THERMAL ANALYSIS OF ENGINE EXHAUST WASTE HEAT REUTILIZING IN AUTOMOTIVE AIR CONDITIONING

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Abstract

Today's scenario, a large number of industrial processes uses significant measurements of energy in the form of heat. The most common forms of energy are fossil fuels like petroleum, natural gas, coal and wood. With the increase hike in fuel consumption and economic changes the vehicle become costlier and uneconomical. Also the refrigerant used in air conditioning of automobile 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 the exhaust temperature can be used as an alternative to run the air conditioning by vapour absorption refrigeration system in automobile. In Vapour absorption refrigeration system uses heat source to run the system as compressor of the engine is replaced by generator and absorber with pump, except for condenser and evaporator. To convert into useful work the waste heat can be utilized whereas the cooling capacity of refrigerator is 0.80 TR. To comfort the humans many new technologies have been developed in automobile and many theories and discussion being done on their performance. Many researchers have suggested that it could be the source for power generation, heat into electric work and many more. Thus a modification also required in automobile air conditioning because of some useful work has to be taken to drive air condition system. Many refrigerants have been banned due to reduce the ozone depletion and increase in global warming. Therefore, it is necessary to have an alternative source which will be reliable and meet the future requirements in automobiles. In this paper thermal analysis of vapour absorption system is done. The different component of vapour absorption system which includes generator, condenser, evaporator, and absorber are analysed at different conditions.

Keywords: *VCRS, VARS, exhaust heat, air conditioning, COP.*

1. Introduction

Today is the big problems about the best ways of utilization of 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. A large number of industrial processes use 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 an expansive part of our energy not from stored, but from non-conventional sources as soon as possible.

The air-conditioning system adds 35% additional costs 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 costly, 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 vehicles is Vapour Compression System, but refrigerants in vapour 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.

1.1 Vapour Compression Cycle

Presently, the 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 of vapour compression cycle are Compressor, Condenser, Expansion valve and Evaporator.

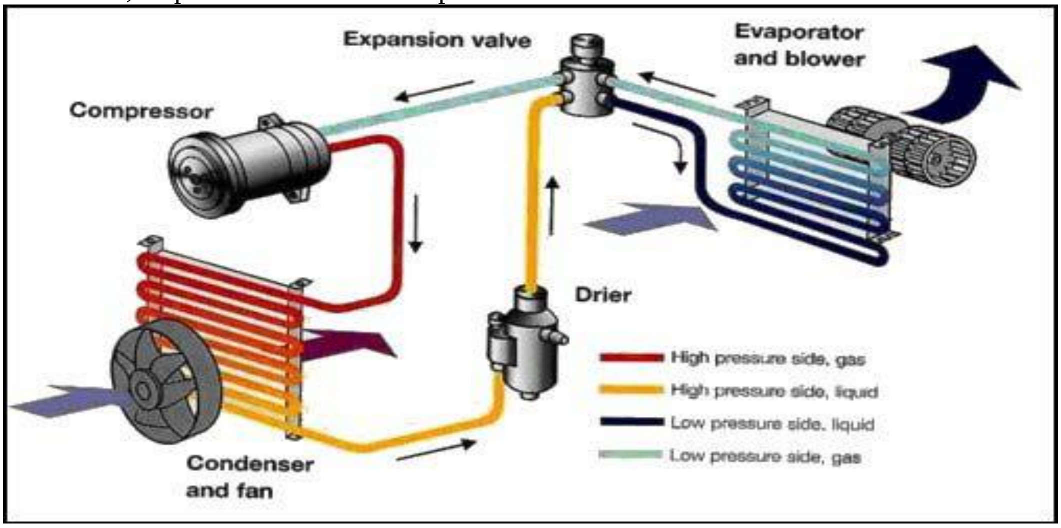

Figure 1. Vapour compressor cycle (source [3])

Compressor

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

Condenser

The hot high pressure refrigerant is received by condenser and it is condense into liquid. The condenser is located in front of the radiator in most automotive air conditioning systems. 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.

1.2 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.

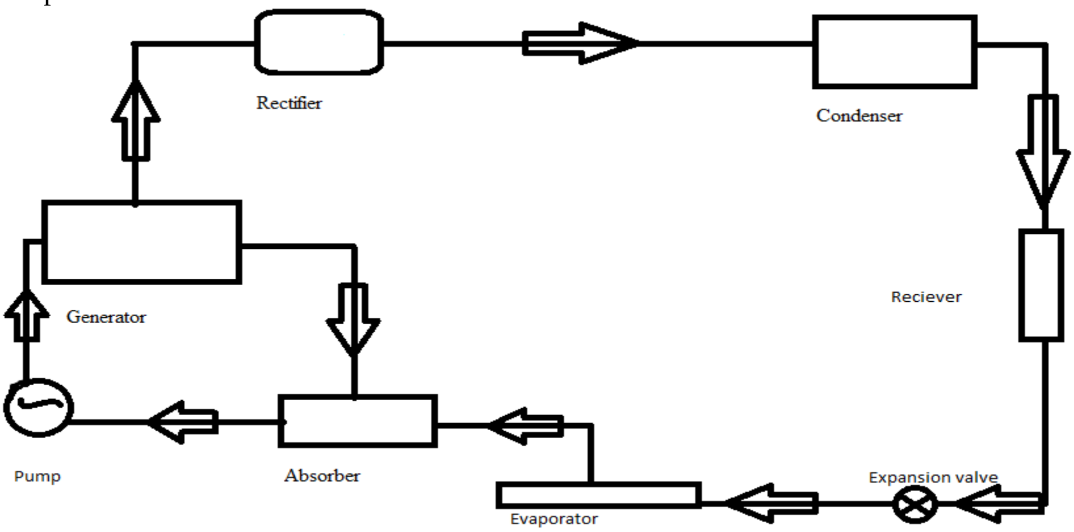

Figure 2. Vapour absorption cycle

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 enter 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.

2. Problem identifications

The refrigerants in vapour compression systems are mainly hydrocarbons like Hydro Chloro Fluoro Carbon (HCFC) and Hydro Fluoro Carbon (HFC), 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 air conditioning system in vehicles from various literature review are as follows.

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 air conditioning in vehicle 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.

3. Methodology

The methodology used in this paper is proposed model based on 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.

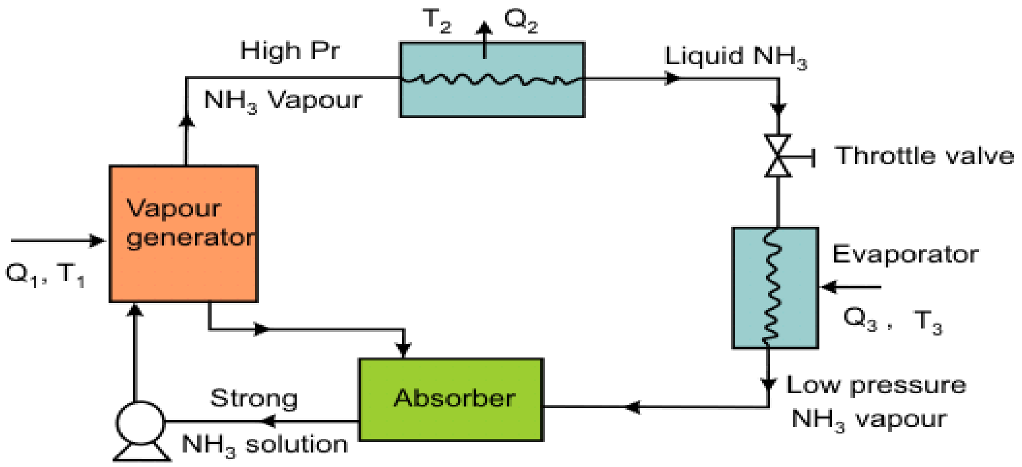

Figure 3. Proposed model of Vapour absorption refrigeration system

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 in Table 1.

Table 1. Load Estimation

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

Source [1]

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

$$\dot{Q}_{exh} = \dot{m}_{exh}\, C_p\, (T_{exh} - T_0) \quad (1)$$

Where; Q_{exh} is the heat lost at the exhaust (kJ/s); m_{exh} is the mass flow rate of exhaust gas; C_p is the specific heat of exhaust gas (kJ/kg^{0}k); T_{exh} is the temperature of exhaust gas; T_0 is the ambient temperature.

The exhaust temperature is calculated by (13).

$$T_{exh} = 0.138N - 17 \quad (2)$$

Where, N is Revolution per minute (RPM) and T_{exh} in ^{0}C

4. Performance Analysis

Heat lost from the engine exhaust gas of IC engine is calculated by following consideration:

Volumetric Efficiency (η_v)	=	0.8 - 0.9
Calorific value of diesel	=	42 - 45 MJ/Kg
Density air fuel	=	0.66 Kg/m^3
Specific heat of exhaust gas	=	1.1 - 1.25 KJ/Kg K
Air Fuel Ratio	=	12-17

Table2. Specification of Engine

Manufacture	Toyota Innova
Engine	Diesel engine with turbocharger, 4 inline cylinders and 16 valves.
Capacity	2393 cc
Air Fuel Ratio	14:1
Maximum output	110 KW@ 1400-2800 RPM
Maximum Torque	343 NM @ 1400-2800 RPM
RPM	1400-2800 RPM
Cooling System	intercooler

4.1 Exhaust Gas Temperature and Heat

For engine N = 1400 rpm

Substitute the value of N in equation (2), yields

$$T_{exh} = 0.138N\text{-}17 = 0.138\times1400 - 17 = 176\ ^0C$$

Mass flow rate of air $\dot{m}_a$:

$$\dot{m}_a = \rho_a \times \frac{N}{2} \times V_s \times \eta_v \quad (3)$$

$$= 0.66 \times \frac{1400}{2\times 60} \times 2393 \times 10^{-6} \times 0.9 = 0.01658 \text{ Kg/s}$$

Mass flow rate of fuel ($\dot{m}_f$):

$$\text{Air Fuel Ratio} = \frac{\dot{m}_a}{\dot{m}_f}, \quad 14 = \frac{0.01658}{\dot{m}_f}$$

$$\dot{m}_f = 0.0011842 \text{ Kg/s}$$

Mass flow rate of exhaust gas ($\dot{m}_{exh}$)

$\dot{m}_{exh} = \dot{m}_a + \dot{m}_f$
$= 0.0011842 + 0.01658 = 0.017764$ Kg/s

From equation (1), yields

Exhaust heat $\dot{Q}_{exh} = 0.017764 \times 1.05 \times (176\text{-}35) = 2.62$ KW

4.2 Vapour Absorption System

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
Absorber Temperature	=	42ºC
Refrigeration Capacity	=	0.80 TR
Degasification Factor	=	0.04

Flow rate of refrigerant in evaporator ($\dot{m}_{ev}$)

$$\dot{Q}_{ev} = \dot{m}_{ev} \times (h_4 - h_3) \tag{4}$$

$0.80 \times 3.5 = \dot{m}_{ev} \times (1620 - 560)$

$\dot{m}_{ev} = 2.641 \times 10^{-3}$ Kg/s

Heat carried from evaporator by cooling air

$$\dot{Q}_{ac} = \dot{m}_{ac} \times C_p \times (T_{in} - T_{out}) = \dot{Q}_{ev} \tag{5}$$

Where, T_{in} = inlet temperature of air inside car cabin before crossing evaporator = 27ºC.
T_{out} = outlet temperature of air inside car cabin after crossing the cooling air = 9ºC.

From equation (5), yields

Mass of cold air in evaporator $\dot{m}_{ac} = 0.1547$ Kg/s

$$\text{Discharge (q)} = \frac{\dot{m}_{ac}}{\rho_a} \tag{6}$$

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

$q = \frac{0.1547}{1.263} = 0.1244\ m^3/s = 440.9\ m^3/hr$

Heat removed from the condenser ($\dot{Q}_{cond}$)

$$\dot{Q}_{cond} = \dot{m}_{cond} \times (h_1 - h_2) \tag{7}$$

$= 2.641 \times 10^{-3} \times (1660 - 560) = 2.9051$ Kg/s

Heat carried out from condenser by cooling air

$$\dot{Q}_{a\,con} = \dot{m}_{a\,con} \times C_p \times (T_{out} - T_{in}) = \dot{Q}_{cond} \tag{8}$$

Mass of air in evaporator ($\dot{m}_{a\,con}$)

$(\dot{m}_{a\,con}) = \frac{2.905}{1.005 \times (42-39)} = 0.9635$ Kg/s

Discharge of hot air from condenser

$q = \frac{\dot{m}_{a\,con}}{\rho_a} = 0.875\ m^3/s = 3153\ m^3/hr$

Here density of air at condenser temperature 48ºC from data book, $\rho_a = 1.10\ Kg/m^3$

Heat removed from absorber

$$\dot{Q}_{ab} = \dot{m}_{ab} \times (h_4 - h_a) \tag{9}$$

$= 2.641 \times 10^{-3} \times (1620 - 80) = 4.06$ KJ/s

Heat carried out from absorber by cooling air

$$\dot{Q}_{a\,ab} = \dot{m}_{a\,ab} \times C_p \times (T_{out} - T_{in}) = \dot{Q}_{ab} \tag{10}$$

$\dot{m}_{a\,ab} = \frac{4.06}{1.005 \times (39-36)} = 1.348$ Kg/s

Discharge of cooling air from absorber

$q = \frac{\dot{m}_{a\,ab}}{\rho_a} = 1.20$ Kg/s $= 4332$ Kg/hr

Here density of air at absorber temperature 42ºC from data book $\rho_a = 1.120\ Kg/m^3$

Heat given in generator

$$\dot{Q}_g = \dot{m}_{a\,g} \times (\Delta h) \tag{11}$$

$= 2.641 \times 10^{-3} \times (1900 - 80) = 4.806$KJ/s

Using mass balance equation

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

$$M_S = M_R + M_W \quad (12)$$

Using Material balance for ammonia

$$M_S C_S = M_R C_R + M_W C_W \quad (13)$$

From Equation (12), Substitute the value of Ms in Equation (13), yields

$$(M_R + M_W) C_S = M_R C_R + M_W C_W \quad (14)$$

For ammonia, $C_R = 1$, $C_S = 0.48$, $C_W = 0.44$, Equation (14) becomes

$$(2.641 \times 10^{-3} + M_W)\, 0.48 = 2.641 \times 10^{-3} \times 1 + M_W \times 0.44$$

$$M_W = 0.034 \text{ Kg/s}$$

Substitute the values in Equation (12), yields

$$MS = 0.036 \text{ Kg/s}$$

Heat from Heat Exchanger

$$\dot{Q}_{exh} = M_W \times (h_7 - h_6) \quad (15)$$

$$= 0.034 \times (330 - 85) = 8.33 \text{ KJ/s}$$

Now, Pump work

$$Wp = M_S \times (p_6 - p_5) \times \dot{\vartheta}_5 \quad (16)$$

Specific volume at 42ºC absorber temperature of ammonia and water is given by

$$\dot{\vartheta}_5 = (1 - C_6) \times \dot{\vartheta}_{H2O} + C_6 \times \dot{\vartheta}_{NH3} \quad (17)$$

$$= (1 - 0.48) \times 0.001008 + 0.48 \times 1.73 \times 10^{-3} = 1.354 \times 10^{-3}\, M^3/Kg$$

Substitute all the values in Equation (16), yields

$$Wp = 0.036 \times (20 - 8) \times 10^5 \times 1.354 \times 10^{-3} = 58.49 \text{ W}$$

4.3 Coefficient of Performance

Practically for Vapour Absorption System the COP is calculated by:

$$COP = \frac{\text{Refrigeration effect}}{\text{Heat given to the generator} + \text{Pump work}} \quad (18)$$

$$= \frac{0.80 \times 3.5}{4.80 + 0.05849} = 0.57$$

5. Results and Discussions

Table 3.Exhaust gas temperature, mass flow rate and exhaust heat at different rpm

S. No	N (RPM)	$T_{exh}(^0C)$	$\dot{m}_{exh}$ (Kg/s)	$\dot{Q}_{exh}$ (Kg/s)
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

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.

Table 4. Exhausts heat and COP at different RPM

S. No.	N (RPM)	$\dot{Q}_{exh}$ (Kg/s)	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

The variation of exhaust gas temperature with the engine RPM at different loads as shown in figure 4. 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 air conditioning.

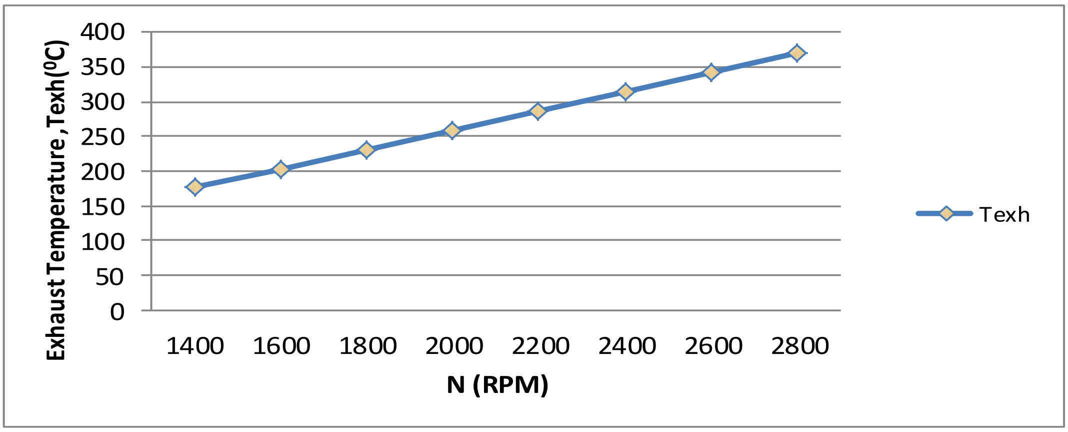

Figure 4. Exhaust Temperature Vs RPM

The variation of mass flow rate with the engine RPM represent in figure number 5. 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 Vapour Absorption Refrigeration System (VARS).

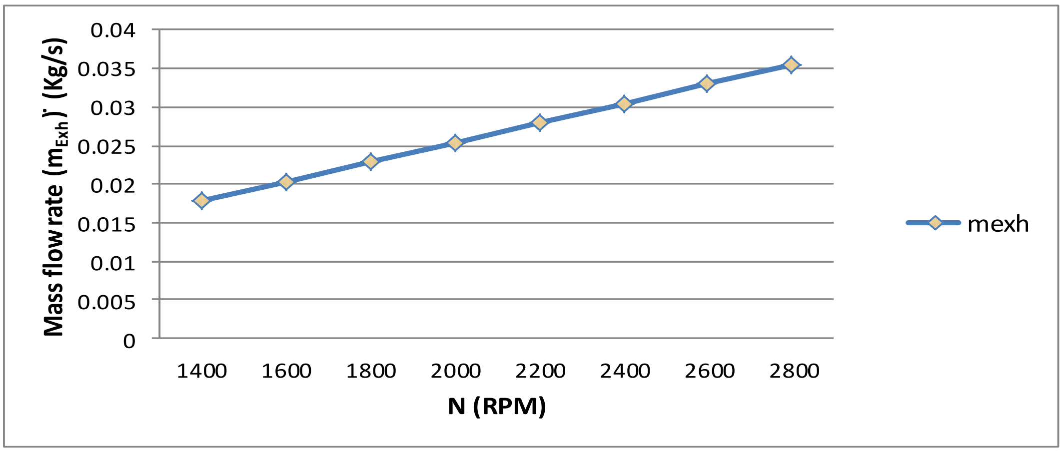

Figure 5. Mass Flow Rate Vs RPM

In figure 6 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.

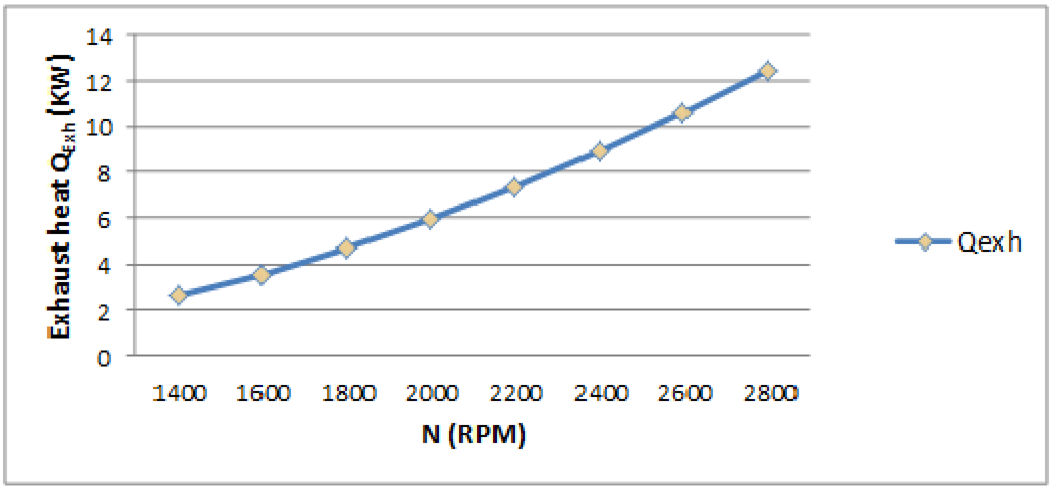

Figure 6. Exhaust heat Vs RPM

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 7 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.

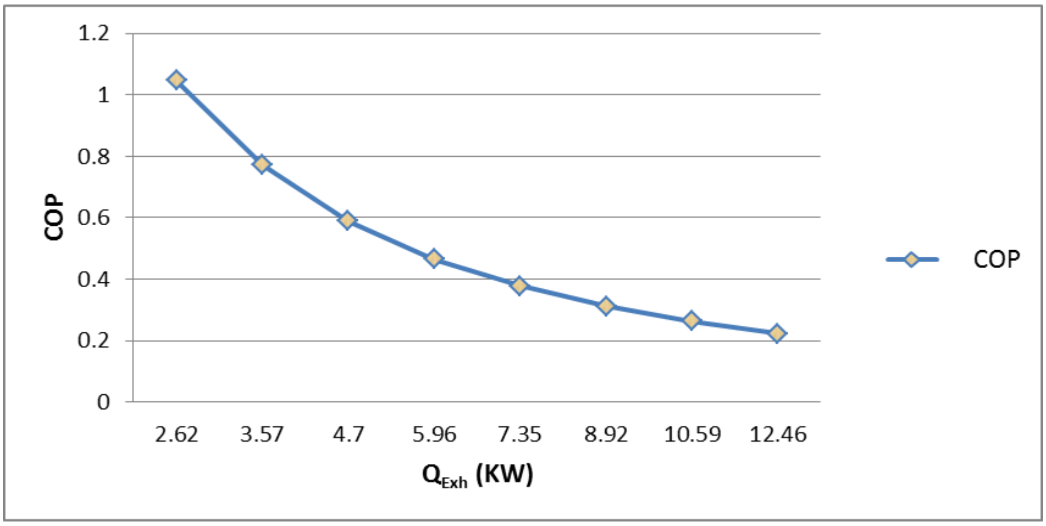

Figure 7. COP Vs Q_{Exh}

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.

6. 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 analysed 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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