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TECHNICAL ASPECTS OF ADSORPTION COOLING SYSTEM

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Abstract: In recent years, adsorption cooling systems are getting attention due to ozone layer depletion issues and global warming potentials related to the conventionally used refrigerants. The adsorption cooling system is the heat driven refrigeration system and hence waste heat energy of the industries or automobiles or solar energy can be used as the heat source in the adsorption system. In adsorption system, the environmental friendly refrigerants such as water, can be used and hence it can cope with the current environmental issues. In adsorption system, different combination of adsorbent-adsorbate pairs is used for successful operation and hence a careful selection of the adsorbent-adsorbate pair is important. With the availability of solar energy and increase in the demand of the air conditioning in the summer, solar adsorption cooling is considered as the best alternative solution to overcome the problems associated with the conventional air conditioning systems. The development in the adsorbent technology provides solution to the shortcomings in solar adsorption systems and helps to achieve higher adsorption capacity per unit mass of adsorbent. In recent years, significant number of simulation work has been carriedout to predict the adsorption system dynamic performance under various operating conditions and accommodate design changes efficiently. This paper discusses the basics of adsorption system and also provides a review of different types of adsorption systems.

Keywords: Cooling system, Adsorption system, engine exhaust powered, solar powered

INTRODUCTION

The use of air conditioners has become almost essential in homes, office, car, I.T Industries, theatre and almost everywhere as it provides more comfortable conditions and improves thermal comfort and indoor air quality. The compressor used in the air conditioning system needs electrical energy and the production of the electricity has an environmental impact, including the release of greenhouse gases. The air conditioning system used in the automobile consumes around 3kW of the engine's power and hence increases the vehicle fuel consumption. Also CFCs, HCFCs and HFCs based refrigerants used in the air conditioning contribute to global warming and also cause ozone layer depletion.

In conventional refrigeration or air-conditioning system, compressor is used to transfer heat from low indoor to the outdoor. The working fluid used in this system is called as refrigerant and it undergoes phase change during heat transfer. During compression process, the refrigerant's pressure and temperature increases and the refrigerant rejects heats to the surrounding and changes it phase from vapour phase to liquid phase. However, the pressure of the refrigerant is high. This liquid refrigerant undergoes expansion from higher pressure to lower pressure and simultaneously its temperature reduces. This low temperature refrigerant goes to the evaporator and absorbs the heat from the indoor and becomes vapour. This low pressure refrigerant goes to the compressor and the cycle repeats. The refrigeration and air conditioning systems are most widely used in the domestic, commercial and industrial applications. Also, the demand of the refrigeration systems are increasing day by day due to change in lifestyle and increase in income level of the families. However the use of refrigeration systems with conventional refrigerants increases the ozone depletion and also increases the global warming. This leads to new environmental regulations which encourage research work in finding suitable refrigeration systems which will be more eco-friendly, cost effective, simple and reliable. Among the different alternative cooling systems, adsorption cooling system is getting popular as it a thermal energy driven system and we can use waste heat or solar energy.

ADSORPTION COOLING SYSTEMS

Adsorption is the process by which molecules of a fluid are fixed on the walls of a solid material. The adsorbed molecules undergo no chemical reaction but simply lose energy when being fixed to the adsorption bed resulting in an exothermic energy output. The vapour compression refrigeration system consists of a compressor, a condenser, an expansion valve, and an evaporator. In adsorption system, the compressor is replaced by a thermal compressor which is operated by heat instead of mechanical energy. The vaporised refrigerant is adsorbed in the pores of the adsorbent in the reaction chamber. Due to the loading of the adsorbent, the thermal compressor is operated intermittently.

A simple adsorption system consists of desorption chamber (solid adsorbent bed), condenser, adsorption chamber and evaporator. In few systems, valves are used between the various components and some utilize expansion valves between the condenser and the evaporator. Figure 1 shows the adsorption system. The adsorption system depends upon the affinity of the adsorbent bed to attract the refrigerant vapour from the evaporator and this process creates a low pressure in the evaporator. When the adsorbent bed is close to the saturation point, the valve between the evaporator and the absorber is closed and heat is applied to adsorbent bed. The addition of heat evaporates the refrigerant and the refrigerant vapour goes to the condenser where it is condensed in the condenser before returning to the evaporator. When this cycle is completed, the adsorbent bed is cooled by the cool water until the adsorption conditions are established. After this process, the valve between the evaporator and the adsorbed is reopened.

Adsorption refrigeration system uses solid adsorbent beds to adsorb and desorb a refrigerant in order to obtain cooling effect. These adsorbent beds filled with solid material adsorb and desorb a refrigerant vapour in response to changes in the temperature of the adsorbent. The adsorbent bed desorbs refrigerant when heated and adsorb refrigerant vapor when cooled [1].

A basic adsorption cycle consists of four thermodynamic processes which is shown in the vapour pressure diagram, Figure 1.

Heating and Pressurization (1-2)

At starting of the process, the adsorbent is cold and saturated with the refrigerant and this state is represented as point 1. When heat is applied, the adsorbent is heated which results in desorbing a certain amount of the refrigerant from the adsorbent. This process causes increase in pressure from evaporator pressure to condenser pressure, without changing the refrigerant uptake and this process continues until the minimum desorption temperature is reached. This process is called as preheating. The end of this process is represented as state point 2. This process is similar to compression in vapour compression refrigeration system.

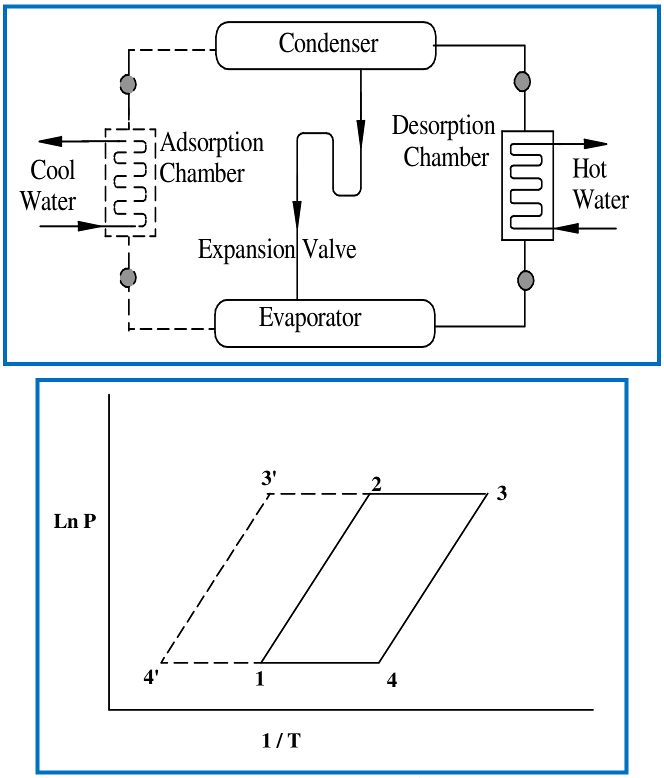

Figure 1. Adsorption Cooling System

Heating, Desorption and Condensation (2-3)

The adsorber continues receiving heat and the desorption process starts from the point 2 and the refrigerant is condensed at a constant pressure in the condenser. The desorption process proceeds until the adsorbent temperature reaches the maximum available desorption temperature and the refrigerant uptake reaches the cycle minimum uptake and end of this process is represented as state point 3. This process is similar to condensation in vapour compression refrigeration system.

Cooling and Depressurization (3-4)

After this process, desorption chamber is cooled and the adsorbent is pre-cooled and becomes able to adsorb refrigerant vapour. This results in decreasing the system pressure, from condenser pressure to the evaporator pressure, without changing the refrigerant uptake within the adsorbent. When the adsorber heat exchanger is further pre-cooled a portion of the previously desorbed and condensed refrigerant is adsorbed and the latent heat of vaporization is drawn from the remaining liquid refrigerant in the evaporator. This results in decreasing the refrigerant temperature from state point 3 to state point 4. This process is similar to expansion in vapour compression refrigeration system.

Cooling, Adsorption and Evaporation (4-1)

The adsorber continues releasing heat while being connected to the evaporator. The adsorbent temperature continues decreasing, which induces adsorption of vapor. This adsorbed vapor is vaporized in the evaporator. The evaporation heat is supplied by the heat source at low temperature. The adsorption process, within which the cooling effect is produced, starts from state point 4and proceeds by further cooling the adsorber–desorber heat exchanger until the whole amount of refrigerant is evaporated upon removing the cooling load from the surrounding space (refrigerator's cabin) and adsorbed in the adsorbent. This is equivalent to the "evaporation" in compression cycles. Line 3' to 4' represents the saturation line.

The processes in loop of 1-2-3'-4' is the refrigeration cycle and the processes in loop of 1-2-3-4 is the adsorption cycle which represents the conditions of adsorbent. The basic adsorption cooling system is not a continuous one. An adsorption bed is charged with refrigerant at low temperature and pressure; when adsorption slows down or stops, the adsorption bed is heated and high temperature and pressure gas is released from the bed. To obtain a continuous cooling effect from an adsorption refrigeration system normally two or more adsorbent beds are used in the system [2].

WORKING PAIRS

The selection of the adsorbent-adsorbate pair is essential for the successful operation of adsorption system. The commonly used adsorption pairs are, silica gel – water, zeolite – methanol, zeolite-water and activated carbon and ammonia. In adsorption system, the refrigerant is chosen based on its evaporating temperature and pressure, heat capacity, ability to be adsorbed on solid beds and environmental impact. In general, refrigerants with high heat capacity per unit volume and low environmental impact are selected. Water can be used as refrigerant due to its high latent heat of evaporation and non-toxicity. However, its freezing point and low vapour pressure limits its application.

ADVANTAGES OF ADSORPTION SYSTEMS

The advantages of adsorption cooling systems are

1. Waste heat energy or solar energy can be used
2. Needs few moving parts
3. Low maintenance
4. Small quantity of electrical energy consumption is required
5. Negligible ozone layer depletion potential

PERFORMANCE ANALYSIS OF ADSORPTION COOLING SYSTEM

Tso et al has developed an adsorption cooling system with silica gel as the adsorbent and water as the adsorbate. Their adsorption cooling system contains two adsorbers, an evaporator, two condensers, one heating and one cooling water tank. The coefficient of performance of their system was about 0.3, at the desorption temperature of 80 degree C, adsorber cooling water inlet temperature of about 34 degree C, evaporating temperature of 14 degree C and adsorption/desorption phase time of 15 minutes. Ahmed Elsayed et al results showed that water/silica gel produce more cooling capacity compared to ethanol/activated carbon adsorbents. Ahmed Shmroukh et al developed an effective heat and mass transfer processes for the adsorbate to obtain applicable adsorption capacity using fin and tube heat exchanger core and the adsorbate is adhesive over its surface and located as the core of the adsorber. They reported that the activated carbon powder/R-134a pair is highly recommended to be used as adsorption refrigeration working pair as compared to activated carbon powder/R-407c, activated carbon powder/R-507A, activated carbon granules/R-507A, activated carbon granules/R-407c and activated carbon granules/R-134a. This is because of its higher maximum adsorption capacity than the other tested pairs, to produce a compact, efficient and reliable for long life performance adsorption refrigeration system.

Halder and Sarkar developed a refrigeration cycle using activated carbon granules as an adsorbent and carbon dioxide gas as an adsorbate. Their experiment has demonstrated that it is feasible to produce a low temperature using an activated carbon bed for adsorption/desorption of carbon dioxide. Skander et al studied the activated carbon / CO_2 based adsorption cooling cycles using the pressure-temperature-concentration (*P-T-W*) diagram. They simulated the specific cooling effect and the coefficient of performance for the driving heat source temperatures ranging from 30 °C to 90 °C in terms of different cooling load temperatures with a cooling source temperature of 25 °C. They found that the maximum COPs of Maxsorb-CO_2 and ACF(A10)-CO_2 based cooling systems are found to be 0.15 and 0.083, respectively.

Jribi et al studied the possibility of using CO_2 as the refrigerant for the adsorption cooling systems due to the system compactness and the ability to operate with low driving heat source of 80°C which could be obtained from waste heat or solar energy. They developed and studied the adsorption uptake of CO_2 on highly porous activated carbon of type Maxsorb III, for temperatures ranging from -18 to 80°C and for pressure up to 10 MPa. The two-stage adsorption refrigeration cycle allows the system operation at relatively lower regeneration temperatures and the COP of the two-stage cycle is found to be higher than that of the single-stage cycle for these low regeneration temperatures typically between 50 and 77 degree C. However, the performance of the single-stage is higher than that of the two-stage cycle for regeneration temperature above 77 degree C. The maximum COP obtained is about 0.16 for evaporation and desorption temperatures of 15°C and 80°C, respectively. Skander et al analysed the dynamic behavior of a 4-bed adsorption chiller using highly porous activated carbon of type Maxsorb III as the adsorbent and R1234ze, as the refrigerant. The simulated results shows that, with 80 kg of Maxsorb III, the system is able to produce 2 kW of cooling power at driving heat source temperature of 85 °C which can be obtained from waste heat or solar energy.

Lu et al studied the feasibility of improving the performance of the adsorption refrigeration of $CaCl_2$–ammonia adsorption system, by distributing activated carbon uniformly in the mass of $CaCl_2$, thereby helping to enhance mass transfer and uplift the cooling power density. They designed and used a multifunctional heat pipe adsorption refrigerator, in which activated carbon-$CaCl_2$ is used as compound adsorbent and ammonia as refrigerant. They used water and acetone as the working liquids in the heat pipe.

Abdual Hadi et al investigated charging and the influence of the key variables on the performance of a 1.5 tons capacity two bed adsorption chiller with activated carbon-methanol as the adsorption pair. The beds functions as methanol generators and the need of using of two generators is to build a nearly continuous adsorption-desorption cycle. The adsorption chiller was driven by hot water, with a temperature range of 70 to 100 degree C. They reported that the COP of this adsorption chiller was about 0.301, at an outdoor temperature of 25 degree C. They reported that the Two beds adsorption unit can give continue cooling effect and suggested that, using the mass recovery process increases the pre desorption concentration, of methanol, in the desorption generator, and hence, improving the cycle COP.

Branka et alreported that the active carbon hollow fibers compared to classic active carbon possess higher ratio of geometric area to volume which improves the heat and a mass transport. Nawel and Hacene reported that the activated carbon can be produced from carbonized olive stones in presence of argon in the temperature range from 700 to 800 degree C and can be activated by $ZnCl_2$ and KOH. Wang et al developed two heat-regenerative adsorption systems, one for ice-making and another for air conditioning. They used activated carbon-methanol adsorption pair and the cycle time is short for the both systems. They also reported that the adsorption systems are capable of producing ice of capability of 6 kg ice per kg-adsorbent per day. Baiju & Muraleedharan determined the adsorption and desorption characteristics of two activated carbon–methanol and activated carbon–R134a, experimentally. Their work shows that the maximum adsorption capacity of activated carbon–R134a working pair is 1.21 times that of activated carbon–methanol.Astina and Bun Kisa,performed experiments on adsorption refrigeration system using activated carbon and propane as the working pair. Two adsorption beds are used to make the refrigeration system working continuously. Each adsorption bed is filled with activated carbon around 2 kg, and refrigerant 0.4 kg. From the experimental results, they reported that the adsorption refrigeration system provides coefficient of performance, cooling capacity and cycle time around 0.15, 50 kJ and 3h30 min, respectively.

Ramji et al simulation results shows that activated carbon-water pair produced the best cooling compared to activated carbon-methanol and activated carbon-ammonia working pairs. The methanol and ammonia showed a COP of 0.37 and 0.4, respectively. The cooling capacity for methanol and ammonia showed a value of 0.65 kW and 0.50 kW, respectively. Tamainot et al developed a model based on the adsorption equilibrium equations of the adsorbent-refrigerant pair and heat flows. The simulation results of 26 various activated carbon-ammonia pairs for three cycles (single bed, two-bed and infinite number of beds) are developed at typical conditions for ice making, air conditioning and heat pumping applications. The driving temperature varies from 80 to 200 degree C. The carbon absorbents investigated are mainly coconut shell and coal based types in multiple forms: monolithic, granular, compacted granular, fibre, compacted fibre, cloth, compacted cloth and powder. Considering a two-bed cycle, the best thermal performances based on power density are obtained with the monolithic carbon KOH-AC. With a driving temperature of 100°C, the cooling production is about 66 MJ m-3 (COP=0.45) and 151 MJ m-3 (COP=0.61) for ice making and air conditioning respectively; the heating production is about 236 MJ per m^3.

CONCLUSIONS

The adsorption air conditioning designed in this work still has some key problems. It requires a high welding technique to keep a high vacuum level in the chambers. The leakage from the exhaust gas flow side to the air flow side in the air/gas switch system is difficult to be avoided. The heat transfer from the heated adsorber to the condenser and even to the evaporator through the heat conduction of the metallic shell cannot be avoided. The adsorber, the condenser and the evaporator are in one vacuum chamber and are not separated in the vapour channel from each other, and so, condensing may occur in the evaporator. Therefore, more refrigeration power loss is generated. Further improvements are undergoing at present.

present a detailed review on the past efforts in the field of solar refrigeration systems. A number of attempts have been made by researchers to improve the performance of the solar powered adsorption subsystems. It is seen that, for successful operation of such systems, a careful selection of the adsorbent-adsorbate pair is essential apart from the collector choice, system design and arrangement of subsystems.

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