Nat. Volatiles & Essent. Oils, 2021; 8(5): 10594-10610

NVEO
Natural Volatiles &
Essential Oils

Performance Studies on Solar Assisted Single and Double Bed Adsorption Refrigeration system

Ashok Kumar K[1,2*], N. Kapilan[3], S Kasthurirengan[4], Dinesh P. A[5]

[1] Research Scholar, Department of Mechanical Engineering, Nagarjuna College of Engineering and Technology (Affiliated to VTU, Belagavi), Bangalore-562164, (Karnataka) India

[2] Faculty, Department of Mechanical Engineering, M.S. Ramaiah Institute of Technology (Affiliated to VTU, Belagavi), Bangalore-560054, (Karnataka) India

[3] Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology, Bangalore-560064, (Karnataka) India

[4]Center for Cryogenic Technology, Indian Institute of Science, Bangalore-560012, (Karnataka) India

[5]Department of Mathematics, M.S. Ramaiah Institute of Technology (Affiliated to VTU, Belagavi), Bangalore-560054, (Karnataka) India

Abstract

The demand on refrigeration and air conditioning is growing day by day and the continuous price rise of fossil fuels and environmental concern have made in search of reliable, pollution free and low-cost refrigeration. The cooling systems that are existing mostly are working on vapour compression principles by using traditional refrigerants are posing a negative impact on the environment in terms of global warming and ozone layer depletion because of the release of harmful gases like HFC's, CFC's and CO2. In this regard heat utilization for cold production is nowadays a desirable challenge in several industrial applications and adsorption refrigerators operated by low heat source temperatures from solar or waste heat energy and gaining significant importance on account of their applications in several areas in order to replace conventional vapour compression refrigeration cycles driven by electricity. The cooling systems operated by vapour adsorption principles are eco-friendly and reliable but possesses lower coefficient of performance (COP) when compared to the traditional systems due to the lack of advancement and research. By taking into account the energy conservation and environmental aspects there is a need to develop the vapour adsorption refrigeration (VAR) system which will appreciably compete the existing cooling systems. In this work, a solar assisted vapour adsorption system is developed and used silica gel-water as the working pair. The experimental results show that the adsorption system is feasible to produce cold even with low temperature source of heat and compare to single bed system double bed system produces continuous cooling effect.

Keywords: Alternative cooling, single bed, double bed, performance

Introduction :

Around 10 to 20% of the electricity produced worldwide is utilized for cooling applications and this necessitates the energy efficient cooling. Until recently the electrical energy originated mostly from fossil fuels has been the main source of cold production in case of vapour compression refrigeration systems. All over the world, the VCR's are successfully used almost in 85% of the refrigeration systems but unfortunately, this method of cold production has been taking part in damaging the environment mainly through attack on the ozone layer by the refrigerants employed and global warming because of the high carbon footprint associated with its operation. This is mainly responsible for the growing interest with the heat operated counterparts. The attractive aspect of the heat operated systems is that they can be operated by low grade heat such as waste heat, solar and biomass. With the waste heat availability from different power plants and industrial operations, adsorption cooling systems pose many advantages when compared to mechanical vapour compression systems. Apart from having little or no moving parts they have simpler controls, lower operating cost, operate more quietly and employ environmental friendly refrigerants. When the source of energy is derived from solar means, the cost of the solar energy harvesting equipment is the only cost associated with it. [1-3].

In recent years' great interest has been shown in developing adsorption refrigeration technology due to some favorable features like no moving parts, lubrication requirements, vibrations and adoptability to different cooling load ranging from few watts to several kilowatts. On the other hand, they also have some limitations like bulkiness, large thermal mass and complex controls while operating multiple adsorption beds lower performance in comparison with vapour compression refrigeration system. [4-6].

Adsorption refrigeration working pair has a significant role in the adsorption refrigeration system, of which the developments directly lead to the improvement of the performance of the systems. Therefore, the utilization of adsorption technology is a first step towards the evolution of an environmentally favourable and energy efficient refrigeration and air conditioning systems. The second step is to use an effective refrigerant with the solid adsorbent, which has lower environmental impact with higher adsorption capacity than the available pairs [7].

In adsorption cooling, the input is primarily heat energy that is available greatly from solar energy or in the form of industrial waste heat. The literature shows that experimental and analytical works have been already carried out by various researchers considerably on adsorption cooling systems with different combinations of adsorbent-adsorbates. The book on Adsorption Refrigeration Technology by Wang et al. highlights appreciable details in this field [8].

Adsorption refrigeration systems (ARS) uses solid adsorbent beds for refrigerant to adsorb or desorb respectively to the changes in the adsorbent material temperature to obtain cooling effect. Adsorbents are the materials which exhibits permanent porous structure that acts like a sponge, soaking up or adsorbing the refrigerant at low temperatures. As the temperatures is elevated, the refrigerant is desorbed or released. From this basic principle one can make use of the system as a thermal compressor to move the refrigerant around the system to cool the space or heat transfer fluid. The basic adsorption refrigeration system usually contains four major components: adsorber or a solid adsorbent bed called adsorber, a condenser, an expansion valve and freezer or an evaporator. The system operates on the principle of reversible adsorption between the adsorbent and the refrigerant, this reversibility relies on the adsorbent temperature and the vapour pressure of the refrigerant. To produce a continuous and stable cooling effect in ARS, generally multiple adsorbers are used. In the two-bed adsorption, one is heated during the period of desorption and the other adsorber is cooled during the adsorption period, then the complete cycle is known as "cycle time". When the adsorbers attain the desired upper and lower temperature limits of the refrigeration cycle depending on refrigerant fluid and the adsorbent used, the heating and cooling periods are reversed [9-10].

Different combinations of working pairs are available for adsorption applications. In most of the working pairs, water is used as the refrigerant or adsorbate since it is non-toxic, can be handled easily and having high enthalpy of evaporation compared to other working fluids possible. The drawback of using water is its limitation to applications above 0^0C. For refrigeration below 0^0C like ice making, methanol or ammonia is used as refrigerant with different adsorbents by mainly focussing on the absorber material from activated carbons [11].

Since the performance of basic adsorption cycle is poor because of its intermittent cooling effect produced, many modifications were recommended and analysed in the literature such as implementation of a multi-bed system with heat recovery, mass recovery, thermal wave, convective thermal wave and cascade system.

The use of solar energy to operate cooling systems is an attractive objective that is of increasing interest among researchers. Being a natural resource, solar radiation is available freely and the running costs of developed solar cooling systems are expected to be less after meeting the capital costs. Furthermore, cooling load is generally high when solar radiation is high. Solar cooling greatly provides an excellent mode of a clean and sustainable technology which drives towards sustainable development [2]. The solar collector replaces the electricity-driven mechanical compressor used in traditional vapour compression systems [33].

Literature Review :

The possibility of using adsorption principles for refrigeration have been studied by many researchers with different thermodynamic cycles, working pairs and operating conditions. Silica gel with water, activated carbon with ammonia, activated carbon with methanol, activated carbon with R134a and zeolite with water are the typical physical adsorption working pairs.

An icemaker was able to produce ice from 4 to 7 kg per square meter of solar collector and the COP generated was in the range of 0.2–0.6. [12]

An experiment on Silica gel-water adsorption by Dim Dim Kumar et al. [13] reported that, the vacuum pressure of the system is the driving force for adsorption process to occur and regeneration temperature from 60^0C to 80^0C is enough for desorption cycle and to achieve cooling at evaporator.

A two-bed Silicagel water and four bed adsorption refrigeration systems with activated carbon-R134a pair were studied experimentally and theoretically by Samson Paul Pinto et al. [14] and reported that Silicagel-water system reaches 5.3^0C of temperature for no load situation and at 18^0C produces a cooling power of approximately 284 W with a COP of 0.52. At 18^0C, the refrigeration effect and COP predicted by the simulation model are 325 W and 0.55 respectively. For the four bed refrigeration system which was operated under three different configurations it was observed that the temperatures are 14.5^0C, 13.3^0C and 11.9^0 C respectively under no-load conditions with COP values measured 0.5, 0.65 and 0.70 for different configurations and reported that the experimental and simulation results are comparable.

Few researchers recommended activated carbon /R-134a adsorption working pair as compared to powdered form of activated carbon with R-507A, R-407c, R-507A, R-407c and R-134a. The reason is its higher adsorption capacity than the other and also for long life performance of the system [15].

A study on double bed adsorption system, using R32 as adsorbate and 2 modified AC adsorbents modified with H_2SO_4 and HNO_3 reported that the COP obtained was 0.14 to 0.25, whereas the SCP obtained was from 4 - 6.3 W/kg AC [16].

Chilled water outlet temperature of 7^0C with the COP value of 0.5 was obtained in a test with the pair of silica gel and water in a single stage chiller and two bed type and reported that for the collector area of 38.64 m^2 and 1100 sec of cycle time, achieved performance is better with 7^0C. [17]

By taking the climatic data of Kaula lampur of Malaysia, a simulation program was made for performance evaluation of solar driven adsorption cooling with a regeneration temperature of 85^0C using ethanol on activated carbon fibre pair and cooling power of 12kW was reported [18].

Few studies are found on solar adsorption for ice making by Boubakri et al. [19], silica gel with water adsorption system run by waste heat of near atmospheric temperature by Saha et al. [20], zeolite– water solar cold storage system by Lu et al. [21], and a combined solar thermoelectric- adsorption cooling system with activated carbon– methanol combination by Abdullah et al. [22].

Using zeolite and water combination, an experimental analysis is made on adsorption system for air conditioning the electric vehicle by Aceves [23] and coefficient of performance (COP) of about 0.28 was obtained. This study revealed that when compared to adsorption systems, conventional air conditioners were superior because of their higher values of COP and compactness.

In a multiple-stage adsorption system presented by Sato et al. [24] for air-conditioning the vehicles, it is reported that even though the performance of multiple-stage adsorption system was improved, the system possesses the problems of increased size and complex controls.

The heat of exhaust gases was used in a bus for air conditioning by Wang et al. [25] with activated carbon and ammonia and obtained a refrigeration effect of 2.58 kW and a COP of 0.16. The activated carbon is subjected to pressurization to achieve a density of around 900 kg/ m^3 to accommodate more adsorbent into the adsorber. The system occupied about 1.0 m^2 with a weight of 248 kg from two adsorbers.

Exhaust heat from a diesel fuelled vehicle was utilized for evaluating the practical performance of an adsorption system with zeolite and water combination by Lu et al. [26] to provide chilled water for conditioning the air in the driver's cabin and indicated that the adsorption system is feasible technically and can be applied for space cooling. The cooling power of about 3.0 to 4.2 kW was reported and felt that this system may not be appropriate for automobile applications due to its larger size and high temperature of regeneration.

Theoretical studies were made on adsorption refrigeration system by many researchers such as Wang et al. [26], Yongling Zhao et al. [28], Larisa Gordeeva et al. [29], Ramji et al. [30] etc. In some of the studies activated carbon fibres along with composite adsorbents are also found [31, 32].

Even with the above developmental studies on adsorption refrigeration has been become a matter of continuous interest of study for many researchers for better understanding of the fundamental concepts and to develop nature friendly refrigeration systems and our present objective or aim is to gain a better level of understanding of its performance parameters and bottlenecks.

Materials and Methods :

To measure the solar radiation flux, a pyranometer with data logger was used in this work as shown in the Figure 1. which has a thermopile sensor having black coating for absorbing the radiations in order to convert heat into electrical energy. It detects the instant radiations and converts the heat of radiation into micro volts and the same may be seen in the form of W/m^2 in digital data logger. For measuring the sunshine hours, a sunshine recorder was used as shown in figure 2. It was used from 9.00 AM to 3.30 PM in May 2019, at the research centre which has a latitude of 12.970 N. It comprises of three seasonal cards such as summer, equinox and winter cards.

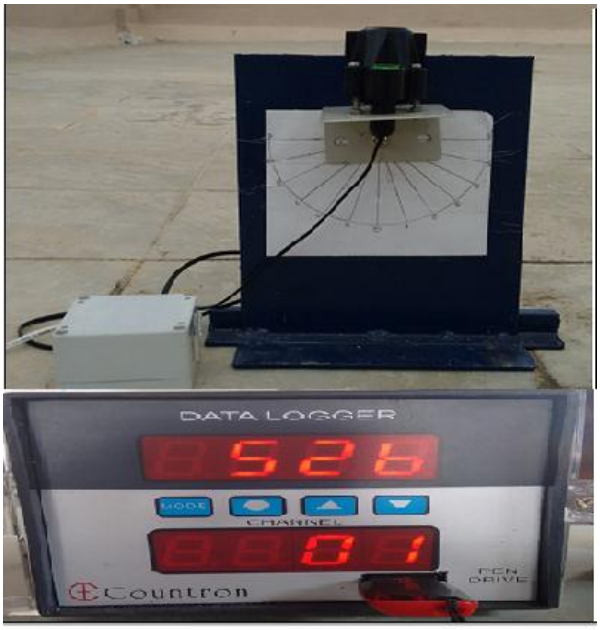

Figure 1. Pyranometer with data logger

Figure 2. Sunshine Recorder

The hot water required for the process of desorption of adsorbent bed is obtained from an evacuated solar collector which is meant to heat the water by absorbing solar radiations. The water tank is having a storage capacity of 150 litres. There are 10 evacuated collector tubes having a length of 68 inches each with an outer diameter of 60 mm.

Figure 3. Evacuated tube solar water heating system

The adsorption pair used in this work is silica gel and water. Water has higher latent heat and is non-toxic and hence it was chosen as the refrigerant. Silica gel synthetically prepared from sodium silicate possess a nano-porous silica micro-structure. It is produced from naturally available mineral and is processed, purified and kept in the form of beads or granules. It adsorbs water due to its higher specific surface area. The regeneration of silica gel can be done with low temperature heat source and hence it was used in this work.

An additional electric immersion coil heater of 1.5 kW is used for further heating of hot water obtained from solar water heater since it may not be possible to get hot water of specific temperature range required for operating adsorption system all the times from solar heating system alone because of the changes in the intensity of solar radiation.

Experimental details :

The following section gives the experimental details and procedures of single bed and double bed ARS which uses silica gel-water as adsorbent-adsorbate pair.

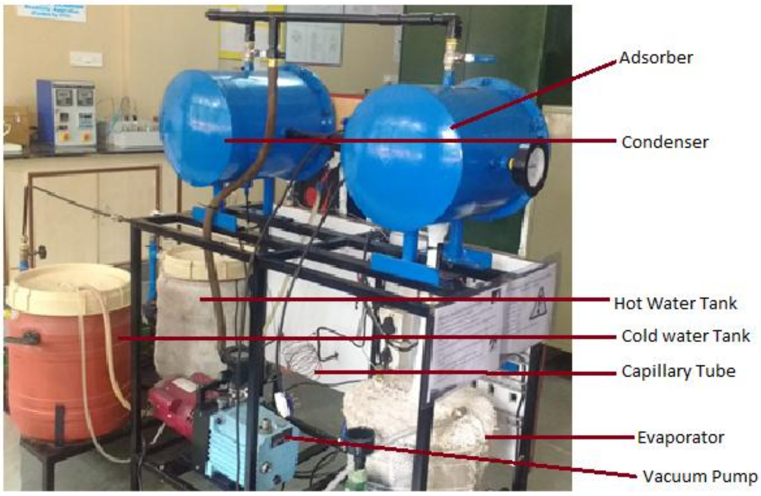

Figure 4. Picture of the single bed Adsorption system

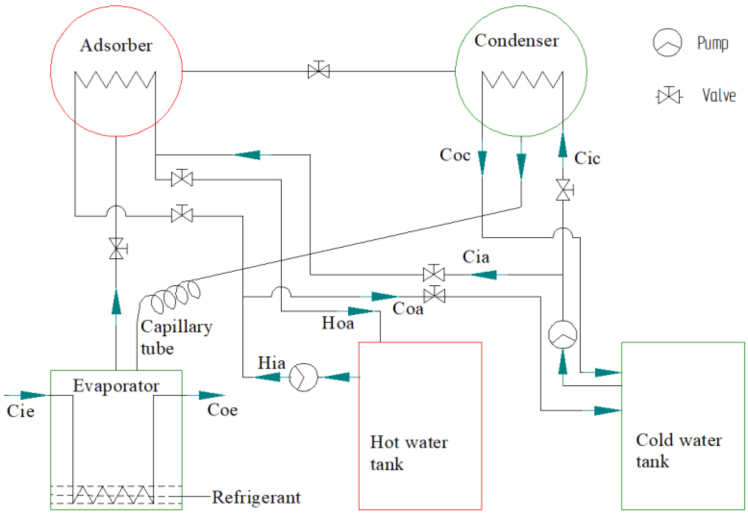

Figure 5. Line diagram showing Single bed adsorption cooling system.

Figure 4 and figure 5 represents the Photograph and schematic of Single bed adsorption system. In the schematic diagram, Cia, Coa, Hia, Hoa, Cic, Coc, Cie, Coe represents water flow to the adsorber, Condenser and evaporator. where C and H refers Cold and Hot water. The letters i and o refers to Inlet and Outlet water flow. The letters a, c, e refers to the adsorber, condenser and evaporator respectively.

Figure 6. Picture of the double bed Adsorption system

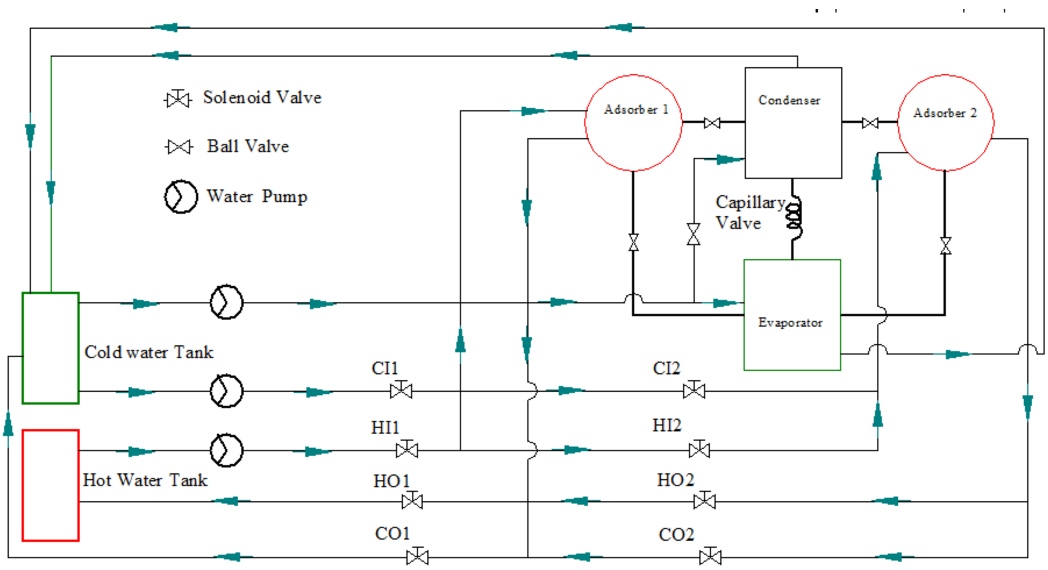

Figure 7. Line diagram of the Double bed adsorption system experimental test setup

Figure 6 and 7 represents the photograph and line diagram of double bed ARS. Where CI1, CO1, CI2, CO2, HI1, HO1, HI2, HO2 represents the valves which regulate the flow of water to the adsorber beds. First letter C or H refers to Cold or Hot water. The second alphabet I or O indicate inlet or outlet water flow. The last number 1 or 2 denotes the adsorber bed.

In the adsorption system, each adsorber bed is made with water cooled rectangular finned tube heat exchanger in which the adsorbent is tightly packed into the aluminium rectangular fins having regular spacing. The size of the metallic vessels used for adsorber, condenser and evaporator of the single bed system resembles that of the double bed type of system.

Operating procedure of silica gel-water ARS :

Initially a known mass of refrigerant (water) is poured into the vessel of evaporator and with the vacuum pump, the system is evacuated. Cold water is made to flow through the heat exchanger tubes of the adsorption beds for precooling and adsorption to happen, whereas for the process of preheating and desorption to occur, hot water is circulated. When bed 1 of double bed system is subjected to the precooling or adsorption phase, bed 2 respectively undergoes the desorption or preheating. For this, the relevant water flow valves are operated for the required amount of time. The cold water is however supplied continuously to the condenser. After a definite time, the concerned valves are opened to allow the desorption of bed 1 or preheating and the adsorption of bed 2 or precooling. The same procedure is repeated during the experiment.

During the phase of adsorption, the evaporator gets connected to the adsorber bed and while desorption the adsorber is coupled with the condenser. The cooling or refrigeration power is evaluated by passing a known quantity of water via the heat exchanger coil of evaporator which is in contact with the refrigerant and taking its inlet and outlet temperatures. The system's performance is assessed at different cycle times and optimized to get the refrigeration power maximum. By using thermocouples at different locations, the temperatures are measured. For single bed system also, the operational procedure is same as that of double bed system except that the system consists of only one bed and cooling effect produced is intermittent.

Results and Discussion :

Figure 8 reveals the results obtained from the sunshine recorder and the solar radiation flux on the Equinox card. The card was placed during 9:15 AM to 3:30 PM and the sunshine was noticed. During the afternoon, the radiation flux was high and was almost constant. The average value of solar radiation flux found was 722 W/m^2.

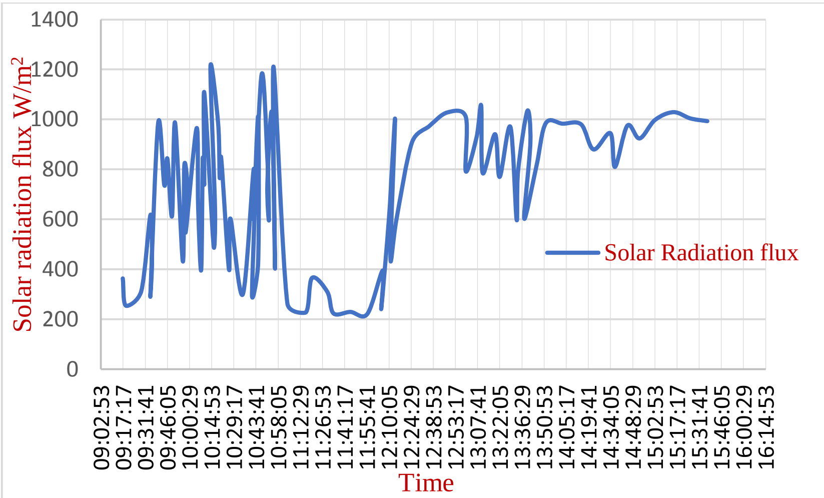

Figure 8. variation of Solar radiation flux with time

The temperature profiles obtained from experimental results under no-load conditions for silica gel-water pair based single bed adsorption system are discussed below.

Figure 9, 10 and 11 indicates the variation of temperatures of evaporator, adsorbent and condenser under no load situation with cycle time for different trials. For regeneration the temperature of hot water used was in the range of 80-85^{0}C. The temperature drop in the evaporator from ambient condition was noted for each cycle of adsorption. The lowest temperature obtained was 12^{0}C, 15^{0}C and 7^{0}C respectively for trial 1, trial 2 and trial 3. It is seen that at the beginning of adsorption cycle temperature falls in the evaporator sharply for all the trials due to the quick evaporation of water on to silica gel and later adsorption rate decreases when silica gel gets saturated with water. It is also observed that evaporator temperature gradually increases during the transition phase from adsorption to desorption. Under no load condition, when the cycle time increases, the average temperature of evaporator increases and this may be due to the energy loss from the evaporator over a period of time.

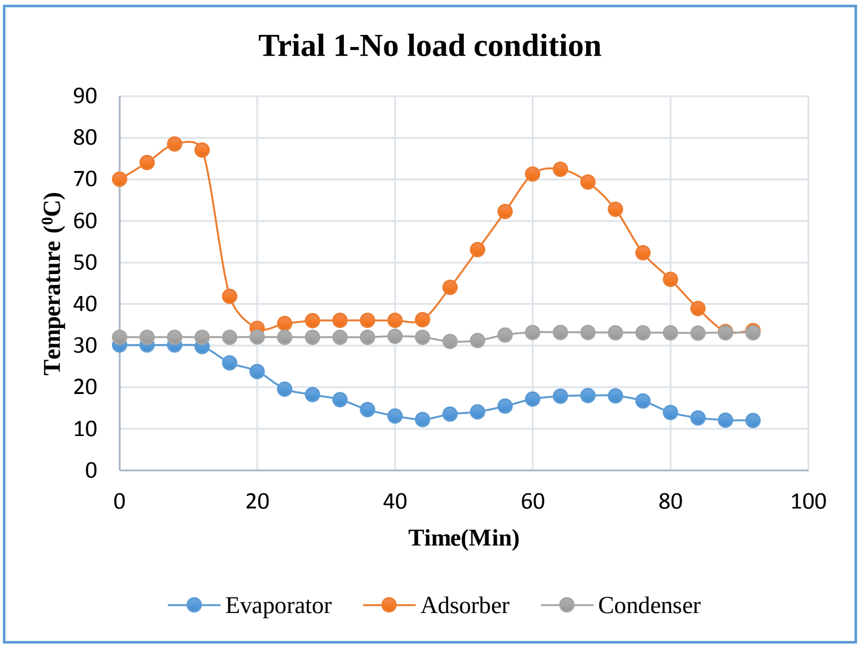

Figure 9. Temperature Variation during adsorption and desorption phase for trial 1 under no load

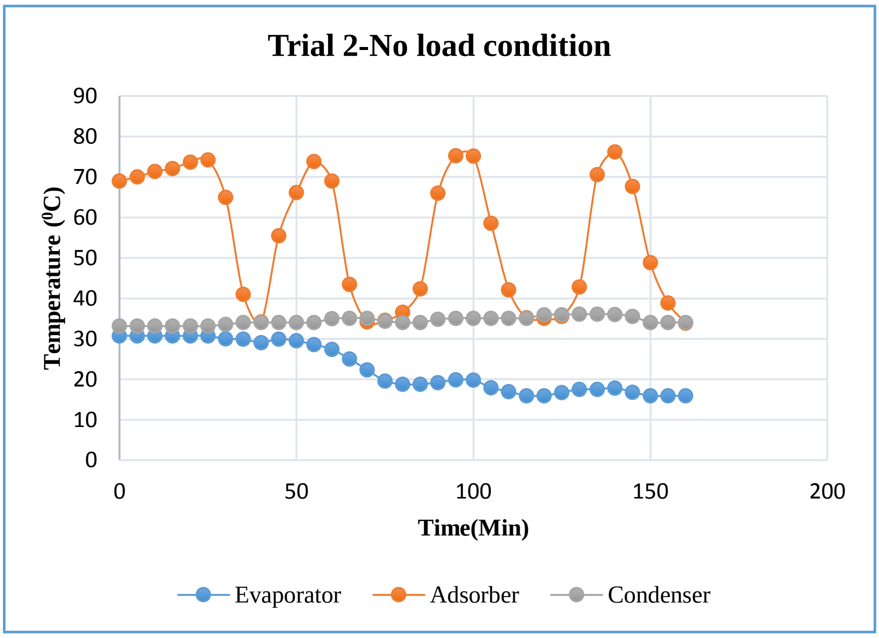

Figure 10. Variation of temperature for adsorption and desorption phase for trial 2 under no load

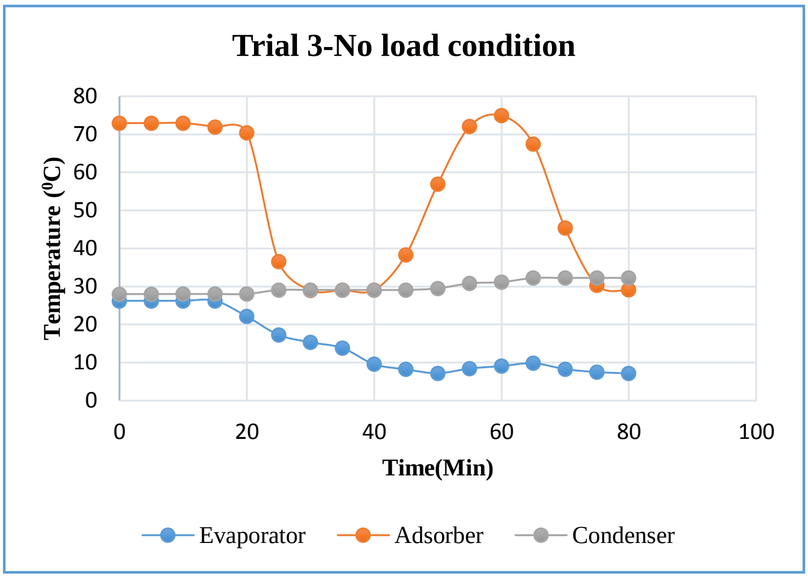

Figure 11. Variation of temperature for adsorption and desorption phase for trial 3 under no load

Performance of the single bed system under load condition :

Under load condition the cooling power or refrigeration effect can be evaluated when a known quantity of water is allowed with different flow rates adjusted by rotameter via the copper coil present in the evaporator as follows.

Refrigeration effect (Cooling Capacity) = $m \times C_p \times (T_i - T_o)$

Where m in kg/s is the mass flow rate and C_p in kJ/kg.k is the Specific heat respectively for flowing water in evaporator coil, T_i and T_0 are the inlet and exit temperatures of flowing water in ^{0}C.

With reference to the cycle time the temperature of adsorber, condenser and evaporator outlet (Ch_o) is measured and plotted for the flow rates of 2LPM, 1 LPM and 0.5 LPM respectively.

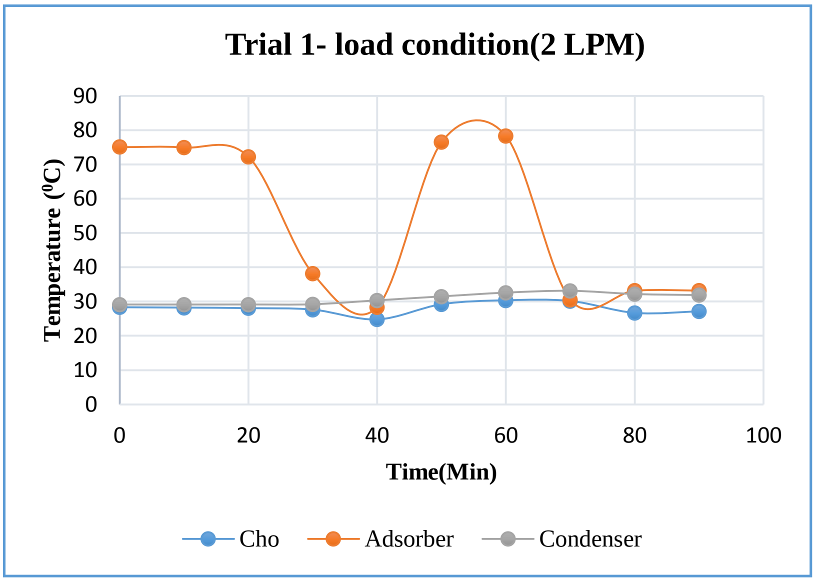

Figure 12. Variation of temperature for adsorption and desorption phase for trial 1 under load condition

From figure 12, for chilled water flow rate of 2LPM during trial 1, the water temperature decreased from 28^{0}C to 24^{0}C, 29^{0}C to 26^{0}C for cycle 1 and 2 respectively.

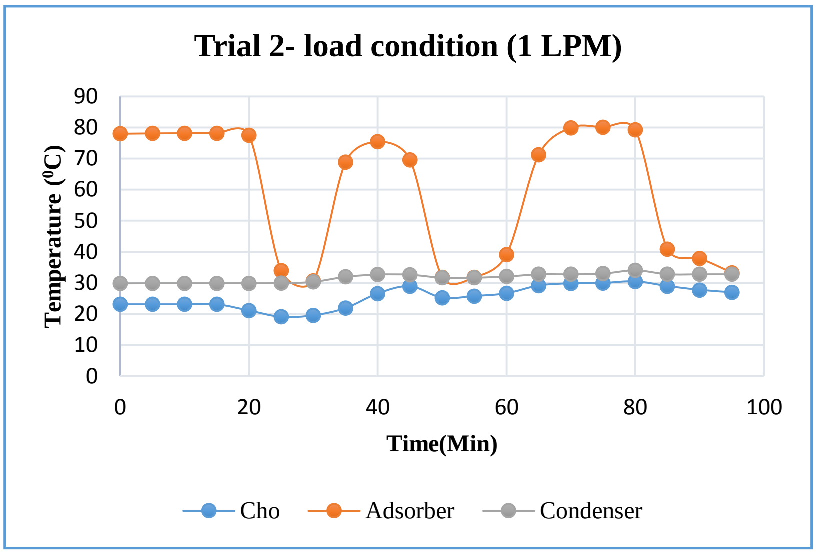

Figure 13. Variation of temperature for adsorption and desorption phase for trial 2 under load condition

For trial 2 the chilled water flow rate was adjusted at 1 LPM as shown in figure 13 and the water temperature was dropped from 23^{0}C to 19^{0}C, 30^{0}C to 27^{0}C and 31^{0}C to 27^{0}C for cycle 1, 2 and 3 respectively.

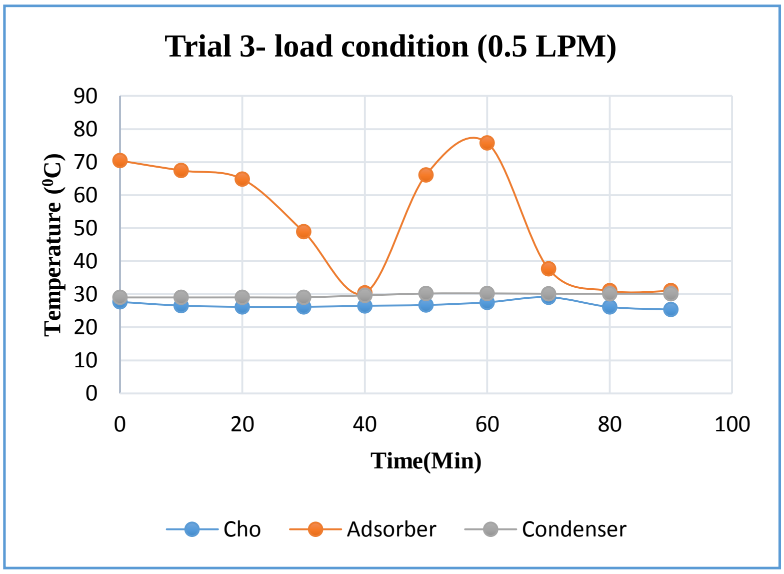

Figure 14. Variation of temperature for adsorption and desorption phase for trial 3 under load condition

During trial 3 as shown in figure 14 the chilled water flow rate was 0.5 LPM and the water temperature dropped from 29^{0}C to 26^{0}C and 30^{0}C to 25^{0}C for cycle 1 and 2 respectively.

Figure 15 indicates the variation of refrigeration or cooling effect with respect to cycle time for different trials for the mass flow rates of 2LPM, 1 LPM and 0.5 LPM through the evaporator respectively. It is observed that for the chilled water flow rate of 2LPM the maximum value of the refrigeration effect produced is the highest and it reduces as the chilled water flow rate reduces and the reason may be due to the quick rate of energy transfer in the form of cold from the evaporator to the large mass of flowing water in the cooling coil.

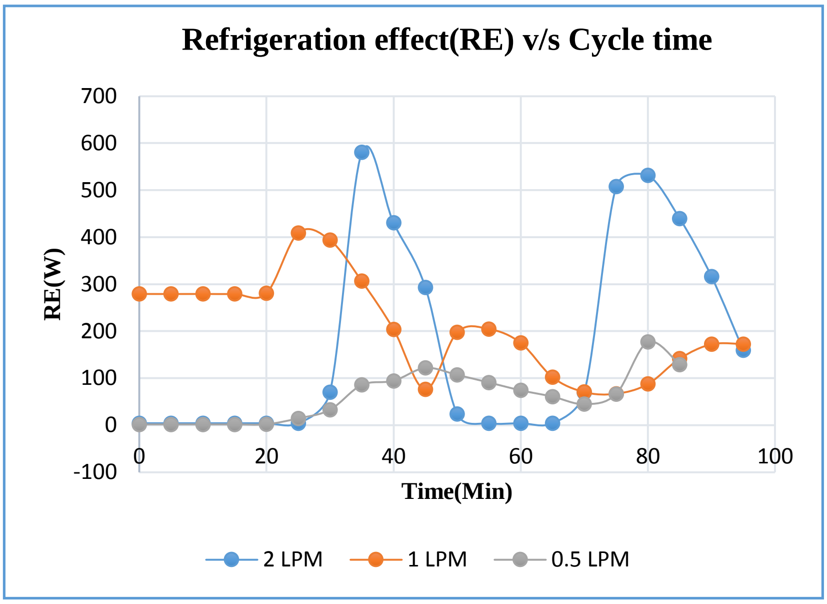

Figure 15. Refrigeration or cooling effect v/s Cycle time for different flow rates

Experimental results for double bed system :

The double bed adsorption system consists of two adsorbent beds in addition to the evaporator and condenser. In view of this, the refrigeration or cooling effect generated in the evaporator is continuous. The temperature profiles for no-load conditions for silica gel-water pair based double bed adsorption system are discussed below. By having 750ml of water in the evaporator some experiments are conducted without load to see the cool down temperature in the evaporator and some experiments are conducted with load to analyse the system performance in terms of cooling capacity and COP. The analysis with graph has been discussed in the following sections.

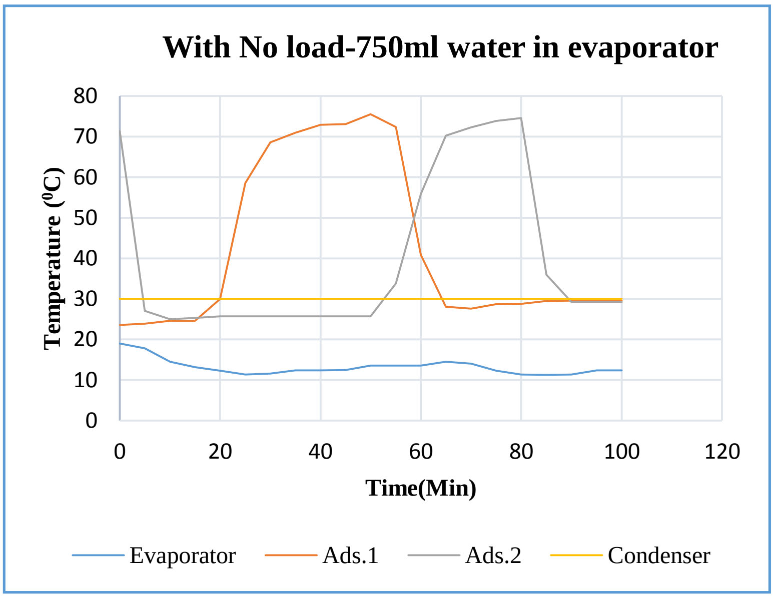

Figure 16. Temperature variation of Evaporator, adsorber 1, 2 and Condenser with cycle time

The temperature profile for each component is showed in the Figure 16 which shows that the minimum cool down temperature in the evaporator is 11^0C.

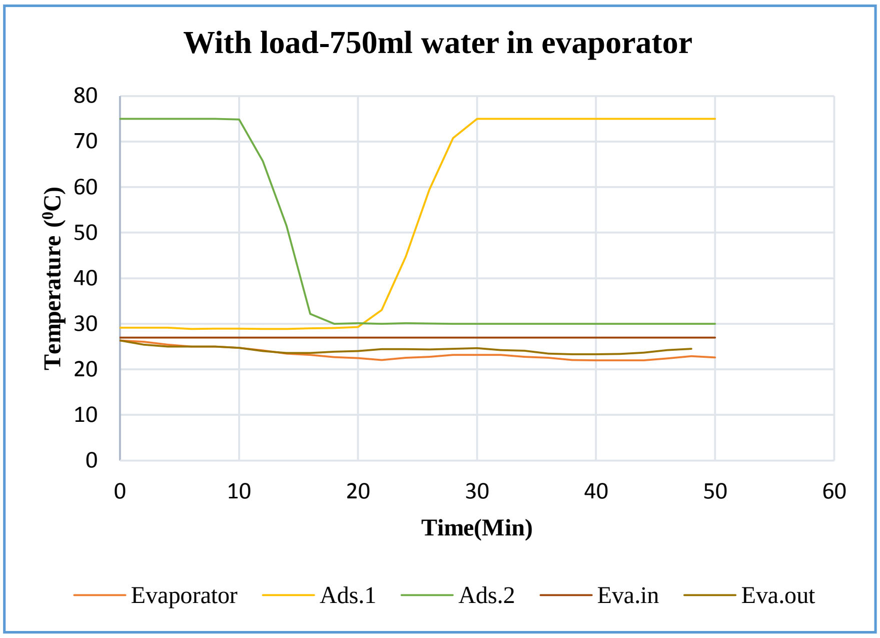

Figure 17. variation of temperature of the components with load

The temperature profile for each component is showed in the Figure17 under load condition for the chilled water flow rate of 2.5 LPM into the evaporator and cooling capacity is calculated as follows. For an inlet temperature of 27^0C the minimum value of outlet temperature observed is 24^0C, accordingly the cooling capacity is found to be 525W and COP is found to be 0.35.

Refrigeration effect (Cooling Capacity) = $m\times C_p\times (T_i - T_o)$ = (2.5/60) × 4200× (27-24) =525 W

COP=525/1500=0.35

Conclusions :

The single bed and double bed adsorption refrigeration systems are successfully operated to produce cooling effect with the desorption temperature of 80-85^0C. The cooling effect produced is intermittent in single bed system and is continuous in double bed system. The lowest temperature observed in the evaporator under no load conditions are 7^0C and 11^0C for single bed and double bed system respectively for the operated cycle time. The refrigeration effect produced from the experiments were around 100 W to 600 W under different operating conditions. The maximum COP obtained for double bed system over a range of operating parameters studied was 0.35. Since the working pair used is silica gel-water, the system has to be operated under sub-atmospheric condition and maintaining low vacuum pressure without any leak in the system for long time is difficult due to the system’s bulkiness. Hot water used in the present study for desorption is produced both by solar energy and electrical energy and in doing so the demand on electricity for producing refrigeration especially in heat operated systems can be greatly reduced by combining adsorption systems with solar thermal systems.

CONFLICTS OF INTEREST :

The authors have no conflicts of interest to declare.

REFERENCES :

1. N. V. Ogueke et al (2014), Exergy Based Performance Analysis of a Solid Adsorption Solar Refrigerator, International Journal of Renewable Energy Research, Vol.4, No. 2.
2. Diwakar Srivastava (2017), Adsorption Refrigeration using Zeolite-Water pair on Pro-e and MATLAB, International Journal of Advance Research, Ideas and Innovations in Technology, ISSN: 2454-132X, Volume3, Issue4.
3. Yogesh H. Kadam et.al (2016), Design Of Waste Heat Driven Vapour Adsorption Cooling System For Vehicle Air-Conditioning And Refrigeration, , International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308, Volume: 05 Issue: 04.
4. Dieng AO and Wang RZ (2001) Literature review on solar adsorption technologies for ice-making and air conditioning purposes and recent developments in solar technology. Renew Sust Energ Rev 5: 313–342
5. Srinivasan K (2006), Activated carbon-based adsorption systems – thermodynamics, heat, and mass transfer aspects of gas storage and refrigeration, in 18th National and 7th ISHMT-ASME Heat Transfer Conference, Guwahati, India, (Paper No. K-14)
6. Ashok Kumar K and N. Kapilan (2020), Studies on the feasibility of adsorption cooling technologies, Journal of Physics: Conference Series, 1473 (2020) 012050, doi:10.1088/1742-6596/1473/1/012050
7. Habib, et al (2011), Performance evaluation of combined adsorption refrigeration cycles. Int. J. Refrigeration 34, 129-137
8. Wang R et al (2014), *Adsorption refrigeration technology- theory and application*. Wiley. Singapore Pte. Ltd
9. L. Yong and R. Z. Wang (2007) "Adsorption Refrigeration: A Survey of Novel Technologies", Recent Patents on Engineering, Vol. 1, No. 1.
10. I. Pilatowsky, et al (2011), Cogeneration Fuel Cell-Sorption Air Conditioning Systems". Green Energy and Technology, Springer Publication 2011. First Edition.
11. State of the art – Survey on new solar cooling developments. IEA SHC Task 38 Solar Air Conditioning and Refrigeration. Subtask C1 Report, 31 October 2010
12. Wang RZ and Oliveira RG(2006), Adsorption refrigeration – an efficient way to make good use of waste heat and solar energy. Prog Energy Combust Sci; 32:424–58
13. Dim Dim Kumar et al (2016), An experimental investigation on adsorption refrigeration system using silica gel-water, Journal of Mechanical Engineering and Biomechanics,Volume 1 Issue 1, Page 56-63.
14. Samson Paul Pinto et al (2018), Development and studies of low capacity adsorption refrigeration systems based on silica gel-water and activated carbon-R134a pairs, Heat and Mass Transfer https://doi.org/10.1007/s00231-018-2441-0, 2018.

15. Ahmed N. et al (2013), Experimental Study on Adsorption Capacity of Activated Carbon Pairs with Different Refrigerants, World Academy of Science, Engineering and Technology International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering, 7(11), 496-512, 2013
16. I. Made Astina, M. et al (2018), Experiment of adsorption refrigeration system with working pairs of difluoromethane and activated carbon modified by sulfuric and nitric acids, AIP Conference Proceedings 1984, 020015 (2018); https://doi.org/10.1063/1.5046599 Published Online: 25 July 2018
17. Begum FA et al (2018), Effect of Flow Rate on Performance of Solar Adsorption Chiller Keeping Fixed Evaporator Outlet Temperature. J Appl Mech Eng 7: 310. doi:10.4172/2168-9873.1000310.
18. Khairul Habib and Bidyut B Saha (2013), Performance evaluation of solar driven activated carbon fiber ethanol based adsorption cooling system in Malaysia, Asian Journal of Scientific research6(2):146-156, 2013 ISSN 1992-1454/DOI:10.3923/ajsr.2013.146.156
19. Boubakri A et al (2000), Adsorptive solar powered ice maker: experiments and model. Sol Energy 2000; 69(3):249–63.
20. Saha BB et al (2001), Solar/waste heat driven two-stage adsorption chiller: the prototype. Renew Energy; 23(1):93–101.
21. Lu YZ et al (2003), Adsorption cold storage system with zeolite-water working pair used for locomotive air conditioning. Energy Convers Manage; 44(10):1733–43.
22. Abdullah MO et al (2003), Cooling performance of a combined solar thermoelectric-adsorption cooling system: an experimental study. Energy Fuels; 23:5677–83.
23. Aceves SM (1996), Analytical comparison of adsorption and vapor compression air conditioners for electrical vehicle applications. Energy Resources Tech Trans ASME 1996; 118(1):16–20.
24. Sato H et al (1997), Adsorptive type refrigeration apparatus. US patent 5619866; 1997.
25. Wang RZ et al (2001), Research and development on waste heat driven adsorption bus air conditioning system. Final Report SJTU-UTRC Joint Research Program, Shanghai Jiao Tong University (SJTU) and United Technologies Research Center (UTRC). China.
26. Lu YZ (2004), Practical experiments on an adsorption air-conditioner powered by exhausted heat from a diesel locomotive. Appl Therm Eng; 24:1051–9.
27. Wang LW (2003), Study of the performance of activated carbon–methanol adsorption systems concerning heat and mass transfer. Appl Therm Eng 23:1605–1617
28. Zhao Y (2012), Dynamic modelling of an activated carbon–methanol adsorption refrigeration tube with considerations of interfacial convection and transient pressure process. Appl Energy 95:276–284
29. Gordeeva L and Aristov Y (2014) Dynamic study of methanol adsorption on activated carbon ACM-35.4 for enhancing the specific cooling power of adsorptive chillers. Appl Energy 117:127–133
30. Ramji HR et al (2014) Parametric study and simulation of a heat-driven adsorber for air conditioning system employing activated carbon–methanol working pair. Appl Energy 113:324–333
31. Hamamoto Y et al (2006) Study on adsorption refrigeration cycle utilizing activated carbon fibres. Part 2. Cycle performance evaluation. Int J Refrig 29:315–327

32. Tso CY et al (2012), Performance analysis of a waste heat driven activated carbon based composite adsorbent – water adsorption chiller using simulation model. Int J Heat Mass Transf 55:7596–7610
33. Sarbu, Ioan and Calin Sebarchievici (2015), General Review of Solar-Powered Closed Sorption Refrigeration Systems." Energy Conversion and Management, vol. 105, Elsevier Ltd, 2015, pp. 403–22, doi:10.1016/j.enconman.2015.07.084