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**Research Article**

# Weather Effect on the Solar Adsorption Air-conditioning System using Activated Carbon Fiber/Ethanol as Pair of Refrigeration: A Case Study of Malaysia

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**Abstract:** This study indicates the simulation analysis of the solar adsorption cycle using the activated carbon fiber/ethanol as the pair of refrigeration in Malaysia. The heat source used was evacuated tube collectors. The cycle is used for the purpose of air-conditioning for two temperature levels, where the cooling load can be 7°C. TRNSYS simulation software was used to model the system with the weather data of Malaysia. The results showed that the weather has a high effect on the performance of the cycle. Both the cooling capacity and the COP were calculated in this study.

**Keywords:** Activated carbon fiber-ethanol, adsorption, air-conditioning, solar energy

## INTRODUCTION

Many researchers have taken place in the estimation of the effect of air conditioning systems on the ozone and the emission of gases to the atmosphere. Two sources that may effect on the global warming in the world, the releasing of refrigerants and the emission of greenhouse gases (Calm, 2002). The noticeable studies in the field of alternative sources of energy take the priority in the recent researches; on the other hand, the cost and the use of waste energy in the air conditioning systems become the most important issues in reaching the human life comforting especially in the hot climate areas or in some countries that have no continuous electricity (Koroneos *et al*., 2009).

The use of solar air conditioning systems instead of electric power air conditioning systems stand an attractive concept in the building, since the synchronization of cooling load with solar energy is available with the availability of solar radiation, so as the highly needed of cooling in high solar incident (i.e., high temperature climate) (Gordon and Choon Ng, 2000). For these reasons, the solar air conditioning systems have the advantages of using some fluids that are not prejudice on the environment or human health like that used in traditional electric power air conditioning systems (Alam *et al*., 2013).

The word "sorption" represents both (adsorption) and (absorption) processes, (solid-vapor) process deals with the splitting of (adsorbate) form phase on addition with its concentration to another (adsorbent) (El-sharkawy, 2006).

Yong and Ruzhu (2007) sets the advantages of the adsorption air conditioning systems as, no moving parts (mechanical parts), no corrosion effect on the mechanical parts, simplicity in structure and need low heat source temperature, all these advantages made this type of systems more attractive in wide range of industrial applications. Alghoul *et al*. (2007) investigated some criteria for choosing the proper adsorbate and adsorbent. For the adsorbate, the preferred evaporation temperature should be below 0°C, should have small molecules size in order to be adsorbed into the adsorbent, low specific volume with high latent heat, have the stability in thermal properties at the variation of temperature during the process, not a corrosive material, non-toxic, non-flammable and finally having low saturation pressure (slightly above the atmospheric pressure). For the adsorbent, the main considerations in choosing the suitable adsorbent are: the ability of adsorb large amount of adsorbate at low temperature, the desorption of adsorbate when exposed to thermal energy, the latent heat must be higher compared to sensible heat, no drop in quality according to use or store, non-toxic, non-corrosive and finally low cost with wide availability.

Many recent works of adsorption air conditioning taken oriented of using activated carbon as and adsorbent, with other component as the (adsorbent/adsorbate) pairs. Yong and Sumathy (2004) used the two beds thermal system with activated carbon and ammonia, they found that only single heat transfer fluid loop was existed in the thermal process, where the system achieved a cooling COP of 1.9 (El-sharkawy, 2006). Ogueke and Anyanwu (2008) used the activated carbon with methanol as (adsorbent/adsorbate) pair; the study investigated the effect of using different collectors' parameters on the overall thermal

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performance of adsorption cycle. The increasing in the coefficient of performance COP was found to be in the range of 29 to 38%.

The using of solar adsorption system was developed by Luo *et al*. (2005) for the practical application of ice maker, using the activated carbon/methanol pair to reach a value of COP of 0.083-0.127 with daily ice production of 3.2-6.5 kg/m$^3$.

Louajari *et al*. (2010) studied the using of finned tube adsorber and its effect on the solar adsorption cooling cycle performance by using activated carbon/ammonia pair. The results showed that the optimal diameter of adsorber with fins is greater than the adsorber without the existing of fins, with the increasing of 20$^o$C in temperature inside the adsorber. Therefore, the COP of the system with fins is higher than the one without fins.

An experimental study of solar adsorption refrigeration cycle for ice making was built by Li *et al*. (2002) using activated carbon with methanol as the refrigeration pair. The bed was constructed of two flat-plate collectors, with 1.5 m$^2$ total surface areas and a quartz lamp as the source of solar radiation. The results showed that the ice production can exceed 4-5 kg after receiving 16 MJ of radiation with 0.75 m$^2$ surface area of the collector, while when receiving 30 MJ of radiation with 1.5 m$^2$ surface area, the system can produce up to 10 kg of ice.

The present study investigates the performance of a solar adsorption air conditioning system using activated carbon fiber/ethanol as the (adsorbent/adsorbate) pair of refrigeration, under the climate conditions of Malaysia in the location of (Universiti Kebangsaan Malaysia), UKM, Bangi, which is located in (2°55 N) longitude and (101°46 E) latitude.

## PRINCIPLE AND OPERATION PROCESS

Two-bed adsorption air conditioning cycle powered by solar heat has been considered in this study. Figure 1 represents the schematic drawing of the system, while Fig. 2 shows the technical drawing for the cooling system connected to the cooling load.

The adsorption equilibrium is the state in which both adsorption and desorption are in the same rates. Desorption is the reverse process of adsorption, where the molecules of (Ethanol) are separated form (Activated Carbon Fiber) by heat (Saha *et al*., 2007) (Fig. 3). However, the adsorption equilibrium can be explained by adsorption isotherms, where temperature, pressure and concentration are correlated together. The basic adsorption cycle consists of four main processes, as shown in Fig. 4, (A-B) when (ACF) is heated by solar heat until the pressure reaches the level of desorption of refrigerant at point (B). Process (B-C) is the desorption of (Ethanol) vapor by the additional solar heat, in which the refrigerant will condensate in the condenser. After this process, the solar radiation will decrease when the (ACF) exceeds its maximum temperature at point (C).

The valve between the evacuated tubes collector and the condenser will closed, which caused drop in temperature. Process (C-D) represents the cooling of the (ACF) with drop in pressure in the collector. At the same time, the liquid (Ethanol) will transferred to the evaporator. The collector now is connected to the evaporator when the pressure is equal to the pressure at the evaporator temperature at point (D). The temperature of the (ACF) will decrease now, therefore, it will pumps the liquid (Ethanol), where the heat will

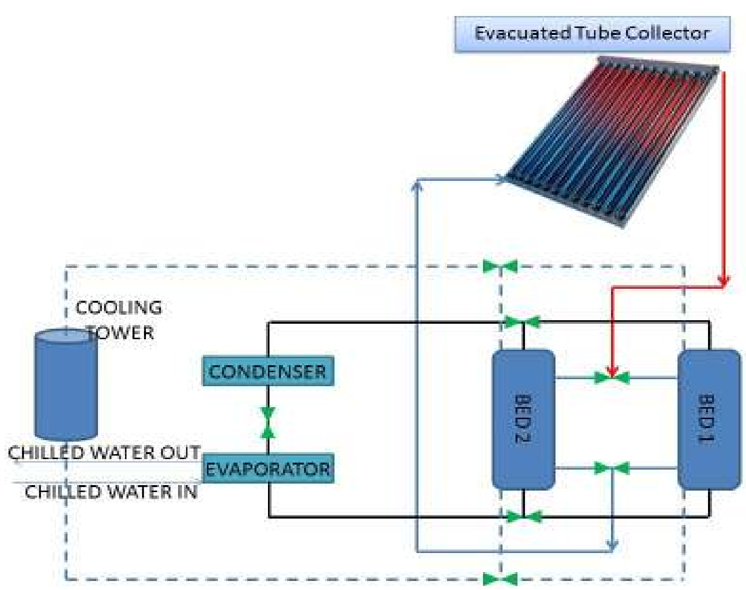


Fig. 1: Schematic drawing of the system

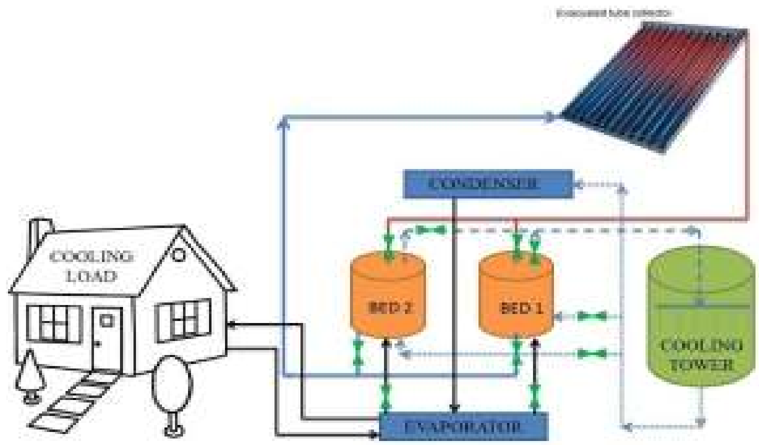


Fig. 2: Technical drawing of the system

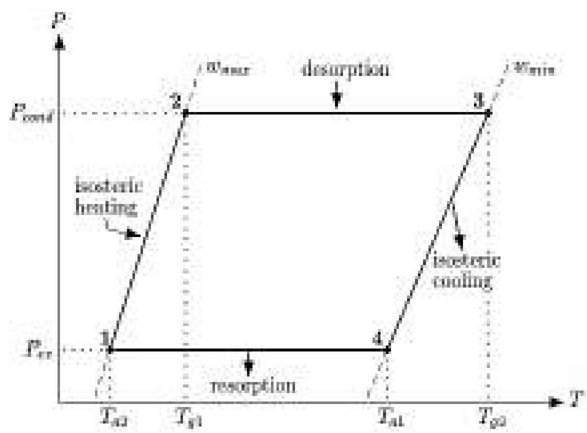


Fig. 3: P-T-w Diagram of the system

extracted from the evaporator at process (D-A) and lead to generate cooling process.

## MATHEMATICAL MODEL

The main assumptions sin this study are that the temperature, pressure and concentration will be uniform. The energy balance equation for the (ACF) bed is represented by El-sharkawy(2006):

$$(\boldsymbol{Mc_p})_{eff}^{bed}\frac{d\,T_i^{bed}}{dt} + [\boldsymbol{m}\;\boldsymbol{c_p}]_{i-phase}\frac{dT_i^{bed}}{dt} = \emptyset\;\boldsymbol{M_{ACF}}\left(\frac{dw_i^{bed}}{dt}\right)(\boldsymbol{Q_{st}}) - (\boldsymbol{\dot{m}c_p})_j(\boldsymbol{T_{j,o}} - \boldsymbol{T_{j,in}}) \quad (1)$$

where,

- $\Phi$ = 0 during switching
- $\Phi$ = 1 during adsorption/desorption cycle
- i = Ads/des bed
- j = Cooling/heating source

The left side of the above equation represents the rate of change of internal energy due to the thermal mass of ACF, while the right side of the equation represents the heat released during adsorption and the heat released to the cooling water during adsorption.

The outlet temperature of the source is very accurate to be presented in the (LMTD) method:

$$\boldsymbol{T_{j,o}} = \boldsymbol{T_i^{bed}} + \left(\boldsymbol{T_{j,in}} - \boldsymbol{T_i^{bed}}\right)\boldsymbol{exp}\left[\frac{-(UA)_i^{bed}}{(\dot{m}c_p)_j}\right] \quad (2)$$

where,

- $A_{bed}$ = Heat transfer area
- $U_{bed}$ = Overall heat transfer coefficient

By considering the same assumptions for the energy balance, for the condenser with the water cooled shell and tube heat exchanger, the energy balance equation for the condenser will be:

$$\left(Mc_p\right)_{eff}^{cond}\frac{dT^{cond}}{dt} = \emptyset\left[h_{fg}M_{ACF}\frac{dw_{des}^{bed}}{dt}\right] - \left(\dot{m}c_p\right)_w\left(T_{w,o} - T_{w,i}\right) \quad (3)$$

The left side of the equation represents the rate of change of internal energy required and the right side of the equation represents the latent heat of vaporization plus the heat released to the cooling water.

Using the (LMTD) method, the condenser's outlet temperature will be:

$$\boldsymbol{T_{w,o}} = \boldsymbol{T^{cond}} + \left(\boldsymbol{T_{w,in}} - \boldsymbol{T_{ads}^{bed}}\right)\boldsymbol{exp}\left[\frac{-(UA)^{cond}}{(\dot{m}c_p)_w}\right] \quad (4)$$

The same energy balance for the evaporator:

$$(\boldsymbol{Mc_p})_{eff}^{evap}\frac{dT^{evap}}{dt} = -\emptyset\left[\boldsymbol{h_{fg}M_{ACF}}\frac{dw_{ads}^{bed}}{dt}\right] - (\boldsymbol{\dot{m}c_p})_{chill}\left(\boldsymbol{T_{chill,o}} - \boldsymbol{T_{chill,i}}\right) \quad (5)$$

Table 1: Trnsys components used in the simulation

| Weather data | Reads weather data from data file (TMY) for Malaysia. |
|---|---|
| Psychometric | Takes the dry bulb temperature and dew point for moist air, and returning the properties of moist air. |
| Sky temperature | Determines an effective sky temperature and calculates long-wave radiation exchange. |
| Controller | Acts like a valve and represents an on/off differential function with a value of 1 or 0. |
| Pump | Calculates the mass flow rate. |
| Evacuated tubes | Models the performance of the evacuated tubes solar collector. |
| Hot storage tank | Represents a storage tank with constant volume and built in heat exchanger. |
| Auxiliary heater | Evaluates the temperature of the flow, and adding heat to the flow at a proper rate. |
| Adsorption chiller | Designed by MATLAB. |

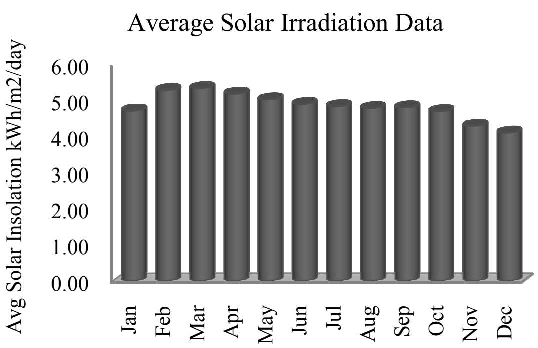

Fig. 4: Solar irradiation data

The left side of the equation represents the change of internal heat, while the right side represents the latent heat of evaporation plus the cooling capacity of evaporation.

Now, the outlet temperature of the chilled water ($T_{chill,o}$) can be expressed by:

$$\boldsymbol{T_{chill,o} = T^{evap} + \left(T_{chill,i} - T^{evap}\right) exp\left[\frac{-(UA)^{evap}}{(\dot{m}c_p)_w}\right]} \quad (6)$$

## SIMULATION PROCEDURE

The generated results used in the study based on the solar data for the same location taken from (Malaysian Meteorological Data) (www.met.gov.my) for January to March 2013 and then validated with the weather data taken in the same location.

The minimum and maximum temperature for that period was in the range of 22°C to 34.15°C. TRNSYS simulation software was used to simulate and connect all the equipment of the cycle as shown in Fig. 5. The TRNSYS components used are: weather data, psychometric, sky temperature, controller, pump, evacuated tubes collector, hot storage tank, auxiliary heater and adsorption chiller. All components are listed in Table 1.

**Weather data:** In all solar energy researches, the most accurate weather data is required, for example, ambient temperature and solar radiation, where these parameters are very important. Figure 4 shows the average monthly solar insolation of the experiment location in kW/m$^2$/day. Clearly, the figure shows that in (February and March), the solar insolation will exceed the maximum value (about 5.3 and 5.35 kW/m$^2$/day), so the maximum solar radiation for these 2 months will be (441.66 and 445.83 W/m$^2$) respectively. Table 2 represents the variation of average ambient temperature, where the ambient temperature is almost constant through the year, with maximum value of (34.15°C).

Table 2: Average ambient temperature

| Month | $T_{max}$ (°C) | $T_{min}$ (°C) |
|---|---|---|
| JAN | 32 | 22 |
| FEB | 33.8 | 24 |
| MAR | 34.15 | 24.5 |
| APR | 33.5 | 23 |
| MAY | 33 | 22 |
| JUN | 33 | 22 |
| JUL | 32 | 23 |
| AUG | 32 | 22 |
| SEP | 32 | 23 |
| OCT | 32 | 23 |
| NOV | 32 | 23 |
| DEC | 31.5 | 22 |

## RESULTS AND DISCUSSION

**Hot water supply:** The hot water supply from the hot water tank to the system is shown in Fig. 5, the daily operating time for the cycle was taken from8:00 AM to 6:00 PM. Obviously, from Fig. 5 the temperature of the hot water at 10:00 AM is about (55$^o$C) and the maximum value was reached at 2:00 PM and it is about (93°C).

**Chiller feedback:** The feedback of the adsorber/desorber heat exchangers is shown in Fig. 6. The hot water inlet temperature for the cycle is taken as (85$^o$C), while the cooling water inlet temperature is (30$^o$C). The brine inlet temperature for the evaporator is (7$^o$C). It can be concluded that the cycle time is 1800 sec (three half cycles) to transfer from transient to steady state status.

Figure 6 shows the profile of the outlet temperature of the ethanol, after a cycle time of about 500 sec, it is showed that the difference between the inlet and outlet hot water temperature is about (5$^o$C), while the outlet temperature of cooling water is (3$^o$C) higher than the inlet temperature of cooling water for the adsorber.

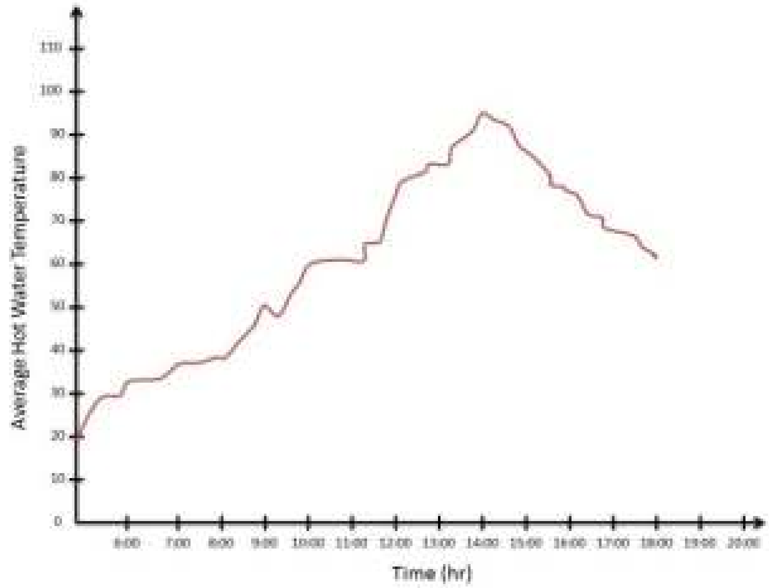


Fig. 5: Average hot water temperature

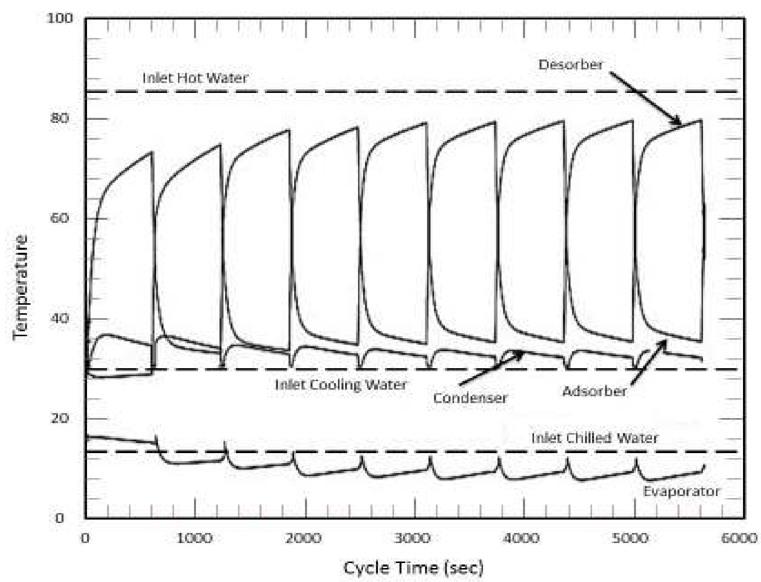


Fig. 6: Temperature profile of the ACF-Ethanol adsorption chiller for different components

**Effect of cooling water inlet temperature:** The effect of inlet cooling water temperature on both the cooling capacity and the coefficient of performance COP was shown in Fig. 7. The mass flow rate for the cooling water passing on each adsorber is 1.5 kg/sec and the same value for the coolant inside the condenser. It is clearly showed that the increasing of cooling capacity is steady with the decreasing of inlet cooling water temperature, due to the fact of lower adsorption temperature occurs in the large amount of ethanol that adsorbed or desorbed during the cycle time. The simulation results also showed that the value of the COP will increased as the inlet cooling water temperature decreased.

**Effect of hot water inlet temperature:** The effect of the hot water inlet temperature on the cooling capacity and COP was presented in Fig. 8. The simulation results showed that the cooling capacity increased as the hot water temperature increased, this is due to increasing of ethanol circulation and due to desorption increasing with high temperature of the driving source. The results also showed that the increasing of the hot water inlet temperature will caused an increasing in the COP.

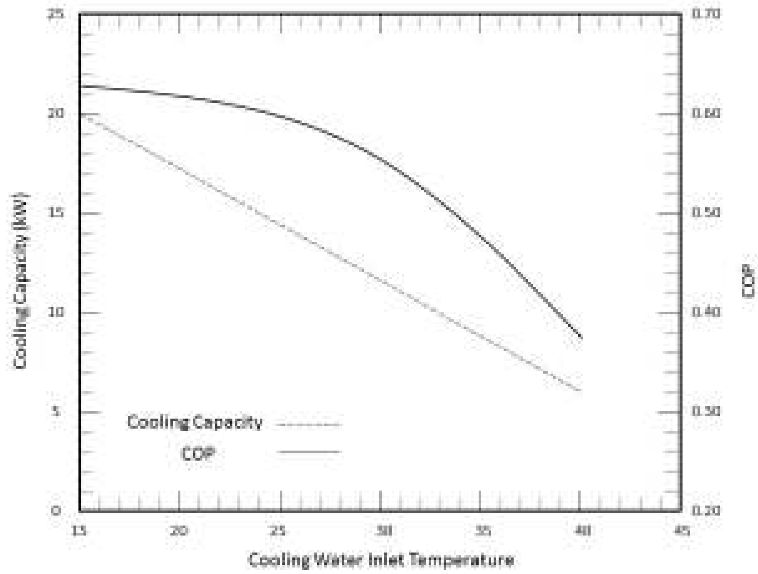


Fig. 7: Effect of cooling water inlet temperature on the cooling capacity and COP

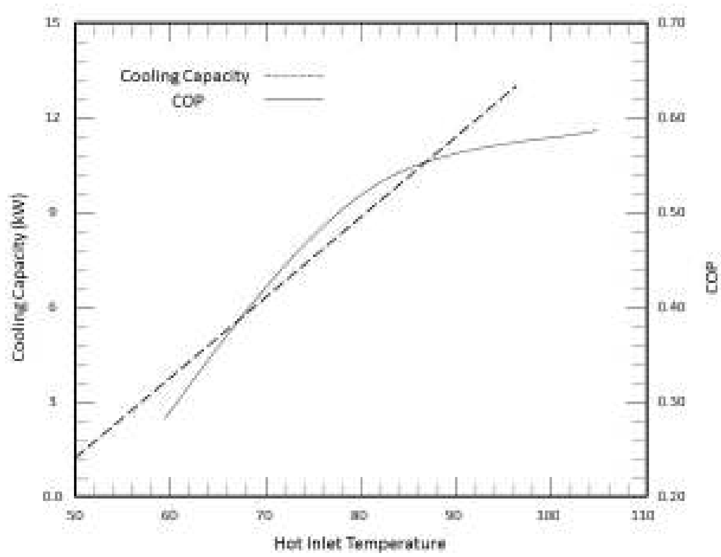


Fig. 8: Effect of hot water inlet temperature on the cooling capacity and COP

## CONCLUSION

The performance for simulation data of solar driven two-bed adsorption air-conditioning system using activated carbon fiber/ethanol as the refrigeration pair was presented in this study. A simulation software called TRNSYS program was used to model the system, with the weather data for (UKM, Bangi) Malaysia was used. The simulation results showed that the ACF/ethanol adsorption system can delivered an evaporation temperature to about (7°C) and the cooling load can be achieved by one heat source of a temperature range (55 -95°C), which is widely available in solar energy sources and waste heat sources. Finally, the cooling effect can be produced at two temperature levels.

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