Engineering Approach to Modeling of a Sorption Bed of a Single-Stage Adsorption Chiller

Karolina GRABOWSKA¹*, Jaroslaw KRZYWANSKI¹, Marcin SOSNOWSKI¹, Wojciech NOWAK², Marta WESOLOWSKA³, Karol SZTEKLER² and Aleksander WIDUCH³

¹Jan Długosz University, 13/15 Armii Krajowej Av; PL42-200 Czestochowa, Poland
²AGH University of Science and Technology, Czarnowiejska 30 Av; PL30-059 Cracow, Poland
³New Energy Transfer S. A., Domowa 6 Av, PL02-913 Warsaw, Poland
*Corresponding author

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Abstract. The paper presents prospects of modeling sorption beds based on analysis of parameters characterizing adsorption chillers. The crucial influence of the heat transfer coefficient \(h\) between the bed and the fluid (water) in the heat exchanger on sorbent bed dimensions of an adsorption chiller is determined. It has been shown that improved heat transfer conditions in a bed will allow to reduce the dimensions of the adsorption chiller at preserved Coefficient of Performance. The results of the calculations are presented as heat exchange surface and Cooling Capacity in function of heat transfer coefficient. Moreover the paper presents the leading directions of optimization of the sorption bed design in terms of heat and mass transfer intensification.

Nomenclature

\(\text{COP}\) Coefficient of Performance -
\(\text{CC}\) Cooling Capacity [kW]
\(\text{HP}\) Heating Capacity [kW]
\(A\) heat exchanger surface [m²]
\(h\) heat transfer coefficient between the bed and the fluid (water) in the heat exchanger [W·m⁻²·K⁻¹]
\(\Delta T\) hot water temperature difference between the heat exchanger inlet and outlet [K]
\(\epsilon\) bed porosity -

Introduction

Effects of developing global warming are experienced all over the world. Higher and higher average temperature in summer months enhance the need for cooling production. Moreover the high usage of compressor devices significantly increase electrical energy consumption and causes release of harmful CFC (chlorofluorocarbons) gases to the environment. Significant overload of natural environment by conventional refrigeration units encourages the search for alternative technologies, which could become part of the worldwide promoted concept of sustainable development [1].

Additionally, the industry generates huge amount of waste heat which currently is not effectively used. These inexhaustible sources of renewable energy are considered to be potential source of environmentally friendly power supply for cooling technology which constitutes adsorption refrigeration systems. Alternative source of power can also be photochemical solar power, which after conversion into useful heat in solar panels, can successfully be used for cooling production and heat produced in cogeneration [2]. The greatest advantage of utilizing the low grade thermal energy sources is significant limitation in electric power used to drive the refrigeration units [3, 4].
Operation of the adsorption chillers is based on the usage of thermal effects, which accompany processes of interchangeable adsorption and desorption of refrigerant in a sorbent bed [5]. The product of working cycle is chilled water, which can be successfully used for air conditioning at cubature buildings e.g., in shopping centres, hospitals, office buildings and industrial halls. Low efficiency of adsorption chillers expressed in Coefficient of Performance (COP): \[ \text{COP} = \frac{CC}{HP}, \] (1)
is the major disadvantage of this ecological technology. Moreover, increasing the efficiency leads to the increase in mass and dimensions of the chiller. In consequence it significantly reduces the potential target market. Therefore the most important challenge for engineers is to reduce the dimensions of the adsorption chiller while maintaining high efficiency of the device [6].

The paper presents the concept of the modeling of bed dimensions at constant COP of the chiller by improving the sorbent bed thermal conductivity.

Modeling of a Sorption Bed
The working part of the adsorption chiller is a sorbent bed in which built-in heat exchangers system is filled with porous media (sorbent). The sorbent is periodically subjected to adsorption/desorption processes of the refrigerant. The number of adsorption beds is increased in order to provide the constant cooling production. When the first bed is subjected to desorption, which is a bed regeneration process, the second bed is working in the adsorption cycle [7]. This situation is demonstrated in Figure 1.

The heat transfer in the adsorption bed work cycle is controlled by the porosity \( \varepsilon \), which determines the gaseous spaces ratio to the volume of the sorbent bed [11]. The high beds porosity is an important limitation to the sorption processes efficiency, because it generates high resistance to heat flow in the volume of sorbent, due to very low thermal conductivity of the gases (only 0.025 [W·m\(^{-1}\)·K\(^{-1}\)] for air). The strong influence of bed total conductivity on the adsorption cycle efficiency was confirmed in [8]. The above mentioned facts indicate the purposefulness of modifying the bed design in the heat exchanger boundary layer, where high thermal resistance of gaseous spaces is responsible for the low value of the heat transfer coefficient between the sorbent bed and the heat exchanger fluid.
The modification in this area is justified by the relationship between the heat exchange surface and operating parameters of the adsorption chiller:

$$A = \frac{CC}{COP \cdot h \cdot \Delta T}. \quad (2)$$

This relation was derived in [1]. By substituting for COP (1) to equation (2) one obtains:

$$A = \frac{HP}{h \cdot \Delta T}, \quad (3)$$

it can be noticed that the modifying the heat transfer coefficient between the sorbent bed and the heat exchanger will allow to reduce the required heat exchange surface. This situation is demonstrated in Figure 2, where for the constant operating conditions of the chiller, the required heat exchanger surface was decreased when the value of coefficient h tends to 1.

![Figure 2. The heat exchanger surface in the function of heat transfer coefficient h.](image)

So according to the relationship:

$$A \sim \frac{1}{h}, \quad (4)$$

the minimal heat transfer surface required to achieve the desired COP by the chiller is inversely proportional to the h coefficient. Therefore, a material with higher thermal conductivity is desirable to fill gaseous spaces in the proximity of heat exchangers and its properties will not reduce adsorption parameters of the porous media.

Moreover, by modifying h coefficient it is possible to improve the parameters which characterize the adsorption chiller as shown in Figure 3, when the h coefficient increases, the Cooling Capacity generated by the chiller increases proportionally. According to (1) the CC directly determines the COP value.

![Figure 3. The Cooling Capacity of the adsorption chiller in the function of heat transfer coefficient h.](image)
These analyses show that the crucial issue in the adsorption beds modeling is the improvement of heat transfer conditions at the heat exchanger-porous media boundary. Possible directions for this optimization are described below.

New Configurations of Sorbent Beds

The COP increase is directly related to the improvement of the efficiency of the sorbent bed work cycle. Therefore an innovative bed design is sought in order to provide more favorable heat flow conditions to reduce the adsorption chiller dimensions.

One of the promising conceptions is to bond the first layer of porous media to the heat exchanger surface with an adhesive material which is characterized by a higher thermal conductivity coefficient than the sorbent and gaseous spaces of the bed volume. The epoxide resins and adhesives based on polyvinyl alcohol PVA have been selected for modifying of the sorption bed construction due to the good thermal conductivity and mechanical strength in humid conditions [9-11]. Another conception is to use a polydisperse bed design. In this approach the gaseous spaces are filled with a grounded sorbent [12]. Mixing different granulations of porous media is beneficial for heat transfer and sorption intensification but it will not bring such a significant improvement in the bed parameters as the coated construction. Therefore these two conceptions are often combined to polydisperse structure with a coated layer of sorbent on the heat exchanger surface. It is also possible to use fine particles of different metals to improve the heat transfer in the sorbent bed. Such experiments were successfully carried out within [13].

Another innovative method of improving the heat transfer is to convert the stationary bed construction to a fluidized bed. With the increase of water vapour velocity in the volume of adsorption bed, the porous media layer is liquefied and the convective heat-transfer coefficient at the boundary of heat exchanger-sorbent is increased. It results from the intensification of mass exchange processes in the fluidized bed [14]. This property of fluidized beds allows to reduce the dimensions of the chiller several times due to high convective heat-transfer coefficient. The intensity of mixing processes at the fluidized bed is principally depended on the type and granulation of porous media [15].

Summary

An adsorption chiller with a conventional construction of the sorbent bed is characterized by a low COP value. This article points to the possibilities of adsorption beds modeling by modifying the heat transfer coefficient \( h \). By increasing its value at constant Coefficient of Performance, it is possible to reduce the necessary heat exchanger surface and therefore reduce the chillers dimensions and to significantly expand the market to new potential customers of chill produced by adsorption chillers. Improving the heat and mass transfer conditions in the sorbent bed requires modifying the conventional bed design in the direction of the innovative approaches presented in this paper.

References


