Cooling power determination by measuring the adsorbed vapor mass variations: comparison of mass adsorption cooling power correlation and external fluid loop power measurement

Paul Gantenbein*, Xavier Daguenet-Frick, Fabian Bont, Patrick Persdorf and Daniel Notter

[1]Institute of Solar Technology SPF HSR University of Applied Sciences Rapperswil, Switzerland

*Paul Gantenbein
Phone : +41552224811, Fax : +41552224844, E-mail : paul.gantenbein@spf.ch

ABSTRACT

The cooling power of a closed solid sorbent – vapor/liquid sorbate system is depending on the thermo-physical properties of the material combination sorbent – sorbate and of the external heat sources and sinks. Beside the afore mentioned conditions, the geometrical structure of the sorbent - vapor flow configuration and the heat transfer in both the sorbent arrangement to a heat exchanger and in the liquid sorbate container are dominating power determining design requirements. A single vacuum chamber adsorption-desorption facility was designed and setup. The water vapor uptake in 7.5 kg of spherical shaped Fuji RD Silica Gel particles was measured in the adsorption-desorption fixed-bed hanging module by means of a beam balance. Considering the heat of evaporation, the cooling power was calculated and reached 1.5 kW or higher values. The comparison with the external fluid loop power – the evaporator power – showed good agreement. From another side, comparing the vapor mass uptake in this adsorption-desorption module with data from a single particle experiment shows a relative lower time resolved mass increase in the fixed bed. On the other hand a far longer possible adsorption (and desorption) cycle time – with a decreasing cooling power – is possible. This behavior can be explained by a pressure drop in the vapor flowing through the fixed bed and thus a longer time until saturation of all the sorbent particles – in the center of the module. With this setup the adsorption-desorption module – and the evaporator-condenser unit – can be characterized and optimized.

1. INTRODUCTION

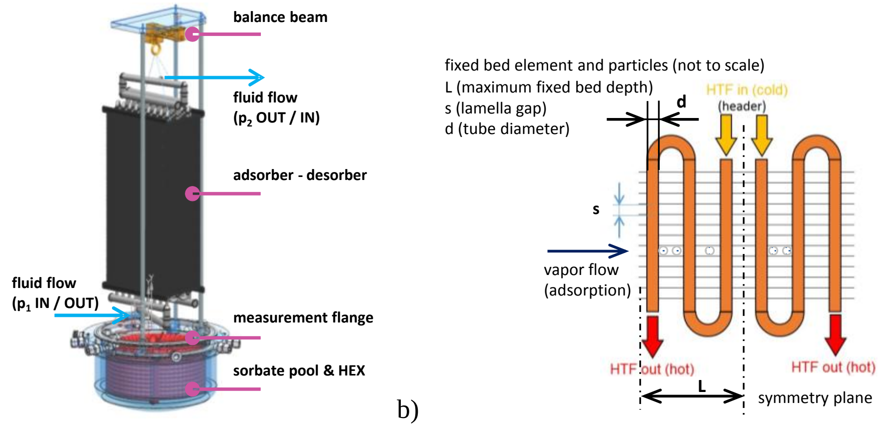
For (quasi-) continuous operating, an adsorption cooling and heating machine in general follows a four chambers concept, consisting of two adsorption-desorption (A-D) modules, an evaporator (E) and a condenser (C) [1]. The condensate is feed back to the evaporator via a pressure reduction device. Recent development converged in double single chamber machines (FAHRENHEIT AG, InvenSor GmbH), in which one chamber contains the combined A-D unit and the E-C unit. For quasi-continuous operation two such chamber are needed.

2. EXPERIMENTAL

Figure 1a shows a single vacuum chamber containing an A-D and an E-C. To measure the amount of water vapor adsorbed in function of time the key element in this set-up is the beam balance with the suspended A-D unit [2]. The mass resolution of the beam balance is lower than 1 gram. To reach this accuracy in the setup for each adsorption-desorption temperature pair an elaborate calibration procedure has to be performed. The geometrical design of the A-D unit is one of the key tasks in the development of an adsorption machine. In order to deal with the particle size as well as the lamella spacing, simulations of an A-D "unit cell" were done. According to this first result, it was decided to work with two lamella pitches and one particles size distribution: 3.0 mm and 5.0 mm lamella pitch and particle size 0.85 mm< d <1.7 mm beads. In this approach we designed a cubic shaped all-aluminum tube-lamella heat exchanger. A lamella thickness of 0.18 mm was defined. The cooling and heating fluid flow direction - inlet and outlet - can be inverted for efficiency measurement reasons. Figure 1b shows a drawing of the A-D with a sketch of the vapor flow (blue arrow) and of the heat transfer fluid (HTF) flow (yellow and red arrows).

3. RESULTS AND DISCUSSION

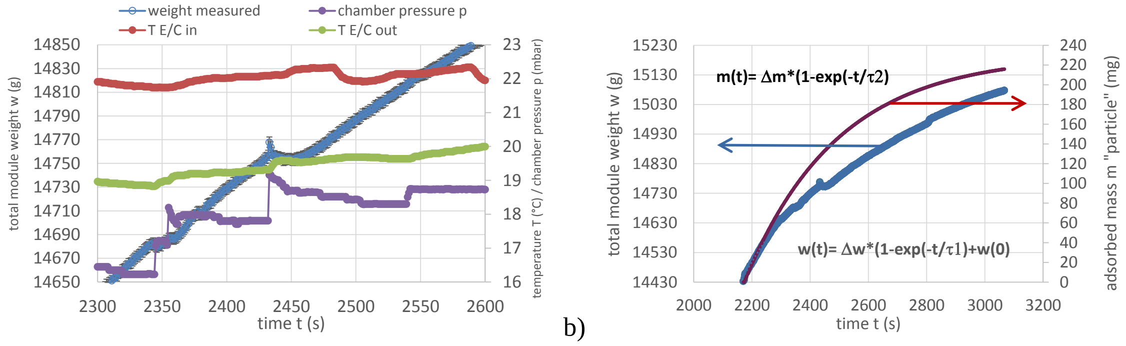
In figure 2a a detail of the measurement data of an adsorption – desorption cycle series is shown. The temperatures in the external loop was for the adsorption 40 °C and for desorption 95 °C and the cycle length 1200 s. In the external loop a maximum cooling power of 1.5 kW was measured. A power comparison with the adsorbed water vapor mass per time (dm/dt) multiplied by the heat of evaporation (Δh_v) shows a good agreement – except in the short time steps of occurring spikes in the mass curve (total module weight w).



a) b)

Figure 1: Experimental single vacuum chamber for adsorption-desorption (A-D) unit characterization. A combined fluid feed-through and sensor flange and vacuum feed-through flange for simpler handling is used. a) left: CAD drawing – tubing not complete, and in the sorbate pool an E-C unit is immersed. b) right: Schematic visualization of the vapor flow into the fixed bed of sorbent particles. Drawing of a side view of lamellas channels of the lamella tube heat and mass exchanger. The fluid tubes (external fluid loop) are shown in orange.

During the design process of an adsorption – desorption module, geometrical structure optimization is possible and the measured mass uptake in function of time will be used as a reference. For this optimization – and even a scale-up to higher power – the comparison with the single particle experiment is important. Figure 2b) shows the "total module weight" in function of time of the data in figure 2a) and the "adsorbed mass m" data of the single particle experiment [3].



a) b)

Figure 2: Weight w, temperatures T and pressure p measurement results in function of time t. a) left: A cooling power of 1.5 kW is obtained in the external fluid loop (T E/C in, T E/C out). The pressure curve shows steps of more than +1 mbar – and this influences the total weight curve (spike at t=2435s). b) right: Comparison of adsorbed mass m in the "particle" experiment [3] and the total module weight w in the single vacuum chamber experiment.

4. CONCLUSIONS

- A closed vacuum tight single chamber adsorption-desorption unit was designed and used in operation.
- The sorbate mass measurement calibration in vacuum was tested and applied in the experiments.
- The adsorbed vapor mass correlates to the power measurement in the external heat transfer fluid loop.
- The experimental set-up can be used for an adsorption-desorption module characterization in the power range of up to 1.5 kW cooling power and an optimization process can be performed.

ACKNOWLEDGEMENT

The funding by the Swiss National Science Foundation SNSF in the frame of the National Research Program NRP 70 and by the HSR University of Applied Sciences Rapperswil is highly acknowledged.

REFERENCES

[1] Ruch, P., Ammann, J., Materials and System design for adsorption heat pumps. 12th International Conference on the Fundamentals of Adsorption, Friedrichshafen Germany, June 3, 2016.
[2] Gantenbein, P., 2018, Fundamental geometrical system structure limitations in a closed adsorption heat storage system, EUROSUN Conference, Lisbon, 2008.
[3] Ammann, J., Ruch P., private communication, 2016.