

REPORT
on research activity of Dr. L. Gordeeva
during her visit in ITAE-CNR on June 14 – 23, 2006
in frame of short mobility grant.

Adsorptive cycles based on methanol as a working media are considered promising for air conditioning driven by low temperature heat. Unlike water vapour, methanol presents low freezing temperature and higher operating pressure. The main drawback of methanol as working media is relatively low evaporation enthalpy of methanol (35 kJ/mol), limiting the efficiency of cooling cycle. In order to overcome it new adsorbents with advanced sorption ability under conditions of typical cooling cycles are required. This study is aimed on developing of composites “salt in porous matrix” as methanol adsorbents for adsorption air conditioning.

Research activity of Dr. L. Gordeeva was focused on the cycling of the lab-scale adsorption cooling unit using the composite “LiCl in silica gel pores” and methanol as working pair under conditions of typical air conditioning cycle. This study continued the investigations of the composite methanol sorbents carried out in period of 2003-2004 in frame of bilateral CNR – RAS cooperation and CNR-NATO grant.

1. Experimental.

The cycle tests of composite sorbent LiCl(17.3 wt.%)/SiO₂ was carried out with lab-scale one-bed adsorption cooling unit, which consisted of an evaporator, a condenser and an adsorber. The adsorbent bed was shaped as loose particles of 250-400 mm diameter applied to the surface of heat exchanger. The amount of the adsorbent was $m_{ads}=0.62$ kg. Water and glycol were used as heat transfer liquids in the evaporator/condenser and adsorber respectively. Temperatures of inlet and outlet heat transfer liquids as well the temperature inside evaporator, condenser and adsorbent were measured during the tests with thermocouple. The pressure inside adsorber, evaporator and condenser was measured with Edwards Barocell pressure sensors.

Operating conditions of the cycles were determined by following parameters: the minimum temperature of adsorbent during adsorption stage T_{ads} , the condenser temperature T_{cond} , the evaporator temperature T_{ev} , the maximum temperature of adsorbent during desorption stage T_{des} , the temperatures of boiler T_{boiler} and chiller $T_{chiller}$. During the testing we varied the parameters T_{des} , T_{boiler} and $T_{chiller}$. Other parameters were fixed over all tests: $T_{ads} = T_{cond} = 30^{\circ}\text{C}$, $T_{ev} = 10^{\circ}\text{C}$.

Typical experimental run was as follows. The unit was pumped until the pressure of ??? mbar. The adsorber filled with adsorbent, was connected with evaporator and methanol was sorbed. Then the adsorber was disconnected and heated until the methanol pressure over the adsorbent became equal to the pressure inside condenser. Then the adsorber was connected with condenser and heated until the temperature of adsorbent reached T_{des} . During this stage methanol was desorbed from the adsorbent and condensed in the condenser. Then the adsorber was disconnected and cooled till the pressure inside the adsorber and the evaporator became equal. The adsorber was again connected with evaporator and cooled down to the temperature T_{ads} . During this stage the methanol evaporated and adsorbed on the adsorbent. Then the cycle was repeated.

The main parameters, which characterise the process efficiency, namely coefficient of performance COP, specific cooling power SCP and specific cooling power during adsorption stage SCP_{ads} was calculated as follows:

$$COP = \frac{Q_{ev}}{Q_h} = \frac{\sum_{t_{III}}^{t_0} \dot{m}_l c_{p,l} (T_{in,l} - T_{out,l}) \Delta t}{\sum_{t_0}^{t_{II}} \dot{m}_h c_{p,h} (T_{in,h} - T_{out,h}) \Delta t} \quad (1)$$

$$SCP = \frac{Q_{ev}}{m_s \tau_{cycle}} = \frac{\sum_{t_{III}}^{t_0} \dot{m}_l c_{p,l} (T_{in,l} - T_{out,l}) \Delta t}{m_s \cdot \sum \Delta t} \quad (2)$$

$$\text{Avg. Ads. Cooling Power} = \frac{Q_{ev}}{\tau_{adsorption}} = \frac{\sum_{t_{III}}^{t_0} \dot{m}_l c_{p,l} (T_{in,l} - T_{out,l}) \Delta t}{\sum_{t_{III}}^{t_0} \Delta t} \quad (3)$$

$$SCP_{ads} = \frac{Q_{ev}}{m_s \cdot \tau_{adsorption}} = \frac{\sum_{t_{III}}^{t_0} \dot{m}_l c_{p,l} (T_{in,l} - T_{out,l}) \Delta t}{m_s \cdot \sum_{t_{III}}^{t_0} \Delta t} \quad (4)$$

where Q_{ev} is the heat consumed in the evaporator, Q_h – the amount of heat supplied to the adsorbent during the cycle, m_s – mass of the adsorbent, τ_{cycle} , $\tau_{adsorption}$ – duration of the cycle and the adsorption stage respectively, \dot{m}_l , \dot{m}_h – mass flow of the heat transfer fluids in the evaporator and adsorber, c_{pl} , c_{ph} – heat capacities of the heat transfer fluids in evaporator and adsorber respectively, T_{in} and T_{out} – the temperature of the heat transfer fluid at inlet and outlet of the evaporator and the adsorber. 3-7 cycles were carried out for each operating conditions and the average values of SCP , SCP_{ads} and COP were calculated.

2. Results and discussion.

A typical adsorption cooling cycle is presented in Fig.1 in a pressure – temperature diagram. The duration of one cycle depended on the operating conditions and varied from 10 to 20 min. The heating power supplied to the adsorber and cooling power produced in the evaporator during the cycle are presented in fig.2. The typical value of the cooling power during the cycles varied from 500 to 1700 W at various operating conditions. It is worth nothing that the temperature inside the evaporator stage continuously decreased lower the temperature of heat transfer liquid during adsorption (fig.3), that mean the actual cooling power even exceeded the value obtained according the equations 2-4.

Fig. 1. The typical pressure – temperature diagram. Operating conditions: $T_{\text{des}}=90^{\circ}\text{C}$, $T_{\text{ads}}=30^{\circ}\text{C}$, $T_{\text{cond}}=30^{\circ}\text{C}$, $T_{\text{ev}}=10^{\circ}\text{C}$, $T_{\text{boiler}}=95^{\circ}\text{C}$, $T_{\text{chiller}}=25^{\circ}\text{C}$.

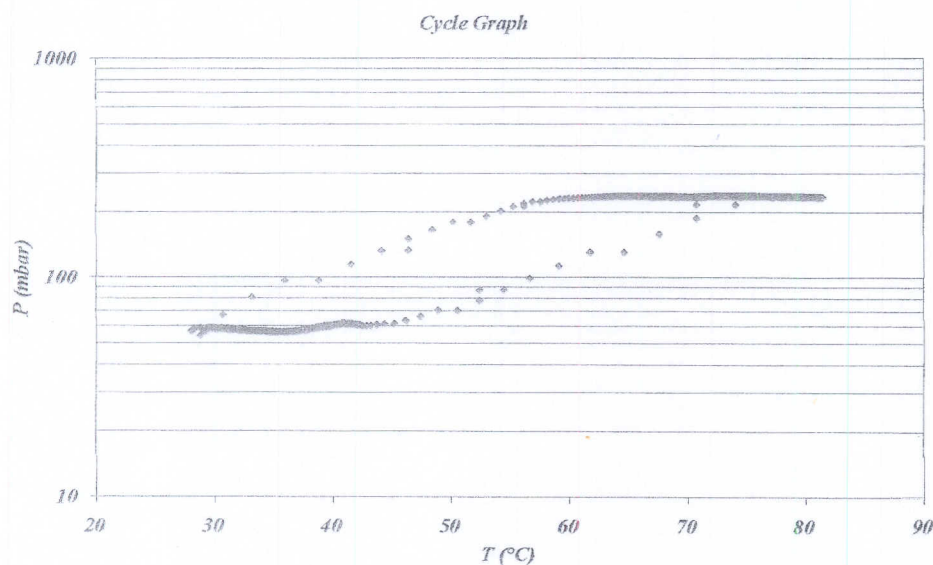


Fig. 2. The heating and cooling power vs cycle time.

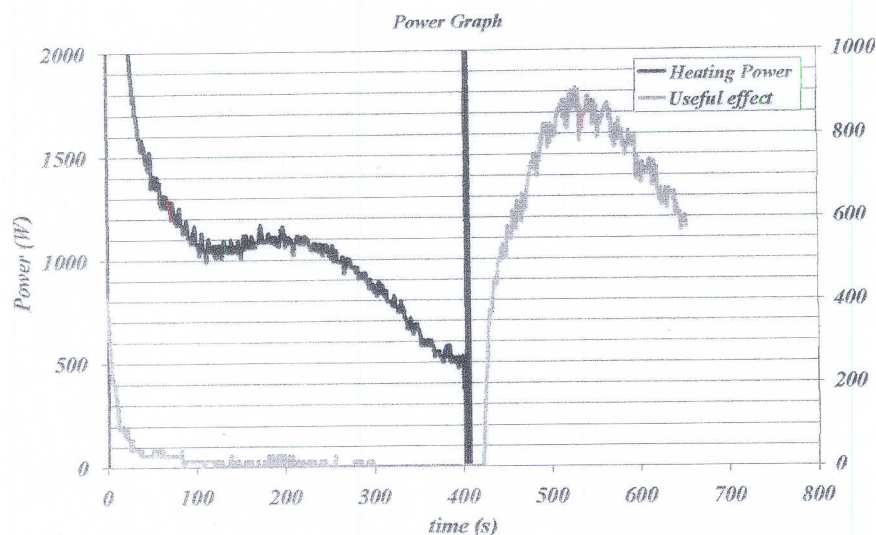
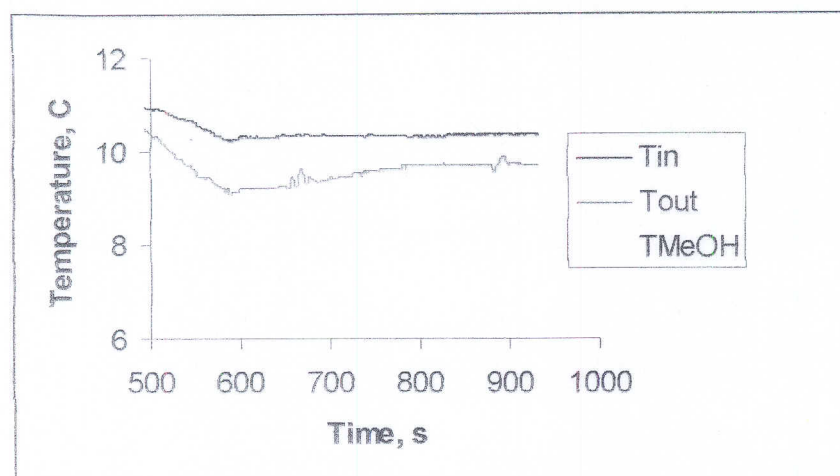


Fig. 3. The temperature of inlet, outlet heat transfer liquid and methanol inside evaporator.

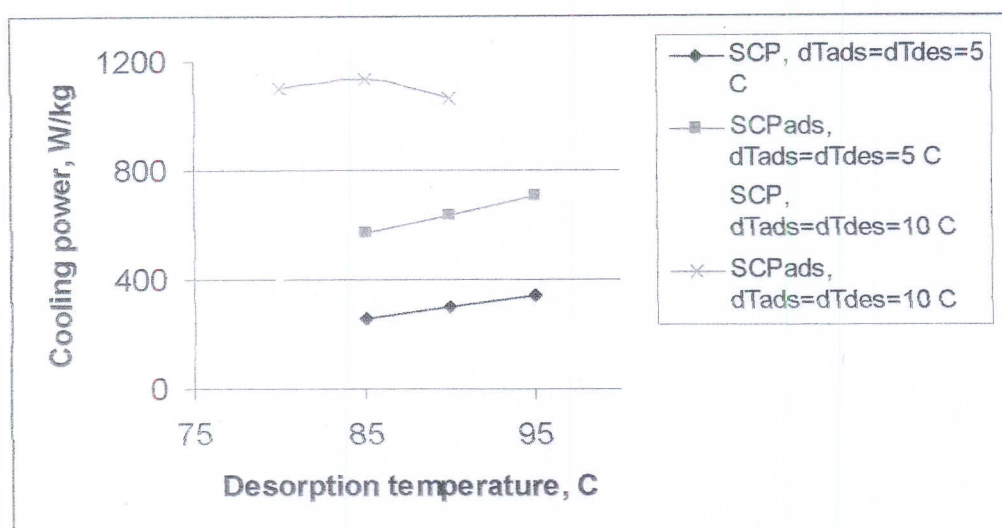


On the base of the data obtained the main characteristics, which determine the cooling efficiency of the cycle, were calculated (Table 1). The increase in desorption temperature resulted in growth of the SCP and SCP_{ads} (fig. 4). This is likely to be caused by the fact, that not all methanol adsorbed is removed from the adsorbent during desorption stage. Increase in the desorption temperature resulted in decrease in the amount of methanol remained on the adsorbent after desorption stage. Dry adsorbent absorbed more methanol and more vigorously, that led to increase in cooling power. Increase in the difference between desorption and boiler temperature $\Delta T_{des} = T_{boiler} - T_{des}$ and adsorption and chiller temperature $\Delta T_{ads} = T_{ads} - T_{chiller}$ also resulted in the growth of cooling power, that is caused by increase in driving force of the desorption and adsorption stages.

Table 1. The operating conditions of the cycles and results obtained.

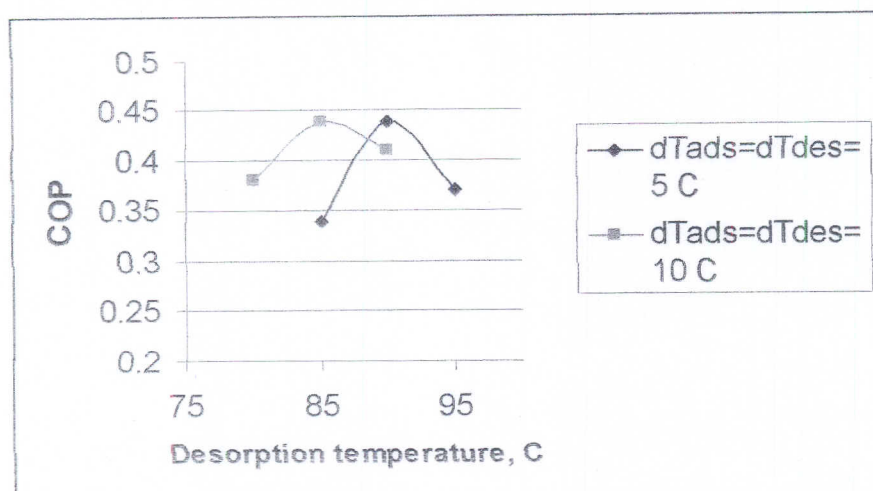
| N | $T_{des}, ^\circ\text{C}$ | $T_{boiler}, ^\circ\text{C}$ | $T_{chiller}, ^\circ\text{C}$ | $SC, \text{W/kg}$ | $SCP_{ads}, \text{W/kg}$ | COP |
|---|---------------------------|------------------------------|-------------------------------|-------------------|--------------------------|-------|
| 1 | 95 | 100 | 25 | 341 | 710 | 0.37 |
| 2 | 90 | 95 | 25 | 297 | 637 | 0.44 |
| 3 | 85 | 90 | 25 | 254 | 572 | 0.34 |
| 4 | 90 | 100 | 20 | 463 | 1067 | 0.41 |
| 5 | 85 | 95 | 20 | 469 | 1136 | 0.44 |
| 6 | 80 | 90 | 20 | 400 | 1100 | 0.38 |

Fig. 4. Specific cooling power of the cycle (SCP) and specific cooling power during adsorption stage (SCP_{ads}) vs desorption temperature at various ΔT_{des} and ΔT_{ads} .



Unlike to the specific cooling power the COP depended on the desorption temperature by more complex way (fig.5). The increase in temperature at first resulted in the increase in COP value, that is likely was resulted from increase of the amount of methanol adsorbed/desorbed during the cycle. The further growth of the desorption temperature, in contrast, led to the COP went down, that is likely to be caused by increase in the energy consumed in the adsorber for heating of the adsorbent Q_h (equation 1).

Fig. 5. COP of the cooling cycles as function of desorption temperature.



Resume

Thus, the cycling of the adsorption cooling unit using the composite adsorbent $\text{LiCl}(17.3\text{ wt\%})/\text{SiO}_2$ and methanol as working pair demonstrated the specific cooling power and the coefficient of performance could reach 450 W/kg and 0.45 respectively, that make the composite tested very promising for adsorptive air conditioning. The further optimization of the cycle parameters, bed configuration and salt content of the composite will be subject of the further investigations.

June 23, 2006

Messina

Dr. Larisa Gordeeva