Adsorption heat pump upscaling from 1 kW to 10 kW of cooling power: experimental based modelling.

Xavier Daguenet-Frick*, Yoann Moullet, Paul Gantenbein, Patrick Persdorf and Daniel Notter

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

*Xavier Daguenet-Frick
Phone : +41552224164, Fax : +41552224844, E-mail : xavier.daguenet-frick@spf.ch

ABSTRACT

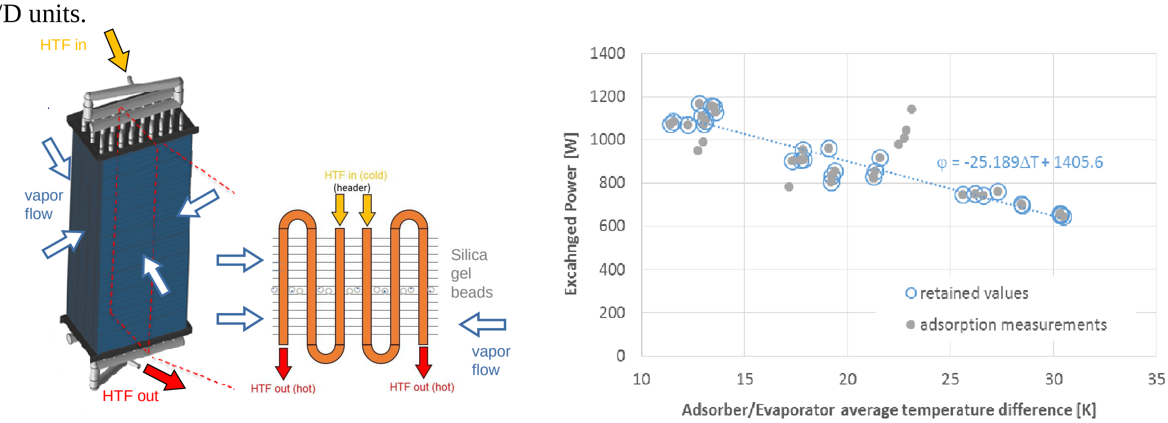
The cooling power of a closed adsorption system is depending on the thermo-physical properties of the material combination sorbent – sorbate. The temperature levels and the mass flow rate of the external heat sources and sinks has to be adapted. Based on experimental results of a 1 kW average cooling power adsorption-desorption test setup using silica gel beads placed in a lamella-tube all-aluminum heat exchanger, a scale-up to 10 kW is proposed and planned. For the steady state modelling, a linear dependence of the exchanged heat in function of the average temperature differences (adsorber minus evaporator temperature and desorber minus condenser temperature) is assumed. Based on this modelling a parametrical study is carried out to optimize the 10 kW prototype. Two different adsorber/desorber geometries as well as two hydraulic designs (in the medium temperature fluid loop, condenser and adsorber connected either in parallel or in serial) are assessed.

1. INTRODUCTION

The subject of solid adsorption heat pump systems driven by waste heat has gain specific attention. Major reasons are because of the heat pumps run by electric energy of fossil fuel driven power stations and their global warming potential though CO_2 emissions. Waste heat, as an alternative, originates of different industrial processes or even out of CPU's in data centers and thus - if the temperature level is high enough - can be used for the desorption of the sorbate. The output power of the adsorption-desorption module is strongly depending on the dynamic behavior in the coupled heat and mass transfer in this unit. The challenge in the design of an adsorption heat pump and/or cooling machine is - like in all thermo-physical processes - the scale up from the Watt (W) power range to the several kW power range. In the following sections we present experimental and simulation results for the design of a 10 kW adsorption cooling machine using Fuji Silica Gel RD-Type sorbent in a fixed bed arrangement and water sorbate.

2. EXPERIMENTAL RESULTS

Experimental measurements were achieved on a double jacket single vacuum chamber facility containing an Adsorber/Desorber (A/D) and an Evaporator/Condenser (E/C) [1]. For the A/D geometrical design a cubic shaped 6.6 m^2 lamella-tube all-aluminum adsorption-desorption module was used (Figure 1a)). It has a surface to volume ratio of 0.54 m^2/l and vapor flow towards the four sides of the cube is considered. The A/D consists of 6 tube columns and 9 of these in parallel. Measurements were achieved with two lamella pitch (s = 3 and 5 mm), a lamella thickness of 0.18 mm and a particle beads size d of 0.85 mm < d < 1.7 mm. The spherical shaped Fuji RD Silica Gel particles filling amounts to 7.5 kg resp. 8.4 kg for the 3 resp. 5 mm lamella spacing A/D units.



a) b)

Figure 1: single chamber 1 kW cooling power setup: a) A/D module installed in the vacuum chamber with heat transfer fluid (HTF) and vapor flow indication and measurement results b): aggregation of time-averaged power measurements φ in function of average temperature difference ΔT A/E for the adsorption process.

Measurements were achieved with external fluid loop temperatures in the range of 30 to 50 °C for the adsorption process and between 70 and 95 °C for the desorption process, while cycle length from 900s up to 3600 s were tried out. Peak cooling power reached values up to 2.2 kW. Figure 1 b) shows power measurement results for the evaporation/adsorption (E/A) process in function of the temperature difference between average heat transfer fluid (HTF) temperature in the adsorber and in the condenser. The data shown in this figure are time averaged values from cycles with a length of 900 s. Similar data post processing was carried out for the desorbtion/condensation (D/C) process. To fulfil the scale up task from the lab setup (1 kW) to 1.6 kW, a linear increase of the A/D length is defined - keeping its cubic structure -. For the further upscaling (reaching a nominal power of 10 kW for the prototype), a hydraulic parallel set of 6 such A/D modules is planned.

3. MODELLING & RESULTS

Temperature levels as well as volume flow rate of the three external fluid loop are defining the 10 kW adsorption heat pump boundary conditions. Based on the linear approximation of the power in function of the temperature differences for both E/A and D/C processes (see paragraph above), a numerical model was set up. Calculations are done in steady state and an ideal efficiency of the machine is assumed (i.e. the power transferred during E/A and D/C processes are identical). Based on the boundary conditions, the heat transfer are calculated by the model for the E/A process and defines the power exchanged for the D/C process as well as the output HTF temperatures. Looping stops as soon as no significant power variation are noticed. For the medium temperature source HTF loop two configurations are investigated: adsorber module hydraulically connected either in serial or in parallel with the condenser unit. For the HTF loops, pressure drop as well as pumping power are calculated. Figure 2 shows some results of a parametrical study carried out on the external fluid loops. According to Figure 2a), volume flow rate above 2.4 m^3/h will dramatically increase the pumping power with only a limited positive influence on the heat exchanged. At this volume flow rate, a serial connection (--) of the A and C units will enhance the heat exchanged by 3% but also requires 39% higher pumping power. Figure 2b) shows that using 3 mm lamella spacing is a good way to increase the exchanged power (+ 6% in comparison to the 5 mm spacing) and that a theoretical minimal pumping power is reached for a distribution ratio of 0.56.

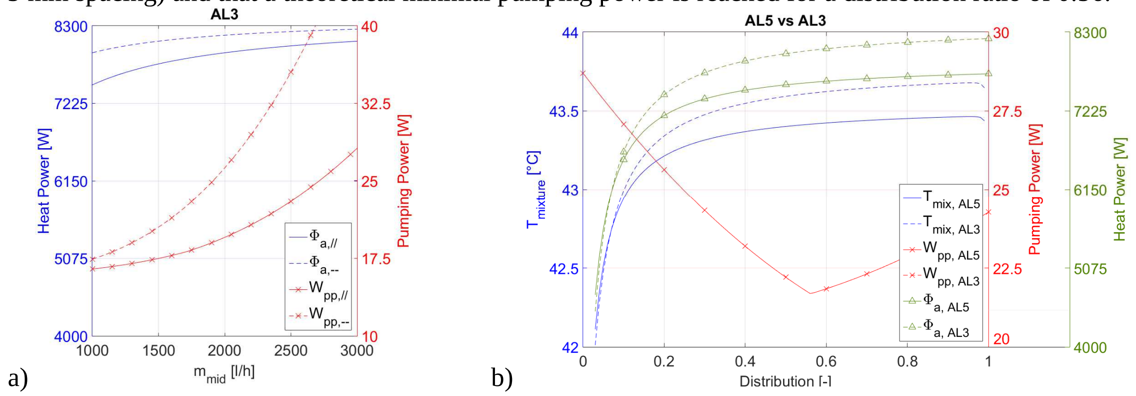


Figure 2: Simulation results: a) heat exchanged by the adsorber (Φ_a) and pumping power (W_{pp}) depending on the mid temperature HTF loop volume flow rate (m_{mid}) for a 3 mm lamella spacing. b) power exchanged by the adsorber, pumping power and temperature at the outlet of the mid temperature HTF loop ($T_{mixture}$) depending on the distribution factor for a 3 and 5 mm lamella spacing - A and C units connected in parallel (//) -.

4. CONCLUSIONS

- Measurements with different adsorption-desorption modules were performed on a single chamber 1 kW cooling power unit and the post-processing of the measurements achieved.
- A model was established to assess the heat pump response depending on the boundary conditions imposed. This model includes pumping power (pressure drop) calculations in the external fluid loop.
- According to the results, a parallel hydraulic connection of the adsorption unit and condenser unit as well as a lamella spacing of 3 mm should be preferred. Optimal HTF mass flow rate was also determinate.

ACKNOWLEDGEMENT

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REFERENCES

[1] Gantenbein, P. et al., Cooling power determination by measuring the adsorbed vapor mass variations, International Sorption Heat Pump Conference 2017, Tokyo Japan, August 7-10, 2017 (submitted).