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Water Cooling System Using Engine Exhaust Heat

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Abstract:*Many new technologies are emerging and developing in automobile sector and moreover it has proven its importance in human life time to time. For the human comfort air conditioning is provided in vehicle. In 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. To avoid this fuel consumption, the same air conditioning effect can be achieved by using vapour adsorption system without using engine power. The work presented in this paper gives the overall idea about design, development & implementation of water cooling system by using exhaust of the engine with same condenser & evaporator unit. The exhaust is feed to adsorber bed which is filled with carbon activated charcoal & R134a as a refrigerant. This refrigerant get evaporated and passed through the stainless steel coil which acts as an evaporator. The normal temperature water is passed through this evaporator coil. For primary stage this concept is implemented on two wheeler engine. This concept will be implement on four wheeler for air conditioning purpose. The water cooling system is powered by exhaust heat using two control valve with same condenser and evaporator unit. The cooling capacity for 2 liter water is estimated 0.28kW. A system has been designed and developed. A cooling effect of 0.28kW can be obtained. The expected COP of the system is in the range of 0.2 to 0.25. The dimensions of the system are compact. It can be easily accommodated on a domestic two wheeler. The total weight of the system for a cooling capacity of 0.28 kW is 5kg. The heating time required to achieve the cooling effect will be around 15 minutes. Total time to complete cycle will be around 45 minutes.*
Keywords: *Absorber bed, Ammonia, Evaporation, R134a, Refrigeration System.*

I. Introduction

The conventional refrigerators use a compressor to deliver the vapour refrigerant at high temperature to the condenser unit. The compressor drives this power from engine of automobile if it is the case of automobile air conditioning. It will responsible for emission of Chloro Floro Carbon (CFC).The cooling effect is produced by sub cooling of refrigerant in condenser unit. Conventional vapour compression refrigeration system, however have a number of limitations like requirement of external power to drive the compressor. In order to achieve this objective of energy efficiency in refrigeration and air conditioning system, vapour adsorption system is the best alternative which is found. The prototype was made to study vapour adsorption system. The prototype was made such that it can work based on any heat source. This developed refrigeration system for two wheeler which will be used to cool around 2 liters of water by using principle of vapour adsorption. The reason for selecting this principle was straight foreword that many researches are going on energy efficiency and conservation.

II. Literature Review

The first automobile refrigeration system was vapour adsorption refrigeration system developed by Packer in 1939[1]. Various research papers has been reviewed for present work done in the field of vapour adsorption in refrigeration and air conditioning applications. Solid vapour adsorption is similar to liquid vapour absorption system, except that the refrigerant is adsorbed on the surface of another solid known as adsorbent.

R.K. Singh and T. Mahala (2014) presented a paper on Theoretical Analysis of Modified Refrigeration Cycle of a Single Effect Lithium Bromide-Water Vapour Absorption System Using Exhaust Gases of IC Engine which gives the idea about vapour absorption refrigeration system. LiBr-H2O vapour absorption system driven by exhaust gases of the engine is used in the automobiles for air-conditioning purpose. Because of this, there is improvement in the engine efficiency and reduction in exhaust emission. The exhaust gases of the engine are used as a heat sources in the generator thus it avoids the extraction of power from the engine. For better improvement of COP LiBr-H2O vapour absorption cycle is modified [2].

S. Bux & A.C. Tiwari (2014) develop a tables of different parameters of four stroke four cylinder diesel engine and drawn different types of characteristic curves like load Vs exhaust temperature, exhaust gas flow rate, air fuel ratio ,brake power, indicated power , specific fuel consumption[3].

V. Baiju & C. Muraleedharan gives Experimental Analysis on Adsorption Characteristics of Methanol and R134A by Activated Carbon in Adsorption Refrigeration System. The paper contains adsorption and desorption characteristics of two different working pairs are activated carbon–methanol and activated carbon–R134a—determined experimentally [4].

L. Sun et.al (2013) presented an Investigation of An Ammonia−Water Based Power Cooling Cogeneration System Using Sensible Waste Heat. He conclude that the turbine exhaust heat is rejected to the environment directly, leading to a large amount of heat waste. The improved system proposed in this paper can make cascade utilization of the turbine exhaust heat, and by varying the turbine outlet pressure, different turbine exhaust vapor temperature can be obtained, resulting in different amounts of heat that can then be used by the refrigeration subsystem [5].

H. Tiwari and Dr. G.V. Parishwad (2012) investigates overall idea about power required to run an air conditioning system can be saved by using waste heat powered cooling system in the field of alternative cooling systems powered by heat, adsorption air cooling systems with activated carbon 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 [1].

III. Proposed System

The proposed system is shown in fig.1.The system is basically contains adsorber bed with activated carbon filled, condenser coil, evaporator coil, two control valves. These valves are manually operated. It is set as cyclic off and cyclic on for ten minutes. Adsorber bed is basically a double pipe heat exchanger.

We are using R134a as a refrigerant and activated carbon as an adsorbent. The property of activated carbon is to adsorb around 60% of refrigerant on its surface. R134a has latent heat of vaporization about 215.9 KJ/Kg. It does not affect the global warming or ozone layer depletion.

The system is arranged such that exhaust port of engine is connected to exhaust in port by using stainless steel hose. The exhaust heat is passed through adsorber bed by using this S.S. hose. An adsorber bed is connected to condenser coil by a long tube. The condenser coil acts as an evaporator. Normal temperature water is passed through this coil and cool water will be taken at outlet of the coil. The adsorberbed, coil and long tube is connected by TIG welding.

An adsorber bed is filled with carbon activated charcoal which is 700gms. For proper charging of refrigerant vacuum is necessary which is done through pressure gauge port. As the hot gases passed through this adsorber bed, after 170 degree Celsius temperature refrigerant starts evaporation at 5-6 bar pressure. As the heat is continuously supplied to bed, pressure of refrigerant is increased to 12-15 bar in condenser coil in ten to fifteen minutes.

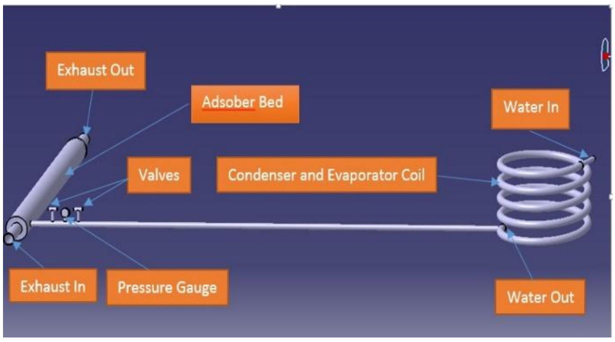

Fig. 1 Proposed System

The property of R134a is that at 15 bar pressure will get condensed to liquid form at 40 degree Celsius. At the same time forced air is passed on condenser coil as vehicle is in mobile condition. It helps to condense the ammonia to liquid form. After this a flow control valve is opened which has a very small opening, it acts as the expansion valve. So large pressure drop starts in valve, so liquid R134a starts to convert into gaseous state as pressure decreases, so it will take latent heat of vaporization i.e. 215 KJ/Kg this all is taken from the surrounding. So we get about 10 degree Celsius temperature evaporator coil. To cool the water in bottle at the evaporator box it is sufficient temperature. After this refrigerant is passed from evaporator coil to adsorber and it starts to adsorb on activated carbon bed. The modelling of system is done by using CATIA V5 software.

IV. Design of Components

4.1. Adsorber Bed:

Adsorber bed is the main element of the adsorption refrigeration system. The adsorber provides the necessary compression effect required for refrigeration in an adsorption refrigeration system by absorbing and rejecting heat of adsorption and desorption. The adsorber bed servers both the function of adsorber and compressor in the present system. It is designed as a tube in tube heat exchanger in which exhaust gases flows through the inner tube and the refrigerant flows through the annulus space present between both the tubes. Perorated tubes are placed inside the bed. Activated carbon granules are filled in the space between the adsorber tubes and perforated tubes. Aluminum chips are proposed to be mixed with activated carbon to enhance heat transfer in adsorber bed. The adsorptivity of activated carbon for refrigerant is below 75^0C is around 30% and that above 165^0C is around 0% as obtained from isotherm curve. Hence adsorber bed temperatures are decided as $T_{ad, max} = 165^0C$ and $T_{ad, min} = 75^0C$. The system is designed for heating and cooling time of 900 s and 1800 s respectively (the time required for adsorption or desorption).

Heat required to heat the adsorber is absorbed in two ways firstly for heating the AC, tube in tube of heat exchanger and can be estimated as the summation of sensible heat (heat absorbed by tubes and adsorbing material) and latent heat of refrigerant at evaporator pressure. The specific heat of AC, C_{pad} = 1.033 KJ/Kg K and ΔT_{ad} = 900C in following equations, ΔT_{ad} is the difference between maximum and minimum bed temperature. The following set of equations is used for these calculations.

$$Q_{sensible, heating} = [(m_{ad} (Cp_{ad} \times \Delta T_{ad})] / \Delta t$$
$$=0.0692KW$$
$$Q_{latent, heating} = [m_{ad}(X_2-X_1) \times (H_2-H_1)] / \Delta t$$
$$=0.2916KW$$

$Q_{adsorber} = Q_{sensible, heating} + Q_{latent, heating}$

$$=0.3608KW$$

The heat required to heat or cool the adsorber is calculated as 0.3608 KW. The overall heat transfer coefficient for heat transfer to the adsorber bed is taken as 25 W/m^{2}K. The Logarithmic mean temperature difference required in overall heat transfer equation can be calculated using eq^n[5].

$$Q = U \times A \times \Delta T_{ad}$$
$$\Delta \text{Tinheating} = \frac{\Delta T1 - \Delta T2}{\ln(\frac{\Delta T1}{\Delta T2})}$$

For the calculation of Logarithmic mean temperature difference Initial and final temperature of adsorber and inlet, outlet temperature of exhaust gases are required. The mass flow rate of exhaust gases is calculated as m_{ex} = 0.003276 Kg/s, considering air fuel ratio 15 and fuel consumption 1 lit/hr. for the available IC engine test rig. Considering $T_{exin} = 200^0C$ T_{exout} can be obtained using following equation is calculated as 108^0C for hat transfer of 03 KW. Logarithmic mean temperature is calculated from Eq^n as 104^0C.

$$T_{ex, out} = T_{ex, in} - (Qe_{x\div} m_{ex} \times C_p) = 108^0C$$

Therefore using equation

$$Q = U \times A \times \Delta T_{ad}$$

360.8=25 X A X 104

$$A = 0.1387 \text{ m}^2$$

For dimensions of adsorber are obtained as

A = pi x [D1+ D2] x L

Hence assuming length 0.6 m calculated diameters of inner and outer tubes are 25 mm and 50 mm respectively.

4.2. Condenser:

Condenser is a heat exchanger in which heat exchange take place between pressurized refrigerant and cooling media in our case atmospheric air. Condenser will be exposed to the atmospheric air striking with bike velocity. Temperature difference is assumed to be 10^0C. Condenser pressure is 15 bar for saturation temperature of 40^0C.

Total Heat Required in Condenser is

$$Q = m \times h_{\text{Latent heat}}$$
$$=213.06KJ$$

This heat should be given out in 10 min of time

$$Q = 0.3551 \text{ KW}$$

We assume air is flowing over condenser tubes at the velocity of 6 m/s and for that taking overall heat transfer coefficient as 100 W/m^{2}K.

$$Q = U \times A \times \Delta T$$

355.1 = 100 x A x10

$$A = 0.3551 \text{ m2}$$

Considering 70 % fin area and 30 % tube

$$\text{Area tube} = A = 0.3 \times 0.3551$$
$$=0.1065 \text{ m}^2$$

Therefore length of condenser coil is calculated by assuming diameter of coil as 12 mm is 4m

Hence minimum length of condenser coil is 4m.

4.3. Evaporator:

Evaporator is major part of refrigeration system as it actually gives cooling effect in cooling chamber. It is a heat exchanger which absorbs heat from cooling chamber by transforming liquid refrigerant into its vapour. Evaporator designed below is a coiled tube with fins placed in cooling chamber. Temperature difference of 15^0C is developed across evaporator.

Total Heat Rejected in Condenser is

$$Q = m \times h_{\text{latent heat}}$$

=4.8KW

This heat should be given out in 10 min of time

$$Q = 0.48 \text{ KW}$$

We assume brine solution is present in chamber in which bottles are placed and for that taking standard overall heat transfer coefficient as 200 W/m^{2}K.

$$Q = U \times A \times \Delta T$$

$$480 = 200 \times A \times 15$$

A = 0.16 m2

Considering 70 % fin area and 30 % tube

Area tube = A = 0.16 x 0.3

$$=0.048 \text{ m}^2$$

Therefore length of evaporator coil is calculated by assuming diameter of coil as 6 mm is 2.5m. Hence minimum length of condenser coil is 1.6m

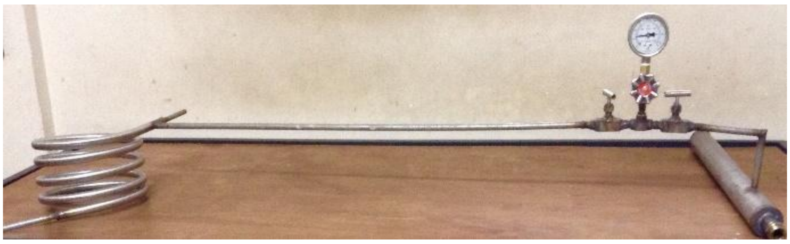

Fig.2. Prototype of System

V. Experimental Results

The experiment have been carried out on prototype using engine exhaust as heat source. The pressure and temperature is note down after certain interval of time.

Sr. No.	Time (min)	Pressure (bar)	Evaporator Temp(^{0}C)
1	0	5	45
2	5	10	47
3	10	17	50
4	15	12.3	40
5	20	7	35
6	25	5	27
7	30	10.5	19

Table 1

VI. Conclusion

This experimental results shows, water is cooled up to 19 within 30 minutes of whole cycle by using waste heat. The engine power required to run an air conditioning system can be saved by using waste heat powered cooling system. As predicted in proposed system, any two wheeler exhaust should be sufficient to drive adsorption system. Proposed system can be used to cool 2 liters of water by using engine exhaust heat. The application is most suited and beneficial in summer season in coastal areas. If it is needed, same system can be used for air conditioning and refrigeration applications which will be driven by stationary diesel engine exhaust. Larger capacity systems can be used for air conditioning in cars and truck cabin cooling. Same layout of system can be used for cargo trailers for food transportation over long distance without proving any mechanical or electrical energy. So vapour adsorption refrigeration is best alternatives for vapour compression refrigeration system.

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