

# Air conditioning: emerging trends in engineering and technology essay sample

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## Adsorption Air-Conditioning (AdAC) for Automobiles Using Waste Heat

Recovered from Exhaust Gases A C Deshpande, R M Pillai

Abstract- According to a cautious estimate, approximately 10% of the energy available at the crankshaft in a diesel operated vehicle is used for operating the compressor of the vehicle's air-conditioning system. This is a huge loss if one takes into account the fact that the thermal efficiencies of most diesel operated vehicles range from 20-30% when in pristine condition. The bottom line is that a great deal of diesel is consumed to generate electricity. In addition to this, alternating current via an alternator is necessary for the operation of the conventional a/c system. The refrigerant, usually R12 or R22 leaks easily. Being a secondary refrigerant, it is also harmful to the environment. Conventional air conditioning systems are also questioned due to the ODP (ozone depletion potential) and GWP (global warming potential) caused by the CFCs or HCFCs.

Increasing recognition of environmental problems associated with CFCs and HCFCs has opened favourable opportunities for the development of green air conditioning technologies. This project report presents a revolutionary silica gel - water adsorption system for air conditioning in automobiles. The cooling effect is achieved by recovering waste thermal energy from the exhaust gases. The system is cheap and easy to fabricate. The refrigerant, being water, is environment friendly. The report provides the details regarding the construction of a prototype fabricated on this technology, by the co-authors. The design of the generator, which is the focal part of the system, is novel yet simple. The experimental results obtained, while

conducting tests on a four stroke diesel engine from Mahindra have been included.

Produced by the subcooling of the refrigerant in the condenser. Conventional vapor compression air conditioning systems, however, have a number of shortcomings which make it unviable and there is a need for a better alternative. One of the alternatives being developed at present is adsorption air conditioning. Adsorption is the phenomenon in which, the liquid molecules (adsorbent) in the adsorbing pair gets deposited on the solid (adsorbate) surface. This is an exothermic process. For example, the silica gel used in many desiccating applications acts as an adsorbate, which adsorbs the water molecules on its surface. Adsorption air conditioning uses the process of adsorption-desorption and the thermodynamics associated with it to create the air conditioning cycle. We selected the adsorption air conditioning system to be the topic of our final year project. We intended to construct a working prototype of a simple adsorption air conditioning system. Our aim was to construct a model at minimum cost using available tools and scrap materials.

Our choice was based on two reasons; the first being the wide scope of the concept. Our system was to provide cooling effect for automobiles using the heat generated in exhaust gases. This could, however, be easily transposed to a variety of similar systems. We could, theoretically, use any heat source to provide cooling for any cooling space. An example that comes to mind is the central air conditioning of any home using solar energy. If an affordable system of this type were to be built, it would have tremendous scope for a

place like Shegaon where our engineering college was located. It would enable even the underprivileged to own an air conditioning system and survive the treacherous summers of Shegaon. In short, the scope for such a system is unimaginable. The second reason was the exciting field which we wanted to be a part of. The ongoing research in the field of adsorption systems was outstanding and the field being nascent was poised for spectacular growth. We gleaned a lot of information from research papers and journals published as recently as early 2009. The relevance of the project in today's world is also magnified as a result of the eco conscious age we are entering. As a consequence of the Kyoto protocol further

## I. INTRODUCTION

Recently, research and development focuses on new natural refrigerants and their refrigeration systems. Adsorption refrigeration technology is obviously one of the possible alternative technologies. This paper covers all aspects regarding a typical adsorption air conditioning system from concept, construction and working to the results of the tests performed on an actual prototype fabricated in SSGMCE, Shegaon.

Activated carbon Activated charcoal forms an adsorption pair with methanol or ammonia. Activated carbon/methanol is one of the most common working pair due to the large adsorption quantity and lower adsorption heat, which is about 1800–2000 kJ/kg. As the main heat consumption in the desorption phase is due to the adsorption heat, low values of adsorption heat are beneficial to the coefficient of performance. Activated carbon is made of materials such as wood, peat, coal, fossil oil, chark, bone, coconut shell and

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nut stone. The microcrystal for the activated carbon produced from bone is a six element carboatomic ring, and the adsorption performance is influenced by the functional group that is connected to the carboatomic ring. For example, arene group increases adsorption, while sulfonic group decreases it. Silica Gel Silica Gel forms an adsorption pair with water. The adsorption heat for this pair is about 2500 kJ/kg. The desorption temperature can be very low, but above 50 °C. The desorption temperature cannot be higher than 120 °C, and it is generally lower than 90 °C. The silica gel is a type of amorphous synthetic silica.

It is a rigid, continuous net of colloidal silica, connected to very small grains of hydrated  $\text{SiO}_4$ . The hydroxyl in the structure is the adsorption center because it is polar and can form hydrogen bonds with polar oxides, such as water and alcohol. The adsorption ability of silica gel increases when the polarity increases. One hydroxyl can adsorb one molecule of water. Zeolite Zeolite also forms a pair with water. The adsorption heat for zeolite/water pair is higher than that of silica gel/water pair, and it is about 3300-4200 kJ/kg. The adsorption ability of zeolites is related to the proportion between Si and Al, and the adsorption ability is higher when this proportion is small. The adsorption and desorption heat of zeolite pairs are high, and the desorption temperature of these pairs is also high, and about 250- 300°C. Most zeolite molecular sieves can be destructed at temperatures higher than 600-700 °C

II. ADSORPTION PROCESSES AND PAIRS The adsorption process is divided into these two types: 1. Physical adsorption 2. Chemical adsorption. Physical

adsorption is caused by van der Waals forces between the molecules of the adsorbent and the adsorbate. Physical adsorbents with mesopores can adsorb consecutive layers of adsorbate, while those with micropores have the volume of the pores filled with the adsorbate. Physical adsorbents develop the selectivity to the adsorbate after the former undergo specific treatments, like react under a gas stream or with certain agents.

The kind of treatment will depend on the type of sorbents. Chemical adsorption is caused by the reaction between adsorbates and the surface molecules of adsorbents. Electron transfer, atom rearrangement and fracture or formation of chemical bond always occurs in the process of chemical adsorption. Only one layer of adsorbate reacts with the surface molecules of chemical adsorbent. The adsorbate and adsorbent molecules after adsorption never keep their original state. Moreover, there are the phenomena of salt swelling and agglomeration, which are critical to heat and mass transfer performance. Adsorbents can be classified into the following three types: 1. Physical adsorbents 2. Chemical adsorbents 3. Composite adsorbents For our prototype, we had decided on using physical adsorbents

A. Physical Adsorbents The common physical adsorbents for adsorption refrigeration are activated carbon, activated carbon fibre, silica gel and zeolite.

B. Chemical adsorbents Chemical adsorbents mainly include metal chlorides, metal hydrides and metal oxides. C. Composite Adsorbents Composite adsorbents started to be studied about 20 years ago, and they aimed to improve the heat and mass transfer performance of the original chemical

adsorbents. This kind of adsorbent is usually obtained by the combination of a chemical adsorbent and a porous medium, that can be or not a physical adsorbent, such as activated carbon, graphite, carbon fibre, etc.

#### IV. BASIC MATHEMATICS INVOLVED

Variation of temperature and pressure according to change in the concentration of adsorbent adsorbed on adsorbate is discussed in this topic. This concentration is denoted by '  $x$ '. For the equilibrium adsorption curves,  $P_e$  is the evaporating pressure and  $P_c$  is condensing pressure. The adsorption quantity is influenced by two parameters, i. e. temperature and pressure. The equilibrium adsorption/desorption quantity of physical adsorption in micropores is usually calculated by the Dubinin-Astakhov (D-A) equations, which are

#### III. FINAL SELECTION OF WORKING PAIR

For the final selection of the working pair, we had to keep in mind three decisive factors, namely: A. Economy Our financial restraints while constructing the project were considerable. We had begun the project with the clear objective of minimizing the costs involved. Our idea was to build an affordable prototype of an adsorption refrigeration system. The thought process was to create a basic working model at minimum cost to showcase the commercial viability of the product. B. Availability After we decided the amount of money we could spend, we came to searching if all the pairs were in fact commercially available. We visited industrial areas in cities like Mumbai and Aurangabad to find out the exact prices of the chemicals.

Silica gel was found to be the cheapest of the trio with little to separate the other two. C. Suitability to application The I. C. engine exhaust gases could develop temperatures up to 200°C. Hence the desorption temperatures of the required pair had to satisfy this condition. Zeolite - Water, with a desorption temperature of 250°C, was eliminated. Upon studying research papers which used Activated Charcoal as the adsorption pair, we found that usage of this pair above the temperature of 120°C was considered unadvisable. This was because of the decomposition of Methanol that takes place at these temperatures. Considering these points, we selected silica gel - water to be the pair for our prototype. With an optimum desorption temperature of 120°C, it was an ideal choice. In addition to this, it is also cheap, easy to handle, transport and use. We procured a majority of our silica gel from Aurangabad.

$$x = x_0 \exp[-k (t / t_s - 1)^n]$$

or

$$x = x_0 \exp[-D (T \ln P_s / P)^n]$$

where  $x_0$ ,  $k$ ,  $D$  and  $n$  are coefficients, which are different not only for different working pairs, but also different for the same working pair, according to the brand and type of the adsorbent,  $T$  is adsorption temperature (K),  $T_s$  is the saturated temperature of refrigerant (K),  $P_s$  is the saturated pressure of refrigerant (Pa),  $P$  is the pressure of the system (Pa) and  $x$  is the adsorption quantity of refrigerant in the adsorbent (kg/kg). The coefficients used in D-A equation have a constant value for each working



pair. These values for some of the working pairs are given below. 1. Silica gel and water

$$n = 1.7, x_0 = 0.35, D = 6 \times 10^{-6}$$

2. Zeolite and water

$$k = 5.36, x_0 = 0.261, n = 1.73$$

3. Activated carbon and ammonia

$$k = 3.57, x_0 = 0.29, n = 1.38$$

4. Activated carbon and methanol

$$k = 13.38, x_0 = 0.45, n = 1.5$$

V. CONSTRUCTION. Using the available literature and the four stroke four cylinder engine, we fabricated an actual working model of an AdAC.

The construction can only be comprehended by including brief descriptions of each component, namely: A. Generator: This was a novel design. The engine exhaust gases flow through the copper tubes as shown in the diagram in black. The space inside the cylindrical volume was filled up with the Silica gel-Water pair. Nine copper tubes, which are spread out evenly in this volume, allow the heat transfer from the exhaust gases to the pair. Two shut off valves are attached to the generator which act as an inlet and outlet for the refrigerant. The cylinder is provided with separate openings for exhaust gas and cooling water. Two domes at each end of the cylinder provide the space for cooling water and exhaust gases to disperse properly and flow through each tube uniformly. The generator is equipped with a

thermocouple to measure the temperature of the adsorbing pair. Schematic diagram and photograph of the generator fabricated by us are shown below.

B. Condenser & Evaporator: These heat exchangers are of air cooled type.

The condenser is made up of Aluminum. C. Fan & Motor:

The arrangement used to circulate the air over the air cooled condenser and to convey the cooling effect to atmosphere. The motor is operated on the same power supply as that of engine starting drive.

D. Shut off valves &

Expansion Device: The purpose of using these manually operated valves in the system is to prevent the flow of refrigerant in unwanted direction. The expansion device is a half open valve.

E. Receiver: Receiver had a simple but leak proof construction. It was a hollow cubical shaped box, with two holes for refrigerant in and out in it, fabricated in sheet metal.

The system was mounted on a 4-stroke, 4-cylinder IC engine at laboratory level.

The arrangement was done to bypass the exhaust gas in case of adsorption cycle (which will be discussed in operation) and excess back pressure.

VI. WORKING An adsorption cycle comprises four steps A. Step I:

Generation/Desorption This cycle starts when the hot exhaust gases starts flowing through the generator. The pair is in adsorbed state at room temperature. As the temperature of the pair increases, the adsorbent starts getting released from the adsorbate surface i. e. desorption process starts.

Due to the desorption process, pressure is increased in the system. As the temperature of an IC engine exhaust is above 200°C, the liquid adsorbent gets evaporated and finds its way out of the generator and finally moves towards the condenser. The shut off valves are provided in system to

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canalize the motion of the refrigerant in right direction. B. Step II: Condensation As the refrigerant get into the air cooled condenser, this step starts. Refrigerant enters the condenser at high temperature and high pressure, heat exchange occurs with atmosphere, and finally refrigerant "throttle valve during the above four cycles can be tabulated as shown under, Step Generation/Desorption Condensation Evaporation Adsorption Valve 1 Open Open Shut Shut Valve 2 Shut Shut Shut Open Throttle Valve Shut Shut Partially Open Partially Open

VII. RESULTS We initially conducted an exhaust gas temperature test on our four stroke, four cylinder Mahindra engine. The exhaust gas temperature peaked at 165°C, which was adequate for our requirements. We then conducted two performance tests. The first test produced a slight unsatisfactory cooling effect. On the addition of a receiver into the system, the second performance test was far more conclusive. It produced a temperature drop of 2. 1°C in the closed volume equivalent to a car. The condenser and evaporator inlet temperatures were measured at 72. 6°C and 31. 2°C respectively. The peak silica gel temperature was 102°C.

Photograph: Complete assembled system. comes out of it in liquid state. Very small temperature drop is obtained, which is due to the little subcooling. Refrigerant is collected in a receiver. C. Step III: Evaporation Refrigerant is passed through an expansion valve. Due to the throttle action taking place, evaporation occurs. Refrigerant absorbs heat from surroundings, giving a cooling effect to the surrounding. This effect is then conveyed to the space to be cooled using evaporator. D. Step IV: Adsorption

To start this cycle, the cold water is circulated inside the generator which not only decreases the temperature of adsorbate, but also cleans the carbon particles from exhaust gas present inside the copper tubes. In this process, the pressure inside the generator starts falling down. When this pressure falls below evaporation pressure, the refrigerant begins to flow from evaporator to generator. In this way refrigerant completes the cycle and the cycle starts again. Cooling effect is obtained only in adsorption cycle and not in desorption. This will provide the cooling only after specific intervals. However, adsorption cycle lasts for a longer duration as compared to adsorption. Hence, cooling is obtained for more than half of the total time.

VIII. CONCLUSION AdAC is energy saving and environmental friendly as it uses only primary refrigerents. It is simple to fabricate and inexpensive to operate. Adsorption systems differ from VCR's in that they use heat, even low grade heat to produce the air conditioning effect. This heat can be procured from waste heat or solar energy. Compared to VCR's, they save about 95% of electricity consumption. AdAC systems are flexible in operation and are unaffected by ambient temperature. There are no rotating components or machined surfaces. They are suitable for vibration, inclined and rotation applications. Commercial production of AdAC is a field that could burgeon in the near future. As our results show, it is a system that can be fabricated easily and with excellent performance. We conclude by stating once again, that the future of air conditioning belongs to AdAC systems.

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