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Review on Exhaust Gas Heat Recovery for I.C. Engine

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Abstract* - The increasingly worldwide problem regarding rapid economy development and a relative shortage of energy, the internal combustion engine exhaust waste heat and environmental pollution has been more emphasized heavily recently. Out of the total heat supplied to the engine in the form of fuel, approximately, 30 to 40% is converted into useful mechanical work; the remaining heat is expelled to the environment through exhaust gases and engine cooling systems, resulting in to entropy rise and serious environmental pollution, so it is required to utilized waste heat into useful work. The recovery and utilization of waste heat not only conserves fuel (fossil fuel) but also reduces the amount of waste heat and greenhouse gases damped to environment. The study shows the availability and possibility of waste heat from internal combustion engine, also describe loss of exhaust gas energy of an internal combustion engine. Possible methods to recover the waste heat from internal combustion engine and performance and emissions of the internal combustion engine. Waste heat recovery system is the best way to recover waste heat and saving the fuel.

***Keywords* - Efficiency, Emission, Waste heat from I. C. Engine, Waste heat recovery system for I. C. Engine**

I. INTRODUCTION

Recent trend about the best ways of using the deployable sources of energy in to useful work in order to reduce the rate of consumption of fossil fuel as well as pollution. Out of all the available sources, the internal combustion engines are the major consumer of fossil fuel around the globe. Out of the total heat supplied to the engine in the form of fuel, approximately, 30 to 40% is converted into useful mechanical work. The remaining heat is expelled to the environment through exhaust gases and engine cooling systems, resulting in to entropy rise and serious environmental pollution, so it is required to utilized waste heat into useful work. The recovery and utilization of waste heat not only conserves fuel, usually fossil fuel but also reduces the amount of waste heat and greenhouse gases damped to environment. It is imperative that serious and concrete effort should be launched for conserving this energy through exhaust heat recovery techniques. Such a waste heat recovery would ultimately reduce the overall energy requirement and also the impact on global warming. The Internal Combustion Engine has been a primary power source for automobiles and automotives over the past century. Presently, high fuel costs and concerns about foreign oil dependence have resulted in increasingly complex engine designs to decrease fuel consumption. For example, engine manufacturers have implemented techniques such as enhanced fuel-air mixing, turbo-charging, and variable valve timing in order to increase thermal efficiency. However, around 60-70% of the fuel energy is still lost as waste heat through the coolant or the exhaust. Moreover, increasingly stringent emissions regulations are causing engine manufacturers to limit combustion temperatures and pressures lowering potential efficiency gains [1]. As the most widely used source of primary power for machinery critical to the transportation, construction and agricultural sectors, engine has consumed more than 60% of fossil oil. On the other hand, legislation of exhaust emission levels has focused on carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). Energy conservation on engine is one of best ways to deal with these problems since it can improve the energy utilization efficiency of engine and reduces emissions [2,]. Given the importance of increasing energy conversion efficiency for reducing both the fuel consumption and emissions of engine, scientists and engineers have done lots of successful research aimed to improve engine thermal efficiency, including supercharge, lean mixture combustion, etc. However, in all the energy saving technologies studied. Engine exhaust heat recovery is considered to be one of the most effective. Many researchers recognize that Waste Heat Recovery from engine exhaust has the potential to decrease fuel consumption without increasing emissions, and recent technological advancements have made these systems viable and cost effective [3]. This paper gives a comprehensive review of the waste heat from internal combustion engine, waste heat recovery system and methods of waste heat recovery system.

II. POSSIBILITY OF HEAT RECOVERY AND AVAILABILITY FROM I.C. ENGINE

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. This heat depends in part on the temperature of the waste heat gases and mass flow rate of exhaust gas. Waste heat losses arise both from equipment inefficiencies and from thermodynamic limitations on equipment and processes. For example, consider internal combustion engine approximately 30 to 40% is converted into useful mechanical work. The remaining heat is expelled to the environment through exhaust gases and engine cooling systems [4]. It means approximately 60 to 70% energy losses

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as a waste heat through exhaust (30% as engine cooling system and 30 to 40% as environment through exhaust gas). Exhaust gases immediately leaving the engine can have temperatures as high as 842-1112°F [450-600°C]. Consequently, these gases have high heat content, carrying away as exhaust emission. Efforts can be made to design more energy efficient reverberatory engine with better heat transfer and lower exhaust temperatures; however, the laws of thermodynamics place a lower limit on the temperature of exhaust gases [5]. Fig. 2.1 show total energy distributions from internal combustion engine.

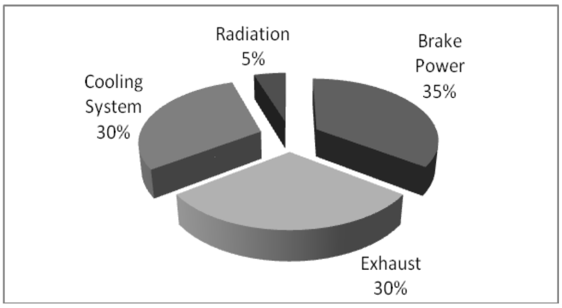

Fig. 1 Total Fuel Energy Content in I. C. Engine

A. Benefits of 'waste heat recovery' can be broadly classified in two categories

1. Direct Benefits:

Recovery of waste heat has a direct effect on the combustion process efficiency. This is reflected by reduction in the utility consumption and process cost.

2. Indirect Benefits:

a) Reduction in pollution: A number of toxic combustible wastes such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM) etc, releasing to atmosphere. Recovering of heat reduces the environmental pollution levels.

b) Reduction in equipment sizes: Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes.

c) Reduction in auxiliary energy consumption: Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption [6].

In automobile engines significant amount of heat is released to the environment. For example, As much as 35% of the thermal energy generated from combustion in an automotive engine is lost to the environment through exhaust gas and other losses. The amount of such loss, recoverable at least partly or greatly depends on the engine load [7]. Among various advanced concepts, Exhaust Energy Recovery for Internal Combustion (IC) engines has been proved to not just bring measurable advantages for improving fuel consumption but also increase engine power output (power density) or downsizing, further reducing CO_2 and other harmful exhaust emissions correspondingly [8]. Which was predicted that if 6% of the heat contained in the exhaust gases were converted to electric power, 10% reduction of fuel consumption can be achieved [9].

B. Possibility of Waste Heat from Internal Combustion Engine

Today's modern life is greatly depends on automobile engine, i.e. Internal Combustion engines. The majority of vehicles are still powered by either spark ignition (SI) or compression ignition (CI) engines. CI engines also known as diesel engines have a wide field of applications and as energy converters they are characterized by their high efficiency. Small air-cooled diesel engines of up to 35 kW output are used for irrigation purpose, small agricultural tractors and construction machines whereas large farms employ tractors of up to 150 kW output. Water or air-cooled engines are used for a range of 35-150 kW and unless strictly air cooled engine is required, water-cooled engines are preferred for higher power ranges. Earth moving machinery uses engines with an output of up to 520 kW or even higher, up to 740 kW. Marine and locomotive applications usually employ engines with an output range of 150 kW or more. Trucks and road engines usually use high speed diesel engines with 220 kW output or more. Diesel engines are used in small electrical power generating units or as standby units for medium capacity power stations [10].

Table I. Various Engine and There Output

Sr. No.	Engine type	Power output kW	Waste heat
1	Small air cooled diesel engine	35	30-40% of Energy Waste loss From I.C. Engine
2	Small agriculture tractors and construction machines	150	
3	Water air cooled engine	35-150	
4	Earth moving machineries	520-720	
5	Marine applications	150-220	
6	Trucks and road engines	220	

The table I. shows that various engine and there power ranges. In general, diesel engines have an efficiency of about 35% and thus the rest of the input energy is wasted. Despite recent improvements of diesel engine efficiency, a considerable amount of energy is still expelled to the ambient with the exhaust gas. In a water-cooled engine about 35 kW and 30-40% of the input energy is wasted in the coolant and exhaust gases respectively. The amount of such loss, recoverable at least partly, greatly depends on the engine load. Mr. Johnson found that for a typical 3.0 l engine with a maximum output power of 115 kW, the total waste heat dissipated can vary from 20 kW to as much as 400 kW across the range of usual engine operation. It is suggested that for a typical and representative driving cycle, the average heating power available from waste heat is about 23 kW, compared to 0.8–3.9 kW of cooling capacity provided by typical passenger car VCR systems [11]. Since, the wasted energy represents about two-thirds of the input energy and for the sake of a better fuel economy, exhaust gas from Internal Combustion engines can provide an important heat source that may be used in a number of ways to provide additional power and improve overall engine efficiency. These technical possibilities are currently under investigation by research institutes and engine manufacturers. For the heavy duty

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automotive diesel engines, one of the most promising technical solutions for exhaust gas waste heat utilization appears to be the use of a useful work.

C Availability of Waste Heat from I.C. Engine

The quantity of waste heat contained in a exhaust gas is a function of both the temperature and the mass flow rate of the exhaust gas:

$$\dot{Q} = \dot{m} \times C_p \times \Delta T \quad (1)$$

Where, $\dot{Q}$ is the heat loss (kJ/min); $\dot{m}$ is the exhaust gas mass flow rate (kg/min); C_p is the specific heat of exhaust gas (kJ/kg°K); and ΔT is temperature gradient in °K. In order to enable heat transfer and recovery, it is necessary that the waste heat source temperature is higher than the heat sink temperature. Moreover, the magnitude of the temperature difference between the heat source and sink is an important determinant of waste heat's utility or "quality". The source and sink temperature difference influences the rate at which heat is transferred per unit surface area of recovery system, and the maximum theoretical efficiency of converting thermal from the heat source to another form of energy (i.e., mechanical or electrical). Finally, the temperature range has important function for the selection of waste heat recovery system designs [12-13].

Table II. Temperature Range from Diesel Engine

Sr. No.	Engine	Temperature in °C
1	Single Cylinder Four Stroke Diesel Engine	456
2	Four Cylinder Four Stroke Diesel Engine (Tata Indica)	448
3	Six Cylinder Four Stroke Diesel Engine (TATA Truck)	336
4	Four Cylinder Four Stroke Diesel Engine (Mahindra arjun 605 DI)	310
5	Genset (Kirloskar) at power 198hp	383
6	Genset (Cummims) at power 200hp	396

(Ref. - This temperature was taken from survey of various internal combustion engines.)

Exhaustive survey was made for measurement of exhaust temperature from internal combustion engine of automotive vehicles and stationary engine it is shown in Table II.

D. Heat Loss through the Exhaust in Internal Combustion Engine

Engine and dynamometer specification is given in table III and IV. Heat loss through the exhaust gas from internal combustion is calculated as follows. Assuming,

Volumetric efficiency (η_v) is 0.8 to 0.9

Density diesel fuel is 0.84 to 0.85 gm/cc

Calorific value of diesel is 42 to 45 MJ/kg

Density air fuel is 1.167 kg/m^3

Specific heat of exhaust gas is 1.1-1.25 KJ/kg°K

Table III. Specification of Engine

Manufacture	Kirloskar Oil Engine Ltd., Pune
Engine	Single Cylinder. 4-Stroke, Vertical Stationary C.I. Engine
Bore	87.5mm
Stroke	110mm
Comp. Ratio	17.5
Capacity	661cc (0.661 Ltrs)
Power	8 hp (5.9kW) at 1800rpm
Sp. Fuel Combustion	220gms/kW-hr (0.22kg/kW-hr)
RPM	1800rpm
BHP@1800 rpm	5.9kW
Cooling System	Water Cooled

Table IV. Specification of Dynamometers

Type	Rope Brake Type Dynamometer
Diameter of Rope	25 mm
Diameter 0f Brake Drum	255 mm
Effective Radius	R = $(255 + 25)/2$ = 140mm

Exhaust heat loss through diesel engine

Compression ratio (V_r)

$$V_r = \frac{V_c + V_S}{V_c}$$

$$17.5V_c = V_c + 6.61 \times 10^{-4}$$

$$V_c = 4 \times 10^{-5} m^3$$

$$\text{Total volume } (V_T) = V_c + V_S$$

$$= 4 \times 10^{-5} + 6.61 \times 10^{-4}$$

$$= 7.01 \times 10^{-4} m^3$$

Mass flow rate of fuel (on the basis of specific fuel consumption) $\dot{m}_f$

$$\text{s.f.c} = \frac{\dot{m}_f}{power}$$

$$\dot{m}_f = \text{s.f.c} \times \text{power}$$

$$= 220 \times 5.9$$

$$= 0.3177\text{gms/sec}$$

$$\text{Volume rate} = \text{swept volume} \times speed$$

$$\text{Volume rate } (\dot{v}) = v_s \times N$$

$$\dot{v} = 6.61 \times 10^{-4} \times \frac{1500}{2}$$

$$\dot{v} = 0.4957 \text{ m}^3/\text{min}$$

$$\dot{v} = 8.262 \times 10^{-3} \text{m}^3/\text{sec}$$

Volumetric efficiency (η_v)

$$\eta_v = \frac{volume\ of\ air}{swe ft\ volume}$$

$$\eta_v = \frac{\dot{m}_a}{\rho_a \times n \times V_s}$$

$$\dot{m}_a = \eta_v \times \rho_a \times n \times V_s$$

$$= 0.9 \times 1.16 \times \frac{1500}{2} \times 6.61 \times 10^{-4}$$

$$\dot{m}_a = 0.5175\text{gm/min}$$

$$\dot{m}_a = 8.625\text{gm/sec}$$

Mass flow rate of exhaust gas ($\dot{m}_E$)

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

$$= 8.625 + 0.3177$$

$$= 8.9427\text{gm/hr}$$

$$= 8.9427 \times 10^{-3} gm/sec$$

Heat loss in exhaust gas (Q_E)

$$Q_E = \dot{m}_E \times C_p \times \Delta T$$
$$= 8.9427 \times 10^{-3} \times 1.1 \times (450 - 30)$$
$$= 4.13 \text{ kJ/sec (or kW)}$$

Therefore the total energy loss by diesel engine is 29.21%. Hence the loss of heat energy through the exhaust gas exhausted from I.C. engine into the environment 29.21% energy.

III. HEAT RECOVERY SYSTEM FOR ENGINE HEAT RECOVERY

Large quantity of hot flue gases is generated from internal combustion engine etc. If same of this waste heat could be recovered, a considerable amount of primary fuel could be saved. It is depends upon mass flow rate of exhaust gas and temperature of exhaust gas. The internal combustion engine energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and losses be minimized by adopting certain measures. There are different methods of the exhaust gas heat recovery namely for space heating, refrigeration and power generation. The mass flow rate of exhaust gas is the function of the engine size and speed, hence larger the engine size and higher the speed the exhaust gas heat is larger. So heat recovery system will be beneficial to the large engines comparatively to smaller engines. The heat recovery from exhaust gas and conversion in to mechanical power is possible with the help of Rankine, Stirling and Brayton thermodynamic cycles, vapour absorption cycle. These cycles are proved for low temperature heat conversion in to the useful power. Engine exhaust heat recovery is considered to be one of the most effective means and it has become a research hotspot recently. For example, Doyle and Patel [14] have designed a device for recovering exhaust gas heat based on Rankine cycle on a truck engine. The commissioning experiment of 450 kilometers showed that this device could save fuel consumption by 12.5%. Cummins Company has also done some research on waste heat recovery on truck engines, and the results showed that engine thermal efficiency could improve by 5.4% through exhaust heat recovery. James C. Conklin and James P. Szybist [15] have designed a six-stroke internal combustion engine cycle with water injection for in-cylinder exhaust heat recovery which has the potential to significantly improve the engine efficiency and fuel economy. R. Saidur et al [16] Rankine bottoming cycle technique to maximize energy efficiency, reduce fuel consumption and green house gas emissions. Recovering engine waste heat can be achieved via numerous methods. The heat can either be reused within the same process or transferred to another thermal, electrical, or mechanical process. Hau xuewjun et al [17] has studied the analysis of exhaust gas waste heat recovery and pollution processing for diesel engine. They analyzed total effect of waste heat on pollution or environment. Waste heat can be utilized for some useful works and it is reduces pollution. The diesel engine exhaust gas waste heat recovery rate increase with increasing diesel engine exhaust gas emission rate.

IV. POSSIBLE WAY OF USING HEAT RECOVERY SYSTEM

The increasing fuel costs and diminishing petroleum supplies are forcing governments and industries to increase the power efficiency of engines. A cursory look at the internal combustion engine heat balance indicates that the input energy is divided into roughly three equal parts: energy converted to useful work, energy transferred to coolant and energy lost with the exhaust gases. There are several technologies for recovering this energy on a internal combustion engine, where as the dominating ones are: Waste heat can utilized for heating purpose, power generation purpose, refrigeration purpose, etc.

A Heating Purpose

Waste heat can be utilized for the heating purpose like space heating, Preheating intake air and fuel, dryer etc. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water etc. waste heat recovery system can utilized for pre heating intake air and intake fuel. Mhia Md et al [18] they investigate effect of preheating intake air on Nox emission on diesel engine. They have design waste heat recovery for preheating intake air, and fabricated and its effect has been tested on diesel combustion and exhaust emissions. Result shows that NOx emission is reduced with the new air preheating waste heat recovery setup. Higher inlet air temperature is caused the lower ignition delay, which is responsible for lower NOx formation with air preheating. Uniform or better combustion is occurred due to pre heating of inlet air, which also causes lower engine noise. They have represented easy vaporization and better mixing of air and fuel occur due to warm up of inlet air, which causes lower CO emission. Heat energy is recovered from the exhaust gases, which causes lower heat addition, thus improving engine thermal efficiency. Low grade fuel, such as, kerosene can be used in diesel engine by blending with conventional diesel fuel. Using the air preheating system and 10% kerosene blend as fuel, the thermal efficiency is improved and exhaust emissions (NOx and CO) is reduced as compared to neat diesel fuel without using air preheating system. F. Karaosmanoglu [19] studied use of alternative fuel in internal combustion engines leads to some problems such as poor fuel atomization and low volatility mainly originated from their high viscosity, high molecular weight and density. It is reported that these problems may cause important engine failures such as piston ring sticking injector coking, formation of carbon deposits and rapid deterioration of lubricating oil after the use of alternative fuel for a long period of time. Waste heat recovery is useful for preheating alternative fuel so reduce viscosity of fuel, better fuel atomization and low volatility of fuel.

B Power Generation Purpose

Waste heat can also be utilized indirectly for the power generation using rankine cycle. Bryton cycle, Stirling cycle and directly used for thermoelectric generator etc,

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1 Direct Method

Generating power from waste heat typically involves waste heat utilization from internal combustion engine to generate mechanical energy that drives an electric generator. Electricity generation is directly from heat source such as thermoelectric and piezoelectric generator. A factor that affects on power generation is thermodynamic limitations for different temperature range.. The efficiency of power generation is heavily depended on the temperature of the waste heat gas and mass flow rate of exhaust gas.

1.1 Thermoelectric generation

The exhaust pipe contains a block with thermo electric materials that generates a direct current, thus providing for at least some of the electric power requirements. In which two different semiconductors are subjected to a heat source and heat sink. A voltage is created between two conductors. It is based on the seeback effect. The Cooling and Heating is done by applying electricity. It is low efficiency approximately (2 to 5%) and high cost.

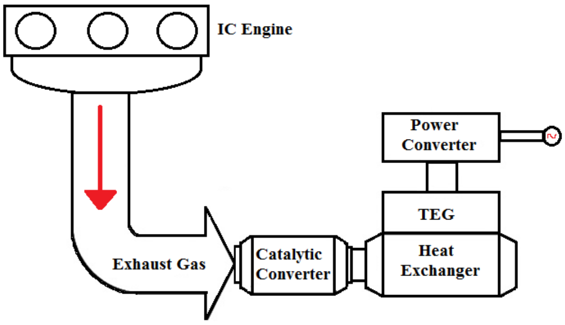

Fig. 2 Thermoelectric Generator

Fig. 2 shows thermoelectric generator and its components. Thermoelectric devices may potentially produce twice the efficiency as compared to other technologies in the current market [20]. Thermo Electric Generator is used to convert thermal energy from different temperature gradients existing between hot and cold ends of a semiconductor into electric energy This phenomenon was discovered by Thomas Johann Seebeck in1821and called the ''Seebeckeffect''. The device offers the conversion of thermal energy into electric current in a simple and reliable way. Advantages of Thermo Electric Generator include free maintenance, silent operation, high reliability and involving no moving and complex mechanical parts. Recycling and reusing waste exhaust gas can not only enhance fuel energy use efficiency, but also reduce air pollution [21]. Thermal power technology such as the Thermo Electric Generator arises, therefore, significant attention worldwide. Thermo Electric Generator is a technology for directly converting thermal energy into electrical energy. It has no moving parts, is compact, quiet, highly reliable and environmentally friendly. Because of these merits, it is presently becoming a noticeable research direction. The mathematical model of a Thermoelectric Generator device using the exhaust gas of vehicles as heat source, and preliminary analysis of the impact of relevant factors on the output power and efficiency of Thermo Electric Generator .Analysis of model simulates the impact of relevant factors, including vehicles exhaust mass flow rate, temperature and mass flow rate of different types of cooling fluid, convection heat transfer coefficient, height of PN couple, the ratio of external resistance to internal resistance of the circuit on the output power and efficiency. The results of analysis shows that the output power and efficiency increase significantly by changing the convection heat transfer coefficient of the high-temperature-side than that of low-temperature-side. **P**ilot program is made to investigate the applicability of thermoelectric generators to the recovery of medium-temperature waste heat from a low-power stationary diesel engine. Experimental investigation to the optimum operating conditions to achieve maximum power outputs from the waste heat recovery system [23]. **S**tudy on waste heat recovery system by using thermoelectric generator from internal combustion engine reviews the main aspects of thermal design of exhaust-based thermoelectric generators (ETEG) systems [24]. Analysis of thermoelectric generator for power generation from internal combustion engine shows results as 20% of energy releasing for the waste heat from engine. It is able to 30-40% of the energy supplied by fuel depending on engine load [25].

1.2 Piezoelectric Generation

It is used for low temperature range of 100 to 150℃. Piezoelectric devices convert mechanical energy in the form of ambient vibration to electric energy. This is thin film membrane can take advantage of oscillatory gas expansion to create a voltage output.

1.3 Thermionic Generation

It is thermoelectric device operate on thermionic emission. In this system a temperature difference drives the flow of electron through vacuum from metal to metal oxide surface at 1000 ℃.

1.4 Thermo Photo-voltaic

It converts radiant energy to electricity. Heating of emitter emits electromagnetic radiation. All direct electric conversion devices has low efficiency but it can be increased by nontechnology. Advantages in alternate power cycle may increases feasibility of power generation at low temperature. All this direct method of power generation devices are high cost and low efficiency. It can be easily handled and with compact in size. So, require minimum space.

2 Indirect Method

2.1 Rankine Cycle

The system is based on the steam generation in a secondary circuit using the exhaust gas thermal energy to produce additional power by means of a steam expander. A special case of low temperature energy generation systems uses certain organic fluids instead of water in so-called Organic Rankine Cycle (ORC). This technique has the advantage compared with turbo-compounding that does not have so an important impact on the engine pumping losses and with respect to thermoelectric materials that provides higher efficiency in the use of the residual thermal energy sources. Waste heat recovery from rankine cycle operated at low temperature difference using unconventional fluids (refrigerants, CO_2, binary mixtures) is shown in fig. 3. At very low heat source temperature the trans-critical CO_2 cycle produces highest net power output [26]. Rankine bottoming

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cycle techniques maximize energy efficiency; reduce fuel consumption and green house gas emissions.

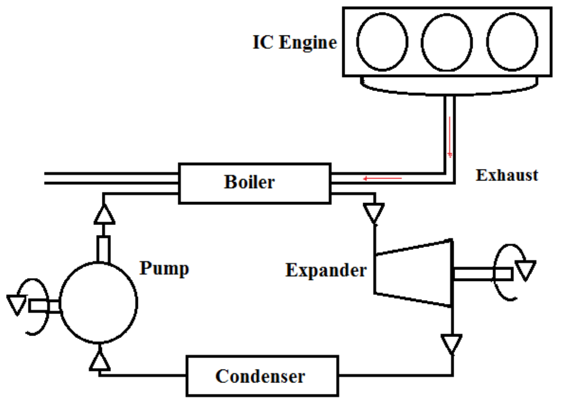

Fig. 3 Rankine Cycle

Recovering engine waste heat can be achieved via numerous methods. The heat can either be reused within the same process or transferred to another thermal, electrical, or mechanical process [16]. Investigation and market evaluation of Organic rankine cycle can be applied in several cost effectively areas. Analysis shows that evaporator pressure gives better efficiencies. Pinch point temperatures, heat exchangers cost, critical temperature of working fluid would be a restriction for maximum working pressure of cycle. Organic rankine cycles as in Combined Heat and Power units are options to improve total efficiency and reduce the cost [27]. Thermoelectric method of exhaust gas waste heat recovery of a three cylinder spark ignition engine is carried on experimental based test. Waste heat recovery using Organic rankine cycle is an efficient method compared with the other techniques; so automobile manufacturers use this method to enhance the efficiency of their products [28]. The economic feasibility of waste heat recovery from diesel engine exhaust gas and analysis of harmfulness of the gases was done by using the methods of purification and processing diesel engine exhaust gas. The computational model developed which determine diesel exhaust emission rate and diesel exhaust waste heat rate and found useful results for diesel engine. The heat recovery is can be done and increases with increasing exhaust mass flow rate [29].

2.2 Stirling Cycle

Linearly reciprocating internal combustion engine offers many advantages over the conventional crank-slider engine. Benefits include improved efficiency, higher power-to-weight ratio and multiple fuel capability. A Stirling engine is a heat engine operating by cyclic compression and expansion of air or other gas, the working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work [30]. Free Piston Stirling Engine is shown in fig. 4. Developments of gamma type Stirling engine which operate at high temperature difference to find out the optimum temperature difference at which model would give maximum thermal efficiency [31]. Waste heat recovery from internal combustion engine analyzed with two different fluids by using organic rankine cycle. The best performance was obtained when R-123 was applied as the working fluid. They have Observe reduction of fuel consumption was also studied [32]. Free Piston Stirling Engine was designed for its Key techniques. Key issues for designing free piston Stirling engine were analyzed during waste heat recovery.

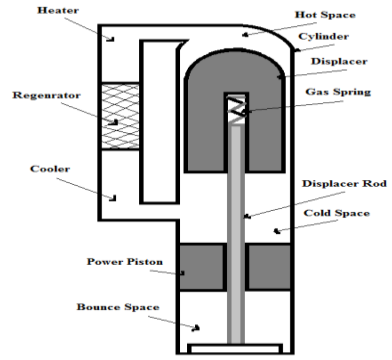

Fig. 4 Free Piston Stirling Cycle

A set of free piston Stirling engine with output power, hot and cold space temperatures and operation frequency designed by coupling structural dynamics analysis and thermodynamics calculation. Fin structure was selected for Heater and cooler to increase heat exchange area and improve heat transfer performance. Size of gap used for clearance seal is designed and completed by precision machining processing, which is a key step of whole engine manufacturing [33]. Design free-piston Stirling engine, which works at relatively low differential temperature. The free piston Stirling engine is a beta type configuration. The free piston Stirling engine couples with a pneumatic cylinder And results by simulation shows the Output power from numerical simulation was higher than that of experiment according to theoretical assumptions [34]. Gamma type Stirling engine was design and developed for application of waste heat recovery system. The performance of low temperature difference Stirling engine was investigated. A twin power piston gamma configuration low temperature differential Stirling engine is tested with non pressurized air by using solar simulator and conclude that Stirling engine working with relative low temperature air of potentially attractive future engine [35].

C Refrigeration

Heat recovery from automotive engines has been predominantly for turbo-charging or for cabin heating with application of absorption chillers. The experiments conducted on the system, prove that the concept is feasible, and could significantly enhance system performance depending on part-load of the engine. Also the concept could be used for refrigeration and air conditioning of transportation vehicles [36]. Systematic view of Vapour Absorption Cycle shown in fig. 5.

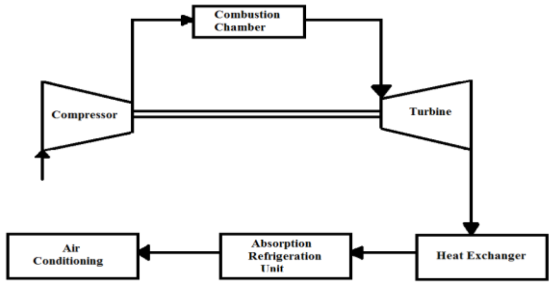

Fig. 5 Vapor Absorption Cycle

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A novel adsorption air-conditioning system used in internal combustion engine for a cooling locomotive driver cabin was investigated. This system employs the zeolite-water as working pairs and is driven by the waste heat from exhaust gas of internal combustion engine. Then the refrigeration capacity can be continuously and steadily provided to the locomotive driver cabin for space cooling instead of the electric vapor compression air-conditioning system. The experiments showed that the single absorber with regenerator locomotive driver cabin air-conditioning system is simple in structure, reliable in operation, and convenient to control [37]. Absorption refrigeration unit interfaced with a Caterpillar diesel engine has been used for cooling the charge air prior to ingestion to the engine cylinder or for other cooling purposes such as air conditioning. They have shown that a diesel absorption combined cycle with pre-inter cooling will have a higher power output and a thermal efficiency than the other configurations. On the other hand the overall efficiency of a pre inter cooled cycle is lower than that of the inter-cooler [38].

D. Mechanical Turbo-compounding

A compressor and turbine on a single shaft, It is used to boost the inlet air (or mixture) density. Energy available in the engine's exhaust gas is used to drive the turbocharger turbine which drives the turbocharger compressor which raises the inlet fluid density prior to entry to each engine cylinder. The fig shows a turbocharged and turbo-compounded internal combustion engine is shows in fig. 6. The turbo demonstrates a method that is presently utilized widely to convert waste energy to improve the efficiency and power output of the internal combustion engine. The problem with current turbochargers is that they do not extract all the possible energy available. The concept of using a turbine to recover energy comes from the turbocharger. The turbocharger is a mechanism that increases the power output of the engine using a turbine. Rather than using the turbine to power a compressor, the turbine could be connected to a generator. Alternatively, a series of turbines could be connected to a series of generators.

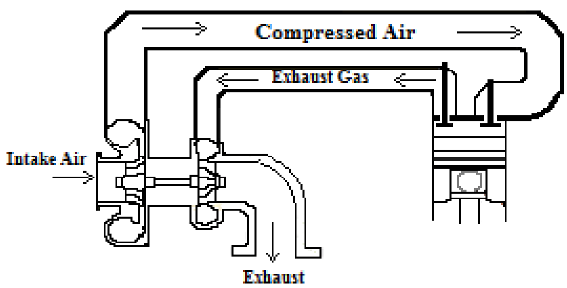

Fig. 6 Turbocharger

If an efficient design was implemented the alternator could be removed from the car to improve the efficiency of the engine by lowering the load on it and by decreasing the weight of the car itself. A turbine of this nature would have to be situated after the catalytic converter [39].

V. CONCLUSION

It has been identified that there are large potentials of energy savings through the use of waste heat recovery technologies. Waste heat recovery defines capturing and reusing the waste heat from internal combustion engine for heating, generating mechanical or electrical work and refrigeration system. It would also help to recognize the improvement in performance and emissions of the engine. If these technologies were adopted by the automotive manufacturers then it will be result in efficient engine performance and Low emission. The waste heat recovery from exhaust gas and conversion in to mechanical power is possible with the help of Rankine, Stirling and Brayton thermodynamic cycles, vapour absorption. For waste heat recovery thermoelectric generator is use low heat, which has low efficiency. It is helpful for the same amount of increases in thermal efficiency and reduction in emission.

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