OPTIMIZATION OF PCM NUMBER IN HOT WATER TANK FOR THE APPLICATION OF SOLAR DRIVEN ADSORPTION CHILLER IN TROPICAL CLIMATE

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Abstract— PCM (Phase Change Material) is becoming more widelyused of thermal energy storage. In fact, PCM is one of the most used thermal energy storage in order to encounter the discontinuity of energy supply. In this paper, PCM is being used for solar adsorption cooling system which attached to the hot water tank to supply hot water into the chiller. Climatic data of tropical climate in Depok, Indonesia is being chosen as the sample area. The most recent chiller developed by SJTU (Shanghai Jiao Tong University) is being applied into the system integrated with a 2 m^3 water tank. The system is being mathematically modelled and simulated using MATLAB®. The simulation is run transiently at working hours in a day. The results demonstrated the running characteristic of chiller in several amount of PCM. The result shows that while using silica gel-water pair adsorption chiller, PCM with the area of 0.2052 m^2 or 180 tubes of PCMs attached to the system has the best performance which has the COP reach 0.3311. On the other hand, while using zeolite-water pair adsorption chiller, the performance has a proportional comparison that more PCM has higher COP.

Keywords— Phase Change Material, Solar Cooling, Adsorption Chiller, Tropical Climate.

I. INTRODUCTION

Energy storage in the form of heat energy is being the most common of storage due to the usefulness and simple method to be stored (Robert C et al, 2011). Water tank is one of the most common usage of storing heat for many applications such solar thermal cooling system, solar hot water system, boiler, power plant, and so on. Moreover, thermal water tank also useful for providing heat energy as the energy source is not available. Unstable source of energy requirement always occurs in many systems such as solar energy system, hydraulic power generation, food preservation, and so on. Solar energy is mainly the most common usage of thermal storage tank. For example in the solar thermal cooling system (Y.M.Han et al, 2009), thermal storage is useful for storing the high temperature water from the solar when it is available at noon, and can be released the heat at night when the cooling system is activated.
Solar adsorption cooling system is one of the most common solar cooling system. In this case, tropical climate has the most suitable area to be applied because of the stable supply of solar energy and cooling demand throughout a year (Meita R. 2012).Therefore, application of solar adsorption cooling is suitable for tropical climate. However, the supply of solar energy is not always in the same value transiently. This also related to the stability of the energy supplied to the system. In previous research work (Nasruddin et al, 2015), it can be shown the maximum and minimum performance within the highest and lowest supply of solar energy in tropical climate.
PCM (Phase Change Material) is one of the main options to improve the performance of thermal storage tank (Murat K, 2007). PCM is being used to keep longer the specific temperature in order to maintain the optimum temperature supply to the chiller.In this paper,it will be described a numerical simulation of the performance of adsorption chiller integrated with thermal storage tank immersed with PCM. There are two types of chiller that being simulated, which material of adsorbent pair is different but both works in the same system.

Nomenclature

A	Area (m^2)
C_p	Specific heat (J kg^{-1} $^oC^{-1}$)
J	Global irradiation heat (Wm^{-2})
k	Conductivity (W m^{-1} $^oC^{-1}$)
E	enthalpy (J)
h	Convective heat coefficient (W m^{-2} $^oC^{-1}$)
L	Water latent heat (J kg^{-1})
Lpcm	PCM latent heat (J kg^{-1})
$\dot{m}$	mass flow (kg s^{-1})
M	mass (kg)
PCM	Phase Change Material
U	Overall heat transfer coefficient (W m^{-2} $^oC^{-1}$)
T	Temperature (^oC)
τ	Time (s)
w	water
hw	water from load
sw	water from solar collector
amb	ambient
lt	tank to ambient

II. METHODOLOGY

2.1. System Description

The system is being adopted from the most recent chiller developed by Shanghai Jiao Tong University

(Pan et al, 2014).The system was modified based on the evaporation temperature in Indonesia which about 7°C and solar panel is applied to collect the solar thermal energy which is stored in a hot water tank. The schematic of the chiller system is shown in fig.1.

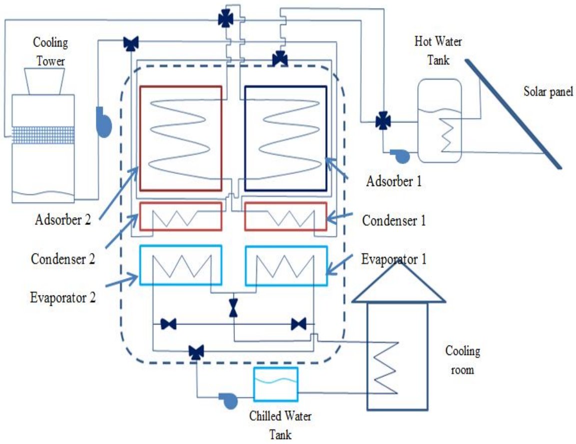

Fig.1 Schematic of Adsorption Chiller

The chiller contains of 2 chambers, which each chamber is arranged with 1 adsorbent, 1 condenser and 1 evaporator. 3 pumps is located 3 different water cycle, which are hot water cycle, cooling water cycle, and chilled water cycle. Chiller is operated in 6 modes which each chamber is operating in 3 modes, such as refrigeration mode, mass recovery mode, and heat recovery mode. The system is being operated with assumption of cooling tower is not effected to the ambient temperature, so cooling water inlet to the chiller is always in 30°C. In addition, the chilled water inlet is also assumed to be stable at 12°C.

- Pressure is homogeneous in adsorber.
- Pressure difference between adsorber and condenser while desorbing or evaporator when while evaporating is neglected.
- There are no pressure drop along the pipe.
- The refrigerant is being adsorb homogeneously, and forms as liquid in the adsorbent
- The chiller system is isolated adiabatically.

Another consideration being simulated is the hot water tank. Hot water tank is developed using thermal stratification method (Y.M. Han et al, 2009), which shown in fig.2.

In case of analyzing thermal water storage tank, thermal stratification is one of the most common method to predict the performance. One dimensional effect of heat transfer is being conducted via multi nodes in the tank which shown in fig.2. It shows a multiple node in vertical direction included the PCM for each node. The PCM is placed in a immersed placement in order to maximize the PCM usage, so that every part of the area in PCM is directly connected to the water in tank. Stratification of tank divided the tank into n-numbers of control volume. Then each control volume is being analyzed transiently.

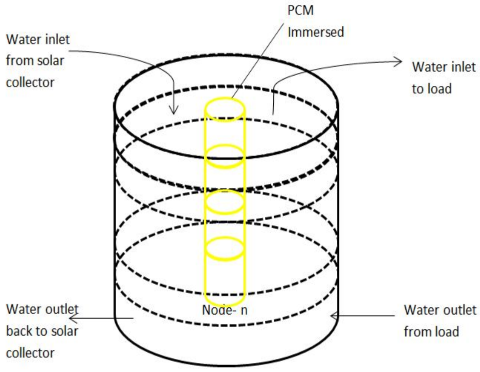

Fig.2 Schematic Stratification of hot water tank

The analysis of stratification tank is conducted via the heat transfer analysis of each node which shown in fig.3. The heat transfer in conduction mode and convection mode. The conduction is carried out by the water layer to the tank and then to the environment via the tank wall. As well as the conduction for each layer of water is being conducted. In most case, the mass flow from the heat souce (in this case from solar collector) or from the chiller is much higher than the natural convection, so the natural convection can be neglected. However, if the tank is not supplied by the heat souce or supplied to the load, then the natural convection should be taken into account. In this case, the analysis is limited if the heat load is being operated with PCM

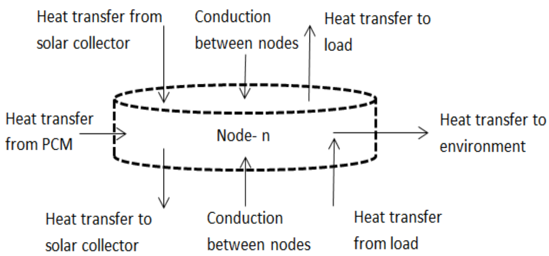

Fig.3 heat transfer at each node

2.2. Mathematical Model

The model is developed according to the energy balance in every process of the chiller. The chiller simulation is based on the previous work (Nasruddin et al, 2015) that being analyzed the chiller simulation using euler method. However, in developing the material using zeolite, the adsorption equation is being adopted from the characteristic analysis (Chan K.C et al, 2012).

Hot water tank is being adopted in the system as the heat source container. The solar collector is being the heat source, then it stored the heat in the tank. The tank is being modelled as the hotter part is in the upper side and cooler part in the lower side, according to difference of density. In consequence, the circulation of water is being modelled on the figure 1. Energy balance is being calculated using a stratification node model as shown in fig.3. The heat transfer is being analyzed in every node as illustrated in fig.3 and calculated using a formula (1) and (2).

$$C_{p,w} M_{water,noden} \frac{dT_n}{d\tau} = \dot{m}_{sw} C_{p,w} (T_{n-1} - T_n) + \dot{m}_{hw} C_{p,w} (T_{n+1} - T_n) + U_{lt} A_{side,n} (T_{amb} - T_n) + k_{air} \frac{A_{crossside,n}}{nodedistance} (T_{n+1} - T_n) + k_{air} \frac{A_{crossside,n}}{nodedistance} (T_{n-1} - T_n) + U_{PCM} A_{side,n} (T_{PCM} - T_n) \quad (1)$$

$$\frac{1}{U_{lt}} = \frac{1}{h_{tankdepth}} + \frac{tankthickness}{k_{tank}} + \frac{1}{h_{\infty}} \quad (2)$$

Where T_{PCM} is the function of PCM stored energy. Energy (enthalpy) of PCM is influenced by the energy transfer from the PCM as shown in formula (3) and (4).

$$dE_{PCM} = C_{p,PCM} M_{PCM,n} \left(T_{PCM}^{t+1} - T_{PCM}^{t}\right) d\tau \quad (3)$$

$$dE_{PCM} = U_{PCM} A_{side,n} (T_n - T_{PCM})\, d\tau \quad (4)$$

Equation (3) and (4) is only valid when the energy changes as the function of temperature. While when the phase change occurs, enthalpy change is also effected by latent heat of PCM, because the temperature changes are extremely small. The PCM is chosen according to the operating temperature of the chiller.

III. SIMULATION PARAMETER

Climatic data being used is a simulation in Depok, Indonesia as the sample area that presented in Fig.4 and Fig.5. Simulation is being carried using MATLAB® software, as the calculation is being counted numerically using euler method. The output will be counted transiently in every second of operation.

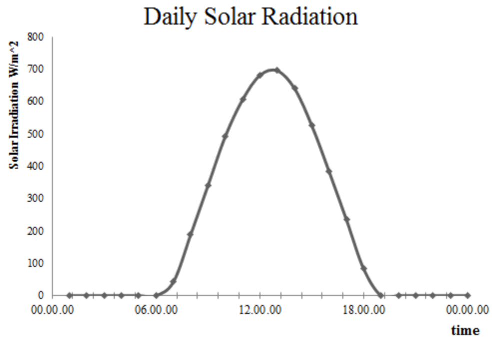

Fig.4Daily solar radiation in Depok, Indonesia

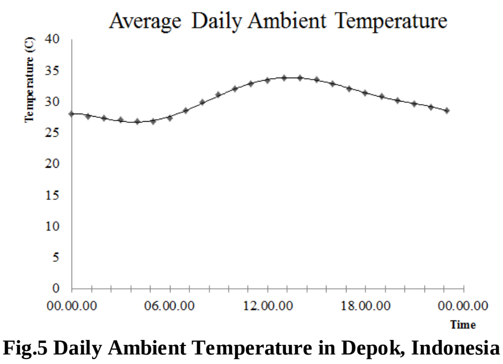

Fig.5 Daily Ambient Temperature in Depok, Indonesia

Simulation is carried under the refrigeration time for 600 s, mass recovery 40 s, and heat recovery 24 s each cycle. Moreover, the temperature of cooling water is stable at 30°C, and chilled water inlet at 12°C. Furthermore, chiller is being operated in the hot water inlet temperature range from 60°C to 90°C. Then the chiller is being simulated for 39,600 s according to the working hours from 07:00 to 18:00. The chiller system parameters are based on previous work (Nasruddin et al, 2015).

The size of hot water tank is being adapted with the commercial water tank of 2 m^3 with the material of steel coating and fiber-glass 0.047 m insulation. At the normal condition, U_{tank}value can be assumed at 1.13 $W/m^2\,°C$. While at the top layer the insulation is has doubled insulation so the U value is 0.66 $W/m^2\,°C$. At the base layer of the tank, it is direcly touch to the ground which is assumed the U value about 3.06 $W/m^2\,°C$. Simulation using PCM is being conducted assuming the PCM is immersed into the center of the tank that using copper pipe. The simulation is conducted using the commercial copper pipe with diameter of ¾ inch and total number of pipes is being simulated from 0 to 400 pipes. The number of pipes is restricted by the size of the tank, when the tank has the bigger size, then more pipes can be immersed into the tank. In this case, 400 pipes is already filled up the tank.The PCM is chosen according to the operating temperature of the chiller, where is chosen the paraffin material RT80, which has the melting point of 80°C.

IV. RESULTS AND DISCUSSION

The simulation is being conducted in a day with and without PCM immersed in the hot water tank. The chiller is being started with condition that already being heated a day before the chiller being operated. The variation of data of irradiation is presented using Meteonorm® and calculated by the average value of the same hour in a year.

Fig.6 demonstrated the operating characteristic of chiller in Depok without PCM.The operating chiller shows that the COP is 0.3304. In addition, the cooling capacity can reach the maximum value of 37.45 kW which is reached at 7 hours after the chiller starts or at 14:00. When the chiller starts in first 1.5 hours, the inlet temperature is decreasing because of the irradiation still in the minimum condition. However in the next hours, the temperature is increasing to above 200 W/m^2 and overcome the energy usage of the chiller. On average, the cooling capacity for the chiller applied in Depok with initial heat is 21.01 kW. In case of the temperature of tank is being used again in the next day, it is unavailable if there is no PCM or other additional heating, because during the night, the temperature of the tank will drop to below 60°C that is unable to start the chiller.

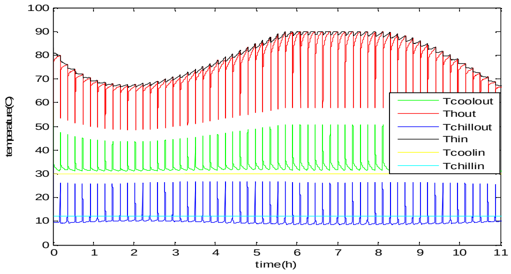

Fig.6 Operating Characteristic Silica gel-water Adsorption Chiller without PCM

On the other hand, when the tank is immersed with additional PCM that shows in fig. 7, the hot water temperature can be maintained a quite stable condition. However the COP is not effected much which the COP becomes 0.3311 as the maximum value at 180 pipes with initial heating the cooling capacity 21.89 kW. The most effected is only the stability of the temperature, and it would be feasible to use the hot water for the next day, because the temperature is still above 65°C.

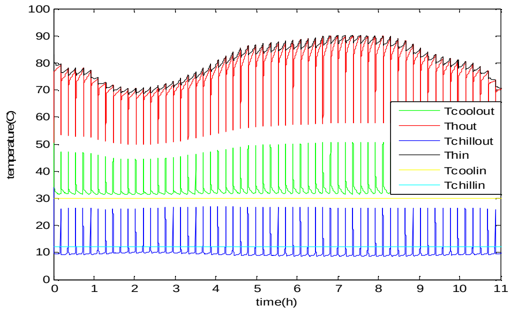

Fig.7 Operating Characteristic Silica gel-water Adsorption Chiller with PCM

Another system that using zeolite-water as the adsorbent pair shows in fig.8 and fig.9. Both of the figure show the operating characteristic that similar to the silica gel-water chiller. However, the zeolite-water pair chiller has a lower heat load than silica gel-water chiller. Therefore, the hot water temperature can be reached maximum temperature faster. Although the temperature is high, the cooling capacity and the COP is not as high as the silica gel-water chiller. In the condition without PCM which characteristic shown in fig.8, the value of COP and cooling capacity are 0.2555 and 12.62 kW.

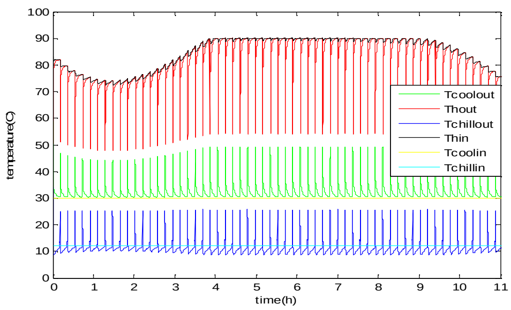

Fig.8 Operating Characteristic Zeolite-water Adsorption Chiller without PCM

For the condition the tank is immersed with additional PCM that shows in fig. 9, the hot water temperature can be maintained always above 80°C. This means the PCM works better when more PCM immersed.This is also effected the COP and the cooling capacity that has the proportional relation which more PCM integrated, then higher performance can be achieved.

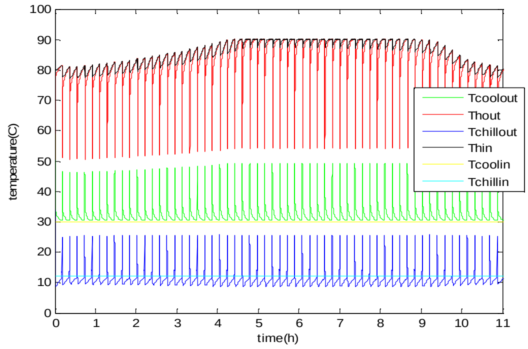

Fig.9 Operating Characteristic Silica gel-water Adsorption Chiller with PCM

Fig. 10 and fig.11 show how the number of PCM can effects the performance of chiller that represented by the COP value.For the silica gel-water adsorption chiller that demonstrated in fig.10, the optimum number of PCM is about 180 pipes or about 0.2052 m^2 of PCM in ¾ inch pipe. More PCM does not improve the COP because the temperature will be harder to reach the maximum. Therefore, after more than 180 pipes of PCM, the performance is decreasing. However, more PCM can make the hot water temperature more stable between 80°C.

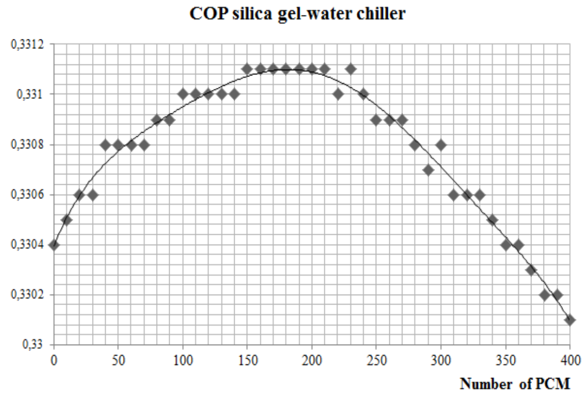

Fig.10 Characteristic of COP vs number of PCM for Silica gel-water Adsorption Chiller

For the zeolite-water adsorption chiller that shown in fig.11, the effect of PCM has a linear trend that more PCM can increase the chiller performance. This is caused by the material characteristic that makes the chiller has a lower heat load. In consequence, the hot water can be easier being heated. In case of more PCM, the hot water temperature can be more maintainable. This relation effects to the better performance when the temperature can be more maintainable.

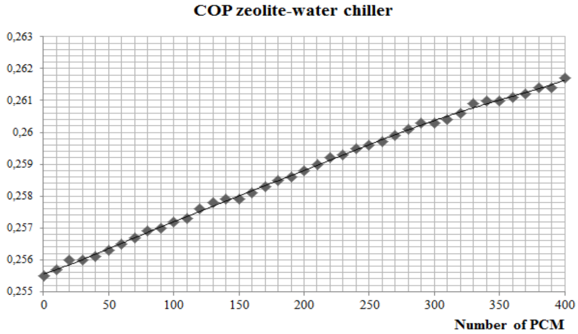

Fig.11 Characteristic of COP vs number of PCM for Zeolite-water Adsorption Chiller

CONCLUSIONS

The immersed PCM in hot water tank can be effected the performance of solar adsorption chiller. The simulation of two types of chiller which has silica gel-water pair adsorbent and another one has zeolite-water pair adsorbent, were studied and can be concluded as follows:

1. PCM can improve the performance of chiller.
2. For silica gel-water adsorption chiller, 180 pipes of PCM or about 0.2052 m^2 of PCM in ¾ inch pipe can reach the highest value of COP.
3. For zeolite-water adsorption chiller, the COP has a proportional relation with the number of PCM, which more PCM can improve better COP.

ACKNOWLEDGMENTS

This work is supported by Indonesian National Research Fund for Higher Education (HIBAH PUPT DIKTI) in 2015 Contract number: 0577/UN2.R12/HKP.05.00/2015

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