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Adsorption Cooling Performance Simulation of Silica Gel-Water Pair

Alzam Altof Ayob[1], Fauziah Jerai[1*]

[1] Fakulti Kejuruteraan Mekanikal, Universiti Teknologi MARA, Shah Alam, Malaysia

*Corresponding Author: fauziahjerai@uitm.edu.my

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Abstract: *Global warming is the current issue that we have right now which is caused by the greenhouse gases. Refrigeration technology such as the adsorption cooling system does not release greenhouse gases in the air. This is due to the fact that the system only uses water as its working fluid. In this project, the silica gel-water is used as a working pair for the adsorption cooling system. The water is the adsorbate, while the silica gel is the adsorbent. The first objective of this study is to compare the simulation result from MATLAB software and the experimental result based on the previous research. The second and third objective are to determine the optimum adsorption/desorption time as well as precooling/preheating time based on the MATLAB simulation. Several mathematical equations are needed in order to develop one stage with two beds adsorption cooling system in MATLAB. The required equations are the adsorption kinetics, adsorption isotherms, COP (Coefficient of Performance), mass balance, heat and energy balance for system beds, condenser as well as evaporator. Adsorption, desorption, preheating and precooling are the processes in this system. By using these processes, four distinct modes are generated and named as Mode A, B, C and D. In this study, there are 3 conditions for the inlet temperature of chilled water, hot water and cooling water. The comparison between the simulation result and experimental result will be made in terms of the COP and the temperature profile of adsorber as well as evaporator.*

Keywords: Adsorption cooling system, adsorber, coefficient of performance, Specific cooling Power, Cooling Capacity

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1. Introduction

The standard air conditioning system brings harm to the environment with the release of greenhouse gases in the air. This is certainly worrying; therefore, the global attention has diverted to another emerging technology which is the adsorption cooling system. In comparison with the standard air conditioning system, the adsorption cooling system is better in terms of the environmental aspect. This is because the system uses adsorbent and adsorbate as it's working pair. Examples of adsorbent are zeolite, silica gel and activated carbon. As its's working pair. Some of the adsorbate used are water and methanol, whilst for adsorbents are zeolite, silica gel and activated carbon. These working pairs do not pollute the environment, anti-corrosive and affordable (Tangkengsirisin et al., 1998).

In this project, we chose to study water with silica gel as it is non-toxic, simple and has high latent heat during evaporation (Sharafian et al., 2013). The processes in the adsorption cooling system are preheating, desorption, pre-cooling and adsorption. Hot water is supplied to the adsorber during preheating, while cold water is supplied to the adsorber during precooling.

Both processes ensure that the temperature and pressure of the bed are suitable for adsorption as well as desorption. During the process of adsorption, the adsorbate (water vapour) attaches itself on the porous surface of adsorbent (silica gel) (Allouhi et al., 20140. The reverse of this process is called desorption. During this process, the adsorbate detaches itself from the porous surface of the adsorbent. Several mathematical equations are needed in order to develop one stage with two beds adsorption cooling system in MATLAB. The required equations are the adsorption kinetics, adsorption isotherms, COP (Coefficient of Performance), mass balance, heat and energy balance for system beds, condenser as well as evaporator (Fernandes at al., 2014). All the constants for the equations are taken from the past research (Ghilen et al., 2017 and (Hassan et al., 2014). An analysis will be done on the performance of the one stage with two-bed adsorption cooling system in terms of Coefficient of Performance (COP). In addition, a comparison will be made between the simulation result and the experimental result based on the previous research.

2. Methodology

In this project, the variable parameters are hot water inlet temperature, cooling water inlet temperature and chilled water inlet temperature. There are three conditions for the parameters which are named as condition 1, 2 and 3. The conditions are summarized in the Table 1 below.

Table 1: Heat transfer Fluid Inlet Temperature Conditions

	Hot water inlet temperature (°C)	Cooling water inlet temperature (°C)	Chilled water inlet temperature (°C)
Condition 1	60-95 (variable)	30 (fixed)	15 (fixed)
Condition 2	60 (fixed)	20-40 (variable)	15 (fixed)
Condition 3	60 (fixed)	30 (fixed)	10-20 (variable)

Adsorption, desorption, preheating and precooling are the processes in this system. By using these processes, four distinct modes are generated and named as Mode A, B, C and D. The operation of the valves and modes are summarized in the Table 2. The schematic diagram of Mode A and Mode C for One Stage Two Beds Adsorption Cooling System are shown in Figure 1 and Figure 2.

Table 2: Operation Schedule of Valves and Sorption Elements in a Two-Bed Adsorption System

Cycle	Mode A	Mode B	Mode C	Mode D
Process	Adsorption (Bed 1) & Desorption (Bed 2)	Preheating (Bed 1) & Precooling (Bed 2)	Desorption (Bed 1) & Adsorption (Bed 2)	Precooling (Bed 1) & Preheating (Bed 2)
Duration	600s	30s	600s	30s
Valve 1	Open	Closed	Closed	Closed
Valve 2	Closed	Closed	Open	Closed
Valve 3	Open	Closed	Closed	Closed
Valve 4	Closed	Closed	Open	Closed
SE1	Cooling water	Hot water	Hot water	Cooling water
SE2	Hot water	Cooling water	Cooling water	Hot water

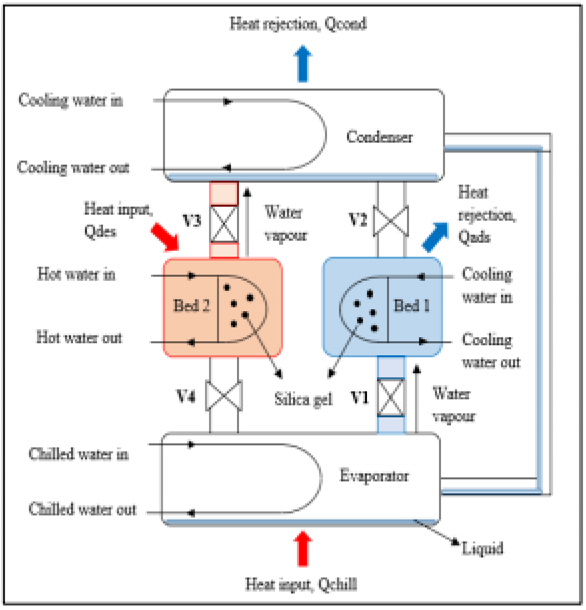

Figure 1: Schematic diagram of Mode A

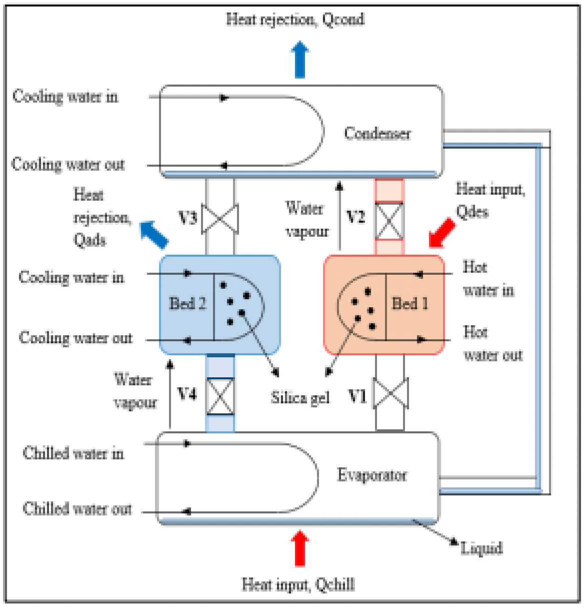

Figure 2: Schematic diagram of Mode C

3. Mathematical Modelling

The mathematical equations that involve in the operation of One Stage Two Beds Adsorption Cooling System are shown in the Table 3 (Merbaki et al., 2016).

Table 3: Lists of mathematical equations

Name of the equation	Mathematical equation	
Adsorption isotherm	$q^* = A(Tsg)\left(\frac{Psat(Tref)}{Psat(Tsg)}\right)^{B(Tsg)}$ $A\,(Tsg) = A_0 + A_1 Tsg + A_2 Tsg^2 + A_3 Tsg^3$ $B(Tsg) = B_0 + B_1 Tsg + B_2 Tsg^2 + B_3 Tsg^3$ $Ps\,(T) = 0.0000888\,(T - 273.15)^3 - 0.0013802\,(T - 273.15)^2 + 0.0857427\,(T - 273.15)^2 + 0.4709375$	(3.1)
Adsorption kinetics	$\frac{dq}{dt} = ksav\,(q^* - q)$ $ksav = 15\frac{D_s}{(R_p)^2}$ $D_s = D_{s0}\exp\left(-\frac{E_a}{RT}\right)$	(3.2)
Energy balance equation of the bed	$\frac{dT_b}{dt}(m_{sg}C_{p,sg} + m_{sg}C_{p,w}q + m_{cu,hex}C_{p,Cu} + m_{Al,hex}C_{p,Al}) = \delta m_{sg}Q_{st}\frac{dq}{dt} - \dot{m}_w C_{p,w}(T_{w,out} - T_{w,in})$	(3.3)

Energy balance equation of the evaporator	$\frac{dT_e}{dt}(m_{ref,eva}C_{p,w} + m_{eva}C_{p,cu}) = -\delta h_{fg}\ m_{sg}\frac{dq_{ads}}{dt} - \dot{m}_{chill}C_{p,w}(T_{chill,out} - T_{chill,in}) + \delta m_{sg}C_{p,w}T_c\frac{dq_{des}}{dt}$	(3.4)
Energy balance equation of the condenser	$\frac{dT_c}{dt}(m_{cond}C_{p,cu}) = \delta h_{fg,des}\ m_{sg}\frac{dq_{des}}{dt} - \dot{m}_{cond}C_{p,w}(T_{cw,out} - T_{cw,in}) - \delta m_{sg}C_{p,w}T_c\frac{dq_{des}}{dt}$	(3.5)
Mass balance equation	$\frac{dm_{ref}}{dt} = -m_{sg}\left(\frac{dq_{des}}{dt} + \frac{dq_{ads}}{dt}\right)$	(3.6)
Heat transfer equation of the bed (adsorption)	$T_{a\_out} = T_b + (T_{in} - T_b)\exp\left(\frac{-U_bA_b}{\dot{m}_{cool}C_{p,w}}\right)$	(3.7)
Heat transfer equation of the bed (desorption)	$T_{d\_out} = T_b + (T_{hot\_in} - T_b)\exp\left(\frac{-U_bA_b}{\dot{m}_{hot}C_{p,w}}\right)$	(3.8)
Heat transfer equation of the evaporator	$T_{chill,\ out} = T_e + (T_{chill,\ in} - T_e)\exp\left(\frac{-U_eA_e}{\dot{m}_{chill}C_{p,w}}\right)$	(3.9)
Heat transfer equation of the condenser	$T_{cw,\ out} = T_c + (T_{cw,in} - T_c)\exp\left(\frac{-U_cA_c}{\dot{m}_{cond}C_{p,w}}\right)$	(4.0)
COP (Coefficient of Performance)	$COP = \frac{Q_{chill}}{Q_{hot}}$ $Q_{chill} = \dot{m}_{chill}C_{p,w}\int_0^{t_{cycle}}(T_{chill,in} - T_{chill,out})dt$ $Q_{hot} = \dot{m}_{hot}C_{p,w}\int_0^{t_{cycle}}(T_{hot,in} - T_{hot,out})dt$	(4.1)

4. Results and Discussion

Figure 3 illustrates the experimental result of the system's performance in terms of Coefficient of Performance (COP) on the variable of Pre-Cooling Pre-Heating/ Time (Al Mubarak at. al, 2020). The blue, orange and grey lines represent the adsorption/desorption time of 5, 7.5 and 10 minutes, respectively. Based on the Figure 3, we can observe that COP is directly proportional to precooling/preheating time. This is because the COP increases as the precooling/preheating time increases. At the precooling/preheating time of 1 minute, the adsorption/desorption time of 5 minutes has the highest COP with the value of 0.28. At the precooling/preheating time of 1.5 minutes, the adsorption/desorption time of 5 minutes also has the highest COP with the value of 0.36. However, this is not the case for precooling/preheating time of 2 minutes as the adsorption/desorption time of 10 minutes has the highest COP with the value of 0.38.

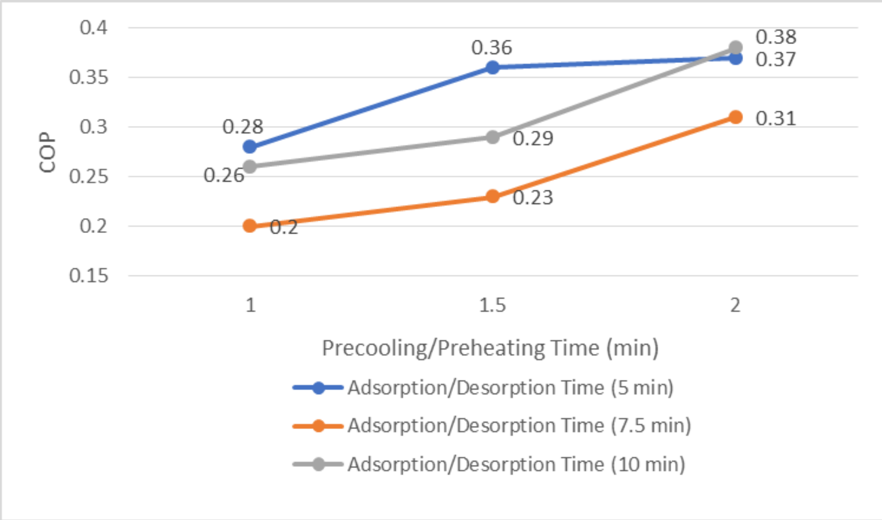

Figure 3: COP vs Variable of Pre-Cooling/ Pre-Heating Variable Time (Experiment)

Meanwhile, Figure 4 shows the simulation result of the system's performance in terms of COP on the variable of Pre-Cooling Pre-Heating Time. In contrast with the result in Figure 3, the values of COP stay constant except for precooling/preheating time at 2 minutes. Since the increase in the value of COP is minimal, therefore we can say that the value of COP is independent with respect to time. Based on the Figures 3 and 4, we can observe that the simulation result has higher COP than the experimental result. The highest value of COP for the simulation result is 0.46, while the highest value of COP for the experimental result is 0.38. This result is in line with the hypothesis that simulation result is higher than experimental result. One of the difficulties that appear when comparing experimental data with predictions coming from simulation tools comes from the fact that the actual thermal loads differ significantly from the estimated ones (Rahman et al., 2014). This is because the thermal load is not constant and its value fluctuates from time to time. From Figures 3 and 4, the optimum adsorption/desorption time is 10 minutes, while the optimum precooling/preheating time is 2 minutes. This is because both parameters recorded the highest value of COP based on the experiments as well as simulations.

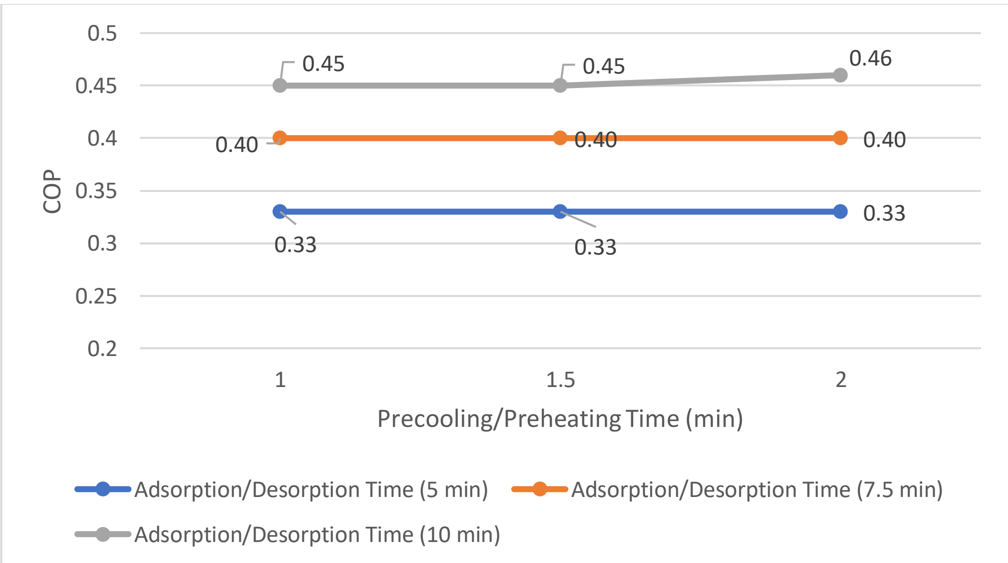

Figure 4: Result of COP vs Variable of Pre-Cooling/ Pre-Heating Time from simulation

4. Conclusion

For this study, there are three objectives namely; to compare the simulation result from MATLAB software and the experimental result based on the previous research, to determine the optimum adsorption/desorption time as well as precooling/preheating time based on the MATLAB simulation. For the comparison, the finding of this study shows that the simulation's result (0.46) has higher COP value than experimental result (0.38). In this study, COP is used as an indicator to determine the optimum adsorption/desorption time as well as precooling/preheating time. The MATLAB simulation results obtained shows that the optimum adsorption/desorption time is 10 minutes, while the optimum precooling/preheating time is 2 minutes.

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