DEVELOPMENT OF AN INNOVATIVE 2.5 kW WATER-SILICA GEL ADSORPTION CHILLER

Ernst-Jan Bakker, Robert de Boer, Simon Smeding, Niels Sijpheer, Michel van der Pal
Energy research Centre of the Netherlands, PO Box 1, 1755 ZG, Petten, The Netherlands
r.deboer@ecn.nl

Abstract: Besides (better) utilization of available solar heat or waste heat, and thereby reduction of fossil fuel consumption, sorption cooling offers several other advantages compared to conventional compression cooling. Such as reduction of summer peaks in the electricity grid, use of natural refrigerants, and low noise & maintenance. Sorption cooling in itself is not a new development. However, the development of small scale sorption chillers (2-20 kW) is new. This development allows sorption cooling to enter the markets for individual homes, small collective systems and small commercial applications. A second trend is gradual reduction of the driving temperatures of the sorption cycles allowing more solar and waste heat to be used. This article describes the design and performance of a new, innovative 2.5 kW adsorption chiller, developed by ECN.
This system was built and tests have been performed in a laboratory and in one of ECN's full-scale research houses.

Key Words: adsorption chiller, silica gel, prototype, performance

1 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).

Water-silica gel 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 low maintenance and installation 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 uses thermal compression, 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 quasicontinuous cooling at least two silica gel beds (reactors) are needed, operating in counter-phase. A schematic system lay-out of an adsorption chiller is shown in Figure 1.

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.

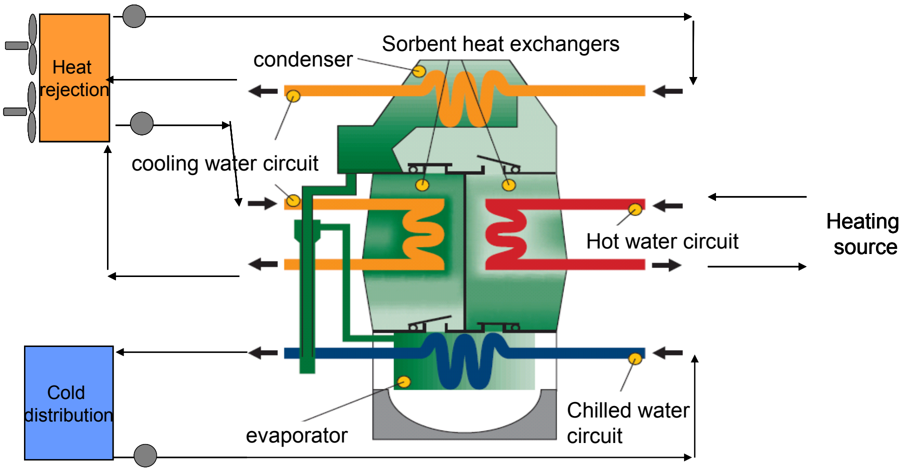

Figure 1: Schematic adsorption chiller lay-out

2 DESIGN AND CONSTRUCTION OF THE 2.5 kW ADSORPTION CHILLER

As part of the European PolySMART project (www.polysmart.org), ECN has developed a small-scale adsorption chiller using water-silica gel as working pair, which is tested and demonstrated. The starting point for this chiller is to supply sufficient cooling power (2.5 kW) for a modern single-family house. A common (challenging!) standard for household appliances is 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 carry 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 vapor 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 vapor flows from the other reactor to the condenser (desorption phase) at a higher pressure. Special check valves have been placed between these components to prevent the water vapor from flowing back. This (low pressure) process requires that the system does not contain any gases or vapors other than water vapor, 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.

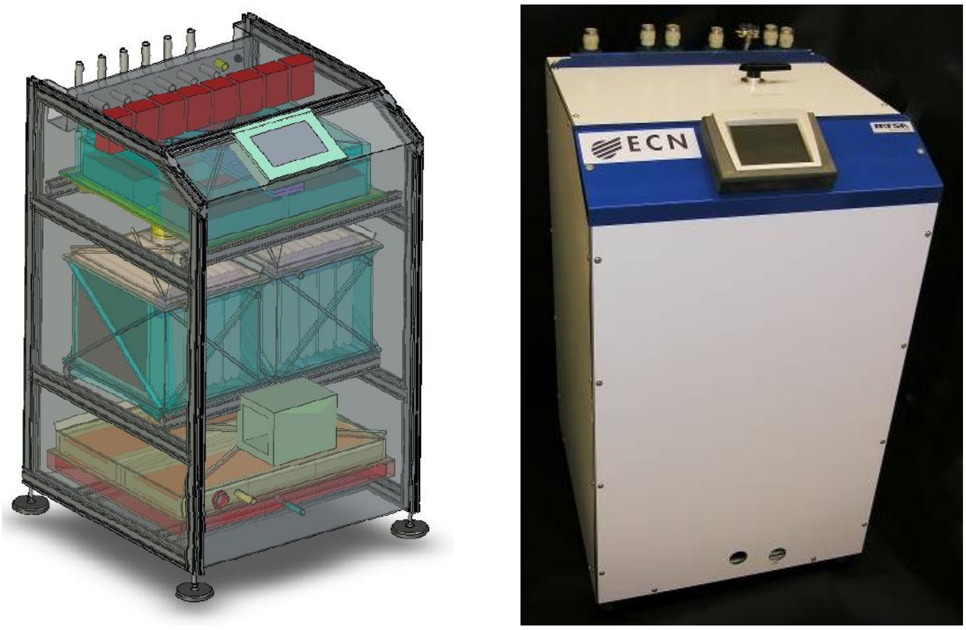

Figure 2: Design drawing and picture of the ECN 2.5 kW adsorption chiller

3 PERFORMANCE MEASUREMENTS

The performance of the chiller was first determined in the laboratory and afterwards in a micro-trigeneration setup in one of ECN's research dwellings.

3.1 Laboratory measurements

The prototype adsorption chiller has been tested in an ECN laboratory, with the facilities to control flow rates 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:

$$COP = \frac{Q_{evaporator}}{Q_{heatsource}} \quad (1)$$

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).

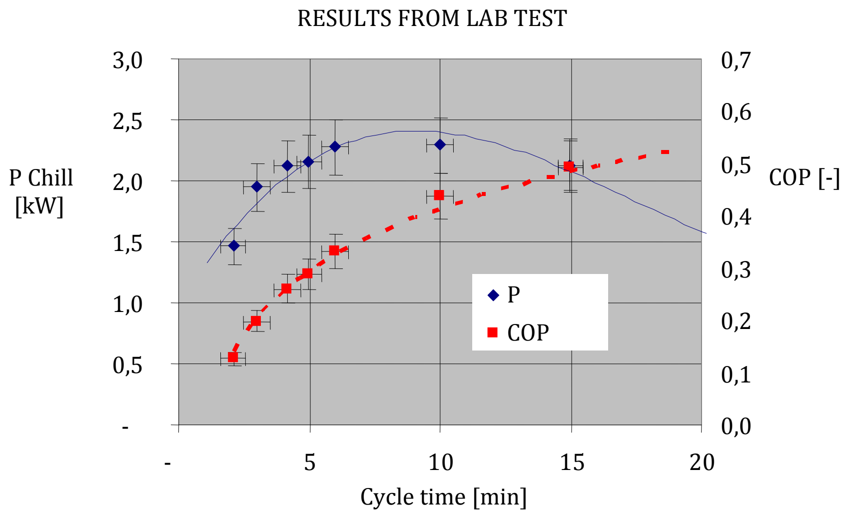

Figure 3: Influence of cycle time on the thermal performance of the adsorption chiller

Figure 4 shows the influence of the cooling water and chilled water inlet temperature on the chiller performance. The measurements were all performed with a fixed cycle time of 12 minutes. Chiller performance clearly benefits from "high chilled water temperatures" and relatively low cooling water temperatures. 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 compact machine (power density of 7 kW/m^3) at a respectable COP.

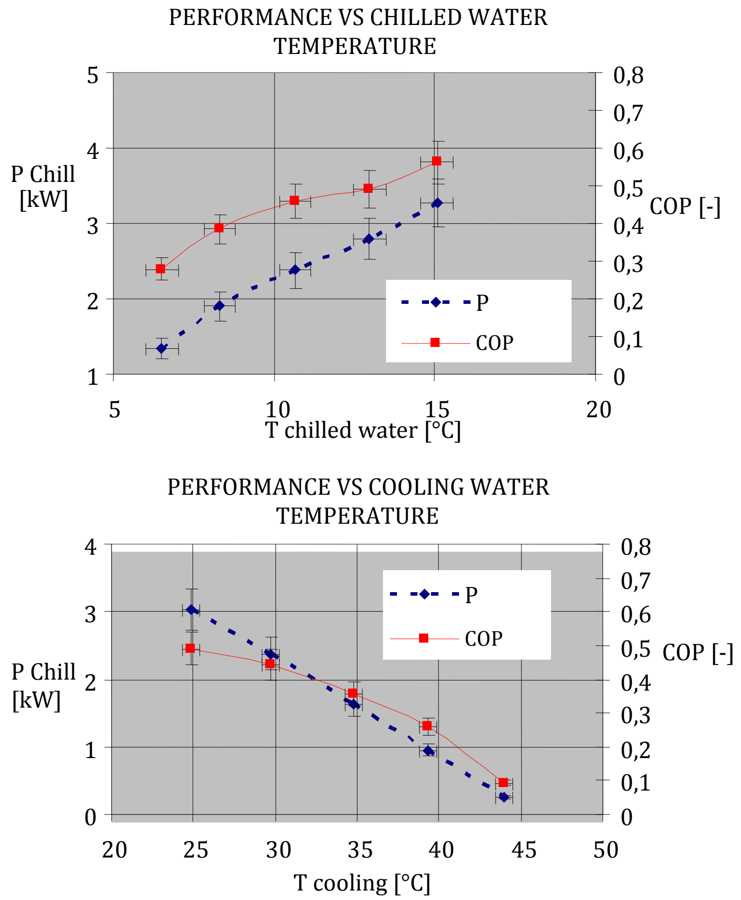

Figure 4: Influence of cooling water (below) and chilled water (upper) inlet temperature on the chiller performance

3.2 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 as 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 every 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 the 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 adsorption chiller are performed with the installation setup as shown in Figure 6.

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

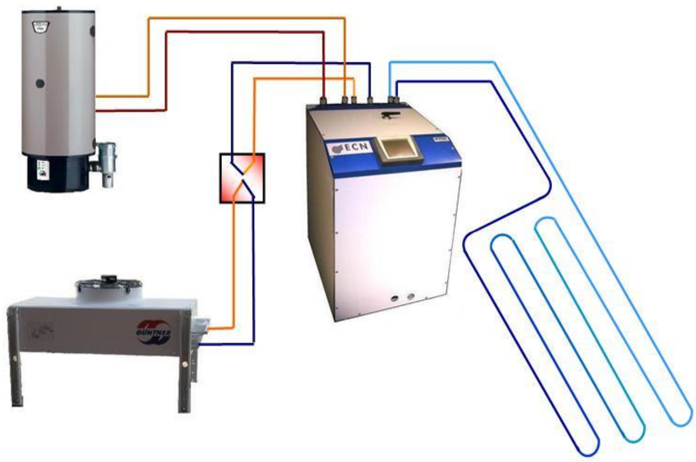

Figure 6: Installation setup of the adsorption chiller and a gas-fired boiler as heat source

In Figure 6 a gas fired boiler is used to supply the heat to the chiller. A dry cooler is positioned outside the building to reject the heat of condensation and the heat of adsorption coming from the chiller. The boiler was applied as a forerunner for the intended micro-chp system (combined heating and power), to provide the driving heat for the chiller. The installation of the micro-chp was delayed due to limited pre-commercial availability.

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 water 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:

$$T_{reduced} = \frac{T_{cooling(in)} - T_{chilledwater}}{T_{hot(in)} - T_{cooling(in)}} \quad (2)$$

The following graphs (Figure 7) 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.

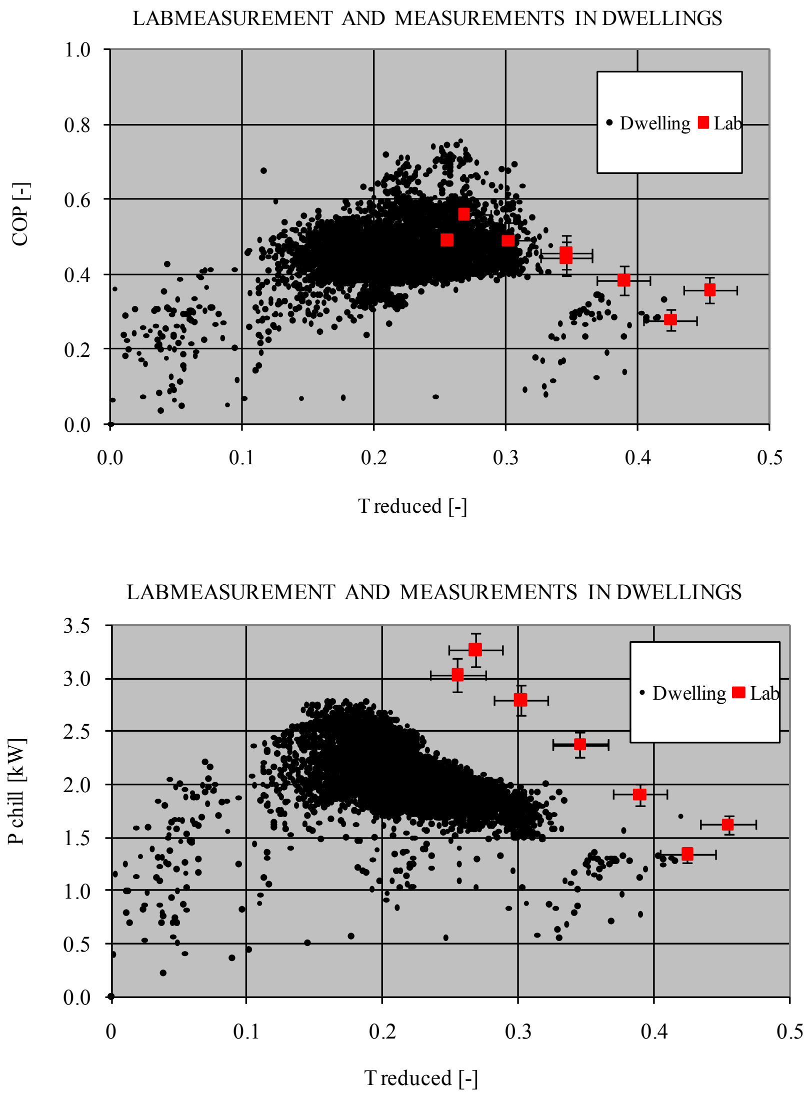

Figure 7: Comparison of the adsorption chiller performance between laboratory and research dwelling measurements

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 research dwelling is shown.

3.3 Measurement analysis

The comparison of the measured data shows reduction in performance of the chiller under operating conditions in the dwelling compared to the performance under laboratory conditions. The available cooling power was reduced by 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;
- improvement of the refrigerant liquid level control in the evaporator;
- reconsider evaporator design to avoid pool boiling;
- reconsider material use to reduce any 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.

4 CONCLUSION AND OUTLOOK

A new adsorption chiller prototype was successfully developed, designed, built, commissioned and tested in laboratory conditions and in more real life conditions in a research dwelling. The laboratory measurements indicated a nominal cooling power of 2.5 kW with a COP of 0.5, in accordance to the design targets. The thermal performance increases with higher chilled water delivery temperatures and with lower heat rejection temperatures. Measurements results under the operating conditions in one of ECN's research dwellings, showed a lower cooling power and COP in comparison to the laboratory measurements. The two sets of measurements helped to address future adjustments to the design that can improve a commercial version. The adsorption chiller that is developed by ECN is ready to be commercialized.

5 REFERENCES

Bakker, E.J., N.C. Sijpheer 2004. "Ecobuild Research: full-scale testing of innovative technologies for energy efficient houses", *Report Energy Research Centre of the Netherlands (ECN)*, Petten, The Netherlands.

Bakker, E.J., N.C. Sijpheer 2008. "Testing a prototype gas-fired residential heat pump", *Proc. 9th Int. Heat Pump Conference 2008*, Zurich, Switzerland.

Boer, R. de., E.J. Bakker 2010. "Development of a new 2.5 kW adsorption chiller for heat driven cooling", *IEA Heat pump Newsletter*, Vol. 28, 1/2010, pp. 39-42.

Boer, R. de., R.J.H. Grisel, S.F. Smeding 2010. "Waste heat driven silica gel/water adsorption cooling in trigeneration", *Applied Thermal Engineering*, Vol. 30, pp. 1039-1046.

Sijpheer N.C. et al. 2007. "Floor cooling and air-cooling, the effects on thermal comfort of different cooling systems", *Report Energy Research Centre of the Netherlands (ECN)*, Petten, The Netherlands.

Part of

Thermally driven heat pumps for heating and cooling. – Ed.: Annett Kühn – Berlin: Universitätsverlag der TU Berlin, 2013

ISBN 978-3-7983-2686-6 (print)
ISBN 978-3-7983-2596-8 (online)

urn:nbn:de:kobv:83-opus4-39458
[http://nbn-resolving.de/urn:nbn:de:kobv:83-opus4-39458]