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Experimental Evaluation of Vapour Adsorption Cooling System Powered by Exhaust Heat of Automobile System

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ABSTRACT

The present work is focused towards the design and development of prototype of vapour Adsorption system which is based on the basic principle of operation of Vapour Adsorption refrigeration cycle and development of Experimental set-up of adsorption refrigeration system for comparative study. This system is design for application of cabine cooling of automobile. It gives information about how much important is heat and using this we can develop a refrigerant system which do not require the electricity as a primary input. For automobile air conditioning normally vapour compression refrigeration cycle is used. The cycle run on engine power and consumes around 10% of the total power produced by the engine and thereby increases the fuel consumption. In case of truck large amount of heat of input around 30% of the total heat supplied is going away with exhaust gases at very high temperature and around 25%to 30% is going away with cooling water. This can be effectively used to develop a heat generated cooling system. The engine power required to run an air conditioning system can be saved by using waste heat powered cooling system. After literature review in the field of alternative cooling systems powered by heat, adsorption air cooling systems with activated carbon+Cacl2(80:20) and NH3 as adsorbent refrigerant pair is selected and used in the present system. In the present system solid material is used as adsorber which makes the system suitable for mobile applications. The design COP of the system is around 0.5 for a cooling capacity of 1 kW. The system is quite compact and can be installed in a Automobile Vehicle.

Keywords— Adsorption, desorption, adsorber bed

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I. INTRODUCTION

Adsorption is, in general, the adhesion of ions or molecules of gases, liquids or dissolved solids to a solid surface. Adsorption phenomenon is an exothermic process in which molecules of a liquid or gas, called adsorbate, accumulate on a solid surface, called adsorbent. Adsorbents are porous materials with ability to take up several times of their volume of gases or liquids. The terms “adsorption” and “absorption” are usually assumed to be the same, but they are, in essence, completely different physical phenomena. In the adsorption process, molecules of gas or liquid adhere on the surface of the solid, whereas in the absorption process, molecules of gas or liquid penetrate into the solid or liquid phase. The main differences between absorption and adsorption are the materials, substance state and circuit layout. In absorption, a base solution dilutes the refrigerant vapor and becomes a weaken solution. The base solution is regenerated by evaporating the refrigerant from the base solution. In adsorption, the refrigerant is adsorbed and refrigerant stays on the surface of the solid-grain adsorber upon cooling. During desorption, the refrigerant evaporates from the solid adsorber material upon heating. For absorption, the adsorber and generator are two different compartments, between which a heat exchanger is always installed. For adsorption, both adsorption and desorption share the same adsorber beds. The adsorber beds are heated and cooled in alternative sequence. The similarity between absorption and adsorption is the two-compartment condenser and evaporator. The condenser will condense the refrigerant vapor evaporated during the desorption/regeneration process. The evaporator will evaporate the refrigerant (thus provide cooling effect), and prepare the refrigerant vapor for the adsorption process. In an adsorption system, there are two adsorber beds, with a switching system (between cooling and heating cycle), a condenser, and an evaporator. The cooling or heating circuit for adsorber beds is normally an individual piping of hot gas, hot water and cold water. These pipes lie within the adsorber bed/grains, so only the adsorber grain is in contact with the refrigerant. Unlike absorption, it contains two compartments for absorption and regeneration, and adsorption shares the same adsorber beds, for both the adsorption and regeneration processes. So it takes time for the adsorber bed to cool down for adsorption, and to heat up for regeneration. 1.1. Adsorption system driven by automobile exhaust In an adsorption system driven by exhaust heat, the exhaust gas passes through the adsorber during desorption. Then, the evaporated refrigerant from the desorber condenses at the condenser. During the adsorption time, the ambient cool air passes through the adsorber, and the refrigerant evaporates from the evaporator to the adsorber.

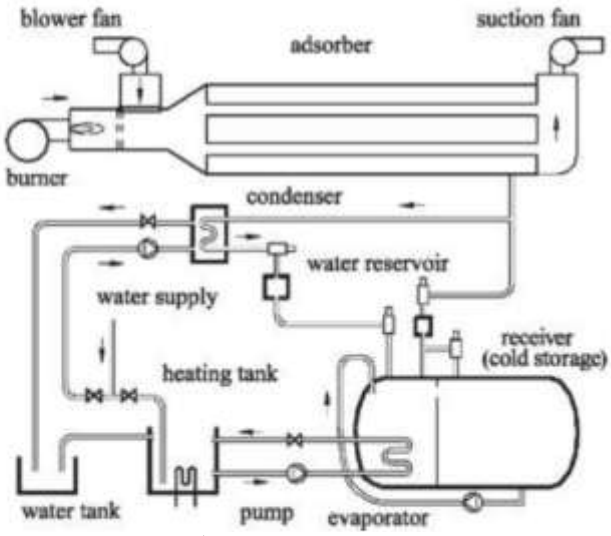

Fig.1. Adsorption refrigeration driven by automobile exhaust

Fig.1. Adsorption refrigeration driven by automobile exhaust The objective of this work is to design and develop a prototype of Vapour adsorption refrigeration system using charcoal + CaCl2 and NH3 as the working pair. The system is designed and tested for various operating conditions using heat source. In this work, performance of the fabricated

system is outlined with respect to various operating conditions related to heat source, condenser, absorber and evaporator temperatures. The scope of the proposed work is to develop a prototype of 1 kW capacity powered by heat source. It is beneficial to environment. The reduction of fossil fuel consumption and the associated decrease in green house gas emission are helpful to reduce global warming. For this purpose design and develop an Adsorption refrigeration system by using a heat source and experimental analysis using experimental setup has to be carried out and matched.

II. LITERATURE REVIEW

Wang et al. [1] adapted activated carbon-methanol pair for their exhaust-gas-driven adsorption system. The adsorber and condenser are cooled down by seawater. The desorber is driven by exhaust gas (through a boiler for hot water storage), and a chilling effect is produced at the evaporator. Adsorber bed 1 and adsorber bed 2 take turns to become the adsorber and desorber, in order to provide continuous cooling for the evaporator and ice maker. The switching of adsorption and desorption for a bed takes place by switching the heat source or cooling source. Before each switching, 1 min of heat recovery, and 2 min of mass recovery process, are required between the two adsorber beds. In the mean time, the refrigerant in the evaporator will be topped up by the condenser. Grisel et al. [2] adopted silica gel–water in their waste-heat- driven adsorption chilling system. In the water vapour supply line to the adsorber, a demister is placed to prevent water from entering the adsorber. The cooling and heating loop / circuit cool and heat the adsorber bed, while the water / refrigerant is adsorbed and desorbed from the adsorber bed. Wang et al. [3] also conducted an experiment with silica gel–water adsorption. They studied the effect of a variable / fluctuating heat source supply (exhaust gas or solar heat) for the adsorption system. Lu et al. [4] utilized 140 kg of zeolite and 185 kg of water in their locomotive. The adsorber bed desorbs when exhaust gas flows through the adsorber bed. The water vapour leaves the bed and condenses at an air-cooled condenser. During the adsorption cycle, the exhaust gas exits the chimney, but fresh air is drawn in through the nosier inlet. When the vapour pressure is low enough at the adsorber, the evaporator starts to veporate water vapour for the adsorber. The cooling effect is transferred to the passenger cabin by chilling water. The water not only plays a role as a refrigerant, but also as a sensible cold storage. Verde et al. [5] adopted Zeolite–water adsorption in their vehicles Heating, Ventilation and Air-Conditioning (HVAC) system for cabin cooling. The researchers generate/ desorb the adsorber with 80–90^{o}C engine coolant. The engine coolant is further heated above 90^{o}C, by recovered heat from exhaust heat. For the adsorption purpose, are act or cooling loop is prepared.

Jiangzhou et al. [6] conducted an experimental study for Zeolite–water adsorption, with adsorption temperature of 200–250^{o}C. 140 kg of Zeoliteand 185 kg of water are able to produce 4.2kW of cooling power. They utilized exhaust gas and hot coolant to desorb the adsorber (heating loop).The cooling loop will cool down the adsorber during adsorption. Vasta et al. [7] Dedicated their research to a mobile adsorption chiller. 4.6 kg adsorbent grains and 60kg of prototypes 'weight could provide 1–2.3 kW of cooling power. Wang et al. [8] described their adsorption system for a locomotive. 350–450^{o}C of heat source could provide10 kW of cooling, at 6.5^{o}C. The adsorbers can be heated up, or cooled down, in 22 min. There is an air switch to control either cooling air to adsorb, or hot gas to desorb the adsorber bed. The bed is connected to the evaporator during adsorption, and is connected to the condenser during desorption. Using a mathematic model, Hu et al. [9] introduced a new composite for the adsorbent bed, which is zeolite/foam aluminium. The water acts as a refrigerant, while the engine exhaust heat drives the adsorption system. The cooling and heating fluid flows alternatively through the tube lying inside the adsorbent bed, during adsorption and desorption. Zhong et al. [10] suggested the Zeolite–water adsorption cooling system for a truck. The system could reduce environmental emissions, and utilize the waste heat to drive the cabin-cooling system. The adsorption system is driven by a back- up heater when the engine is off.

III. DESIGN OF SYSTEM

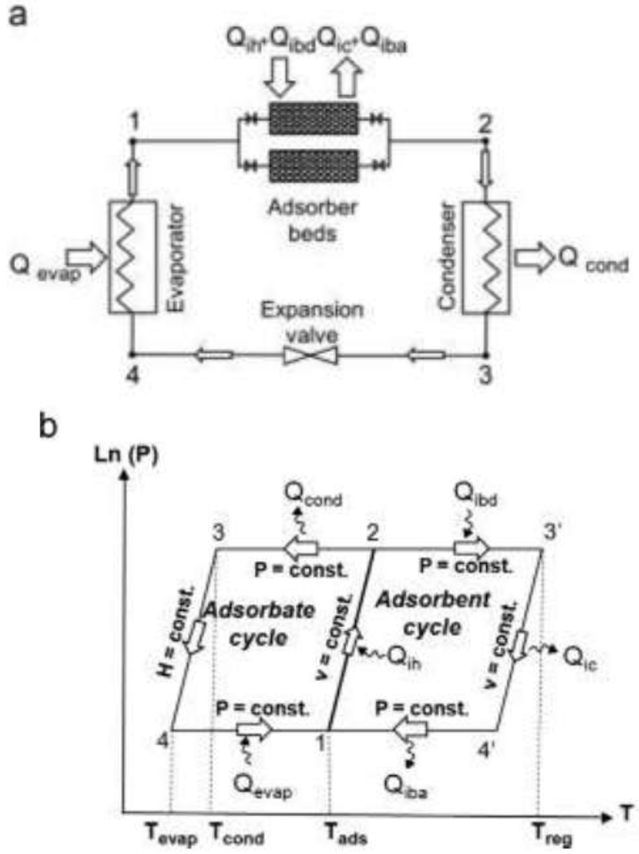

Fig 3.1. (a) Schematic and (b) Thermodynamic cycle of a 2-adsorber bed Adsorption Cooling System

Figure 3.1 shows schematic layout of a adsorption refrigeration system running on exhaust gas energy. The adsorption cooling system consists of an adsorbent bed, a condenser, an evaporator, as well as connecting pipes. For this system vacuum gauges are used to measure vacuum pressure, the structure of the system is very simple.

Coefficient of performance (COP)

To evaluate the efficiency of refrigeration cycles, a dimensionless parameter called COP is used. In ACS, the COP is defined as the ratio of evaporative cooling energy to the amount of supplied heat.

$$COP = \frac{Qevap}{Qwaste\ heat}$$

Where Qevap and Qwaste heat are the evaporative cooling energy (J) and the amount of waste heat energy supplied during the desorption process (J), respectively.

IV. RESULTS AND DISCUSSION

In figure 4.1 to figure 4.5 below, analysis of the adsorption system is presented.

Experimentation was carried out at different flow rate of water as 25LPH, 50LPH, 75LPH, 100LPH.

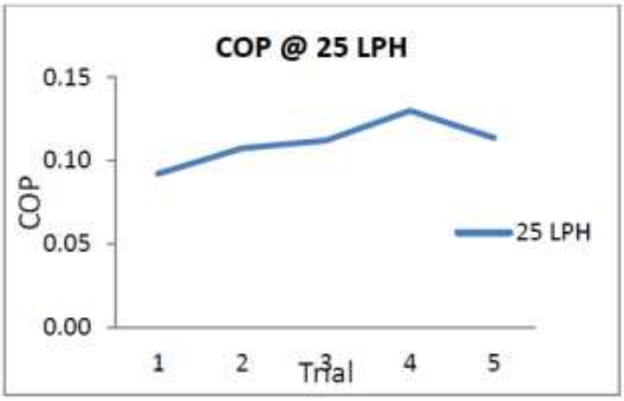

Fig. 4.1 Variation in COP at 25 LPH

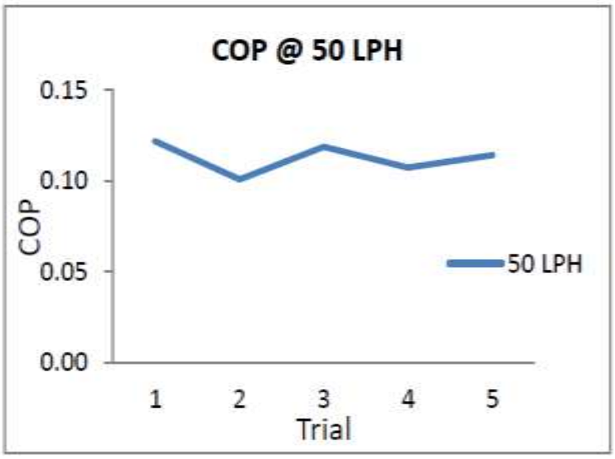

Fig. 4.2 Variation in COP at 50 LPH

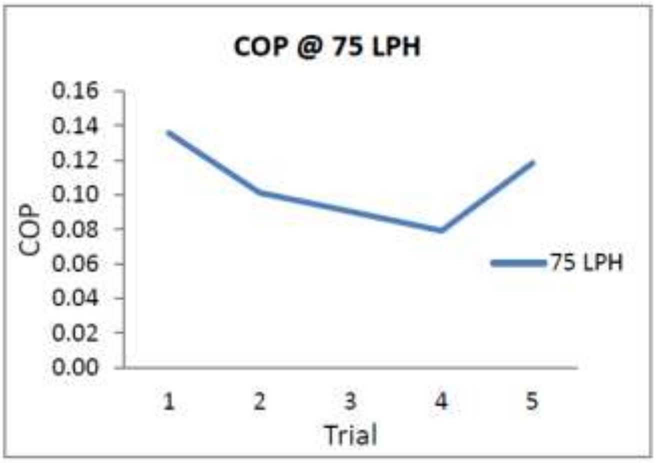

Fig. 4.3 Variation in COP at 75 LPH

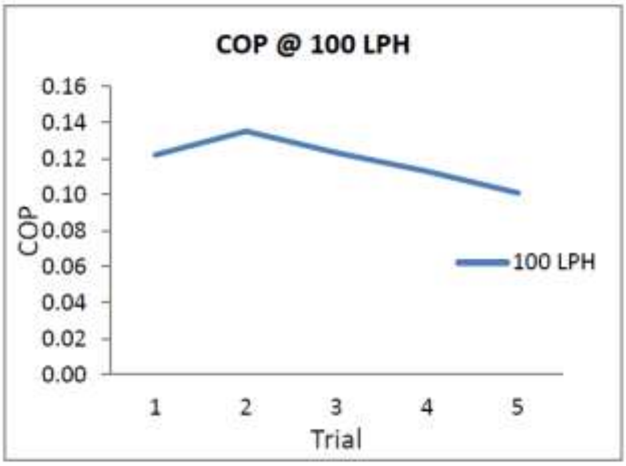

Fig. 4.4 Variation in COP at 100 LPH

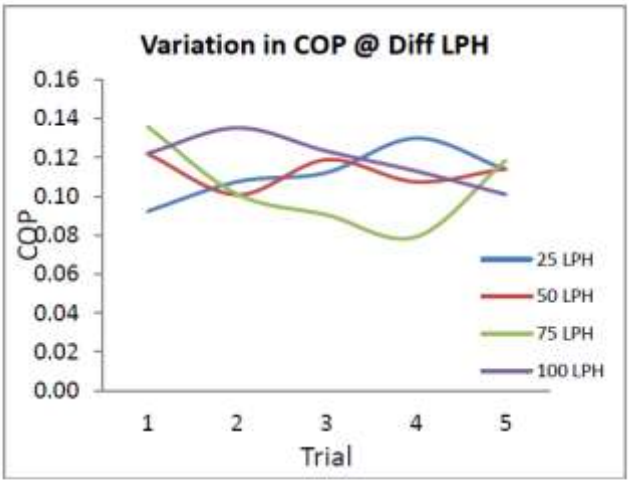

Fig. 4.5 Variation in COP at different LPH

V. CONCLUSION

- The evaporator temperature decreases gradually as mass flow rate increases. The load of 25, 50, 75, 100 litres of water for 1 hour is tested, Adsorption system shows the temperature drop of 7.7^{o}C, 3.9^{o}C, 2.42^{o}C, 2.01^{o}C respectively.
- COP of adsorption system at 25, 50, 75, 100 litres of water are 0.11, 0.11, 0.10, 0.12 respectively.

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