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Testing a Prototype Adsorption Cooler in a Research Dwelling

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ABSTRACT

Cooling with heat is hot. Demand for cooling often coincides with the supply of solar heat. This makes thermally driven chillers (TDC's) in combination with solar collectors interesting for improving the energy efficiency of comfort cooling. Several TDC's are already available on the market. Only small scale (comfort) TDC's for applications in dwellings are not commercially available yet. This is why the Energy research Centre of the Netherlands (ECN) developed a prototype adsorption chiller, based on silicagel-water, with a nominal cooling capacity of 2.5 kW. This paper will explain the working principle of the water-silica adsorption chiller, and will summarize executed measurements and their results. These results show that the choice of water and silica is successful and that the technology is ready to be commercialised.

INTRODUCTION

Triggered by the potential of waste heat (e.g. from industry) and renewable heat (e.g. from the sun), the Energy research Centre of the Netherlands (ECN) initiated development of sorption cooling technology several years ago. Recent work was done within the framework of the European (FP6) PolySMART project (www.polysmart.org).

Silica – water was chosen as a working pair for the cooling machine: a choice that has proven to be successful so far. Compared to conventional compression cooling, thermally driven cooling (TDC) offers several advantages, e.g.:

- Using heat instead of electricity reduces peaks on the electricity grids
  Using renewable heat reduces carbon emissions.
- Many sorption cycles are based on natural refrigerants.
- TDC's have low noise levels and maintenance requirements.

Just like a conventional compression chiller, an adsorption chiller uses a cycle where a refrigerant condenses at high pressure/temperature and evaporates at low pressure/temperature. However, this cycle is not driven by a mechanical compressor but by a thermal compressor, based on the sorption reaction of silica gel and water, using heat as the driving force. Dry silica gel (a porous, glass-like solid) attracts and adsorbs water vapour until it is saturated, and must then be regenerated. Heating the silica gel releases the water vapour at a pressure that allows it to condense at ambient temperatures, after which the cycle of adsorption and de-sorption can be repeated. This cycle is not unlike absorption cycles (with e.g. LiBr-solution), there are two important differences:

1. The silica gel can be regenerated efficiently at lower driving temperatures
2. The silica gel is a solid that cannot be pumped from generator to absorber

The silica gel is applied to the surfaces of heat exchangers, which are supplied intermittently with hot and cooling water. The adsorption cycle is therefore a batch process, and for quasi-continuous cooling at least two silica gel beds (reactors) are needed, operating in counter-phase.

The lowest possible chilled water temperature of this adsorption cycle is about 4 °C, making it perfectly suited for air-conditioning and chilled water systems in the built environment and in industry.

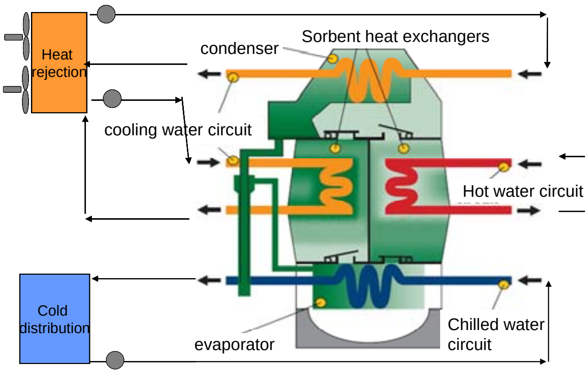

Figure 1: Schematic adsorption chiller lay-out

Design of the chiller As part of the European PolySMART project (www.polysmart.org), ECN has developed a small-scale adsorption chiller using silica gel - water as working pair that is tested and demonstrated. The objective for the design is to supply sufficient cooling power (2.5 kW) for a modern Dutch single family house. Common standard sizes for household appliances are used to determine the physical size limits: a 60 x 60 cm footprint, and a height of about 100 cm.

Compact light-weight aluminium heat exchangers from the automotive industry have been used to support the silica gel, creating a large surface while maintaining low weight and volume. For the same reason, this type of heat exchanger has also been used for the condenser and for the evaporator. Figure 2 shows the layout of the new chiller: the evaporator at the bottom, two silica gel reactors above the evaporator, and the condenser on top.

Water vapour flows at low pressure from the evaporator (creating a cooling effect) and is adsorbed in one of the two silica gel reactors (adsorption phase). At the same time, water vapour flows from the other reactor to the condenser (de-sorption phase) at a higher pressure. Special check valves have been installed between these components to prevent the water vapour from flowing back. This (low pressure) process requires that the system does not contain any gases or vapours other than water vapour, and that all components are hermetically sealed. The water from the condenser flows back to the evaporator via a condensate return line. The flow for heating and cooling of the silica gel is controlled by eight valves, which intermittently supply both reactors. A PLC unit is included in the chiller to control these valves and to monitor temperatures and pressures.

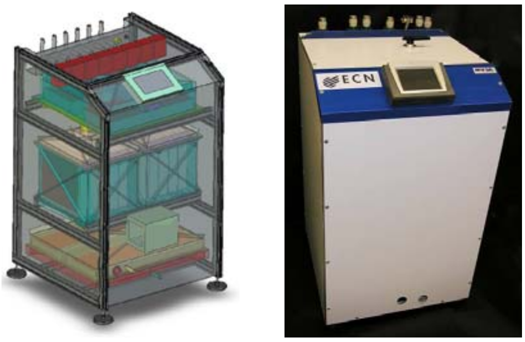

Figure 2: Design drawing and picture of the ECN 2.5 kW prototype adsorption chiller

Laboratory testing The prototype adsorption chiller has been tested in an ECN laboratory, with the facilities to control flows and temperatures for hot, cooling and chilled water. Hot, cooling and chilled water temperatures strongly influence the chillers' performance. The following inlet temperatures are used as nominal operating conditions for driving heat, regeneration and chilling: 80°C, 30°C and 15°C respectively. The influence of cycle time on thermal performance has been determined for these operating conditions. The cycle time is the duration of a complete cycle of heating up and cooling down of one reactor. Figure 3 shows the cooling power (left axis) and coefficient of performance (right axis, ratio of cooling power and driving heat). For this application, the coefficient of performance is defined as:

$$COP = \frac{Q_{evaporator}}{Q_{heatsource}}$$

Figure 3 shows that cycle times under six minutes are not useful, because both cooling power and COP show a decrease (because this short cycle time does not allow all the silica gel to go through the complete temperature cycle). With increasing cycle times (>10 minutes), a decrease in cooling power is compensated by an increase in efficiency (because fewer changes between heating and cooling of a reactor mean less thermal losses).

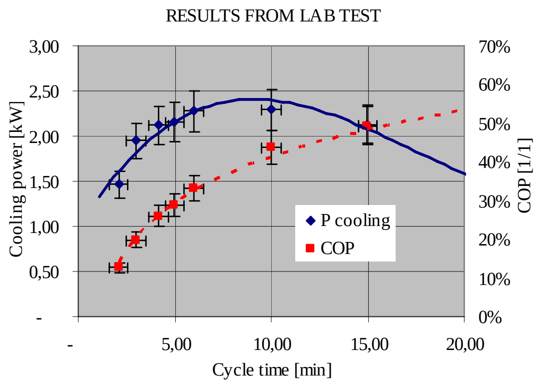

Figure 3: Influence of cycle time on thermal performance of the adsorption chiller

Figure 4 shows the influence of the cooling water and chilled water inlet temperature on the chiller's performance. Chiller performance clearly benefits from "high-temperature cooling" and relatively low cooling water temperatures. When designing a complete (solar) cooling system, these aspects must be taken into consideration.

The laboratory tests show that the ambitious design specifications for this prototype have been achieved. Nearly 2.5 kW cooling power can be produced with a very compact machine (power density of 7 kW/m^3) at a very respectable COP.

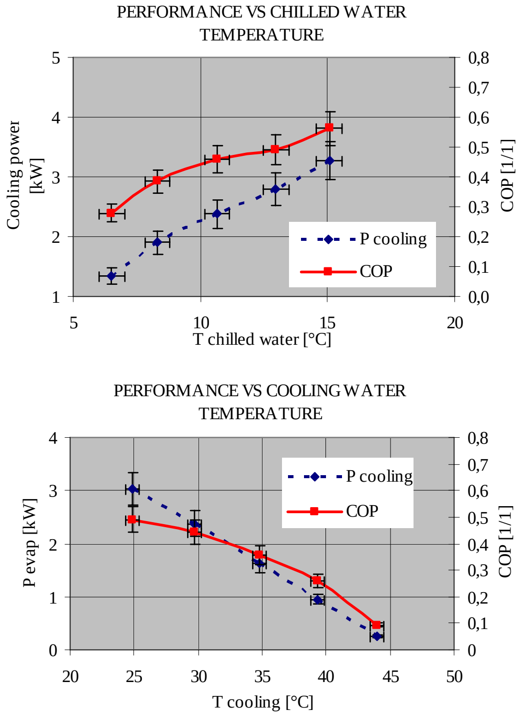

Figure 4: Influence of cooling water (below) and chilled water (upper) inlet temperature

Measurements in research dwellings The research dwelling that is used, is in one of the four full-scale single family dwellings at ECN in Petten, Netherlands and shown in figure 5. The size of these dwellings represents the Dutch average for new dwellings. The research dwellings are equipped with an extensive data acquisition system, logging each 10 minutes more than a 100 sensors. These systems register energy flows such as passive (windows) and active (collector) solar radiation, electricity use but also temperature, humidity and if necessary carbon dioxide levels. The data acquisition also allows to measure on component level such as: electricity use of circulation pumps or controls, heat supplied by heating systems, temperature and humidity (comfort aspects) etc. The measurements with the TDC are performed with the installation setup as shown in figure 6.

Figure 5: Above the four single family dwellings. The second house to the left is used for measurements with the adsorption chiller

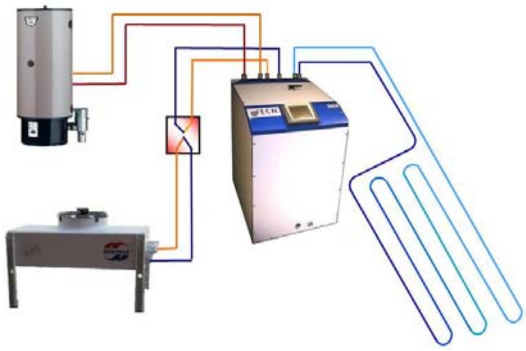

Figure 6: Installation setup of measurements with the TDC and a HE gas-fired boiler as heat source.

As can be seen in the graphs in figure 4, the performance of the chiller is strongly influenced by the chilled water temperature and the cooling temperature. To be able to compare measurements that are performed under different conditions, COP and cooling power can be plotted against the so-called reduced temperature. The reduced temperature is defined as:

$$T_{reduced} = \frac{T_{cooling(in)} - T_{chilled\ water}}{T_{hot(in)} - T_{cooling(in)}}$$

The following graphs show the results from measurements in the research dwelling and the laboratory. The horizontal axes represent the reduced temperature, allowing comparing the results from lab and research dwelling.

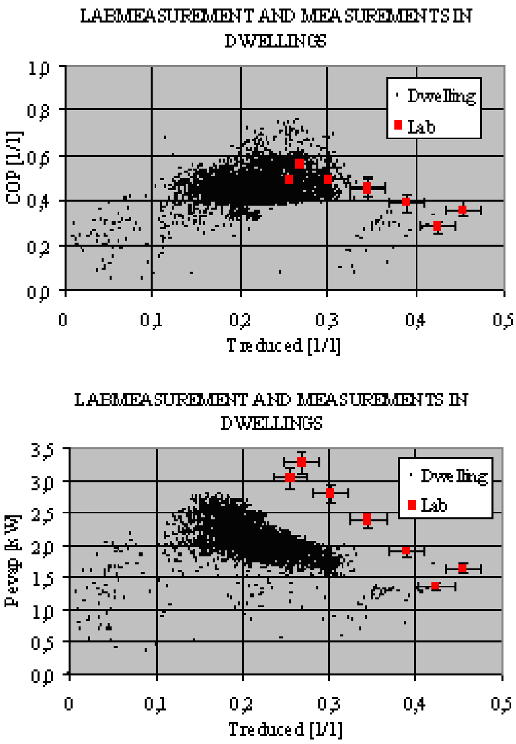

Figure 7: Measured results from the lab and dwelling

The measurements in the research dwelling demonstrate that the prototype adsorption chiller can also operate successfully under realistic operating conditions. Also, the difference in performance from measurements in the laboratory and the lab is shown.

Analysis Comparison of the measured data shows reduction in performance of the chiller under operating conditions compared to the performance under laboratory conditions. The available cooling power reduced between 25 to 30% compared to the laboratory results. The performance of the prototype chiller under operating conditions in the dwelling can be improved by the following design adjustments:

- improvement of the refrigerant valve design;
- an alternative method to measure refrigerant level in the evaporator;
- reconsider evaporator design to avoid pool boiling (vapour that rises up from the bottom to the top of the water level in the evaporator);
- reconsider material use to reduce corrosion.

If these adjustments are being incorporated in a second prototype, the expectation is that the performance will increase with 10%. Also the difference in performance between lab and practical conditions will be reduced.

Conclusion ECN successfully developed, designed, built, operated and tested a unique prototype adsorption chiller for domestic cooling applications. Lab measurements showed respectable performance of the chiller that has a very compact design. Measurements under realistic operating conditions in one of ECN's research dwellings helped to address adjustments to the design that can improve a commercial version. The adsorption chiller that is developed by ECN is ready to be commercialised.

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