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Development and lab-test of a mobile adsorption air-conditioner

Salvatore Vasta, Angelo Freni, Alessio Sapienza, Fabio Costa, Giovanni Restuccia*

CNR – Istituto di Tecnologie Avanzate per l'Energia "Nicola Giordano", S. Lucia sopra Contesse 5, 98126 Messina, Italy

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ABSTRACT

This paper is focused on the description of a mobile adsorption chiller for cooling in a truck cabin and its experimental performance. The prototype, designed and built at CNR – ITAE, consists of a double-bed adsorber connected with an evaporator and a condenser and driven by the low grade thermal energy coming from the engine coolant loop. Overall volume and weight of the machine are 170 dm^3 and 60 kg, respectively. Performance assessment was preliminarily carried out at ITAE laboratory under the typical EU car air conditioning conditions. The experimental results obtained showed that the system is able to deliver an Average Cooling Power $ACP = 1–2.3$ kW and a Cooling $COP = 0.25–0.45$, at a desorption temperature of about 90 °C ($T_{ev} \sim 8–14$ °C and $T_{con} \sim 28–35$ °C). Afterwards, the cooling system was integrated in a real truck cabin (IVECO STRALIS) and tested on a laboratory test bench, where the engine cooling loop was simulated through an ideal heat source, so demonstrating that the chiller is able to provide cooling comfort to the passengers.

Conditionneur d'air mobile à adsorption : développement et essais en laboratoire

Mots clés : Adsorption ; Conditionnement d'air ; Zéolite ; Eau

1. Introduction

Recent progresses in adsorption cooling systems demonstrated that such devices can efficiently replace conventional vapour compression chillers and heat pumps, especially when low grade waste or solar heat is available (Wang and Oliveira, 2006). Nowadays, adsorption chillers have been successfully tested mainly for stationary applications such as solar air conditioning and tri-generation (Henning, 2007; Critoph and Zhong, 2005). Thermally driven adsorption machines are also attractive for application in automotive air conditioning (Meunier, 2001). Indeed, utilization of waste heat from the I.C. engine to drive the adsorption chiller reduces fuel overconsumption for air conditioning, which can be translated to lower CO_2 emissions. Moreover, water is the most convenient and environmentally- friendly alternative to R134a, which is banned in new cars by 2011 according to the EU Directive 2006/40/EC. As far as the authors know, the first dedicated study on

* *Corresponding author*. Tel.: +39 090624296; fax: +39 090624247.
E-mail address: angelo.freni@itae.cnr.it (A. Freni).
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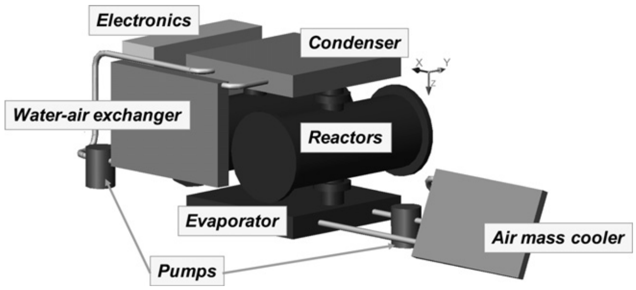

Fig. 1 – Conceptual scheme of the ITAE adsorption mobile air conditioner.

application of adsorption cooling systems to automobiles was presented by Suzuki (Suzuki, 1993), that suggested the use of the working pair zeolite 13X/water regenerated by the exhaust gas of the engine. Suzuki also stressed that the actual application of an adsorption cooling systems to automobiles requires appropriate design of thermally efficient adsorbers.

Some studies on different engines (Tchernev, 1999; Hoppler, 1993) established that at full load 40–50% of the fuel energy is rejected with the exhaust gases, while at idle and city driving conditions, this available heat is reduced to only 10–20% of the fuel energy, that may be not sufficient to drive the chiller.

Consequently, Tchernev (Tchernev, 1999) proposed utilization of the heat contained in the engine coolant loop to drive the adsorption chiller. Obviously, the temperature level of 90 °C discourages utilization of traditional water adsorbents such us zeolites 4A/13X, which require higher temperature for regeneration. To overcome this problem, Tchernev proposed utilization of zeolites with ZSM or Y structure as adsorbents and methanol as adsorbate, whose desorption temperature is lower than 90 °C. However, the correspondent performance is rather limited mainly due to the limited adsorption capacity of the investigated zeolites and the low latent heat of methanol (Restuccia et al., 2005).

Zhang (Zhang, 2000) realised and tested in laboratory a cooling unit driven by the exhaust gas of a diesel engine. The adsorber was a double-tube pipe packed with zeolite 13X grains. The obtained *COP* was satisfying (0.38), but the specific cooling power measured (*SCP* 25.7 W kg^{-1} of adsorbent) was too low for practical application in vehicles. Jiangzhou (Jiangzhou et al., 2002) realised a prototype of zeolite/water adsorption chiller for a locomotive driver-cabin air conditioning. The prototype was able to deliver about 4.5 kW cooling power with *COP* of 0.25. Also in this case, the weight of the prototype (>300 kg) was not suitable for practical application in vehicles.

In recent years, the EC VI-FP project "TOPMACS" – Thermally Operated Mobile Air Conditioning Systems – was entirely dedicated to the development of original adsorption cooling systems for automotive applications. The partners of the project developed cooling machines based on three different adsorption working pairs (activated carbon/ammonia, silica gel/water, zeolite/water). Specifically:

- Warwick University (UK) developed a novel AC/ammonia generator based on the original plate heat exchanger (PLATEX) concept (Tamainot-Telto et al., 2009). The resulting generator was very compact (total weight: 9 kg) and provided 1.6 kW cooling power and *COP* = 0.23 at an operating temperature of 90 °C.
- ECN – Energy research Centre of the Netherlands, in cooperation with FIAT, designed and realised a silica gel/water chiller to fit a FIAT Punto car (de Boer and Smeding, 2008). The sorbent reactor assembly (volume and weight 30 dm^3 and 24 kg, respectively) was based on aluminium tube-fin heat exchangers. Special vacuum check valves were used to regulate the direction of the refrigerant flow. The

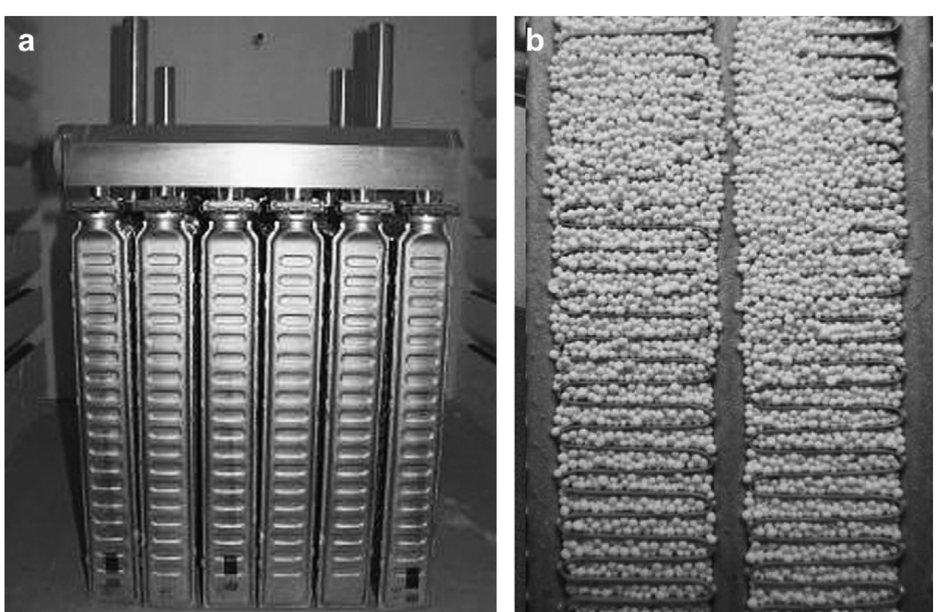

Fig. 2 – a, b. Overall and detailed view of an adsorber reactor filled with adsorbent grains.