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A REVIEW ON WASTE HEAT RECOVERY FROM INTERNAL COMBUSTION ENGINES

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***Abstract*— Automobile industry in India is consuming maximum energy from conventional fuels. The share of consumption increasing rapidly due to increase in civilization and urbanization as the living standard is increasing. The Diesel Generating set(DG Set) which uses diesel engine is also gaining popularity in rural areas as it produces electricity for irrigation and agricultural purposes. This also contributing in increasing the share of energy consumption .The energy consumption can be reduced by minimizing the losses associated with internal combustion engines. There are various losses associated with internal combustion engines which tend to reduce its efficiency and performance. Among these exhaust heat loss is major loss which contribute almost 33-36% and leads to the waste of heat which could be recovered and a considerable amount of primary fuel could be saved. Also this would lead to the environmental pollution. The literature survey reviews that exhaust gases from diesel engine having heat potential that can be recovered. The focus of this study is to review the technologies developed to recover this waste heat in order to improve the performance of the engines and thereby reducing the exhaust emissions. These technologies include Six stroke internal combustion cycles, thermoelectric energy conversion technologies, Rankine bottoming cycle techniques and turbocharger**

Keywords*— Internal Combustion Engines;, Waste Heat; Efficiency; Turbocharger; Turboelectric Generator; Emissions;

I. INTRODUCTION

Internal Combustion engines are the backbone of economy of many developed countries. In India also the transportation sector increasing rapidly and consumes almost 32% energy. The Diesel Generating (DG) sets are gaining more popularity because of frequent load shading problems. The diesel engine driven vehicles give maximum efficiency of 35-37 % as against the 100% chemical energy provided .The rest of energy is lost due to various losses associated with the engines. Among these stack loss or exhaust flue gases contributes almost 33% of total input supplied. The researchers have been continuously working to minimize these losses in order to improve the overall performance of the diesel engines. This would also resulted to minimize the emissions from the exhaust of the engines. Waste heat recovery in DG Set is significant and Alternator losses (4%), Stack loss through flue(33%), Coolant losses (24%)and Radiation losses(4%) are major losses associated with it. Among these, stack losses through flue gases or the exhaust flue gas losses on account of existing flue gas temperature of 350ºc to 550ºc, constitute the major area of concern towards operational economy. Also diesel engine produces a large amount of smoke and NOx which is harmful to the environment and the civilization in the nearby vicinity of the industries. It would be realistic to assess the waste recovery potential in relation to quantity, temperature margin. There are few technologies developed by these researchers and adopted in internal combustion engines to study the performance of such engines. Six stroke internal combustion Engine Cycles, thermoelectric generators, turbochargers are few technologies developed to recover the waste heat from exhaust of the engines and to study its effect on the performance of diesel engines and its emissions. The present paper reviews such technologies developed for waste heat recovery from Internal Combustion Engines.

II. ORGANIC RANKINE CYCLE

Tahani et al.[1] Investigated on 12 litre compression ignition ignition six cylinder engine with linear arrangement. In this two different configurations viz. Preheat and two stage were proposed for simultaneous coolant and exhaust gas recovery.

A. Preheat configuration

This configuration was conventional preheat Rankine cycle where a preheater was used for waste heat recovery from the coolant. The working fluid was preheated in the heat exchanger then entered the evaporator and was converted to saturated vapour by absorbing heat from the exhaust gas. After that it is expanded in expander and generated mechanical power by expanding. Due to limitations in working fluid mass flow rate, this configuration is unable to absorb the total heat released by the coolant. An air cooled heat exchanger should be used to reduce the temperature of coolant before returning the engine.

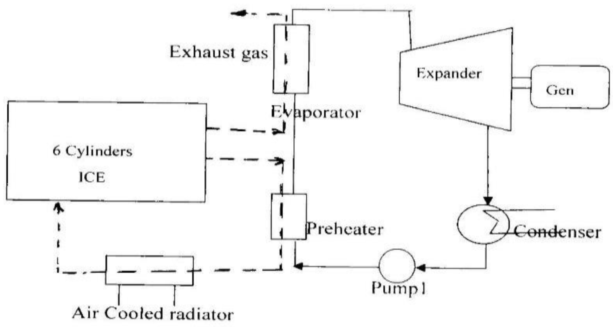

Figure 1 Preheat configuration combined with the ICE

B. Two Stage Configuration

In this configuration the working fluid flows in two different stages with different pressures after leaving the condenser. Low pressure stage relates to heat recovery from the coolant and another one relates to heat recovery from exhaust gas. Using this configuration, total wasted heat of coolant can be recovered and there is no need to air cooled heat exchanger for coolant.

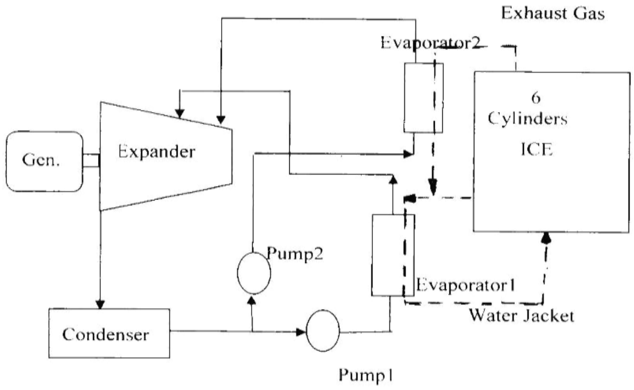

Figure 2 Two stage configuration combined with the ICE

III. SIX STROKE INTERNAL COMBUSTION ENGINE CYCLE

Six Stroke Internal Combustion Engine cycle uses Six cycles instead of four cycles as in conventional internal combustion engines. Six Stroke Internal Combustion

Engine cycle proposed by Conklin & Szybist [2] consists of trapping exhaust gas after four stroke and recompressing it by two additional strokes. As there is no additional fuel injection but already expanded gas has given additional power strokes and therefore improves the fuel economy of the engine. The concept of injection of water directly into combustion chamber and closing the exhaust valve earlier than its normal time entraps the residual gases inside the combustion chamber. The injected liquid receives the energy from recompressed residual gases and expands which increases the pressure inside the cylinder. The expansion of gases produces more work output. Coklin & Szybit [2]suggested to inject water directly into engine exhaust instead of using combustion chambers as injection of water at exhaust is more practical. Coklin & Szybit [2] concluded that the mean effective pressure(MEP) can be maximized by injection of liquid in the range of 0.75-2.5 bars. This shows the potential to improve engine efficiency and fuel consumption.

IV. THERMOELECTRIC GENERATORS (TEG)

Many researches have been taking on automotive thermoelectric generator. Thermoelectric generators may become future of automotive waste heat recovery. Thermoelectric generators or TEG is used to convert thermal energy from different temperature gradients existing between hot and cold ends of semiconductor into electric energy. This phenomenon is called as Seeback effect discovered by Thomas Seeback. TEG may potentially produce twice the efficiency as compared to other technologies. Mori et al.[3] reviewed the potential in fuel saving of thermoelectric devices for vehicles. They concluded that there could be achieved fuel economy efficiency of 4.7%. There are mainly two possible sources of waste heat (i) The exhaust gas system & (ii) radiator. Zhang & Chan [4] reported that TEG is mostly installed for exhaust gas system. This basically consists of exhaust gas system, heat exchanger, TEG, Power conditioning system and a battery pack.

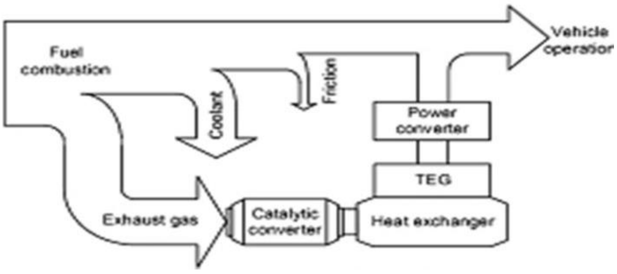

Figure 3: Waste Heat Recovery System using TEG

The heat exchanger mounted on the catalytic convertor captures the exhaust heat from engine exhaust gases. This heat captured is transferred to TEG where it is converted to electricity. Power conditioning is performed by the power convertor to achieve maximum power transfer. Yu & Chau [5] proposed & implemented TEG waste heat recovery system using Cuk Convertor.

V. TURBOCHARGER

A naturally aspirated internal combustion engine produce large amount of waste heat. This wasted exhaust energy can be recovered using a turbocharger. Fundamentally a turbocharger is supercharger driven by exhaust energy. A turbocharger is a type of gas turbine where heat and pressure in the expanding exhaust gas is used to increase engine power by compressing the air that goes into the engines combustion chambers.

Recent development of turbocharger is two stage turbocharger. A two stage turbocharger has two different sized turbochargers assembled in serial configurations. The smallest sized turbocharger responds at lower speed by producing a higher torque that will reduce fuel consumption on the road. Furthermore, the larger unit provides boost at higher engine speeds. The study can conclude that the advantages of a two stage turbocharger over a conventional 1-stage turbochargers include (i) total pressure ratios are higher than that of a 1-stage turbocharger. Hence higher outputs are possible. (ii) Better efficiencies at low pressure stage (iii) Produces better low end torque (iv) Dynamic performances are better with smaller High pressure. Musu et al.[6] proposed a novel combustion concept called Homogeneous Charge Progressive Combustion (HCPC) that permits reduction in soot and NOx emissions in all operating conditions. Also this concept permits engine speed to increase upto 6000 rpm with indicated thermal efficiency of 45%, power density of 64 kw and 300 kpa of intake pressure.

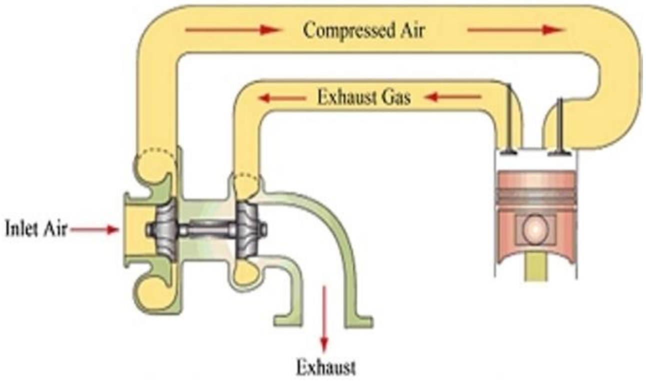

Figure 4: Typical Turbocharger used in Automobile

VI. RECENT WASTE HEAT RECOVERY TECHNIQUES

In recent years lot of attention have been focused on increasing the efficiency and reducing the emissions from automotive engines. Homogeneous charge compression ignition (HCCI) combustion concept that constitutes a valid approach to achieve high efficiencies and low nitrogen oxides and particulate emissions in comparison with traditional compression ignition direct injection engines. HCCI process operates on the principle of having a lean, premixed, homogeneous charge that reacts and burns volumetrically throughout the cylinder as it is compressed by the piston.

Rathavi et al.[7] used heat exchanger accumulator mechanism for mixture formation. They modified four stroke, single cylinder, direct injection diesel engine to operate in dual mode without diesel vapour mixture and with diesel vapour mixture formation of fuel. A heat exchanger accumulator mechanism was used to vaporize the diesel fuel and catalytic cracking. It was mounted in the intake system to prepare the homogeneous diesel vapour air mixture. The use of exchanger accumulator mechanism resulted substantial reduction of NOx, fuel consumption and smoke emission can be achieved. It also increased efficiency of engine.

VII. CONCLUSION

Waste heat recovery techniques proven to be beneficial to avoid heat losses and maximum fuel consumption. The techniques such as Turbogenerator, TEG, Organic Rankine cycle, six stroke cycle engines proved to be useful for recovery of waste heat. The recent techniques like use of heat exchanger accumulator mechanism resulted into reduction of NOx, fuel consumption and smoke emission. There is scope to adopt few new techniques to improve performance of engines by waste heat recovery techniques.

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