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Three adsorbers solar cooler with composite sorbent bed and heat pipe thermal control

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Three adsorbers solar cooler was experimentally investigated. Ammonia was chosen as a working fluid. Two adsorbers (twins) were filled with the same complex compound (activated carbon fiber with $MnCl_2$ microcrystals on the filament surface). The third low temperature adsorber has second complex compound (activated carbon fiber with $BaCl_2$ microcrystals on the filament surface). The cycle of physical adsorption and chemical reactions in the sorbent bed of adsorber was followed by condensation/evaporation of ammonia inside the pores. This combination of adsorption/condensation and evaporation/desorption is a novelty of cooler design, which increases the heat and cold generation in adsorber. The specific feature of third adsorber is the time of its cold generation. This time includes the liquid evaporation and desorption/regeneration time of ammonia in the sorbent bed. The cooler thermal management is based on heat pipes. The solar heating is a source of energy for cooler. The sink of the cold is the air flow.

1. Introduction

Refrigeration technologies have been critical in the evolution of production and distribution systems a long period of time. Reduction in use of synthetic refrigerants and production of CO_2 provide a new opportunity for solar cooling and refrigeration. The concept of solar-powered refrigeration cycles is known at least two decades and several refrigerators operating on this principle are commercially available.

There were many projects for the development or demonstration of solar refrigeration technologies and solar refrigeration continued to be an important issue, J. Bougard, G. Veronikis, 1992 [1]. Adsorbents like zeolite, silica gel, activated carbon and alumina oxide are considered as physical adsorbents having highly porous structures with surface-volume ratios in the order of several hundreds that can selectively catch and hold refrigerants. When saturated, they can be regenerated simply by being heated. If an adsorbent and a refrigerant are placed in the same vessel, the adsorbent would maintain the pressure by adsorbing the evaporating refrigerant. The process is intermittent because the adsorbent must be regenerated when it is saturated. For this reason, multiple adsorbent beds are required for continuous operation. Conventional working pairs include activated carbon and methanol, or ammonia, Pons and Guilleminot, 1986 [2]; Wang et al., 1997, 2001 [3,4], Critoph, 2002 [5], and silica gel-water, Grenier et al., 1988 [6]. Current solar adsorption technology can provide a daily ice production of 4–7 kg per unit square meters of solar collector with a solar-to-cooling COP between 0.1 and 0.15, Wang and Oliveira, 2005 [7]. Different small-capacity silica gel-water adsorption chillers have been developed for solar air conditioning, Saha et al., 2001 [8]. Its cooling capacity was reported between 3.2 and 3.6 kW; COPs ranged from 0.2 to 0.6 for the working temperature diapason from 55 to 95 °C. Unlike the more common single-staged double-bed systems, Saha et al. (2001) [8], developed a double-staged four-bed cycle machine to use at very low driving temperatures. The machine produced 3.2 kW cooling and 55 °C hot water output with COP of 0.36.

However, there has been a little research made into the integration of short time cycles sorption machines of solar power with natural gas, or electrical immersion heater as a back-up, Vasiliev at al., 1999 [9].

The combined action of physical adsorption and chemical reactions for the cold production in the same space and at the same time is attractive initiative to enhance the COP of a system, Vasiliev et al., 1994 [10]. The use of heat pipes to improve the performance of carbon-ammonia adsorption refrigerator was suggested by Vasiliev et al., 1996 [11]. It was shown that heat transfer in the sorbent bed

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can be improved by the use of finned heat pipe as the heat exchanger. The concept aim of such research program was to extract the most enthalpy from the low-grade heat before it is purged into the surrounding. A solar-gas refrigerator based on a reversible solid sorption phenomena is competitive, if the process allow to store the energy of a high density, and if the heating, or cooling power is enough for consumers, Vasiliev et al., 2001 [12].

Recently it was shown, Akisawa and Miyzaki, 2010 [13], that compression chillers with high energetic COP have the same efficiency as that of adsorption chillers in terms of exergy. It means that physical performance of adsorption chiller is not low, taking Carnot efficiency into account. Actually it is evident that adsorption coolers are very efficient from the view point of the second Law of thermodynamics.

It is known, that cascading cycles are options to improve the adsorption coolers efficiency because they recover heat from one cycle to another internally, Douss and Meunier, 1989 [14], and Liu Y., Leonig, K. 2006 [15]. The cascading cycles, which couple solid gas reactions with the liquid-gas absorption process, Stitou, D.; Spinner, B.; Satzger, P.; Ziegler, F., 2000 [16], Vasiliev et al., 1996 [17], have COP more than 30% compared with conventional double effect of adsorption cycles.

Three adsorbers chiller was experimentally tested by Chua et al., 2001 [18], which operated similar to a single stage cycle. The next improvement to the three adsorbers cycle was incorporated by Saha et al., 2003 [19]. A new three adsorbers cycle was suggested by Khan et al., 2006 [20]. The cycle is working like a single stage (two adsorbers) and one additional third adsorber is connecting to the other two adsorbers. The main particularity of the cycle is as follows: the third adsorber runs twice as quickly as the other two adsorbers. The working fluid purged from the third reactor in mass recovery process is absorbed into the other two reactors. The novel dual evaporator type three-bad absorber chiller was analyzed by T. Miazaki et al. [21]. Efficient waste heat driven multi-bed adsorption chiller was suggested by B.B. Saha et al. [22].

2. The three adsorbers cooler design

Our intention is to design and test a chiller, which would operate consuming a chip energy (solar concentrator and autonomous, low pressure adsorbed natural gas storage vessel as the back-up system), that can be built and maintained in the country of use, be light and portable and that is low enough in cost [12]. This can be achieved if we use a solar energy as a main source, a gas flame as a second (alternative or additional) source of energy and a set of sorbent beds which are heating and cooling alternatively. The original heat pipes (thermosiphon) are used as heat exchangers for external heat recovery and adsorbers thermal control. Activated carbon fiber (ACF) “Busofit” is used for ammonia adsorption/desorption. The micro/nano crystals of $MnCl_2$ and $BaCl_2$ are used as the chemical sorption material to increase the sorption capacity of the sorbent bed.

The schematic of the three adsorbers cooler is shown on Fig. 1 – Fig. 2. The experimental set-up includes two medium temperature adsorbers (ACF + $MnCl_2$), one low temperature adsorber (ACF + $BaCl_2$), Fig. 1. The thermal management system (Fig. 3) consists of four unites: vapor-dynamic thermosiphon, two loop thermosiphons [23] and a loop heat exchanger joint to the low temperature adsorber.

Vapor-dynamic thermosiphons (VDT), Fig. 3 have principal distinction from conventional thermosiphons and heat pipes of the same diameter. VDT can transfer the heat in horizontal position on the long distance. Its condenser is near isothermal with the length of meters. Recent innovations to VDT design related to nano technologies anticipate a significant impact on heat pump/cooler designs and its thermal solutions. The main distinction of VDT is the *long annular gap* between the vapor pipe line and the tubular condenser (tube–in-tube). The vapor generated in the VDT compact evaporator pass through the long pipe line and enters into the annular gap of the condensation zone, where it condenses. There is an intense radial heat transfer with phase change between the vapor channel and the condenser envelope. The hydraulic diameter of the condenser mini gap is less than a capillary constant of the working fluid. The fundamental difference of such a scheme consists in the fact that the motion of vapor and liquid flow proceeds being separated spatially. This makes it possible to avoid a negative hydrodynamic interaction between the opposite flows of the vapor and liquid typical for the conventional thermosiphons. Among the additional advantages of VDT is the possibility to use flexible pipelines (pipe in pipe) of the condensation zone, which may have small diameter.

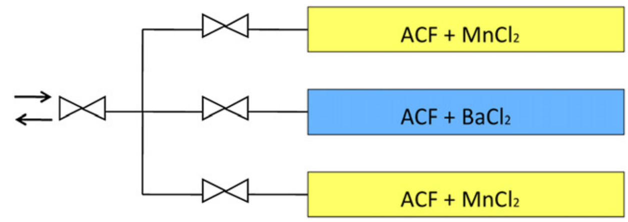

Fig. 1. The schematic of the three adsorbers cooler.

In Fig. 3 the alternate regime of activating and deactivating of VDT occurs with the help of two valves, thus heating/cooling of adsorbers proceeds. When the procedure of desorption is occurred in the left adsorber, the adsorption procedure is realized in the right one.

The system management consists only in actuating valves to change the direction of the fluid inside the heat exchangers.

The main characteristics of the cooler efficiency are the Coefficient Of Performance (COP) for cooling:

$$COP_c = Q_e/Q_{des}$$

Dynamics of the cooling cycle is defined by the Specific Cooling Power (SCP)

$$SCP = Q_e/(\Delta w \cdot \tau),$$

where Δw is the adsorbate uptake exchanged during the cycle; τ - the time of the cycle.

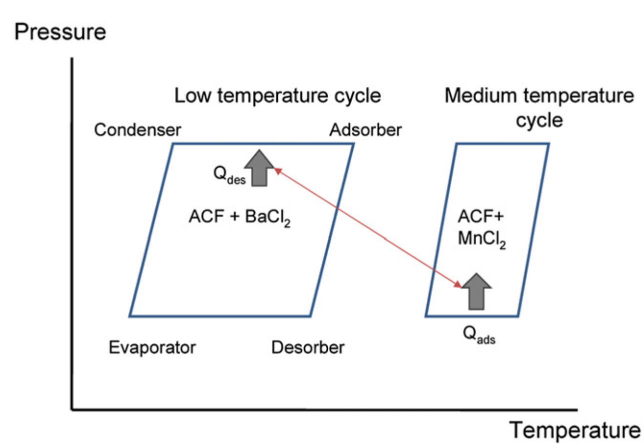

Fig. 2. Schematic of the three adsorber’s cycle with complex utilization of energy of low temperature adsorber.