International Journal of Technology (2016) 2: 254-263
ISSN 2086-9614

THE EFFECT OF ZEOLITE ADSORBENT GRANURAL SIZE ON SOLAR ADSORPTION CHILLER FOR UNIVERSITAS INDONESIA AREA

Nasruddin[1*], Dicky Alamsyah[1], Dylan Budiman[1], Jeremy Ericsson[1]

[1] *Departement of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia*

(Received: October 2015 / Revised: December 2015 / Accepted: January 2016)

ABSTRACT

Cooling systems in tropical countries consume a large portion of the overall energy usage in a building, especially in tropical climates, where there is an especially high demand on cooling systems throughout the year. This paper presents a simulation of the effect of zeolite adsorbent granular size on a zeolite-water solar adsorption chiller for Universitas Indonesia. The adsorption chiller is being mathematically modeled and calculated numerically, using MATLAB®. The mathematical modeling is based on heat transfer principles inside the system for the water inlet and outlet of the system. The adsorption chiller is based on the most recent chiller developed by Shanghai Jiao Tong University (SJTU). The simulation results generally demonstrated the running characteristics of the chiller under a range of different values of granular size. The average granular sizes used in the simulation ranged from 0.5 mm to 1.5 mm. Furthermore, the simulation results showed in detail that the smaller the average granular size of zeolites, the faster the time needed to reach the maximum hot water temperature and the balance state of chilled water outlet temperature.

Keywords: Adsorption chiller; Granular size; Water; Zeolite

1. INTRODUCTION

Air conditioning has been identical to a vapor compression system. Although a vapor compression system is an easy way to produce cooling, it uses a high level of energy and contributes to global warming as a result of its use of clorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) gas refrigerants. According to Wang et al. (2013), buildings use 41% of the world's available energy, 33% of which is used by their air conditioning systems. Today, another kind of cooling system—an adsorption chiller—is very popular among scientist (Fernandes et al., 2014). Besides being able to utilize natural refrigerants, this kind of system can also use waste heat from industrial activities or solar energy to generate cooling from adsorption chillers, which will have no negative effect on global warming. Solar irradiation in Indonesia can reach 1,000 W/m^2 during mid-day (Jacobs, 2010), which is a high amount of heat that can be used by the adsorption chiller as a source of power. Since Indonesia is a tropical country, it has continuously high irradiation throughout the year for constant use of the adsorption chillers. The heat generated from solar irradiation can easily meet the heating required to generate cooling power from an adsorption chillers, which can range from 50-600^{o}C. An adsorption chiller is a simple mechanism with a low operating cost, since it needs little maintenance.

*Corresponding author's email: nasruddin@eng.ui.ac.id Tel. +62-21-7270011, Fax. +62-21-7270077
Permalink/DOI: http://dx.doi.org/10.14716/ijtech.v7i2.2988

These advantages will help the system to be more beneficial when used in the future. However, there are also some disadvantages to this system as well, such as a low Coefficient of Performance (COP) and a price that is more expensive than that of vapor compression systems.

2. EXPERIMENTAL SETUP

The adsorption chiller uses two adsorbers, two condensers, and two evaporators, as shown in Figure 1 (Pan et al., 2014), in order to ensure that cooling is generated continuously.

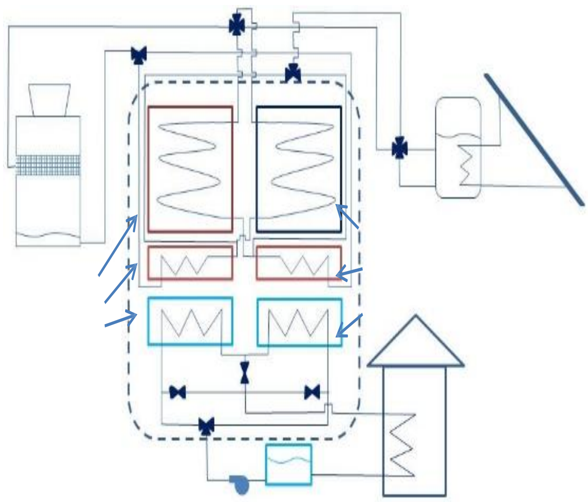


Figure 1 Schematic of adsorption chiller

The condenser and evaporator are both heat exchangers with water constantly flowing through them, using an automatic control with a time-based valve control. The solar panel and the cooling tower are essential components to the adsorption chiller because without it, heating and cooling process will not work since there will be no heat source and no heat rejected from the system. Heat and mass recovery procedures are also used in this system. The Euler numerical method is used with the MATLAB® to run the adsorption chillers simulation. The simulation is counted every second for 30 cycles, with one cycle run for 664 seconds, 600 seconds cooling time, 40 seconds mass recovery, and 24 seconds heat recovery. The solar heat input is based on the average daily value of solar intensity in Depok, West Java, which can be seen in Figure 2.

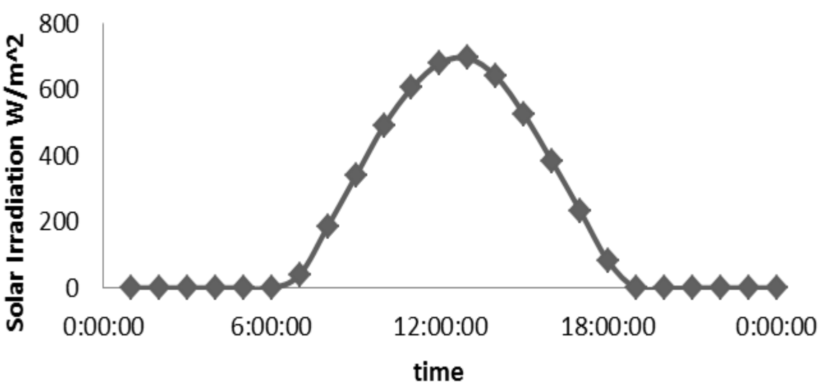


Figure 2 Daily solar irradiation

The conditions of this simulation follow that of Pan et al. (2014), even though the heating source is not stable. At the beginning of the simulation, it is assumed that hot water was heated first to 83°C, and then the solar collector was allowed to conduct the heating process, which is assumed to have been running for 11 hours by 8:00 AM. The zeolite properties used are based on Chan et al. (2012) experiment, albeit with different granular sizes. The granular sizes of zeolite used in this simulation are 0.5 mm, 1 mm, and 1.5 mm, and therefore analyzable.

Table 1 Parameters of simulation

Parameters	Value	Unit
Ac	400	m^2
H	0.35	%
Ca	836	J/kg/°C
Cal	905	J/kg/°C
Ccu	386	J/kg/°C
Cp,w	4180	J/kg/°C
Cw,v	1850	J/kg/°C
Dso	3.92E-06	m^2/s
Ea	2.80E+04	J/mol
ΔH	3.40E+06	J/kg
UAad	51315	W/°C
UAc	79326.5	W/°C
UAe	35352.6	W/°C
L	2.50E+06	J/kg
Ma	250	kg
Mtube	94.85	kg
Mfin	48.8	kg
Mc	172.62	kg
Me	471.68	kg
R	8.314	J/mol/°C
mhw	6.8055	kg/s
$mchill$	2.63888	kg/s
$mcool$	9.583	kg/s
Mhwt,w	2180	kg
Rp_1	0.0005	m
Rp_2	0.001	m
Rp_3	0.0015	m

3. MATHEMATICAL MODELING

The simulation is based on heat transfer principles inside the system for the water inlet and outlet of the system. The simulation properties and constants are shown in Table 1.

3.1. Adsorption Isotherms

The non-equilibrium equation of adsorption isotherms of zeolite-water adsorption kinetics (Wang & Oliveira, 2006) is shown in Equation 1:

$$\frac{dX}{dt} = 15\ Dso\ exp\left[\frac{-Ea}{R.Tb}.\frac{(X^{*}-X)}{(Rp2)}\right] \quad (1)$$

where X* is the equilibrium capacity in the adsorber and can be calculated with the Dubinin-Radushkevich model (Yildirim, 2011) shown in Equation 2:

$$X^{*} = Xo\ exp\left[-k\left(\frac{T}{Tsat-1}\right)^{n}\right] \quad (2)$$

where X_o is the maximum water uptake value of zeolite water at 0.122 kg/kg, where *k* and *n* are dimensionless constants at 5.052 and 1.4, respectively.

3.2. Adsorption and Desorption Process

The equations used in the adsorption and desorption process of the adsorption chiller are adopted from Nasruddin et al. (2015). At the beginning of the process, the adsorbent should be heated to begin the desorbing process. In this case, solar energy is being used to produce heated water in order to desorb water from the adsorber. The solar energy equation is shown in Equation 3.

$$q = \eta A_{solar\ panel} J \tag{3}$$

The heat from the solar panel is transferred to hot water held in a tank. The energy balance is calculated in Equation 4.

$$Cp,w\, Mhwt,w \frac{dTh,in}{dt} = q + \dot{m}hw\, Cp,w\, (Th,in - Th,out) \tag{4}$$

To get an alternating use of the adsorption and desorption processes, two adsorption/desorption beds are required to accomplish each process. The energy balance of the bed is expressed in Equation 5.

$$\frac{dTb}{dt}[Mad\,(Cad + Cp,w\,X) + Ccu\,Mtube,ad + CAl\,Mfin,ad] =$$

$$Mad\,\Delta H \frac{dx}{dt} + \dot{m}hw\, Cp,w\,(Tad,in - Tad,out) - \delta\, Ma\, Cw,v\,(Tb - Te)\frac{dx}{dt} \tag{5}$$

where δ acts as a logic value; δ = 1 is for an adsorption process, and δ = 0 is for a desorption process.

The temperature difference is calculated using the LMTD method, which is expressed in Equation 6.

$$\frac{Tad,out-Tb}{Tad,in-Tb} = exp\frac{-UAad}{\dot{m}hw\,Cp,w} \tag{6}$$

For the energy equilibrium, the condenser energy balance is given in Equation 7.

$$Mc\,Ccu \frac{dTc}{dt} =$$

$$(1 - \delta)[-L\,Ma \frac{dx}{dt} + Cw,v\,Ma \frac{dx}{dt}(Tc - Tb) +$$

$$\dot{m}cool\,Cp,w\,(Tcool,in - Tcool,out)] \tag{7}$$

The temperature difference is also calculated by the LMTD method, expressed in Equation 8. The evaporator energy balance is therefore given in Equation 8.

$$\frac{Tcool,out-Tc}{Tcool,in-Tc} = exp\frac{-UAc}{\dot{m}cool/Cp,w} \tag{8}$$

$$\frac{dTe}{dt}[Me,w\,Cp,w + Ccu\,Me] =$$

$$\delta\left[-L\,Ma\,\frac{dx}{dt}+\dot{m}chill\;Cp,w\,(Tchill,in-Tchill,out)\right]+$$
$$(1-\delta)\left[\Theta\,Cp,w\,(Te-Tc)\,Ma\,\frac{dx}{dt}-(1-\Theta)\,L\,Ma\,\frac{dx}{dt}\right] \tag{9}$$

where Θ is a flag equation, which has a value of Θ = 1 if $T_c \leq T_e$, while Θ = 0 if $T_c > T_e$

The temperature difference can also be calculated by the LMTD method, expressed in Equation 10.

$$\frac{Tchill,out-Te}{Tchill,in-Te}=exp\,\frac{-UAe}{\dot{m}chill/Cp,w} \tag{10}$$

3.3. Mass and Heat Recovery Equations

Mass and heat recovery are critical to the adsorption and desorption process, since it will increase overall efficiency of the adsorption chillers. The energy balance for the mass recovery used is expressed in Equation 11.

$$\frac{dTe}{dt}\,[Me,w\;Cp,w\;+\;Ccu\;Me]=$$
$$\delta\left[-L\;Ma\,\frac{dx}{dt}+\dot{m}chill\;Cp,w\;(Tchill,in-Tchill,out)\right]+$$
$$(1-\delta)\left[\Theta\;Cp,w\;(Te-Tc)Ma\,\frac{dx}{dt}-(1-\Theta)L\;Ma\,\frac{dx}{dt}\right]-$$
$$(1-\zeta)\;[Cp,w\;(Tchill,in,-Tchill,in)] \tag{11}$$

where $T_{chill,in}$ is the chilled water outlet temperature after the chilled water flows through the inactive evaporator, and ζ represents the flag values of 1 and 0, when the evaporator is active and inactive, respectively.

There is no change in the energy balance of heat recovery; however, there are substitute variables, as shown in Equation 12 and 13 respectively.

$$Tad,out,ads\;=\;Tad,in,des \tag{12}$$
$$Tcool,out\;=\;Tad,out,des \tag{13}$$

3.4. Cooling Capacity and COP

COP is used to judge the reliability of the system. The COP is calculated using the ratio between the cooling capacity (Qr) and the heating power (Qh), as shown in Equation 14, 15, and 16.

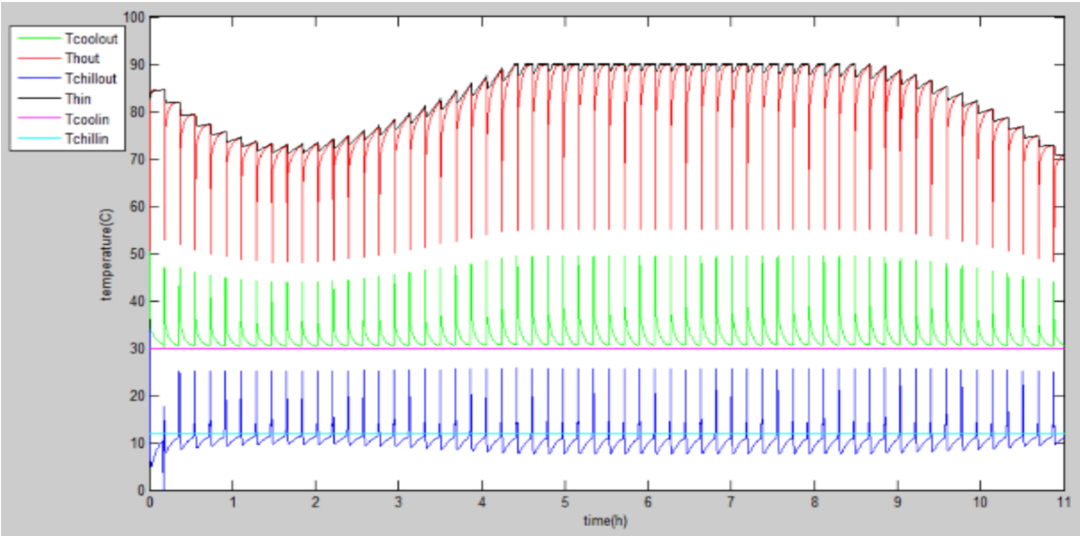
$$Qr\;=\;\frac{\int_0^{tcycle}\;Cp,w\;\dot{m}chill\;(Tchill,in-Tchill,out)\;dt}{tcycle} \tag{14}$$
$$Qh\;=\;\frac{\int_0^{tcycle}\;Cp,w\;\dot{m}hw\;(Th,in-Th,out)}{tcycle} \tag{15}$$

$$COP = \frac{Qr}{Qh} \tag{16}$$

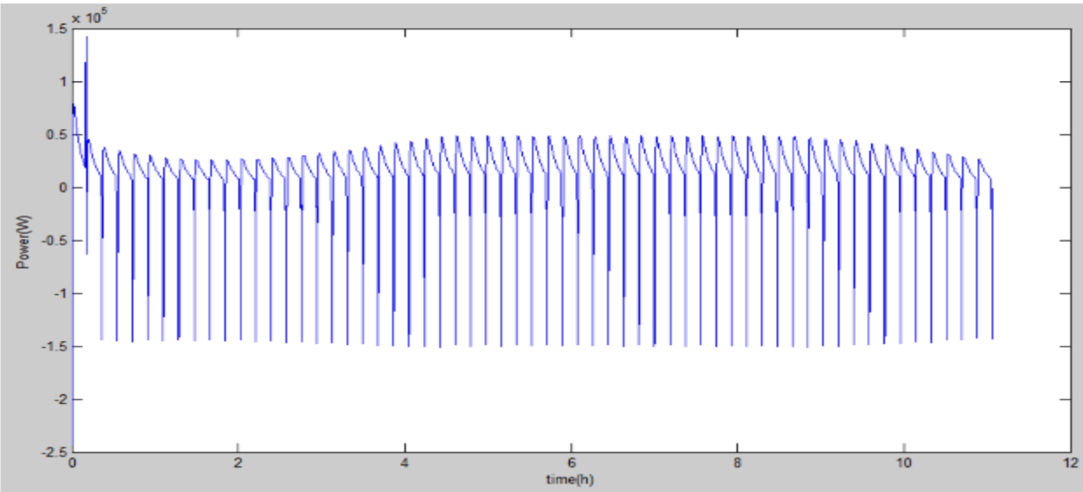
4. RESULTS AND DISCUSSION

4.1. Spiral Chaotic Move

At the center of this related study, zeolites have a higher porosity rate than silica gel. Zeolites are crystalline microporous alumina silicate minerals and well-known physical adsorbents. Their heat of adsorption is 3300-4200 kJ/kg, and their regeneration temperature is 250-300^{o}C. The free variable taken part in the running characteristic of the adsorption chillers is the zeolite diameter, which is divided into 0.5 mm, 1.0 mm, and 1.5 mm.



(a)

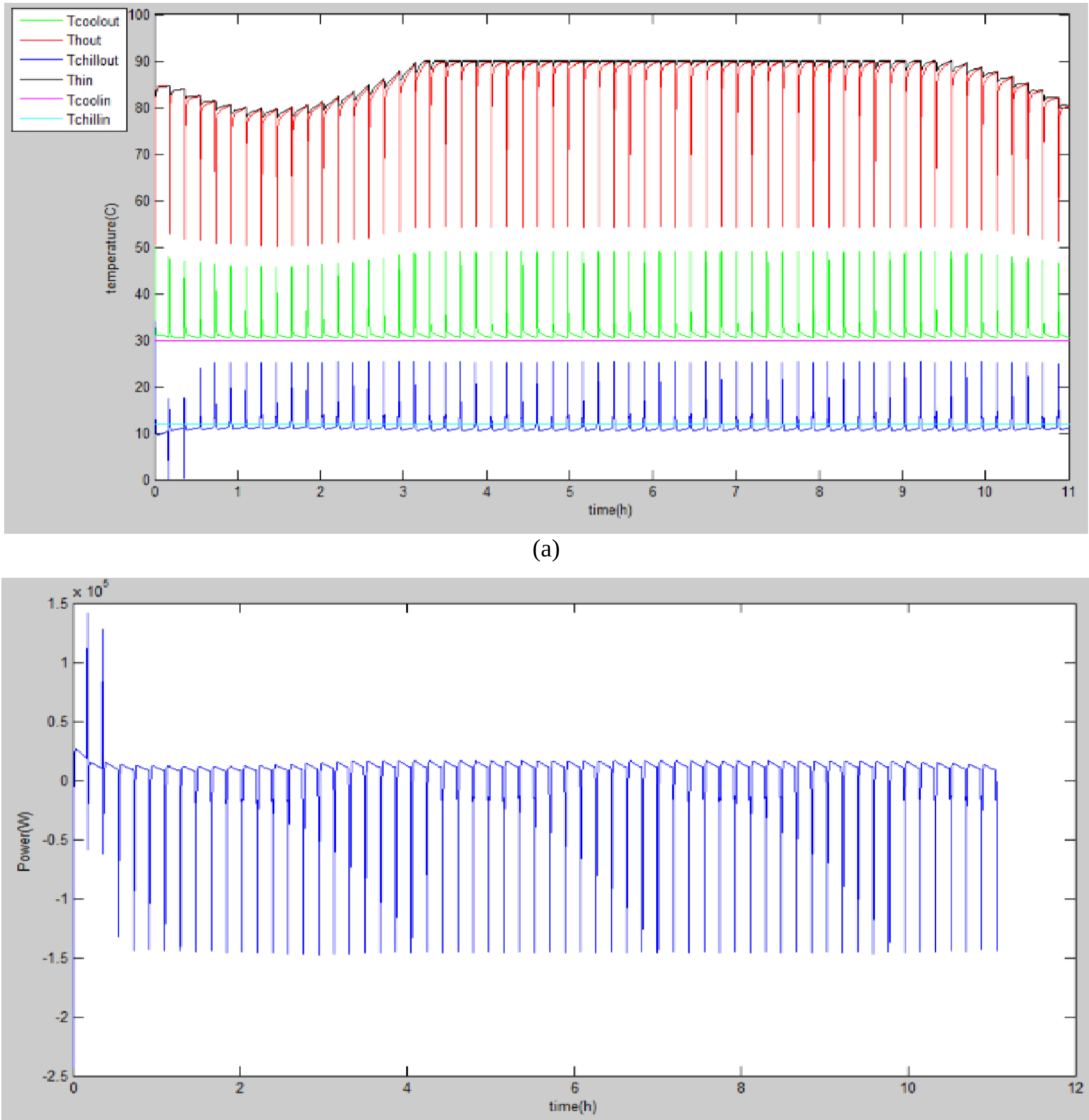


(b)

Figure 3 Running characteristic for Zeolites' diameter of 0.5 mm: (a) temperature; and (b) cooling power

The total running time of the simulation is 11 hours; as a result, a certain allowance was considered when the heat transfer area was calculated. The hot water tank temperature of the adsorption chiller system must be higher than 60^{o}C in order to function well, but it should not exceed 100^{o}C; at that point, the system would run out of water and could disturb the entire system cycle. Consequently, at the time (h) of 0, the initial hot water temperature was set around 83^{o}C, as shown in Figures 3a, 4a, and 5a. Figures 3b, 4b, and 5b show the cooling power generated by the chiller. In each running cycle, the solar panel was applied in order to increase the temperature of the hot water tank and utilize the solar energy. Afterwards, each of the running characteristics was followed by a decrease in the hot water temperature, as a result of decreasing solar irradiation throughout the day.

In Figure 3a, the temperature reaches the lowest declining rate of nearly 71°C for about 1.75 hours from the starting point, and then it rises up to 90°C after 4.25 hours. However, in Figure 4a, it reaches the lowest declining rate of nearly 79°C only for about 1.5 hours from starting point, and then it raises up to 90°C at the point of 3.25 hours. In Figure 5a, regarding the next comprehensive result, it reaches the lowest declining rate temperature of nearly 81°C at about 1.25 hours after the starting point, and then it rises to 90°C after nearly 2.5 hours. From the comparative results, we can conclude that the smaller the granular diameter of the zeolite, the more heat is needed to perform the desorption process.



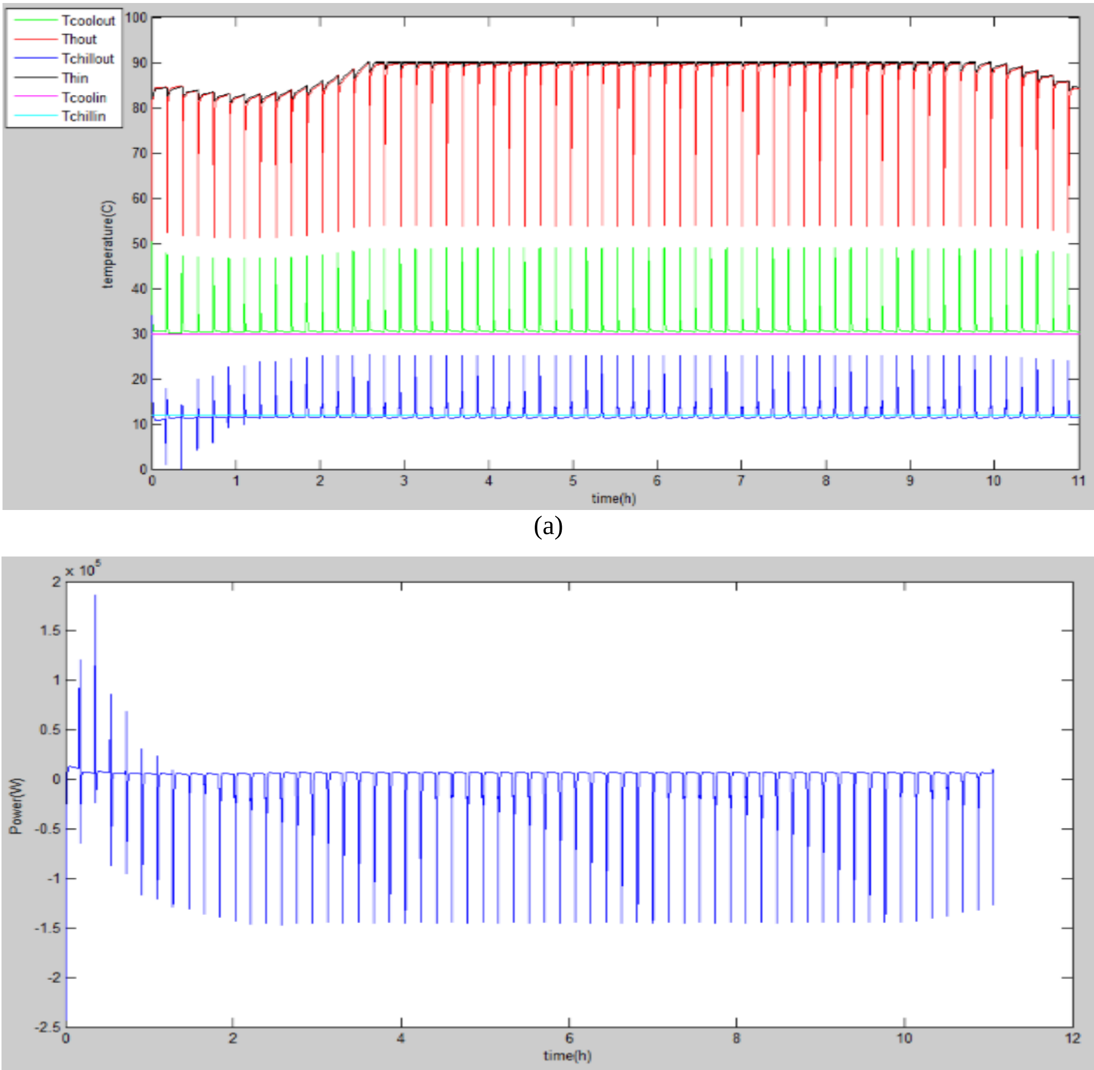
(a)

(b)

Figure 4 Running Characteristic for a Zeolite Diameter of 1.0 mm (a) Temperature and (b) Cooling Power

4.2. Running Characteristic of Chilled Water Temperature and Thermal Energy Approach

The chilled water temperature inlet is kept at a constant temperature of 12^{o}C. As we can see in Figures 3a, 4a, and 5a, at the starting point, the unsteady state of chilled water outlet temperature is revealed. Moreover, the difference in the zeolite diameter also demonstrates the proportional segment of chilled water outlet temperature. With a diameter of 1.5 mm, it takes three cycles of fluctuation to reach an equivalent balance. Compared to the other, lower diameter sizes of the granule, the 1.5 mm size takes fewer fluctuation cycles. As a result, it can also be concluded that the smaller the zeolite diameter, the faster the time needed to reach the steady state of chilled water outlet temperature, because of the faster reaction time involved. Conversely, the smaller their diameter, the colder the chilled water outlet water temperature is.



(a)

(b)

Figure 5 Running Characteristic for a Zeolite Diameter of 1.5 mm (a) Temperature and (b) Cooling Power

4.3. Running Characteristic

Cooling power is calculated for the diameter of each of the granules; we can see this fact as a result of the observation that the smaller a zeolite diameter, the greater the cooling power produced by the system. In short, the granule size affects both the heat and mass transfer beds.

Decreasing the adsorbent granular size reduces the contact thermal resistance between the granules and the heat exchanger's surface. The heat transfer rate of adsorbent bed with small granules size is higher than that with large granules, due to the reduction voids between granules.

5. CONCLUSION

Simulation of a zeolite-water adsorption chiller driven by solar energy is based on life in a tropical climate, with Universitas Indonesia as one of the local tropical regions in Depok that is being developed and investigated in this research. Its main goal is to increase the use of adsorption chillers in the educational sector of society, specifically in Universitas Indonesia. Different diameters of granule zeolites are being simulated to determine the running characteristics of adsorption chillers in a tropical climate. The conclusions are as follows. The running characteristics of the adsorption chiller shows that: (1) the smaller the granule diameter of zeolites, the greater the need for hot water; (2) the smaller the granule diameter of zeolites, the faster the time needed to reach the steady state of chilled water outlet temperature; (3) a smaller granule size allows a bigger contact surface area between the wall of the zeolite and the zeolite granule, resulting in better heat transfer of the interface; (4) the smaller the zeolite diameter, the colder the chilled water; (5) the smaller the zeolite diameter, the greater the cooling power generated.

6. ACKNOWLEDGEMENT

This work is supported by International Collaboration Research Grant, Fiscal Year 2015 No. 1785/UN2.R12/HKP.05.00/2015.

7. REFERENCES

Chan, K.C., Chao, C.Y.H., Sze-To, G.N., Hui, K.S., 2012. Performance Predictions for a New Zeolite 13X/$CaCl_2$ Composite Adsorbent for Adsorption Cooling Systems. *International Journal of Heat and Mass Transfer*, Volume 55, pp. 3214–3224

Fernandes, M.S., Brites, G.J.V.N., Costa, J.J., Gaspar, A.R., Costa, V.A.F., 2014. Review and Future Trends of Solar Adsorption Refrigeration System. *Renewable and Sustainable Energy Reviews*, Volume 39, pp. 102–123

Jacobs, G., 2010. *Training Course on Renewable Energy Part II*, MEMR-CASINDO, Jakarta, 14-18 June

Wang, R.Z., Oliveira, R.G., 2006. Absorption Refrigeration— An Efficient Way to Make Good Use of Waste Heat and Solar Energy. *Progress in Energy and Combustion Science*, Volume 32, pp. 424–458

Nasruddin, Lemington, Alhamid, I.M., 2015. Numerical simulation of a two-bed solar-driven Adsorption chiller in a tropical climate, *International Journal of Technology*, Volume 4, pp. 594-603.

Pan, Q.W., Wang, R.Z., Wang, L.W., Liu, D., 2014. Design and Experimental Study of Adsorption Chiller with Module Type Adsorber. In: *Proceedings of the International Conference of Solar Heating and Cooling for Building and Industry*, SHC 2014, Beijing, 13-15 October 2014

Wang, D., Zhang, J., Tian, X., Liu, D., Sumathy, K., 2013. Progress in Silica Gel–water Adsorption Refrigeration Technology. *Renewable and Sustainable Energy Reviews*, Volume 30, pp. 85–104

Wang, R.Z., Oliveira, R.G., 2006. Absorption Refrigeration—An Efficient Way to Make Good Use of Waste Heat and Solar Energy. *Progress in Energy and Combustion Science*, Volume 32, pp. 424–458

Yildirim, E.Z., 2011. *A Study on Isotherm Characteristics of Adsorbent-adsorbate Pairs Used* *in Absorption Heat Pumps*. İzmir Institute of Technology, Urla, İzmir, Turkey