THE EFFECT OF DIFFERENT AMBIENT TEMPERATURE TO SOLAR COOLING PERFORMANCE

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THE EFFECT OF DIFFERENT AMBIENT TEMPERATURE TO SOLAR COOLING PERFORMANCE

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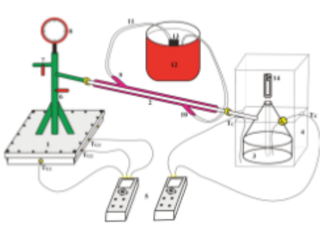
Graphical abstract



Abstract

The density of adsorbent bed significantly contributed to solar cooling performance (COP). The density determines how well the heat and mass transfer are. Besides that, the COP is also determined by ambient temperature. This research aims to investigate the affect of temperature of a connecting pipe, as a representative of different ambient temperature against a solar cooling machine performance. The experiment will show in what condition a solar cooling is going to have a better cooling result. The data used in this case was taken experimentally and conducted using a solar cooling machine equipped with temperature measurement units such as thermocouple logger. For cold ambient temperature, in adsorption process, refrigerant vapour flows to the generator through the connecting pipe cooled by water and kept steady. The results show that the COP, heat and mass transfer of adsorbent bed of the system in the adsorption process on a warm condition are better than in a cold environment. In the warm condition the COP system is 0.24, the heat transfer rate is 0.06 °C/minute, and the mass transfer rate is 1.09 ml/minute. Whereas, in the cold condition the COP system is 0.23, the heat transfer rate is 0.05 °C/minute, and the mass transfer rate is 1.04 ml/minute.

Keywords: Solar cooling, adsorption, ambient temperature, COP, heat transfer, mass transfer

1.0 INTRODUCTION

Indonesian hotels consume electricity about 60% to fulfil the need of air conditioning (AC) machines [1]. Since the electricity in Indonesia is 88% [2] produced from fossil fuel therefore the electric consumption contributes to greenhouse emissions which cause the global warming effect [3]. The vast majority of ozone depletion is caused by fluorocarbon usage, such as CFC, HCFC, and HFC as the refrigerant in cooling machines [4]. That is why the Vienna convention and Montreal Protocol in 1987 refused fluorocarbon usage and stop the production of these refrigerant types.

One of cooler refrigeration technology, which may be used as an alternative technology, is Solar Cooling technology. This technology is a cooling system based on open and closed cycle influenced by solar heat [5]. Solar energy has become promises power source because of its sustainability. It can be generated into electricity and heat [5] to drive solar cooling machine. One type of these technologies is adsorption refrigeration technology.

Adsorption cooling has a unique characteristic such the mechanical compressor can be altered by the adsorption process using heat energy to produce a cooling cycle (heat-operated cycle) [7]. Therefore, this kind of this technology seems suitable to be implemented as a small solar cooling system [8, 9, 10]. In addition, solar cooling technology has advantages such as low energy, easy operation, no vibration, and low cost [10].

Solar cooling system has three main components [11], such as Condenser, Evaporator and Generator. Generator contains of adsorbent-pair which is very important for desorption and adsorption process. Commonly it is used as adsorbent-pair are zeolite-water [12], silica gel-water [13], and active carbon-methanol [14].

Working pair carbon active-methanol has the highest COP and cheaper price compared with the other adsorbent-pair [15, 16]. Based on the experiments, granule carbon active-methanol adsorbent-pair produced COP from 0.10-0.23 [17, 18, 19, 20].

The performance of solar cooling (COP) is affected by the evaporation rate in the evaporator tank and depends on the ambient temperature [21]. The ambient temperature effects to the connecting pipe temperature passed by refrigerant vapour in which it flows from the evaporator to the generator. Latterly, the effect of the operating temperature environment of the system performance will be revealed.

This paper will show the effect of temperature of connecting pipe which is passed by refrigerant vapour resulted by heat transfer from chiller into evaporator. Moreover, the heat and mass transfer rate which effect to the cooling rate on adsorption process would be discussed as well. This simple technique can be used as an alternative to find out the affect of different climates developed by Clausse *et al*. [21].

2.0 EXPERIMENTAL

This research uses the simplest solar cooling machine with one connecting pipe which is installed as shown in Figure 1. Generator, evaporator, and chiller were equipped with instruments (thermocouples logger) to record each of the temperatures changes. As the result, data such as volume changes (ΔV) of refrigerant and temperature changes (ΔT) for each component obtained. After that, the data are analysed to find the heat transfer rate and mass transfer rate during adsorption process, and the COP of the system.

To know the effect of condenser temperatures against the COP of solar cooling, the experiment is conducted twice especially on the adsorption process. The first experiment is done at low temperature where the connecting pipe is flowed by water (cold condition), and the second experiment conducted without watering the connecting pipe (warm condition).

2.1 Solar Cooling Construction

The construction of solar cooling experiment is shown in Figure 1.

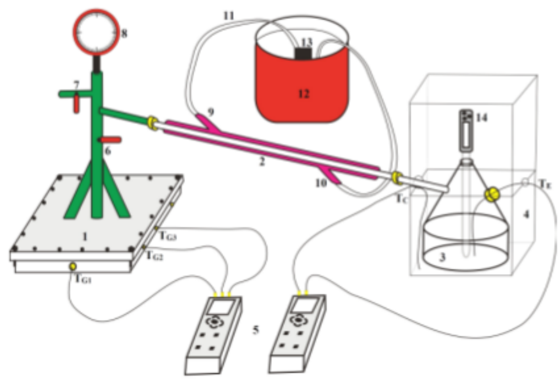


Figure 1 Solar Cooling Construction Design , 1) Generator; 2) Condenser Pipe/Connecting pipe; 3) Evaporator; 4) Chiller; 5) Thermocouple logger; 6) Valve control; 7) vacuum valve; 8) Pressure Gauge; 9&10) Inlet & Outlet condenser water; 11) water tube; 12) Water container; 13) Water pump; 14) Digital Thermometer

2.1.1 Generator

The generator is made from stainless steel with size (22x22x6) cm^3. Generator contains solid adsorbent from active carbon and refrigerant from methanol. The solid adsorbent bed is set with heat sensor thermocouples logger to record the temperature changes during desorption and adsorption processes.

2.1.2 Condenser Pipe

The condenser is made from stainless steel, 31 cm long and 0.6 cm in diameter. The adsorbate phase change happens in this pipe. It changes from vapour to liquid because the heat of the vapour is transferred to the water which is flowing surrounding the pipe.

2.1.3 Evaporator

As an important container from the system, evaporator is made from stainless steel. It is equipped with digital thermometer and thermocouples logger to record the refrigerant temperature inside.

2.1.4 Chiller

The chiller is filled with water, which is also installed with thermocouples logger sensor to record the temperature changes during desorption and adsorption processes. The chiller temperature usually remains stable while desorption process and declines during adsorption process.

2.1.5 Solar Cooling Support System

The solar cooling machine is designed for laboratory scale experiment. The solar heat source is changed with 300W electric stove. Whereas the water pump is used to ensure cold condition of the connecting pipe/condenser running well. Furthermore, the manometer is placed on top of the generator pipe to measure the pressure changes which happens during the cycles.

2.2 The Working Principle of Solar Cooling

Basically, solar cooling machine works based on desorption process (heating) and adsorption process (cooling). On desorption process, generator with solid adsorbent bed inside is heated until the refrigerant evaporates completely and move to evaporator. Once the vapour passing through the condenser pipe, it will be condensed and dropped into evaporator.

The next process after desorption process complete is adsorption process. Adsorption process can be started at any time if there is no heat in the generator. In this experiment, adsorption begins once the temperature of the system is in balance state. In this process, refrigerant in liquid form inside the evaporator will evaporate and move to the generator. This evaporation needs heat which is taken from environment. In this case the environment is water in the chiller. Therefore, there would be a temperature decreasing in the chiller.

2.3 COP (Coefficient of Performance)

COP (Coefficient of Performance) of refrigeration describes the efficiency of the solar cooling machine system. COP defined as ratio of heat energy removed from the chiller (Q_e) to heat energy used (Q_g) and the work performed (W).
The mathematics equation of Coefficient of Performance [9,22,23] is shown in Eq. 1.

$$COP = \frac{Q_e}{Q_g + W} \quad (1)$$

Q_e is defined as the heat removed from the cooled space. The work input to the pump is usually trivial then W~0, thus the COP of adsorption refrigeration can be defined as in Eq. 2.

$$COP = \frac{T_{ichiller} - T_{lchiller}}{T_g} \quad (2)$$

Where $T_{ichiller}$ (°C) is initial chiller temperature, $T_{lchiller}$ (°C) is last chiller temperature, and T_g (°C) denotes the temperatur derived from the heat source to the generator (desorber).

3.0 RESULTS AND DISCUSSION

3.1 Full Hardware Setup

Solar cooling system is one of technologies uses renewable energy source to produce cooling effect. This system works based on two cycles, desorption and adsorption cycles. In this experiment, desorption process needs heat to release the refrigerant (methanol) from adsorbent bed in generator to vaporize and flow to evaporator through condenser pipe. This process conducted for ±2.5 hr with maximum heating up no more than 120 °C. Reference [23] said that heating methanol more than 120 °C will cause the methanol decomposes to be another product.
Hence, inside generator equipped with temperature control and set at 69 °C. The set up is done in order to meet with average temperature produced by solar water heater available in the market. Besides that, it considers the boiling point of methanol at 67 °C as well. As the result of desorption process is presented in Figure 2.

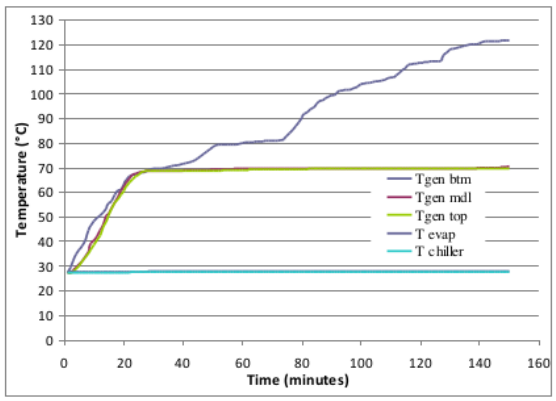


Figure 2 Adsorbent bed's temperature behaviour against desorption time

Desorption is begun from initial temperature at ±27 °C and ambient temperature at (T_{amb}) 29 °C. As can be seen in Figure 2, the temperature for each solar cooling component increased steadily. Particularly for the lowest part of adsorbent bed ($T_{gen\text{-}btm}$), it has increased significantly after 69 °C. In this case the bottom bed temperature is the first to rise up, followed by the middle part ($T_{gen\text{-}mdl}$) and the upper part ($T_{gen\text{-}top}$), respectively.

It happens because the heat transfer from bottom to upside is not fast enough. The heat is still slowly induces to the middle and upper part to change the methanol from liquid phase to gas. Once the methanol reaches the boiling point, it begins to evaporate. The heat rises the temperature of adsorbent gradually.

However, in the minute 26th the temperatures meet at the same point at 68.3 °C. After that the bottom adsorbent's temperature ($T_{gen\text{-}btm}$) preserves to rise significantly whereas the others remain stable. Adsorption process so called cooling process since in this process the evaporator absorbs the heat from water in the chiller. As consequence, the chiller's (environment) temperature begins to drop.

Once the heat from environment is absorbed by refrigerant inside the evaporator tank, the refrigerant evaporates as vapour and moves to generator through the condenser pipe.

In this experiment, the adsorption process is done twice. The first is done with water flows surrounding the pipe (low temperature), and the second is without water (warm condition). These treatments were done to observe the effect of temperature of the connecting pipe to the COP of the solar cooling. Here, heat and mass transfer inside the adsorbent bed were calculated as well. The results are shown in Figure 3 and Figure 4.

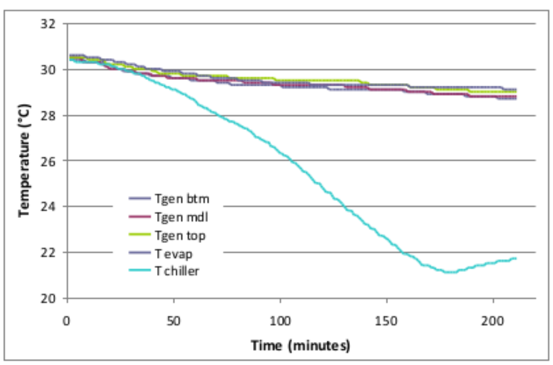


Figure 3 Adsorbent bed's temperature against adsorption time for cooled connection pipe

Figure 3 shows that on the first adsorption process experiment with watered condenser (low temperature) and keep stable in 27 °C, there was a gradual temperature drop from 30,4 °C to 21,1 °C within 184 minutes. In other word, the chiller's temperature dropped by 9.3 °C but then rise back at once. It was caused by limited adsorption ability of active carbon to adsorb the refrigerant from the evaporator tank.

Meanwhile, the result of adsorption process without cooled condenser (no watered connecting pipe) is shown if Figure 4.

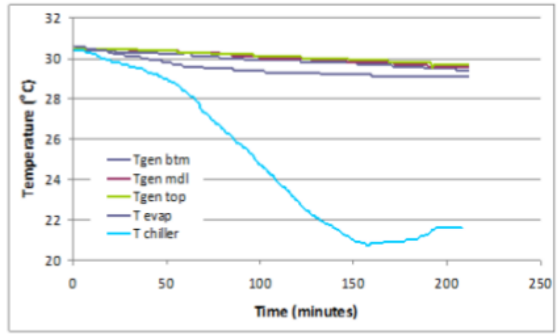
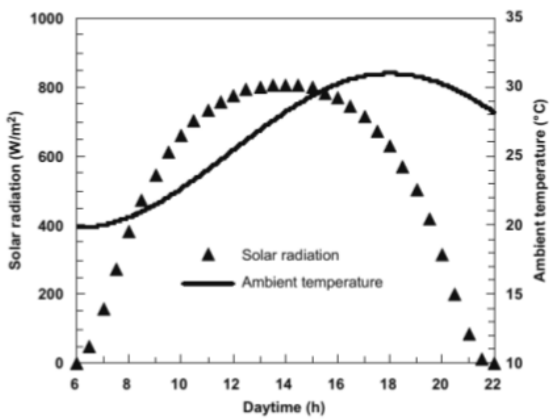


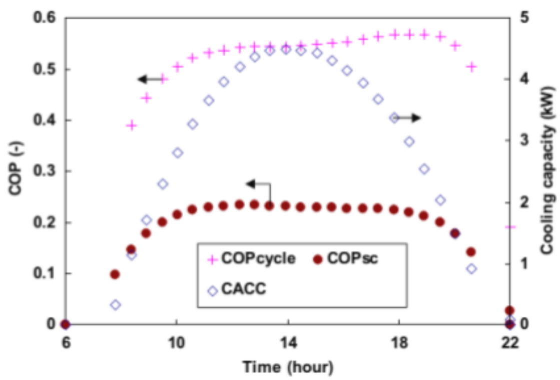
Figure 4 Adsorbent bed's temperature against adsorption time for no cooled connection pipe

There are noticeable differences between Figure 3 and Figure 4. Decreasing of chiller temperature on Figure 4 happens in a period of 158 minutes by 9,7 °C from 30,4 °C to 20,7 °C. It means that heat removed by the system without cooled connection pipe is higher than the system using cooled connection pipe. Both processes were done under the same initial temperature system at ±30 °C.

Besides the system with no cooled junction pipe have higher heat removed from the environment better than the cooled one, the temperature dropped quicker as well. It is because there are many vapour of refrigerant consistently condensed and dropped back to evaporator tank. Therefore it needs longer time to be adsorbed by the adsorbent bed in the generator. In these processes, the system with cooled connecting pipe has 90 mL methanol left in evaporator higher than other system which has 80 mL remains on its evaporator tank. These results are in line with reference [21] and shown on Figure 5.



(a)



(b)

Figure 5 The COP clearly determined by ambient temperature; a. Ambient fluctuates in daytime, b. COP changes in daytime

To support the hypothesis that higher COP has higher mass and heat transfer rate, then the heat transfer rate of adsorption process on the chiller needs to be investigated. It could be done by calculate the time needed by the chiller to remove its heat inside. The heat transfer is calculated as mention here.

$$\dot{v}_{aHT1} = \frac{30{,}4 - 21{,}1}{183} = \frac{9{,}3}{183} = 0{,}05\,{}^{\circ}\mathrm{C}/\mathrm{minute}, \text{ and}$$

$$\dot{v}_{aHT2} = \frac{30{,}4 - 20{,}7}{158} = \frac{9{,}7}{158} = 0{,}06\,{}^{\circ}\mathrm{C}/\mathrm{minute}$$

From the calculation above we can see that the heat transfer rate ($\dot{v}_{aHT1}$) of adsorption process with cooled connecting pipe is less rather than the heat transfer rate ($\dot{v}_{aHT2}$) of the other one. This result supports the hypothesis that higher heat transfer rate produce higher performance for the cooling process. Furthermore, to know the relation of cooling quality with mass transfer then calculation of the mass transfer from the system is conducted. Regarding adsorption process, for the system using cooled connecting pipe, the volume of refrigerant adsorbed by the active carbon adsorbent bed is 220 mL in 211 minutes. Whilst, for the system without cooled junction pipe, the volume adsorbed is 230 mL in the same period of time. Therefore, the mass transfer rate ($\dot{m}_{aMT}$) of the refrigerant is calculated as below.

$$\dot{m}_{aMT1} = \frac{220\,\mathrm{mL}}{211\,\mathrm{minutes}} = 1{,}04\,\mathrm{mL}/\mathrm{minute}, \text{ and}$$

$$\dot{m}_{aMT2} = \frac{230\,\mathrm{mL}}{211\,\mathrm{minutes}} = 1{,}09\,\mathrm{mL}/\mathrm{minute}$$

As can be seen from the calculation, the mass transfer rate of the cooled junction pipe ($\dot{m}_{aMT1}$) is less than mass transfer rate of the non-cooled connecting pipe ($\dot{m}_{aMT2}$). It means that higher mass transfer rate for adsorption process will accelerate the heat removed from the chiller. In other word, it produces more cooling.

The calculation of coefficient of performance (COP) is needed to determine in what extent efficiency of the refrigerant system. Based on experimental processes, it revealed which is more efficient between two treatments; wherein this experiment compare the effect of cooling process using cooled connecting pipe and without cooled connecting pipe.

Based on the experiments, to evaporate refrigerant from adsorbent bed, it needs heat up to 40 °C. Hence the COP of system with cooled connecting pipe is 0.23, less than the system without cooled connecting pipe which is 0.24. This result is agree with the reference that bigger COP has better performance of the refrigerant machine [25].

4.0 CONCLUSION

The experiment results proved higher heat and mass transfer rate on solar refrigeration make a better performance based on the heat removal from the chiller and speed up cooling. It can be concluded that the performance of solar cooling machine without cooled connecting pipe (higher ambient temperature) on adsorption process is better than solar cooling machine with cooled connecting pipe (lower ambient temperature).

Acknowledgement

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