

Review of Experimental Evaluation of Adsorption Cooling System Powered By Exhaust Heat of an Automobile

Prof.S.A.Wani¹, Prof.Amod.P.Shrotri², Mrs.S.P.Mane³, Prof.S.M.Gheji⁴

Assistant Professor, Padmabhooshan Vasantrodada Patil Institute of Technology, Budhgaon, Sangli, India^{1,3,4}

Associate Professor, Padmabhooshan Vasantrodada Patil Institute of Technology, Budhgaon, Sangli, India²

ABSTRACT: Adsorption refrigeration cycles rely on the adsorption of a refrigerant gas into an adsorbent at low pressure and subsequent desorption by heating the adsorbent. The adsorbent acts as a chemical compressor driven by heat. When the adsorber is cooled, the adsorbate gets adsorbed onto the adsorbent. While the adsorber is heated in the next cycle, this adsorbate gets desorbed at high temperature. With the use of a pressure vessel and a check valve its pressure value can be increased. The rest of the refrigeration system remains the same as that of a vapour compression system. Exhaust heat recycling is gaining prominence these days because of the increased stress on fuel consumption and also because it helps to reduce pollution levels to an extent there by making it environmental friendly. The major disadvantage of general adsorption refrigeration system is that the COP of the system is comparatively lower than the conventional vapour compression system. In future, there can be scope for improvement of the same so as to be used in vehicles.

KEYWORDS: Adsorption Refrigeration, Cooling Systems, Exhaust heat, Automobile

I. INTRODUCTION

The increasing concerns related to the environment and ecology of recent years has brought about escalating interests in using heat sorption systems for cooling applications. This is due to its capability of directly utilizing thermal energy sources, including low grade waste heat from various sources, including solar hot water, industrial waste heat as well as geothermal sources. The adsorption (AD) is advantageous when lower temperature heat sources, as low as 55^oC are available. Much work has been carried out to find novel solutions to integrate the AD Chiller technology into the existing refrigeration market. The current state of the art of cooling applications is mostly water based with silica gel or zeolite as the adsorbent, most of which has successfully been implemented in Japan and parts of Europe. The main drawback of water based silica gel and zeolite systems lies in its requirement of advanced technologies and intricate design considerations so that high vacuum could be maintained, as leakages will drastically reduce its performance. Furthermore, due to the triple point of water, cooling systems which utilizes water as a refrigerant are inoperable as the evaporator approaches 0^oC. This makes it restrictive in terms of application. In this work, refrigerants with lower normal boiling points (NBP) which relates to its operational ranges (below 0^oC) are considered. Propane, for example which has a low NBP of 42.14^oC may be utilized in extremely low temperature cooling. Another motivation of studying these refrigerants is that higher differential uptakes of the reactor beds at the condenser and the evaporator pressures may possibly result in greater cooling capacities and hence higher performances since they operate beyond Henry's region.

In a thermally driven solid sorption system, there are three essential components that must be present. They are (i) the sorption beds where adsorption or desorption occurs, (ii) the evaporator and (iii) the condenser. As shown in Figure, the basic processes that the bed undergoes are as follows -

1. First, the bed is isolated from both the evaporator and the condenser and is cooled by an external coolant. This is known as the pre-cooling switching stage.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015

2. Then, adsorption occurs when the valve connecting the bed to the evaporator is opened. The adsorbent adsorbs the refrigerant vapor from the evaporator resulting in the release of heat which continues to be cooled by the external coolant.
3. The valve to the evaporator is closed and isolated from both the condenser and the evaporator. The external coolant supply is stopped while external heat source is applied to the sorption bed. As a result, there is pressure build up in the bed. This is known as the pre-heating switching stage.
4. Finally, the valve to the condenser is opened and the external heat source continues to be applied to the sorption bed resulting in refrigerant from the bed to be released to the condenser.

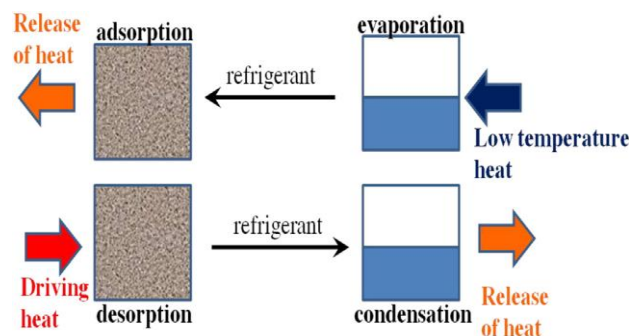


Figure No. 1

Cold production (cooling, freezing, and air-conditioning) is an expensive industry which requires considerable amount of electrical energy. The rapid growth of economy, human prosperity, and propagation of the conventional air conditioning machines cause a shortage of grid electricity especially during summer season. approximately 10–20% of all the electricity produced in the whole world is consumed by various kinds of the refrigeration and air-conditioning machines. However, the development of refrigeration technology presents the thermally driven cold production systems. These systems are considered good alternative for the electricity powered vapour compression machines in terms of electricity consumption as well as environmental issues. Recently, the booming progress in the field of green cooling technology offers cooling systems which can be powered by exhaust heat and renewable, green energy sources like solar energy.

The use of waste heat for refrigeration and air conditioning purposes have been accepted by people and various systems have been developed and proven attractive but its implementation in real applications is still limited. Electric driven air conditioning systems have reached a COP of over 4, while absorption systems are usually in the range of 1.1–1.25. The adsorption system is advantageous in small scale systems if compared with absorption systems. For exhaust heat utilization, a solid adsorption system is possibly the best system for refrigeration purposes. A large part of the energy from the fuel that is burnt gets wasted through the exhaust gases. If a system that uses all the energy from the exhaust of an engine to run its air conditioning system can be designed, it could be very well accepted.

Adsorption refrigeration cycles rely on the adsorption of a refrigerant gas into an adsorbent at low pressure and subsequent desorption by heating the adsorbent. The adsorbent acts as a “chemical compressor” driven by heat. When the adsorber is cooled, the adsorbate gets adsorbed onto the adsorbent. While the adsorber is heated in the next cycle, this adsorbate gets desorbed at high temperature. With the use of a pressure vessel and a check valve its pressure value can be increased. The rest of the refrigeration system remains the same as that of a vapour compression system. Exhaust heat recycling is gaining prominence these days because of the increased stress on fuel consumption and also because it helps to reduce pollution levels to an extent there by making it environmental friendly. The major disadvantage of general adsorption refrigeration system is that the COP of the system is comparatively lower than the conventional vapour compression system. In future, there can be scope for improvement of the same so as to be used in vehicles.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015

While going through the material we find that, adsorption cooling system has its own merits and demerits in application depending on the application area, the driving heat source temperature, and the climatic conditions at the location of the application.

II. LITERATURE REVIEW

Solid vapour adsorption is similar to liquid vapour absorption system, except that the refrigerant is adsorbed at the surface of another solid known as adsorbent. A report, presented by Metrons transportation centre suggests the suitability of Adsorption systems for vehicles (**Christy, 2001**). In that report the performance of VCR system and VAR system has been compared. Series of carried experimental results suggest about the feasibility of adsorption systems. NH₃ - activated carbon has been suggested as refrigerant - adsorbent pair. “**Wang et al. (2009)** after comparing the performances of various suitable systems has claimed that adsorption system is more suitable for automobile cooling”.

Saha et al (2003) in the presented work have demonstrated dual mode silica gel water adsorption chillers design along with various temperature ranges and obtained optimum results for temperature range of 50 °C and 55 °C. Comparison of COP has been presented for three stage mode and single stage multiple modes. Simulation has been presented and the COP is in the range of 0.2 and 0.45 respectively.” **Wang and Oliveira (2005)** have presented the achievements in solid sorption refrigeration prototypes, obtained since the interest in sorption system was renewed at the end of 1970s. The applications included ice making and air conditioning. **Wang (2005)** in his work claimed to obtain COP of 0.15 for solar application. In the review work the details of performance of adsorption system for different applications with COP has been presented in a tabular form. The COP is in the range of 0.3 to 0.6.” **Kong et al. (2005)** have presented an experimental investigation of the performance of a micro combined, cooling heating and power system driven by a gas engine. In the described system a COP of 0.3 for refrigeration at 13°C has been obtained successfully. The suggested system can supply electricity of 12 kW and heat load of 28 kW and cooling load of 9 kW simultaneously.

Maggio et al. (2006) presents the results of a predictive two dimensional mathematical model of an adsorption cooling machine consisting of a double consolidated adsorbent bed with internal heat recovery. Internal heat recovery enhances the COP”. It is suggested that the adsorbent thickness should be limited to 2 to 3 mm for optimum results. **Lambert and Jones (2006)** has presented a detailed study of vapour adsorption refrigeration system specifically for automobile air conditioning. Adsorption cooling has been compared with other heat generated cooling technologies and it is claimed that adsorption system is the best alternative in terms of size and mass. In the second part of his work he has demonstrated air conditioner for a car successfully. The detailed design of the critical components has also been presented. It has been claimed that the overall weight of the system is ~3.5 percent to the total vehicle mass, which is at par with the mass of current systems. Similar work has been done to demonstrate a cooling system for a car developing 2 kW cooling power with COP 0.22, bed thickness (δ_{ad}) of 4 mm and an eight way valve has been suggested in this work (Tamainot et al., 2008).

Wang et al (2006) has presented a design of an adsorption air conditioner for locomotive driver cabin, powered by 350°C – 450°C exhaust gases. The cooling power and COP is 5 KW and 0.25 respectively”. The cycle time of 1060 s with exhaust temperature of 450°C cooling air temp of 40°C and chilled water temp. of 10 °C is achieved. The specific cooling power of 164 W/kg to 200 W/kg has been obtained.

Hugess and Beyene (2008) has presented an approach for the heat recovery from the automotive engine to improve COP. Some innovative methods like use of fuzzy controller, heat pipe, additives in adsorber bed, suction pump with adsorber have been demonstrated in some papers to enhance the performance of adsorption systems (Farzaneh, and Tootoonchi, 2008),(Fadar et al., 2009),(Tassou et al., 2009),(Hiro et al., 2008).

Harish Tiwari (2012) presented design development and experimentation of an adsorption refrigeration system powered by exhaust heat with only two control valves. The cooling capacity for a truck cabin is estimated as 1

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015

TR a scale of 3.5:1 is decided and a prototype of 1 kW has been designed and developed and tested in laboratory. A cooling effect of 1 to 1.2 kW has been obtained. The COP of the system is in the range of 0.4 to 0.45. The dimensions of the system are compact. It can be easily accommodated on a Transport Truck. The total weight of the system for a cooling capacity of 1 kW is 30 kg. The heating time required to achieve the cooling effect is around 10 minutes.

Attempts have been made by researchers to improve the performance of the exhaust heat powered adsorption subsystems. It is seen that, for successful operation of such subsystems, a careful selection of the adsorbent-adsorbate pair is essential apart from system design and arrangement of subsystems.

III. SUMMARY OF REVIEW

From the above literature review, it has been seen that very few researchers have worked on Adsorption cooling systems by using the waste heat of an automobile. The work has been carried out for –

- 1) Vapour compression refrigeration system by using various refrigerant – adsorbent pairs.
- 2) Comparison of performance in solid sorption systems with the regular systems.
- 3) Micro combined, cooling and heating systems for a gas engine.

So, as per the available literature, it is a necessity to design, develop and evaluate automobile exhaust heat assisted adsorption refrigerator with composite adsorbent. The aim of the present work is also to explore the benefit of such a system..

IV. OBJECTIVES

The objectives of the study are -

- ❖ To design, develop and evaluate a automobile exhaust heat powered Adsorption Refrigeration system with composite adsorbent
- ❖ To assess the cooling capacity of the system.

The main problem stated above is solved by breaking it down into the following sub problems.

- ❖ To investigate the feasibility of pairing composite adsorbent and refrigerant with reference to adsorption capabilities in order to find scope for development of a exhaust heat assisted adsorption refrigeration system.
- ❖ To investigate the design parameters of proposed cooling system, these being the adsorber, condenser and evaporator.

V. PROPOSED WORK

With a single adsorber, cooling is intermittent, which is undesirable because it wastes much of the continuous supply of exhaust heat. Therefore, at least two adsorbers are needed for an automobile. Multiple adsorbers beyond two can improve COPC by permitting incrementally more effective 'thermal wave' regeneration but add volume and mass, decreasing SCP. Thus, a compromise must be struck between SCP and COPC to satisfy constraints on both.

The exhaust of an I.C. engine test rig is used to supply the necessary heat to the adsorber. The schematic diagram of the system is shown in Figure 1. The set up consists of two adsorber, two condensers and one evaporator. The condensers are connected to the evaporator through control valves. Two adsorber beds are proposed one in heating mode and another in cooling mode. One of the adsorber is charged with refrigerant ammonia. Two condensers, one evaporator .two control valves and one evaporator are connected as shown in Figure .The condensers and evaporator is fitted with a fan for forced air circulation.

From the point of view of above stated objectives the proposed Adsorption Refrigeration system with composite adsorbent is to be designed, fabricated tested The components is to be selected/designed includes,

- ❖ Choice of working pair (Composite adsorbent and refrigerant) and Calculation of adsorption capacity
- ❖ Design of cooling cabinet

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 6, June 2015

- ❖ Design of Evaporator
- ❖ Design of Condenser

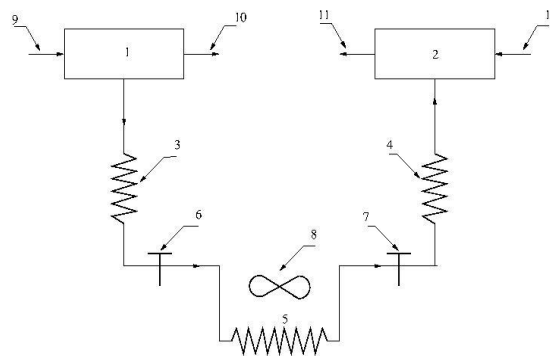


Figure No. 2

Where, 1 and 2 are adsorbers, 3 and 4 condensers, 5 evaporator, 8 fan, 9 and 10 heat input and output, 11 and 12 cooling inlet and outlet, 6 and 7 control valves

REFERENCES

- [1] Alam, S., 2006, A Proposed model for Utilizing Exhaust Heat to run Automobile Air-conditioner, The 2nd Joint International Conference on Sustainable Energy and Environment 21-23 November 2006, Bangkok, Thailand.
- [2] Aprachi, V., Kao S. H., Selamet A., "Introduction to Heat Transfer", 1999, Prentice Hall, Inc. Upper Saddle River, NJ, U.S.A
- [3] Christy.C. and Toossi,R., 2001 Absorption air conditioning for containership and vehicles, Final report metrons transportation center California state university.
- [4] Furzanchy, A., Ali, A. and Tootoonchi, 2008, Controlling automobile thermal comfort using optimized fuzzy controller, 2008, Applied Thermal Engineering, 29, 1267 – 1270.
- [5] Hirota, Y., Sugiyama, M., Kubota, F., Wutunable, N., Kobayashi, M., Hasatami, M. and Kanamori, 2008, Development of a suction pump assisted thermal and electrical hybrid absorption heat pump. Applied Thermal Engineering, 28, 1687 – 1693.
- [6] Johnson, V. H., 2002, Heat-Generated Cooling Opportunities in Vehicles, SAE technical paper, 2002-01 - 1669.
- [7] Jakob, U., Eicker, U., Schneider, D., and Teuber, A., 2007, Experimental Investigation of Bubble Pump and System Performance for a Solar Driven 2.5 KW Diffusion Absorption Cooling Machine.
- [8] Heat Set 2007, Heat transfer in components and systems for energy technologies Chambéry, France.
- [9] Kim, B., and Park, J., 2007, Dynamic Simulation of a Single-effect ammonia-water absorption chiller, International Journal of Refrigeration Vol. - 30, 535-545.
- [10] Kong, X., Wang, R., Wu, J., Hung, X., Huang, Y., Wu, D. and Yu, Y., 2005, Experimental investigation of a macro combined cooling, heating and power system by a gas engine. International journal of refrigeration, 28, 77 – 87
- [11] Lambert, M. and Jones B., 2005 a, Automotive absorption air conditioner powered by exhaust heat part 1, Automobile Engineering proc. I Mech. Vol 220.
- [12] Lambert, M. and Jones, B., 2005 b, Automotive absorption air conditioner powered by exhaust heat. Part 2, detailed design and analysis. Automobile Engineering proc. I. Mech. Vol 220.
- [13] Maggio, G., Freni, A., and Restuccia G., 2006, A dynamic model of heat and mass transfer in a double bed absorption machine with internal heat recovery, International Journal of Refrigeration 29, 589 – 600.
- [14] Saha B., Komaya, S., Kashiwagi, T., Kisawa, A.A., Ng, K., and Chau, H., 2003, Waste heat driven dual mode, multistage, multiplied regeneration absorption system, International journal of refrigeration 749-757.
- [15] Tassou, S., Lille, G. and Y. Ge, Y., 2009, Food transport refrigeration approach to reduce energy consumption and environment impacts of road transport, Applied Thermal Engineering, 29, 1467 – 1477.
- [16] Tumainot, Z., Metacolf, S. and R. Critoph, 2009, Novel compact sorption generators for car air conditioning, International journal of Refrigeration 32. 727 – 733.
- [17] Wang R. and Oliveira, R., 2005, Absorption refrigeration an efficient way to make good use of waste heat and solar energy, International sorption Heat Pump Conference, Denver, June 22, 2005.