Continuous Adsorption Refrigeration System:
Experiments of Methanol and R-134a with Activated-Carbon

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Abstract—Heat driven adsorption refrigeration systems have drawn considerable attention due to their potential uses of solar energy and waste heat from other process. Although they are not predominant in the area of heat driven refrigeration technologies, adsorption systems have some distinct advances over the other systems in view points of their ability to be driven by relatively low temperature heat source. Indonesia as an agrarian country with large farming and fishing areas will be supported to handle their products with cheap and simple storage technology due to the adsorption system can be operated without electric power and is easily operated in rural area. Research on the adsorption refrigeration system was conducted with local activated carbon as solid sorption and two refrigerants as absorbate were introduced in experiments, i.e. methanol and R-134a. Two beds with 3370 cm³ of solid sorption volume were used to work as generator and absorber intermittently so that evaporator can work continuously. The main results show that both pairs can performs in the experiment with different performances. For a simple configuration and testing bed used, cycle time of the experiments is 150 minutes for methanol and 105 minutes for R-134a, respectively. COP (coefficient of performance) and specific cooling capacity of pair of methanol + activated carbon are 0.12 and 4385.76 kJ/m³ activated carbon, and COP and specific cooling capacity of pair of R-134a + activated carbon are 0.15 and 12014.84 kJ/m³ activated carbon. These all are for operating set at 100°C of hot water temperature, 12°C of cold water temperature.

Index Terms—adsorption system, R-134a, methanol, activated carbon, experimental adsorption

INTRODUCTION

A conventional refrigeration system is driven mechanically by a compressor, on the other hand a sorption refrigeration system is driven by a heat source. The heat could be widely available in world. It may be gotten from fuel, waste heat and solar heat. Therefore, sorption refrigeration systems offer a great advantage compared with conventional systems. There are two types of sorption refrigeration system, i.e. liquid sorption which commonly called as vapor absorption, and solid sorption which also called as adsorption system [1]. The adsorption system likes the simple vapor compression refrigeration system but the mechanical compressor is replaced with a thermal compressor or the adsorption bed. The bed is composed of porous medium that has the ability to absorb the refrigerant (absorbate).

The use of sorption system is more easily in the remote part of developing countries where no electricity supply is used for storage of medical products, foods or habitat needing. Other reason is that sorption system are driven by heat rather than electric power. It causes a number of implementation areas in which they may be energetically advantageous, for examples tri-generation systems which burn a fuel to produce electricity, heating and/or cooling, solar powered cooling system, gas fired heat pumps, and so on. It means that sorption systems have drawn considerable attention due to their lower environmental impact and large energy saving potential as the systems neither use ozone depleting gases nor the fossil fuel and electricity as driving source.

Adsorption cycle can be illustrated in Clapeyron diagram as shown in Fig. 1. The process 2 → 3’, process 3’ → 4’ and process 4’ → 1’ are serial processes of condensation, isenthalpy expansion, and evaporation. These processes are similar in vapor compression cycle. However, the compressor is replaced by the adsorption bed which will operate process 1’ → 2’, process 2 → 3, process 3 → 4, and process 4 → 1.

Fig. 1. Adsorption cycle on Clapeyron diagram

Adsorption bed working principle can be explained from state 1. Starting with the state 1, in which the adsorption bed is cold and saturated with the absorbate/refrigerant, adsorption
bed is then heated so that heating up the adsorbent inside the bed, and as consequently in desorbing a certain amount of the refrigerant. The bed pressure increases and ideally without changing the refrigerant in the bed as so-called isosteric preheating. This process undergoes until the minimum desorption temperature up to state 2. At this temperature the bed pressure becomes equal to the refrigerant saturation pressure corresponding to the temperature \( T_0 \) of the heat sink available for receiving the heat of condensation. The desorption process starts from this point on and the refrigerant is condensed in condenser. The desorption process proceeds until the adsorbent temperature in the bed reaches the maximum ability desorption temperature and the refrigerant release until minimum mass fraction \( c_{\text{min}} \) at state 3. The adsorbent is pre-cooled and becomes able to adsorb refrigerant vapor again due to decreasing the bed pressure. Adsorption bed with \( c_{\text{min}} \) is cooled with initially isosteric process (process 3 – 4) until all remaining refrigerant to be liquid and then isobaric cooling process (process 4 - 1) so that adsorption bed temperature decreases. As long as process 4 – 1, adsorption bed absorbs refrigerant.

Any simulation work were reported by researchers. Simulation for 26 various activated carbon + ammonia pairs for single bed, two-bed and infinite number of beds were reported by Tamainot-Telto et al. [2] at typical conditions for ice making, air conditioning and heat pumping applications. Considering a two-bed cycle such as done in present work, the best thermal performances based on power density are obtained with the monolithic carbon KOH-AC, with a driving temperature of 100°C. The cooling capacity and COP are 66 MJ/m³ and 0.45 for ice making, and 151 MJ/m³ and 0.61 for air conditioning, respectively.

Other work for solar powered adsorption was conducted by Qasem and El-Shaarawi [3]. It was reported that double glazing cover, thin stainless steel absorber tubes with selective coating, suitable monthly collector tilt angle and suitable time for starting the cycle can improve the performance of a system with 14.1 kg of activated carbon NORIT RX3-Extra per m² of solar collector.

Experimental work to investigate system performance by finding pair of refrigerant absorbent and enhancement of heat and mass transfers in adsorption bed were conducted by researchers. Three types of adsorption bed and two types of activated carbon + methanol adsorption systems are studied to reveal the structure of adsorption bed, performance of adsorbents, performance of different adsorption bed and different systems [4]. It were reported that the heat transfer coefficient of solidified absorbent are much higher than the granular absorbent, the design of gas flow channels in adsorption bed is very important to the performance of mass transfer and the performance of the whole system. Performance of the adsorption bed with good design of gas flow channels is much better than that of other two types of adsorption bed observed.

The challenges of technology development for adsorption system are still remaining since the adsorption drawbacks such as poor performance either in specific cooling power and COP caused by the poor heat and mass transfers within the adsorbent and adsorbent deterioration. Therefore it is vital for the development and applications of the adsorption refrigeration technology. Enhancement of heat and mass transfers in the adsorption bed, increasing the sorption ability of the absorbate absorbent pairs and a better heat management plays important role on technology development of adsorption refrigeration system. The sorption capacity of solid absorbent–absorbate pair depends on the thermo physical properties including pore size, pore volume and pore diameter of the adsorbent and isothermal characteristics of the pair. In this paper, comparisons of R-134a and methanol with local activated carbon are conducted from experimental aspect to reveal possibility of adsorption machine development.

**EXPERIMENT AND SET-UP**

Experimental apparatus was designed and manufactured to conduct experimental works. Fig. 2 shows schematic of the experimental apparatus used in this research. The apparatus has two beds for undergoing sorption and desorption processes intermittently and they are installed with a condenser and an evaporator. The bed will get heating and cooling processes intermittently so that the evaporator can operate continuously in order to get cooling effect. Hot and cold water are used to perform the heating and cooling processes for both adsorption beds so that each bed is covered by water jacket as unit of reactor as written Reactor 1 and Reactor 2 in the figure.

Several valves are used in the apparatus to operate refrigeration cycle. Before testing, it is started by putting the activated carbon in the both adsorption beds, and then create vacuum them in hot condition by hot water 100°C for 12 hours. After the vacuum process finished, temperature of the activated carbon is decreased using cold water until reaching 15°C. The refrigerant (absorbate) is then charged into an adsorption bed among two beds and make it in an equilibrium state. Desorption process starts on the first bed which contains the refrigerant, and the adsorption process starts on the second bed which does not contain refrigerant.

The heating temperature range of adsorption bed is 15°C to 85°C by using hot water 100°C, and the cooling temperature of adsorption bed is 85°C to 15°C by using cold water less than 15°C. Next step, after desorption process reaching temperature of adsorption bed 85°C, the refrigerant in the adsorption bed is released into condenser. After the refrigerant condensed, it flows into the evaporator through capillary tube to reduce the pressure. The evaporator, which is submerged in 3 liters of water, to give its cooling effect. Refrigerant vapor exiting from the evaporator enters second adsorption bed and adsorption process undergoes insides. The temperature of adsorption bed and evaporator are recorded by data acquisition every 1 minute, and the temperature of water in evaporator is recorded manually. On the other hand pressures are manually recorded. Finally, the COP analysis of the system is done after data were recorded from the experiment and is changed to another refrigerant for experimental parameter. If the system does not work, it will be done again that start from activated carbon
degassing by using vacuum pump and hot water 100°C during 12 hours.

The adsorption bed plays important role on the experimental apparatus. The bed is wrapped with water jacket so that hot or cold water can be flowed for heating or cooling process as shown in Fig. 2. Since the fluid used for heating and cooling is water, temperature range of higher temperature is not able more than 100°C and so for lower temperature is not able lower than 4°C as a limited condition of the apparatus besides constraints of heater and cooler capacities. Each bed is filled by 1.8 kg of activated carbon.

The reactor is manufactured based on the volumes of activated carbon and refrigerant, and mass flow rate of water jacket. The reactor is made from steel in cylindrical form. The reactor is divided into two parts: water jacket as outside part and adsorption bed inside such as shown in Fig. 3. The adsorption bed has three serial cylindrical components and they are connected by pipe. Each the component has uniform holes with diameter 12.7 mm and covers with stainless steel net. The connecting tube is in center line of the reactor that is used for the way of refrigerant during adsorption and desorption processes.

Activated carbon is a highly porous, amorphous solid consisting of microcrystalline with a graphite lattice. It is usually prepared in small pellets or powder. The carbon drawback is reactivity with oxygen at moderate temperatures over 300°C. Activated carbon used in this experiment is made from coconut shell. The manufacturing process consists of two phases, carbonization and activation. The carbonization process includes drying and then heating to separate by products, including tars and other hydrocarbons from the raw material, as well as to drive off any gases generated. The process is completed by heating the material over 400°C in an oxygen-free atmosphere that cannot sustain combustion. Activated carbon in granular form is manufactured by Brachem, Co. It is initially purposed for water filter and the visual of the activated carbon is shown in Fig. 4.

Methanol is a colorless organic liquid which usually called as methyl alcohol or wood alcohol. It is originally produced by destructive distillation of wood and so called methyl alcohol as its chemical formula is CH₃OH. On the other hand, R-134a is a haloalkane refrigerant without ozone depletion potential. R-134a is a clear, colorless vapor that has a faintly sweet odor and has a molecular mass of 102.03 kg and also has chemical name as 1,1,1,2-Tetrafluoroethane. 1,1,1,2-Tetrafluoroethane is an inert gas used primarily as a high-temperature refrigerant for domestic refrigeration and automobile air conditioners.
A. Temperature Control System

Hot and cold water have to keep in temperature set. Two temperature controllers are installed to control both temperatures. Both of them use the same system to control the temperature. Thermocouple is installed into the system to measure temperature points. A measured temperature is then compared to the temperature setting in the controller. The temperature controller will switch on/off current to the contactor. Temperature is higher than the temperature setting for heating and the temperature is lower than the temperature setting for cooling. The current will drive the contactor to open circuit block so that the current from source through the contactor circuit block to drive the apparatus. The apparatus will operate and change the temperature of the system as desired.

B. Leakage Test and Vacuum

Leakage test has to be conducted to keep refrigerant content in the apparatus. Vacuum condition has to be achieved before refrigerant charging. Vacuum condition plays important role on system’s process. Before testing, the activated carbon in two adsorption beds is degassed at about 100°C under high vacuum pressure for around 12 hours depends on the amount of water has in the activated carbon. In the vacuum process, inherent moisture in the activated carbon release the water vapor out from the system trapping in vacuum pump oil so that change the vacuum pump oil pump must be replaced every four hours. Reducing contaminant content in refrigerant gas, methanol is dropped in the system several times during the vacuum process so that the gas contaminant to be very low.

The most critical condition of system operation is leakage especially for the system that has to be operated under atmospheric pressure. The system has to be assured in 100 percent seal to get a very accurate data from experiment. After the design, fabrication and instrumentation are already done, some work for well preparation have to be done. Since the pressure of the system might varies from 0 inHg up to 60 inHg, a leakage test with pressure of compressed air 5 bar would be enough to check if there is leakage from any of the component in the system. The whole system is closed and compressed to 5 bar of air and keep for several hours to make sure that no pressure drop.

C. Measurement

The system performance is derived from operation parameters measured. The pressures are manually recorded from bourdon manometer. Data acquisition is recording apparatus points for getting the data of temperature. K-type thermocouple is used as temperature sensor with 0.1°C of accuracy. Omega data acquisition Multi-function I/O USB model OMB-DAQ-2416 has 32 channels for recording data from thermocouple. The data acquisition is highly accurate, multi-function measurement, and control modules for the USB bus.

A pump is a device that moves fluids using mechanical action. The pump is used to flow the water through the piping system to the reactor for conditioning adsorption bed inside. Normally, water flow rate is measured by flow meter which is commercially available, but the flow rate will be regulated by adjusting the pump head pressure in this experiment water. It is basically simple and more reliable, even though it requires characteristic of the pump. The pump will be used to circulate both hot and cold water with temperature varies from 15°C – 100°C.

D. Cycle Operation

The apparatus is operated manually by opening or closing valve so that the adsorption cycle can undergo. Table I gives an time of operation procedure of the experiment apparatus which being supported by two adsorption beds.

<table>
<thead>
<tr>
<th>Sorption Pairs*</th>
<th>Cycle time (min)</th>
<th>Desorption time (min)</th>
<th>Adsorption time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC + methanol</td>
<td>150</td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td>AC + R-134a</td>
<td>105</td>
<td>50</td>
<td>60</td>
</tr>
</tbody>
</table>

*AC: activated carbon

FORMULATION EVALUATION

Any formulation of mass and energy balance for analyzing the cycle of the system are needed to perform thermodynamic analysis. In accordance with processes undergoing in the cycle, a number of formulations are needed to reveal performance of the cycle.

Adsorption isotherm

Dubinin-Astakhov (D-A) model, which is expressed by Eq. (1), which is used to estimate the equilibrium uptake of activated carbon + refrigerant on the mass basis.

\[
\frac{c}{c_0} = \exp\left(-D \left( \frac{T \ln \frac{p}{p_0}}{p_0} \right)^n \right)
\]  

(1)
Where \( c \) is absorbate mass fraction in adsorption bed, \( c_0 \) is maximum absorbate mass fraction in adsorption bed, \( D \) is energy constant, \( p_0 \) is vapor pressure at operating temperature, \( T \) is operating temperature of the bed, \( p \) is operating pressure and and \( n \) is constant of absorbate-absorbent pair. The numerical of \( c_0\), \( n \) and \( D \) are evaluated experimentally as written Saha et al. [5].

**Isosteric process**

The pressure will increase when the bed is heated. The relation of pressure and temperature as relation given in Eq. (2).

\[
\ln \frac{p_1}{p_2} = \frac{\Delta H_{ads}}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)
\]

(2)

Where \( \Delta H_{ads} \) is adsorption enthalpy, \( T_2 \) and \( T_1 \) are final and initial temperature of the process, \( p_2 \) and \( p_1 \) are final and initial pressure of the process, and \( R \) is refrigerant gas constant. \( \Delta H_{ads} \) can be found by using Eq. (3), also can be estimated by using graph which is defined by Saha et al. [6]. Adsorption enthalpy can be evaluated with Eq. (3).

\[
\Delta H_{ads} = h_{fg} + E \left[ \ln \frac{c}{c_0} \right]^\frac{1}{2} + a \left( \frac{T}{T_e} \right)^b
\]

(3)

Where \( h_{fg} \) is evaporation enthalpy at operating temperature, \( T \) is operating temperature of the bed, \( c \) is the same parameter in equation (1), \( E \) is energy characteristics, and \( T_e \) is critical temperature of absorbate. On the other hand \( E \), \( a \) and \( b \) are empirical constants. The numerical values of \( E \), \( a \) and \( b \) are evaluated experimentally as the way written by Saha et al. [6] and El-Sharkawy et al. [7].

**Experimental formulation**

The quantity of energy used to generate refrigerant vapor from the adsorbent during the generation process (\( Q_{gen} \)) is calculated by Eq. (4).

\[
Q_{gen} = m_c \Delta T_{13} + (m_{r_2} - m_{r_3}) c_{p,m} \Delta T_{13} + m_{r_1} (h_2 - h_1) + m_{r_3} h_{fg}
\]

(4)

Where right sides of the equation consisting of four terms. The first term is activated carbon sensible heat, second term is remaining refrigerant in bed, third term is bed-released refrigerant sensible heat, and forth term is bed-released refrigerant latent heat.

The quantity of heat transferred into the evaporator (\( Q_{eva} \)) during refrigeration process is evaluated by Eq. (5).

\[
Q_{eva} = m_{w,c} c_{p,w} (T_1 - T_e)
\]

(5)

Where \( T_i \) is initial temperature of the water, \( T_e \) is evaporator temperatures, \( m \) is water mass in evaporator box, and \( c_{p,w} \) is specific heat of water in evaporator box.

The cooling coefficient of performance (COP) for this system is ratio of cooling capacity and desorption heating heat as a relation presented in the Eq. (6).

\[
\text{COP} = \frac{Q_{eva}}{Q_{gen}}
\]

(6)

This COP considers heating heat received from the heating process without including heat loss from the heat source in heating process and energy needed for the control system.

**EXPERIMENTAL RESULT**

The experiment is carried out within only one sample of activated carbon and two refrigerants (methanol and R-134a) to figure characteristic adsorption refrigeration system. The experimental works need to test several times in order to get a good data because some data may be error value by operation and apparatus. In this experiment, the system is continuous cooling process of evaporator, so that the data were taken four cycles per time to make variety of the data. Partial data points are recorded manually and the others are recorded by data acquisition with a data sampling rate 0.017 (1 sample per minute). Notation 1, 2, 3 and 4 for temperature and pressure in the following figure just indicate serial time of the experiments for the same operating apparatus set-up as long as cycle.

The Fig. 5 presents the heating pressure of methanol in the adsorption bed and all curves of each pressure is not significant difference so that the curves of pressure in the heating confirm that the system works well and has stability. On the other hand, the pressure 1 and pressure 3 of first adsorption bed is different from pressure 2 and pressure 4 of the second adsorption bed because of the indicator of pressure gauge of the bed has small deviation. This deviation occurs as consequence of different content concentration of methanol in adsorption bed. It agrees with recharging based on pressure.

![Fig. 5. Bed pressure of methanol related to time during heating process](image-url)
water temperature is not stable due to high initial heat transfer in the transient condition and effect of manually control of hot water flow by gate valve in discharge section of the pump.

Fig. 6. Bed temperature of methanol related to time during heating process

Fig. 7 shows the temperature curves during cooling process. The curves are not significantly different among the others. The final temperature for each curve is reached at almost the same time for each curve. The deviations are only in middle of the process.

Fig. 7. Bed temperature of methanol related to time during cooling process

Fig. 8 shows the COP of methanol that works on different cycle. The COP in the first cycle is smaller than other because the system is not stable on the initial operation, and then it is stable for the next cycles.

Fig. 8. Coefficient of performance four cycles of methanol

For the R-134a, the data are always recorded manually every 5 minutes. The pressure curves of the R-134a adsorption bed during heating process are given in Fig. 9. The curves are only slightly difference among the others. It means the system is working well and stable when the heating process.

Fig. 9. Bed pressure of R-134a related to time during heating process

Fig. 10 shows the heating temperature of both adsorber bed of R-134a, and the temperature does not significantly change through all curves of four cycle operations. This result means that eventhought the valve is operated manually, the system can work stable.

Fig. 10. Bed temperature of R134 related to time during heating process
In cooling process, bed temperature of R-134a start cooling process at same temperature until the same final temperature at same period time as shown in Fig. 11. The results for four cycle operations are stable.

![Fig. 11. Bed temperature of R-134a related to time during cooling process](image)

The Fig. 12 shows the curve of COP in every cycle operation of R-134a activated carbon system. At the beginning, the COP is very high then in the third cycle the COP is significantly changed. In the last cycle the COP is very low, much lower than the mean COP. This is caused by manually operated and effect of operating pressure set at high pressure.

![Fig. 12. Coefficient of performance four cycles of R-134a](image)

**DISCUSSION**

Experimental data were obtained to know characteristics of the system. In revealing the system potency, the data have to be analyzed. Experimental data are compared with theoretical calculation. For methanol, the experimental data are slightly different with theoretical calculation, so the performance of this adsorption refrigeration system can be accepted from academic view. For R-134a, the experimental performance of R-134a is better than methanol’s performance because the quantity of R-134a is larger than methanol quantity for the same activated carbon set due to worry strength of the apparatus eventhough the experimental operating pressure is still lower than optimum pressure from analysis result. Besides, the heating time of activated carbon + R-134a pair is shorter than activated carbon + methanol pair. Working pressure also affects the performance of the system. Unlike activated carbon + methanol pair which is working on vacuum pressure, activated carbon + R-134a pair is working on positive pressure. On vacuum pressure, first vacuuming process must be strictly controlled. If this process is not good, the performance will be decreasing. The operating time of the adsorption refrigeration system with R-134a is 1 hour and 30 minutes, and cycle’s process of this system is around 45 minutes.

The comparison between experiment of the present continuous adsorption refrigeration systems and other reported adsorption refrigeration systems gives in Table II. Some main data of experiment are compared such as cycle time, desorption time, adsorption time, evaporator temperature, and COP. Moreover, the four references are cited from journal to make comparisons. An experimental study on adsorbent of activated carbon with refrigerant of methanol for solar ice maker as reported in reference [8] is a system which could be practically related to solar adsorption refrigeration field, and the COP of this ice maker system is about 0.10-0.11. It is not significant difference from present adsorption refrigeration system, but it still some differences especially for operating temperatures. The difference of solar ice maker and this continuous adsorption refrigeration system with activated carbon is time for desorption/adsorption because the solar ice maker works under the condition of accepting radiation energy 17-22 MJ/m² both inside the door with quartz lamps and outside with real solar radiation. The first cycle of solar ice maker accepts the radiation energy 15.2 MJ and the time of adsorption/desorption is 1080 minutes and 300 minutes. The second cycle accepts the radiation energy 18.2 MJ and needs time of adsorption/desorption 1080 minutes and 360 minutes because this system requires the heat from solar energy to process, so this process takes a long time per cycle while the present continuous adsorption refrigeration system takes only 120 minutes for adsorption process and 90 minutes for desorption process. In contrary, the performance of solar ice maker and adsorption system is not quite different as presented in Table II.

The other experiment used working pair activated carbon + methanol, i.e. the performance of two adsorption ice making test units using activated carbon and a carbon composite as adsorbents given in a reference [9] is compared with the present adsorption system. The reported system is a kind of adsorption refrigeration working with activated carbon, but it uses thermal energy of a hot gas from oil burner was utilized to simulate diesel engine and the cooling source is from cooling tower. The best cycle time of adsorption ice making system is 66 minutes, and its COP is 0.125, and other cycle time’s data gives in Table II. In spite of the maximum of our
adsorption refrigeration system uses 150 minutes because the system uses hot water 100°C in desorption process, so it needs time for heating the system while the adsorption ice making system uses waste heat from Diesel engine that has high temperature, but the performance of both systems is not significant difference as presented in Table II.

**Table II. Experimental Result and Comparison**

<table>
<thead>
<tr>
<th>Sorption Pairs*</th>
<th>Condition and Performance Parameters</th>
<th>Cycle time (min)</th>
<th>Desorption time (min)</th>
<th>Adsorption time (min)</th>
<th>Evap. temp. (°C)</th>
<th>COP</th>
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<tr>
<td>AC + methanol</td>
<td></td>
<td>1</td>
<td>150</td>
<td>90</td>
<td>120</td>
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<td></td>
<td></td>
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<td>0.165</td>
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<tr>
<td>AC + R-134a</td>
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<td>1</td>
<td>15</td>
<td>9</td>
<td>9</td>
<td>-10</td>
</tr>
</tbody>
</table>

*AC: activated carbon

Investigation on two stage activated carbon + R-134a solar powered adsorption refrigeration system reported in reference [10] is a kind of adsorption system that processes full day because this system needs solar energy as heat source in day time for making desorption process and needs cold temperature at night for adsorption process so that it needs 24 hours for processing per cycle. However, the adsorption system with activated carbon + R-134a uses electric heater as heat source and cooling unit to make cold water has cycle time of adsorption process is shorter than solar powered adsorption system, but the performance of both systems are quite the same as given in Table II.

An article of the other experiment with working pair activated carbon + R-134a which is performance evaluation of combined adsorption refrigeration cycles is reported in reference [11]. This system compares with our adsorption refrigeration system with activated carbon. The combined adsorption refrigeration cycle has function for processing the system that is same as the present refrigeration system, and the COP of this system is not quite different from our system as given in Table II, but it has some differences. The differences are time of adsorption, desorption, and cycle time. Besides, the processing time of this system is very fast than the present adsorption refrigeration system, and it uses only 9 minutes for adsorption, 9 minutes for desorption, and 15 minutes for cycle time. This means that the present adsorption bed performs lower heat and mass rate than the work in the article.

**CONCLUSION**

A continuous adsorption refrigeration system was developed and Dubinin equation was applied to evaluate performance of the system. Activated carbon with methanol and R-134a were considered as the working pairs in the adsorption refrigeration system to compare their performance. The theoretical analysis method is useful to apply in the system to find the time for heating/cooling the adsorption bed, and the result of numerical analysis method is accepted by using approximated method to verify its value. The time for heating/cooling of adsorption bed is around 20 minutes. The inlet and outlet temperature of heating water are 95°C and 80°C, and the inlet and outlet temperature of cooling water are 15°C and 25°C, respectively. COP of methanol and R-134a is 0.17 and 0.148. The adsorption refrigeration system uses time for heating/cooling the system around 90 minutes. The COP of the continuous adsorption refrigeration system is 0.12 when evaporating temperature at 15°C, and cooling capacity ($Q_{eva}$) is 14.78 kJ. For R-134a refrigerant, the system needs time for heating/cooling 60 minutes and gives cooling capacity ($Q_{eva}$) of 40.49 kJ corresponds to the COP of the system is 0.15 for evaporating temperature 10°C, respectively.

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