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Optimization of a three-bed adsorption chiller by genetic algorithms and neural networks

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ABSTRACT

Adsorption cycles have a distinct advantage over other systems in the ability to use low grade heat, especially waste heat of near ambient temperature. A Tri-bed twin-evaporator adsorption chiller constitute an innovative design in cooling production which allows more efficient conversion and management of low grade sources of thermal energy due to more effective way of utilization adsorptive abilities of the beds during a single work. Although it is the most effective way in chilled water production the complexity of the Tri-bed twin-evaporator adsorption chiller operation is still not sufficiently recognized and the improvement in cooling capacity (CC) of the cooler is still a challenging task. The paper introduces artificial intelligence approach for the optimization study of a Tri-bed twin-evaporator adsorption chiller using low-temperature heat from cogeneration. Genetic algorithms (GA) and artificial neural networks (ANN) are used to develop the model which allows estimating the behaviour of the adsorption heat pump. Cooling capacity (CC) as one of the main energy efficiency factor in cooling production is examined during the study for different operating sceneries.

The presented non-iterative approach gives quick and accurate results as an answer to the input data sets. The CC of the chiller, evaluated using the developed model, is in good agreement with the experimental data. Maximum relative error between measured and calculated data is lower than ± 10%. The developed model permits to study the influence of operating parameters on the cooling capacity of the chiller. For the considered range of input parameters the highest cooling capacity which can be obtained by the heat pump is equal 93.3 kW. The method constitutes an alternative, easy-to-apply and useful, complementary technique, comparing to the other techniques of data handling, including the complex of numerical and analytical methods as well as high costs of empirical experiments. The model can be applied for optimizations purposes and can constitute a sub model or a separate module in engineering calculations, capable to predict the CC of the Tri-bed twin-evaporator adsorption cooler, integrated into multigenerative systems.

1. Introduction

Waste heat recovery is one of the main methods allowing improving the total energy efficiency utilization of variety processes with low parameters of heat generated as by-product. Therefore low grade heat utilization is nowadays a desirable challenge in several industrial applications.

Waste heat driven heat pumps seem to be increasing competitors for mechanical coolers. Essential attention is currently paid to adsorption chillers, as they can be powered with low-temperature heat sources and allow to be integrated into cogenerative systems [1,2].

Typical design of a single stage-adsorption chiller includes two fixed-beds which are packed in separate reactors, an evaporator and a condenser [3–5]. Non-standard configurations such as the ones applied in a Tri-bed twin evaporator adsorption chiller exist in industry [1,2]. The application of more than one bed allows to improve the efficiency of the chiller. The odd (three) number of deposits constitutes an innovative solution. Additional novelty of such a design is the use of two evaporators, i.e. systems where chill power is generated in.

Although it is the most effective way to produce chilled water in adsorption coolers [1,2] the improvement of total efficiency of adsorption processes is still a challenging task. As the experiments are the basic cognitive methods which allow one to specify empirical dependencies in Energy Engineering Science, most of discussed in

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Nomenclature

$B_{i,\ L}$	bias neuron i on a layer L, –
CC	cooling capacity, kW
C_{pchill}	isobaric specific heat of chilled water, J kg^{-1} K
m_{chill}	chilled water mass flow rate, kg s^{-1}
T_c	cooling inlet water temperature, °C
T_{Ichill}	chilled inlet water temperature, °C
T_{Ochill}	chilled outlet water temperature, °C
T_h	heating inlet water temperature, °C
T_{hp}	HP inlet temperature, °C
T_{lp}	LP inlet temperature, °C
$W_{i,L,j}$	weight between a neuron i on a layer L and a neuron j on a layer L + 1, –

Greek symbols

τ	cycle time, s
δ	the relative error, %

Subscripts

calc	calculated
exp	measured
i, j	numbers of neurons, $i = 0–4$, $j = 0–1$
L	number of a layer, $L = 0–3$

Acronyms

ANN	Artificial Neural Networks
GA	Genetic Algorithms
LP	low pressure, –
HP	high pressure, –

literature results are usually obtained via expensive and laborious measurements on real objects. In such cases the question is: are obtained values still valid when the object's operational parameters have changed? In such a situation it is sometimes necessary to make another experiment.

So the big challenge, high costs, time-consuming and limitations make the experiments sometimes an insufficient method of data mining.

A mathematical modeling approach constitutes an alternative method of data handling. Different in details or/and sophistication models of adsorption chillers can be found in literature. Modeling of an adsorption desalination cycle and the distributed-parameter approach for transient and steady state behaviors of an adsorption chiller have been shown in [6,7], respectively. A dynamic model of a two-bed adsorption chiller was developed in [8] whilst an advanced three-stage adsorption chiller as well as the entropy generation analysis and performance analysis of a pressurized adsorption chiller can be found in [9–11].

A dynamic simulation model and a thermo-economic analysis of a polygeneration system including photovoltaic/thermal collectors coupled with a solar-assisted heat pump, an adsorption chiller and an electrical energy storage were presented in [12,13]. The TRNSYS environment was used during the study. A mass diffusion algorithm was considered in the numerical model [14] whereas a dynamic model of the adsorption chiller using composite adsorbent employing lithium chloride in silica gel, based on the adsorption isotherms, was shown in [15]. Some interesting data, sometimes necessary to use when modeling of adsorption chillers can be found in [16–18]. Aristov et al. [16] used the ratio "heat transfer surface"/"adsorbent mass" (S/m) which can be helpful in assessing the degree of dynamic perfection of an "adsorbent bed – heat exchanger". The authors established the "grain size insensitive" regime which existed for small grains ($d < 9.5–0.8$ mm) and $(S/m) \geqslant 2\ m^2\ kg^{-1}$. They pointed out that there are many ways of improving of adsorption chillers construction to increase its specific power. Several possible drawbacks were listed there, related to not enough efficient heat transfer through the secondary fins surface, large intergrain mass transfer resistance, low speed or improper distribution of liquids, possible presence of residual air leading to the adsorption rate reduction, improper selection of evaporator/condenser power with respect to power of adsorption/desorption process, not-optimized durations of the cycle or individual steps [16].

Okunev and Aristov [18] performed an interesting analysis and described how the proper choice of adsorbent in terms of its isobar shape can improve the cycle dynamics. They concluded that solely improving this shape allows obtaining the specific cooling power larger by factor of 1.5 as the result of shorter cycle [18].

Lu et al. [17] designed a novel heat pipe solar adsorption chiller with mass-heat recovery. The adsorption cooling performance increased with the increase in hot water inlet temperature and chilled water outlet temperature as well as with the decrease in cooling water inlet temperature. The authors also reported cooling capacity 17.9 kW and coefficient of performance 0.63 for the hot water inlet temperature, cooling water inlet temperature and chilled water outlet temperature of 79.0 °C, 25.4 °C and 13.7 °C, respectively [17].

On the other hand the dynamic behavior of a single effect of loose grain configurations, silica gel particle sizes and design parameters on the switching frequency was discussed by Chakraborty et al., [19] and Alam et al. [20], respectively. Analytically and experimentally investigated silica gel-water system was described in [21,22]. Saha et al. [10] investigated the effect of operating conditions on cooling output and coefficient of performance. The most influential parameters turned out to be the operating temperatures fallowed by water flow rates and cycle time. Boelman et al. [21] reported that the chiller was operational with a hot water inlet temperature of 50 °C. The influence of hot water flow rate was most pronounced below 0.75 k s^{-1}. As they observed, above this value cooling output tends to stabilize.

Long cycle times (360 s and more) leads to the decrease in cooling capacity, so they are suited to partial load operation [22].

Saha et al. presented also a three-bed and a dual mode, three stage non-regenerative and six bed regenerative silica gel – water chillers [23,24]. The innovation solution, dual mode, multi-stage six-bed regenerative adsorption silica gel-water chiller allowed to utilize waste heat sources of temperature 40–95 °C. The advanced cooler operated in two modes: as a highly efficient conventional chiller, where the driving source temperature is between 60 and 95 °C and as an advanced three stage adsorption chiller, where the available driving source temperature was very low (between 40 and 60 °C) [23].

Analytical investigations revealed that both cooling capacity and coefficient of performance increase with lower coolant inlet temperatures. Optimum CC values were observed for adsorption/desorption cycle time between 180 and 300 s [24].

The use of multiple equations, correlations and models sometimes helps to evaluate process parameters. However the correlations given in literature usually differs from one another and being valid only for limited ranges of operating parameters also limits their accuracy and generality.

On the other hand models usually need some additional data, e.g. to adjust parameters or to obtain a trackable solution. The algorithms are often complicated and are based on the solution of complex and time consuming sets of differential equations. That is why they can also be