American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-9, Issue-1, pp-372-377
www.ajer.org
Research Paper
Open Access

Improving Adsorption Capacity of Activated Carbon for Cooling Applications

Ali Kamel[a], Ahmed Askalany[a],K. Harby[b],Kamal M.S. Khalil[c]

[a]*Mechanical Engineering Department, Faculty of Industrial Education, Sohag University, Sohag 82524, Egypt*
[b]*Department of Mechanical Power Engineering and Energy, Faculty of Engineering, Minia University, Minia 61517, Egypt*
[c]*Chemistry Department, Faculty of Science, Sohag University, Sohag 82524, Egypt*

Abstract: *In this paper adsorption properties of activated carbon (Aquasorb 2000) as adsorbent material were improved using several chemical ways to obtain high adsorption capacity. Zinc chloride, $ZnCl_2$, phosphoric acid solution, H_3PO_4, and ammonium carbonate, $(NH_4)_2CO_3$ have been added as aqueous solutions to the Aquasorb 2000 individually. The addition of these materials to the activated carbon was done at room temperature, followed by aging, drying and calcination at 500°C for an hour in flow of nitrogen gas. Adsorption isotherms of the improved adsorbent have been investigated experimentally using HFC-404a as adsorbate.Experimental results showed that Aquasorb 2000 treated with $(NH_4)_2CO_3$ can adsorb up to 0.99 kg of HFC-404a per kg of adsorbent which is the double of the its capacity before the improvement.*

I. INTRODUCTION

Thermal adsorption systems are driven by heat using natural coolers to make use of modern energy. They have many advantages (1) Low maintenance cost,(2) No emissions (3) Usage of environmentally benign materials [1,2] (4) Can work with low temperature driving energy sources (5) No noise and vibration (6) Have simple principle of operation(7) Can be employed as thermal energy storage device [3-6]. However, the drawbacks of these adsorption systems are(1) Long cycle times(2) Difficulty in obtaining vacuum tightness (3) Having greater volume and weight than conventional types.Over the past several decades, different adsorption cooling systems with different adsorbent pairs have been presented. For example, exhaust gas-driven adsorption air conditioners [7,8], exhaust gas-driven adsorption ice makers ,solar-powered adsorption air conditioners [9, 10], solar-powered adsorption ice makers [11, 12],and solar-powered adsorption air conditioners [13-18] have been conducted. Studying new adsorption pairs are still needed to be investigated, and their characteristics in adsorption cooling should be defined accurately. The activated carbon particle either in a granular or powder forms has a porous structure of interconnected macrospores, mesopores, and micropores that makes it a good due to its high surface area [19]. Some studies of granular activated carbon have already been performed [20, 21].

HFC-404A is a blend refrigerant developed as asubstitute for HFC-22 and HFC-502 (HCFC/CFC blend refrigerant).It is a mixture of HFC-143a (44%), HFC-125 (44%) and HFC-134a (4%), and is a pseudo-azeotropic refrigerant. It has zero ODP, non-toxic, non-flammable (A1) according to ASHRAE 2007. HFC-404A has been approved by many cooling systems manufacturers for using it in new refrigeration equipment, such as food display and storage cases. Accurate information about thermo-physical properties and adsorption characteristics of activated carbon/HFC-404A are essential in designing either adsorption cooling system or a storage system for it [16].

The objective of this paper is to improve the performance of thermally powered adsorption cooling system by the properties of activated carbon (Aqua sorb 2000) as adsorbent substance were improved using several chemical ways to obtain high adsorption capacity. Thus, Zinc chloride, ZnCl2, phosphoric acid solution, H3PO4, and ammonium carbonate (NH4)2CO3 have been added as aqueous solutions to the activated carbon (Aquasorb 2000) individually. The addition of these materials to the activated carbon was done at room temperature, followed by aging, drying and calcination at 500°C for an hour in the flow of nitrogen gas.

selecting new adsorbent–refrigerant pair. Adsorption capacity of adsorbent–refrigerant pair depends on the thermophysical properties (pore size, pore volume and pore diameter) of adsorbent and isothermal characteristics of the pair. In this paper, Adsorption characteristics of granular activated carbon After optimization/HFC-404A has been investigated in terms of adsorption isotherms. Experimentally and theoretical investigations have been conducted within temperature range of 25 °C. Adsorption isotherms of the improved adsorbent have been investigated experimentally using HFC-404a as adsorbate. Experimental results showed that (Aquasorb 2000 treated with (NH4)2CO3 can adsorb up to 0.99 kg of HFC-404a per kg of adsorbent which is the double of the its capacity before the improvement.

II. EXPERIMENTAL SECTION

2.1. Materials

$ZnCl_2$ 5% was added to 20g ofAquasorb 2000 [22]. The mixture was refluxed in distilled water and dried in oven a 120°C for 24 h. followed by aging, drying and calcination at 500°C for an hour in flow of nitrogen gas. After cooling to the ambient temperature,thereafter, the mixture was filtered and the residue was washed with hot distilled water for several times and dried in oven at 120^{o}C for 24 h.These steps were thus performed on phosphoric acid solution, H_3PO_4 50% and ammonium carbonate $(NH_4)2CO_3$ 5% at the same temperature

2.2 Adsorbent material

HFC-404A has been approved by many cooling systems manufacturersfor using it in new refrigeration equipment, such as food displayand storage cases.Accurate information about thermo-physical properties andadsorption characteristics of activated carbon/HFC-404A are essentialin designing either adsorption cooling system or a storage systemfor it [23]. These characteristics are isotherms, kinetics andisosteric heat of adsorption at different temperatures and pressures [24, 25].

III. EXPERIMENTAL SETUP AND DESCRIPTION

Fig. 1 demonstrates a schematic graph of the test mechanical assemblyincludes predominantly of (1) an adsorber, (2) an evaporator, (3) constant temperature water bath, (4) vacuumed pump, (5) water circulator, (6) valves and (7) data acquisition system connected to a personal computer. The absorber contains 2 gm of AquaSorb 2000 improved while the evaporator acts as a reservoir for HFC-404A. The absorber and evaporator are installed inside a stainless steel water tank of 0.02 m^3 volume. To achieve a certain homogenous temperature 25°C a water circulator has been connected to the tank**.**

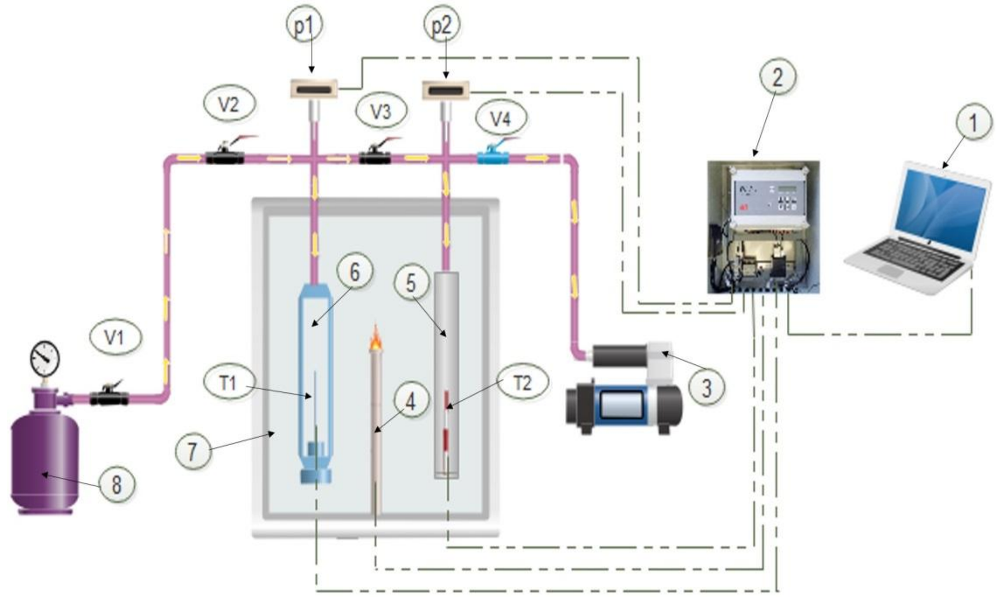

Fig. 1. Schematic diagram of the experimental apparatus. 1: personal computer.

2: Data Logger 3: Vacuum pump 4: Electrical heater5: Adsorption tank filter 6: Evaporator tank 7: Water tank 8: Cylinder refrigerant . P: Pressure gauges. T: Thermocouples. V: Valves.

3.1. Instrumentations

Temperatures of the adsorber and the evaporator are controlled by a water bath and a water circulator with ±0.5°C accuracy. Temperatures of the evaporator, adsorber, water tank, and connecting tubes are measured using a set of type K thermocouples. Thermocouples are calibrated by standard platinum resistance thermometer with ±0.1°C accuracy. Pressure transducers with an accuracy of ±0.1% in range of 0–1 MPa of the reading are used. Data logger has been used to record the data every 1 s. Volumes of the absorber and evaporator and connecting tubes are estimated by the filling-water method.

IV. ADSORPTION ISOTHERMS

4.1. Test procedure

Besides, (Aquesorb 2000) sample is evaporated by warming it to 120°C under vacuum conditions for 12 h to oust dampness substance and guarantee total desorption. The sample is then weighted and stacked inside the adsorption cell. Before beginning each run the entire framework is emptied for 24 h by utilizing the vacuum siphon to a vacuum level of 0.05 mbar. During the clearing procedure, the adsorbent sample is recovered up to 120°C for 12 h to desorb any leftover gases. Through this procedure, V4 is shut and different valves are opened. procedure up to a specific weight. Weight of the evaporator is lower than the immersion weight of the refrigerant to keep away from buildup. Subsequent to getting steady states of introductory weight and temperature at the evaporator cell, the adsorption procedure begins by opening V2 between the evaporator and the adsorption cell at temperature 25°C. After reaching equilibrium state, V2 is shut. This procedure has been rehashed ordinarily where the weight of the evaporator has been expanded bit by bit each time at same adsorption temperature.

4.2. Data reduction

The adsorbed amount has been estimated using Eqs. (1-4) at a certain adsorption temperature.

$$\Delta m_{lood,n} = \{\rho_{ads,i}(p_i, T_{ads}) - \rho_{ads.f}(P_f, T_{ads})\}_{lood\,cell}(V_{lood} + V_{tube}) \quad (1)$$

$$V_{void} = V_{ads} - (\frac{m_{ads}}{\rho_s} + V_{pore}) \quad (2)$$

$$\Delta m_{void,n} = \{\rho_{ads,n}(p_i, T_{ads}) - \rho_{ads.n-1}(P_f, T_{ads})\}_{ads\,cell}(V_{void}) \quad (3)$$

$$m_n = m_{n-1} + \Delta m_{load,n} - \Delta m_{void,n} \quad (4)$$

where m is the adsorbed mass of the refrigerant and n is the number of the measurement. All densities as a function of temperature and pressure are determined by REFPROP9.

V. RESULTS

Figure 3 shows linear fitting of adsorption of HFC-404A onto AquaSorb 2000 activated carbon.Adsorption isotherms of AquaSorb 2000/HFC-404A pair have been investigated experimentally and theoretically at a temperature of 25°C. Experimental results show that, the maximum adsorption capacity of AquaSorb 2000/HFC-404A pair is about 0.52 $kg.kg^{-1}$.

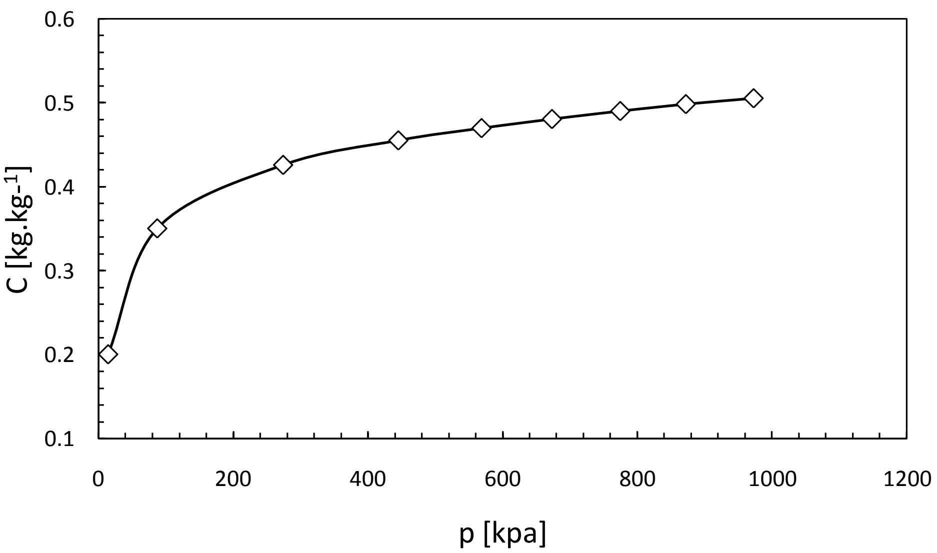

Fig. 2. The experimental adsorption isotherm data of granular activated carbon AquaSorb 2000/HFC-404A pair
.

5.1 Aquasorb 2000 treated with Zinc chloride ($ZnCl_2$)

Linear fitting of adsorption of HFC-404A onto aquasorb 2000 treated with Zinc chloride(5%,10%) is shown in Fig. 3.Adsorption isotherms of aquasorb 2000 treated with Zinc chloride (5%,10%)/HFC-404A pair have been investigated experimentally and theoretically over a temperature range of 25°C.

Experimental results show that, the maximum adsorption capacity of aquasorb 2000 treated with Zinc chloride (5%,10%)/HFC-404A pair respectively is about0.85, 0.64 $kg.kg^{-1}$.It has been reported that maximum adsorption capacity is improved from 0.5 kg $kg^{-1}$to about 0.85 $kg.kg^{-1}$.

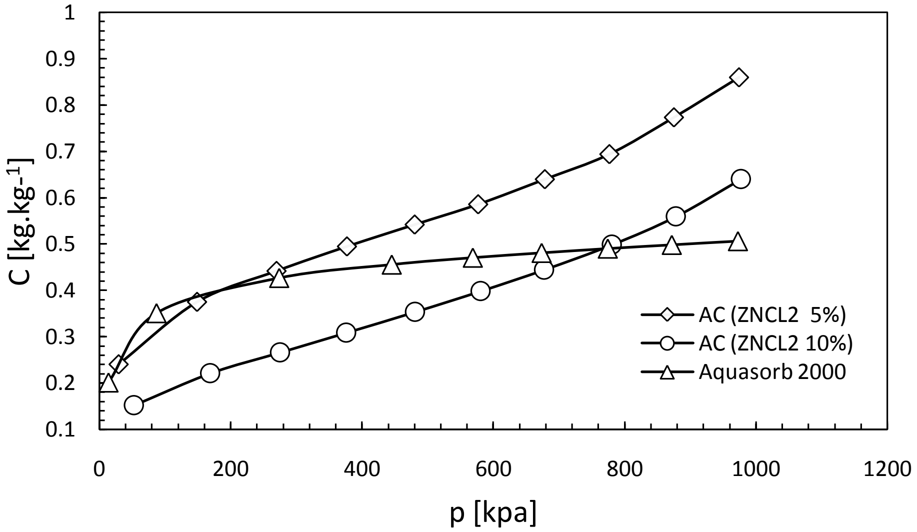

Fig. 3. The experimental adsorption isotherms data of AquaSorb 2000/HFC-404A pair and aquasorb 2000 treated with Zinc chloride (5%, 10%) /HFC-404A pair.

The lower the concentration of zinc chloride the greater the surface area, which leads to an increase in the rate of adsorption and this is shown in the fig. 3. 5% concentration of zinc chloride gives the highest capacity value.

5.2 Aquasorb 2000 treated with phosphoric acid solution (H_3PO_4)

Figure 4 shows linear fitting of adsorption of HFC-404A onto aquasorb 2000 treated with phosphoric acid solution (10%,50%).Adsorption isotherms of aquasorb 2000 treated with phosphoric acid solution (10%,50%)/HFC-404A pair have been investigated experimentally and theoretically at a temperature of 25°C. Experimental results show that, the maximum adsorption capacity of aquasorb 2000 treated with phosphoric acid solution (10%,50%)/HFC-404A pair is about0.84, 0.87 $kg.kg^{-1}$ respectively.It has been reported that maximum adsorption capacity is improved from 0.5 $kg.kg^{-1}$ to about 0.87 $kg.kg^{-1}$.

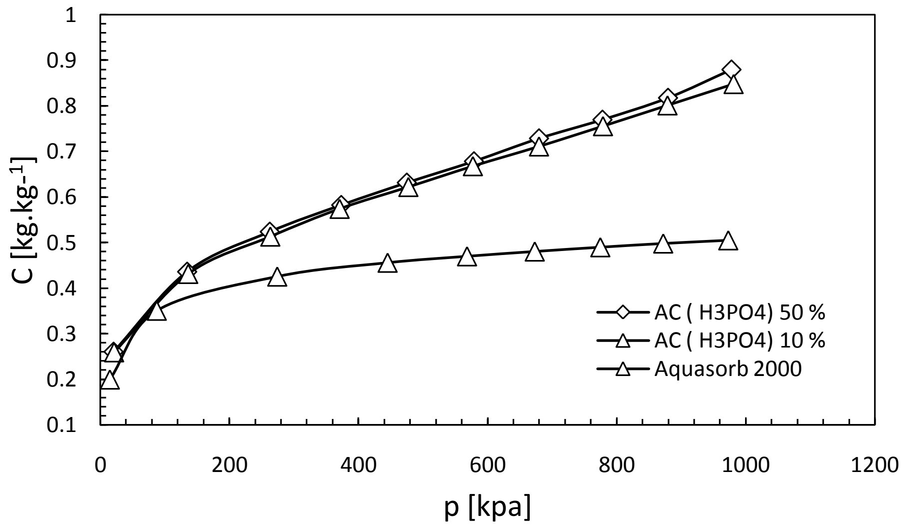

Fig. 4. The experimental adsorption isotherm data of AquaSorb 2000/HFC-404A pair and aquasorb 2000 treated with H_3PO_4(10%, 50%)/HFC-404A pair.

The higher the concentration of phosphoric acid solution the greater the surface area, which leads to an increase in the rate of adsorption and this is shown in fig. 4. 50% concentration of phosphoric acid solution gives the highest capacity value.

5.3.aquasorb 2000 treated with ammonium carbonate ($(NH_4)_2CO_3$)

Figure 5 shows linear fitting of adsorption of HFC-404A onto aquasorb 2000 treated with ammonium carbonate **(5%,10%,50%)**.Adsorption isotherms of aquasorb 2000 treated with ammonium carbonate **(5%, 10%,50%)**/HFC-404A pair have been investigated experimentally and theoretically at a temperature of 25°C. Experimental results show that, the maximum adsorption capacity of aquasorb 2000 treated with ammonium carbonate **(5%,10%,50%)**/HFC-404A pair respectively is about 0.99, 0.94,0.93 kg kg^{-1}. It has been reported that maximum adsorption capacity is improved from 0.5 $kg.kg^{-1}$ to 0.99$kg.kg^{-1}$.

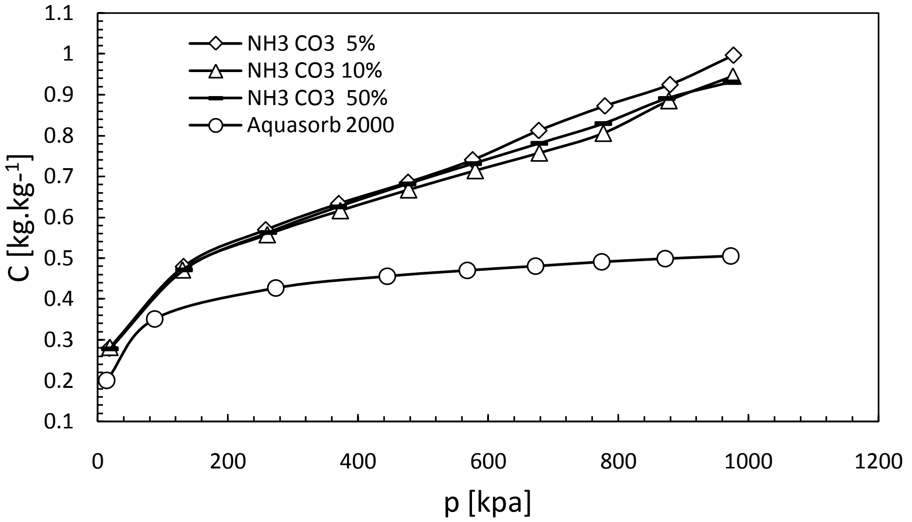

Fig. 5. The experimental adsorption isotherm data of AquaSorb 2000/HFC-404A pair and andaquasorb 2000 treated with $(NH_4)_2CO_3$(5%,10%,50%)/HFC-404A pair.

The lower the concentration of ammonium carbonate the greater the surface area, which leads to an increase in the rate of adsorption and this is shown in the fig. 5. 5% concentration of ammonium carbonate gives the highest capacity value.

Figure 6 shows that ammonia carbonate gives the highest adsorption value compared to phosphoric acid and zinc chloride.

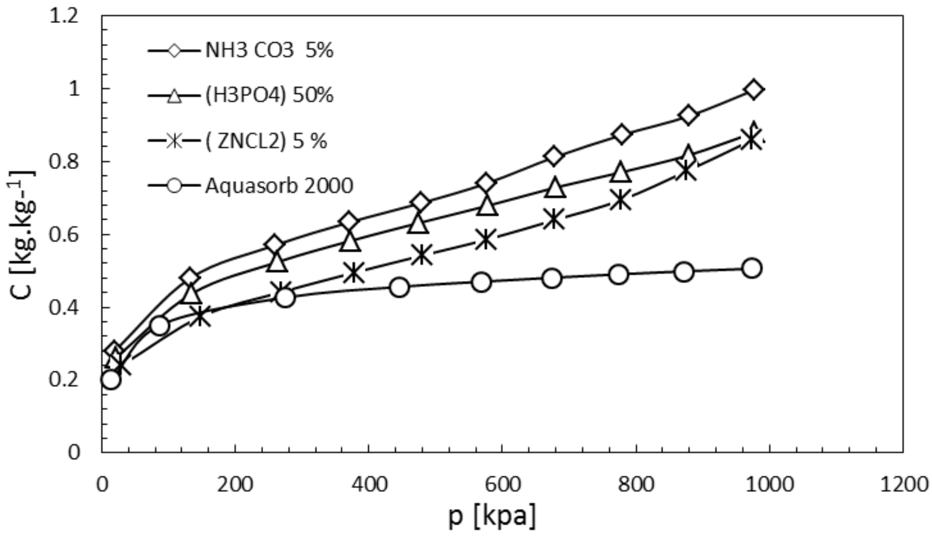

Fig. 6. Experimental adsorption isotherm data of AquaSorb 2000/HFC-404A,aquasorb 2000 treated with ammonium carbonate 5% /HFC-404A,aquasorb 2000 treated with phosphoric acid 50%/HFC-404A and aquasorb 2000 treated with zinc chloride 5% /HFC-404A.

VI. CONCLUSIONS

Three different materials have been studied as additives to improve the adsorption capacity of an activated carbon. Different concentrations of the materials were used. Ammonia carbonate is found to be thebest material among the three studied improving materials (Ammonia carbonate, zinc chloride and liquid phosphoic acid) in rising up the adsorption capacity of the aquasorb 2000. Adsorption isotherms of the treatedaquasorb 2000 with HFC-404A have been measured experimentally at a temperature 25°C. Experimental results show that, the maximum adsorption capacity of aquasorb 2000 treated with ammonium carbonate 5%/HFC-404A pair is about 0.99 $kg.kg^{-1}$ which is the double of the original capacity of the aquasorb 2000.

REFERENCES

[1]. M. A. A. A. H. K. &. A. M. S. Ghazy, "Adsorption isotherms and kinetics of HFC-404A onto bituminous based granular activated carbon for storage and cooling applications," Applied Thermal Engineering, pp. 639-645, 2016.

[2]. M. M. E.-S. I. I. K. A. E. &. S. B. B. Younes, "A review on adsorbent-adsorbate pairs for cooling applications," Applied Thermal Engineering, pp. 394-414, 2017.

[3]. M. A. Y. I. A. R. G. A. M. &. A.-M. A. A. Al-Ghouti, "Characterization of diethyl ether adsorption on activated carbon using a novel adsorption refrigerator," Chemical Engineering Journal, no. 162(1), pp. 234-241, 2010.

[4]. A. C. N. B. A. K. S. P. W. Chekirou, "Dynamic modeling and simulation of the tubular adsorber of a solid adsorption machine powered by solar energy,," Int. J. Refrig, p. 137–151., (2014).

[5]. T. C. C. L. Z. L. L. C. K.F. Fong, "Comparative study of different solar cooling systems for buildings in subtropical city,," Sol. Energy, no. 84, p. 227–244., (2010).

[6]. A. M. H.Z. Hassan, "Review on solar-powered closed physisorption cooling systems, Renew. Sustain.," Energy Rev, p. 2516–2538, 2012.

[7]. B. S. P. M. D. P. &. S. K. Akkimaradi, "Adsorption of 1, 1, 1, 2-tetrafluoroethane on activated charcoal," Journal of Chemical & Engineering Data,, no. 46(2), pp. 417-422, 2011.

[8]. K. S. B. B. N. K. C. D. P. &. P. M. Srinivasan, "A method for the calculation of the adsorbed phase volume and pseudo-saturation pressure from adsorption isotherm data on activated carbon," Physical Chemistry Chemical Physics, pp. 12559-12570, 2011.

[9]. S. &. H. J. R. Sircar, "Intraparticle adsorbate concentration profile for linear driving force model ," AIChE journa, no. l, 46(3), pp. 659-660, 2000.

[10]. A. A. S. M. I. I. M. A. A. H. H. &. M. M. Askalany, "A review on adsorption cooling systems with adsorbent carbon," Renewable and Sustainable Energy Reviews, no. 16(1), pp. 493-500, 2012.

[11]. R. W. J. W. K. W. S. W. L.W. Wang, "Adsorption ice makers for fishing boats driven by the exhaust heat from diesel engine: choice of adsorption pair," Energy Conversion and Management, p. 2043–2057., 2004.

[12]. S. M. R. C. Y. Z. R. T. Z. Tamainot-Telto, "Carbon–ammonia pairs for adsorption refrigeration applications: ice making, air conditioning and heat pumping,," Int. J. Refrig, no. 32, p. 1212–1229., (2009.

[13]. R. W. Y. D. J. W. J. S. B. Z. H.L. Luo, "An efficient solarpowered adsorption chiller and its application in low-temperature grain storage,," Sol. Energy, no. 81, p. 607–613., 2007.

[14]. K. A. M. K. R.A. Rouf, "Effect of operating conditions on the performance of adsorption solar cooling run by solar collectors," Procedia Eng., p. 607–612., 2013.

[15]. A. C. N. B. A. K. S. P. W. Chekirou, "Dynamic modeling and simulation of the tubular adsorber of a solid adsorption machine powered by solar energy," Int. J. Refrig, no. 39, p. 137–151, 2014.

[16]. A. A. K. H. M. A. M.M. El-sharkawy, "Adsorption isotherms and kinetics of a mixture of Pentafluoroethane, 1,1,1,2-Tetrafluoroethane and Difluoromethane (HFC-407C) onto granular activated carbon," Appl. Therm.Eng., no. 93, p. 988–994., 2016.

[17]. B. C. K. D. R. P. Sah Ramesh, "A review on adsorption cooling systems with silica gel and carbon as adsorbents," Renew. Sustain. Energy Rev, p. 123–134., 2015.

[18]. B. S. M. A. I. I. A.A. Askalany, "Adsorption cooling system employing granular activated carbon-R134a pair for renewable energy applications," Int. J. Refrig, no. 36 , p. 1037–1044., 2013.

[19]. E. K. Z. Aksu, "Batch adsorption of 2,4-dichlorophenoxy-acetic acid (2,4-D) from aqueous solution by granular activated carbon," Separation and Purification Technology, pp. 223-240, 3 March 2004.

[20]. I. Y. R. A. A. G. A. A.-M. M.A. Al-Ghoutia, "Characterization of diethyl ether adsorption on activated carbon using a novel adsorption refrigerator," J. Chem. Eng, no. 162, p. 234–241., 2010.

[21]. V. T. C. G. E. N. L. A. S. E. Salehi, "Theoretical and experimental study on the adsorption and desorption of methane by granular activated carbon at 25 C,," J. Nat. Gas Chem, no. 16, p. 415–422., 2007.

[22]. A. A. A. ,. K. H. ,. M. S. A. Mohamed Ghazy, "Adsorption isotherms and kinetics of HFC-404A onto bituminous based granular activated carbon for storage and cooling applications," Applied Thermal Engineering, p. 639–645, 22 March 2016.

[23]. A. A. K. H. M. A. M.M. El-sharkawy, "Adsorption isotherms and kinetics of a mixture of Pentafluoroethane, 1,1,1,2-Tetrafluoroethane and Difluoromethane (HFC-407C) onto granular activated carbon,," Appl. Therm.Eng, no. 93 (93), p. 988–994, 2016.

[24]. B. B. E.-S. I. I. T. R. &. C. R. E. Saha, "Accurate adsorption isotherms of R134a onto activated carbons for cooling and freezing applications," international journal of refrigeration, no. 35(3), pp. 499-505, 2012.

[25]. I. I. H. M. S. B. B. K. S. &. N. M. M. El-Sharkawy, "Study on adsorption of methanol onto carbon based adsorbents," international journal of refrigeration, no. 32(7), pp. 1579-1586, 2009.

[26]. P. D. M. P. F. B. C. Hildbrand, "A new solar powered adsorption refrigerator with high performance," Sol. Energy, no. 77, p. 311–318., 2004.

[27]. R. W. Y. X. J. W. A. D. M. Li, "Experimental study on dynamic performance analysis of a flat-plate solar solid-adsorption refrigeration for ice maker," Renew. Energy, p. 211–221., 2002.

Ali Kamel,etal. "Improving Adsorption Capacity of Activated Carbon for Cooling Applications". *American Journal of Engineering Research (AJER)*, vol. 9(01), 2020, pp. 372-377.