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Article

Adsorption Cooling Technology for Utilization of Waste Heat and Solar Energy

Pratap Ramesh Sonawane[1], Vijay S Kulkarni[2]

[1,2]Department of Mechanical Engineering, MCOERC Nashik, India.

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Corresponding Author:
Pratap Ramesh Sonawane, Department of Mechanical Engineering, MCOERC Nashik, India
E-mail Id:
Pratap.sonawane4@yahoo.com
Orcid Id:
https://orcid.org/0000-0002-6681-5208

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A B S T R A C T

Warmth driven cooling advancements like fume ingestion and adsorption frameworks are earth amicable. Utilization of warm pressure in these frameworks spares valuable and quick draining petroleum product assets. Sunlight based vitality and poor quality waste warmth can be adequately utilized in running these cooling frameworks. The current work centers around the improvement of a sun based controlled fume adsorption based cooling framework, which can possibly be a sans carbon option in contrast to fume pressure cooling cycles, particularly for meeting residential and office space prerequisites. Poor warmth and mass exchange properties of the adsorbents lead to greater sizes and more expense. Utilization of dainty beds alongside indispensably finned tubes has been embraced in this work to enlarge the warmth move through the bed. A temperature dissemination profile of the silica gel bed has been created through limited distinction strategy, to have an in - profundity investigation of the warmth move process during adsorption. A test unit of adsorption chiller has been produced for round the year parametric investigation with a warmth pipe based emptied tube sun oriented water radiator introduced on the rooftop.

Keywords: Vapour Absorption and Adsorption Systems

Introduction

Adsorption refrigeration innovations, for example, ingestion and additionally adsorption are thermally determined frameworks, in which the traditional mechanical blower of the regular fume pressure cycle is supplanted by a ‘warm blower’ and a sorbent. The sorbent can be either strong on account of adsorption frameworks or fluid for assimilation frameworks. At the point when the sorbent is warmed, it desorbs the refrigerant fume at the condenser pressure. The fume is then melted in the condenser, courses through an extension valve and enters the evaporator. At the point when the sorbent is cooled, it reabsorbs fume and accordingly keeps up low weight in the evaporator. The melted refrigerant in the evaporator ingests heat from the refrigerated space and disintegrates, delivering the cooling impact. Adsorption refrigeration dissimilar to retention and fume pressure frameworks, is a characteristically repetitive procedure and various adsorbent beds are important to give around consistent limit. Adsorption frameworks inalienably require huge warmth move surfaces to move warmth to and from the adsorbent materials which naturally makes cost an issue. High productivity frameworks necessitate that warmth of adsorption be recuperated to give some bit of the glow expected to recuperate the adsorbent.These regenerative cycles thusly need products of two-bed heat exchangers and complex warmth move circles and controls to recoup and utilize squander heat as the warmth exchangers cycle among adsorbing and desorbing refrigerant. Because of quick industrialization and quickly developing economies worldwide vitality request increments radically. This expansion in vitality request isn’t just because of industrialization yet additionally because of improved leaving standard of present day society. Vitality gracefully for refrigeration and cooling framework assume significant job in all out vitality flexibly and request.

According to International Institute of Refrigeration (IIR) approximately 15% of all electricity produced world-wide is used for refrigeration and air conditioning.[1] Refrigeration system consume considerable amount of power for domestic as well as industrial applications. The Vapor Compression Refrigeration System (VCRS) is most commonly and popularly used in many applications. However, refrigerants used in VCRS contribute to greenhouse gas emission and some of refrigerants such as Chlorofluorocarbons (CFCs), Hydro Cchlorofluorocarbons (HCFCs) and Hydrofluorocarbons (HFCs), causes depletion of stratospheric ozone layer. Due to lot of power consumption and identification of environmental problem with CFCs and HCFCs many researchers turns to-wards development of green refrigeration and air conditioning technology. Adsorption refrigeration is one of the green technologies which can address above problems and give same output as that of present heating, ventilation and air conditioning. It is heat driven cycle which utilizes solar or low grade waste heat e.g., heat from engine exhaust, industrial waste heat, etc. Adsorption refrigeration system is environment friendly system and has large energy saving potential. It replaces compressor in conventional VCRS by adsorber bed, so vibration problems also get eliminated. In last decade, many researchers worked on ad-sorption cooling system and proposed new cycles, new adsorption pair, design of adsorber beds, new research methods, etc. However, poor heat and mass transfer performance prevent this technology in practice. In this seminar various working pairs of adsorber and adsorbate for cooling system and selection of adsorption pairs for particular application are analyzed.[1-3]

Literature Review

Azhar Bin Ismail et al. performed investigation of single-stage two bed adsorption refrigeration cycles working at pressurized conditions. Four examples of initiated carbon adsorbent and refrigerant sets, which are Maxsorb III with Propane, n-butane and presumed that the particular cooling impact increments with the require evaporating temperature and recovering temperatures. It anyway diminishes with expanding surrounding temperatures because of the higher cold repository accessible to the framework and At higher required chilling temperatures and lower encompassing temperatures, R-32 is favored with higher explicit cooling limits.[1]

L.X. Gong and R.Z.Wang et al. performed work on design and performance prediction of new generation adsorption chillers using composite adsorbent which was lithium chloride in silica gel as adsorbent and water as adsorbate and found that COP and cooling capacity augmented by using this working pair. [2] Kai Wang et al. in ASHRAE journal performed work on performance of adsorption refrigeration system and composite adsorbent material and found that silica gel –water and activated carbon-methanol are appropriate working pair for solar energy and low temperature heat source due to their low desorption temperature. Zeolit–water, activated carbon–ammonia and composite adsorbent-ammonia are used for high temperature waste heat applications.[3]

Harish Tiwari introduced structure advancement and experimentation of an adsorption refrigeration framework controlled by exhaust heat with just two control valves. The cooling limit with respect to a truck lodge is evaluated as 1 TR a size of 3.5:1 is chosen and a model of 1 kW has been structured and created and tried in research center. A cooling impact of 1 to 1.2 kW has been acquired. The COP of the framework is in the scope of 0 4 to 0.45. The absolute load of the framework for a cooling limit of 1 kW is 30 kg.[4] Wang et al, has introduced a structure of an adsorption forced air system for train driver lodge, fueled by 3500C – 4500C fumes gases. The cooling force and COP is 5 KW and 0.25 individually". The process duration of 1060s with exhaust temperature of 4500C cooling air temp of 400C and chilled water temp. of 100C is accomplished.

The particular cooling intensity of 164 W/kg to 200 W/kg has been acquired.[5] Sahaet et al., in the introduced work have exhibited double mode silica gel water adsorption chillers plan alongside different temperature extends and acquired ideal outcome its for temperature scope of 500C and 550C. Examination of COP has been introduced for three phase mode and single stage numerous modes. Recreation has been introduced and the COP is in the scope of 0.2 and 0.45 individually."[6] Amir Sharafian et al. in 2014, took a shot at the plan of adsorbed bed for squander heat driven adsorption cooling arrangement of vehicle and found that in various sorts of adsorbed, finned tube adsorbed bed was seen to have better execution.[8]

YZ Lu and RZ Wang et al. performed take a shot at Experimental examinations on the commonsense exhibition of an adsorption cooling framework controlled by depleted warmth from a diesel train product gave zeolite and water as working pair and found that this structure is suitable to cool the driver lodge effectively.[9] Pons and Guilleminot presumed that the strong sorption frameworks could be the reason for effective sunlight based controlled fridges, and they built up a model with the pair enacted carbon-methanol. This machine created very nearly 6 kg of ice for each m2 of sunlight based board with a sun oriented COP of 0.12. This pace of ice creation stays one of the most noteworthy got by a sunlight based fueled icemaker.[12]

Li et al. performed explores different avenues regarding the sun based ice producer that is demonstrated schematically in Figure 2. This icemaker that pre-owned carbon-methanol as working pair had a COP going from 0.12 to 0.14, and created somewhere in the range of 5 and 6 kg of ice for every m2 of gatherer. Examining the temperature inclination inside the adsorbent bed.[13] Wang et al. built up an adsorption framework in which the sorption beds could be Li et al. performed explores different avenues regarding the sun based ice producer that is demonstrated schematically in Figure 2. This icemaker that pre-owned carbon-methanol as working pair had a COP going from 0.12 to 0.14, and created somewhere in the range of 5 and 6 kg of ice for every m2 of gatherer. Examining the temperature inclination inside the adsorbent bed.[13] Wang et al. built up an adsorption framework in which the sorption beds could be recovered by utilizing fumes gases of diesel motors.

Adsorption

Adsorption is adhesion of atoms, ions, or molecules from gas, liquid or dissolved solid to a surface. This process creates thin layer of adsorbate on the surface of adsorbent. Adsorption process is restly recorded by Faraday in 1848. He found cooling effect is produced when AgCl adsorbed NH3. Adsorption process is mainly classified as physical adsorption and chemical adsorption. Physical adsorption is due to weak van der Waal forces between adsorbent and adsorbate molecules. Physical adsorption is not a selective process. The adsorption can form in multiple layers and there is no decomposition of molecules during desorption. Whereas in case of chemical adsorption, chemical reaction between adsorbate and adsorbent will form new type of molecule in adsorption process and de-compose this molecules during desorption process.[10]

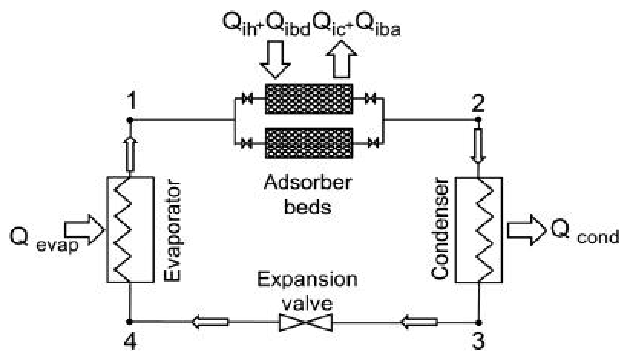


Figure 1.Schematic of adsorption cooling cycle

Thermodynamic Adsorption Cycle

Adsorption cooling system (ACS) created on two main steps: heating–desorption-condensation and cooling–adsorption–evaporation. By using this steps ACS produces cooling effect. Thermodynamic cycle consists of following four processes:

Process 1-2, adsorbent temperature increases which induces a pressure increase from the evaporation pressure to condensation pressure. This phase is equivalent to "compression" phase in compression cycle.

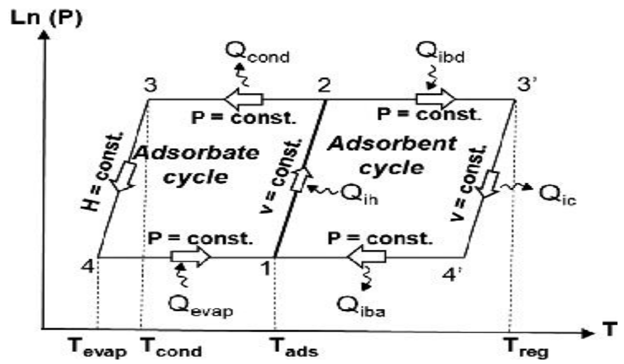


Figure 2.Thermodynamic cycle

Process 2-3, during this period, the absorber continuously receiving heat while being connected to the condenser, which now superimposes its pressure. The adsorbent temperature continues cumulative, which encourages desorption of vapour. This desorbed vapour is liquefied in the condenser. This retro is equal to the "condensation" in compression cycles.

Process 3-4, During this period, the absorber releases heat while being closed. The adsorbent temperature decreases, which induces the pressure decrease from the condensation pressure down to the evaporation pressure. This period is equivalent to the "expansion" in compression cycles

Process 4-1, during this period, the adsorber continues releasing heat while being connected to the evaporator, which now superimposes its pressure. The adsorbent temperature continues decreasing, which induces adsorption of vapor. This adsorbed vapour is evaporated in the evaporator. The evaporation heat is supplied by the heat source at low temperature. This period is equivalent to the "evaporation" in compression cycle.[8]

Generally in chemical adsorption monolayer of adsorbate react with adsorbent and is a selective process i.e., H2 can be adsorbed by W or Pt, not by any other material. Chemical adsorption will pro-duce much higher heat of adsorption–desorption than physical adsorption.[4] For adsorption refrigeration most refrigerant molecules are nonpolar molecular gases that can be absorbed under the van der Waals force, such as ammonia, methanol and hydrocarbons that can be absorbed by activated carbon, zeolite and silica gel. For physical adsorption the cycle adsorption quantity is generally from 10% to 20%. The advantage of chemical adsorption refrigeration over physical ad-sorption is the larger adsorption/desorption quantity, which is essential for the improvement of the specific cooling capacity per kilogram adsorbent Specific Cooling Power (SCP). But the expansion and agglomeration will happen in the chemical adsorption process-4. The general adsorption cooling cycle consist of desorption-condensation–expansion-evaporation and adsorption. Basic adsorption cooling cycle is intermittent but if source is available continuously then multiple adsorber beds can be designed which minimize intermittency of cooling cycle.

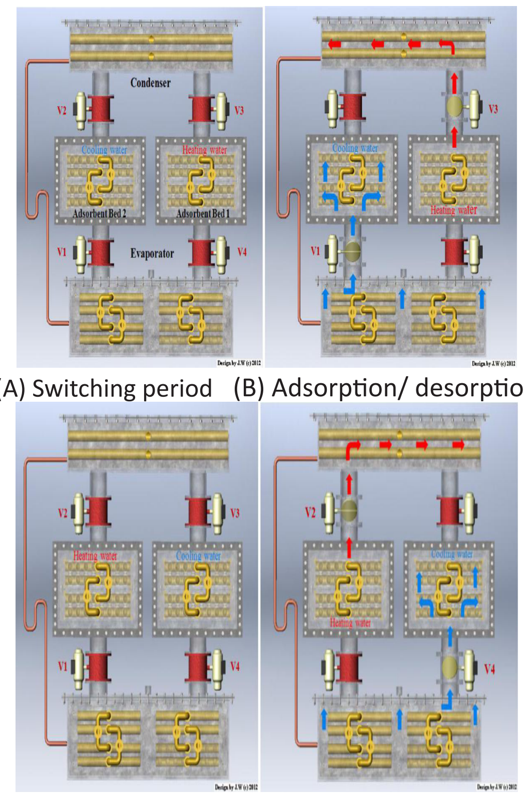
The Operating Principle of an Adsorption Cooling System.

The adsorption cooling system generates cold through the process of adsorption on porous material.

Step 1: Desorption drying of the adsorbent (zeolite or silica gel) is dried by heat input. Water vapour flows into the condenser and is liquefied under heat emission. When the adsorbent is dry, the heated water input is stopped and the condenser valve closes.

Step 2: Adsorption water vapour is adsorbed on the surface of the adsorbent.

After a cool down phase the reverse reaction and the evaporation of the liquid condensate starts. The valve to the evaporator opens and the dry adsorbent aspirates water vapour. In the evaporator, water evaporates and generates cold, which can be used for air-conditioning. During the adsorption process heat is rejected which has to be dissipated. In a final phase, the condensate is returned to the evaporator and the circuit close.



(A) Switching period (B) Adsorption/ desorption

(C) Reversing (D) Adsorption/ desorption

Figure 3.Operating Cycle of the adsorption cooling system

Porous Adsorbents Materials

Almost all porous adsorbents materials have the capacity to adsorb water vapour and gases by physical and or chemical forces. The porous media materials used on adsorb purpose are called the adsorbents. The moisture or gases adsorbed can be driven out from the adsorbent by heating, and the cooled 'dry' adsorbents can adsorb moisture or gases again. The popular adsorbents are silica-gel, zeolite, and activated carbon.[7,8] The common porous adsorbents used as packing in a adsorption bed cooling system are silica gel, zeolite and activated carbon see Figure 4.

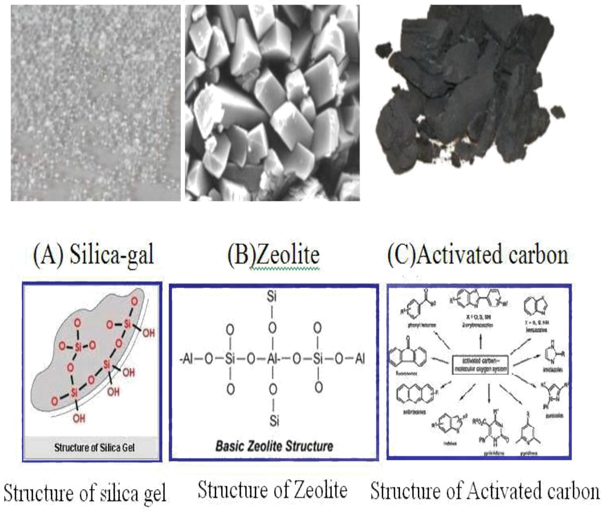


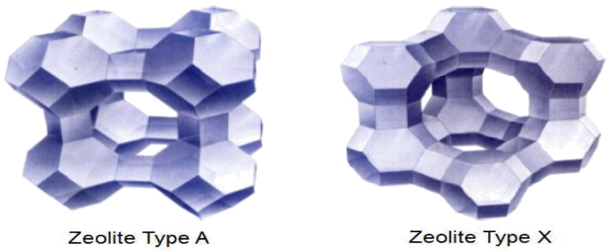
Figure 4.Porous Adsorbents Materials

Silica Gel

Silica gels have been the object of many studies in adsorption cooling in recent years. This is due to the adsorption capability of water vapour because of the physical porous structure of silic agel and large surface area. It has the adsorption capability to adsorb 50% of its mass of vapour without changing its mass. The adsorption ability of silica gel increases when the polarity increases. One hydroxyl can adsorb one molecule of water. Each kind of silica gel has only one type of pore, which usually is confined in narrow channels. The pore diameters of common silica gel are 2, 3nm (Atype) and 0.7 nm(B type) and the specific surface area is about100–1000m2/g. Type A-silica gel isa fine pore silica gel it has alarge in ternal surface area. Having a high moisture-adsorbing capacity at low humidity and is used as an adsorbent in adsorption cooling system. Type B contains large pores so type B adsorbs water vapour at low heat and releases it at high heat so this type of silica gel would be more practical for system design to desorbs water vapor at high humidity and at adsorb at low humidity.

Zeolite

Zeolite is a highly porous adsorbent material, which belongs to the class of alumina-silicates. These adsorbent are characterised by a three-dimensional porestructure. The corresponding crystallographic structure is formed by crystal of (AlO4) and (SiO4). Thesecrystal are the fundamental construction forvarious zeolite such as zeolites A and X, the common adsorbents used in theapplication of adsorption cooling system. The porosity of the zeolite is between 0.2 and 0.5. There are about 40 types of natural zeolite.



(A)crystal cell unit of type A zeolite

(B) Crystal cell unit of type X, Y zeolite

Figure 5.Crystal cell unit of zeolite

Activated Carbon

Activated carbon has been a key adsorbent material in adsorption cooling technology for many years due to their porous surface. The structure of activated carbon is shown in Figure. The specific area of activated carbon is between 500 and 1500 m2/g. The net structure of activated carbon pores is composed of irregular channels, which have larger pore area at the surface of the grain, and narrow pore area within the grain. The difference between activated carbon and other types of adsorbent is the surface feature. The whole surface of activated carbon is covered by an oxide matrix and by some inorganic materials, and therefore, it is non-polar or has a weak polarity. The adsorption heat of activated carbon pairs is lower than that of other types of physical adsorbent pairs. Pores in Activated Carbon is classified into three types: Micropores (pore dia less than 20 nm), Mesopores (pore dia. 20-200 nm) and Macropores (200 nm & above)

Working Pairs For Adsorption Cooling System

Working pair is one of the important elements in adsorption cooling system. The performance of ad-sorption cooling system mainly depends on thermal and physical properties of working pair. The selection of working pair is primarily based on particular application and type of source of heat. However, other properties such as adsorption capacity, change of adsorption capacity with temperature variation, desorption isotherm, adsorber compatibility with refrigerant, latent heat per volume, freezing point and saturation vapor pressure of adsorbate, toxicity, flammable, corrosion, thermal stability, etc. also has same importance while selecting working pair. The common adsorption refrigeration working pairs mainly include activated carbon–methanol, activated carbon absorber–methanol, activated carbon– ammonia, zeolite–water, silica gel–water, metal hydrides–hydrogen, calcium chloride–ammonia and strontium chloride–ammonia, and so on. Some of them are explained

Adsorbent-Rerfrigerant	COP	Desorption Temperature
Zeolite/ water	0.9	> 150_C (exhaust gas)
Activated Carbon/ Ammonia	0.6	100-1500C
		(Engine Coolent)
Silica-gel/ water	0.4	70–1000C
		(Engine coolant,Solar)
Activated carbon/ methanol	0.67	80–1000C
		(engine coolant, solar)

Applications Based on Waste Heat Recovery

Solar Powered Adsorption Icemakers

The principle of adsorbtion is concerned with the interaction of gases and solids. This is a similar system to absorption but uses a solid as a refrigerant instead of a liquid. In this case, the molecular interaction between the solid and the gas allow the gas to be adsorbed into the solid. The adsorbtion chamber is usually a packed bed of solid material. This allows for no moving parts and quiet operation. The primary choice for the adsorbant material is activated carbon, zeolites or silica gel. Water, methanol (ethanol) or ammonia are the most widely used adsorbates in low temperature waste heat operations. The issue with these materials involves low thermal conductivities and poor porosity characteristics .Adsorbtion systems consist of a generator, a condenser, a pressure-relief valve and an evaporator. When the adsorbtion chamber is heated the gas is desorbed and carried through the vapor-compression cycle. In order to be absorbed the chamber needs to be cooled again. Since the adsorbant is a solid this has to take place in the same chamber. To prevent the intermittent interruption, a two bed system is used as seen in Figure 2, this adds complexity and cost. Most solar icemaker prototypes have a daily ice production between 4 and 7 kg per m2 of solar collector, with a solar COP between 0.10 and 0.15. These values could increase even more if the future machines start to be manufactured with consolidated adsorbent. Solar energy can also drive desiccant systems that can be are used to remove the latent load and humidity of the air. Simple systems as applied for air conditioning in grain storage. These systems can also be combined with evaporative cooling or with mechanical compression systems to increase their performance. In both cases, the desiccant material can be regenerated by waste heat or solar energy. Such applications are already found in some buildings in Europe.

After several projects aimed to increase the performance of the adsorption chillers with the pair silica gel-water, these chillers can be currently found on the market and they are already under operation as part of the air conditioning systems located in buildings or in a chinese grain depot. As the adsorptive beds of the chillers can be regenerated by low-grade temperatures, waste heat or solar energy can be used as heat source.

Places with high isolation usually have a large demand for cooling to preserve food, drugs and vaccines, and much research has been devoted to develop machines that could employ solar energy efficiently for such purpose. The development of sorption refrigeration systems powered by solar energy emerged in the late 1970s following the pioneering work of T chernev, who studied a basic solid sorption cycle with the working pair zeolite-water. Since then, a number of studies have been carried out, both numerically and experimentally, but the costs of these systems still make them non-competitive for commercialization. Therefore, the focus of some research is placed on cost reduction and on the increase of the efficiency of the machines, and promising results have already been obtained.[16] Based on the results of a previous study, concluded that the solid sorption systems could be the basis for efficient solar powered refrigerators, and they developed a prototype with the pair activated carbon-methanol. This machine produced almost 6 kg of ice per m2 of solar panel 1, with a solar COP of 0.12. This rate of ice production remains one of the highest obtained by a solar powered icemaker. Critoph mentioned a solar vaccine refrigerator studied in his laboratory in the early 1990s . Such machine, shown in Figure 7, could keep the cold box at 0 °C during the daytime, after one adsorption cycle performed during the previous night. According to this author, although the COP and ice production of this machine, that used the pair activated carbon-ammonia, were smaller than those produced by a machine with the pair activated carbon-methanol, the former is less sensitive to small leakages, which makes it more reliable to be applied in remote areas where the maintenance is not readily available.[17]

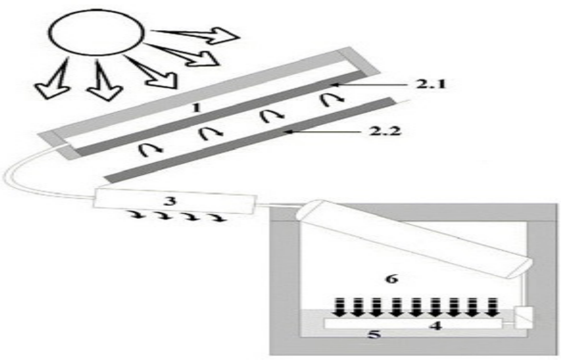


Figure 6.Solar cold box for vaccine preservation

Figure 7.Scheme of the solar powered refrigerator: 1) solar collector/adsorber; 2) ventilation dampers (.1)closed, (.2) open; 3) condenser; 4) evaporator; 5) icestorage; 6) cold box

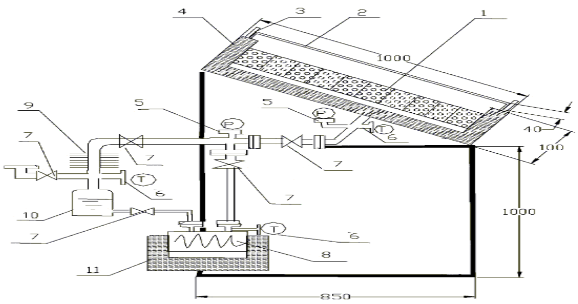


Figure 8.Scheme of the solar adsorption icemaker: 1) adsorbent bed; 2) glass cover; 3) damper; 4) insulation; 5) pressure gauge; 6) temperature gauges; valves; 8) evaporator; 9) condenser; 10) refrigerant reservoir; 11) ice box

Experiments are performed with the solar ice maker that is shown schematically in Figure 8. This icemaker that used carbon-methanol as working pair had a COP ranging from 0.12 to 0.14, and produced between 5 and 6 kg of ice per m2 of collector. Analyzing the temperature gradient within the adsorbent bed, the heat transfer properties of the adsorber needed to be enhanced. This could be achieved by increasing the number of fins or using consolidated adsorbent. An adsorption icemaker, also with the pair of activated carbon-methanol.

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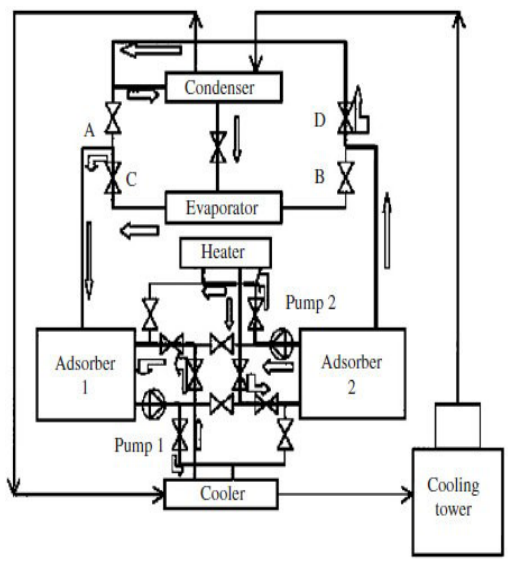

Figure 9.Adsorption refrigeration system with two bed recovery

A recent study from Tokyo University details a waste heat driven three bed adsorption chiller with mass recovery. The study uses 60° C to 90° C waste heat water and a cooling source of 30° C. This fits right into the goals of this work. This paper shows that there is a noticeable increase in system efficiency when mass recovery is considered. The adsorption chiller uses a silica gel/ water as the adsorbent/ adsorbate pair. Given the temperature requirements this system may not be feasible for generation possibilities. As temperatures rise, this may be a good way to reduce the heat in the room and discharge it out of the data center.

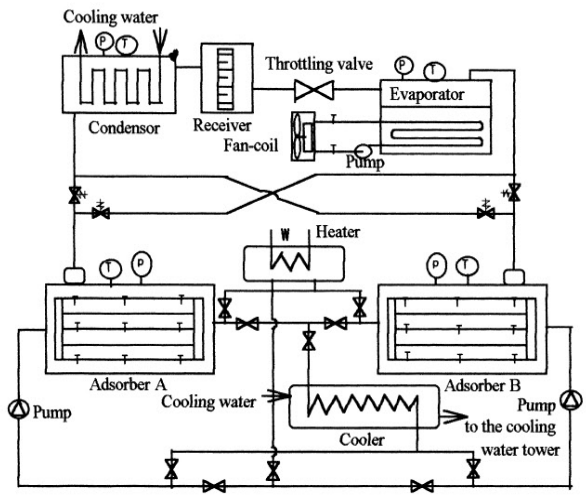

Figure 10.Second generation of the adsorption chiller developed in SJTU

Solar Powered adsorption Air Conditioners

In many countries during summer, the demand for electricity importantly intensifications due to the intense use of air conditioners. Problems, like blackouts, can occur if the capacity of the power plants is not sufficient to meet this demand, especially during peak hours. As this period usually coincides with the higher insolation hours, the use of solar powered air conditioners seems to be an attractive solution. At the end of the 1980s, Grenier presented a solar adsorption air conditioning system that had 20 m2 of solar panel and used the working pair zeolite-water. This system, shown in Figure 11 , was designed to refrigerate a 12 m3 room for food preservation., the cold room could store 1,000 kg of vegetables with a rotation of 130 kg per day for a temperature difference of 20°C between the ambient outside and the cold room.[18]

The COP, in this case, was 0.10. Saha experimentally investigated a double-stage, four-bed, non-regenerative adsorption chiller that could be powered by solar/waste heat sources at between 50 and 70 °C.An adsorption air conditioning system was to be powered by heat sources with temperatures close to 100 °C. Evacuated tube collectors could be used to supply hot water at this level of temperature. The system, which the scheme is shown in Fig , had two adsorbers with 26 kg of carbon inside each one and used methanol as refrigerant. The COP of this system were significantly influenced by the cycle time. The operation of the system with a cycle time of 30 minutes leads to a COP of 0.15 and a cooling power of 3.84 kW while operation with a cycle time of 60 minutes leads to a COP of 0.21 and cooling power of 3.03 kW. In both situations, the evaporation temperature was close to 6°C. To improve the performance of the system, the authors changed the adsorbers, keeping the same charge of carbon, and used a tube and plate heat exchanger being the carbon placed outside the tubes, between the plates. With this new design, the COP obtained was 0.4 and the cooling power was 3.80 kW. The experimental conditions in this case were: a heat source temperature of 100 °C, an evaporation temperature of 10 °C, a condensing temperature of 24 °C and a cycle time of 50 minutes.[19]

Figure 11.Second generation of the adsorption chiller developed in SJTU

Liu et al., developed an adsorption chiller with the pair silica gel-water that had no refrigerant valves. This feature reduces the cost of the chiller, and makes it more reliable as there are fewer moving parts that could lead to air infiltration. The sorption bed of such a chiller could be regenerated by hot water at between 75 and 90 °C.The whole chiller contains 52.8 kg of silica gel divided between two adsorbent beds, which operate out of phase and, thus, produce constant cooling. Experiments with the first prototype showed that a cooling power of 3.56 kW and a COP of 0.26 could be obtained when the mass and heat recovery processes are employed under the follow operation conditions: an evaporation temperature of 7 °C, a heat sink temperature of 28 °C, and a heat source temperature of 85 °C. A scheme of this chiller integrated into a solar water heater is shown in Figure 12.

To enhance the performance of the chiller, the research team industrialized a new prototype, show in Fig, with some developments. The new prototype had less non-continuous and movable pieces to reduce the number of possible places for inward air leakage. The condenser was changed to avoid undesirable refrigerant evaporation that occurred inside this device during the operation of the first machine. The configuration of the absorber was changed to improve the heat and mass transfer. Although there was some difficulty in testing both prototypes under the same operation conditions, the second prototype proved to have better performance than the first one. The second prototype had a cooling power and a COP about 34% and 28 % higher than the first one, even if the bed of the former was regenerated by lower generation temperature. Experiments performed at a generation temperature of 80 °C and an evaporation temperature of 13 °C showed that the COP and the cooling power of this new system could reach 0.5 and 9.0 kW, respectively.

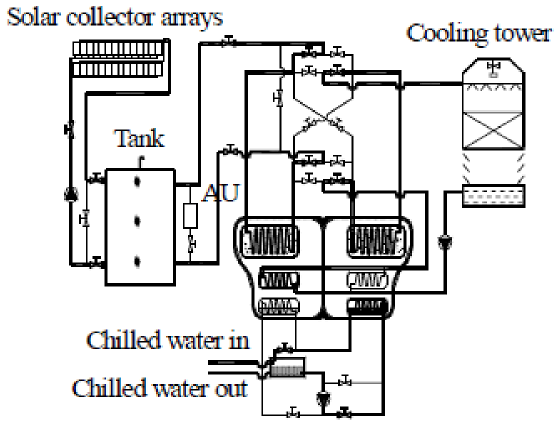

Figure 12.Scheme of the silica gel–water adsorption chiller powered by the Solar water heater

Xia applied for a patent of a silica gel-water adsorption chiller driven by a low temperature heat source. This chiller has two indistinguishable chambers and a second stage evaporator with methanol as working liquid. Each chamber contains one adsorber, one condenser and one evaporator (the main stage evaporator). There is likewise a mass recuperation tube between the two chambers. Such a chiller is utilized to cool a grain warehouse in the Jiangsu Province, in China. The entire refrigeration framework, appeared in Figure 13, primarily comprises of four subsystems, specifically, sun oriented controlled water warming unit, adsorption chiller, cooling tower and fan curl unit. The sun based fueled water-warming unit incorporates very nearly 50 m2 of emptied tube gatherers, a water siphon and a boiling water stockpiling tank.[20]

Figure 13.Scheme for adsorption solar power chiller used for cooling a grain depot

Adsorption Icemakers Driven By Exhaust Gases

The efficiency of diesel engines is about 35% and in the operation of water-cooled engines, about 35 and 30% of the input energy is wasted in the coolant and exhaust gases,respectively. Thus, recovering the waste heat can improve the energy management where such engines are employed. The use of this heat to regenerate the bed of adsorption systems is one of the alternatives to increase the overall efficiency of the diesel engine. The mechanical vapour compression system is currently the most available technology nowadays for refrigeration purposes on fishing boats, but it has certain drawbacks such as the increase of fuel consumption on the boats, because some extra energy is needed to drive the compressor. Fishing boats are generally powered by diesel engines, and the employment of adsorption refrigeration systems instead of mechanical compression ones, could reduce their fuel consumption.

Figure 14.Consolidated carbon block

Wang developed an adsorption system in which the sorption beds could be regenerated by using exhaust gases of diesel engines. This system was designed for ice production, and the working pair employed was activated carbon and methanol. The exhaust gases holding a temperature of about 500 °C heated water in a heat exchanger and this water was used to heat the adsorbent at the generation phase. The temperature of the hot water was adjusted to always be lower than 120 °C, because methanol, when in contact with activated carbon, is not stable at temperatures higher than this. In this setup used solidified adsorbent, instead of granular one because of the difference in the heat transfer coefficient of these two materials. Although the heat transfer performance of the solidified adsorbent was superior to that of the granular one, the mass transfer was inferior due to its low permeability. The authors stressed the importance of refrigerant flow channels inside the adsorbent to ensure that the rates of desorption and adsorption would not be influenced by the low permeability. The experiments with this prototype were performed with and without refrigerant mass recovery. The mass recovery proved to increase the ice production by 11%. With a cycle time of 72 minutes and an evaporation temperature of –11 °C, the COP was 0.12. The consolidated carbon block was also used in a prototype developed by Wang and Wang . The experiments with this machine employed heat and mass recovery processes to increase the COP. An oil burner simulated the heat from the exhaust gases of a diesel engine. The system achieved a COP of 0.18, which resulted in a flake ice production from 18 to 20 kg/ h at –7 °C. The Figure 20 shows a photo of the prototype producing flake ice. The experiments with this prototype were performed with and without refrigerant mass recovery. The mass recovery proved to increase the ice production by 11%. With a cycle time of 72 minutes and an evaporation temperature of –11 °C, the COP was 0.12. The consolidated carbon block was also used in a prototype developed by Wang and Wang . The experiments with this machine employed heat and mass recovery processes to increase the SCP and the COP. An oil burner simulated the heat from the exhaust gases of a diesel engine. The system achieved a COP of 0.18, which resulted in a flake ice production from 18 to 20 kg /h at –7 °C. The Figure shows a photo of the prototype producing flake ice.[14]

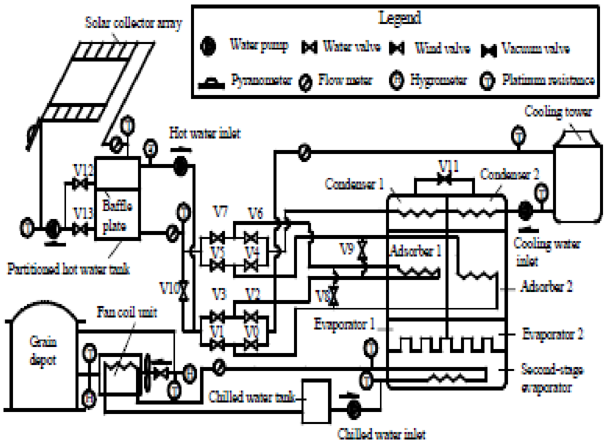

Figure 15.Adsorption icemaker during ice production

Critoph developed an adsorption system with combined carbon block, and utilized ammonia as refrigerant. This system obtainable a SCP of 35 and a COP of 0.10 when the evaporation temperature was –17 °C, the condensing temperature was 25 °C and the generation temperature was 105 °C.

Adsorption Refrigerators Integrated With Heat Pipe

Adsorption refrigeration systems integrated with heat pipes are quite efficient for real applications. The research work has proved that heat pipes could be used as heat exchangers for adsorbers, evaporators or condensers. Proper designing may help to simplify the adsorption refrigeration system, make the system cost lower, and solve the problems of corrosions, etc.Based upon various types of heat-pipe design, adsorption water chiller, adsorption room air conditioner and adsorption ice maker for fishing boats have been success- fully demonstrated. Some of adsorption the refrigeration systems have been even commercialized. Since the interest in adsorption systems was renewed in the last 20 years, the COP of these systems greatly increased due to the work of several research groups. some of the best performances obtained by different prototypes manufactured during this period, for the applications and heat sources discussed in this paper. The results should not be compared to one another, as they were obtained under different working conditions, but they should be used as a reference of what can be expected from these systems. The first example of such systems is a small scale adsorption refrigeration water chiller with a cooling power from 5 to 200 kW.

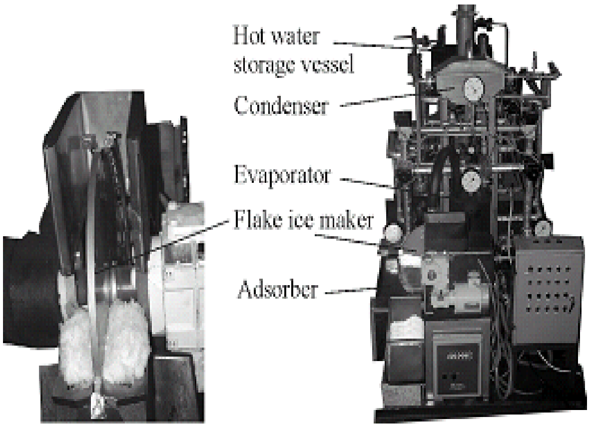

Figure 16.Photograph of the heat-pipe type adsorption chiller

Such systems need continuous cooling output and low or no consumption of electric energy. show the drawing and photograph of the heat-pipe type adsorption chiller driven by low temperature heat source with rated 10 kW cooling power. There are two vacuum chambers inside this chiller, each of them encloses one adsorber, one condenser, and one evaporator. Mass recovery piping is installed between the two chambers. Cooling power of this adsorption chiller is 6–10 kW. The 6 Kw cooling power and a COP of about 0.35 are obtained when the system is powered by hot water at 65 °C, which is the lowest working temperature of hot water, while 10 kW cooling power and a COP of about 0.4 are obtained when the temperature of hot water is 85 °C. This adsorption chiller could be used for solar powered air conditioner and also as the chiller for CCHP system. An adsorption system could provide 10–15 °C chilled water for normal air conditioning systems, or 15–20 °C chilled water for the cooling of dry fan coils, according to the requirements in which a COP of about 0.5 could be reached.

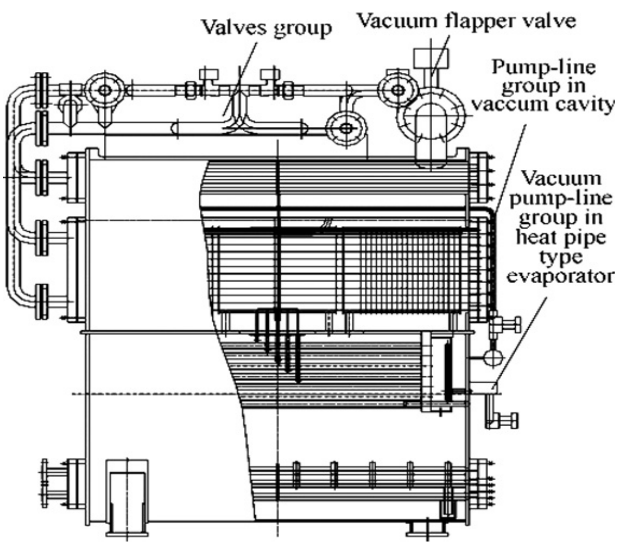

Figure 17.Adsorption chiller with heat and mass recovery and heat pipes to output cooling

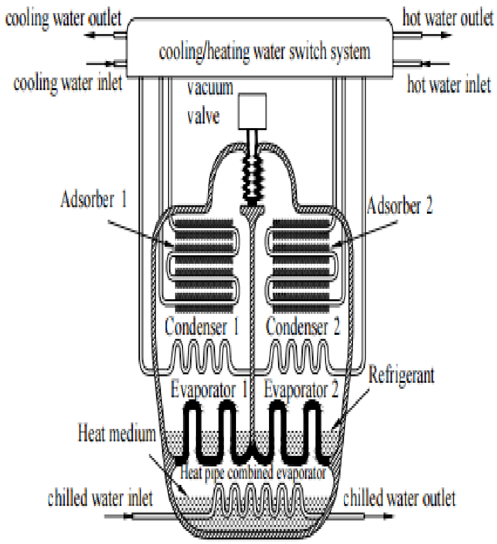

Figure 18.Shows the structure of the heat-pipe type silica gel–water adsorption chiller

This silica gel–water adsorption chiller is composed of three working vacuum chambers, including two desorption/adsorption chambers and one heat-pipe working chamber. In the adsorption chambers, water is taken as the refrigerant, while in the heat-pipe.

Conclusion

1. Due to advantages of environmental friendliness and use of low grade thermal energy adsorption cooling system would be substitute for conventional cooling system in future.
2. The commonly used working pairs like activated carbon–ammonia; methanol; ethanol, silica gel– water, zeolite–water have some limitation. Some of them can be rectified by composite adsorbents but it will decrease desorption temperature and number of life cycles.
3. The selection of working pair mainly depends on availability of heat source temperature and application.
4. The main criteria for design of adsorber bed increase heat transfer surface area with less cost and compatibility of material.
5. Cycle time and adsorption rate are factors that affect performance of adsorption system.
6. In adsorption cooling system there is scope of enhancement of system by using waste heat recovery like solar energy, exhaust gases, heat pipe etc.

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