Journal of Thermal Engineering, Vol. 3, No. 1, pp. 1044-1051, January, 2017, Manuscript Received 29 December 2014, Accepted 17 July 2015, Yildiz Technical University Press, Istanbul, Turkey

STUDY OF SOLAR DRIVEN ADSORPTION COOLING POTENTIAL IN INDONESIA

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Keywords: Adsorption Chiller; Indonesia Climate; Solar Drive; Pre-heat

ABSTRACT

Indonesia has a big potential in utilizing solar energy. In fact, tropical area like Indonesia has a quite stable solar radiation. This paper presented a study using simulation to investigate the performance of solar driven two bed adsorption chiller based on Indonesia climate. Climatic data of several cities in Indonesia is being used. The chiller is being mathematically modeled and calculated numerically using MATLAB®. The simulation is run transiently at working hours to achieve temperature in some points in the system. Moreover, additional PCM is also added to the hot water tank in order to achieve a better performance. The results demonstrated the running characteristic of the chiller with the range of COP 0.043-0.342. In general, the chiller performance can reach COP 0.282 with 17 kW cooling capacity when utilize the solar radiation varies between some cities as input energy. Moreover, Adding PCM in hot water tank also can improve the chiller's performance. Since the amount of heat is essential to the performance of the adsorption chiller, it is better to pre-heat the water before using. By pre-heating and getting the water to a higher temperature, it will generate a higher cooling power needed to meet demand which can be sustained and stable throughout the use of adsorption chiller.

INTRODUCTION

Today, we are experiencing global warming which leads to higher surrounding temperature especially in tropical countries such as Indonesia. Most of electricity generation in Indonesia is still dominated by fossil fuel as main energy source like coal, oil, and gas [1]. It contributes a lot in increasing ambient temperature and concentration of NOx, COx and SOx. In addition, many conventional refrigeration systems used HFC and HCFC refrigerant which has potency on ozone depletion and global warming. The use of natural refrigerant is environmentally friendly [2]; however it is flammable and has low efficiency. Therefore the development of renewable energy for air conditioning can be considered as alternative solution to create clean technology which is safe for environment.

Several researches regarding utilization of solar energy to provide district cooling in the building has been carried out [3, 4]. Study of biodiesel development is provided in [5, 6]. In this paper, the study regarding adsorption cooling system will be presented. Unlike conventional air conditioner, adsorption chiller uses heat waste to generate cooling needs without the potential to deplete ozone layers. The low waste heat such as gas burner waste, industrial heat waste, and even heat from the sun can be used by the adsorption chiller to generate cooling. The high level of solar irradiation in Indonesia, can reach 1,000 W/m2 on average at the ground surface during mid-day [7], which is more than enough to be used for adsorption chiller. An adsorption system has several advantages, including simple control mechanism, low operating costs and lower vibration levels [8] even though the COP is generally low at range 0.043-0.342.

Silica-gel has been widely used as an adsorbent in adsorption cooling but in this simulation, we use zeolite as the adsorbent. Zeolite is a more abundance and cheaper alternative to silica-gel which means it is easier to get than silica-gel. When using zeolite as an adsorbent, the heat input is usually need to be higher than that of silica-gel for the system to run. In general, the chiller performance can reach COP 0.282 with 17 kW cooling capacity when utilize the solar radiation varies between some cities as input energy. However, in this simulation we want to know the effect of initial hot water temperature to the performance of the adsorption chiller by analyzing the outlet temperature of chilled water and the cooling capacity.

SYSTEM DESCRIPTION

The adsorption chiller is based on the model developed by Shanghai Jiao Tong University by Pan et al [8]. The schematic of an adsorption chiller on figure 1 shows the schematic of the model chiller. The chiller contains 2 adsorbers, 2 condensers, and 2 evaporators.

This paper was recommended for publication in revised form by Regional Editor Omid Mahian
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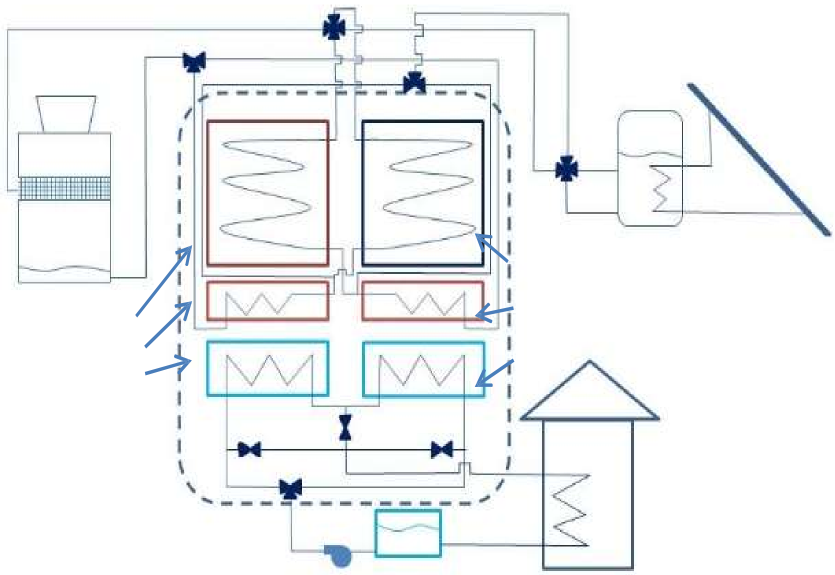


Figure 1. Schematic of Adsorption Chiller [9]

The adsorption chiller uses two bed so that the adsorption-desorption process can be done simultaneously and the chilled water can be produce continuously. The hot water is supplied to and from the solar hot water collector, cool water is supplied to and from cooling tower, and chilled water is supplied to the load that needs cooling.

MATHEMATICAL MODELLING

The mathematical modeling 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.

Adsorption Isotherms

The non-equilibrium equation of adsorption isotherms of zeolite-water adsorption kinetics is expressed by

$$\frac{dx}{dt} = 15D_{so}\exp(-\frac{Ea}{R}.Tb)\ \frac{(X^{*}-X)}{(R_p{}^2)} \tag{1}$$

Where X* is the equilibrium capacity in the adsorber and can be calculated with Dubinin-Radushkevich model [10]

$$X^{*} = X_o\ exp\left[-k\ (\frac{Tb}{T_{sat}} - 1)^n\right] \tag{2}$$

Where X_o is the maximum water uptake value of zeolite-water, k and n are dimensionless constants. The value is given in table 2.

Adsorption and Desorption Process

The adsorption chiller uses solar energy as a heat input. The solar energy equation is expressed as [9]

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

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

$$C_{p,w}\ M_{hwt,w}\frac{dT_{h,in}}{dt} = q + \dot{m}_{hw}\ C_{p,w}\ (T_{h,in} - T_{h,out}) \tag{4}$$

Table 1. Parameter of simulation [9]

Parameters	Value	Unit
Ac	400	m^2
H	0.35	%
Ca	836	J/kg/ºC
Cal	905	J/kg/ºC
Ccu	386	J/kg/ºC
Cp,w	4180	J/kg/ºC
Cw,v	1850	J/kg/ºC
Dso	3.92E-06	m^2/s
Ea	2.80E+04	J/mol
ΔH	3.40E+06	J/kg
UAad	51315	W/ºC
UAc	79326.5	W/ºC
UAe	35352.6	W/ºC
L	2.50E+06	J/kg
Ma	200	kg
Mtube	94.85	kg
Mfin	48.8	kg
Mc	172.62	kg
Me	471.68	kg
R	8.314	J/mol/ºC
m_{hw}	6.8055	kg/s
m_{chill}	2.63888	kg/s
m_{cool}	9.583	kg/s
Mhwt,w	2180	kg
Rp	0.0005	m

Table 2. Constants for adsorption isotherm

Parameter	X_o(kgw/kgad)	k	n
Adsorption	0.1219	5.052	1.4
Desorption	0.1249	3.62	1.2

The energy balance of the bed is expressed as

$$\frac{dT_b}{dt}\left[M_{ad}\left(C_{ad}+C_{p,w}\,X\right)+C_{cu}\,M_{tube,ad}+C_{al}\,M_{fin,ad}\right]=M_{ad}\Delta H\frac{dx}{dt}+\dot{m}_{hw}\,C_{p,w}\left(T_{ad,in}-T_{ad,out}\right)-\delta M_a C_{w,v}(T_b-T_e)\frac{dx}{dt} \quad (5)$$

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

The temperature difference is expressed as

$$\frac{(T_{ad,out}-T_b)}{(T_{ad,in}-T_b)}=exp\left[\frac{-UA_{ad}}{\dot{m}_{hw}C_{p,w}}\right] \quad (6)$$

For the energy equilibrium, the condenser energy balance is given by

$$M_c C_{cu}\frac{dT_c}{dt}=(1-\delta)\left[-L\,M_a\frac{dx}{dt}\,(T_c-T_b)\right]+\dot{m}_{cool}C_{p,w}\left(T_{cool,in}-T_{cool,out}\right) \quad (7)$$

With the temperature difference is expressed as

$$\frac{(T_{cool,out}-T_c)}{(T_{cool,in}-T_c)}=exp\left[\frac{-UA_c}{\dot{m}_{cool}C_{p,w}}\right] \quad (8)$$

The evaporator energy balance is therefore given by

$$\frac{dT_e}{dt}\left[M_{e,w}\, C_{p,w} + C_{cu} M_e\right] = \delta\left[-L\, M_a \frac{dx}{dt} + \dot{m}_{chill} C_{p,w}\left(T_{chil\ ,in} - T_{chil\ ,out}\right)\right] + (1-\delta)[\theta\, C_{p,w}\, (T_e - T_c) M_a \frac{dx}{dt} - (1-\theta) L\, M_a \frac{dx}{dt}] \quad (9)$$

Where Θ is a flag equation, which has a value of:

$$\theta = 1\ if\ T_c \leq T_e, while\ \theta = 0\ if\ T_c > T_e$$

The temperature difference is expressed as

$$\frac{(T_{chill,out} - T_e)}{(T_{chill,in} - T_e)} = \exp\left[\frac{-UA_e}{\dot{m}_{chill} C_{p,w}}\right] \quad (10)$$

Mass and Heat Recovery Equations

Mass and heat recovery are critical to the adsorption and desorption process as it will increase overall efficiency. The energy balance for mass recovery used is expressed as

$$\frac{dT_e}{dt}\left[M_{e,w}\, C_{p,w} + C_{cu}\, M_e\right] = \delta\left[-L\, M_a \frac{dx}{dt} + \dot{m}_{chill}\, C_{p,w}\left(T_{chill,in} - T_{chill,out}\right)\right] + (1-\delta)\left[\theta C_{p,w}(T_e - T_c) M_a \frac{dx}{dt} - (1-\theta) L\, M_a \frac{dx}{dt}\right] - (1 - \zeta)\left[C_{p,w}\left(T_{chill,in} - T_{chill,out}\right)\right] \quad (11)$$

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

$$T_{ad,out,ads} = T_{ad,in,des} \quad (12)$$

$$T_{cool,out} = T_{ad,out,des} \quad (13)$$

Cooling Capacity and COP

The performance is judged using the most common parameter which is COP. The COP is calculated using a basic formula that is the ratio between the cooling capacity (Qr) and heating power (Qh) as shown

$$Q_r = \int_0^{t_{cycle}} C_{p,w}\, \dot{m}_{chill}\, (T_{chill,in} - T_{chill,out}) \frac{dt}{t_{cycle}} \quad (14)$$

$$Q_h = \int_0^{t_{cycle}} C_{p,w}\, \dot{m}_{hw}\, \left(T_{h,in} - T_{h,out}\right) \frac{dt}{t_{cycle}} \quad (15)$$

$$COP = {}^{Q_r}/_{Q_h} \quad (16)$$

RESULTS AND DISCUSSION

The simulation of adsorption chiller uses MATLAB® as simulator software using Euler numerical method as computation. We are testing for two heat input which is 60°C and 80°C to see if it has an effect on the chiller performance. The half-cycle time is 864s, 800s cooling time, 40s mass recovery, 24s heat recovery running for 10 cycles.

The solar heat input is based on the average daily value of solar intensity in Depok, Jawa Barat which can be seen on Figure 2. In this simulation, it is assumed that the start of the simulation is at 8 A.M.

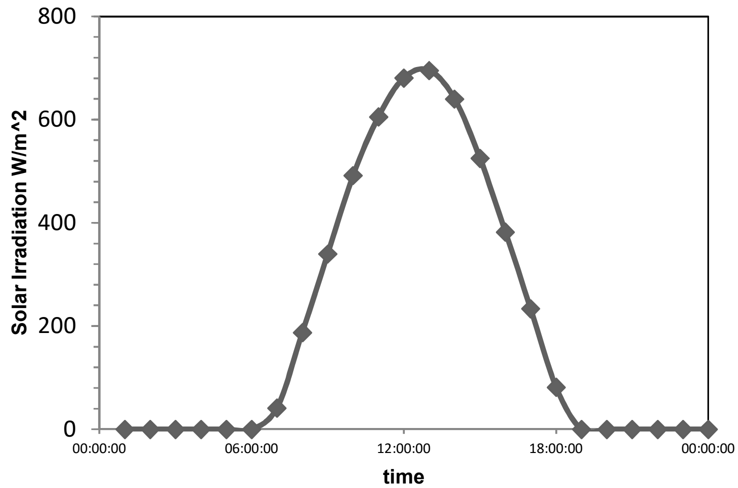


Figure 2. Daily solar irradiation, Depok, Indonesia

The results of the simulation are given in Figure 3 and Figure 4.

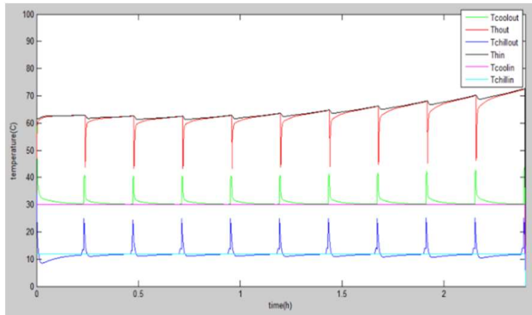
Chilled Water Outlet Temperature

As we can see at figure 3, the chilled water outlet temperature is cooler at high hot water inlet. In this case, the chilled water outlet can get as low as 10^{o} C with 80^{o} C initial hot water inlet compared to 11.5^{o} C with 60^{o} C initial hot water inlet. With more heat at the inlet means that the desorption capabilities will be better so the zeolite will have less water content to then be able to adsorb more during the adsorption process, thus creating less pressure on bed and generate more cooling.

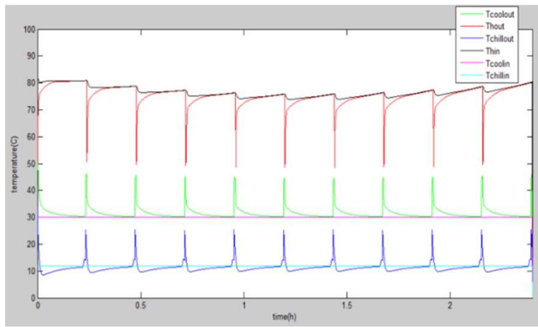
During this 10 cycle, we can see the trend of the hot water inlet with the use of solar collector. We can see that in figure 3a that the hot water inlet increase over time and reached 70^{o} C in 2.4 hours while in figure 3b, the hot water inlet slightly decrease but in the end still maintain 80^{o} C water inlet at the end of 2.4 hours. While the increasing temperature in figure 3a is attributed to increasing solar intensity during the process, it is the slight decrease in figure 3b that captures our attention. The slight decrease is due to the fact that during the desorption process, more heat is then release to desorb the water which then lower the outlet temperature to the solar collector. With the solar collector still at low input irradiation, the inlet temperature will then be lower than the previous until the solar irradiation picks up.

Cooling Capacity

Looking at the cooling capacity of the simulated system, we can see that the cooling capacity is generally higher and more constant at higher inlet temperature compared to the lower one. This is due to the colder generation of the chilled water at higher initial temperature which means that the ability to cool is significantly higher than those with lower initial temperature. The striking part is that the cooling capacity in figure 4b is very stable compared to figure 4a which shows increasing cooling power overtime. This becomes a major talking point because in order to get the cooling power required to cool the room, the one with a lower starting temperature will need more time to reach it while the one that is “pre-heated” or have a higher starting temperature will generate a stable and higher cooling power from the start.

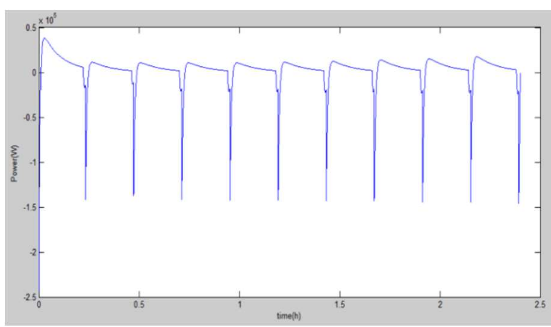


(a)

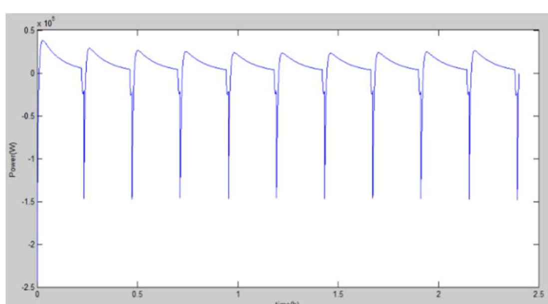


(b)

Figure 3. Water Outlet Temperature (a) 60º input heat (b) 80º input heat



(a)



(b)

Figure 4. Cooling Capacity (a) 60o input heat (b) 80o input heat

CONCLUSION

The simulation of zeolite-water adsorption chiller is being developed and investigated in this research. The aim is to make adsorption chiller well known and efficient enough to be used commercially and to replace conventional air conditioners. Waste heat can be used in adsorption chiller with varying degree of performance. In a zeolite-water adsorption chiller, higher starting temperature means:

- Colder chilled water outlet
- Higher cooling power generated
- More stable cooling power generated

This simulation shows that when using a solar driven adsorption chiller for cooling purposes, one must "pre-heat" the hot water first before using it. Doing this will give a higher cooling power to meet demands from the start while maintaining its stability throughout the day.

ACKNOWLEDGMENTS

This work is supported by Hibah Riset Kolaborasi Internasional Tahun Anggaran 2015 No. 1785/UN2.R12/HKP.05.00/2015 and Hibah Penelitian Unggulan Perguruan Tinggi Tahun Anggaran 2016 No. 1169/UN2.R12/HKP.05.00/2016

NOMENCLATURE

ΔHads	Isosteric heat of adsorption, J/kg
Ac	Area of the solar collector, m^2
A	Area, m^2
COP	Coefficient of performance
Cp	Specific heat, kJ/(kg K)
d/dt	Change rate, 1/s
Dso	Pre-exponential constant, m^2/s
dT/dx	Average temperature gradient, K/m
Ea	Activation energy, J/mol
g	Gravitational acceleration, m/s^2
L	Latent heat of vaporization, J/kg
J	Solar irradiation, J/m^2
M	Mass, kg
m	Mass flow rate, kg/s
P	Pressure, kPa
q	solar heating power, kW
Q	Heat, kW
R	Universal gas constant, J/(mol K)
Rp	Particle radius, m
T	Temperature, K
t	Time, s
U	Overall conductance, kW/K
X	Uptake value, kgw/kgZeolite
X*	Equilibrium uptake, kgw/kgZeolite
η	efficiency of solar collector

Greek symbols

Δ	Difference
Σ	Summation
Θ	Flag
δ	Logic value
ξ	Flag

Subscripts

ad	Adsorbent
al	aluminium
b	Bed
chill	Chilled water
c	Condenser
cool	Cooling water
eff	Effective
e	Evaporator
h	Hot water
ht	Hot water tank
in	Inlet
out	Outlet
sat	Saturation
w	water
v	Water vapor

Superscript

·	Rate
_	Average

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