Experimental Analysis Of An I.C Engine Exhaust Driven Ammonia-Water Absorption Refrigeration System

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***Abstract*—The increase in cost and demand for energy lead the researchers to think about proper utilization of available energy sources and to minimize waste energy. A vapour absorption refrigeration system attracts attention as it can be operated with low grade heat energy such as solar energy or waste heat energy. Major part of the energy supplied by the fuel in an automotive internal combustion engine is wasted as heat in the exhaust system. This waste heat could be recovered and applied to power auxiliary systems in a vehicle and can be contributed to its overall energy efficiency such as a vapour absorption system. In the present work, the experimental analysis of an absorption refrigeration system is to be performed. The exhaust system of an automotive internal combustion engine is connected to the generator element of an absorption refrigeration system. The performance of the refrigerator is to be evaluated as a function of the supplied heat. The performance of absorption refrigeration system will be analyzed based on varying test conditions.**

1. INTRODUCTION

Major part of energy generated by an automotive internal combustion engine is wasted as heat in exhaust system (around 2/3rd). The recovery and utilization of waste heat not only conserves fuel, but also reduces the amount of waste heat and greenhouse gases damped to environment. The waste heat could be recovered and applied to power auxiliary systems like air conditioning system. The air conditioning system used usually in a vehicle is a vapour compression refrigeration system which draws significant power from engine output for its operation. Also the refrigerants used in VCR system (mainly HCFCs and HFCs) are not ecofriendly. A vapour absorption refrigerating system can replace the conventional system which is driven by the low grade heat energy from engine exhaust. Partial recovery of energy from exhaust gases will increase the IC engine efficiency and also will reduce the emissions. To this end, the exhaust system of an automotive ICE was connected to the generator element of a commercial ammonia water absorption refrigerator originally designed to operate with the heat produced by electric heating and experimental study is conducted on the same.

1.1 WORKING PRINCIPLE OF VAPOUR ABSORPTION REFRIGERATION SYSTEM

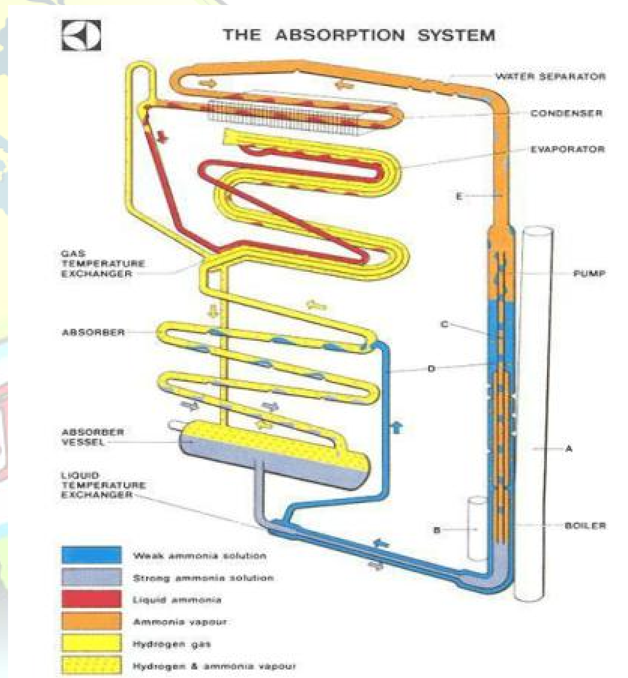

Fig1: Schematic representation of VAR system

The unit consists of four main parts - the boiler, condenser, evaporator and the absorber. The unit can be run on waste exhaust gas heat. When the unit operates on the exhaust gas, the heat is supplied by the exhaust gas which is fitted underneath the central tube (A) and when the unit operates on electricity the heat is supplied by a heating element inserted in the pocket (B). The unit charge consists of a quantity of ammonia, water and hydrogen at a sufficient pressure to condense ammonia at the room temperature for which the unit is designed. When heat is supplied to the boiler system, bubbles of ammonia gas are produced which rise and carry with them quantities of weak ammonia solution through the siphon pump (C). This weak solution passes into the tube (D), whilst the ammonia vapour passes into the vapour pipe (E) and on to the water separator. Here the water vapor is condensed and runs back into the boiler system leaving the dry ammonia vapour to pass to the condenser. Air circulating over the fins of the condenser removes the heat from the ammonia vapour to cause it to condense into liquid ammonia which flows into the evaporator. The evaporator is supplied with hydrogen. The hydrogen passes across the surface of the ammonia and lowers the ammonia vapour pressure sufficiently to allow the liquid ammonia to evaporate. The evaporation of the ammonia extracts heat from the cabin , as described above, thereby lowers the temperature inside the refrigerator. The mixture of the ammonia and the hydrogen vapour passes from the evaporator to the absorber. Entering the upper portion of the absorber is a continuous trickle of weak ammonia.

The main disadvantage of vapour compression refrigeration system is that the required power to run the compressor is taken from the engine main shaft, hence to maintain the same power the engine has to produce more work consuming more fuel. In a Vapour Absorption Refrigeration System, a physicochemical process replaces the mechanical process of the Vapour Compression Refrigeration System by using energy in the form of heat rather than mechanical work. VAR system has less moving parts so reduced wear and tear as compared to VCR system. An important point to mention absorption refrigeration systems is the continuing substitution of chlorinated fluorocarbons (CFCs) by alternative refrigerants. CFC causes environmental pollution and global warming

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In the absorption refrigeration system, two working fluids are used: a refrigerant and an absorbent. The refrigerant used in this experiment is NH_3 and the absorbent is H_2O, with the third fluid hydrogen. The third fluid used is an inert gas which remains mainly in the evaporator thus reducing the partial pressure of the refrigerant to enable it to evaporate at low pressure and hence low temperature. Hydrogen is chosen as the third fluid as it is non-corrosive and insoluble in water.

NH_3 is naturally, environmentally benign less toxic and inexpensive. It has a molecular weight of 17.031, boiling point of -33.313^{0}C and freezing point of -77.7^{o}C. Both NH_3 and H_2O are highly stable at a wide operating temperature and pressure range. Ammonia has a high enthalpy of vaporization, which is necessary for satisfactory system performance.

The main objective of this project work is to investigate the performance of a vapour absorption refrigeration system driven by engine exhaust at varying input parameters.

In the journal "Energy and Exergy analysis on gasoline engine based on mapping characteristics experiment" Jianqin

Fu et al.[1]. explained about the exergy efficiency of exhaust gas energy. He pointed that gasoline engine fuel efficiency can come upto 60% through waste heat recovery. So this heat energy can be recovered and can be used to power a vapour absorption refrigeration system for cabin cooling.

Hugues L. Talom et al.[2]. explains about the advantages of vapour absorption refrigeration system over conventional vapour compression refrigeration system. In his work he modified a 3 ton (10.55KW) absorption chiller for hot gas intake and matched to a 2.8 L V6 I.C engine. He concluded that the system is feasible but further research is needed to improve the reliability and regulatory issues of the system.

K.Balaji et al.[3]. studied about the use of refrigerant pair LiBr – H_2O in a VAR system which is driven by using waste heat in sugar industry. In Li-Br- H_2O pair H_2O acts as the refrigerant and LiBr acts as the absorbent. It cannot be operated under 4^{O}C because of crystallization. Also LiBr is corrosive in nature.

Manzela et.al.[4]. used a commercial 215- l refrigerator coupled with 1.6 – l , 8 valve 4 cylinder automotive engine. They concluded that engine exhaust is a potential power source for absorption refrigeration system. They also noticed that carbon monoxide mission has decreased when the absorption refrigerator was installed.

Christo Ananth et al. [5] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

In their research paper Janardhanan.k et al.[6]. Also mentioned about the advantages of VAR system over conventional VCR system. They suggested a LiBr – H_2O system for the cooling purpose.

Y.Z. Lu et al.[7]. conducted experimental studies on the practical performance of an adsorption air conditioning system powered by exhausted heat from a diesel locomotive. They observed that the adsorption system can provide the desired cooling effect to the driver's cab except when the locomotive tracts a way train. The average cooling effect ranging from 3.0 to 4.2 kW is achieved.

Satish Raghuvanshi et al.[8]. Analyzed a single stage VAR system using first law of thermodynamics. They carried out energy analysis of each component in the VAR system and numerical results for the cycle were tabulated.

J. S. Jadhao et al.[9]. The studied about the possibility of waste heat recovery from internal combustion engine, also calculated the exhaust gas energy of an internal combustion engine. He suggested that the waste heat can be used for heating purpose, power generation purpose etc. Thus the fuel economy can be improved.

M.I. Karamangil et al.[10]. done a detailed review on ARSs and working fluids used. And also thermodynamic analysis of single-stage ARS using different refrigerant–absorbent pairs was performed and the theoretical performances of the cycles were compared. The simulation results showed that the COP values of the cycles increase with increasing generator and evaporator temperatures, but decrease with increasing condenser and absorber temperatures as expected. They observed that the generator temperature has significant influence on the COP.

Christy V Vazhappilly et al.[11] developed a prototype of an absorption system for refrigeration using heat from the exhaust-gases. They replaced the heating coil generator system of commercial vapour absorption refrigeration system by the frame plate type heat exchanger.

A.Ramanathan et al.[12] simulated an absorption refrigeration system powered by engine exhaust gases. They observed that for engine rotations as low as 1300 rpm, up to 2 kW power could be extracted from the engine exhaust.

A. Zohar et al.[13] developed a thermodynamic model for an ammonia–water diffusion absorption refrigeration (DAR) cycle with hydrogen or helium as the auxiliary inert gas. Performance of the system was examined parametrically by computer simulation. The DAR showed best performance for a concentration range of the rich solution of 0.2–0.3 ammonia mass fraction and the recommended concentration of the weak solution was 0.1. They found that as the degree of rectification decreased, the performance of the DAR cycle decreased. They also observed that the COP of a DAR unit working with helium as inert gas was higher by up to 40% than a cycle working with hydrogen.

EXPERIMENTAL PROCEDURE

2.1 ENGINE AND REFRIGERATION SYSTEM

2.1.1 TEST ENGINE

The engine used for this experimental study is a single cylinder 4 stroke diesel engine.

Table 1. Test engine specifications

Engine type	Single cylinder 4 stroke.
Displacement	395 cc
Compression ratio	18.1
Maximum power	7.5 HP@3600 RPM
Specific fuel consumption	0.295 Kg / KWh

2.1.2 REFRIGERATION SYSTEM

Table 2. Refrigerator specifications

Capacity of the system	40 L
Capacity of the evaporator	0.0625 TR
Type	3- Fluid absorption system
COP	0.1 - 0.4

2.2 EXHAUST HEAT FLOW MEASUREMENTS

No. of cylinders – 1
Displacement – 395 cc
Specific fuel consumption – 0.295 Kg/Kw- hr
Power – 7.5 HP (5.6 KW)
RPM – 3600
Density of air (ρ_a) – 1.16 Kg/m^3
Ambient air temperature – 29^{0}C

<u>Mass flow rate of fuel</u>

Fig 2 Test engine

Specific fuel consumption $= \dfrac{\text{mass of flow rate of fuel}}{\text{power developed}}$

Mass flow rate of fuel, $\dot{m}_f$ $= 0.295 \times 5.6$

$= 0.46$ g/sec

Mass of air consumed :

Assuming volumetric efficiency of 0.8

$= \eta_v \times \rho_a \times 3600/2 \times 3.95\times 10^{-4}$

$\dot{m} = .8 \times 1.16 \times (3600/2) \times 3.95\times10^{-4}$

$= .011$ Kg/sec

Fig .3 VAR system

Mass flow rate of exhaust gas

$$\dot{m}_g = \dot{m}_a + \dot{m}_f$$

0.46 + 11

= 11.46 gm/sec

Exhaust heat availability from the engine

$Qe = \dot{m}g \times Cp \times \Delta T$

$= 11.46 \times 10^{-3} \times 1.1 \times (240 - 29)$

$= 2.66$ KW

2.3 EXPERIMENTAL SET UP

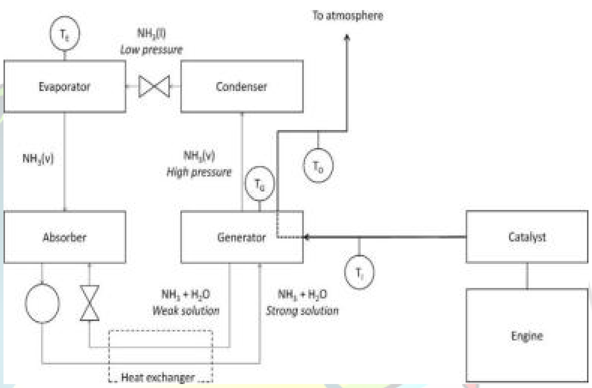

Fig.4 Basic layout of the experimental setup showing the absorption cycle and the circuit used to transfer heat from the engine exhaust to the generator element of the refrigeration system.

In this system, high-pressure ammonia vapour, heated by the exhaust gases at the generator, enters the condenser where it transfers heat to the surroundings and becomes liquid. The liquid ammonia passes through an expansion valve and reaches the evaporator pressure. This low-pressure ammonia removes heat from the cold source (evaporator) and reaches the vapour state once again. In the absorber, a weak solution of ammonia and water absorbs the refrigerant, transferring heat to the vicinity. The resulting ammonia-rich solution is then pumped to the generator where it is once again heated and the cycle restarts.

Exhaust gas temperature was monitored before (T_I) and after (T_O) heat exchange with the generator using type K thermocouples. The evaporator and generator temperatures (T_E and T_G, respectively) were also monitored continuously during the tests using type K thermocouples and a stick thermometer. The coefficient of performance (COP) of the absorption refrigeration system is given by a ratio of refrigerating effect produced in the evaporator Q_{ref} and the heat transfer rate from the energy source $Q_{generator}$ to the absorption refrigeration system, both given in W:

$COP = Q_{ref} / Q_{generator}$

Fig 5. Absorption refrigerator adapted to engine exhaust system.

3. RESULTS AND DISCUSSION

Experiments were conducted at constant engine speeds at a timeframe of 1 hour to evaluate the refrigerator performance at constant torque. At low engine RPM of 1100 no noticeable cooling is observed in 1 hour due to low exhaust heat input. At 1500 RPM, noticeable cooling is observed after about 45 minutes. The temperature dropped up to 18^{o}C and the maximum generator temperature observed is around 93^{o}C. When the RPM is set at 2000 the generator temperature evolved is 120^{o}C and cooling is observed after 30 minutes and the minimum temperature at the evaporator is 10^{o}C. At 2500 RPM the temperature at the generator raised to about 163^{o}C.and evaporator temperature dropped to 8^{o}C. above 3000 RPM no noticeable cooling is observed due to excess heat transfer in the generator. The generator temperature rose to around 210^{0}C.

Table 3. Average generator temperature and minimum evaporator temperature observed after I hour test at various RPM

Rpm	Evaporator (^{O}C)	Exhaust inlet (^{O}C)	Generator (^{O}C)	Exhaust outlet (^{O}C)
1100	30	71	61	62
1170	23	80	71	69
1500	18	100	93	85
2000	10	140	120	109
2500	8	163	148	121
3000	11	210	170	153

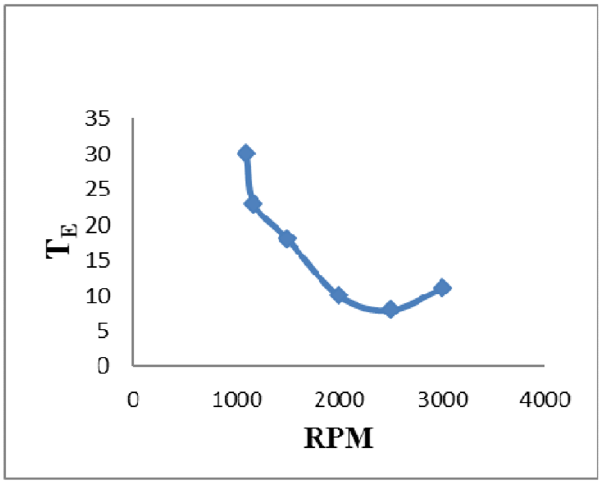

Fig.6 Variation of minimum evaporator temperature observed with engine RPM

3.1. THE EFFECT OF DIESEL ENGINE SPEED ON THE EXHAUST GAS TEMPERATURE

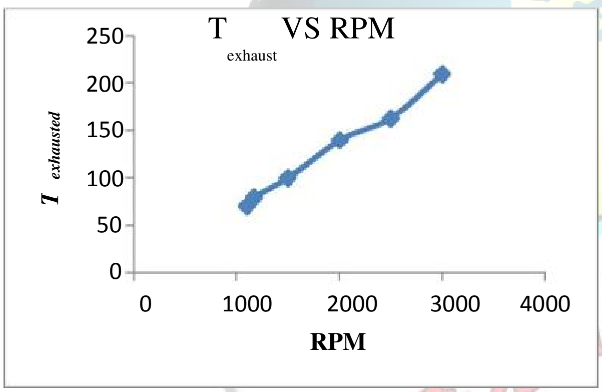

Fig.7.Variation of exhaust temperature with engine RPM

3.2. EFFECT OF DIESEL ENGINE SPEED ON THE EXHAUST HEAT GENERATION

Heat transferred to the generator is measured using conventional equations of heat transfer. It is clear that as the engine speed increases the flow gases temperature and flow rates and hence energy available will increase so the engine speed will directly affect the performance of the air conditioning unit through increasing the energy produced by the engine exhaust.

Table 4. Generator heat load variation with engine RPM

RPM	QGENERATOR (KW)
1100	0.11
1170	0.134
2000	0.534
2500	0.805
3000	1.31

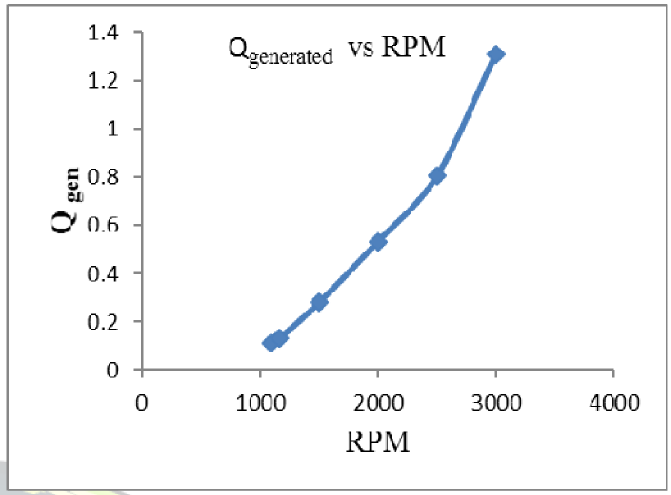

Fig.8. Effect of diesel engine speed on the exhaust heat generation (Qg).

At low rpm's the energy available at the engine exhaust is not sufficient to drive the absorption unit. When RPM increased to 1500, sufficient heat is transferred to the generator, and temperature drop is observed in the refrigerator cabin.

3.3. VARIATION OF COP WITH HEAT TRANSFERRED TO THE GENERATOR

Increased values of exhaust heat energy will directly affect system COP. COP varied between 0.7 and 0.16.

Table 5. COP variation with heat load in the generator

QGENERATED (KW)	COP
0.28	0.7
0.534	0.4
0.805	0.2
1.31	0.16

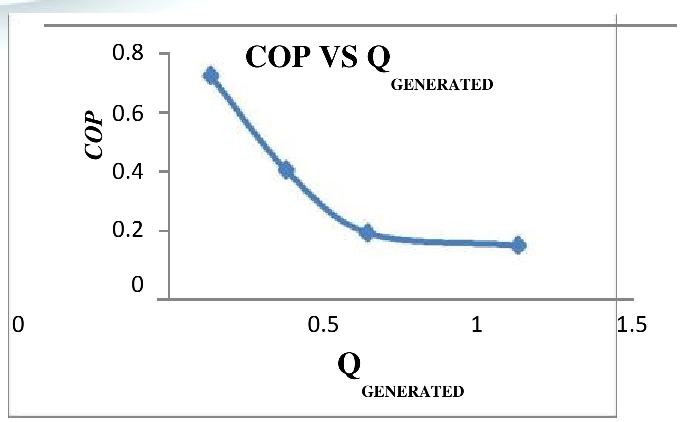

Fig.9. COP variation with heat load in the generator

4. CONCLUSION

Performance of VAR system using exhaust waste energy from diesel engine has been carried out in this investigation. The absorption system used in this experiment is 3 fluid absorption refrigeration system, or Electrolux refrigeration system. It requires no work input as it works purely on gravity and buoyancy forces. The experiments show a low value of COP, ranged between 0.7 and 0.1. The VAR system shows better performance with increase in RPM. The exhaust heat energy available is directly proportional to the engine speed and exhaust gas flow rates. At high RPM, excess heat transfer occurs at the generator which causes heating of the whole unit. This can be controlled by providing control valves at exhaust flow inlet. From the experiment conducted in the prototype it can be concluded that it is feasible to use a VAR system in automobiles for cabin cooling and to transport perishable food materials. It has advantages like flexibility in operation, absence of compressor noise, very low maintenance and high reliability. The VAR system will show better performance in real traffic conditions due to continues change in parameters like torque and RPM.

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