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Development of an adsorption chiller and heat pump for domestic heating and air-conditioning applications

Tomas Núñez [a,*], Walter Mittelbach [b], Hans-Martin Henning [a]

[a] Fraunhofer Institut for Solar Energy Systems ISE, Heidenhofstraße 2, 79110 Freiburg, Germany
[b] SorTech AG, Weinbergweg 23, 06120 Halle a.d. Saale, Germany

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Abstract

The scope of this paper is to present the development of a prototype of a small adsorption heat pump working on the adsorption pair silica gel–water. The development of this prototype with remarkable high power densities has been carried out during the last year and is a result of continued joint work on adsorption heat transformation systems carried out at SorTech AG and the Fraunhofer Institute.

Keywords: Adsorption; Chiller; Heat pump; Silica gel; Solar cooling

1. Introduction

With the aim to reduce the amount of primary energy used for domestic heating purposes the introduction of heat driven heat pumps can provide a significant improvement in fossil fuel utilisation. Furthermore, if the design of the heat pump allows the additional use of its cooling properties, year round operation becomes possible using waste or solar heat in summer in order to provide cooling for air-conditioning applications. Combining such a thermally driven heat pump/chiller with a combined heat and power system a tri-generation system for heat, cold and power is made available. But up to now no small power heat pumping system with such characteristics is available on the market although an increased demand is currently observed.

The results presented in this contribution are results obtained with the first and second prototype that has been constructed and tested in the last six months. Therefore they should be considered as preliminary results. The present machine has still a high potential for improvement and optimisation in the near future.

2. The developed heat pump prototype

2.1. Description of the heat pump

The developed system consists of two identical modules. Each module contains a heat exchanger for the adsorption material and a second heat exchanger for evaporation and condensation of the process water. Both heat exchangers are assembled into one single vacuum tight container forming a sealed unit that is connected to the surroundings only by hydraulic piping. At the present stage of development the adsorption heat exchanger is filled with silica gel as adsorbent. But the design of the reactor is such, that also other sorption materials could be used.

Both modules are interconnected through a hydraulic switching unit. This hydraulic unit connects both

* Corresponding author. Tel.: +49 761 4588 5134.
E-mail address: nunez@ise.fhg.de (T. Núñez).

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Nomenclature

T_{high}	driving temperature for the heat pump (high temperature source), inlet temperature to the heat pump.
T_{medium}	re-cooling (cooling application) or heating temperature (heating application). Inlet temperature to the heat pump, temperature of the medium temperature sink.
T_{low}	cooling temperature. Outlet temperature of the heat pump, low temperature level.
$T_{reduced}$	reduced temperature
P_{high}	mean driving (desorption) power
P_{medium}	mean power at the medium temperature level.
P_{low}	mean cooling power.
t_{cycle}	cycle duration (phases 1–4)
$COP_{cooling}$	coefficient of performance for cooling
$COP_{heating}$	coefficient of performance for heating
A1	adsorber 1
A2	adsorber 2
VK_1	evaporator/condenser 1
VK_2	evaporator/condenser 2
RK	re-cooling circuit
VL	inlet temperature
RL	outlet temperature

modules to the heat source and sink and allows their operation in a quasi-continuous mode. An internal control unit ensures proper operation of each module providing the switching signals for the valves in the hydraulic unit switching between the different internal phases of the heat pump. In Fig. 1 a schematic of the heat pump is presented.

The dimensions of both modules together without the hydraulic switching unit are 355 mm × 520 mm × 1360 mm. The total weight of both modules is 258 kg. Each module is filled with about 35 kg of silica gel.

2.2. Operation

The two modules are designed in order to be operated with hot water at temperatures of 75–95 °C. Design heating temperatures of 35–40 °C which are delivered in the heating mode are suitable for low temperature heating systems such as wall or floor heating installations. For cooling application this is the temperature level of the heat rejection. In the cooling operation chilled water of 10–15 °C is produced in an almost continuous mode. Further on these three temperature levels are denoted T_{high}, T_{medium} and T_{low}.

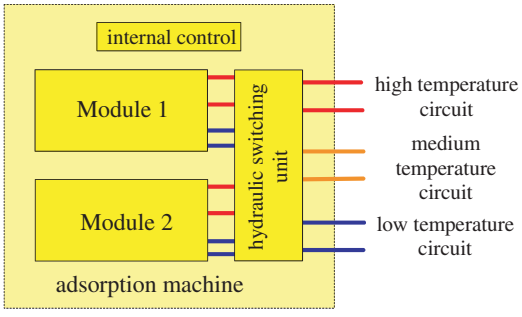

Fig. 1. Schematic of the heat pump. The main components are: two modules, the hydraulic switching unit and the control unit.

According to the type of operation the heat pump can be connected to different heat sources and sinks. Table 1 gives some possible connections.

The two modules of the heat pump are operated in a periodic and phase-shifted mode. While one module is in the adsorption phase the other module is being desorbed. This results in four consecutive operation phases of the four heat exchangers. The four phases are summarised in Table 2. The duration of each phase and therefore the duration of the whole cycle depends on the required heating or cooling power. For the results presented here it is in the order of 15–30 min. During the phases of internal heat recovery no heating or cooling power is provided to the external circuits. These phases have a duration of about 30–60 s.

2.3. Measurements

The first tests of the system were carried out at the test facilities for heat driven heat pumps and chillers installed at SorTech AG. Different values of the driving temperature, the medium temperature and the low tem-

Table 1
Sources for the three temperature levels for heating and cooling applications of the sorption system

Hydraulic circuit	Cooling application	Heating application
High temperature heat source (T_{high})	Driving heat source; e.g. solar system	Driving heat source, e.g. gas furnace
Medium temperature heat sink (T_{medium})	Heat rejection; e.g. dry or wet cooling tower; ground coupled heat exchanger	Useful heat, heating system
Low temperature heat source (T_{low})	Useful cooling, chilled water circuit	Low temperature heat source; e.g. ground heat exchanger