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# A REVIEW OF AUTOMOBILE WASTE HEAT RECOVERY SYSTEM

**Prof. Murtaza Dholkawala[1], Mr. Ahire Durgesh Vijay[2]**

*[1]Sr.Assistant Professor, [2]Student Department of Mechanical Engineering,*

*MIT Academy of Engineering, Alandi (D), Pune, (India)*

## ABSTRACT

*Waste heat to a productive work. The objectives of this report are describing current waste heat recovery practices in automobile and providing an overview of conventional and developing heat recovery technologies. Thermodynamic limitations on equipment or processes and equipment inefficiencies are mainly responsible for the waste heat losses. The I.C engine does not efficiently convert fuel energy into mechanical energy. A major part of this energy is dissipated as heat in the coolant and exhaust. The demand for development of efficient vehicles has led us to find various ways to utilize waste heat from the I.C Engine to increase vehicle fuel economy. Numerous technologies are available for converting.*

***Keyword: Waste Heat Recovery, Organic Rankine Cycle, Thermoelectric Generator, Absorption Cooling.***

## I. INTRODUCTION

Waste heat can be defined as a heat which is generated in a system or a process by combustion or chemical reaction and then released into the environment even though it could be reused for some useful purpose. Large amount waste heat is generated in industries and vehicles.A considerable amount of fuel could be saved, if we could recover some of this heat. The energy lost cannot be fully recovered. However, some of the heat could be recovered and losses can be minimized. New technologies can recover waste heat more efficiently from these sources. Basically waste heat recovery means capturing the waste heat in process and reusing for heating or generating mechanical or electrical work. It includes space heating, preheating of combustion air, absorption cooling, generating electricity etc. Main requirements of waste heat recovery are an accessible source of waste heat, a waste heat recovery technology and use for the recovered energy. Waste heat can be recovered via numerous methods. The heat can either be transferred to another system/process or reused within the same process. The strategy of how to recover this heat depends on the temperature of the waste heat gases. Usually higher the temperature, more cost effective is the heat recovery.

In automobiles, around 50 to 60% of the fuel energy is lost in the form of heat. In diesel engine, less than 45% of energy is converted into useful power output, while the remaining energy is mainly lost through the engine exhaust gas, jacket cooling water and other means. Various techniques are used to recover this heat like organic rankine cycle, thermoelectric generators, absorption cooling etc. are discussed in this report.

## II. NEED FOR WASTE HEAT RECOVERY

Conventional energy sources are becoming less available due to the depletion of fossil fuels. The world is facing energy crisis. In spite of this, energy is still being wasted. According to studies 20 to 50% of energy consumption is ultimately discharged as waste heat. Recovery of waste heat has a direct effect on the efficiency of the process. Waste heat utilization increases energy efficiency and saves the primary energy. About 20% of released heat can be recovered and used for work output. Waste heat recovery reduces the fuel consumption, thereby reduction in the exhaust gas produced. This results in reduction in equipment sizes of all exhaust gas handling equipment, hence there is reduction in capital costs. Reduction in equipment sizes reduces auxiliary energy consumption like electricity for pumps, fans etc. Operating costs for facilities are reduced by increasing their energy productivity using heat recovery technologies. Waste heat recovery techniques also reduce the greenhouse gas emissionsin addition to the economic benefits. Hence waste heat recovery technology increases the engine output, reduces fuel cost, and pollution. Many recovery technologies are already well developed and technically proven. [1]

## III. WASTE HEAT RECOVERY IN AUTOMOBILES

Internal combustion engine is a device that uses fossil fuel i.e. Chemical energy, converts it into the heat energy and then finally in the mechanical energy. The diesel engine is a primary power source for automobiles mainly due to its high operational reliability and excellent thermal performance. The energy consumption in automobiles has increased rapidly in recent decades with the development of the transportation industry. However, the depleted energy supply and the global greenhouse effect are crucial issues that the developing world has to face. Strict regulations for fuel economy standards and diesel engine emissions have been introduced by governments of many countries.Therefore, in automobile industry there is a strong need to increase the efficiency of diesel engines. In diesel engine, large amount of energy is lost through the engine exhaust gas. It means a large fraction of the fuel energy remains untapped and gain of energy by waste heat is appreciable. Generally, there are two main methods to improve efficiency. One is by optimizing the combustion process and the other one is by recovering waste heat of the engine. Most of the scientist's research prefer the field of waste heat recovery.The recovery and utilization of waste heat conserves fuel and reduces the amount of waste heat. Various technologies can be used to achieve this such as

1. Organic Rankine cycle
2. Thermoelectric generators
3. Absorption cooling

## IV. ORGANIC RANKINE CYCLE

In vehicles, exhaust gas is emitted to the environment. By applying a thermodynamic process the heat of exhaust gas can be converted into mechanical power for the vehicle. A suitable process for this is the Rankine process. The Organic Rankine Cycle (ORC) is a very promising technology for the recovery of engine waste heat. The mechanical energy generated by the Rankine process can be directly delivered to the engine or the expansion machine can drive a generator in order to provide electrical energy. A medium speed generator can be used for this purpose. The electric energy can be stored in a batterydepending on the application and fed to the vehicle's electrical system. In case of hybrid vehicles it drives an electric machine.

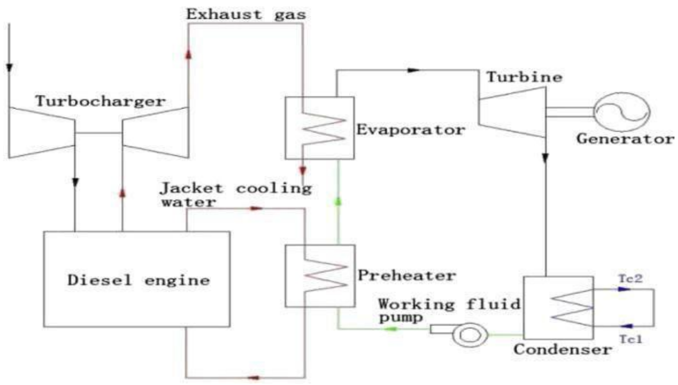


**Fig. 1.The schematic diagram of a basic ORC system [3]**

An Organic rankine cycle system consists of an evaporator, apump,a condenser and an organic expander. Fig.1shows a basic ORC system for waste heat recovery. Waste heat is normally extracted from two sources: 1. from exhaust gases, 2. from cooling jacket water.

## V. WORKING

From the condenser, the liquid organic working fluid is pumped to a high pressure state. Then, firstly in preheater some heat is gained by working fluid from hot cooling jacket water and then it is heated by the exhaust flue gases in the evaporator, where it turns into a saturated or superheated vapour. Next, in the expander the vapour expands to produce power. Then generator produces the electricity. Finally, the exhaust organic gas from the expander enters into the condenser, where the cooling water condenses it into liquid.[2,3,4]

## VI. THERMOELECTRIC GENERATORS

Thermoelectric generator (TEG) is a promising energy conversion device for vehicle exhaust waste heat recovery. By using waste heat recovery system we can convert some of this waste heat into electricity and thereby by reducing the load on alternator.We can reduce the fuel consumption of the vehicle. TEGs work on principle of the Seebeck effect which is explained in fig.2.

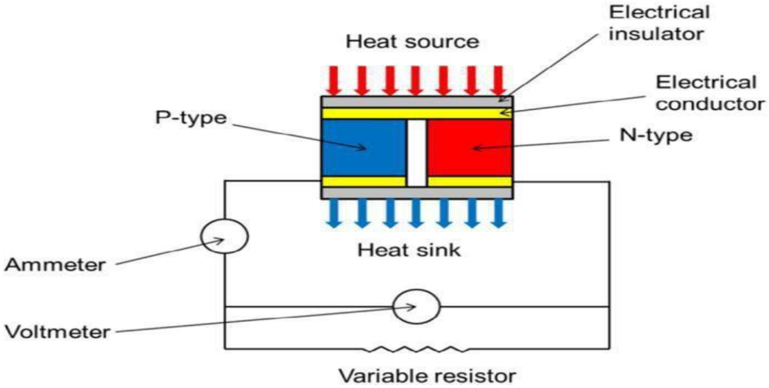


**Fig. 2 Seebeck effect [5]**

The construction of TEG is very simple. It consist of many N type and P type semiconductors which are connected thermally in parallel and electrically in series. A voltage is generated when one side of the TEG is cooled and the other side is heated. Hence there are lots of applications for these thermoelectric generators to generate electricity, where temperature gradient is present. TEGscan generate power from any temperature difference. Their efficiency depends on the temperature difference. The higher the temperature difference, the more efficient they will be. Generally the efficiency of TEG is 5%. Another factor which can be used to compare the efficiencies of different TEGs which are operating at same temperatures is the thermoelectric figure of merit (ZT). The higher the thermoelectric figure of merit, the better the TEG. The ZT of thermoelectric material has improved over time but presently ZT of the best commercially available TEGs is approximately 1. Various techniques and materials are used to improve the efficiency and power generation of TEGs. Materials used for TEGs in exhaust heat recovery systems are rated for a high temperature. This means a larger temperature difference can be present and more power and higher efficiency can be achieved. The use of the high temperature TEGs prevents the TEGs from overheating and it also simplifies the design. Calcium manganese and Lead telluride have been used as materials in TEGs due to their ability to handle higher temperatures. Large multinational car companies like BMW, Renault, Ford, and Honda have demonstrated their interest in exhaust heat recovery systems that make use of TEGs. All of their design are relatively similar. Generally the TEGs are placed on the exhaust pipe surface and cooled with the help of engine coolant. The BMW system uses a shell and tube type of heat exchanger. High temperature TEGs are used and from a number of 20 W rated TEGs the system produces 750W energy. The Ford system heat exchanger uses many small parallel channels lined with thermoelectric material for the exhaust gases to pass. In this case liquid cooling is used. This system produces approximately 400W. The Renault system is used on a diesel truck engine. This system uses a counter flow heat exchanger arrangement using liquid cooling. The Honda system uses a simple design of a thin flat rectangular box with TEGs placed on the top and bottom surfaces. Liquid cooling is used in this design. The system produces a maximum of approximately 500W. The claimed fuel consumption reduction is 3%.

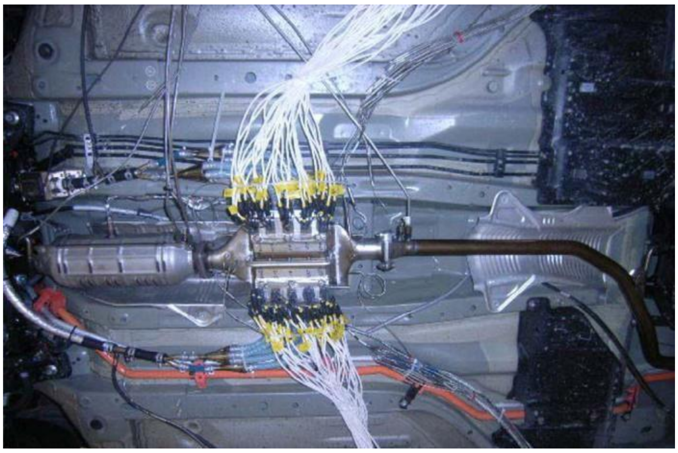

**Fig. 3.Thermoelectric generator used in Honda [5]**

The use of TEGs in a waste heat recovery system has many desirable attributes compared to other waste heat recovery technologies such as silence, small size, and durability. Their key attribute is that they have no chemical reactions and no moving parts therefore there is little maintenance required due to corrosion and wear. Their efficiency is relatively low compared with a Rankine cycle waste heat recovery system but efficiency is not the most important factor as there is no costs associated with waste heat [5,6].

## VII. ABSORPTION COOLING

In conventional air conditioning (a/c) system a compressor is used to deliver the vapor refrigerant at high pressure to the condenser unit. The compressor derives its power from the engine itself. According to studies approximately 10% of the energy available at the crankshaft in a diesel operated vehicle is used for operating the compressor of the vehicle's air- conditioning system. Which means the large amount of diesel is consumed for the air conditioning. In addition to this, conventional a/c system requires alternating current through an alternator. Therefore, conventional vapor compression a/c systems have a number of shortcomings which make it unviable and hence we require a better alternative. Absorption air conditioning is the alternative for it. The vapor absorption refrigeration is one of the oldest methods of producing refrigerating effect. Instead of using mechanical energy as in vapor compression systems, the vapor absorption system uses heat energy in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle. Heat required for this is obtained from the exhaust of internal combustion engines. This refrigeration system consists of an evaporator, a condenser and an expansion valve similar to a vapor compression refrigeration system but the compressor of the vapor compression refrigeration system is replaced by an absorber, a small pump and a generator. A vapor absorption refrigeration system utilizes two or more than two fluids having high affinity towards each other, in which one is the absorbent and the other is the refrigerant.

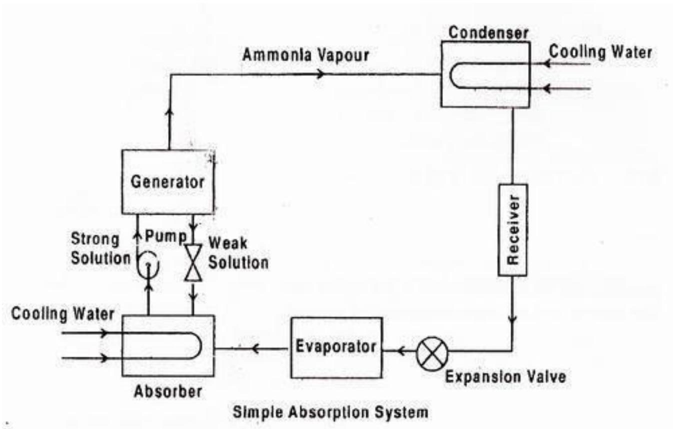


**Fig. 4 Vapor Absorption Refrigeration System [9]**

## VIII. WORKING

The vapor absorption refrigeration cycle comprises four steps

A. Step I: Generation

This cycle starts when the hot exhaust gases starts flowing through the generator. At room temperature the pair is in absorbed state. When the temperature of the pair increases, the mixture starts to separate i.e. refrigerant starts getting released from the absorbent. Due to this process, there is increase in pressure in the system. We know that the temperature of an internal combustion engine exhaust is above 200°C, liquid refrigerant gets evaporated and finds its way out of the generator and finally moves towards the condenser and remaining weak mixture of refrigerant and absorbent returns to the absorber.

B. Step II: Condensation

Refrigerant comes into the air cooled condenser from the generator. It enters in it at high pressure and high temperature .Then heat exchange takes place with atmosphere, and finally refrigerant comes out of the condenser in liquid state. It is collected in a receiver. In this stage very small temperature drop is obtained

C. Step III: Evaporation

Refrigerant is passed through an expansion valve. Due to the throttle action, evaporation occurs.Hence there is a sudden drop in temperature of a refrigerant is observed. Refrigerant gives cooling effect to the surrounding by absorbing heat from the surrounding.

D. Step IV: Absorption

Absorber receives refrigerant from the evaporator and also theweak mixture of refrigerant and absorbent from the generator. Here heat is dissipated out from the refrigerant and absorbent. Hence, at low temperature refrigerant gets absorbed by absorbent and again the pair goes in the absorbed state. This strong solution is pumped again and thus cycle restarts. [7, 8, 9]

## IX. CONCLUSION

Waste heat recovery technology is an environment friendly energy conservation technology which makes contribution not only to the environment but it also reduces the production cost. The study shows the possibility and availability of waste heat from internal combustion engine. It is possible to save the large amount of energy through waste heat recovery. There are different technologies available and have their own benefits from the review, it has been identified that there are large potentials of energy savings through the use of waste heat recovery technologies.

1. Engine waste heat can be recovered via numerous methods. The heat can either transferred to another thermal, electrical, or mechanical process or it can be reused within the same process.
2. The common technologies used for waste heat recovery from engine include preheating, Organic Rankine Cycle, thermoelectric device, refrigeration and air conditioning etc.
3. The study identified that the advanced technologies reduce emissions and maximize energy efficiency with improved power.
4. The waste heat recovery leads to less production of pollutants like $SO_2$ and $NO_x$ during obtaining the same amount of power

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