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Adsorption refrigeration system using waste heat

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***Abstract*: Adsorption refrigeration systems that work on waste heat have extensive refrigeration and air conditioning applications in water chillers, automobile air conditioning systems, and ice making. The adsorption heat exchangers can replace compressors as they can be used for compressing the refrigerant at constant volume. There is a huge amount of heat exhausted from engines, boilers, various power plant furnaces etc. Generally this exhaust heat is let into the atmosphere as waste heat. Hence, there is a huge need for waste heat energy recovery system.**

The main drawback of the adsorption refrigeration system is its low thermal conductivity. Hence, the main scope of this project is to improve the design of adsorber bed to increase its thermal conductivity. This is done by introducing spherical metal balls of small diameters equivalent adsorber thickness, into the adsorber bed. Activated carbon and R134a pair is considered for the project. In this project mathematical investigation is carried out and experimental setup has been manufactured to evaluate overall thermal conductivity of adsorption heat exchanger system.

***Index Terms*: Adsorber Bed, Adsorption, Desorption, Extended surfaces, Granular Activated Carbon, Specific Cooling Power.**

I. INTRODUCTION

Various adsorption heat exchanger systems are available in the market based on the type of adsorber, refrigerant material, heat exchanger material used.

Aim of project

The aim of the project is to increase the thermal conductivity by making changes in the adsorber bed design.

Need of project

The low thermal conductivity of adsorption heat exchangers have limited them from being used commercially. Hence, there is a need for improvement in design.

II. PROBLEM STATEMENT

Performance of adsorber bed is dependent on its design. There are many methods to improve the heat transfer performance like using different nanofluids for bed. The materials of the heat exchanger components can also be varied to increase conductivity. Increasing effective surface area of adsorber bed to increase the heat transfer rate between the exhaust gas (waste heat) and the adsorbent particles, reducing cycle time by increasing adsorbate diffusion rate within the adsorbent particles during the adsorption/desorption processes can improve the performance of adsorber bed.

New adsorber bed has to be design and should be compared with commonly used design. Here extended surface areas are provided on adsorber beds to improve the heat transfer. These extended surfaces are in the form of metal balls within the activated carbon adsorber bed. Investigation of the performance of adsorber bed with extended surface areas needs to be done and should be compared with the adsorber bed without extended surface areas.

III. LITERATURE REVIEW

In ASHRAE Journal (2011), Kai Wang et al. [1] explained Basic adsorption refrigeration cycle. Different working pairs for adsorption refrigeration system are studied for their adsorption properties based on temperature and heat of adsorption. Also classification of pairs based on applications like ice-making chilled water and air conditioning is studied.

Wang and Oliveira (2006) [2] studied adsorption refrigeration as a mean of waste heat recovery and solar energy. The applications included are ice making and air conditioning. It includes not only cooling and heating, but also dehumidification by desiccant systems. The prototypes presented were designed to use waste heat or solar energy as the main heat source. The solid sorption systems still present some drawbacks such as low specific cooling power (SCP) and coefficient of performance (COP). Thus, some techniques to overcome these problems are also contemplated, together with the perspectives for their broad commercialisation. Among these techniques, a special attention was devoted to innovative adsorbent materials, to advanced cycles and to heat pipes, which are suitable devices not only to improve the heat transfer but also can help to avoid corrosion in the adsorbers.

Zhang and Wang (1997) [3] performed numerical study on dynamic performance of an adsorption cooling system for automobile heat recovery. The effects of various operating temperature and overall heat transfer coefficient on system performance are studied. It is found that improving the overall heat transfer coefficient is most effective way to obtain increased SCP.

T. X. Li et al. (2014) [4] discussed the progress in the development of solid-gas sorption refrigeration thermodynamic cycles like heat recovery sorption cycle, mass recovery sorption cycle, mass and heat recovery sorption cycle, double/multi-effect sorption cycle, combined double-way sorption cycle, double-effect and double-way sorption cycle, two/ multi-stage sorption cycle, etc. The results from experimental works showed that the advanced sorption cycle can produce two useful cooling-effects at the expense of only one high-temperature heat input during one cycle.

IV. CONCEPT OF ADSORPTION AND DESORPTION

Adsorption is the general phenomenon based on a physical or chemical reaction process, resulting from the interaction between a solid (adsorbent) and a gas/liquid (refrigerant). Physical adsorption, is caused by the Van der Waals forces. It is an exothermic process due to the gas–liquid phase change. The energy liberated depends on the nature of the adsorbent–adsorbate pair and is called the isosteric heat of adso. The atoms, molecules or ions in a liquid are diffused to the surface of a solid in a liquid phase adsorption. They are bonded with the solid surface or are held by weak intermolecular forces. In heating the adsorber bed, more is the temperature of the bed, better is desorption. As the temperature increases, after gaining sufficient energy, the bond between adsorbent and adsorbate gets broken. Similarly, to get maximum amount of adsorbate quantity adsorbed, temperature should be as low as possible. This gives rise to need for effective heating and cooling of adsorber bed.

A basic adsorption cycle consists of four steps : heating and pressurization, desorption and condensation, cooling and depressurization, and adsorption and evaporation. In the first step, the adsorber bed is heated by any low grade thermal energy source. The pressure of the adsorber bed increases from the evaporating pressure up to the condensing pressure while the adsorber bed temperature increases. This step is equivalent to the ―compression in the vapour-compression cycle. In the second step, the adsorber bed continues receiving heat and its temperature keeps increasing, which results in desorption (or generation) of refrigerant vapour from adsorbent in the adsorber bed. This desorbed vapour is liquefied in the condenser and the condensing heat is released to the heat sink. This step is equivalent to―condensation in the vapour-compression cycle.

At the beginning of the third step, the adsorber bed is disconnected from the condenser. Then, it is cooled by heat transfer fluid at the second heat sink. The pressure of the adsorber bed decreases from the condensing pressure down to the evaporating pressure due to the decrease in the adsorber bed temperature. Refrigerant vapours et expanded in thermostatic expansion valve and enters in evaporator. This step is equivalent to the ―expansion in the vapour-compression cycle. In the last step, the adsorber bed keeps releasing heat while being connected to the evaporator. The adsorber bed temperature continues decreasing, which results in the adsorption of refrigerant vapour from the evaporator by adsorbent, producing the desired refrigeration effect. This step is equivalent to the ―evaporation in the vapour-compression cycle. The basic adsorption refrigeration cycle is an intermittent system and the cooling output is not continuous. A minimum of two adsorbers beds are required to obtain a continuous cooling effect (when the first adsorber bed is in the adsorption phase, the second adsorber bed is in desorption phase). These adsorber beds will sequentially execute the adsorption-desorption process.

V. COMPONENTS OF ADSORPTION REFRIGERATION IN AUTOMOBILE AIR CONDITIONING

Adsorber bed

The adsorber bed replaces the compressor in a conventional vapour compression refrigeration system with heat exchanger. Hence, the adsorber bed is the part which separates the adsorption refrigeration system with the commonly used vapour compression refrigeration cycle system.

Adsorbent

Granular activated carbon- charcoal is used as a refrigerant. It has granule size of 1.5mm. Since it has very small granule size, filters (strainers) are fixed at inlet and outlet of adsorber beds so that only gas will flow. Granules will not flow inside other parts of the system.

Adsorbate

R134a (1-1-1-2 tetrafluroethane) is used as adsorbate. It is non-flammable, non-toxic in nature. It has zero ODP. R134a is widely used in different refrigeration and air-conditioning applications.

Heat Gun (Hot Air Gun)

In actual applications adsorption refrigeration system is run on low grade thermal energy source like exhaust gases. It is difficult to control temperature and flow of exhaust gases coming out from internal combustion engines. So for testing purpose, hot air coming from heat gun is used instead of exhaust gases.

Condenser

Function of Condenser in adsorption refrigeration is same as that of the one used in vapour compression refrigeration system. It converts gaseous high pressure refrigerant to high pressure. In current experimental setup air cooled condenser is used. Heat is rejected due to forced convection to the air flowing over condenser.

Thermostatic Expansion Valve (TXV)

Throttling also called as isenthalpic expansion process is done at TXV. TXVs are precision devices designed to regulate refrigerant liquid flow into the evaporator in exact proportion to evaporation of refrigerant liquid in the evaporator. It is constant superheat type TXV. Refrigerant gas leaving the evaporator can be regulated since the TXV responds to the temperature of the refrigerant gas leaving the evaporator and the pressure in the evaporator.

Evaporator

Cooling effect is obtained at this part of the experimental set up.

Vacuum pump

R134a refrigerant is used as an adsorbate in the system. Before charging the R134a inside the system vacuum must be created. Vacuum pump is used to create such vacuum. Yellow pipe connected to middle port of manifold gauge is connected to suction port of vacuum pump.

Water Pump

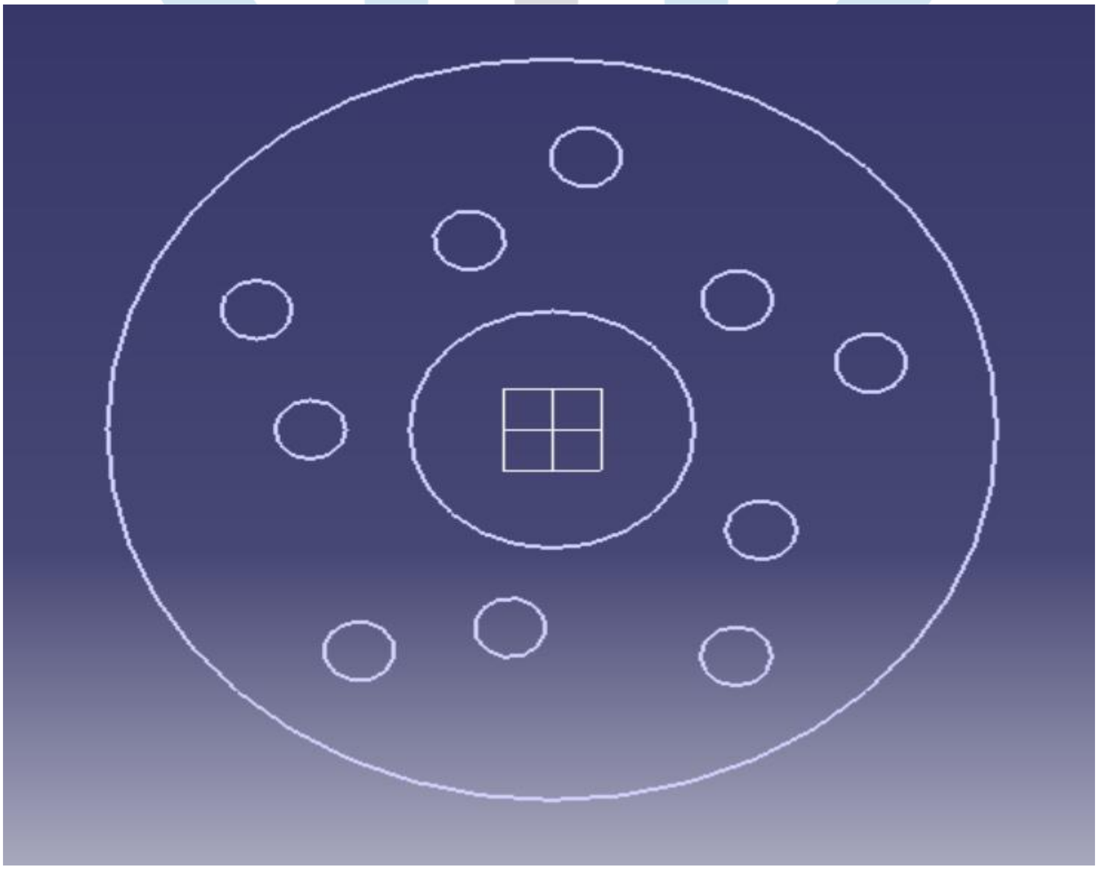
Water flow is essential for cooling of bed and better adsorption. Water pump is used to circulate water in the system. Flow divider is used to divide and distribute the water flow in all the water pipes properly.

Spherical metal balls

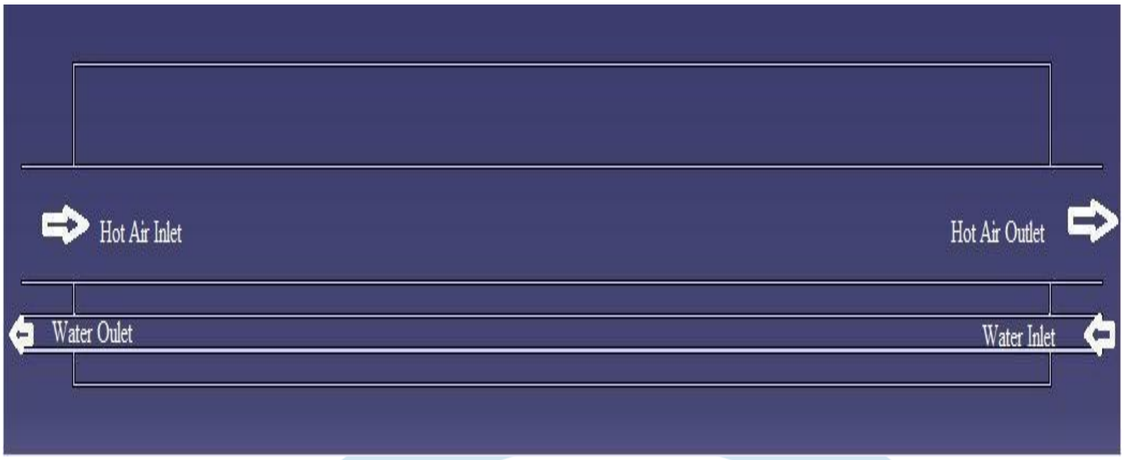
They are used to increase the thermal conductivity of the heat exchanger. This is done by introducing them into the adsorber bed. The diameter of the metal balls is less than the thickness of the adsorber granular material thickness. The material of balls should be of higher conductivity and should be resistant to corrosion.

VI. Adsorber Bed Design

Total two designs of adsorber beds are used in testing. One design is bed without Spherical metal balls (bed 1) and other is the bed with Spherical metal balls (bed 2). Hot air pipe is concentric with cylindrical bed body. Ten pipes are provided for cooling of bed by water as shown in fig. Rest of the volume is filled with activated carbon in bed 1. Detailed specification of bed is given in Table below. In this design, only outer surface of hot air pipe is available for heating of bed. Only activated carbon is filled in the space in between the pipes in bed design without metal balls, bed 1. In the bed design with metal balls i.e. bed 2 the activated carbon along with metal balls having good conductivity like mild steel are used.



Front view cut section of adsorber bed



Side view cut section of adsorber bed

Adsorber bed dimensions

Dimensions	Adsorber Bed Parameter
32 mm	Hot Fluid Pipe Dia:
125 mm	Outer Stainless Steel Casing Dia:
12 mm	Water Tube Dia:
940 mm	Adsorber Bed Length:
15.5mm	Coolant Tube Dia:
8 mm	Refrigerant Tube Dia:
1.5 mm	Mild steel metal ball diameter
2 mm	Activated carbon granules thickness

VII. Conclusion

Maximum bed pressure is increased to some extent for adsorber bed with Spherical metal balls i.e. Bed 2. This is due to enhanced heat transfer rate by metal balls. Higher heat transfer rate increases bed temperature and correspondingly bed pressure is also increased.

Adsorber bed temperature for adsorber bed 2 is more than bed 1, hence desorption capacity of bed 2 is better than bed 1 for same cycle time, source temperature and airflow rate.

For the same size of adsorber beds if metal balls are introduced in the adsorber bed then quantity of refrigerant adsorbed decreases due to less volume of adsorbent.

Due to increased thermal conductivity the cycle time is reduced in bed 2 as compared to bed 1. This coupled with increase in the number of adsorbers in the system will make the system more efficient and continuous.

SCP (specific cooling power) of system increases when higher desorption is obtained. As hot air flow rate and temperature increases, heat supplied increases in bed 2. Hence, better desorption and higher SCP values are obtained.

VIII. Future Scope

- Cycle time can be reduced by implementing multiple adsober bed in system. This will make system continuous and more efficient. Performance of adsorber bed can be enhanced by improving the design.
- Simulation study of adsorber bed can be done. No standard model is available to simulate adsorption and desorption process. For simulation study user defined functions need to be created.

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