A REFRIGERATED ROAD TRANSPORT APPLICATION

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ABSTRACT

The study included an investigation into the use of Vapour Absorption Refrigeration (VAR) systems in road transport vehicles using the waste heat in the exhaust gases of the main propulsion unit as the energy source. This would provide an alternative to the conventional Vapour Compression Refrigeration (VCR) system and its associated Internal Combustion (IC) Engine. The proposed system is almost maintenance free, having only one component, the solution pump, with moving parts. Additionally, the VAR system runs quietly and primary fuel energy used to drive the independent engine of the VCR system will be saved. There should also be savings in capital costs with the exclusion of the IC engine and the compressor of the conventional system. The effect on the main propulsion unit of inserting the VAR system into the exhaust system and how cooling can be provided during off-road/slow running conditions are also included in the studies.

ÖZET

BİR KARAYOLU TAŞIMACILIĞI UYGULAMASI

Bu çalışma, karayolu taşımacılığında, enerji kaynağı olarak egsoz gazındaki atık ısıyı kullanan Absorpsiyonlu Soğutma Sisteminin(ABSS) kullanılmasının araştırılmasını içermektedir. Bu durum, içten yanmalı(İY) bir motorla tahrik edilen klasik Buhar Sıkıştırmalı Mekanik Soğutma Sistemine(BSMSS) bir alternatif sağlayacaktır. Önerilen sistem, hemen hemen bakım gerektirmemekte olup tek hareketli parçası eriyik pompasıdır.

İlave olarak, ABSS sessiz olarak çalışmakta ve BSMSS'yi tahrik eden bağımsız İY motoru içermemektedir. Klasik sisteme göre İY motor ve kompresör içermediğinden ilk yatım maliyetide düşük olacaktır. Çalışmada, ABSS'nin egsoz sistemine yerleştirilmesinin motor üzerindeki etkisi ve duraklama/yavaş seyir durumlarında soğutmanın nasıl sağlanacağı da incelenmiştir.

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NOMENCLATURE

COP	Coefficient of Performance (-)
E	Energy (kW)
P	Power (kW)
Q	Heat capacity (kW)

Subscripts

abs	Absorber
con	Condenser
eng	Engine
exh	Exhaust gas
evap	Evaporator
fuel	Fuel oil
gen	Generator
wat	Cooling water

INTRODUCTION

The refrigeration 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. Although, in smaller system, the compressor can be belt driven from the main propulsion engine, in large systems, it is normally driven by a dedicated Internal Combustion (IC) engine.

In the Vapour Absorption Refrigeration (VAR) system, a physico-chemical process replaces the mechanical process of the VCR system. It uses energy in the form of heat rather than mechanical work. The advantage of this system lies in the possibility of utilising e. g. waste energy from industrial plants or solar energy as the heat input.

The efficiency of the IC engine is about 35%-40% meaning that only about one third of the energy in the diesel fuel used is converted to useful work. This also means that the remaining 60%-65% of the primary energy is rejected to the environment by cooling water/lubricant losses of approximately 28%-30%, exhaust gas losses of approximately 30%-32% and the remainder by radiation (see Figure 1). These losses include losses arising from friction effects within the system.

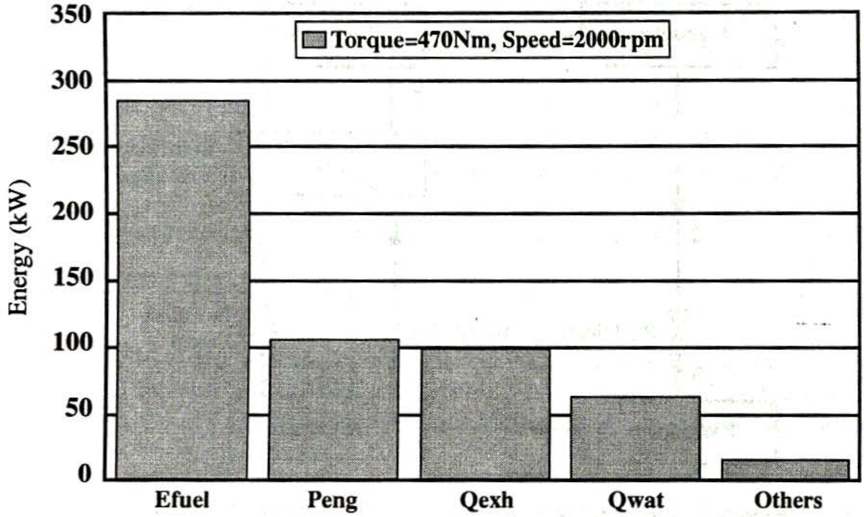

Figure 1 Energy distribution of a 6 Liter diesel engine [1]

The study aims to investigate the use of a VAR system utilising the waste heat in the exhaust gases from a main propulsion unit of a road vehicle. If this system can be used in this way, there would be no need for the IC engine and the compressor of the VCR system. There should also be a reduction in exhaust gas pollution.

MATERIAL AND METHOD

VAPOUR ABSORPTION REFRIGERATION UNIT

A VAR system is similar to a VCR system. In both systems the required refrigeration is provided by refrigerants vaporising in the evaporator.

As Figure 2 illustrates, the fundamental VAR cycle contains four main components; a generator, an absorber, a condenser and an evaporator. The condenser and the evaporator function in the same manner as they do in the VCR cycle.

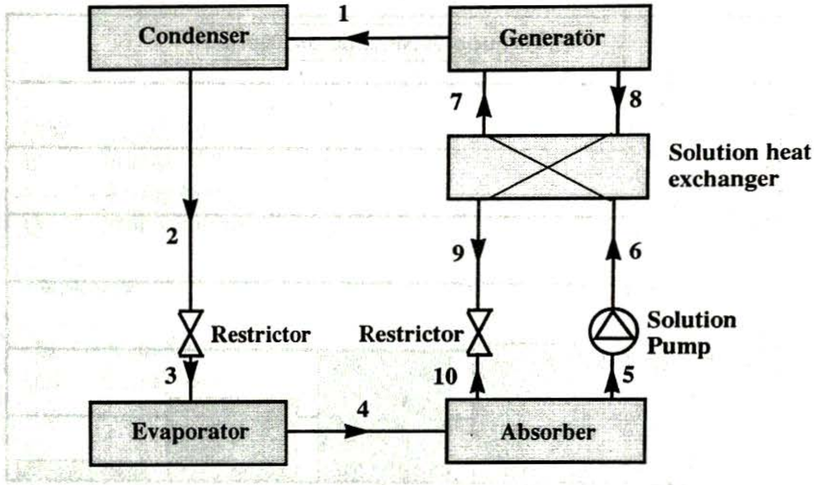

Figure 2 The schematic illustration of a fundamental VAR cycle

The combination of the generator, the absorber and solution pump may be thought of as a means of transferring refrigerant vapour from the low pressure side of the cycle back to the high pressure side, the function performed by the compressor of the VCR system.

The VAR cycle uses a refrigerant-absorbent solution rather than pure refrigerant as the working fluid. The absorbent acts as a secondary fluid to absorb the primary fluid which is the refrigerant in its vapour phase.

The refrigerant-absorbent solution passing through the solution pump is referred to as strong solution, being relatively rich in refrigerant. The solution returning from the generator to the absorber contains only a little refrigerant and is therefore referred to as weak solution.

In the absorber, weak solution meets refrigerant vapour from the evaporator. The solution absorbs the vapour, giving out heat as it does so, until all the vapour is absorbed to produce strong solution. The process occurring in the absorber is normally referred to as absorption, but it can also be thought of as condensation of a binary mixture, where the vapour phase contains predominantly one component.

Solution from the absorber (5) is transferred to the high pressure side of the circuit by the solution pump. Between the solution pump and the generator is a solution heat exchanger (SHE) where the cold strong solution from the absorber (6) is counter flow to the hot weak solution coming from the generator (8). The strong solution is thus heated and the weak solution is cooled in this process. The strong solution entering the generator (7) is still subcooled at the higher pressures present there. The heat source to the generator must therefore first heat it to the state where it begins to boil. As it boils, evolving the refrigerant vapour which passes to the condenser, the solution in the generator becomes progressively poorer in refrigerant and finally leaves the generator as weak solution (8). After passing through the SHE (9), the weak solution at high pressure passes through an expansion valve back to the absorber

(10), completing the cycle. It can be seen that the SHE is important in that the more heat the strong solution recovers from the weak solution leaving the generator, the less it needs from the external sources in the generator.

The coefficient of performance (COP) is a measure of a cycle's ability to transfer heat between various temperature levels. Since the primary use of the VAR systems has been for refrigeration purposes, the conventional definition of the COP is:

$$\text{COP} = \frac{\text{Heat taken in at low temperature (in the evaporator)}}{\text{Net energy supplied (in the generator)}} \qquad (1)$$

In the VAR system, heat energy being reduced in temperature from Tgen (in the generator) to Tabs (in the absorber) provides the driving force to lift heat from Tevap to Tcon. Carnot cycle operating between these temperatures sets an upper limit to the COP of;

$$\text{COPideal} = \frac{\text{Tgen - Tabs}}{\text{Tgen}} \quad \frac{\text{Tevap}}{\text{Tcon - Tevap}} \qquad (2)$$

THE INTERNAL COMBUSTION ENGINE

The IC diesel engine is a device used to convert the chemical energy of the fuel into heat energy and then convert this heat energy into usable mechanical energy. This is achieved by combining the appropriate amounts of air and fuel and burning it in an enclosed cylinder at a controlled rate.

The history of the diesel engine extends back into the closing years of the 19th century when Dr. Rudolf Diesel began his pioneering work on air blast injected stationary engines. In the engine invented by Dr. Diesel, which first appeared in 1893, the heavy oil fuel was injected into the cylinder mixed with a jet of compressed air. This air-blast injection principle is not used today. In the engine invented by Hubert Akroyd Stuart, two years before Dr. Diesel filed his first patent, the oil was injected into the engine cylinder without any compressed air, i. e. as a spray of mist of oil particles. A hot bulb or other external source of heat was used for ignition. This airless or solid injection principle is now used on the majority of modern diesel engines.

Determining an engine capability to drive a VAR system requires the study of the power and heat distribution of the diesel engine under various conditions. Experimental results proved that a refrigerated road transport vehicle's diesel engine was capable of providing enough energy to drive a VAR system via its waste exhaust heat [1].

THE COMBINED SYSTEM

The aim is to investigate the utilisation of exhaust gases from the refrigerated road transport vehicle's diesel engine to drive a VAR system for refrigeration purposes. For this reason, the VAR system and the diesel engine can be combined together in order to utilise the waste heat in the exhaust gases.

DISCUSSION

It is experimentally proven that, it is possible to use a VAR system utilising the waste heat in the exhaust gases from the main propulsion unit of a refrigerated road transport vehicle for refrigeration purposes [1]. If this can be achieved, there is no need for the IC engine and compressor of the VCR system. Money can, therefore, be saved and there is a reduction in the weight of the unit. Additionally, the VAR system runs quietly, is almost maintenance free, and the primary energy used to drive he independent engine of the of the VCR system can be saved.

It should be noted, however, that there are difficulties that would need to be overcome should the VAR system be used. One such difficulty would occur should the vehicle be at rest or in a very slow moving traffic conditions. In either of these conditions the resulting reduction in heat input to the generator would cause a corresponding drop in the cooling effect of the system. Built in eutectic plates could provide temporary cooling during 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.

The current development of natural gas powered IC engines together with the provision of a network of refueling centers would ease the solution of some of the above problems. With such a provision the VAR system could be designed to utilise engine exhaust gases or those from a gas burner depending on the prevailing conditions. Under the off-road situation mentioned above, it would be possible to connect the system to a mains or bottled gas supply which would provide the necessary heat input.

When the VAR system is used in road transport vehicles, in order to utilise the waste heat in the exhaust gases without excessive pressure drops in the exhaust systems and hence without excessive reduction in efficiency of the vehicle's engine, a longitudinally finned square or circular shaped generator can be designed. The corrosion effect of the exhaust gas to the generator material can be reduced by using the materials which can accommodate the exhaust gases, such as galvanised or stainless steel. This solution will overcome the corrosion problem but will increase the cost.

The VAR system can be mounted to the same location on the vehicle as the conventional system, and for trailer type vehicles can be connected to the vehicle's exhaust pipe by flexible pipe work. In this case, the exhaust pipe work connection arrangement and the exhaust gas flow control valve arrangement should be designed. The generator should be as close as the exhaust manifold in order to reduce the heat losses and the pressure drops along the flexible pipe.

Providing electricity to the fans of the evaporator, the condenser and the absorber could be another problem, however main engine alternator could generate the required energy to drive the fans as well as the solution pump.

CONCLUSION

Experimental results proved that it was possible to drive a Vapour Absorption Refrigeration system using the exhaust gases from a diesel engine. This suggests that such a system could be used in road transport vehicles [1]. However, further consideration is required with respect to,

- the design of a heat exchanger to extract waste heat without excessive pressure drops in the exhaust systems,
- the effect of increased back pressure on the engine performance,
- the corrosion effect of the exhaust gases on the heat exchanger material,
- the fluctuations in the cooling capacity due to variations in vehicle speed,
- an alternative energy input while vehicle is stationary,
- the effect of varying ambient conditions on the system performance,
- accommodating the system on the vehicle.

The author believes that this study is worth pursuing in terms of energy and cost savings and suggest that a prototype design study should be undertaken.

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