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A Review Paper on Extracting Waste Heat from the Engine Exhaust and Reutilizing in Car Air Conditioning

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Abstract— *Taking view on today's scenario, a large number of industrial processes uses significant measurements of energy in the form of heat; all forms of energy are derived from fossils. However, the most common forms of energy-fossil fuels are petroleum, natural gas and natural gas liquids, coal and wood. With the increase hike in fuel and economic changes the cars become costlier and uneconomical. Also into the account that refrigerant used in the cars air conditioning is harmful for climatic conditions and needed to be recharge over a period of time. It requires some useful work from engine to vaporize the refrigerant, thus looking into the matter it was found that cars exhaust temperature can be used as an alternative to run the cars air conditioning by vapour absorption refrigeration system. Vapour absorption refrigeration system uses only the heat source to run the system as compressor of the engine is replaced by generator and absorber with pump, except for condenser and evaporator. The cooling capacity of refrigerator is 0.80 TR and the waste heat can be utilized and converted into useful work. Current scenario is like various modifications have been done in cars to make it luxurious. Many new technologies have been developed in cars to comfort the humans and many theories and discussion being done on car performance, speed and automatic transmission. Many researchers have found that it could be the source for power generation, heat into electric work and many more. Thus a modification also required in air conditioning because of some useful work has to be taken to drive air condition system. Now to reduce the ozone depletion many refrigerant has been banned and due to increase in global warming. It is necessary to have an alternate source which will be reliable and meet the future requirements in cars.*

Keywords—*VCRS, VARS, exhaust heat, conventional air conditioning waste engine heat.*

I. INTRODUCTION

Today, a worldwide worry about the best ways of using the renewable sources of energy and for developing techniques to diminish pollutions. It encouraged research and development efforts in the field of alternative energy sources, and the utilization of waste forms of energy. As the fuel prices keeps on increasing, the relevant efficient energy management is required all over the place, from the smallest concern to the largest multinationals Industries. The methods and techniques adopted to improve energy utilization will vary depending on situations. But the normal standard principles of reducing energy cost relative to productivity will be same. A large number of industrial processes uses significant measurements of energy in the form of heat, all forms of energy are derived from fossils. However, the most common forms of energy-fossil fuels are petroleum, natural gas and natural gas liquids, coal and wood. hence these stored, energy forms are now being used at such a rapid rate that they will be depleted in the future, we must begin to use a expansive part of our energy not from stored, but from non conventional sources as soon as possible.

There is an impact on the running cost of a vehicle due to expanding fuel cost. The air-conditioned system adds 35 % additional cost in fuel expenses.

An automobile engine utilizes only around 35% available energy and rests are lost to cooling and exhaust system. Adding conventional air conditioning system to automobile, it utilizes about 5% of the total energy. Therefore automobile becomes more costlier, uneconomical and less efficient. So to overcome this there should be some renewable source of energy which can be used to save fuels and meet the potential, from this refrigeration should be so efficient to cool the place and meet the human comfort. The method of cooling presently used in Cars is Vapour Compression System, but refrigerants in vapor compression systems are hydrocarbons like HCFCs and HFCs, which are not ecology friendly, creating in undesirable changes in the climate and environment like global warming, ozone layer depletion, etc. Also the system required more load from the motor shaft to work the condenser.

The objective of implementing Vapour Absorption Cycle in automobiles is to lower the temperature of a space inside the vehicle by utilizing waste heat gases from engine exhaust.

Vapour Compression Cycle

Presently, in cars vapour compression cycle is used for cooling the space in vehicles. The basic components of an automobile air conditioning system are same as conventional air conditioning system except for their control and drives are different from conventional. The basic components are Compressor, Condenser, Expansion valve and Evaporator.

Compressor

The manufacturer uses a 2 cylinder compressor driven by engine shaft pulley by belts. Magnetic clutch is used so that the compressor can be disengaged when air conditioning is not required. Magnetic clutch operates on electromagnetism. In compressor the refrigerant is compressed and sends to condenser.

Condenser

The purpose of condenser is to receive the hot high pressure refrigerant and condense into liquid. In most automotive air conditioning systems, the condenser is located in front of the radiator. The high temperature refrigerant gas forced from the compressor into the condenser turns into liquid as it is cooled by the air flowing across the condenser fins. The high pressure refrigerant liquid from condenser flows into the receiver drier unit.

Receiver-Drier

Automobile air conditioner units are more prone to leak than other units because of vibrations. Over a period of time, small leaks will occur requiring the addition of refrigerant. Also the evaporator requirements vary because of changing heat load.

A small receiver is used in the system to compensate for these variables. Refrigerant is stored in the receiver until it is needed by the evaporator.

Expansion Valve

Before the high pressure liquid refrigerant reaches the evaporator, the liquid refrigerant is under 7 to 17 bar as it leaves receiver. The rate of liquid refrigerant evaporation is controlled by expansion valve positioned in lines between the receiver and the evaporator.

The expansion valve sends enough refrigerant into the evaporator to meet cooling requirements and reduces the pressure on the refrigerant to cause evaporation.

Evaporator

Evaporator is a place where the refrigerant evaporates and absorbs heat from the air passed over it. Air is forced to flow over the evaporator with the help of blower and cooled before distributing in the automobile seating space.

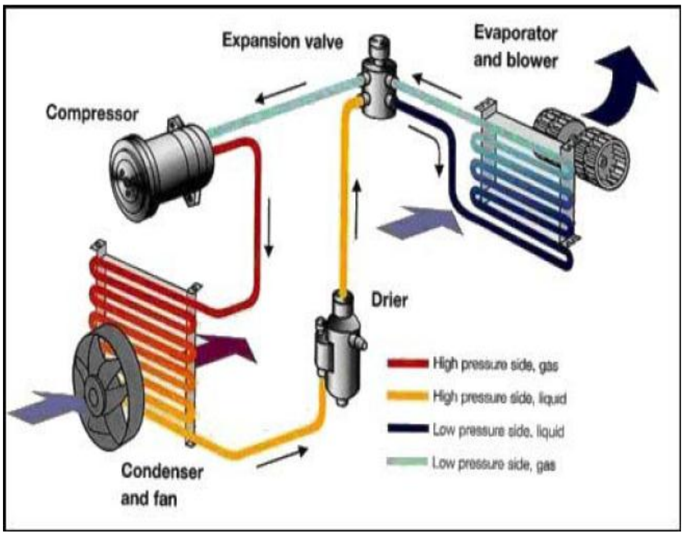

Fig. 1. Vapour compressor cycle (3).

Vapour Absorption Cycle

Vapour Absorption Cycle uses heat source to run the refrigerant in the system. The refrigerant used are Ammonia-Water solution, Lithium-Bromide solution, the basic components of Vapour Absorption System are Generator, Receiver, Condenser, Evaporator.

Generator

Generator is a heat source added to the system from external source which can be any heat source it may be steam, heat from any source, waste heat, gas burner, electric heater connections are provided for strong solution from absorber and return from rectifier to enter for the vapour and weak solution to leave.

Rectifier

Rectifier is used to cool the vapour leaving the analyser so that water vapour is condensed leaving dehydrated ammonia gas to pass to the condenser. The rectifier is generally water cooled, low temperature may cause ammonia to go into solution and leave with liquid drip that returns to analyser and to generator.

Analyser

The water vapour from the ammonia and water vapour mixture is difficult to remove; a very small fraction may be condensed or absorbed by process of cooling. The strong aqua ammonia from the absorber which is cool and the aqua ammonia from the rectifier enters the analyser and flow into the generator.

Absorber

The solution which is weak from generator and vapour from the evaporator comes in the absorber and the strong solution is send to generator the cooling water is used in tubes to remove the heat of condensation and absorption.

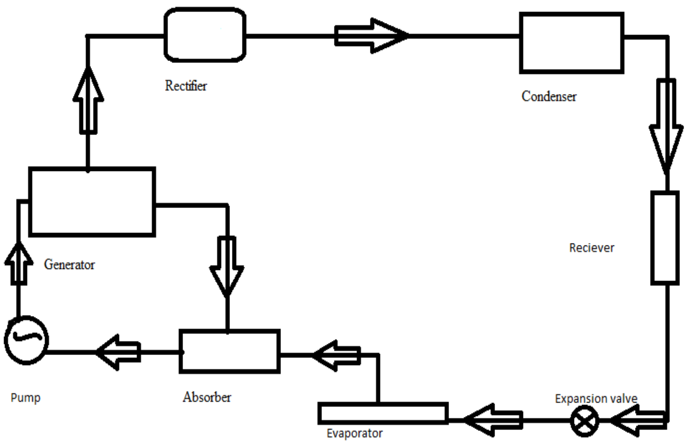

Fig. 2. Vapour absorption cycle.

II. PROBLEM IDENTIFICATIONS

The refrigerants in vapor compression systems are mainly hydrocarbons like HCFCs and HFCs, which are not environmental friendly, resulting in undesirable changes in the climate and environment like global warming, ozone layer depletion, etc. Also the system required more load for the power from the engine shaft to operate the condenser. This results in the excessive work and energy which accumulates and results in adverse environmental changes.

There are various problems that has been identified in car air conditioning system from various literature review are as follows.

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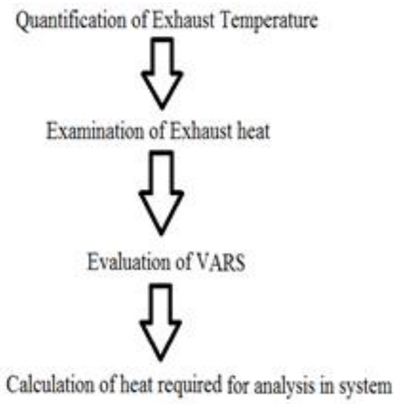
1. Due to increase cost of vehicle fuel there is a great influence on running cost of vehicle. Nearly 35% extra cost in fuel expenses is added in conventional air conditioning system of cars.
2. The life of the engine decreases due to the use of conventional air conditioning system in cars.
3. The use of conventional air conditioning system in cars increase maintenance cost.
4. Presently the air conditioned used in cars is vapour compression refrigeration system. In this refrigerant like R134 and R134a is used which is costly.
5. Environmental pollution caused by exhaust gas and heat of exhausted gases.

This Problem has been viewed and the car air conditioning is proposed using exhaust heat gas. The benefit of using Vapour Absorption Refrigeration System is that it does not affect the climate and environment conditions.

III. METHODOLOGY

Execution of Proposed Plan



Proposed Method

The proposed model is based ammonia water solution in this system; the low pressure ammonia vapour leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber. The water has the ability to absorb ammonia vapour and the solution formed is aqua ammonia. The ammonia vapour absorbed in water lowers the pressure in the absorber which takes more ammonia vapour from evaporator and rises the temperature of solution. Cooling arrangement is done in absorber to remove the heat from solution over there. To increase the absorption capacity of water it is necessary, water absorbs less ammonia at higher temperature due to which the strong solution thus formed in the absorber is pumped to generator by pump from absorber. The strong solution of ammonia is heated by exhaust heat gas. At the heating process, the ammonia vapour leaves the solution at higher pressure leaving back the hot weak solution in the generator. The weak ammonia solution comes back to absorber at low pressure after passing to pressure reducing valve. The high pressure ammonia vapour is condensed in the condenser from generator to high pressure liquid ammonia. The liquid ammonia is passed to receiver to expansion valve then to evaporator. The generator is mounted as close to the exhaust manifold as possible to save on heat losses from the gases before they are routed through the generator heat exchangers.

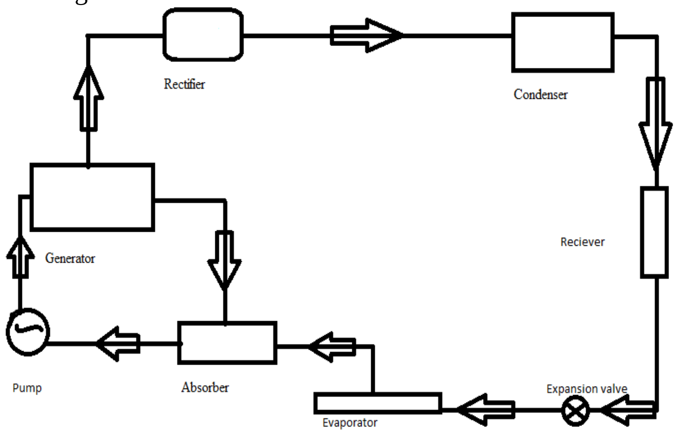


Fig. 3. Proposed model of VARS.

Load Estimation

One of the critical issues or tasks in designing a system, like car air conditioning system, is to calculate the cooling load that should be removed from the required place. There are many considerations taken into account in calculating the cooling load. Heat sources, will impose loads on the cooling equipment, and may be listed as follows (1):

S. No	Heat Load	Amount of Heat(kJ/hr)
1.	Solar radiation (roof, walls glasses)	300
2.	Normal heat gain through glasses	1200
3.	Normal Heat gain through walls	4300
4.	Air leakage	1000
5.	Passenger including driver (5)	1200
6.	Heat radiated from engine	2000
	Total	10000

Available Waste Heat from Engine Exhaust

The available waste heat at the exhaust is proportional to the mass flow rate of exhaust gas and the temperature of exhaust gas.

$$Q_{exh}=m_{exh}C_p\,(T_{exh}-T_\infty)$$

Where, Q_{exh} is the heat lost at the exhaust (kJ/min); m_{exh} is the mass flow rate of exhaust gas; Cp is the specific heat of exhaust gas (kJ/kg^{o}k); T_{exh} is temperature of exhaust gas; T_∞ is the ambient temperature. The exhaust temperature is calculated by (13).

$$T_{exh}=0.138N-17$$

Where, N is Revolution Per Minute (RPM)

Calculation of Heat Loss from Exhaust of IC Engine

Heat lost from the engine exhaust gas of IC engine is calculated by taking following assumptions.

a. Volumetric Efficiency (η_v) = 0.8 - 0.9
b. Calorific value of diesel= 42 - 45 MJ/Kg
c. Density air fuel = 0.66 Kg/m^3
d. Specific heat of exhaust gas = 1.0 - 1.25 KJ/Kg K
e. Air Fuel Ratio = 12-17

Taking engine of Toyota Innova, diesel engine with intercooler, variable nozzles, turbocharger, 4 inline cylinders, and 16 valves.

TABLE I. Engine specifications.

Capacity	2393 cc
Maximum Output	110 KW @ 3400 RPM
Maximum Torque	343 NM @ 1400-2800 RPM
RPM	1400-2800 RPM

Calculations of Exhaust Gas Temperature and Heat

The engine at 1400 rpm

$N=1400$

$T_{exh}=0.138N-17$

$T_{exh}=0.138\times1400-17$

$T_{exh}=176\ ^0C$

Mass flow rate of air at 1400 rpm

$$m_a = \rho a \times \frac{N}{2} \times vs \times \eta v$$

$$=0.66 \times \frac{1400}{2\times60} \times 2393 \times 0.9$$

$$=0.01658 \text{ Kg/s}$$

Mass flow rate of fuel (m_f)

For diesel engine Air Fuel Ratio is 14:1

$$\text{Air Fuel Ratio} = \frac{m_a}{m_f}$$

$$14 = \frac{0.01658}{m_f}$$

$$m_f = 0.0011842 \text{ Kg/s}$$

Mass flow rate of exhaust gas (m_{exh})

$m_{exh} = m_a + m_f$

$m_{exh} = 0.0011842 + 0.01658$

$m_{exh} = 0.017764$ Kg/s

We get exhaust heat (Q_{exh})

$Q_{exh} = 0.017764\times1.05\times(176-35)$

$Q_{exh} = 2.62$ KW

TABLE II. Calculated exhaust gas, mass flow rate and exhaust heat at different rpm.

S. No	N (RPM)	T_{exh} (°C)	m_{exh} (Kg/s)	Q_{exh} (KW)
1.	1400	176	0.01776	2.62
2.	1600	203	0.02027	3.57
3.	1800	231	0.02284	4.70
4.	2000	259	0.02538	5.96
5.	2200	286	0.02791	7.35
6.	2400	314	0.03045	8.92
7.	2600	341	0.03298	10.59
8.	2800	369	0.03552	12.46

In table exhaust gases at certain temperature can be calculated by equation at different engine rpm. Exhaust gas flow and exhaust heat at different engine rpm can be calculated by equation . This table shows that at different rpm sufficient heat is available at engine exhaust to drive car air conditioning at 0.80 TR at all climatic conditions.

Mathematical Analysis of Air Conditioning

Assuming the following parameter needed for calculations for air conditioning in cars.

The assumption is based on the cars capacity and cooling load required to cool the space. Here the system must be efficient to cool the required space, the calculation needed for vapour absorption system to exist in cars.

Condenser Temperature =48ºC
Evaporator Temperature =8ºC
Refrigeration Capacity =0.80 TR
Absorber Temperature =42ºC
Degasification Factor =0.04

Vapour Absorption System Calculations

Flow rate of refrigerant in evaporator

$Q_{eva} = m \times (h_4 - h_3)$

$0.80 = m \times (1620 - 560)$

$$m = 2.641 \times 10^{-3} \ \frac{kg}{s}$$

Heat carried from evaporator by cooling air

$$Q_{cooling\ air} = m_a \times C_p \times (t_{inlet} - t_{outlet}) = Q_{eva}$$

T_{inlet} is inlet temperature of air inside car cabin before crossing evaporator (27ºC).

T_{outlet} is outlet $_{temperature}$ of air inside car cabin after crossing the cooling air (9ºC).

Mass of cold air in evaporator

$$m_a = 0.1547\ Kg/s$$

Discharge

$$q = \frac{m_a}{\rho_a}$$

Taking density of air at evaporator temperature 6.5ºC from data book

$$q = \frac{0.1547}{1.263}$$

$q = 0.1244\ m^3/s$

$q = 440.9\ m^3/hr$

Heat removed from the condenser

$Q_{cond} = m \times (h_1 - h_2)$

$Q_{cond} = 2.641 \times 10^{-3} \times (1660 - 560)$

$Q_{cond} = 2.9051$ KJ/s

Heat carried out from condenser by cooling air

$$Q_{air} = m_a \times c_p \times (t_{out} - t_{in}) = Q_{cond}$$

$$m_a = \frac{2.905}{1.005\times(42-39)}$$

$m_a = 0.9635$ Kg/s

Discharge of hot air from condenser

$$q = \frac{m_a}{\rho_a}$$

Density of air at condenser temperature 48ºC from data book

$\rho_a = 1.10\ Kg/m^3$

$$q = \frac{0.9635}{1.10}$$

$q = 0.875\ m^3/s$

$q = 3153\ m^3/hr$

Heat removed from absorber

$Q_{ab} = m \times (h_4 - h_a)$

$= 2.641 \times 10^{-3} \times (1620 - 80)$

$Q_{ab} = 4.06$ KJ/s

Heat carried out from absorber by cooling air

$$m_a = \frac{4.06}{1.005\times(39-36)}$$

$m_a = 1.348$ Kg/s

Discharge of cooling air from absorber

$$q = \frac{m_a}{\rho_a}$$

Density of air at absorber temperature 42ºC from data book

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$$q = \frac{1.348}{1.120}$$
$$q = 1.20 \text{ Kg/s}$$
$$q = 4332 \text{ Kg/hr}$$

Heat given in generator

$$Q_g = m \times (h_{12} - h_a)$$
$$Q_g = 2.641 \times 10^{-3} \times (1900 - 80)$$

Using mass balance equation

Mass of strong solution = Mass of Refrigerant + Mass of weak solution

$$M_S = M_R + M_W$$

Using Material balance for ammonia

$$M_S C_S = M_R C_R + M_W C_W$$
$$(M_R + M_W) C_S = M_R C_R + M_W C_W$$

For ammonia $C_R = 1$

$$C_S = 0.48$$
$$C_W = 0.44$$
$$(2.641 \times 10^{-3} + M_W)\, 0.48 = 2.641 \times 10^{-3} \times 1 + M_W \times 0.44$$
$$M_W = 0.034 \text{ Kg/s}$$
$$M_S = M_R + M_W$$
$$= 2.641 \times 10^{-3} + 0.034$$
$$M_S = 0.036 \text{ Kg/s}$$

Heat from Heat Exchanger

$$Q_{exh} = M_W \times (h_7 - h_6)$$
$$Q_{exh} = 0.034 \times (330 - 85)$$
$$Q_{exh} = 8.33 \text{ KJ/s}$$

Now, Pump work

$$W_p = M_S \times (p_6 - p_5) \times \vartheta_5$$

Specific volume is given by

$$\vartheta_5 = (1 - C_6) \times \vartheta_{H2O} + C_6 \times \vartheta_{NH3}$$

Specific volume at 42ºC absorber temperature of ammonia and water

$$= (1 - 0.48) \times 0.001008 + 0.48 \times 1.73 \times 10^{-3}$$
$$\vartheta_5 = 1.354 \times 10^{-3}$$
$$W_p = 0.036 \times (20 - 8) \times 10^5 \times 1.354 \times 10^{-3}$$
$$W_p = 58.49 \text{ W}$$

Coefficient of Performance

Practically for Vapour Absorption System the COP is calculated by:

$$COP = \frac{\text{Refrigeration Effect}}{\text{Heat given to the generator} + \text{Pump work}}$$
$$= \frac{0.80 \times 3.5}{4.80 + 0.05849}$$
$$COP = 0.57$$

TABLE III. Calculated exhaust heat and COP at different RPM.

S. No	RPM	Q_{gen}	COP
1.	1400	2.62	1.0456
2.	1600	3.57	0.7712
3.	1800	4.70	0.5884
4.	2000	5.96	0.4652
5.	2200	7.35	0.3779
6.	2400	8.92	0.3118
7.	2600	10.59	0.2629
8.	2800	12.46	0.2236

IV. Results and Discussions

The COP is generally controlled by two components i.e. evaporator and generator, when these values changes the value of COP changes.

From the results obtained it is seen that Air conditioning in cars by Vapour Absorption System may be feasible with reduction in fuel cost and with less effect in climatic conditions. The heat generated found from the exhaust temperature from the figure 4 shows the heat from the generator directly proportional with the exhaust gas temperature meaning lower COP is obtained at higher exhaust gas temperature. It is clear that the system is feasible to be design with reduction in fuel cost and power consumption.

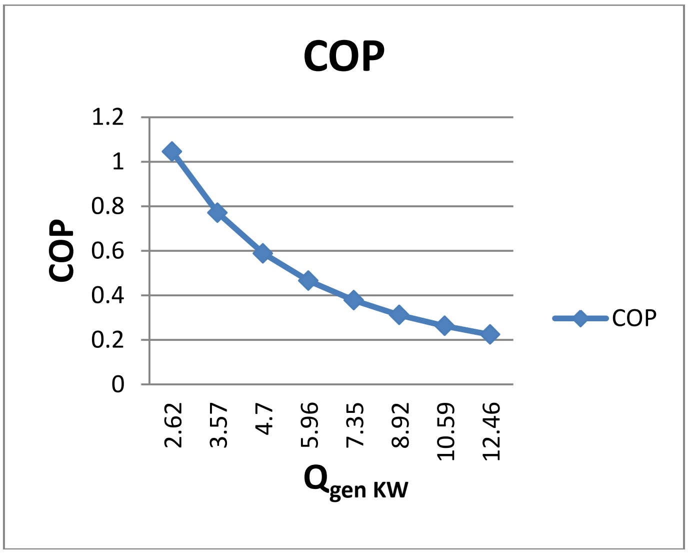

Fig. 4 COP Vs Q_{gen}

In figure 5 shows the variation of exhaust gas temperature with the engine RPM at different loads. The temperature increases with the engine speed, it means that the higher the engine speed higher will be the exhaust temperature obtained and the temperature is sufficient for driving A/C.

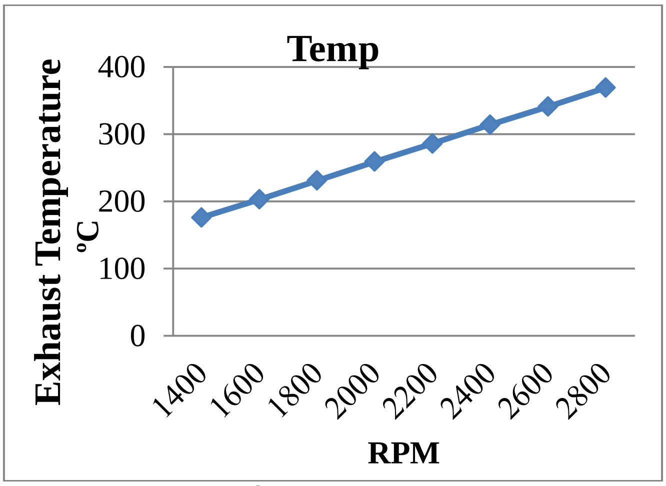

Fig. 5. Exhaust Temperature Vs RPM.

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In figure 6 shows the variation of mass flow rate with the engine RPM. It shows that when the speed of engine increases the mass flow of exhaust gas through exhaust manifold increases, so there is enough flow that can vaporize the refrigerant of VARS.

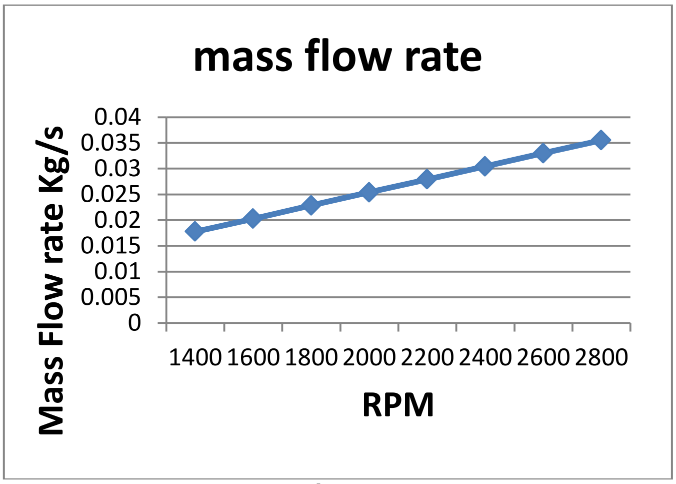

Fig. 6. Mass Flow Rate Vs RPM.

In figure 7 shows the variation of exhaust heat with the engine RPM. It shows the exhaust gas is proportional to the engine speed, the heat available in the exhaust gas can able to vaporize the aqua ammonia solution to run the cycle.

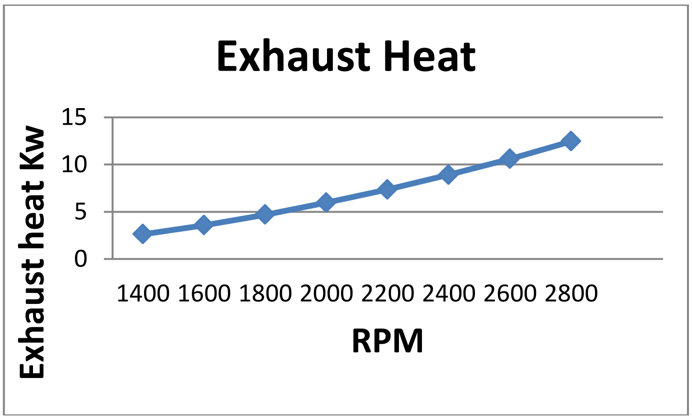

Fig. 7. Exhaust heat Vs RPM.

The data reported in tables and graphs shows the variation in COP and the heat available in the exhaust or heat available at the generator. From the equation the COP is inversely proportional to heat available at the exhaust and the pump work.

V. CONCLUSIONS

It may be concluded from the previous tables and graphs that it may be possible to design the system which can able to run A/C from the exhaust gas by Vapour Absorption System which only requirement is exhaust heat. And from various factor that affect the climate and environment condition the system is good for ecology as the refrigerant which cause depletion of ozone can be replaced by the refrigerant which is eco-friendly. The waste heat can be utilized and converted into useful work. The COP is in between 1.0456 to 0.2236 from this it can be said that the vapour absorption system can be enough to cool the require space.

Scope of further work may be done if it can be analyzed and design can be used in future by implementing in cars. It would be great impact on cars running condition and system load and may be influence in car fuel prices.

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