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NUMERICAL SIMULATION OF A COMPLETELY NOVEL INTEGRATED AD-AB SORPTION REFRIGERATION SYSTEM

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ABSTRACT

In response to some serious issues like the energy crisis and environmental problems associated with the conventional compression refrigeration system, thermal air-conditioning systems were therefore developed to overcome the mentioned problems. A completely novel integrated adsorption and absorption (AD-AB) refrigeration system driven by low-grade temperature heat sources is proposed in this investigation. This novel cycle focuses on the inherent characteristics of the adsorption and absorption phenomena. The innovation here is that the generator of the absorption cycle becomes the evaporator of the adsorption cycle. Therefore, the generation and evaporating pressure are associated with the heat source temperature. Moreover, the adsorber in the adsorption system replaces the condenser in the standard absorption system. Thus, the generation pressure is associated with the heat source temperature and can be adjusted according to the solution concentration and generation temperature.

Keywords: **i**ntegrated AD-AB system, absorption, adsorption, COP, low-grade thermal energy, energy Efficiency.

NONMENCLATURE

Abbreviations	
AD-AB	Adsorption-Absorption
COP	Coefficient of Performance
Symbols	
M	Total amount of mass in each component (kg)
T	Temperature of components (K)
C	concentration of solution
h	specific enthalpy ($\mathrm{jkg^{-1}}$)
ρ	Density ($\mathrm{kgm^{-3}}$)
c_p	specific heat capacity ($\mathrm{jkg^{-1}K^{-1}}$)
V	volume of components ($\mathrm{m^3}$)
q^*	adsorption equilibrium uptake ($\mathrm{kgkg^{-1}}$)
q	instantaneous adsorption uptake ($\mathrm{kgkg^{-1}}$)
R	universal gas constant (8.314472 $\mathrm{jmol^{-1}K^{-1}}$)
θ	temperature of working fluids (K)
X	Concentration of solution at the exit of the absorbent and the generator
$\dot{m}$	mass flow rate between components ($\mathrm{kg}s^{-1}$)
UA	conductance ($\mathrm{KWK^{-1}}$)
A	area ($\mathrm{m^2}$)
R_p	adsorbent particle radius (m)
E_a	activation energy ($\mathrm{jmol^{-1}}$)
D_{S0}	Pre-exponential term ($\mathrm{kg}s^{-1}$)

1. INTRODUCTION

In recent years, the increasing fossil fuels price, the energy crisis and environmental problems such as global warming and ozone layer depletion have been extremely significant issues in international community as most countries are endeavoring to find alternative ways to reduce the carbon dioxide emission from combustion of fossil fuels. Such critical problems therefore made researchers to concentrate on innovative technologies, which can either utilize low-grade energy sources like the waste energy from industrial processes, or solar and geothermal energy. Sorption refrigeration system is one of the most reliable and favored technologies widely used recently in most countries all over the world.

The first commercial sorption refrigeration system is the absorption cooling system. Over the last 50 years, a

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plenty of novel absorption systems have been designed and developed and researchers have performed various studies on different areas such as system components, heat and mass recovery, different working pairs to increase the system performance and avoid crystallization. Published review papers on the absorption refrigeration technology have summarized these research efforts and achievements and [1]. These efforts led to the wide application of absorption systems in solar energy and geothermal energy [2]. However, recently researchers found that absorption systems are not the best option for utilizing high temperature heat sources (>150℃) from the variability and economics point of view. Therefore, efforts have been devoted to developing advanced absorption cycles that work for low heat source temperatures. The single-effect absorption system was theoretically and experimentally demonstrated as an effective means of energy conversion in the temperature range of 90-150℃ and is capable of producing cooling ranging from 1 to 1000 tones [3]. Nevertheless, the performance of the single-effect absorption system is very poor when the heat source temperature is lower than 85℃.

With regard to associated problems related to the absorption, another sorption system called adsorption was received a great attention from the early 1990 [4], and therefore many investigators shifted their research efforts to this new system [5]. Adsorption systems have been widely applied in geothermal energy and solar energy over the last two decades [6]. The choice of the working pair as adsorbent/adsorbate for adsorption cooling has a significant influence on system performance. The current commercial adsorption system uses silica-gel water as working pair and is driven by a heat source with a temperature of 85℃ [7]. The adsorption system works very well at 80℃ without losing much system efficiency. However, the adsorption system did not show a suitable system performance at the low heat source temperature and the Coefficient of Performance (COP) was less than 0.3 with a sizeable cooling capacity.

In this work, a completely novel integrated adsorption-absorption (AD-AB) refrigeration system which combines the absorption cycle and adsorption cycle in one united cooling cycle proposed. As it will be described comprehensively in the following section, the integrated system could be driven by a low temperature heat source with greater efficiencies. Of particular importance, this novel cycle will focus on the inherent characteristics of the adsorption and absorption

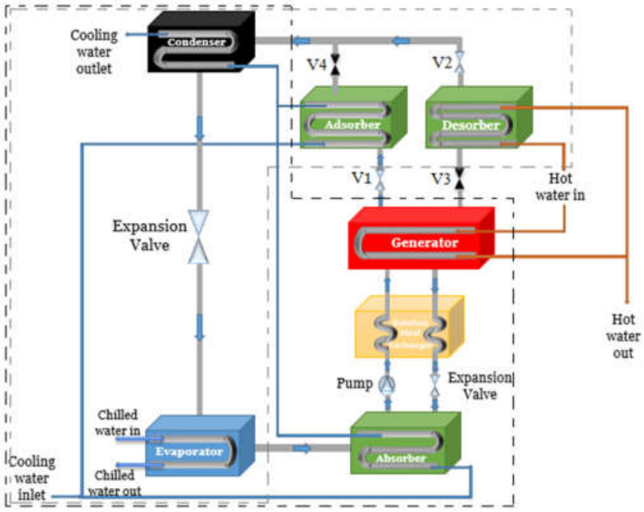

Fig 1 A schematic of an integrated AD-AB refrigeration system.

phenomena in the system. The innovation here is that the generator of the absorption cycle becomes the evaporator of the adsorption cycle. Therefore, the generation and evaporating pressure is no longer determined by the cooling and chilled water temperatures and the pressure is associated with the heat source temperature. This results in a new phenomenon of absorption, adsorption and the coupling of generation of solution and adsorption of refrigerant.

2. INTEGRATED AD-AB SORPTION REFRIGERATION SYSTEM

2.1 Principal operation

Fig. 1 illustrates a schematic of an integrated AD-AB sorption cooling system. As seen from the figure, the system components are an integration of the main components of both absorption and adsorption systems in one integrated system. The integrated system comprises six main components including a condenser, an evaporator, an absorber, a generator, and two adsorption beds called the adsorber and the desorber.

The thermodynamic process of the integrated system can be initially described in the evaporator where the water vaporizes to provide the cooling of the system. The produced vapour is then absorbed by the solution which is actively cooled in the absorber. The produced weak solution is then pumped to the generator to generation whereas the strong solution in the generator is throttled back to the absorber to absorb the water vapour coming from the evaporator. In the generator, the water vapour is desorbed from the solution and is next adsorbed by the adsrobents in the adsorber. Once the adrorber is saturated at the corresponding temperature and pressure, the adsrober is then switched to work as a desorber, where the water vapour is thermally desorbed from the adsorbents with the input heat, and then flows into the condenser. Next, the water vapour is cooled and condensed in the condenser. Thereafter, the liquid water phase expands to a lower pressure through an expansion valve and flows back to the evaporator to make up the evaporator water. Simultaneously, the desorber is switched to work as an adsorber, which continues to adsorber the water vapour generated in the generator.

2.2 Mathematical modeling

A lumped-parameter approach is employed to derive the mathematical modelling of the integrated system. Conservation of mass and energy is applied to all components comprising the integrated system:

$$\frac{\partial M}{\partial t} = \sum_{in} \dot{m} - \sum_{out} \dot{m} \quad \text{Eq. (1)}$$

$$\frac{\partial (MC)}{\partial t} = \sum_{in} (\dot{m}X)_{weak} - \sum_{out} (\dot{m}X)_{strong} \quad \text{Eq. (2)}$$

$$Mc_p \frac{\partial T}{\partial t} = \sum_{in} (\dot{m}h) - \sum_{out} (\dot{m}h) \pm UA\Delta T_{lm} \quad \text{Eq. (3)}$$

$$(\rho c_p V) \frac{\partial \theta}{\partial t} = \dot{m}_{water} (h_{in} - h_{out}) \pm UA\Delta T_{lm} \quad \text{Eq. (4)}$$

Where M stands for mass of refrigerant or solution inside each component, C is for concentration of absorbent inside the generator and the absorber, T represents the temperature of each component and θ is defined for the working fluid circulating through components.

The rate of adsorption and desorption in sorption beds is calculated by the linear driving force (LDF) kinetic equation:

$$\frac{dq}{dt} = 15 \frac{D_{S0} exp(-E_a/RT)}{R_P^2} (q^* - q) \quad \text{Eq. (5)}$$

The energy performance of the system is calculated by the following equation:

$$COP = \frac{\int_0^{t_{cycle}} \dot{m}_{chilled} (h_{in} - T_{out})_{chilled} \, dt}{\int_0^{t_{cycle}} \dot{m}_{hot} (h_{in} - T_{out})_{hot} \, dt} \quad \text{Eq. (6)}$$

3. DISCUSSION

In the integrated AD-AB system, the generation pressure is associated with the heat source temperature and can be adjusted according to the solution concentration and generation temperature. From Fig. 2 it is obvious that the generation pressure, Pgen, at low

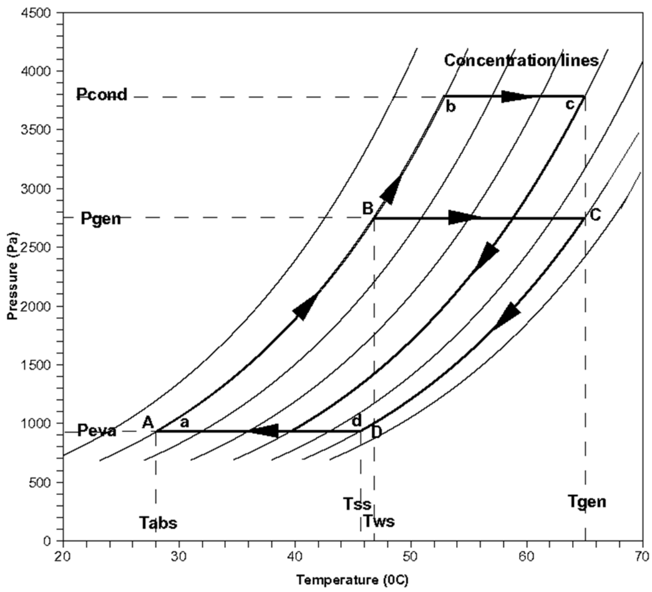

Fig 2 Solution concentration difference between the absorber and generator in an absorption cycle (abcd) and an integrated AD-AB cycle (ABCD) in P-T-X diagram.

heat source temperature is much lower than the normal condensing pressure, Pcond. When the generation happens at this new pressure, the solution concentration difference between the generator and absorber of the integrated system (ABCD) is greater or stays at least the same as that in the high temperature driven absorption system (abcd). This generation pressure is also the evaporating pressure for the adsorption cycle which is much higher than that in the standard adsorption system as shown in Fig. 3. The diagram reveals that the difference of adsorption uptake in the adsorber and desorber at this new evaporating pressure in the integrated system (ABCD) is much larger than that in the standard adsorption cycle (abcd) even though the driven temperature is much lower. It means that the COP of an integrated AD-AB cooling system may be higher than that of an adsorption cooling system due to larger adsorbed concentration difference for the same heat sink and heat source temperatures.

Fig. 4 indicates the variation of the integrated system performance at a wide range of driving heat source temperatures. The COP at each heat source temperature has been obtained at the optimum generation pressure which is determined by the generation solution and hot water temperature. It is revealed from this diagram that the COP tends to increase as the heat source temperature increases and it reaches its maximum value when the heat source temperature varies between 60-75°C. However, it can

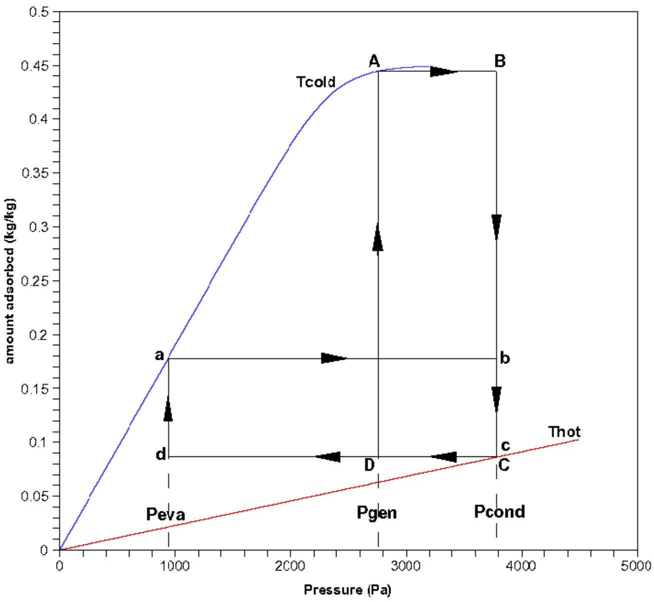

Fig. 3. Adsorption uptake difference in the adsorber and desorber in an adsorption cycle (abcd) and an integrated AD-AB cycle (ABCD) in P-T-q diagram.

be seen a relatively small decline in COP value for higher hot water inlet temperatures applied to the system. It is also observed that the increase in the heat source temperature leads to an increase in the amount of cooling produced in the system. Moreover, the amount of cooling produced in the integrated system is considerably higher than that produced in the individual adsorption system under the same heat source temperature.

4. CONCLUSION

A completely novel integrated AD-AB sorption cooling system is numerically investigated. In the integrated system, the adsorption process happens in the generation pressure which is determined through the generation temperature and solution concentration in the generator. The result reveals that the system indicates a great promise for use with low driving heat source temperature varying between 60-75°C with a relatively high efficiency. Thus, the proposed system could be a very effective design when low-grade thermal sources are available.

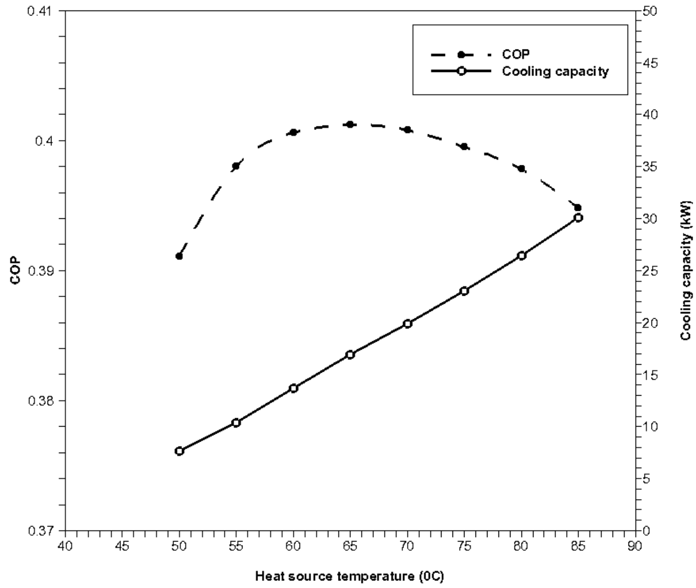

Fig. 4. Variation of COP and cooling capacity with heat source temperature.

REFERENCE

[1] Z. Xu and R. Wang, "Absorption refrigeration cycles: Categorized based on the cycle construction," International Journal of Refrigeration, vol. 62, pp. 114-136, 2016.

[2] M. Siddiqui and S. Said, "A review of solar powered absorption systems," Renewable and Sustainable Energy Reviews, vol. 42, pp. 93-115, 2015.

[3] A. Ochoa, J. Dutra, J. Henríquez, and C. Dos Santos, "Dynamic study of a single effect absorption chiller using the pair LiBr/H 2 O," Energy Conversion and Management, vol. 108, pp. 30-42, 2016.

[4] B. B. Saha, E. C. Boelman, and T. Kashiwagi, "Computer simulation of a silica gel-water adsorption refrigeration cycle--the influence of operating conditions on cooling output and COP," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA (United States) 0001-2505, 1995.

[5] A. Alahmer, S. Ajib, and X. Wang, "Comprehensive strategies for performance improvement of adsorption air conditioning systems: A review," Renewable and Sustainable Energy Reviews, vol. 99, pp. 138-158, 2019.

[6] M. Fernandes, G. Brites, J. Costa, A. Gaspar, and V. Costa, "Review and future trends of solar adsorption refrigeration systems," Renewable and sustainable energy reviews, vol. 39, pp. 102-123, 2014.

[7] Z. He, X. Wang, and H. T. Chua, "Performance study of a four-bed silica gel-water adsorption chiller with the passive heat recovery scheme," Mathematical Problems in Engineering, vol. 2015, 2015.