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CFD Simulation of A Heat Exchanger For Adsorption Cooling Application

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ABSTRACT

The adsorption cooling system powered by solar energy is one of the cooling systems used in Malaysia. The usage of renewable energy may help to reduce the demand of petroleum due to global warming issues. There are many researches and findings about this system but the best system is yet to be accomplished. Adsorber is one of the components involved in the cooling system, while the desorption process is the process in the adsorber. The silica gel-water as the adsorbent-adsorbate working pairs is selected in this study because of the low grade heat sources required and low regeneration temperature. The heat exchanger performance is affected by the heating water temperature variation. In this study, ANSYS FLUENT software is utilized to evaluate the performance of a heat exchanger which is also an adsorber of an adsorption cooling system. The heat transfer of the heat exchanger was investigated with variation of heating water temperature starting from 70°C until 90°C at a constant outside temperature of 30°C. It was found that the overall heat transfer coefficient of the heat exchanger has a direct linear relationship with the hot water inlet temperatures,

Keywords: *Adsorption System, Heat Exchanger, Heat Transfer Coefficient.*

Introduction

Demand for air conditioners is increasing as more heat is trapped in the atmosphere and the earth becomes hotter. Today, air conditioning and refrigeration consumes more than 50% of energy in many buildings which leads to severe strain on electricity. Therefore, cooling systems which are economically and environmentally friendly must be adopted. One of the options is through the adsorption cooling system.

An adsorption cooling system is a heat-activated cooling system. It works based on the solid sorption process where an adsorber adsorbs the refrigerant vapour into a solid. The molecules of water vapour or gas are compelled to the surface of porous adsorbent by Van-der-Waal forces. The main types of popular adsorbents are silica gel, activated carbon, activated alumina, polymeric substances and molecular sieve zeolites. Since ecological refrigerants are used, the system is easier to be controlled with lower operating cost [1]. The system can be environmentally friendly since solar energy can be utilized as the heat source [2-5]. Other additional advantages of solar energy are low electricity consumption, low operating costs, less dangerous chemicals and materials used today, such as zeolites and silica gel [6,7].

The selection of working pairs which contains adsorbent-adsorbate is the most vital part in an adsorption system. The adsorbent must be having good compatibility with refrigerant, large adsorption capacity, a large change of adsorption capacity with temperature variation and flat desorption isotherm [8]. However, these accurate understandings of the adsorption phenomenon for the desorption process are difficult to estimate through experimental work.

The key elements in the system are an adsorbent bed, a condenser and an evaporator. Four basic processes involved to complete a cycle of this work include heating of the bed, desorption process, cooling and adsorption process [9]. Figure 1 shows the adsorption cooling system cycle. At point A, the adsorbent bed is saturated with an adsorbate. Temperature and pressure rise because of the heating process. At point B, the desorption process which the adsorbate in the adsorber is heated by hot water flowing through the tubes. Then the water vapour desorbed from the adsorbent condenses in the condenser, through which cooling water flows. The pressure remains invariable, whereas temperature increases. At point C, the bed is ideally entirely regenerated and at that point, the bed is cooled by cooling water. Last at point D when pressure begins to drop, the adsorbate begins to boil. Water evaporates from the evaporator and is absorbed by the adsorbent. The heat is taken from the space to be cooled. The complete cycle is reiterated. Here, a device which provides a flow of thermal energy between two or more fluids at different temperatures or transfers heat from one medium to another is known as the heat exchanger.

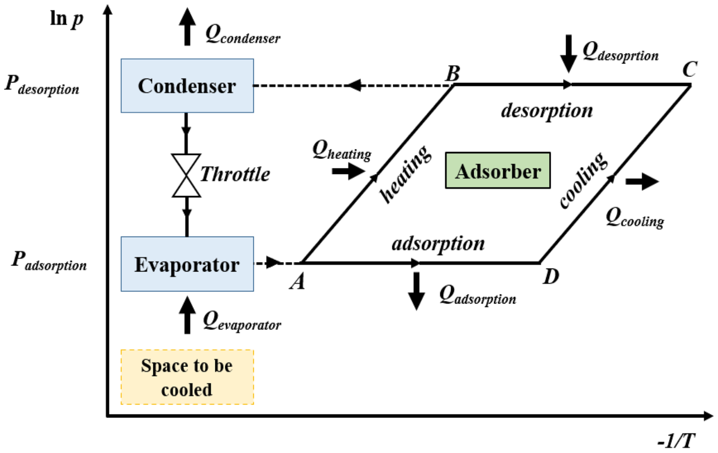


Figure 1: Cycle of the adsorption cooling system.

In this study, the variation of the heating water temperature effect of the heat exchanger (adsorbent bed) was investigated by using the student version of Computational Fluid Dynamic (CFD) software ANSYS Fluent. Here, silica gel-water pair as the adsorbent-refrigerant pair is used. The effect of the heating water temperature, which was treated as the inlet adsorption temperature on absorber heat transfer is presented.

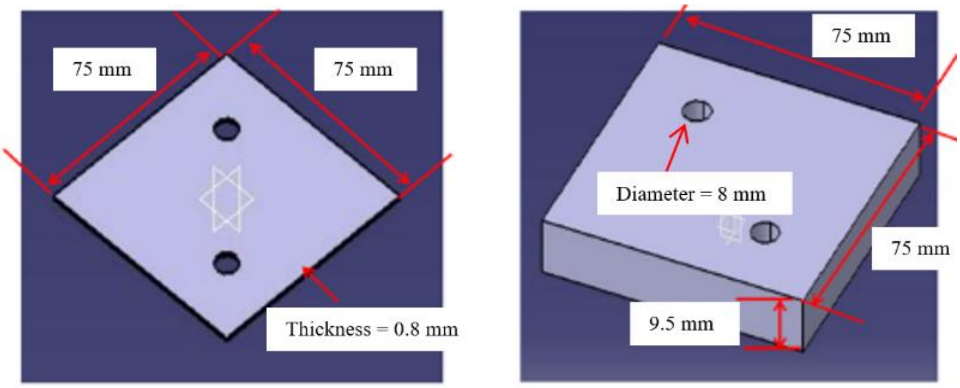
Methodology

The heat exchanger has to transfer heat from the fin to porous adsorbents and the transfer process can be done in three basic forms of conduction, convection and radiation. The mathematical models applied are continuity, Navier Stokes equation and energy equation that incorporated in the Fluent software [10, 11]. Mass conservation, momentum and energy equation for porous media was applied for the silica gel to consider the adsorption phenomena [12-14]. The CFD approach in this study can be divided into three stages: (i) Pre-Processing, (ii) Solving and (iii) Post Processing and details on each stage are as follows.

Pre-Processing Stage

In this stage, the process can be divided into another three processes, namely (i) design geometry, (ii) meshing and (iii) design analysis.

The design of the geometry is an assembly of copper u-tube and silica gel which is packed between aluminium fins. The copper u-tube has a total length of 300 mm plus with a half circumference with a radius of 25 mm. It is a hollow u-tube with an outer diameter of 8 mm and 6 mm in inner diameter. The fin is made from an aluminium plate with a thickness of 8mm and the surface area 75 mm x 75 mm, which is used to transfer the heat from surrounding to the tube as shown in Figure 2(a). For simplicity, the silica gel which is an adsorbate to adsorb or desorb heat dimension is having the same dimension of 75mm x75mm square length but the thickness of 9.5mm (Figure 2(b)). The geometry is initially designed in CATIA software and later imported into ANSYS FLUENT software for further analysis.



(a) (b)

Figure 2 : (a) Aluminium fin designed in the CATIA, and (b) Silica gel (packed) designed in the CATIA.

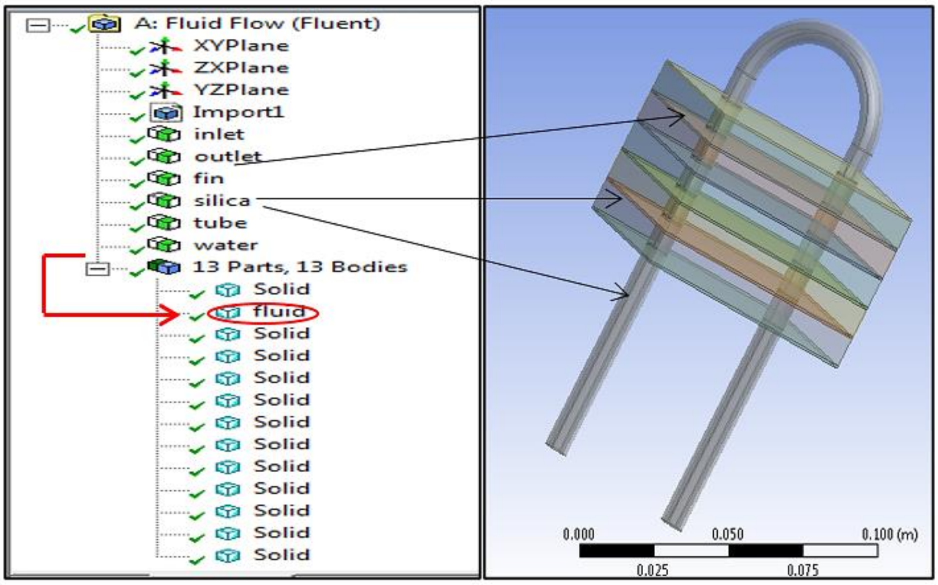


Figure 3 : Geometry of the heat exchanger for simulation purpose.

Figure 3 shows the design of the heat exchanger. The geometry design was imported from the CATIA and labelled in the geometry section. It is important to define the inlet, outlet and other parts for the setup purpose. The "water" is drawn as a body and set as "fluid" and labelled as "water". Then, meshing is done by the tetrahedron method. Inflation method is selected for one body geometry which is defined as a 'fluid' in the geometry part and has six faces of boundary. An element size of 1mm uses the face sizing method. These methods are applied to both simulations. After that, the analysis is selected by using the following boundary conditions:

a) Flow inlet and exit boundaries: pressure inlet, velocity inlet, pressure outlet,
b) Wall, repeating, and limit boundaries: wall, symmetry,
c) Internal fluid, solid,
d) Internal face boundaries: porous, wall, interior.

Solving and Post Processing Stage

After the boundary condition is selected, the solving process is done by using ANSYS FLUENT software. The setup needs to be checked and modified before the simulation is conducted. Table 1 shows the thermo-physical properties of silica gel used in the study. In addition, the desorption heat is Q=2800 kJ was used from the previous experimental results [15]. Total of 300 iterations was done.

Table 1: Thermo-physical properties of silica gel [7]

Parameter	Values
Specific surface area (m²/g)	*450*
Porous volume (mL/g)	*0.85*
Average pore diameter (A)	*22*
Apparent density (kg/m³)	*730*
pH value	*5.0*
Water content (wt. %)	*<2.0*
Specific heat capacity (kJ/kg K)	*0.921*
Thermal conductivity (W/m K)	*0.174*

For this study, the simulation will only focus on the temperature variation for inlet hot water into the u-tube. The chosen parameter for hot water temperature is 70°C, 75°C, 80°C and 90°C and cool water temperature 30°C was selected.

Data Analysis

The rate of heat transfer in a heat exchanger can be related to Newton's law of cooling as equation (1) as shown in Table 2, where U is the overall heat transfer coefficient, A_S is the heat transfer surface area, and ΔT_m is the mean temperature difference between hot water and chilled water. The surface area A_s can be determined using the dimensions of the heat exchanger. The average value of the overall heat transfer coefficient can be determined by using the average convection coefficient for each fluid. The overall heat transfer coefficient U can be determined from equation (2). Where h_i and h_o are the convection heat transfer coefficient inside and outside the tube, which are to be determined using the forced convection relations in equation (3). After calculating both the value of h_i and h_o, the value of U can be determined. Then the value of ΔT_m can be obtained from equation (4).

Table 2: Governing equation

Proces	Governing equation
Heat transfer	$\dot{Q} = UA_s\Delta T_m$ (1)
Overall heat transfer coefficient	$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$ (2)
Convection heat transfer coefficient	$h = \frac{k}{D}Nu$ (3)
Mean temperature difference	$\Delta T_m = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{In(\frac{T_{h,in} - T_{c,out}}{T_{h,out} - T_{c,in}})}$ (4)

Results and Discussions

Solving and Post Processing Stage

Figure 4 shows the temperature contour of the heat transfer for the fins without silica gel and fins packed with silica gel at heating water inlet temperature 80°C. The contour shows that the temperature inside the heat exchanger ranges from 79°C to 77°C. This shows that the tube efficiently transfers the heat from the heating water uniformly to the fins.

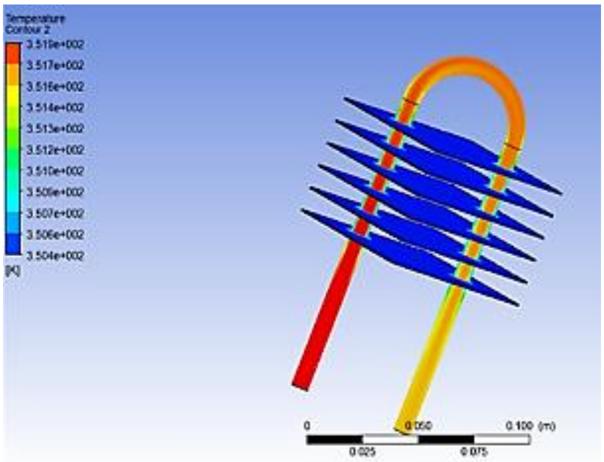


Figure 4 : Temperature contour of the fins without silica gel.

Figure 5 demonstrate the temperature contour of the heat transfer for the fins packed with silica gel and inlet heating water temperature 90°C. The contour shows that the temperature inside the heat exchanger is range from 90 to

80 °C at the tube and range from 30 to 90 °C at the fins area. A higher temperature value can be detected near the u-tube due to the concentrated temperature difference between the fin surface and the surrounding porous silica gel covering the fins. However, a few ‘cool spots’ can be seen at the fins edge due to the heat transfer of the heat exchanger temperature decreasing as it flows through the flat plate fins. This reduction in temperature is partly due to the heat transfer from the aluminium fin to the porous adsorbent.

Figure 6 shows the effects of the heating fluid inlet temperatures on the heat exchanger heat transfer for fins with silica gel and fins without silica gel. As shown in the figures, increasing the heating fluid inlet temperature to the heat exchanger from 70 to 90°C increases the value of the heat transfer from 1.7 to 3.9 W. Increasing the temperature of the heating fluid to the heat exchanger also causes faster heat transfer to the adsorbent material, namely silica gel and the fins. Figure 6 also demonstrates that the heat exchange rate is lower for fins with silica gel as more resistance occurs due to the convection and conduction process through the silica gel, hence increasing the overall heat transfer coefficient. Consequently, the rate of heat exchange for fins without silica gel is much higher as the heat transfer was only through the convection and conduction of the fins and the u-tube.

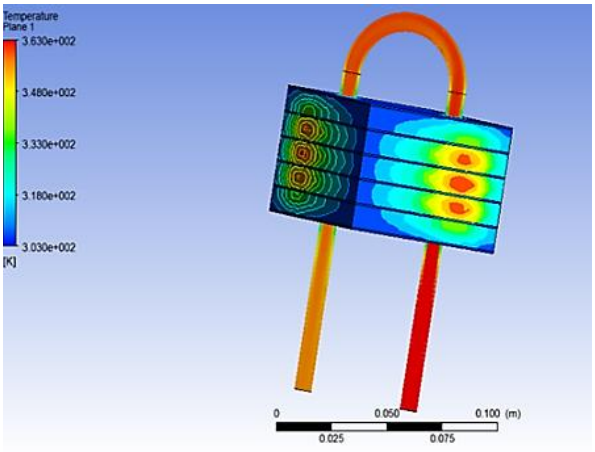


Figure 5 : Temperature contour of the fins packed with silica gel.

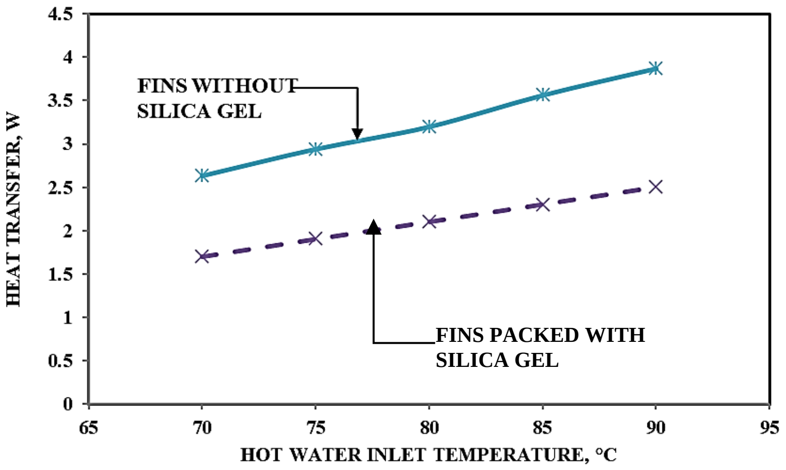


Figure 6 : Heat transfer versus inlet temperature for constant outside temperature 30 °C.

Conclusion

The simulation of heat transfer along the copper u-tube has been done by the aids of CATIA and ANSYS Fluent software. The effect of cooling temperature variation towards adsorber performance was identified. The heat exchange process uses 5 inlet temperatures, which 70°C, 75°C, 80°C, 85°C and 90°C and comparison is made with the outside temperature in the heat exchanger at 30°C. It was observed from CFD simulation carried out on heat transfer on contact points between fins and porous adsorbents that the contact points between the adsorbent and heat exchanger had a significant effect on heat transfer.

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