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Short Communication

Analysis of Cooling Cycle in Single-Stage Adsorption Chiller

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Abstract

Thermochemical technologies of cooling capacity production are ecologically effective processes of utilizing a heat stream combined with electricity production. Apart from poly-generation systems, their applications are found in air conditioning systems cooperating with solar installations and other industrial installations generating heat as a by-product. Unlike the widely commercialized absorption chillers, continuous research on improving the heat utilization efficiency in adsorption systems gives innovative nature to this technology.

This paper presents a work analysis of the adsorption cooling device. The construction, working principle, and variability of defined performance parameters in time for a representative cooling cycle were also presented.

Keywords: adsorption chiller, coefficient of performance, cooling capacity, silica gel

Introduction

Sorption phenomenon has been in wide use for many years in various industrial technologies, mainly in the purification of exhaust gas processes from pollutants. These processes are also used in heat pumps and thermochemical cooling technologies [1]. As an alternative to refrigeration compressors there are ecological solutions leading to primary energy conservation, and therefore limitation of pollutants emissions into the atmosphere. In addition, in contrast to the compressor chiller, adsorption cooling is not destructive to the ozone layer of the atmosphere, because the processes do not use medium such as chlorofluorocarbon (CFC) and hydro chlorofluorocarbon (HCFCs).

The origins of the use of thermochemical phenomena for the production of cooling are noted in the mid-19th century, when the first absorption chillers were constructed [2]. The first patents on the use of adsorption are noted in the 1920s [3]. Nowadays we can observe again the increase of interest of these technologies because of the necessity of utilizing the heat flux generated as a byproduct with energy conversion processes. They are used in air conditioning systems that cooperate with solar collectors and polygeneration systems. The clear advantage for adsorption chillers in respect to absorption is the possibility of supplying with a heat carrier at lower temperature, thereby creating a greater opportunity to use the heat, including low-temperature heat. This paper presents the variability of basic performance parameters during the cooling cycle in an adsorption chiller, which can constitute the outline of heat and mass exchange in the system.

Experimental Procedures

The scheme of the research station and sensor placement are presented in Fig. 1. Readings were registered every 3 seconds with an accuracy of ± 0.2ºC. In the presented system water is applied as a refrigerant and silica gel as an adsorbent.

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Working Principle

Cooling capacity is achieved in the evaporator via chilled water flowing through tubes placed inside the evaporator. The temperature of flowing chilled water into the evaporator is reduced as a result of taking up heat by the refrigerant (water) changing its physical state. The refrigerant evaporates and flows to the adsorber, where this exothermic adsorption takes place. The heat of adsorption is removed from the reactor to the cooling water circuit. Due to the fact that the sorption capacity of the silica gel bed in the reactor is limited and the process of refrigerant evaporation takes place continuously, to ensure the continuous production of cooling capacity in a single-stage device requires installing at least two beds operating with time-shifted relative to each other, which enables their alternating work. After the adsorption process the regeneration of bed is needed. In the system presented in Fig. 1, two beds were working as desorbers, while at the same time, on the other two, adsorption was occurring. Regeneration of the bed is preceded by preheating the bed for a short time (switching time). The vapor released in the desorption process flows to the condenser, and after their condensation passes through the U-tube flows into the evaporator. After the desorption process, the bed is prepared for the adsorption process by pre-cooling in a short time (switching time). The bed is packed around an indirect coil inside the reactor as shown on Fig. 1, so that it is possible, depending on the process taking place in the reactor, to supply the hot or cooling water.

Calculation Methodology

Based on registered readings for fluxes of water used in the adsorption refrigeration system, the parameters defined by equations (1-3), were calculated to observe their changes in cycle time.

The main parameter characterizing the performance of adsorption cooling device is coefficient of performance COP:

$$COP = \frac{CC}{HP}\text{, [-]} \tag{1}$$

...representing the ratio of the generated cooling capacity (CC):

$$CC = \dot{m}_{ch} cp_{ch} \Delta T_{ch}\text{, [W]} \tag{2}$$

...to the supplied heating power (HP),

$$HP = \dot{m}_{h} cp_{h} \Delta T_{h}\text{, [W]} \tag{3}$$

...where:

$\dot{m}_{ch/h}$ – the flow of chilled/hot water [kg/s],

$cp_{ch/h}$ – specific heat of chilled/hot water in inlet temperature [kJ/kg ºC],

$\Delta T_{ch/h}$ – temperature difference (between inlet ant outlet) for chilled/hot water, [ºC].

Operation Parameter

The effectiveness of vapor released in the desorption process increases with the regeneration temperature of the bed. This relationship has been confirmed experimentally [4]. Therefore, to this analysis was assumed a constant of -85ºC regeneration temperature, which has been pointed out by authors of [5] as a typical regeneration temperature for a water-silica-gel system pairing. The temperature of chilled water inlet to condenser was set to 10ºC. The inlet cooling water temperature for beds and condensers was set to 29.5ºC. The mas of silica gel per bed was 36 kg. Physical properties of applied silica-gel can be found i.a. in [6]. Flows for hot, chilled, and cooling water were set to 48 dm^3/min and for condenser cooling water to 120 dm^3/min. Time of desorption is the same as adsorption time due to the specificity and construction of the device, which enables alternating operation of beds and was set to 480 sec. Pre cooling/heating time for the bed was 45 sec.

Results and Discussion

From the dependence received on Fig. 2a for cooling capacity it can be seen that the greatest value of CC is achieved at the beginning of the cycle time, and further we can observe the trend showing the decrease of generated cooling capacity together with passage of cycle time for these experimental conditions. This trend has a justification because the greatest gradient of increased CC is observed in the period where the rate of sorption processes is the highest, and further time passage, together with a decreasing of rate of processes, results in slowing vapour adsorption on the surface bed and as a consequence declining in CC generation. Slowing the adsorption process when the water vapor-silica gel system is going to reach equilibrium can influence the cooling capacity generation process. Mass transport of refrigerant between the condenser and the evaporator is slowed down, which causes the disturbances on the refrigerant evaporation process – receiving heat from the chilled water circuit.

Calculating the instantaneous value of the COP presented in Fig. 2b, we can observe that the value of the COP increases with cycle time. This dependence can be explained by the differences in rate of sorption and desorption processes and also adsorption dynamism changes in time. Together with cycle time duration, the concentration of refrigerant on bed surface increases, wherein the adsorption process takes place more slowly. The desorption process occurs with the greater rate than adsorption, which means that after a certain time heating power supplied to bed cannot be fully used for desorption. Observing the heating power profile in Fig. 2a, it should be noted that the increase of COP is caused by lower HP values, which is the denominator of equation (1). Low HP value is associated with a lower use of heat supplied with hot water flowing through the bed (lower ΔTh), which results in a significant decrease of HP and means that transported thermal power is not used. In other words,

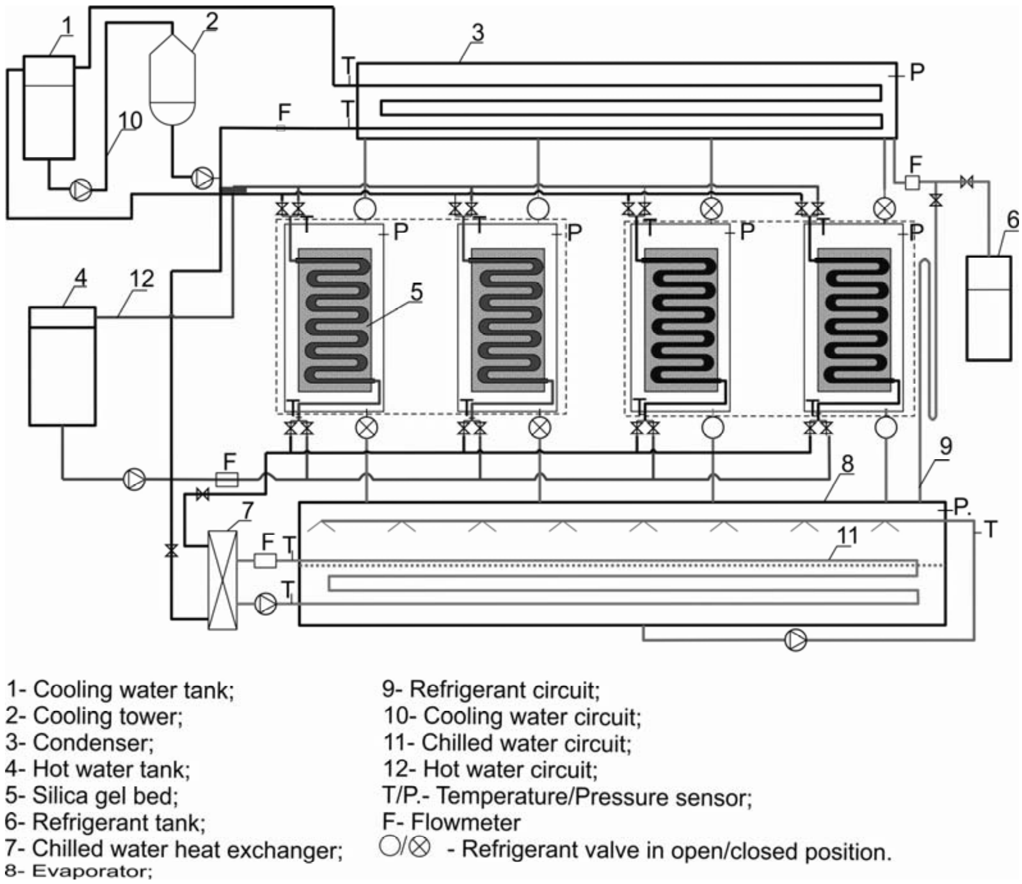

Fig. 1. Scheme of research station.

chilling the hot water supplied to the desorption is smaller, which at a constant flow of hot water reduces the instantaneous value of the output stream (HP), which as a consequence can cause a nearly monotonic rise of COP with cycle time.

Conclusions

Based on our research and calculations, it was found that:

- The changes of investigated parameters during the adsorption/desorption time are associated with both – the heat exchange efficiency in the reactor during desorption as well as the dynamism of achieving the equilibrium state in water vapor-silica gel system.
- The processes of adsorption/desorption occur most intensively on their initial stages of cycle time.
- The highest gradient of generated cooling capacity is observed at the initial stage of cycle time.
- The most intense heat from the hot water supplied to the bed occurs at the beginning of desorption.

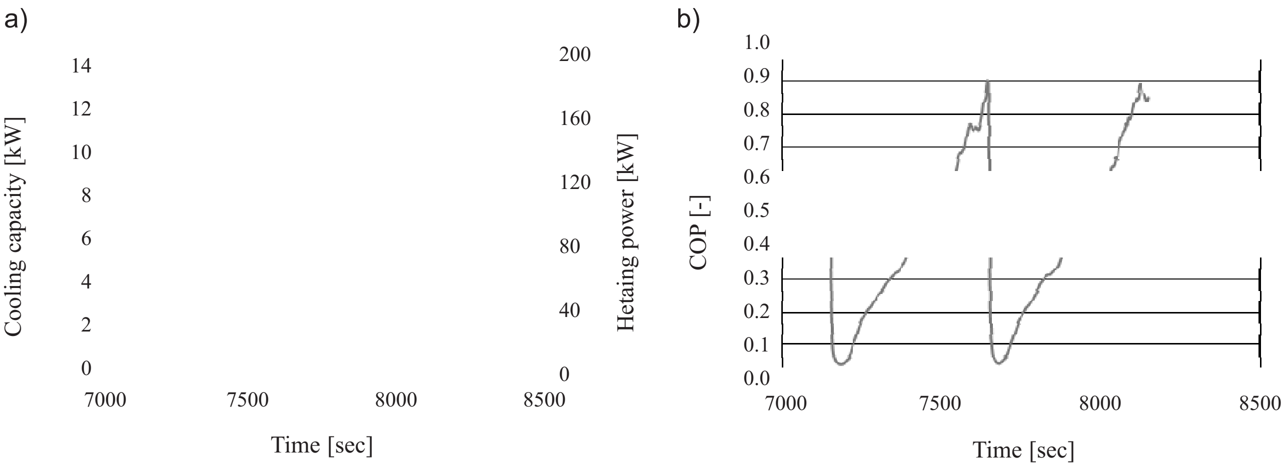

Fig. 2. Variability of investigated parameters in time.

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