International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

Development of Adsorption Cooling Technology using Waste Heat Energy Sources: A Review

Vikas H.Chaudhari
Research Scholer, D.Y.Patil Institute of Engineering & Technology,Pune.
Savitribai Phule Pune University, Maharashtra, India.

Dr. Avinash D. Desai
Principal, Shree Ramchandra College of Engineering,Pune.
Savitribai Phule Pune University, Maharashtra, India.

ABSTRACT

The common use of CFCs and HFCs refrigerants in mechanical VCR systems are contributing for ozone layer depletion such an issue is nonexistent in vapour absorption and adsorption system. Adsorption cooling system is gaining more popularity and here they said system as well as use of adsorbent adsorbate working pairs is studied. This paper presents an overview of research and development of adsorption cooling technology which utilizes waste heat energy sources. Many researchers here developed a solution and that uses various types of adsorbents pairs commonly for air conditioning and food storage field. This study reveals that adsorption cooling technology has more future scope and is preferred where large amount of low grade thermal energy source is available which takes care of experimental issues.

Keywords

Adsorption refrigeration, waste heat energy, adsorbents pair, coefficient of performance

I. INTRODUCTION

In the refrigeration sector, the demand of energy consumption is increasing day by day, with the worldwide development of the economy and technology growth. The main issue of is environmental pollution and the issue of energy shortage. The use of chlorofluorocarbons(CFC) and hydroflurocarbon (HFC) refrigerants in mechanical vapour compression refrigeration systems are contributing to increase the intensity of ozone layer depletion issue. Therefore more scope is to developed refrigeration system which can use natural refrigerants and utilization of lower rate of energy. One of the thermal cooling systems of adsorption refrigeration system is a better alternative to be use in refrigeration and air conditioning fields. These refrigeration systems have been preferred when larger amounts of waste heat, low grade thermal energy, solar energy and geothermal energy sources are available to drive these systems. It provide advantages in terms of electricity consumption and environmental issues such as ODP and green house effects and the protection of environment [1]-[6].The main objective of this paper is to present the information about development of adsorption cooling technology,its applications in refrigeration sector.Further,to determine the scope of improvement in its various parameter. This paper is organized into following sections. Section II and section III respectively elaborates operating principle and current literature review of adsorption cooling system. In the section IV studied various adsorptions working pair commonly used is present for various applications. The section V and section VI present the information about methods used to improve performance of system and its applications respectively.This paper is concluded in section VII.

II. OPERATING PRINCIPLE OF ADSORPTION COOLING CYCLE

Adsorption is defined as the phenomenon of concentration of molecules of a gas or liquid at a solid surface without any chemical change.When a solid surface is exposed to gas or a liquid, molecules from the gas or the solution phase accumulate or concentrate at the surface. The substance that concentrates at the surface is adsorbate and the solid on whose surface the concentration occurs is called as adsorbent. Adsorbent atoms or molecules are not surrounded by atoms or molecules of their kind and they have unbalanced attractive forces on the surface which can hold adsorbate particles [2].

The physical adsorption and chemical adsorption processes are commonly used for cooling purpose. The physical adsorption mainly depends on the heat and mass transfer performance of the adsorbents. The chemical adsorption is influenced by heat and mass transfer process, chemical reaction process and the kinetics of the molecules. There are certain materials which show the property of adsorbing of the various gases when they are cooled and desorption of the gases when heated. This working principle is used for increasing pressure of refrigerant and further to develop a refrigeration system to produce desired cooling effect. The adsorption cooling process works by moving refrigerant from the low pressure evaporator to the high pressure condenser [2]. These cooling system consists of adsorber, condenser, evaporator and expansion valve as shown in Fig.1.These cycle consists of four processes like heating of the bed, desorption, cooling and adsorption.

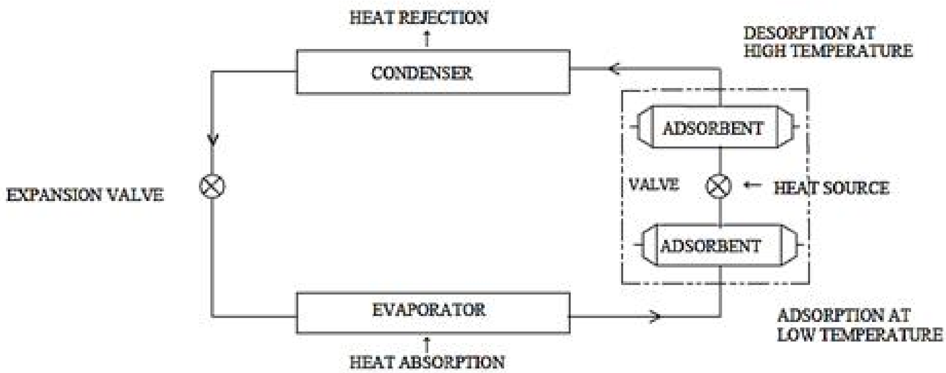

Fig. 1 Block Diagram of Adsorption Cooling Cycle

The hot water is avialable heat source receives used in adsorber for heating purpose. when the adsorbent temperature increases, simantenuasly also increase from evaporator pressure(P_a) to condenser pressure(P_d).The adsorber continues receiving heat and the adsorbent temperature progressively increases.The refrigerant vapour is driven out from the adsorbent and induces desorption of vapour. The desorbed vapour is condensed in the condenser by rejecting sensible heat.The adsorber releases heat and the adsorbent temperature decreases further induces the pressure decrease upto evaporator pressure which induces adsorption of vapour. The lower pressure causes the refrigerant liquid contained in evaporator to boil, absorbing heat and produces the necessary cooling effect[3].

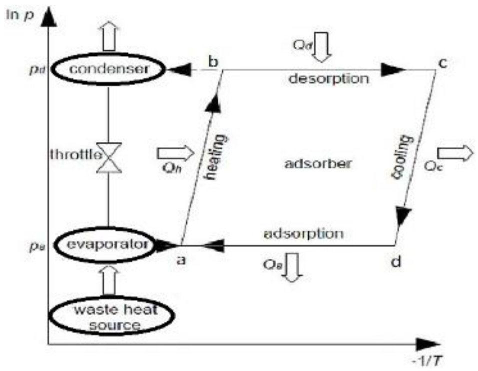

Fig. 2 Adsorption Cooling Cycle

The adsorbent bed is saturated with adsorbate at point a. Heat is applied to the adsorbent bed leads to an increase in temperature and pressure in the system. Then the refrigerant vapours releasing which collected and condensed in the condenser before returning to the evaporator. At point b condensation pressure is reached and the process of desorption starts, during which the adsorbate is removed from the adsorbent surface and flows into a reservoir or directly into a condenser. The pressure remains approximately constant, while the temperature rises. The temperature reaches the highest value at point c and cooling start with decreasing the pressure at cooling of the bed begins and the pressure decreases. When the pressure drops to the evaporation pressure at point d, the adsorbate begins to boil. The heat necessary for this process is taken from the space to be cooled and the cooling effect is produced. Adsorbate molecules are adsorbed on the surface of the adsorbent and the cycle is closed. Once this cycle is completed the heat on the adsorbent bed is removed and in some cases forced cooling is introduced onto the adsorber until the adsorption conditions are established then the valve between the evaporator and the adsorbed is reopened [4],[5].

The performance of the system can be evaluated in terms of two factors the coefficient of performance (COP) and the specific cooling capacity (SCP). The COP is the ratio of heat absorbed from the space to be cooled during evaporation of the refrigerant to the amount of heat delivered to the system for heating and desorption process. The COP is highly dependent on the temperature of heat source available conditions. The higher the temperature utilization should give the greater the COP value. The specific cooling capacity SCP is defined as cooling capacity per kg of the adsorbent. SCP takes the mass of the adsorbent and the cooling power of the device into account, so it indicates the compactness of the system. The greater the SCP value, the more compact the device [6].

Low grade waste heat or solar energy or geothermal energy sources would be an ideal heat source to drive adsorption cooling systems. The availability of waste heat source is utilized for heating of adsorbent pair. The refrigerant is driven out from the adsorbent during desorption process and rise of pressure of the system. The refrigerant vapour is condensed in condenser by rejection of heat. Then adsorption vapour is adsorbed on the surface of the adsorbent and cooled to its initial temperature with reducing pressure [7].

Therefore, there is a potential need for a technology which can provide alternative solution of refrigeration system using waste heat source in refrigeration field. It will give results in terms of saving of a large amount of energy required, protection of environment and a problem of refrigerant pollution. This system have simple control and low operation cost as compared to VCR system. Therefore, this refrigeration method has more scope for its technical development to be used in in the refrigeration field and energy saving refrigeration method. The adsorption refrigeration which has more scope to utilize waste heat energy released in power plants, chemical plants, process industries, automobile engines and waste heat energy sources.

III. LIERATURE REVIEW

In literature review the current development of adsorption refrigeration technology that focuses on working principle of adsorption refrigeration, energy conservation in refrigerated food storage area, review of waste heat energy utilization in adsorption refrigeration systems and the future scope of adsorption refrigeration in various applications. Faraday originated earliest adsorption cooling capacity could be generated at Silver chloride (AgCl) adsorbed ammonia (NH_3) in year1848.The research adsorption refrigeration originated from European researchers and Shanghai Jiao Tong University, China have contributed to develop the adsorption refrigeration technology. They proposed utilization of heat sources such as solar energy and low waste heat for various applications. In 1920,G.E.Hulse design and proposed a refrigerator in which implement silica gel and sulperdioxide (SO_2) as working pair for preservation of food products in train by utilization of low grade heat energy and achieve lowest refrigerating temperature about 12^{o}C [8]. K.Oertel *et.al.* designed and developed the Adsorption cooling using methanol silica gel pairs for the cold storage of agricultural products at temperature range 2-4°C in India. This cooling system has been used heat sources as solar energy from flat plate collectors and the waste heat energy at low temperature 80-90°C and use for air conditioning application purpose. The performance of this system is reduced for produce a chilled water temperature of -2°C at heating water temperature of 85°C and a condenser temperature of 30°C [9]. Lu *et al.* reported design ,fabrication and tested the performance of solid adsorption air conditioning of working pair of zeolite water for cooling of the driver's cab of a diesel locomotive at 25^{o}C.This system required power 4.1kW for cycle at the ambient temperature 33^{o}C and the COP of these systems is achieved as 0.25 [10]. Harish Tiwari designed and developed the adsorption refrigeration system powered by exhaust heat with only two control valves for cooling of a truck cabin is estimated as one TR the cooling capacity. A prototype of 1 kW has been taken for study and found results such as cooling effect of 1 to 1.2 kW and COP of the range of 0.4 to 0.45. It can be easily accommodated on a transport truck due to compact size [11]. Lim and Abdullah carried out an experimental study of an automobile exhaust heat driven adsorption air conditioning laboratory prototype by using palm methanol activated carbon pair. It shows results that the COP of system and specific cooling power were approximately 0.19 [12].

In this literature review, researchers has focus on the research developed a better alternative solution to protect environment and focus on efficient way to make good use of available waste heat energy sources at variable temperature. Many researchers suggest the alternative adsorption refrigeration cooling technologies for the replacements of traditional VCR systems with the economical feasibilities application areas.

IV. ADSORPTION WORKING PAIRS

In adsorption refrigeration cooling system, the working pairs are important part of a system. They are mainly classified into two areas as physical adsorption and chemical adsorption or composite adsorption working pairs. Adsorption pair consists of adsorbent and refrigerant. It play important role in the adsorption refrigeration cycle. The selection of any pair of adsorbent adsorbate for refrigeration applications depends on certain desirable characteristics of their constituents, their thermodynamic, chemical properties and also their costs or availability is important [13].The different types of adsorption refrigeration working pair are commonly used are shown in Table 1.

Table 1 Adsorption refrigeration working pairs

Adsorbate	Adsorbent	Pair Types	COP
Water	Silca Gel	Physical	0.61
Ammonia	Silca Gel	Physical	0.71
Methanol	Activate Carbon	Physical	0.78
Ethanol	Activate Carbon	Physical	0.80
Ammonia	Calcium chloride	Physical	0.61
Ammonia	Calcium chloride	Physical	0.30
Water	Zeolite	Physical	0.25
Ammonia	Metal Chloride	Chemical	0.60
Hydrogen	Metal hydrides	Chemical	0.83
Water	Zeolite & foam aluminum	Composite adsorbents	0.55
Water	Silica gel & chlorides	Composite adsorbents	0.33
Ammonia	Chlorides & porous media	Composite adsorbents	0.35
Methan	Silica gel & chlorides	Composite adsorbents	1.65

The selection of an adsorbate or refrigerant is carried out on the following properties:

- Evaporation temperature should be below 0°C.
- Small molecular size to enable it to be adsorbed into the adsorbent.
- High latent heat of vaporization and low specific volume.
- Thermally stable with the adsorbent at operating temperature range of a cycle.
- Non-toxic, non-corrosive and non-flammable.
- Low saturation pressures at normal operating temperature.

The selection of adsorption working pairs for waste heat cooling is based on availability of waste heat source. The working pair of silica gel-water and activated carbon-methanol is not useful at the highest temperature of heat sources and applicable when the heat source temperature under controlled. These pairs are commonly applied for air conditioning and freezing temperature applications The highest temperature of heat source for the working pairs of metal hydrides-hydrogen, zeolite-water, metal chloride-ammonia and the composite metal chloride adsorbent-ammonia can be used to produce cooling effect and often suitable the direct recovery of waste heat process. The working pairs of zeolite water and metal chloride-ammonia give better performance at the highest temperature of heat sources and also used in waste heat recovery process[14].

V. METHODS USED TO IMPROVE PERFORMANCE OF ADSORPTION SYSTEM

The efficiency of adsorption cooling cycle is very low and not a continuous cooling, due to higher temperature fluctuations in adsorption bed. To obtain a continuous cooling effect from an adsorption refrigeration system two or more adsorbent beds are used in the system. In two bed cycle, the evaporator and the condenser would be connected to both beds, through a series of valves. The heated bed would be opened to the condenser to allow desorption while the other would be opened to the evaporator to allow for adsorption. The heating and cooling of the beds and valve directions would be change position between the two every cycle to provide continuous heating or cooling. The heated bed would be opened to the condenser to allow desorption while the other would be opened to the evaporator to allow for adsorption. The heating and cooling of the beds and valve directions would be swapped between the two every cycle to provide continuous heating or cooling. The addition of more adsorption beds allows a steadier cooling rate and also permits the use of heat rejected from the adsorption process to be used as part of the energy input for the regeneration of the fully charged beds. These cycles also improve efficiency at the cost of adding a pump and heat recovery loops.

In order to improve the performance and practical feasibility of the adsorption refrigeration cycles, the various advanced adsorption refrigeration cycles like heat recovery cycle, mass recovery cycle, thermal wave cycle, convective thermal wave cycle, cascade cycles are employed[15].The different type advance cycles are discussed below:

a) Heat recovery cycle:

In heat recovery cycle, adsorption cooling cycles consisting of at least two or more adsorbent beds has worked out during process and then the heat recovery cycle is implementing. The heat recovery process is carried out between time of changing from adsorption to desorption process and may recover the sensible heat to improve COP by 25% .

b) Mass recovery cycle:

In mass recovery cycle, the process involves changing the pressure in adsorbent beds. In the cold adsorbent bed connected with the evaporator at the pressure of closer to the evaporation pressure which is much lower than the condensing pressure. Simultaneous in the hot adsorbent bed connected with the condenser and inside pressure is close to the condensing pressure. In these conditions, connecting the hot bed with cold bed at the switching time may greatly increase the desorption rate of the hot bed, which will be helpful for the improvement of the adsorption quantity of the hot bed in the next half cycle for the cooling and adsorption process. The mass recovery cycle is greatly improving the system performance. The heat and mass recovery cycle is currently one of the most commonly and successfully used cycles.

c) Thermal wave cycle:

Firstly the use of the thermal wave cycle in the adsorption system was proposed by Shelton. In thermal wave cycle, the heat can be transfer from the hot adsorbent bed to the cold adsorbent bed due to higher temperature difference. The concept of the thermal wave stipulates that heat is effectively utilized and that the external heat source, which is necessary for the desorption process, is greatly reduced. 80% of heat required in the desorption process may be provided by the heat released in the adsorption process. The basic principle of such a cycle is using single heating and cooling fluid circuit to connect two adsorbent beds, the cooler and the heater. The circuit of the fluid may transfer the released heat from the adsorption bed to the desorption bed, and recover the adsorption heat for the improvement of the energy efficiency of the system.

d) Convective thermal wave cycle:

Critoph proposed convective thermal wave cycle method. The refrigerant is initially heated outside the adsorbent bed and circulated to heating the adsorbent. The force convection occurs between refrigerant gases and adsorbent and required pump for supply the refrigerant in circuit. Theoretical COP value of the forced convective thermal wave cycle reaches 0.9 at the evaporating temperature of 9°C, the condensing temperature of 40°C, and desorption temperature of 200°C.

e) Cascade cycle:

In cascading adsorption cooling cycles, different working pairs are used in different temperatures ranges. The main characteristic of the cycle is that the heat will be transferred from the working pair with a higher equilibrium adsorption/desorption temperature to the working pair with the lower equilibrium adsorption/desorption temperature. Douss and Meunier designed and experimented the cascading adsorptive heat pump with adsorption working pair of worked on the activated carbon-methanol worked intermittent cycle and the two adsorber zeolite-water pairs. The external heating source was supplied to zeolite adsorbers while activated carbon adsorber was heated by heat recovered from zeolite adsorber under adsorption and to obtain the better cooling effects [16].

f) Heat exchanger used for adsorbent bed:

To increase heat and mass transfer within adsorbent beds, the different types of heat exchangers are used to increase heat transfer surface area between the heat transfer fluids and adsorbent particles during adsorption and desorption processes. The commonly heat exchangers used for adsorber bed of waste heat driven cooling system like spiral plate, shell and tube, hairpin, annulus tube, plate fin, finned tube, plate type, tube and plate and improve performance of adsorption cooling system [17].

VI. APPLICATIONS

Such system finds application where waste hot water is abundantly available viz.in power generation plant, industrial processes, solar thermal fields, data center, air conditioning field, and internal combustion engines area. This adsorption cooling method is used in a fuel cell-electric vehicle, food cooking and frying, glass production, steel production, refineries, pharmaceutical industries, fruit storage field. Now-a-days adsorption cooling system is being utilized in potato chip frying Industries and a luxury shopping center in Hong Kong, large solar thermal cooling application in North America. Shanghai Jiao Tong University, China (SJTU) design and manufactured 5kW adsorption air conditioning using activated-ammonia as the adsorption work pair. SJTU also developed adsorption air conditioning system for locomotive cab with zeolite-water adsorption pair and also adsorption ice maker for fishing boats with activated carbon-methanol [18[,[19].

VII. CONCLUSION

In this review paper, study of adsorption refrigeration cooling technology, its working principle, limitations and applications are presented. Many researches have focused the methods for improvement in heat transfer, reductions of manufacturing costs; improve the performance and the comparison of various parameters. The most common working pair is silica gel-water, due to its lower operate temperature. To improve performance and feasibility of these cooling cycle, employed heat recovery cycle, mass recovery cycle, thermal wave cycle, convective thermal wave cycle and cascade cycles to increase COP. To minimize the problem of poor heat transfer rate in the adsorbent, the different types of heat exchanger are used. The more scope is being made to improve performance of system and to reduce the weight and cost. It is studied that the most commonly finds application where waste hot energy is abundantly available and scope to use in refrigeration field and air conditioning area. The adsorption cooling system is driven by waste heat; it not only improves energy efficiency, but also decreases the emissions of greenhouse gas. It is indicates that the sufficient background available to develop these technology to propose it. This is to find out possible promising alternative solutions to energy conservation and helpful to protects environment.

REFERENCES

[1] Biplab Choudhury, Bidyut Baran Saha, Pradip K Chatterjee, Joyti Prakas Sarkar, "An overview of development in adsorption refrigeration systems towards a sustainable way of cooling", Applied energy, 2013.

[2] Pawel Szymanski " Adsorption cooling as a promising method of waste heat utilization in ship technology" Journal of Polish CIMEEAC Poland ,

[3] R.Best,W.Rivera,"A review of thermal cooling systems", Applied Thermal Engineering, 2015.

[4] Monika Gwadera,"Adsorption cooling an effective method of waste heat utilization " Technical transactions chemistry issues 2011.

[5] Wang R.Z, Oliveira, R.G," Adsorption refrigeration : an efficient way to make good use of waste heat and solar energy", International sorption heat pump conference, Colorado USA 2005.

[6] Chaudhari V H, "Development of Adsorption Cooling Technology using Waste Heat Energy sources: A Review", NACCTESTM-2017 Maharashtra, India.

[7] Ruzhu Wang, Liwei Wang, Jingyi Wu, , "Adsorption Refrigeration Technology: Theory and Application", Shanghai Jiao Tong University, China Wiley Publication 2014.

[8] John White,"Literature review of adsorption cooling technology",School Engineering, University of Birmingham , UK.2008

[9] K.Oertel, M.Fischer, "Adsorption cooling system for cold storage using methanol silica gel", Applied Thermal Engineering 1998.

[10] Y Z Lu, R Z Wang, S Jianzhou, M ,Zhang, Y.X. Xu and J.Y. Wu," Performance of a diesel locomotive waste heat powered adsorption air conditioning system",2004.

[11] Harish Tiwari, Dr G V Parishwad, "Adsorption refrigeration system for cabin cooling of trucks", International journal of emerging technology and advanced engineering 2012.

[12] Abdullaha Omar, Limb, Ivy Ai Wei Tana, "Automobile adsorption air conditioning system using oil palm biomass based activated carbon: A review", Renewable and Sustainable Energy Reviews 2011.

[13] Mahmoud Salem Ahmed, Ahmed-abd el-kader shehata,"A review: future of the adsorption working pairs in cooling", Sohag University, Sohag, Egypt 2010.

[14] R.Z.Wang, R.G.Oliveira, L.W.Wang "A review on adsorption working pairs for refrigeration" Science Direct Elsevier 2016.

[15] R.Z.Wang," Performance improvement of adsorption cooling by heat and mass recovery operation", International Journal of Refrigeration 2001.

[16] Eliza Wolak, "The cooling effect by adsorption desorption cycles", Energy and fuel 2016.

[17] Wang Ruzhu, Wang Liwei, "Adsorption refrigeration green cooling driven by low grade thermal energy", Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai, Chinese Science Bulletin 2005.

[18] R.Z.Wang," Adsorption refrigeration research in Shanghai Jiao Tong University", Renewable and Sustainable Energy Reviews 2000.

[19] Mohamed Hamdy, Ahmed A Askalany, K. Harby, Nader Kora " An overview an adsorption cooling systems powered by waste heat from internal combustion engine", Renewable and sustainable Energy Reviews 2015.