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Performance Analysis of a Triple Fluid Vapor Absorption System using Engine Exhaust Gas

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Abstract— ***The air conditioning units currently used in road transport vehicles are predominantly of the vapour compression refrigeration (VCR) type. In such a unit, the compressor requires an input of energy in the form of work. In order to obtain refrigeration, possibility of triple fluid vapour absorption refrigeration (VAR) systems utilizing waste heat from the engine exhaust gas has been investigated. This work presents an experimental study of a triple fluid vapour absorption refrigeration system using the exhaust of an internal combustion engine as energy source. From the study, it has been concluded that engine exhaust gas can be used as a power source for a vapour absorption system. When load on the engine increases, power availability in the generator increases and cooling capacity of the system increases but COP of the system reduces.***

Index Terms— ***Absorption refrigeration system, triple fluid system, engine exhaust.***

I. INTRODUCTION

Energy efficiency has been a major topic of discussions on natural resources preservation and costs reduction. Based on estimates of energy resources reduction at medium and long terms, it is vital to develop more efficient processes from energy and exergy standpoints. Environment preservation must also be considered through energy optimization studies. The Montreal Protocol, signed in 1987 by 46 countries and revised in 1990 to protect the ozone layer stresses the substitution of CFC refrigerants by alternative refrigerants and other types of refrigeration systems which are friendly to the environment. In recent years, air-conditioning has shifted from being a luxury option, reserved for up-market saloons, to basic equipment requested as standard. What's more, as well as the comfort provided, air-conditioning contributes to safety. These systems improve passenger security by allowing windows to remain closed, improve driver alertness with temperature choice, and increase visibility by de-misting and de-fogging windows during inclement weather. Fuel combustion necessary to power current mobile air conditioners can result in increased vehicle exhaust emissions that affect local air quality and carbon dioxide (CO_2) that is a greenhouse gas. Refrigerants in use today are also greenhouse gases that account for approximately 0.1 percent of global greenhouse gas emissions from all human activities, due to system leaks as well as losses during service and at vehicle end-of-life disposal. Vehicle air conditioning loads are the most significant auxiliary loads present in vehicles today.

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The AC energy use even outweighs the energy loss to rolling resistance, aerodynamic drag, or driveline losses etc. This power draw is equivalent to a vehicle driving steady state down the road at 56 kph [1]. The fuel economy of a vehicle drops substantially when the AC compressor load is added to the engine. The effect is larger with higher fuel economy vehicles. Engineers can reduce the amount of fuel consumption and emissions necessary to cool a vehicle by a system and vehicle design that uses vapour absorption type refrigeration system. Internal combustion engines are potential energy sources for absorption refrigeration systems, as about one third of the energy availability in the combustion process is wasted through the exhaust gas. Thus, use of the exhaust gas in an absorption refrigeration system can increase the overall system efficiency. Absorption refrigeration system differs from vapor compression refrigeration system due to utilization of thermal energy source instead of electric energy. In the absorption refrigeration system two working fluids are used: a refrigerant and an absorbent. Among the most applied working fluids are the pair ammonia refrigerant– water absorbent (NH_3–H_2O) and water refrigerant–lithium bromide absorbent (H_2O–LiBr). From launch of absorption refrigeration system, the pair ammonia– water has largely been used. Both fluids are highly stable at a wide operating temperature and pressure range. The system ammonia–water has as a disadvantage the requirement of extra components. A limitation of the pair water–lithium bromide is the difficulty to operate at temperatures lower than 0^0 C. Besides, lithium bromide crystallizes at moderate concentration, and, at high concentration, the solution is corrosive to some metals and is of high cost. Triple fluid refrigeration system uses ammonia as refrigerant; hence no problem of crystallization and it has no extra components or moving parts. Objective of this work is to study the feasibility of using the internal combustion engine exhaust gas as energy source for a triple fluid vapour absorption refrigeration system. Experiments have been conducted on a household refrigerator operating on this principle and variation of evaporator temperature with time and variation of temperature with load on the engine were studied.

II. LITERATURE REVIEW

Absorption refrigeration was discovered by Nairn in 1777, though the first commercial refrigerator was only built and developed in 1823 by Ferdinand Carré, who also got several patents between 1859 and 1862 from introduction of a machine operating on ammonia–water. By 19th century, systems operating on ammonia–water found wide application in residential and industrial refrigerators. Systems operating on lithium bromide–water were commercialized in the 1940's and 1950's as water chillers for large buildings air

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conditioning [2]. Horuz [3] conducted experimental investigation into the effect on the performance of the IC engine of introducing the VAR system into the exhaust system and also the provision of appropriate off-road/slow running cooling systems, in order to take account of the reduction in exhaust gas flow in slow running traffic or stationary situations or when the vehicle is parked and cooling is still required. Built-in eutectic plates could provide temporary cooling under such conditions. Such plates could be recharged by redirecting the cooling effect from the main body to the eutectic plate during off-load periods of continuous full-load travel. Longer stopover periods as, for example, in a depot may also be accommodated using eutectic plates. In the absorption refrigeration system two working fluids are used: a refrigerant and an absorbent. Among the most applied working fluids are the pair ammonia refrigerant–water absorbent (NH_3–H_2O) and water refrigerant–lithium bromide absorbent (H_2O–LiBr). A limitation of the pair water–lithium bromide is the difficulty to operate at temperatures lower than 0^0 C. Besides, lithium bromide crystallizes at moderate concentration, and, at high concentration, the solution is corrosive to some metals and is of high cost [4]. Alam [5] studied the possibility of operating a triple fluid vapour absorption system using engine exhaust power. From the analysis it was concluded that there is a possibility of operating a triple fluid system using engine exhaust power. Vicatos et al. [6] designed a car air-conditioning system based on an absorption refrigeration cycle using energy from exhaust gas of an internal combustion engine. The theoretical design was verified by a unit that is tested under both laboratory and road-test conditions. Manzela et al. [7] conducted an experimental study of an ammonia–water absorption refrigeration system using the exhaust of an internal combustion engine as energy source. The exhaust gas energy availability and the impact of the absorption refrigeration system on engine performance, exhaust emissions, and power economy were evaluated. The calculated exhaust gas energy availability suggested the cooling capacity can be highly improved for a dedicated system. Exhaust hydrocarbon emissions were higher when the refrigeration system was installed in the engine exhaust, but carbon monoxide emissions were reduced, while carbon dioxide concentration remained practically unaltered. AlQdah [8] also conducted an experimental study of an aqua-ammonia absorption system used for automobile air conditioning system, using the exhaust waste heat of an internal combustion diesel engine as energy source. The energy availability that can be used in the generator and the effect of the system on engine performance, exhaust emissions, auto air conditioning performance and fuel economy were evaluated. The engine exhaust gas was confirmed as a potential power source for absorption automobile air conditioner system.

III. TRIPLE FLUID VAPOUR ABSORPTION REFRIGERATION SYSTEM

In a triple fluid refrigeration system, there is no need of a pump and it is run entirely by heat. It uses a third fluid, to regulate the partial pressure of the refrigerant, and therefore, its saturation temperature. A low partial pressure of the refrigerant allows the refrigerant's saturation temperature to decrease and create cooling. The system remains at constant total pressure and eliminates the use of expansion valves.

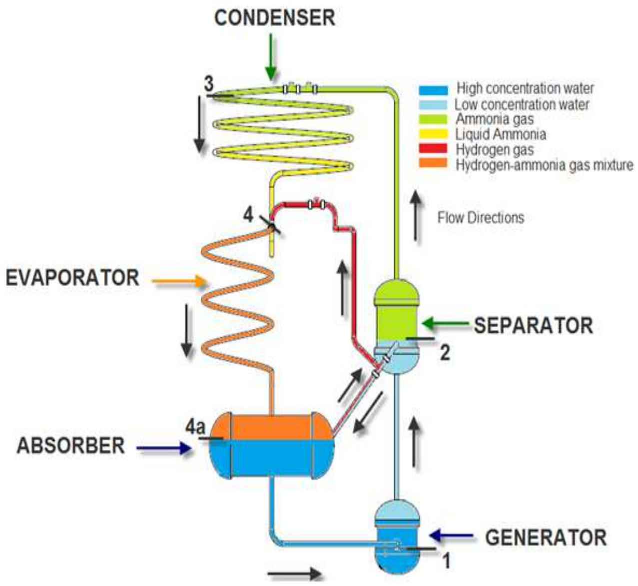

Fig. 1.Schematic Diagram of a Basic Three Fluid Absorption System

Schematic diagram of a three fluid absorption refrigeration system that uses ammonia and hydrogen is shown in Fig 1. Beginning with point 1 the seven stations have the following characteristics: at (1) the application of heat vaporizes the strong ammonia-water solution up into the bubble pump. At (2) the solution and gas passes into the separator where the water vapor condenses to liquid and passes through a separate series of tubes back to the absorber. Superheated ammonia vapor now rises to the condenser, leaving a small amount of weak ammonia-water solution pooled in the separator. At (3) the ammonia is traveling through the condenser, releasing heat to the surroundings and condensing back to a liquid state. At (4) liquid ammonia meets with hydrogen and enters the evaporator. Here, the partial pressures of the hydrogen and ammonia lower the saturation temperature of the liquid ammonia, causing the ammonia to evaporate. This expansion lowers the temperature of the hydrogen-ammonia mixture, allowing it to absorb heat from the refrigerator compartment, which provides cooling. At (4a) the hydrogen-ammonia mixture exits the evaporator into the absorber in a gaseous state. In the absorber the gaseous ammonia and hydrogen meet with liquid water. The ammonia is less dense than hydrogen, causing it to sink and consequently accumulate under the hydrogen. This increases its partial pressure and induces a phase change back to liquid. Ammonia and water are capable of forming a solution together as ammonia is soluble in water. Hydrogen is incapable of mixing and continues to circulate back to the top of the evaporator as a pure gaseous substance. The ammonia and water solution exit the absorber and travel to the generator. It then begins the cycle again.

IV. EXPERIMENTAL SET UP

The experimental set up consists of a 10 HP single cylinder diesel engine and a 170cc triple fluid refrigeration system with air cooled condenser. The exhaust from the engine is passed over the generator of the refrigeration system. Generator temperature, condenser temperature, evaporator

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temperature and temperature of exhaust gas at inlet and exit of generator were measured using thermocouples.

Fig. 2. Photograph of Experimental Set Up

Variations of temperatures at various points of refrigerator were plotted against time at different engine loads and specific fuel consumption of the engine was compared before and after installing the refrigeration system.

V. RESULTS AND DISCUSSIONS

The experiments were conducted from no load to full load conditions on the engine. Variation of evaporator temperature, condenser temperature and generator temperature were plotted against time for these conditions. Variation of evaporator temperature with time is shown in Fig 3.

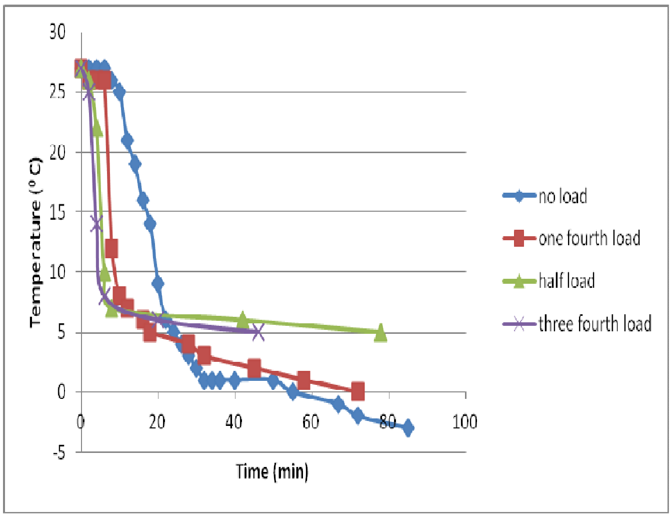

Fig. 3. Variation of Evaporator Temperature for Different Loads

From this graph, refrigerator shows lowest temperature when the engine is at no load. Initially, rapid reduction in evaporator temperature is shown by ¾ load condition. At higher loads, rate of reduction of evaporator temperature decreases as time passes. Since at high loads the condenser temperature is high, heat transfer takes from condenser to evaporator. This is due to the lack of cooling at the condenser.

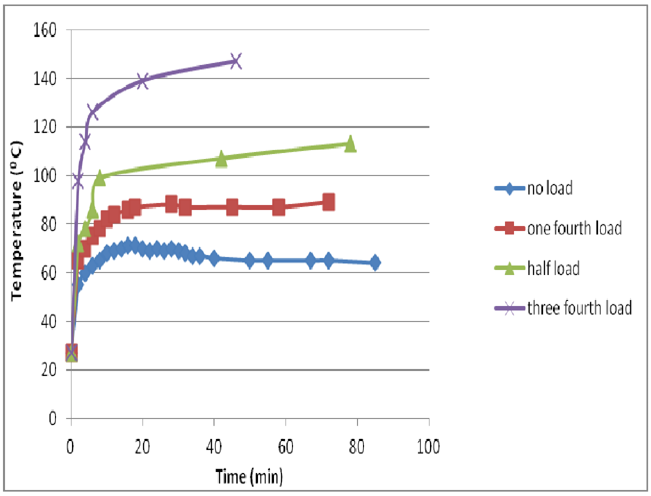

Fig. 4. Variation of Condenser Temperature for Various Loads

Variation of condenser temperature and generator temperature with time is shown in Fig 4 and Fig 5 respectively. Condenser temperature and generator temperature is high for higher loads. This is quite reasonable because the input heat in the generator is high in case of higher load.

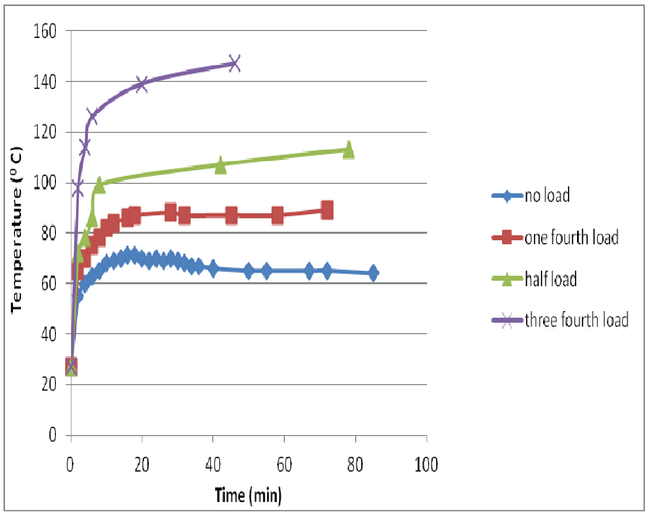

Fig. 5. Variation of Generator Temperature for Different Engine Loads

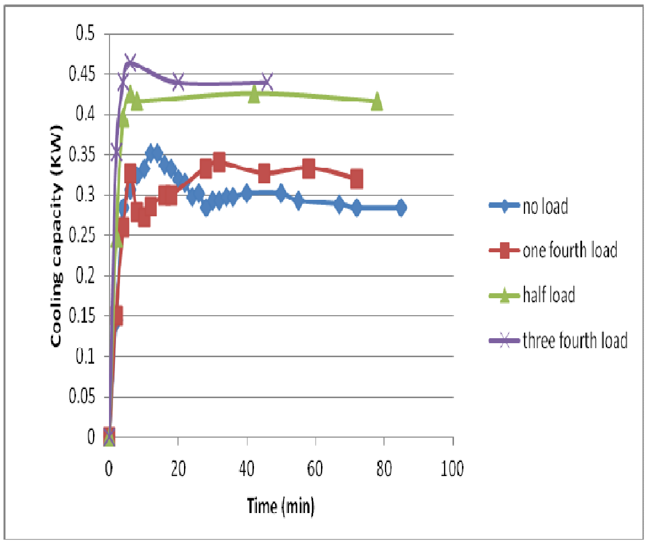

Fig. 6. Variation of Cooling Capacity for Different Engine Loads

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Variation of cooling capacity with time is plotted for different engine loads in Fig 6. It shows that cooling power increases at a faster rate for higher loads. That implies that when engine is running at a lower load, it may take some more time to achieve the required level of cooling. Cooling capacity is high for higher loads because input energy at the generator is high when the engine is running at higher load. The effective performance of a refrigeration system is measured in terms of COP. Higher COP implies the system uses the input heat more efficiently that is, with minimum loss. Variation of COP is shown in Fig 7. Even though cooling capacity is high for higher engine loads, COP is very low at high loads. It is because cooling capacity or heat transfer in the evaporator does not increase as much as the heat input in the generator increase. Since generator temperature increase at high loads, loss of heat also increases. Hence all the available excess energy at inlet does not produce useful effect. That is why COP decreases at higher loads.

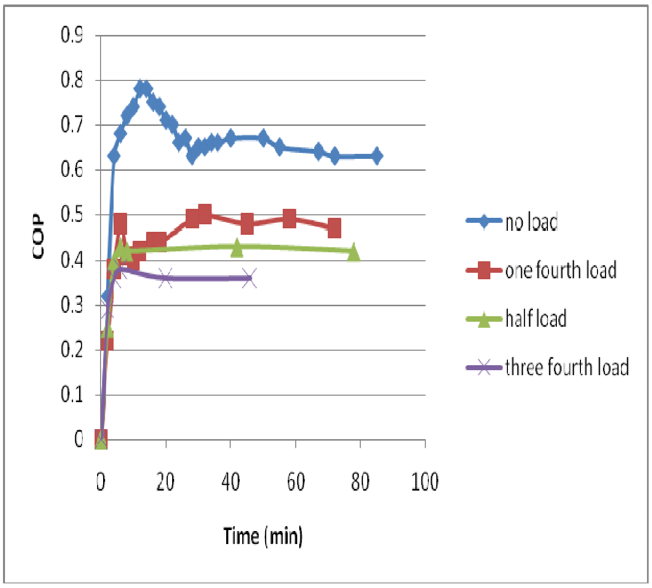

Fig. 7. Variation of COP for Different Engine Loads

Heat transferred by the engine exhaust to the generator increases as load on the engine increases. Available energy in the exhaust gas is more at higher loads. This variation is shown in Fig 8.

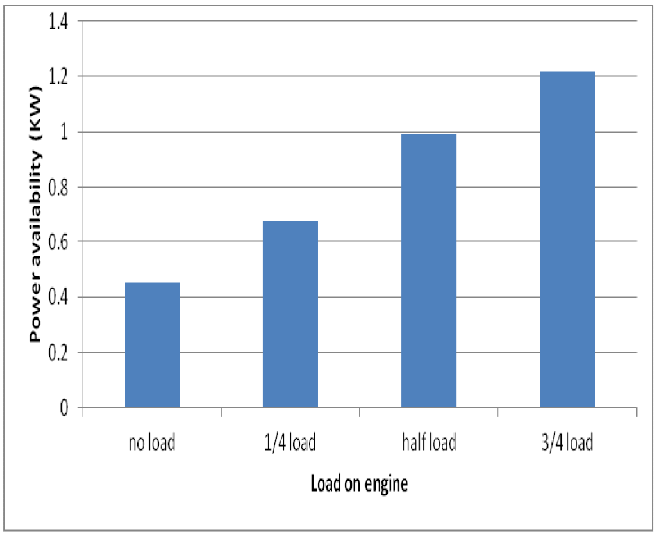

Fig. 8. Engines Exhaust Gas Power Availability for Different Loads

Fuel consumption of the engine was measured with and without the refrigeration system. Fig 9 shows that the installation of VAR system does not significantly affect the fuel consumption of the engine.

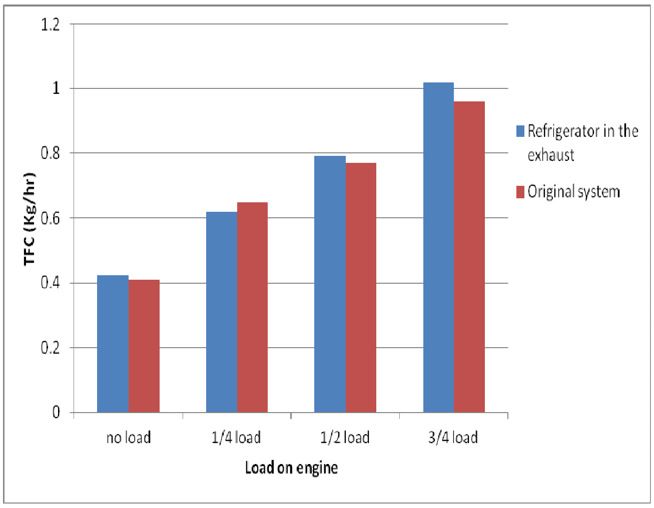

Fig. 9. Influence of Refrigerator on Fuel Consumption

VI. CONCLUSIONS

It can be seen that three fluid refrigeration system is a potential alternative for the present air-conditioning system used in automobiles. Engine exhaust gas can be used as a power source for a vapour absorption air-conditioning system. A distinctive advantage of this system is that when load on the engine increases, power availability in the generator increases and cooling capacity of the system increases. There is a scope for further research in this field by using an air-conditioning system of higher capacity and by providing effective cooling for condenser.

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