanger for the SHX. The components of the auxiliary gas circuit falling film evaporator, gas heat exchanger and falling film absorber were constructed as vertical tubular heat exchangers. The condenser and the absorber are water-cooled. Cold brine is used for the refrigeration circle of the evaporator.

The smaller overall height of the second prototype meant that the lifting height of the bubble pump could be reduced. This led to a higher efficiency of the bubble pump and a noticeable reduction in generator heating temperatures. The temperatures of the indirect heating system of the generator can currently be reduced to 130°C.

The near-market prototype is designed for air conditioning and refrigeration. Table 1 summarizes its design and site data.

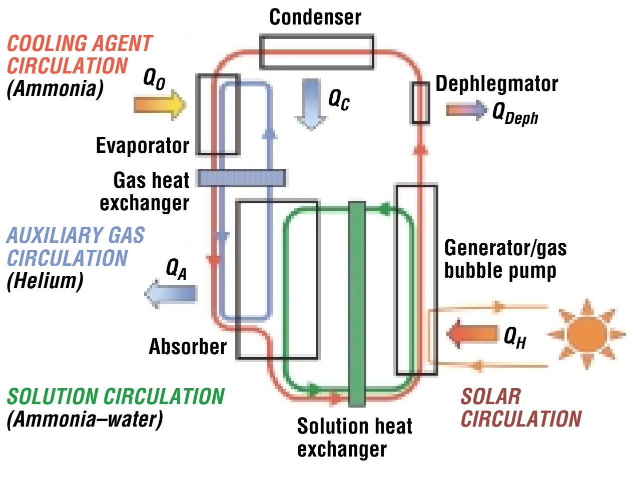


FIGURE 1 The DACM process ULI JAKOB HFT STUTTGART

TABLE 1. Site and design data of near-market DACM (second prototype)

Dimensions	0.8 x 0.8 x 2.4 metres	
Weight	240 kg	
Generator	Heating capacity QH	5.2 kW
	Heating water in/out	130°/120°C
Dephlegmator	Cooling power QDeph	0.9 kW
	Cooling water in/out	42°/47°C
Condenser	Cooling power QC	2.8 kW
	Cooling water in/out	35°/37°C
Evaporator	Cooling capacity Q0	2.5 kW
	Chilled water in/out	13°/10°C
Absorber	Cooling power QA	4.0 kW
	Cooling water in/out	30°/35°C
COP (Coefficient of performance)		0.48

RESULTS AND PERFORMANCE

A series of measurements was made between November 2000 and March 2002 on the first prototype DACM at generator heating inlet temperatures of 150°–170°C; evaporator temperatures from 0°C to 25°C were reached. The results showed that COP values ranged from 0.1 to 0.2 and that the cooling capacity could reach 0.5–1.5 kW. However, the operational stability was inadequate; in most experiments, the evaporator capacity decreased with time[6].

After a number of safety and pressure tests, the second prototype DACM was tested from July 2003 to June 2004. The evaluated continuous cooling capacities of the first measurements were around 0.5 kW, with COPs of between 0.1 and 0.2. The maximum cooling capacity reached was 0.8 kW at an initial ammonia mass fraction of 30%.

After refilling the system with an initial ammonia mass fraction of 40%, the results again showed a cooling capacity range of 0.5 kW. As a result, the SHX was replaced. After this change, the test runs and subsequent data acquisition analysis showed a remarkably improved COP of 0.2–0.3 (see Figure 2) and a continuous cooling performance of 1.5 kW. A top performance of 2 kW could be reached if the evaporator inlet temperature was set up a relatively high value of 25°C.[7]

After further modifications to the second prototype and refilling it with an initial ammonia mass fraction of 37%, a further period of measurements began in September 2004. The new results showed a further improved COP of 0.3–0.5 and a continuous cooling performance up 1.6 kW at evaporator outlet temperatures for air-conditioning of between 22°C and 15°C. The generator heating inlet temperatures could be reduced from 135°–185°C down to 110°–155°C; the lowest recorded constant evaporator outlet temperature is currently –5°C at a generator heating inlet temperature of 145°C. Figure 3 shows the test results obtained with the second prototype after these modifications.

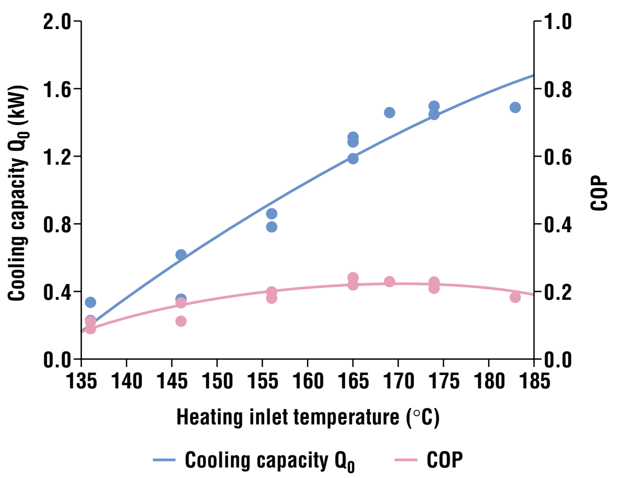


FIGURE 2. Results from the second prototype ULI JAKOB HFT STUTTGART

Near-market prototype DACM produced in the laboratory of the Stuttgart University of Applied Sciences ULI JAKOB HFT STUTTGART

The lowest recorded constant evaporator outlet temperature is currently –5°C at a generator heating inlet temperature of 145°C

CONCLUSIONS

Two solar-driven diffusion-absorption cooling machines have been developed and built to date at the Stuttgart University of Applied Sciences. The first prototype achieved low COP values of 0.1–0.2 and a cooling capacity of 1.5 kW, but its operating stability was not sufficient.

A second optimized near-market prototype was built

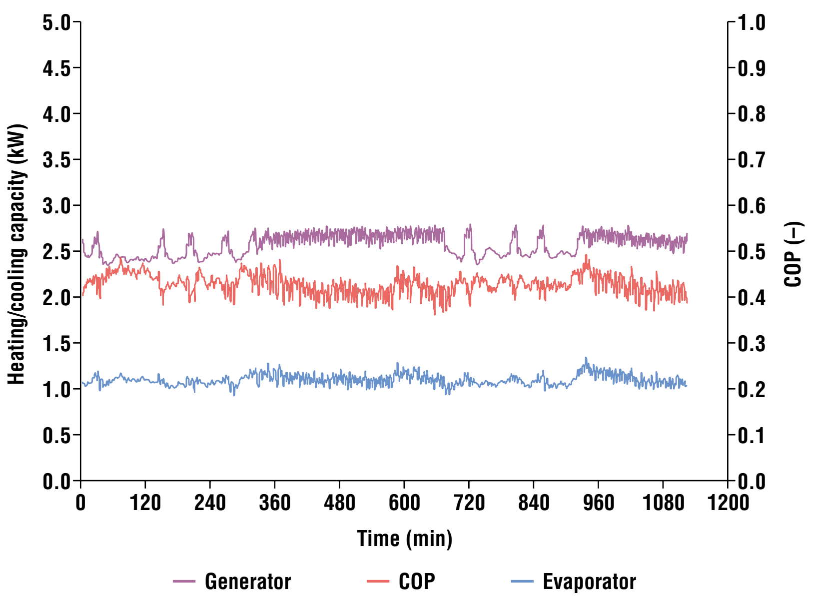
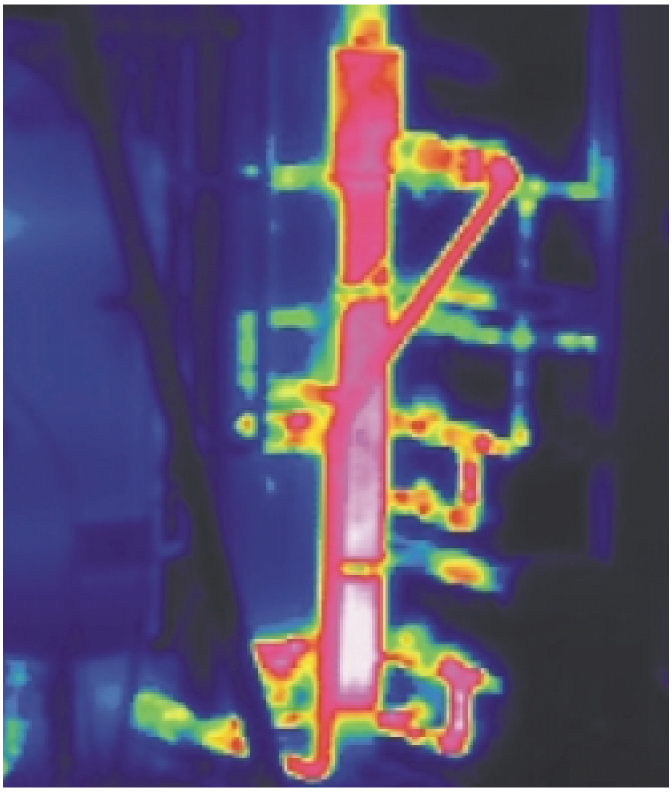


FIGURE 3. Long-term measured heating/cooling capacity and COP of the DACM No. 2 after the latest improvements ULI JAKOB HFT STUTTGART

based on experiences with the initial unit, partly using standard components such as a nickel-soldered plate heat exchanger and a coaxial heat exchanger. The auxiliary gas circuit was constructively reworked and a further generator was developed for this much more compact prototype. The second prototype began operating in July 2003 and is running stably. Good COPs of between 0.2 and 0.5 and a cooling capacity ranging from 1.0 to 2.0 kW have been obtained.

Further development is required with respect to the cooling power and COP, as well as further reductions in weight and production costs. The first step have been taken towards these reductions. For example, by changing one of the five main components of the cooling machine, it was possible to simultaneously reduce costs, reduce the weight of the unit by about 20% and double performance.

Infrared thermal photography of a gas bubble pump of the second pilot plant of the DACM ULI JAKOB HFT STUTTGART



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