COMPACT ADSORPTION CHILLERS WITH COATED ADSORBER HEAT EXCHANGERS

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Abstract: Beside the well-known liquid absorption chillers using LiBr-water as sorption pair also solid adsorption chillers may be used for generating chilled water with low-temperature heat. In the range of cooling capacities of 70 kW and higher Japanese products are on the market for many years using silica gel as adsorbent and water as refrigerant. But due to the much larger volume and weight of the machines compared to LiBr absorption chillers adsorption chillers only found niche markets up to now.

The main reason for the large volume of the adsorption chillers sold up to now is the low heat transfer rate between silica gel and the heat exchanger surfaces. SorTech AG developed a coating process, which allows to paste up the heat exchanger surfaces directly with the adsorbent. This enabled the development of more compact and lightweight adsorption chillers. Based on this technology SorTech AG developed a prototype of a small adsorption chiller with a nominal cooling capacity of 5.5 kW. The objective is to provide a compact machine, which may be used for solar air-conditioning in private homes and small offices.

Key Words: ***Adsorption, sorption, solar cooling, thermal-driven cooling***

1 WORKING PRINCIPLE

The basic process of cold generation is the compression of a refrigerant fluid, which causes evaporation of the liquid at low temperatures and pressures and condensation of the vapor at higher temperatures and pressures. Instead of mechanical compression like in electrical air-conditioners, thermal driven chillers use thermal energy for the compression of the fluid.

The basic principle of the thermal compression is the ab- or adsorption of the refrigerant in a liquid or solid material. Whereas absorption chillers most commonly use the liquid lithium-bromide in adsorption chillers solid adsorbents like silica gel or zeolites are applied. In both machines the refrigerant is water, which results in the technical task that the machine has to be operated at very low pressures in a vacuum tight containment.
In our chiller we use silica gel as adsorbent. Silica gel is a porous glass with a high capacity of adsorbing water vapor. For that reason it is widespread used as a desiccant.

The working process of the adsorption chiller is described below (compare figure 1).

- Step 1: Desorption – Drying of the adsorbent
  The adsorbent is dried by heat input. Water vapor is set free, flows in the condenser and is liquefied there under heat emission. When the material is dry, the heat input in the adsorber is stopped and the upper check valve closes.
- Step 2: Adsorption – water vapor is adsorbed at the surface of the adsorbent
  After a cool down phase the reverse reaction and the evaporation of the liquid condensate starts. The lower check valve to the evaporator opens and the dry adsorbent aspirates water vapor. In the evaporator, water evaporates and generates

chilled water, which can be used for air-conditioning. During the adsorption process heat is rejected which has to be dissipated.

- Step 3: Return of condensate
  In a final step the condensate is returned to the evaporator and the circuit closed.

In order to achieve a continuous cold production two adsorbers work in combination, i.e. one adsorber is being desorbed while the other adsorber generates cold by adsorbing in the meantime.

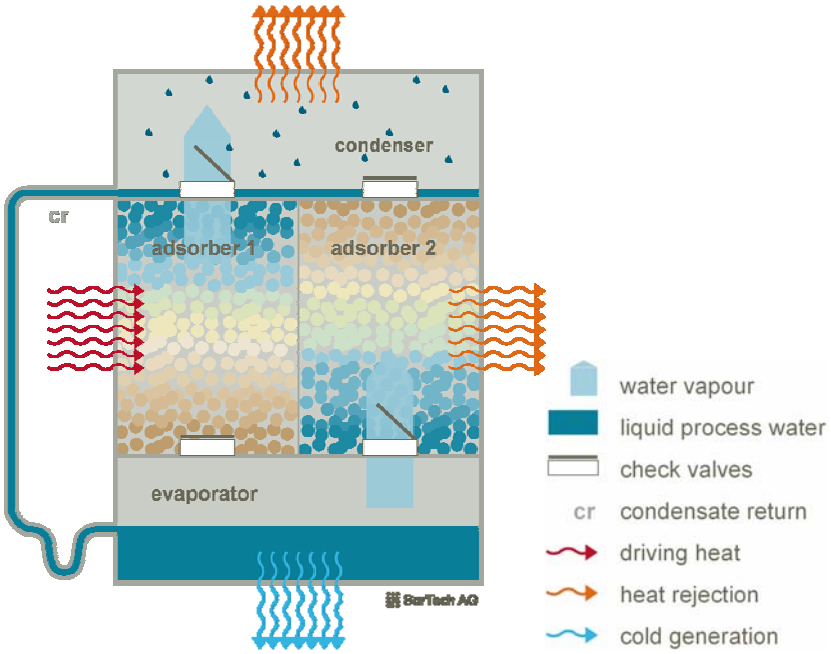

Figure 1: Working process of the adsorption chiller

2 CONSTRUCTION PRINCIPLES

SorTech AG has developed and patented two construction principles, which are important for achieving a compact and lightweight chiller design:

- Coating of the adsorber heat exchangers with silica gel
  Silica gel is typically sold in small circular pellets with diameters between 1 and 3 mm. Generally the heat and mass transfer in a solid bed of silica gel pellets is very low. Therefore it is the crucial for enhancing the power density of adsorption chillers to apply the silica gel directly on the surface of the adsorber heat exchanger. In order to overcome this constraint a process was developed, where the heat exchanger surface is pasted with silica gel with the aid of epoxy resin (Fig.2). In general, all types of granulate can be applied by this technique.

Figure 2: Photo of a silica gel coated tube and fin adsorber heat exchanger

- Compact self-supporting construction
  One of the major problems of the construction of adsorption chillers is the need to design a vacuum vessel containing the adsorber heat exchangers, the evaporator and the condenser. Typical design rules for vacuum vessels result in very heavy and voluminous constructions due to the demands of stability against atmospheric pressure. In order to overcome this disadvantage we developed a design, where the heat exchangers and the internal construction of the machine are used as a support for the vacuum-tight envelope. This dual-use allows to utilize thin stainless steel metal sheet as vacuum containment (See fig.3). This light and very simple construction results in very high savings of material and volume and is a major step for the construction of an economical adsorption chiller.

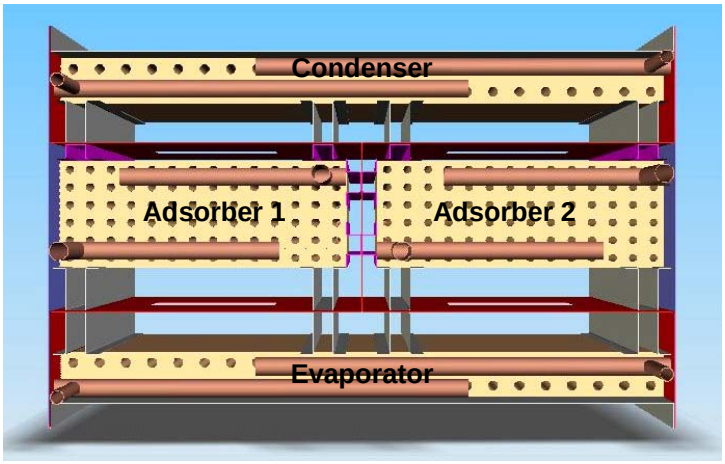

Figure 3: Internal construction of the adsorption chiller. All heat exchangers are of the tube and fin type. About 50 % of the volume is empty in order to provide enough space for vapour flow. The weight of the basic unit is about 80 kg.

3 ACS 05 – A FIRST GENERATION PROTOTYPE

At the beginning of 2007 SorTech AG developed a first generation prototype named ACS 05, which was manufactured in a small series of about 20 units.
The machine has the following technical data:

Technical data ACS 05

Cooling Capacity	**5.5 kW**
Thermal COP	**0.6**
Electrical Power Consumption	**57 W**
Chilled Water Circuit	**18/15°C at 1.7 m³/h**
Heat Rejection Circuit	**27/32°C at 2.7 m³/h**
Heat Supply Circuit	**75/67°C at 1.0 m³/h**
Dimensions	**795 x 1100 x 1190 mm**
Weight	**ca. 200 kg**

Figure 4: ACS 05

The machine may also be used under other temperature conditions (see as an example the variation of cooling capacity and COP as a function of heat rejection temperature in fig. 5).

The control of the adsorption chiller is managed in a way, that it is easy to operate the machine under partial load. The inner adsorption-desorption cycle of the system is automatically adjusted to the cooling demand. Therefore under certain temperature conditions there is not a single value but a range of COP and cooling powers under which the machine may be driven.

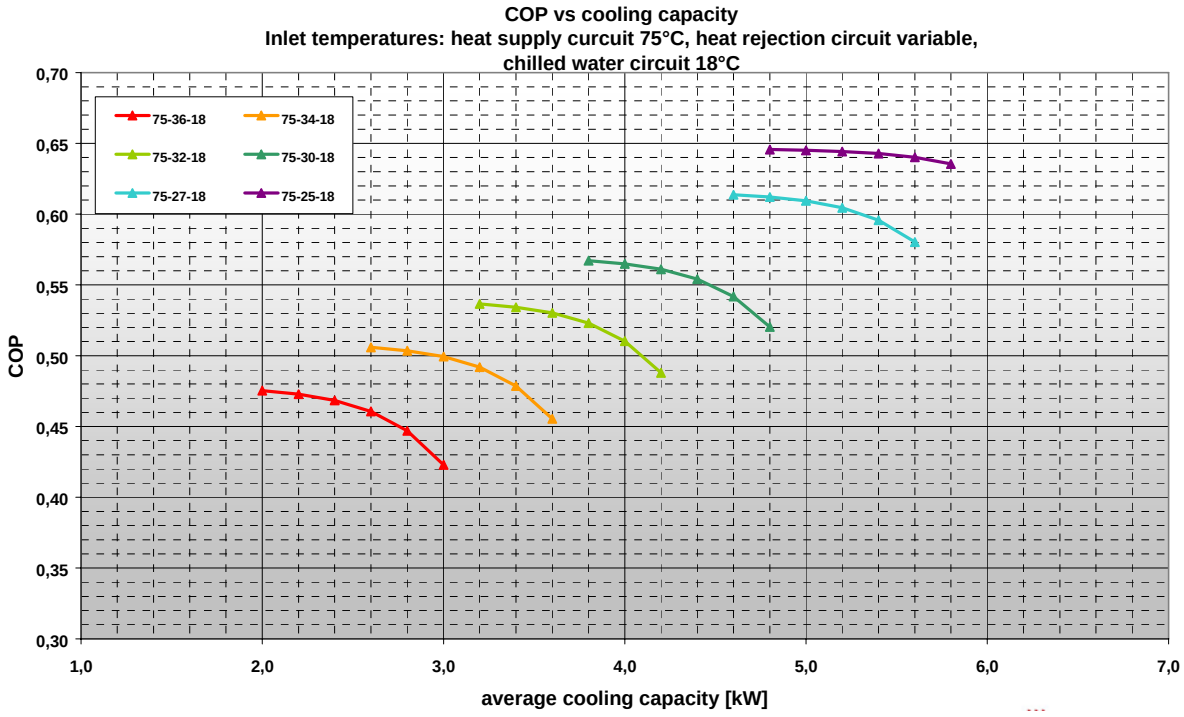

Figure 5: Cooling capacity and COP depending on the heat rejection temperature. Hot water and chilled water circuits are fixed on 75/67°C and 18/15°C. The inlet temperature of the heat rejection circle with respect to the chiller is varied from 25°C to 36°C at fixed volume flow of 2.7 m³/h. Similar graphs may be generated by variation of the other cycle temperatures. SorTech provides a calculation program based on Excel, which generates cooling capacity and COP under all temperature conditions.

3.1 Pilot testing

A series of pilot tests are being carried out with ACS 05 during the cooling season of 2007. The applications range from solar air conditioning of small offices and homes, solar assisted heating and cooling of the canteen kitchen at Fraunhofer Institute for Solar Energy Systems to small tri-generation and installation in a district heating network.

Up to now the field tests are located in Germany and Austria. Field tests in Mediterranean climatic regions like Spain and Italy are being prepared. For cold distribution mainly fan coils, wall heating systems and ducted air handling units were used. In all systems ACS 05 was used only for cooling with the exception of Fraunhofer ISE, where the combination of cooling in summer and heating assistance during winter time is being tested. In the heating mode ACS 05 is operated as a thermal driven heat pump. The system at Fraunhofer ISE is using ground coupled vertical bore holes for heat rejection during summer and as a heat source in winter. The system looks attractive for private homes in heating dominated regions such as Germany with a rather short cooling season.

At the time of writing this article no overall evaluation of the tests could be carried out, because the tests are still running. Subsequently some preliminary results are summarized:

- Up to now all machines worked well – no breakdown or serious problem occurred.
- The installation procedure proved to be too complex, consequently SorTech is working on a simplified installation for the product.
- Basic problem is the overall electricity consumption of the system. Although ACS has a consumption of only 57 W, pumps and fans consume much more electricity

especially on the heat rejection circle. As a consequence hydraulic design was improved in order to reduce pressure losses on all three circuits.

- The most important component for solar air conditioning after the chiller is the heat rejection unit. In order to combine the advantages of dry (no legionella problems) and wet re-cooling (better performance at high air temperatures) a dry re-cooler with an additional spraying system was designed and tested. This type of heat rejection unit is mainly driven in the dry mode the additional spraying system is only used under high air temperatures above 30 °C. After a first cooling season of continual operation we think that this is a feasible product for solar air-conditioning under moderate climatic conditions like Central Europe or the northern and central parts of the Mediterranean Region. Under more severe climatic conditions a wet cooling tower is still necessary.

3.2 Conclusions

Small compact adsorption chillers seem to be an attractive option for thermal driven air conditioning. The preliminary test results from our ACS 05 units are positive. Therefore SorTech AG will continue the project and provides an improved version - the ACS 08, with a nominal cooling capacity of 7.5 kW - in 2008.