CNR – ITAE

ISTITUTO DI TECNOLOGIE AVANZATE PER L'ENERGIA

"NICOLA GIORDANO"

SHORT TERM MOBILITY PROGRAM 2013

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"Test of components for in adsorption cooling applications"

Host institution

Fraunhofer, Instituts für Solare Energie systeme, ISE

Freiburg (Germany)

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1 INTRODUTION

Technologies and systems based on adsorption heat transformation (AHT) processes represent nowadays a fascinating option to meet the growing worldwide demand of space heating and air conditioning [1-4]. Nevertheless still considerable efforts must be made in order to enhance the performance aiming at competing with commonly used electrical systems as well as with absorption machines. For this purpose, an intelligent design of an adsorption machine should be firstly focused on a proper design of the adsorber (adsorbent material integrated into an heat exchanger) by a comprehensive analysis that takes into account both thermodynamic and dynamic aspects [5].
The development of new adsorber (AdHEX) concepts requires specific experimental activities aimed to assess the heat and mass transfer properties of the combined system “sorbent material & heat exchanger” as well as to measure dynamically its global performance under typical operating conditions.
The aim of the activity at ISE was to measure the kinetic performance of AdHEXs under operating conditions typical for air conditioning. In particular two AdHEXs have been realized embedding SAPO 34 into a fin-tube heat exchanger. The first AdHEX have been obtained filling the HEX with grains of the selected sorbent while the second HEX was coated with a thin layer of SAPO 34. The activity will be extended by the test of the same AdHEX by a lab scale adsorption chiller available at ITAE labs in order to measure the overall performance in terms of cooling power density and COP. The synergy between the two testing set up will allow to reach a complete knowledge of the performance of the tested adsorbers.

2 EXPERIMENTAL

2.1 The tested adsorbers

The testing activity was carried out employing a state-of-art fin-tube heat exchanger whose main parameters are given in table 1. The tubes are made of copper, the fins from aluminum.

Figure 1 Blank HEX and tested AdHEX

Dimensions (finned part)	256 mm x 173mm x 50 mm
Volume (finned part)	2.2 dm³
HEX area	2.59 m²
Number of tubes	16
Inner diameter of tubes	9 mm
Weight (metal+net+fittings)	1.737 kg

Table 1 Key figures of the exchanger

Table 2 reports the main parameters of the two AdHEXs realized while figure 2 shows the granular AdHEX.

	Coated AdHEX (WT-K18)	**Granular AdHEX**
Adsorbent	SAPO 34	SAPO 34
Grain size		250-400 µm
Adsorbent dry mass	120 g	977 g
Total mass	1257 g	2117 g

Table 2 Main parameters of the two AdHEXs realized

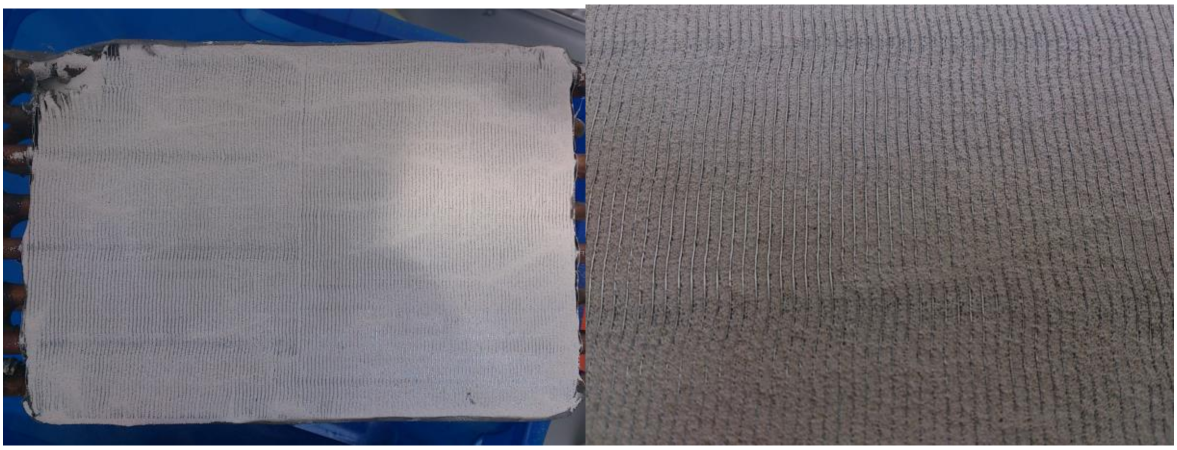


Figure 2 View of the granular AdHEX

2.2 ISE Testing set-up

The investigation of the kinetic behavior of water uptake for whole AdHEXs has been done with the set-up shown in Figure 3. The core part of the test rig for small adsorbers is a vacuum chamber with a volume of around 0.22 m³. In order to avoid heat losses to the ambient, the chamber is thermally insulated (not shown in Figure 2). The amount of water adsorbed or desorbed is measured by weighing the AdHEX inside this chamber. Therefore, the adsorber is attached to a balance with electromagnetic force compensation with a weighing capacity of 8200 g and an accuracy of ± 0.01 g. (WZA8202, Sartorius).
The connection of the AdHEX to the hydraulic system is done via flexible corrugated tubes which can be done as only the difference in weight and not the total mass of the adsorber is needed.
Additionally, an energy balance of the AdHEX as well as of the E/C-HEX is carried out. The temperature is measured at the fluid inlet (Tin) and the fluid outlet (Tout) of the heat exchangers with the help of Pt100 temperature sensors with an accuracy of 0.02 K. Flow sensors determine the volume flow rate in the hydraulic cycles which have an error of 0.2% of the measured value.
A flooded heat exchanger unit (E/C-HEX) is situated below the chamber. It supplies water vapour for adsorption and can serve as condenser during desorption. Two hydraulic cycles with temperature levels low (-10°C to 100°C, connected to the E/C-HEX) and high (-10°C to 200°C, connected to the AdHEX)) are used to set the temperature for evaporation, condensation, adsorption and desorption, respectively. Water is used as heat transfer fluid for measurements below 100°C. Labview® is used as software for data acquisition.

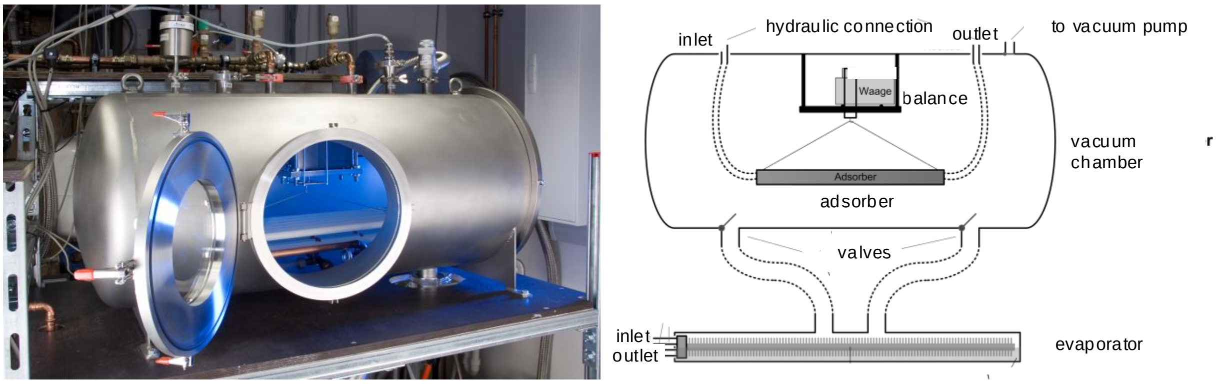


Figure 3 Vacuum chamber of set-up for measurement of kinetic behavior

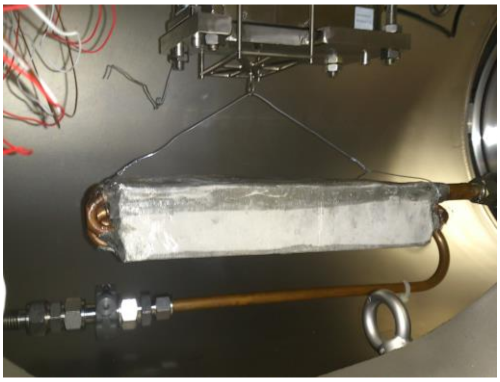


Figure 4 Granular AdHEX placed into the ISE kinetic set-up

2.3 Performance evaluation methodology

The amount of water that is adsorbed or desorbed is determined by weighing the adsorber unit inside the vacuum chamber. Therefore, the adsorber is attached to a balance with electromagnetic force compensation with a weighing capacity of 8200 g and an accuracy of ± 0.01 g. (WZA8202, Sartorius).

The connection of the AdHEX to the hydraulic system is done via flexible corrugated tubes which can be done as only the difference in weight and not the total mass of the adsorber is needed. The uptake can be determined with an uncertainty of around 5%. Continuous cycling of the AdHEX with several ad- and desorption periods in a row can't be characterized using the signal of the balance with sufficient accuracy.

Additionally, an energy balance of the AdHEX as well as of the E/C-HEX is carried out. The temperature is measured at the fluid inlet (T_{in}) and the fluid outlet (T_{out}) of the heat exchangers with the help of Pt100 temperature sensors with an accuracy of 0.02 K. Flow sensors determine the volume flow rate in the hydraulic cycles which have an error of 0.2% of the measured value.

The focus of the characterization lies on the thorough investigation of the adsorption phase. There is no fixed cycle time; the experiments are carried out until no uptake is observed for at least one hour, thus reaching equilibrium state.

After the desorption phase, the AdHEX is cooled down to adsorption temperature with the valve to the condenser closed until pressure and temperature in the vacuum chamber are constant and no water uptake is observed. The volume of the vacuum chamber in which the AdHEX is placed has a volume of around 220 liters. Hence, the sorbent adsorbs water from the vapour volume (non isosteric cooling) and the pressure inside the chamber decreases. If desorption has been carried out against the condenser, the loading at the beginning of adsorption is not the value that one would expect from equilibrium data for the temperature and pressure during desorption period. As the decrease in pressure in the chamber is recorded, the amount of water adsorbed during the cooling phase and thus the loading at the beginning of adsorption can be calculated. For the measurements presented here, this loading equals a condenser temperature during desorption of 30°C (T_{Des} = 95°C) and 25°C (T_{Des} = 80°C), respectively instead of 20°C which is the actual temperature of the condenser.

The measured uptake of water (Δm_{AdHEX}) is used to calculate the cooling power delivered in the evaporator for each time step Δt_i.

$$\dot{Q}_{Ev,i} = \frac{Q_{Ev}(\Delta t_i)}{\Delta t_i} = \frac{\Delta m_{AdHex}(\Delta t_i) \cdot \Delta h_{lv}(T_{Ev})}{\Delta t_i} \quad 1)$$

The sum over all time steps of the adsorption phase gives the total amount of cooling energy produced:

$$Q_{Ev,mean} = \Delta h_{lv}(T_{Ev}) \cdot (m_{AdHEX}(t_D) - m_{AdHEX}(t_A)) \quad 2)$$

with t_D and t_A indicating the start and end of the adsorption phase, respectively.

As the water uptake is detected almost instantaneously by the balance, the very fast changes in the beginning of adsorption can be investigated in detail – similar to the characterization of small samples in the kinetic test apparatus.

2.4 Testing conditions

The tests were carried out at three different condensation temperatures (30-35-40°C) while the thermal levels of the heating source and the evaporation temperature were kept constant at 90°C and 10°C respectively. The test conditions are reported in the following table.

Desorption temperature	*95 °C*	
Desorption against	*vacuum pump*	*Vapour dosing*
Adsorption temperature (T_{Ads})	*30°C-35°C-40°C*	
Evaporation temperature (T_{Ev})	*10°C*	
Condensing temperature (T_{Cond})	*30°C-35°C-40°C*	
Volume flow (AdHEX)	*2,27 l/min*	

Table 3 Tested operating conditions

2.5 Results

The performance of the two adsorbers were calculated in terms of characteristic time (time to reach a specific percentage of the final adsorption) and specific cooling power. In particular, the specific cooling power was referred to the volume of the AdHEX as well as to its mass.

Figure 5 shows the characteristic time at 80% and 90% as function of the condensation temperature both for the granular and coated adsorber. The characteristic time 90% increases from 86 to 160 s going from 30°C to 40°C for the coated adsorber while for the granular one from 1071 to 1348 s. The figure shows clearly how the increasing of the condensation temperature influences the sorption kinetics. Similar behaviours were found for t80%.

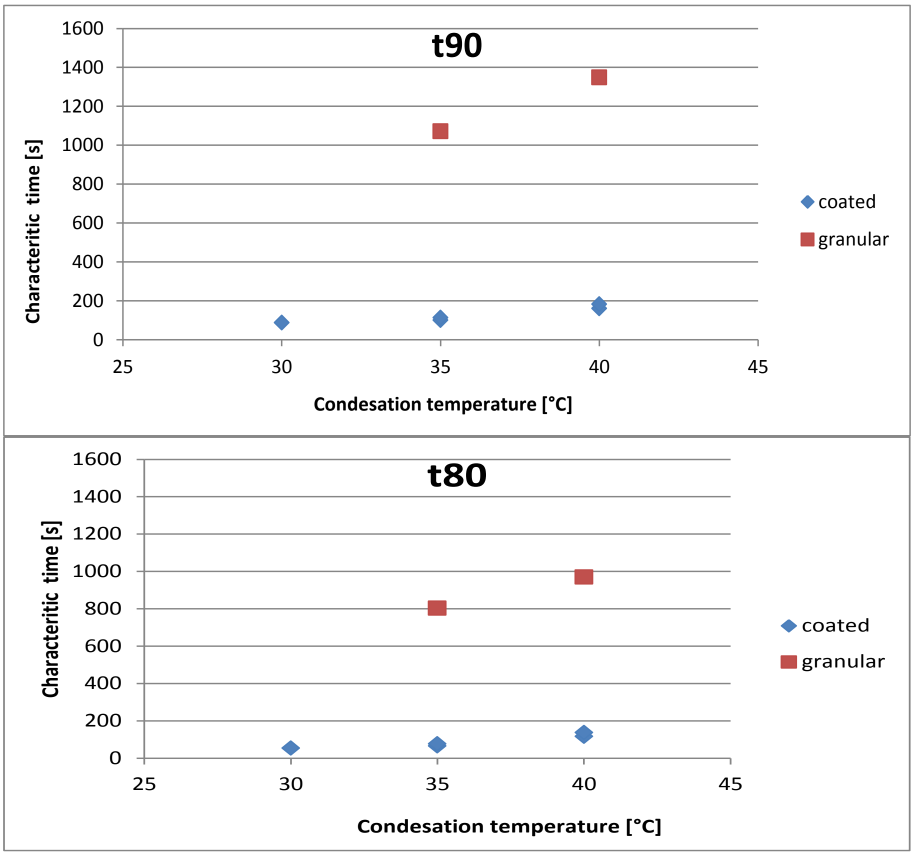


Figure 5 Characteristic time at 80% and 90% of the final adsorption as function of the condensation temperature

Figure 6 depicts the water uptake measured at t90% and t80% for different condensation temperatures.

As expected, the less heat and mass transfer resistances of the thin coated layer allow to reach an higher value of the uptake ranging from 21 to 24 %. For the granular adsorber the uptake varies from 18 to16%.

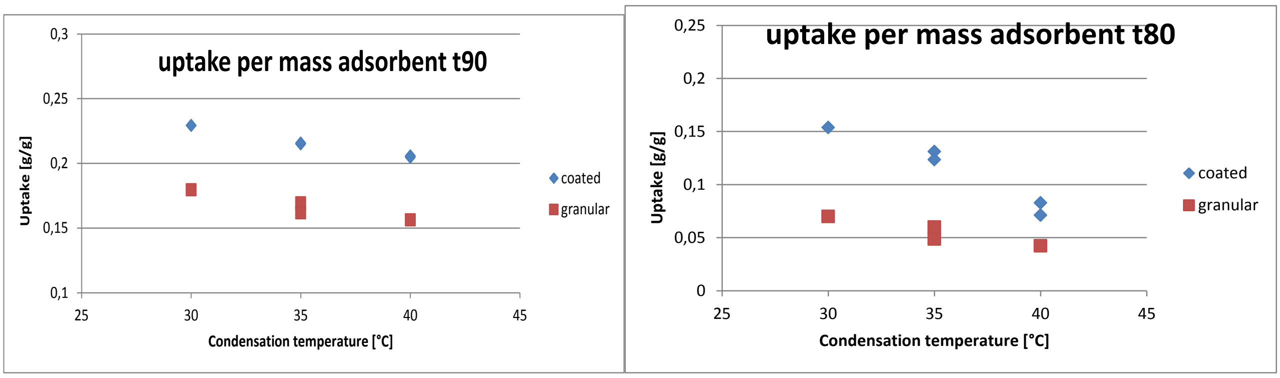


Figure 6 Water uptake at 80% and 90% as function of the condensation temperature

Figure 7 shows the specific cooling power calculated, at t90% and t80% for different condensation temperatures, taking into account the overall volume of the AdHEX. At t90%, the coated adsorber performs better and the specific cooling power ranges from 168 to 345 W/l while for the granular adsorber from 123-165 W/l. The best performance are reached at t80% where the coated adsorber performs better and the specific cooling power ranges from 123 to 423 W/l while for the granular adsorber from 50-100 W/l.

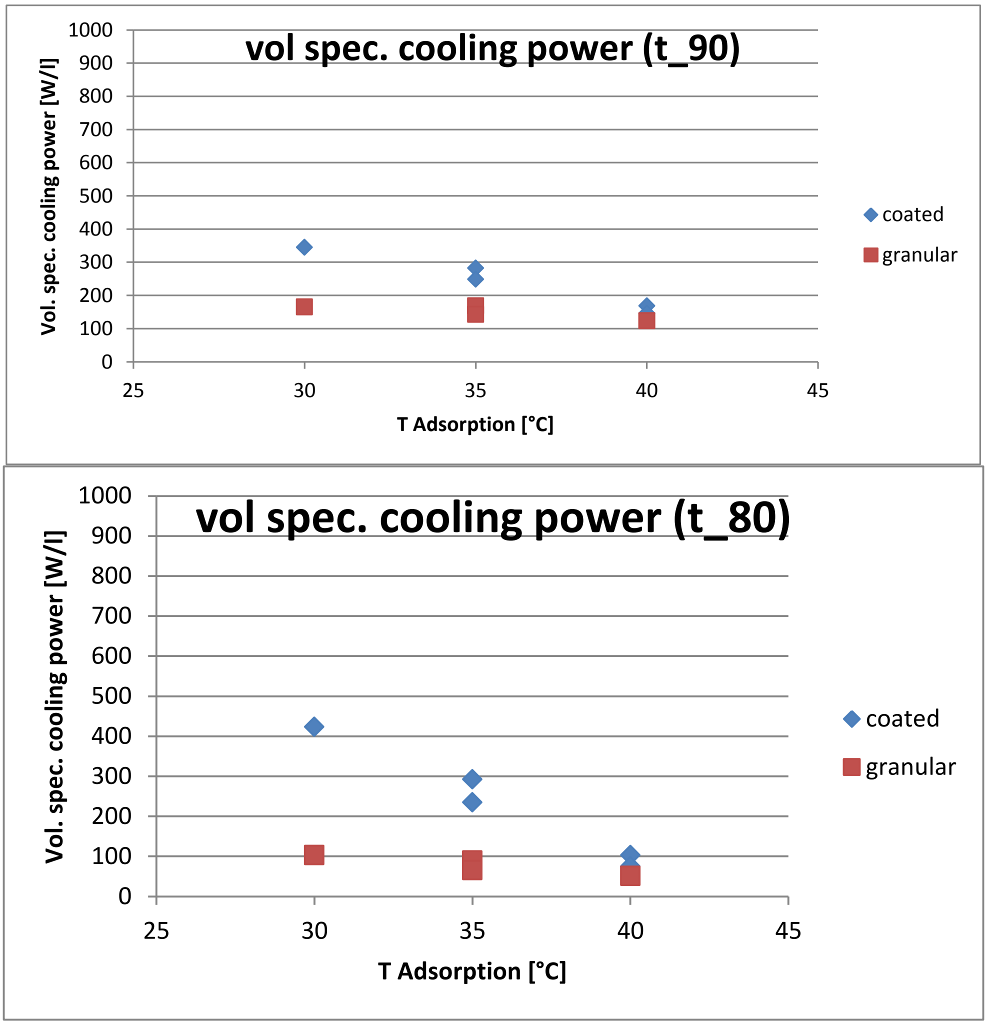
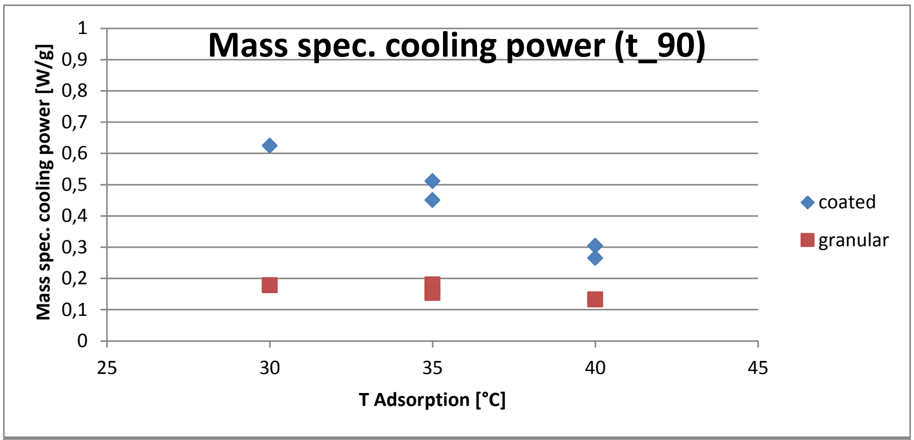


Figure 7 Volumetric specific cooling power at 80% and 90% as function of the condensation temperature

Similar behavior have been observed for the mass specific cooling power showed in Figure 8. The specific cooling power of the coated ADHEX ranges from 0,3 to 0,62 W/g and from 0,19 to 0,76W/g at t80%. Lower results were obtained for the granular ADHEX.



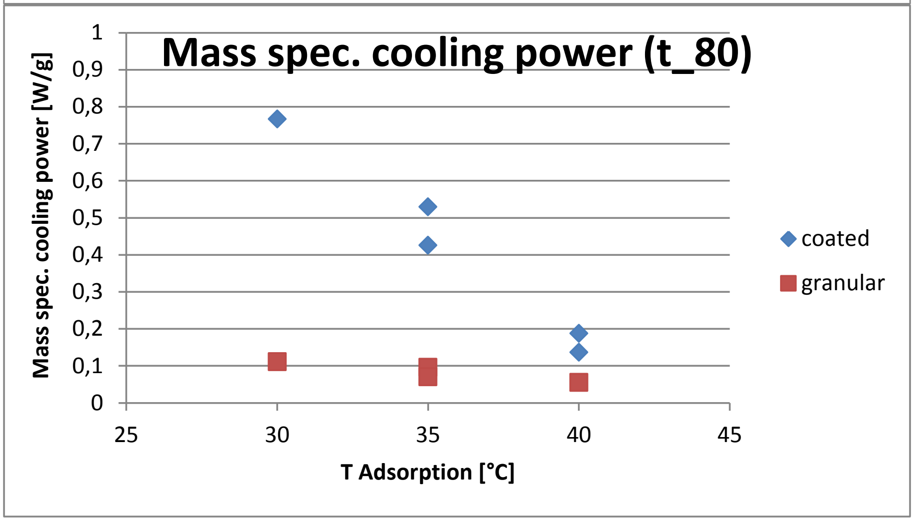


Figure 8 Mass specific cooling power at 80% and 90% as function of the condensation temperature

3 CONCLUSIONS

The activity carried out at ISE allowed us to measure the kinetic performance of granular and coated ADHEX. The results showed that the coated solution allow a good increasing in power density that is one of the main goals of the research activities on adsorption cooling systems.
The work will be extended by the test of the same granular AdHEX by a lab scale adsorption chiller available at CNR-ITAE. The synergy between the kinetic measurements (ISE) and the test under real operating conditions (ITAE) will produce a complete map of the performance of the adsorber.

4 REFERENCES

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