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Research Article

Design and Comparative analysis of Adsorption Refrigeration System for Refrigerants R-134a and R-410a

Pratik P. Kulkarni*, V. N. Kapatkar and Ameya C. Lohokare

†Mechanical Engineering Department, SCOE, SPPU, Pune India

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Abstract

Adsorption refrigeration is becoming popular due to it's environmentally friendly nature and use of low GWP and ODP value refrigerants. This system gives advantage of use of low temperature source such as waste heat. In present study, for better heat and mass transfer, refrigerants R 134a and R 410a are used in the system and their performance is compared. R 134a is commonly used refrigerant in automobile system. Adsorption performance is compared for temperatures at 30°C, 35°C, 40°C, 45°C and 50°C. COP and SCP performance for both refrigerants is compared. Activated carbon granules (ACG)/R 134a gives highest adsorption quantity of 1.4 Kg/kg at temperature of 30 °C at 850 kpa pressure. ACG/R 410a gives highest adsorption capacity of 1.19 Kg/kg at temperature of 30°C. Investigation showed that ACG/ R 134a has promising future in the adsorption refrigeration technology due to its highest adsorption capacity.

Keywords: *Adsorber Bed, Azeotropic mixture, Cycle time, Equilibrium model, Isotherms, Maxsorb III.*

1. Introduction

In this era, there is lot of work done about theoretical and experimental aspect of the adsorption refrigeration technology. New cycles, new working pairs and new research methods has been proposed. Adsorption refrigeration technology which attracts the researchers in the world despite of problems such as poor heat and mass transfer performance causes to keep this method away from practical world. Many researchers have attempted to design some practical systems.

Hence, the effective utilization of adsorption refrigeration technology is a first step for developing an efficient air conditioning and refrigeration systems. The other step is to find an effective refrigerant which has lower environmental impact with higher adsorption capacity than the other pairs. The adsorption cooling and refrigeration system is having the advantages no free of moving parts, efficiently driven by low-temperature waste heat and do not require any synthetic lubricants.

The basic adsorption cycle contains four processes represented in Fig. 1. From A to B adsorbent in bed is heated to the pressure such that desorption of the refrigerant gets started. At stage B refrigerant starts to desorb from adsorbent. Process B to C takes place in the condenser which causes heat addition and it causes desorption of vapor refrigerant that condenses in a condenser. At point C, the adsorbent reaches its maximum temperature and it starts to decrease. Process C to D causes pressure drop in the collector. The refrigerant is then comes into evaporator with decrease in temperature of adsorbent. This leads to addition of refrigerant into evaporator. In process D-A refrigerant in the evaporator takes heat from surrounding area and hence cooling effect is obtained.

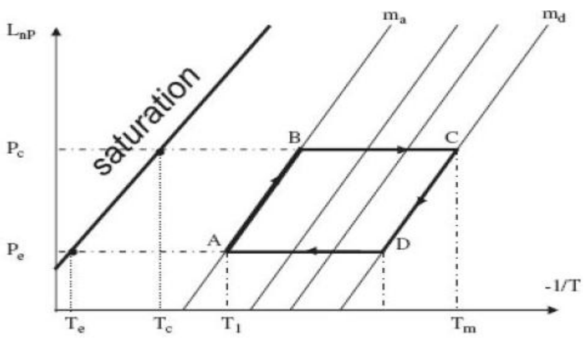

Fig. 1 Adsorption Refrigeration Cycle (Ahmed A. Askalany *et al*, 2013)

R-134a is another commonly used refrigerant in automobile air conditioning system. In new adsorption pairs R-134a gives better performance as compared to other pairs to reduce cycle time. But soon R-134a will be phase out due to high HFC content.

*Corresponding author: **Pratik P. Kulkarni**

R410A is a near-azeotropic mixture of difluoromethane (R32) and pentafluoroethane (R125) in equal ratio. A device was developed with minimum heat and mass transfer limitations between adsorbent and adsorbate, and practically applicable adsorption capacity data was obtained. Finned-tube heat exchanger was used. Pairs of refrigerants such as (ACP)/R-134a, ACP/R-507A, ACP/R-407c, activated carbon granules (ACG)/R-507A, ACG /R-407c and ACG /R-134a, were studied at different adsorption temperatures of ranging from 25, 30, 35 and 50°C. At adsorption temperature of 25 °C maximum adsorption capacity of 0.8352 kg kg-1 for activated carbon powder with R-134a was obtained. Study showed the minimum adsorption capacity for R407c with activated carbon granules as 0.1583 kg kg-1. Results at the temperature of 50 °C showed maximum adsorption capacity as 0.3207 kg kg-1 for ACP with R-134a whereas the minimum adsorption capacity came as 0.0609 kg kg-1 for activated carbon granules/R-407c. They found out as the adsorption temperature increased, the adsorption rate decreased. (Ahmed N. Shmourkh *et al*, 2015)

The application of adsorption pairs in cooling was studied and a classification along with a comparison for the working pairs according to its use was made. The description of adsorbate or refrigerant properties was made. The comparison of important parameters such as maximum COP, driving temperature, evaporation temperature and SCP was introduced. Comparison of traditional pairs along with new adsorption pairs was done. Many new pairs showed a promising future for cooling application. Silica gel-chloride with water showed highest COP where as zeolite water pair showed lowest COP (Mahmoud salem Ahmed *et al*). With use of fin tube heat exchanger adsorption capacity data for various adsorbates such as ACG/R-134a, ACG/407-C, and ACG-507a for adsorption temperature of 25, 30, 35, and 50°C was obtained. Results showed maximum capacity for ACG/R134a where as lowest of 0.1583 kg/kg for ACG/407-C at 25 C. It also showed more adsorption capacity was found with activated carbon powder than activated carbon granules. (Ahmoud N. Shaomukh *et al*, 2013)

Theoretical and experimental investigation of HFC-407c on activated carbon was also studied in past. Experimental data was fitted with D-A and Toth equation and adsorption kinetics was studied with FD and LDF models. It was shown that D-A model with volume correlation correlates better with experimental data. Results showed maximum adsorption capacity of 0.43 kg/kg (M.M. El-Sharkawy *et al*, 2015). A study was done for the adsorption kinetics of granular activated carbon/R- 134a pair with the temperature range from 20˚C to 60˚C and at 10 bar of pressure. The Dubinin-Astakhov adsorption equilibrium model was found fitted to experimental data with acceptable error limit. It was designed for the bed and built it with finned tubes heat exchanger to increase the heat transfer area. It was found that the adsorption capacity/kg of adsorbent increases rapidly when relative pressure at the beginning of the adsorption process is increased. The maximum adsorption capacity was founded as 1.92 kg/kg at 20˚C after 1200 s cycle time. The maximum adsorption capacity decreases to 1.31 kg/kg with the increase in adsorbent temperature at 60˚C (M. Attalla *et al*, 2014). A study was made for adsorption isotherms of R-134a (HFC-134a) on Maxsorb III activated carbon in the temperature range of 5–70 °C and pressures upto 12 bar, using desorption method. Correlation of data for Dubinin–Astakhov (D–A) equation was studied and compared with the results performed by other researchers. Heat of adsorption was obtained in the range from 22,000 to 28,000 J/mol. (Bidyut Saha *et al*, 2009). Comparison of equilibrium of activated carbon was studied with refrigerants such as R134a, R410a and 507a at temperature range of 278K to 338K and pressure of 1.4MPa. Results showed the limiting uptake (q_o) increases with density of refrigerants. (Wai Soong Loh *et al*, 2012).

2. Experimental Setup

Fig.2 Experimental Setup

Experimental setup consists of one adsorber bed with pressure gauges of 30 bar rating connected to it. The hot air is supplied to the bed with help of hot air gun as shown in the figure 3. Gun has variable flow capacity from 0.25 m^3/min to 0.5 m^3/min and temperature variation from 50°C to 610°C.

Fig.3 Hot air Supply Unit

Condenser with the capacity of 9 kW is used to cool the refrigerant. Thermal Expansion valve of 1 Ton capacity is connected in the system. Evaporator of 4 kW capacity is used. Two solenoid valves for a bed are used to control the flow of refrigerants. 12V DC Supply is used to run condenser fan and solenoid valves. Adsorber bed is made of Stainless steel material. J Type thermocouples are used to measure the temperature at the various points in the system. Two digital display with 8 switches each are used to note down the temperature readings.

A rotameter is used to control the flow of cooling water. A 0.3 hp AC pump is used to circulate cooling water through adsorber bed. Two refrigerants R-134a and R-410a are used each at a time in the system. A vacuum pump is used to create negative pressure in the system and then refrigerant is filled.

Table 1 Component Specification

Component	Description
Condenser	9 kW, Size: 390mm×290mm×16mm
Evaporator	4 kW, Size: 240mm×240mm×58mm
Thermal Expansion Valve	Capacity - 1 TR
Pipes	Liquid Pipes : Φ 8 mm Suction Pipes : Φ 16mm Discharge Pipes : Φ 12 mm Material used : Stainless steel.
Refrigerants	R-410a R-134a
Adsorbent	Activated Carbon Granules (Charcoal)
Hot Fluid Supply	Temperature 100 to 200°C
Radiator	Water at ambient temperature 30°C

3. Mathematical Model

For adsorption refrigeration system each parameter such as adsorber capacity, adsorption rate, total power input, evaporative effect, COP, SCP are mathematically modelled as follows:

3.1 Adsorber

The Dubinin-Astakhov (D-A) equation relates the concentration and temperature is represented as

$$x = x_0 \exp\left[-K\left(\frac{T}{T_s}-1\right)^n\right] \qquad (1)$$

X is the concentration of refrigerant adsorbed in bed at the temperature of the adsorption, T. Ts is the saturated temperature in the adsorber at given pressure, P. The saturated adsorption capacity of the working pair is given by *xo*. The parameter *k* and *n* are constants which varies with different working pair.

3.2 Adsorption Rate

System is divided into two phase adsorption and desorption. Cycle time will depend upon the adsorption and desorption rate.

Adsorption:

$$\frac{dx_{ads}}{dt} = K_{ads}\,(x_{ads,eq} - x_{ads}) \qquad (2)$$

Desorption:

$$\frac{dx_{des}}{dt} = K_{des}\,(x_{des}) \qquad (3)$$

3.3 Total Heat Input

$$P = \dot{m_h} c_{ph}(T_{in} - T_{out}) \qquad (4)$$

3.4 Condenser and Evaporator Heat Balance

Condenser Balance:

$$\dot{m}_{ref} C_{p,ref}(T_{des} - T_{cond}) + h_{v,ref} = \dot{m}_{air} C_{p,air}(T_{out} - T_{in}) \qquad (5)$$

Evaporator Balance:

$$h_{v,ref} - \dot{m}_{ref} C_{p,ref}(T_{cond} - T_{eva}) = \dot{m}_{air} C_{p,air}(T_{in} - T_{out}) \qquad (6)$$

3.5 COP and SCP

Adsorption refrigeration system evaluation is done with the parameters such as Coefficient of performance (COP) and Specific cooling power (SCP)

$$COP = \frac{Q_{eva}}{Q_{in}} \qquad (7)$$

$$SCP = \frac{Q_{eva}}{\dot{m}_{ads}} \qquad (8)$$

4. Result and discussion

Adsorption refrigeration system is implemented for refrigerants R134a and R410a. Adsorption quantity of refrigerants is measured for different pressures starting from 0.5 bar upto 8.5 bar at 30°C bed temperature.

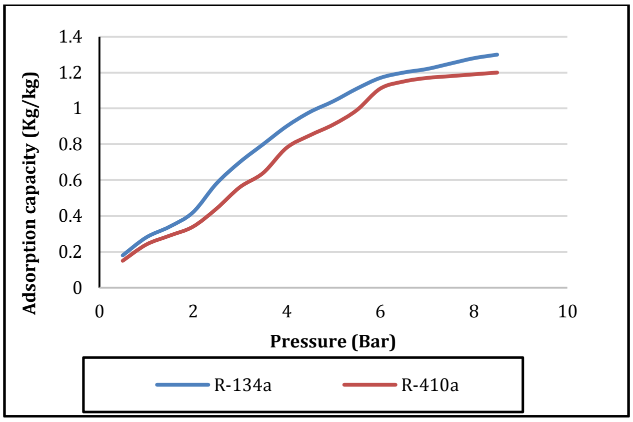

Fig 4. Adsorption capacity for various pressure at constant bed temperature of 30°C

Test results showed that R-134a gives highest value of adsorption capacity 1.4 Kg/kg at 8.5 bar whereas R 410a gives capacity of 1.2 Kg/kg for same pressure. Adsorption capacity at 45 °C for R-134a shows capacity of 1.22 Kg/kg and R-410a shows 1.18 Kg/kg.

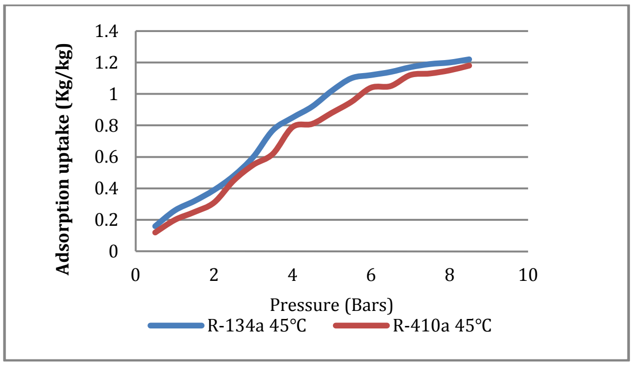

Fig 5. Adsorption capacity for various pressure at constant bed temperature of 45°C.

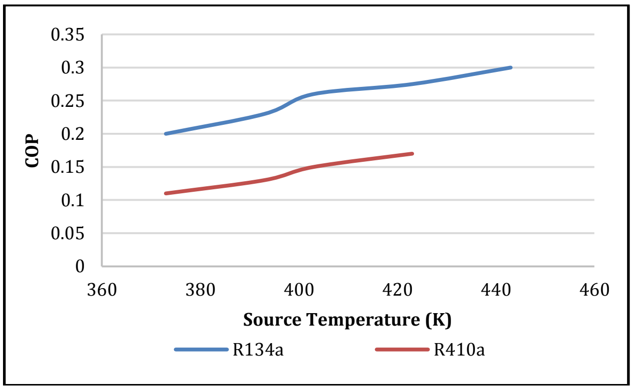

Fig 6 COP values for different source temperature

Fig. 6 shows the Coefficient of performance (COP) values at various source temperature for R134a and R410a. Figure shows that increasing source temperature increases the refrigerating effect at constant evaporator temperature. Due to lower critical point, R410a don't show COP values after 423K.

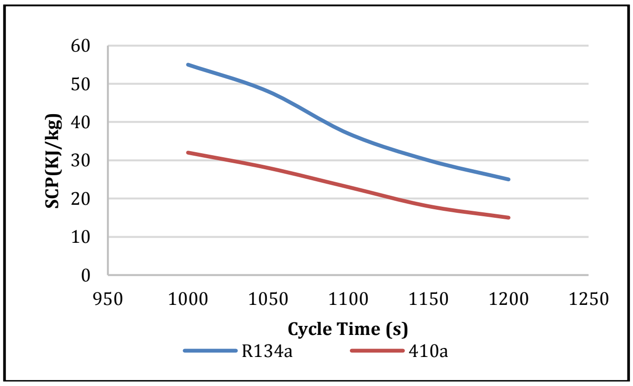

Fig 7 Specific cooling power of system at varying cycle time

Specific cooling power for both refrigerants decreases with rise in cycle time at constant source temperature. Due to lower mass adsorbed in bed R134a, at start, shows sudden rise in SCP. In case of R410a system mass adsorbed in decreasing slowly due to its low adsorption kinetics. Hence R410a shows nearly horizontal nature for increasing cycle time. Highest SCP shown by R134a at cycle time of 1000s is 55 KJ/kg.

Conclusion

When adsorption refrigeration system with single bed is provided with two refrigerants R134a and R410a separately following conclusions are obtained:

1) With proper Adsorbent/refrigerant pair, performance of adsorption refrigeration system can be enhanced.
2) When bed temperature is increased the adsorption capacity goes on decreasing.
3) R 134a shows highest adsorption capacity of 1.4Kg/kg at the bed temperature of 30°C. R410a shows capacity of 1.2 Kg/kg for the same temperature.
4) COP and SCP values are higher in case of R134a as compared to R410a.
5) R410a shows poor performance at higher source temperature.
6) From comparison results showed that R134a is having high scope in adsorption refrigeration technology among new refrigerants.

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