Advance Physics Letter

Design of Ammonia Water Vapour Absorption Air Conditioning System for a Car by Waste Heat Recovery from Engine Exhaust gas

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Abstract : Conventional automobile air conditioning systems is mostly based on vapour compression system with refrigerant-134a. An attempt to use vapour absorption system in which. In this system, the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve. Design calculations have been made for different components of the system like evaporator, generator, absorber, heat exchanger of vapour absorption for a capacity of 0.75 TR. The vapour absorption system is used for air conditioning of four stroke four cylinder passenger car. The exhaust heat of car is used to heat the ammonia solution in the generator. The analysis shows that the maximum amount of useful heat available in the exhaust gas is about 9.4 kj/s. In this study it is found that the amount of heat required for generator 4.5 kj/s to run for a capacity of 0.75 TR. However the heat present in the exhaust heat is more than this amount.

Key word – Exhaust gas, vapour absorption system, air conditioning system.

I. INTRODUCTION

Air conditioning of a vehicle can be done by two methods. First is Vapor Compression Refrigeration System (VCRS) and another is vapor absorption refrigeration system (VARS).Presently, in the vehicles VCRS is use in most of the cases. In lieu of VCRS, if, VARS is used in vehicles the refrigeration system could be operable in a vehicle without adding running cost for air conditioning. There is a great impact on the running cost of a vehicle due to increasing cost of fuel. The A/C system adds nearly 35 % extra cost in fuel expenses.

Alternately, it becomes a matter of investigation that waste heat recovery of an engine for application in car A/C can reduce the fuel economy of vehicles. Literature review gives that there is an indication that reducing the A/C load decreases A/C fuel consumption. An automobile engine utilizes only about 35% of available energy and rests are lost to cooling and exhaust system. If one is adding conventional air conditioning system to automobile, it further utilizes about 5% of the total energy. Therefore automobile VCRS become costlier, uneconomical and less efficient. Additional of conventional air conditioner in car also decreases the life of engine and increases the fuel consumption. For very small cars compressor needs 3 to 4 bhp, a significant ratio of the power output. Keeping these problems in mind, a car air conditioning system is designed from recovery of Exhaust waste heat using as source / generator for VARS.

II. HEAT LOAD CONSIDERED IN THE ANALYSIS

The determination of actual cooling load becomes very difficult in car air conditioning because of the variation of the load in the climatic conditions when the car is exposed during the course of long journey. The cooling load of a typical automobile is also considered at different steady state conditions. The cooling capacity is affected by outdoor infiltration into car and heat gain through panels, roofs, floors etc. The cooling load considered in this analysis is given in Table 1.The table shows that heat load inside the car is approximately 2.2 kW.

Therefore, 0.75 ton air conditioning unit is sufficient to fulfill the cooling requirement and capable to run this air conditioning system from exhaust gas heat as further calculation.

Table 1 Heat load considered in small automobile [2]

Heat load	Amount of heat (Kj/hr)
Solar radiation (roof ,walls, glasses)	300
Normal heat gain through glass	1200
Normal heat gain through wall	4300
Air leakage	1000
Passenger including driver	1200
Total	8000 Kj/hr or 2.22 Kj/s

III. AVAILABILITY OF HEAT IN ENGINE

Consider internal combustion engine approximately 30 to 40% is converted into useful mechanical work. The remaining heat is expelled to the environment through exhaust gases and engine cooling systems. It means approximately 60 to 70% energy losses as a waste heat through exhaust (30% as engine cooling system and 30 to 40% as environment through exhaust gas). Exhaust gases immediately leaving the engine can have temperatures as high as 450-600°C. Consequently, these gases have high heat content, carrying away as exhaust emission. In order to enable heat transfer and recovery, it is necessary that the waste heat source temperature is higher than the heat sink temperature. Moreover, the magnitude of the temperature difference between the heat source and sink is an important determinant of waste heats utility or "quality". The heat available at different rpm shows in table 2 and at 2800 rpm 9.4 kJ/s which is sufficient to run absorption air conditioning system.

Table2 Exhaust heat at different rpm

S.N.	**RPM**	Exhaust Heat In kW (Q_e)
1	2200	5.5
2	2400	6.7
3	2500	7.3
4	2600	8.0
5	2800	9.4

The quantity of waste heat contained in a exhaust gas is a function of both the temperature and the mass flow rate of the exhaust gas [7]:

$$Q=m.C_p(T_{exh}-T_o) \qquad (i)$$

The temperature of the exhaust gas in ^{0}Celsius is estimated by [11]-

$$T_{exh} = 0.138RPM - 17 \quad (ii)$$

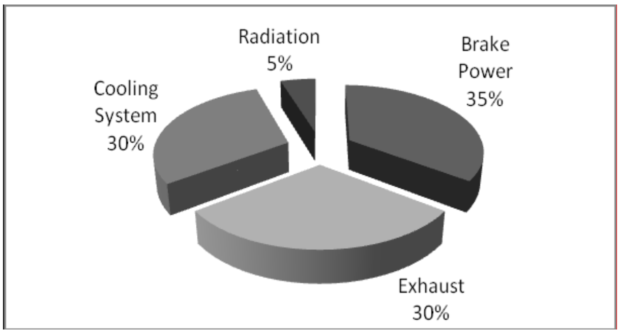

Fig.1 Total Fuel Energy Content in I. C. Engine [7]

There are many problem identified of conventional air conditioning system of automobile from literatures review as following.

1. There is a great impact on the running cost of a vehicle due to increase cost of fuel. The conventional air conditioning system of automobile ads nearly 35% extra cost in fuel expenses.

2. Additional conventional air conditioning system in car also decreases life of engine and increases maintenance cost.

3. Today's automobile air conditioning system is based on vapour compression system and refrigerant (R-134) is used. Eventually this refrigerant is very costly thus uneconomical.

4. Refrigerant in vapour compression refrigeration system are mainly Hydro chlorofluoro carbon (HCFC) and Hydro fluoro carbon (HFC) which are not environmental friendly because itcauses global warming and damage ozone layer.

IV. DESCRIPTION OF ABSORPTION SYSTEM

This refrigeration system consists of a condenser, an expansion valve and an evaporator similar to a Vapor Compression Refrigeration System. But the compressor of the Vapor Compression Refrigeration System is replaced by a generator, an absorber and a small pump. A Vapor Absorption Refrigeration System utilizes two or more than two fluids which has high affinity towards each other, in which one is the refrigerant and the other is the absorbent.

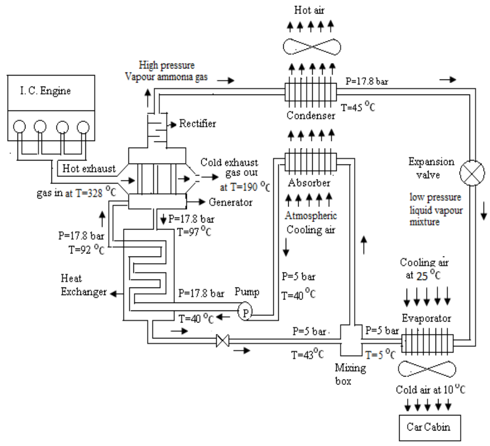

Fig. 2 Schematic diagram of air conditioning system

V. METHODOLOGY

The working method is vapour absorption system close to the exhaust manifold. Due to the supplied heat to the mixture in the generator the refrigerant is separated from the strong solution and forms vapour. The remaining weak solution flows back through a restrictor in to the absorber. The refrigerant is then allowed to pass through a condenser where the heat of the vapour is extracted and the refrigerant temperature is brought to the desired temperature. This cooled refrigerant is then passed through an expansion device where during expansion the temperature of the refrigerant falls below the atmospheric temperature. The cold refrigerant is then allowed to pass through an evaporator from where the refrigerant absorbs heat and produces refrigerating effect. The refrigerant coming from the evaporator is hot and it is passed to the absorber.

The weak solution coming from the generator mixes with the refrigerant coming from the evaporator in the absorber due to high affinity towards each other for the two fluids, hence forming a strong solution. The formed strong solution is again pumped into the generator and the cycle repeats itself.

VI. COMPONENT DESIGN-

A sample calculation for generator has been presented. The generator is the main unit of whole refrigeration system. This is located nearest to exhaust manifold where the heat is available from exhaust gases. The generator is used to evaporate mixture of ammonia with water that reacts and leave pure ammonia or mixture with high ammonia concentration.

The space available in the automobile for that so it has been installed 50cm long, 12cm wide and 8cm height. Assuming Inside and outside diameter of steel tube is 25 mm and 27 mm. As stated earlier the air conditioning system for small car can run at 0.75 TR and needs 4.5 kW heat for evaporating refrigerant. Therefore the generator is designed to have capacity of 4.5 kW with temperature around 97^0C and pressure of 17.8 bars from previous calculation. A car mostly runs between 1800 rpm to 2800 rpm and therefore generator has been designed for 2500 rpm at 328^0C temperature.

The external heat transfer area (A) required is calculated [4]:

$$A = \frac{Q_g}{U_0 \times LMTD} \qquad \text{(iii)}$$

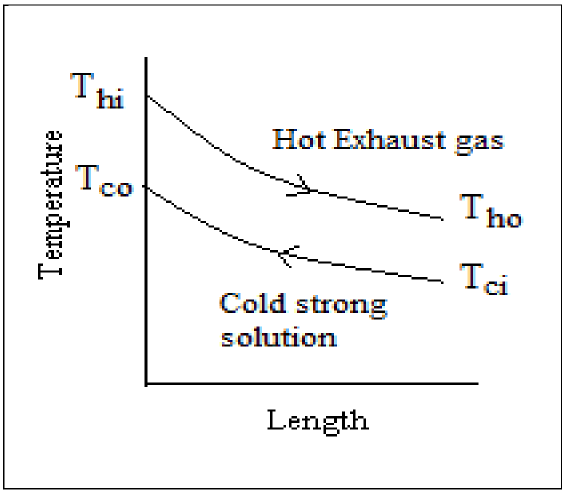

Fig. 3 Temperature change in generator

LMTD:

Assuming cross flow type heat exchanger arrangement for heating process for generator so the logarithmic mean temperature difference is[4],

$$LMTD = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln(T_{hi} - T_{co})/(T_{ho} - T_{ci})} \qquad \text{(iv)}$$

Where,

T_{hi} = Inlet temperature of hot exhaust gas.

T_{ho} = Outlet temperature of cold exhaust gas.

T_{co} = Outlet temperature of ammonia vapour

T_{ci} = Inlet temperature of strong solution

The hot fluid and cold fluid inlet and outlet temperature has been calculated using empirical relation-

LMTD= 123.5 °C

To find inside heat transfer coefficient of generator (h_i):

The Inside heat transfer coefficient of generator calculated from Nusselt number [15].

$$Nu_{D_i} = \frac{h_i d_i}{k_l} \qquad \text{(v)}$$

As the flow inside the generator is two phase flow and liquid wets the surface. The Nusselt number of two phases for generator is [4].

$$Nu_{D_i} = 0.06 \times \left(\frac{\rho_l}{\rho_v}\right)^{0.28} \times \left(\frac{d_i G_x}{\mu_l}\right)^{0.87} \times (Pr)^{0.4} \text{(vii)}$$

Mass flux is calculated [15]-

$$G_x = \frac{\text{mass of strong solution}}{A_i} = 93.7 \text{ kg/m}^2\text{s}$$

Thermo-physical properties of water at mean temperature 95^0C is [15] -

Density of liquid (ρ_l) = 961 kg/m^3, Dynamic viscosity (μ_l) = 0.297×10^{-3} N-s/m^2, Prandtlnumber (Pr) = 1.85, Density of vapour (ρ_v) = 0.505 kg/m^3, Thermal conductivity (K) = 0.677 w/mk.

Nusselt no, Nu_{D_i}

$$= 0.06 \times \left(\frac{961}{0.505}\right)^{0.28} \times \left(\frac{0.025 \times 93.7}{0.297 \times 10{-3}}\right)^{0.87} \times (1.85)^{0.4}$$

$$= 1561.6$$

And, $h_i = \frac{1561.6 \times 0.677}{0.025} = 42289.5$

h_i = 42.289 kW/m^{2}k

To find outside heat transfer coefficient of generator (h_o):

Outside heat transfer coefficient from Nusselt Number [4]-

$$Nu_{D_o} = \frac{h_o d_o}{k_l} \text{(ix)}$$

For flow outside the tube, The Nusselt number of air flowing through the tube in generator [15]

$$Nu_{D_0} = 1.13C(Re_{D_0})^n (Pr)^{0.33} \qquad \text{(x)}$$

Where, C and n are constant.

Thermo-physical properties of the exhaust gas have been calculated at mean temperature at 238 ^{0}C or 511 K of exhaust gas [4]-

Density of exhaust gas,

$$(\rho_g) = \frac{353}{T_g} = \frac{353}{511} = 0.69 \text{ (kg/m}^3\text{)},$$

Viscosity of exhaust gas,

$$(\mu_g) = 1.348 \times 10^{-3} + 2.68 \times 10^{8} \times (T_g)$$

$$= 1.348 \times 10^{-3} + 2.68 \times 10^{-8} \times 511$$

$$= 2.717 \times 10^{-5} \quad \text{(Ns/m}^2\text{)},$$

Thermal conductivity of exhaust gas,

$(k_g) = 8.459\times 10^{-3} + 5.7\times 10^{-5}\times (T_g)$

$=459\times 10^{-3} + 5.7\times 10^{-5}\times 511$

$=0.03757$ (W/mk),

Specific heat of exhaust gas

$(C_{pg}) = 962.097 + 0.1509\times (T_g)$

$=962.097+0.1509\times 511$

$= 1040$ (J/kgk)

Vertical spacing between tubes,

$S_t = 1.5do$

$=1.5\times.027$

$= 0.0405$ m,

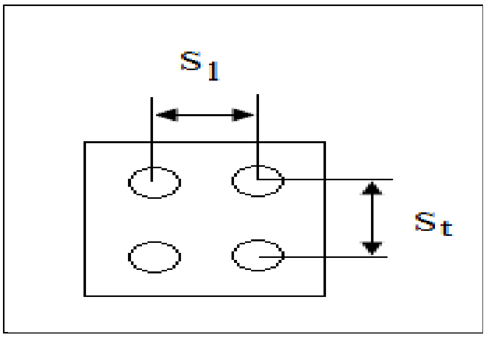

Fig.4 Diagram for in line design of generator tube

Horizontal spacing between tubes,

$S_l = 1.25d_o$

$= 1.25\times 0.027$

$= 0.03375$ m,

Face Velocity of exhaust gas[13,14],

$$U_f=\frac{m_{exh}}{\rho_g\times\frac{\pi}{4}\times d_{eq}{}^2} \quad \text{(xii)}$$

Where, m_{exh} is the mass of exhaust gas, ρ_g is the density of exhaust gas and d_{eq} is the equivalent diameter.

Equivalent diameter[13,15]

$$(d_{eq}) = \frac{2\times w\times h}{w+h}$$

Here, w is the width of generator and h is the height of generator. Using values as below,

$= 0.096$ m

Face Velocity of exhaust gas from equation (xii),

$U_f = 4.9 \approx 5$ m/s

Maximum velocity of exhaust gas[13],

$$U_{max}= \frac{U_f\times St}{St-d_o}= 15 \text{ m/s} \quad \text{(xiii)}$$

Reynolds number,

$$Re_{D_0}=\frac{\rho_g\times U_{max}\times d_o}{\mu_g} \quad \text{(xiv)}$$

Thus, $Re_{D_0} = 10285$

And, $Nu_{D_0} = 84.6$,

Using values in equation (x),

$$h_o = \frac{Nu_{D_0}\times k_l}{d_o}$$

$=117.7$ W/m^{2}k

The overall heat transfer coefficient:

The overall heat transfer coefficient, neglecting the fouling resistance of the tube,

$$\frac{1}{U_o}=\frac{1}{h_i}\times\frac{d_o}{d_i}+\frac{d_o}{2k_s}\times\ln\left(\frac{d_o}{d_i}\right)+\frac{1}{h_o} \quad \text{(xv)}$$

$U_o = 117$ W/m^{2}k

The external heat transfer area (A) required is calculated [4]-

$$A= \frac{Q_g}{U_o\times LMTD}= 0.3 \text{ m}^2$$

$A = \pi d_o l$

$$l =\frac{A}{\pi d_o} = 3.5 \text{ m}$$

Number of tube

$$N = \frac{\text{Total length of tube}}{\text{Length of each tube}} = 44$$

Number of row

$$=\frac{\text{Height of generator}}{\text{vertical space between tube}}=2.9 \approx 3$$

Number of tube per row

$$= \frac{\text{length of generator}}{\text{Horizontal space between tube}}$$

$= 14.8 \approx 15$

Likewise calculation for individual component has been done and results have been recorded and placed in tabular form in result section.

VII. RESULTS &DISCUSSION-

As calculated the air conditioning system for small car can run at 0.75 TR and needs 4.5 kW heat for evaporating refrigerant from mathematical modeling calculation. Therefore the generator is designed to have capacity of 4.5 kW with temperature around 97 ^{0}C and pressure of 17.8 bars from previous calculation. A car mostly runs between 1800 rpm to 2800 rpm and therefore generator has been designed for 2500 rpm at 328 ^{0}C temperature. It needs 2.73 kW heat rejections for running 0.75 TR air conditioning in car from calculation. Therefore condenser is designed to have capacity 2.73 kW. Air conditioning system of car depends on size of the car. For running air conditioning system in small car for sitting comfortably 0.75 TR is required which is equivalent to 2.625 kW. Hence the evaporator is designed to have capacity 2.625 kW heat transfer.

There is important role of absorber in vapour absorption refrigeration system. The system needs 3.85 kW heat absorption for running car air conditioning system according to calculation. Hence, an absorber capable of absorbing 3.85 kW has to be designed. Heat exchanger is important part of absorption system. It is required 11.10 kW heat transfer for running air conditioning system in car.

Table 2 Main calculated parameters for design of components

Descriptions	Generator	Condenser	Evaporator	Absorber	Heat Exchanger
Tube diameter (mm)	ϕ 25	ϕ 15	ϕ 15	ϕ 25	ϕ 10
Tube thickness (mm)	2	2	2	2	2
Dimensions (L× W × H) (mm)	50×12×12	50×450×420	90×250×240	70×600×450	-
Tube length (m)	3.5	14.6	9.1	12.5	35.5
Inside area (m^2)	-	0.69	0.429	0.98	
Outside area (m^2)	0.3	9	4.7	11.6	1.34
No. of tube	44	32.4 =32	36.4 = 36	28	
No. of tube row		2.3 = 2	4.2 = 4	2	
No. of tube per row		16.4 =16	9.4 = 9	14.8	
Inside coefficient (W/m^2k)	42289.5	7531.6	7410.4	44858	4324.6
Outside coefficient (W/m^2k)	117.7	92.4	70	77.6	4605
No. of fins	-	252	158	205	
Thickness of fins (mm)	-	0.16	0.126	0.15	
Space of fins (mm)	-	1.62	1.5	2	
Shell diameter (mm)					156
Shell length (mm)					234
Weight (kg)	2.2	9	5.5	12.15	9.6

In the above results, the feasibility of the exhaust heat to run vapour absorption system has been reasonably proved. The COP value is found0.57.

VIII. CONCLUSIONS &FUTURE SCOPE

Theuseful heat available in the exhaust gas is sufficient to run 0.75 TR air conditioning units. Vapour absorption system air conditioning system is totally eco-friendly in nature. As power output increase, the heat recovered from exhaust gas also increase. The use of VAR in road vehicles has the advantage of reducing the dedicated IC engine, fuel costs, maintenance, atmospheric pollution and noise pollution. One difficulty may occur when the vehicles at rest or in very slow moving traffic conditions. In either of these conditions the resulting reduction heat input to the generator would cause a corresponding drop in the cooling effect of the system. For this situation heater system shall be very helpful.

IX. ACKNOWLEDGEMENT

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Abbreviations &Nomenclature

A/C : Air conditioner
BHP : Brake horse power
CFC : Cloroflouro Carbon
COP : Coefficient of performance
HCFC : Hydro chloroflouro carbon
HFC : Hydro flouro carbon
ICE : Internal combustion engine
NH_3 : Ammonia
RPM : Rotation per minute
TR : Tone of refrigeration
TXV : Thermal expansion valve
VARS : Vapour absorption refrigeration system
VCRS : Vapour compression refrigeration system
LMTD : Log mean temperature difference
A : Area of tube, m^2
C_p : Constant pressure specific heat, kJ/kgk
D : Diameter
g : Gravitational acceleration, m/s^2
G : Mass flux, kg/m^2
h : Convective heat transfer coefficient, W/m^2k
k : Thermal conductivity, W/mk
LMTD : Log mean temperature difference, ^oC
M : Mass flow rate of refrigerant, kg/s
Pc : Condenser pressure
Pe : Evaporator pressure
Qe : Heat absorb in evaporator
Qg : Heat given in generator
To : Outlet temperature
Ti : Inlet temperature
U : Overall heat transfer coefficient, W/m^2k

Greek Symbols

ρ : Mass density ,kg/m^3
β : Volumetric thermal expansion coefficient, 1/k
ΔT : Temperature difference, ^0C
ν : Kinematic viscosity, m^2/s

Subscripts

a : Air
g : Gas
i : Inside
l : Liquid
o : Outside
s : Strong solution
w : weak solution

Non-dimensional Number

Nu_D : Nusselt number based on diameter
Pr : Prandtls
Re_D : Reynolds number based on diameter

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