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# Influence of Outside Temperature on the Operation of the Adsorption Chiller

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**Abstract.** Adsorption refrigeration systems are characterized by a lower coefficient of performance than the compressor type device or even absorption, but can utilize waste heat at lower temperature. The aim of the study was to determine which external parameter has the greatest impact on the efficiency of the adsorption device. As a result of experimental studies there was found that this is not the temperature of the feed but particularly the temperature of external air. For this reason, it is recommended that the adsorption device should cooperate with evaporative spray coolers, instead of with popular dry coolers. This solution will increase annual efficiency of adsorption unit approx. by 25% and significantly reduce the costs of cold generation.

**Keywords:** refrigeration, adsorption refrigeration, energy efficiency.

**Conference topic:** Energy for buildings.

## Introduction

Adsorption refrigeration systems are increasingly used in industrial and commercial refrigeration. In the industrial refrigeration systems are widely connected with waste heat (Grzebielec *et al.* 2015a, 2015b). In the case of commercial refrigeration are mostly used as installations of solar refrigeration and heat recovery in other commercial installations (Fernández *et al.* 2015; Hadij Ammar *et al.* 2017; Jaworski *et al.* 2016). The development of adsorption devices is due to three reasons. On the one side, regulations prohibit the use of another refrigerants commonly used in the compressor type of refrigeration (Grzebielec *et al.* 2014; Kuczyński *et al.* 2013; Rusowicz *et al.* 2014; Śmierciew *et al.* 2017). On the second side, adsorption units are able to work at lower heat sources temperatures than the absorption units types (Fernandes *et al.* 2014; Lucia 2013; Rusowicz, Ruciński 2011). On the third side technical solutions should increase general energy conservation coefficient (Ruciński *et al.* 2016; Rusowicz *et al.* 2013). Adsorption units unlike the absorption devices operate in a cyclic manner. This is due to the fact that the sorptive substance is in the form of a solid. In addition, decreasing the driving temperature there is needed a sufficiently low temperature during refrigerant condensation. And just on the condensing temperature, which is related to the outside temperature this research is focused. There is shown what are restrictions for adsorption refrigeration unit cooperating with the dry cooler and how to expand the area of application equipment using spray-evaporative condensers.

## Experimental apparatus

Test stand of adsorption device is connected to the three systems, in every one there was used secondary fluid (Fig. 1).

The device is connected to a source of heat in the water circuit. The heat source system consists of an electric heater with a maximum power of 25 kW. Next one is recooler system – a circuit utilizing heat from the condenser of the adsorption refrigeration apparatus. The third system is a cooling cold water system. In the case of an experiment there was used air type heat exchanger. The thermal power was regulated by changing the fan speed.

Working pair in the test device was water/silica gel. It is typical solution for air conditioning, so refrigeration system operated at the 7/12 °C values – the most common in water air conditioning systems (Cyklis, Janisz 2015; Freni *et al.* 2016; Wang *et al.* 2014). On the heat source side there can be set up any temperature control in the range of 50 to 90 °C. There was decided to use a 72 °C as a heat source temperature as a temperature commonly available in direct heating systems in Poland (Jędrzejuk, Dybiński 2015; Jędrzejuk, Rucińska 2015).

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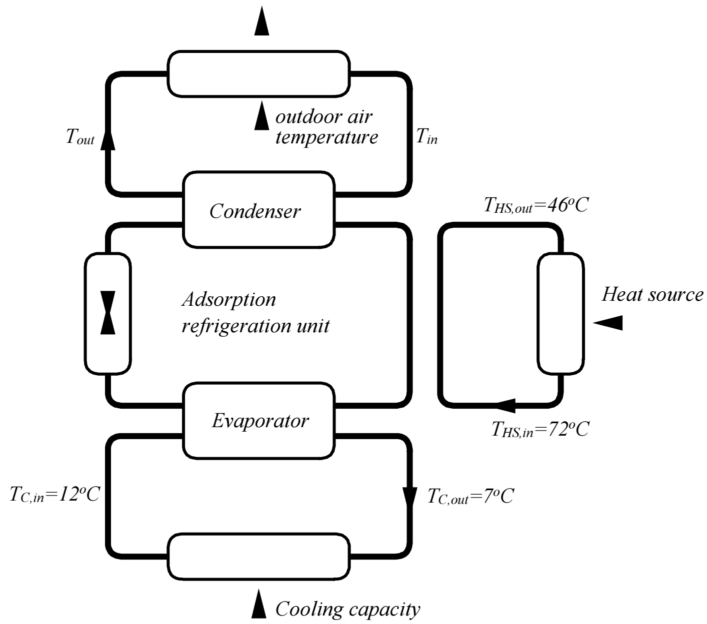



Fig. 1. Adsorption refrigeration unit connected with water circuits

**The methodology of calculation**

Earlier publications shows that the temperature of the water returning from recooler is the most important parameter that determines the efficiency of the adsorption refrigerating equipment. In order to determine the influence of outside air temperature on efficiency of the adsorption refrigeration apparatus firstly there was tested recooler device in form of dry cooler. Figure 2 presents dry cooler used during the research.

Fig. 2. Dry cooler used in the experiment

*EER* coefficient was determined as the ratio of the amount of heat flux in the refrigerant circuit to the heat flux in the heat source during the one hour (Eq. (1)) (Grzebielec *et al.* 2015a; Xu 2011; Cacciola, Restuccia 1995).

$$EER = \frac{Q_C}{Q_{HS}}, \tag{1}$$

where: $c$ – specific heat (J·kg$^{-1}$·K$^{-1}$); $EER$ – energy efficiency ratio (-); $Q$ – heat (J).

where amount of cold generated in one hour $Q_c$ is:

$$Q_C = \int_{\tau=0}^{\tau=3600} \dot{m}_w \cdot c_{p,w} \left(T_{C,in} - T_{C,out}\right) d\tau, \tag{2}$$

where: $t, T$ – temperature (°C, K); $\dot{m}$ – mass flow (kg·s$^{-1}$); $C$ – cooling; $fg$ – phase change; $HS$ – heat source; $in$ – inlet; $out$ – outlet; $p$ – constant pressure; $se$ – spray-evaporator; $w$ – water; $\Delta$ – difference; $\tau$ – time (s).

and the amount of heat supplied in heat source $Q_{HS}$ was calculated according to the Eq (3):

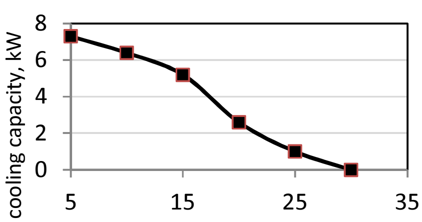
$$Q_{HS} = \int_{\tau=0}^{\tau=3600} \dot{m}_w \cdot c_p \left(T_{HS,in} - T_{HS,out}\right) d\tau. \tag{3}$$

In the next stage of the study there was determined the characteristics of the work of spray- evaporative cooling device for liquids according to a study in the publication (Pluta 2008). Decreasing the air temperature in the apparatus is mainly due to the water evaporation

$$\dot{m}_{w,se} \cdot \Delta h_{fg} = \dot{m}_a \cdot c_{p,a} \left(T_{a,in} - T_{a,out}\right). \tag{4}$$

## Results

Figure 3 shows the results of experimental research for the adsorption device cooperating with dry cooler.



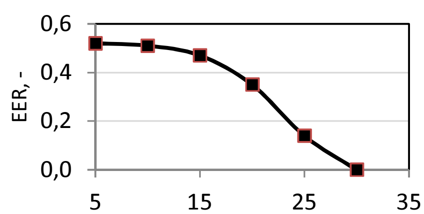




Fig. 3. Experiment results for adsorption refrigeration unit connected with dry cooler type of recooler

Bearing in mind that the evaporation of water has a direct impact on decreasing the air temperature. On decreasing the temperature of the water returning from recooler it is affected only indirectly taking into account the efficiency of the heat exchanger (Wang *et al.* 2011; Xu *et al.* 2016).

The analysis determined the efficiency of the cooling apparatus as a function of humidity in the air (Fig. 4). The analysis shows that the efficiency is greater at higher humidity, but it must be remember that the higher humidity makes lower cooling potential. At high apparatus efficiency the temperature changes slightly. The limitation is the dew point temperature – in case of high humidity the air temperature is close to dew point temperature.

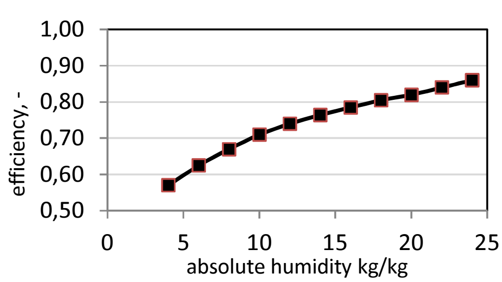



Fig. 4. Spray-evaporative apparatus efficiency as function of absolute humidity

Knowing the efficiency of the humidification apparatus, inlet air temperature, dew point temperature there was calculated the water temperature in the recooler back line. Based on the new water temperature it was determined cooling capacity and the efficiency ratio EER. The Figure 5 presents the experiment results of the cooling power for the unit cooperating with dry cooler and spray evaporator in the period from May 1 to September 30 for the typical weather for Warsaw. Provided that the device will operate between the hours of 8 to 20 inclusive. It is clear that a device with a spray evaporator generates far more cooling power.

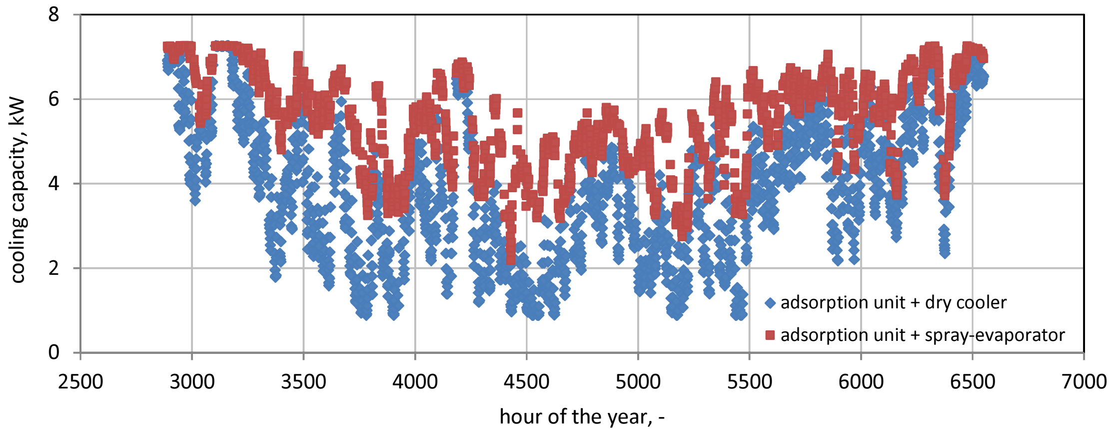



Fig. 5. The cooling capacity for the same adsorption device cooperating with dry cooler and spray-evaporator

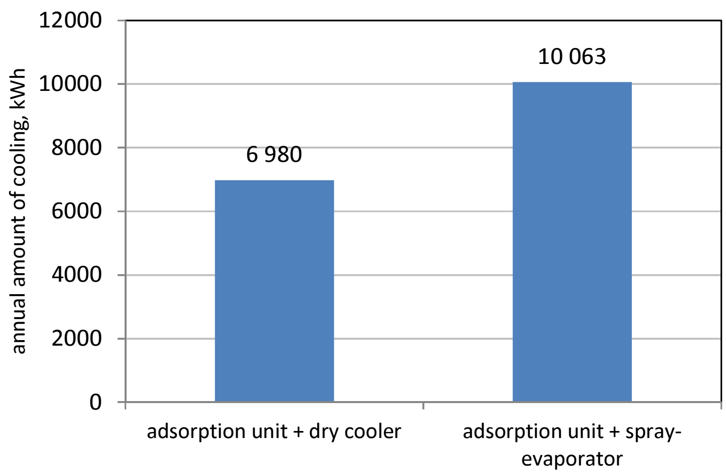



Fig. 6. Cold amount during the year

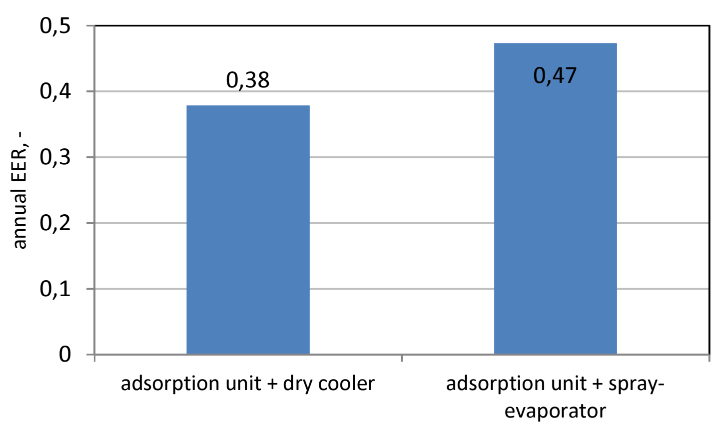



Fig. 7. The average annual EER

Figure 6. presents the amount of cold generated annually by both systems. Tested adsorption refrigeration unit with dry cooler is able to generate 6980 kWh of cold, while the device cooperating with an evaporative spray unit is able to generate 10,063 kWh. Figure 7 shows the average rates of energy efficiency ratio EER: device cooperating with dry cooler has value of 0.38 while for the device to the evaporative spray has value 0.47. The ratios of power and EER are not the same as the adsorption units operate in a cyclic mode, which means that also the driving power consumption varies with time. It also puts additional challenges for automation devices adsorption – drive power must also be able to change over the time.

## Conclusions

The experimental and calculation results confirm that the outside air temperature plays a key role in the efficiency of adsorption refrigeration. When the dry cooler is used – the temperature of the water returning from the external cooler is always higher than the temperature of the water returning from the evaporator spray apparatus – in the experiment annual is higher by 4.99 K. In the case when the air temperature exceeds 30 °C, the apparatus with dry cooler do not produces cold. However, in the case of a device cooperating with the spray-evaporator heat exchanger, it is possible to obtain the water temperature lower than the temperature of the air, provided that just the humidity is low. The result of the analysis is the fact that the EER for devices with an spray-evaporative heat exchanger is higher by 25% and the average cooling capacity is higher by 44% than in the case of dry cooler devices. There should be noted that in the case of the economic analysis the spray evaporative heat exchanger additionally uses water. In the present case, the consumption of water during the entire season was only 14.7 $m^3$.

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