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Adsorption Cooling System Employing Activated Carbon/R32 Adsorption Pair

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Abstract. This paper reports the performance of an adsorption cooling system employing activated carbon powder (Maxsorb III)/R32 adsorption pair. The system has been modeled and simulated numerically and the effect of changing the operating conditions has been studied. The system has been simulated to driven by a low-grade heat source temperature below 90ºC and effectively employs solar heat and/or waste sources to drive the system.

1 Introduction

Energy reduction has become one of the most interesting points of research due to the global energy crisis. Renewable and/or waste energies may be considered as one of the solutions for the energy problems. Unfortunately, most of these energies are usually having a low grade temperature below 100ºC which is difficult to use. One of the smart solutions is to use the adsorption cooling system which could be driven by the low grade heat source temperatures. Many researches tried to introduce an adsorption cooling system powered by low grade heat source temperature but they faced the problem of low COP and high specific volume due mainly to batched cycle operation and poor thermal conductivity in the adsorbent bed [1-10]. This paper introduces an adsorption cooling cycle employing activated carbon powder (ACP)/R32 adsorption pair.

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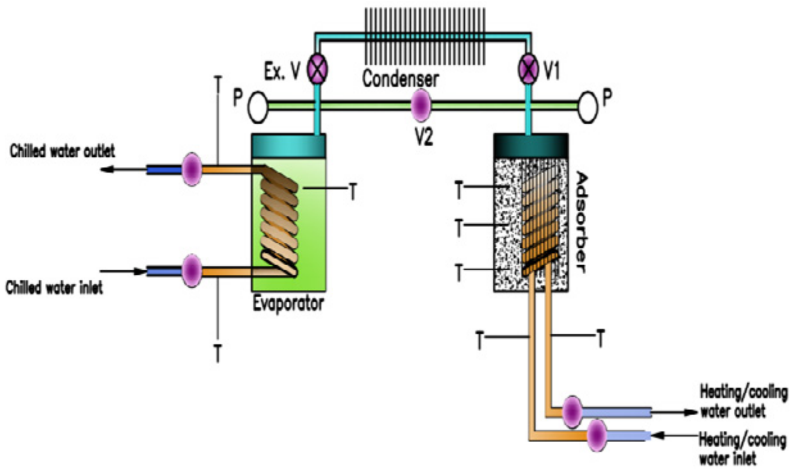
2 System Description

An adsorption cooling cycle has been simulated employing ACP/R32 adsorption pair. A proposed design as shown in Fig. 1 which is mainly consists of an adsorption bed, an evaporator and a condenser. The adsorber is a finned tube type heat exchanger with 500 W capacity. The condenser is cooled using ambient air directly by natural convection. An expansion valve has been attached after the condenser to throttle the refrigerant to evaporator pressure. Both of the adsorber and the evaporator are assumed to be isolated. The adsorber is assumed to contain 200 grams of the adsorbent. A bypass tube has been allocated between the adsorber and evaporator. This bypass tube is assumed to be used during adsorption process. Table 1 shows the designing parameters of the system.



V: Valve, P: Pressure transducer, T: Thermocouple

Figure 1. Single bed ACP/R32 based adsorption cooling system.

Table 1. Design parameters of ACP/R32 adsorption cooling system

$\dot{m}_{hw}$, kg/s	C_0, kg/kg	E, kJ/kg	n	c_{pw}, kJ/kg.K	c_{pac}, kJ/kg.K	m_{ac}, kg	$(UA)_{bed}$, W/K	$(UA)_{con}$, W/K	$(UA)_{eva}$, W/K
0.1	1.514	92.17	1.32	4.18	1.4	0.2	12	20	20

3 Mathematical model

Dubinin-Astakhov (D-A) (Eq. 1) and linear driving (LDF) model (Eq. 2) are used to estimate the adsorption isotherms and kinetics respectively for the various adsorption pairs.

$$C = C_{o} exp\left(-\left(\frac{RT}{E} ln\left(\frac{P_s}{P}\right)\right)^{n}\right) \tag{1}$$

$$\frac{\partial c}{\partial t} = \frac{F\,D_s}{R_p{}^2}(C_0 - c) \tag{2}$$

The isosteric heat of adsorption has been determined in the model by using Eq. 3.

$$H_{st} = h_{fg} + E\left[ln\left(\frac{C_0}{C}\right)^{\frac{1}{n}}\right] + \frac{ET\alpha}{n}\left[ln\left(\frac{Co}{C}\right)\right]^{\frac{1-n}{n}} \tag{3}$$

Using lumped approach for the adsorption bed, the heat exchanger fins and tubes, the energy balance equation, is given by [11]:

$$\left[\left(m_{ac}c_{p_{ac}} + m_{ac}c_{p_{ref}}C\right) + \left(m_{hex}c_{p_{hex}}\right)\right]\frac{dT_{bed}}{dt} = m_{ac}\Delta H_{st}\frac{dC_{bed}}{dt} - \dot{m_w}c_{p_w}\left(T_{w,out} - T_{w,in}\right) \tag{4}$$

$$T_{w,out} = T_{bed} + \left(T_{w,in} - T_{bed}\right)exp\left[\frac{-(UA)_{bed}}{(\dot{m}c_p)_w}\right] \tag{5}$$

$$\left(m_{hex}c_{p_{hex}}\right)_c\frac{dT_c}{dt} = m_{ac}h_{fg}\frac{dC_{des}}{dt} + m_{ac}c_{p_{ac}}(T_{des} - T_{\infty})\frac{dC_{des}}{dt} - U_c(T_c - T_{\infty})A_{hex} \tag{6}$$

The energy balance equation of the evaporator can be expressed as,

$$\left(m_{ref}c_{p_{ref}} + m_{hex}c_{p_{hex}}\right)_{eva}\frac{dT_{eva}}{dt} = -m_{ac}h_{fg}\frac{dC_{ads}}{dt} - \dot{m}_{chill}c_{p_{chill}}\left(T_{chill,out} - T_{chill,in}\right) \tag{7}$$

The mass balance of refrigerant in the adsorption chiller is expressed by,

$$\frac{dm_{ref}}{dt} = -m_{ac}\left(\frac{dC_{des/ads}}{dt}\right) \tag{8}$$

$$SCE = \frac{1}{t_{cooling\ effect}}\int_0^t (\dot{m}\,cp_w)_{chill}\left(T_{chill,out} - T_{chill,in}\right)dt \tag{9}$$

$$COP = \frac{\int_0^t (\dot{m}\,cp_w)_{chill}(T_{chill,out} - T_{chill,in})dt}{\int_0^t (\dot{m}\,cp_w)_{des}(T_{hw,in} - T_{hw,out})dt} \tag{10}$$

4 Results and discussion

Figure 2 shows the heat transfer fluids (heating, cooling and chilled) and temperature profile of the adsorbent adsorption bed at 350 K regeneration temperature and 277 K evaporator temperature. It is clear from the figures that the cycle time of ACP/R32 is about 550 seconds and about 270 seconds of them are consumed in heating. Figure 3 shows the effect of regeneration temperature on specific cooling capacity (SCC) respectively. The figure indicates that raising the evaporator temperature up to 283 K raises the SCC. Increasing regeneration temperature also has a positive effect on the SCC. The cycle achieves the highest SCC value of about 0.25 kW/kg at 283 K evaporator temperature and 350 K regeneration temperature. Figure 4 shows the relation between COP and regeneration temperature of ACP/R32 adsorption cooling cycle at different evaporator temperatures. It is clear from the figure that raising the regeneration temperature up to 350 K raises the COP of the system. The cycle achieves the highest COP value of about 0.23 at 283 K evaporator temperature.

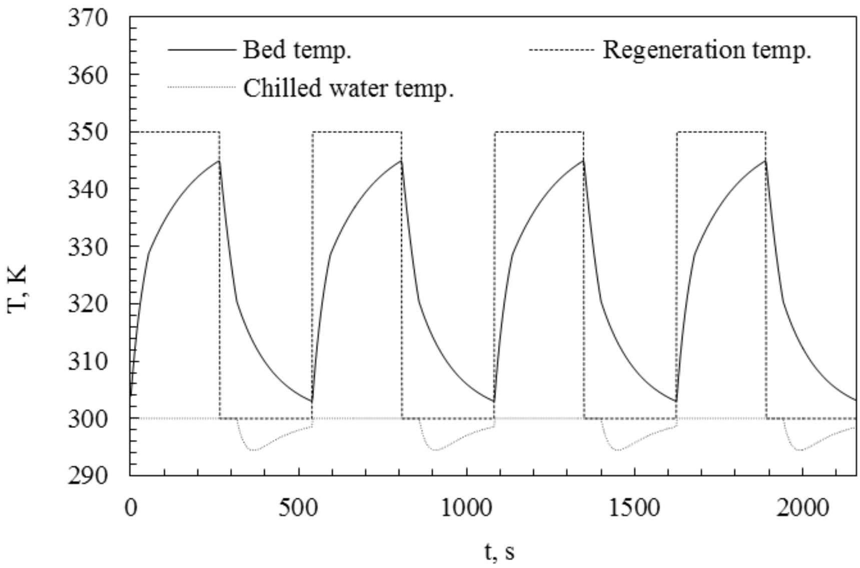


Figure 2. Heat transfer fluids and temperature profile of the proposed adsorption bed.

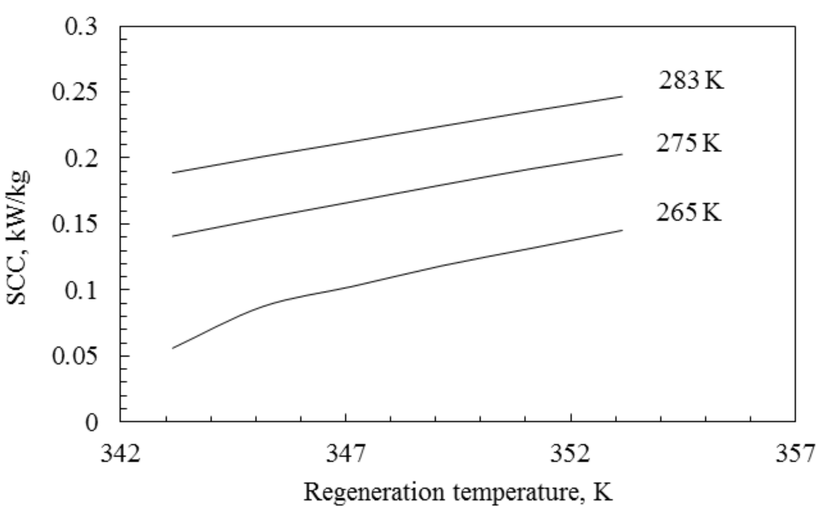


Figure 3. Effect of regeneration temperature on SCC of ACP/R32 at various evaporator temperatures.

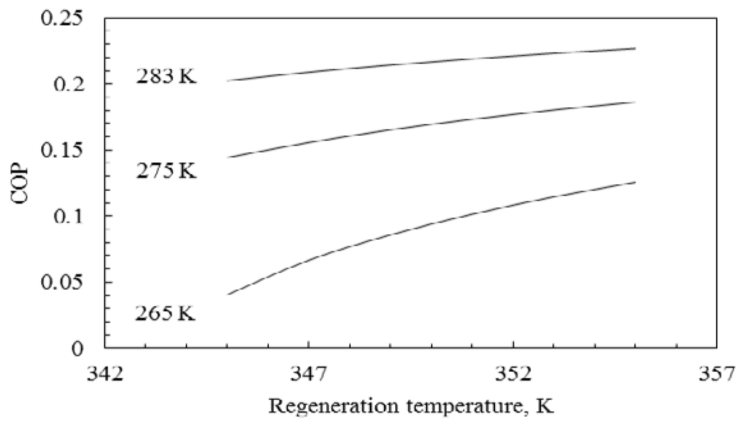


Figure 4. Effect of regeneration temperature on COP of ACP/R32 at various evaporator temperatures.

5 Conclusions

A single bed adsorption cooling system employing ACP/R32 has been simulated and a proposed design has been introduced. The system has been powered a heat source temperature below 90ºC. The effect of changing the operation conditions (regeneration temperature and evaporator temperature) on the SCC and COP has been studied. It has been noted that the cycle time of the system is less than 10 minutes. The system has been found to a achieve SCC and COP values of about 0.25 kW/kg and 0.23 respectively at 355 K regeneration temperature and 383 K evaporator temperature. Raising the regeneration or evaporator temperatures is found to increase the SCC and COP of the system. It can be concluded that ACP/R32 adsorption pair can be employed effectively in an adsorption cooling system. However, the COP of the system is relatively low but the system could be driven by low grade solar heat and/or waste heat sources otherwise it should be purged to the ambient.

References

1. M. Louajari, A. Mimet, A. Ouammi, Appl. Energy **88** (2011) 690-98.
2. R.E. Critoph, Appl. Therm. Eng. **22** (2002) 667-77.
3. R.E. Critoph, S.J. Metcalf, Appl. Therm. Eng. **24** (2004) 661-78.
4. L.W. Wang, R Z. Wang, Z.S. Lu, C.J. Chen, K. Wang, J.Y. Wu, Carbon **44** (2006) 2671-80.
5. J. Eric Hu, Sol. Energy **52** (5) (1998) 325-29.
6. Z. Huizhong, M. Zhang, L. Zhenyan, L. Yanling, M. Xiaodong, Energy Convers. Manage. **49** (2008) 2434-38.
7. F. Lemmini, A. Errougani, Renewable Energy 3**2** (2007) 2629-41.

8. L.W. Wang, J.Y. Wu, R.Z. Wang, Y.X. Xu, S.G. Wang, X.R. Li, Appl. Therm. Eng. **23** (2003) 1605–17.
9. I.I. El-Sharkawy, M. Hassan, B.B. Saha, S. Koyama, M.M. Nasr, Int. J. Refrig. **32** (2009) 1579-86.
10. L.W. Wang, R.Z. Wang, R.G. Oliveira, Renewable Sustainable Energy Rev. **13** (2009) 518-34.
11. L. Turner, *Improvement of activated charcoal-ammonia adsorption heat pumping/refrigeration cycles. Investigation of porosity and heat/mass transfer characteristics*, Ph.D. Thesis, University of Warwick (1992).