A Review on Waste Heat Recovery and Utilization from Exhaust Gas of I.C Engine

Pradip G. Karale[1] Dr. J.A Hole[2]
[1]Student [2]Professor
[1,2]Department of Mechanical Engineering
[1,2]Rajarshi Shahu College of Engineering, Pune, Maharashtra

Abstract— In many applications I.C engine is used as primary power source. Out of the total heat supplied to the I.C engine in the form of fuel 30-40% heat is converted into useful work and remaining 60-70 % as a part of waste heat as friction, exhausts gas and engine cooling system. Through the exhaust of engine 30-40 % of heat is lost to the environment. Rapid economy development results in increasing energy demand, consequently fuel consumption and fuel prices which results in environmental pollution. This attracts the researchers to find more energy efficient techniques and concentrates on hard work on investigation of suitable waste heat recovery system. Waste heat utilization reduces the fuel (fossil fuel) consumption and reduces the amount of waste heat and greenhouse gases. A significant waste heat recovery systems or methods have been developed to recover the heat from exhaust gas of I.C engine. This article shows the Benefits of waste heat recovery, the available waste heat from I.C engine, Amount of heat carried away by exhaust gas and possible techniques to recover the heat from exhaust gas of I.C. engine. Waste heat recovery system is the best solution to recover waste heat to reduce waste heat, fuel consumption and pollution.

Key words: I.C Engine**,** Green House

I. INTRODUCTION

The I.C engine is a device which converts the chemical energy of fuel into heat and again heat energy in to mechanical work. It is the fact that the total heat supplied to the engine in the form of fuel approximately only 30-40% get converted in to useful mechanical work and remaining almost 70% of the energy released from fuel due to combustion is lost mainly in the form of Heat. Approximately 25-30% of the total energy generated by the engine is dissipated in the form of Exhaust loss energy [1]. Increase in economy the energy demand also increases which results in more usages of fossil fuels which causes the emission of harmful greenhouse gases. Large amount of heat is released in the atmosphere from the engines without utilizing for any purpose. if some amount of this waste heat could be recovered it possible to reduce the primary fuel required. Waste heat utilization is the major source of cost saving. If exhaust gases of engines are directly released into atmosphere it will not only waste heat but also causes the environmental problems, so it is required to utilize the waste heat for useful work to increase the efficiency of engine.[2] The- recovery and utilization of waste heat from engine results in reduction in fuel consumption, reduction in waste heat loss and engine emission, increases the engine efficiency. It is necessary that continuous and serious efforts should be taken for conserving this waste heat by using proper waste heat recovery techniques. This paper shows the review of waste heat from I.C engine, Heat available from engine exhaust and existing and possible waste heat recovery systems for I.C engine.

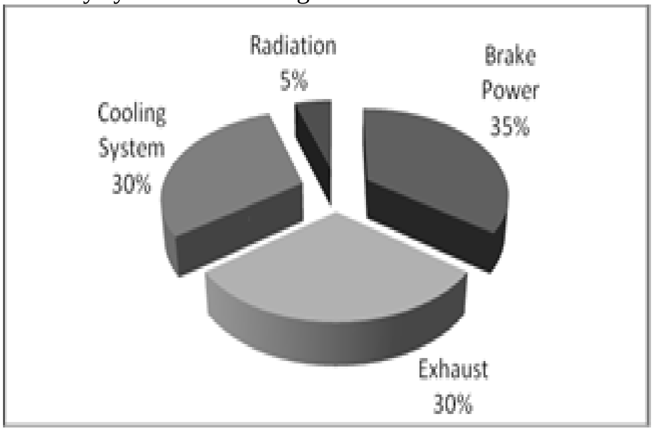

Fig. 1: Fuel Energy Balance in I.C Engine

II. BENEFITS OF WASTE HEAT RECOVERY FROM I.C. ENGINE

Benefits of waste heat recovery from engines can be broadly classified in two categories

A. 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.

B. Indirect Benefits:

1) 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.
2) 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.
3) Reduction in auxiliary energy consumption: Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption. [3]

III. WASTE HEAT AVAILABLE 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.

Engine Type	Power output (KW)	Waste Heat
Small air cooled diesel engine	35	30-40 of energy waste loss from I.C engines
Water cooled Engine	35-150	
Earth moving machineries	520-720	
Marine applications	150-220	
Trucks and road engines	220	

Table 1: Engine Types with Their Output Power

Diesel engines are widely used for heavy loads and low load application such as bus, locomotive and tractors because of their high thermal efficiency. Small air cooled engines of up to 35 kW are used for agriculture purpose, irrigation and construction purpose, and small power generation units.

IV. HEAT CARRIED AWAY BY EXHAUST GAS

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:

$$Q = m \times Cp \times \triangle T \quad (1)$$

Where, Q is the heat loss (kJ/min); m is the exhaust gas mass flow rate (kg/min); Cp is the specific heat of exhaust gas (kJ/kg°K); and T is temperature gradient in °K.

For maximum heat transfer the temperature difference should be maximum. So to recover waste heat the source temperature should be more as compare to sink temperature. The magnitude of this temperature difference is an important determent of waste heats Quality. The range has an important function for selection of waste heat recovery system.

Sr.No	Engine	Temperature in ^oC
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 198 hp	383
6	Genset (Cummins) at power 200 hp	396

Table 2: Temperature Range from various Diesel Engine.

V. ADVANCED METHODS OF WASTE HEAT RECOVERY

Increasing of fuel costs and diminishing petroleum supplies are focusing governments and industries to increase the power efficiency of engines. There are several technologies for recovery this energy from C.I engine, where as a controlling ones are: Waste heat can be used for power generation purpose, refrigeration purpose and heating purpose etc.

Waste heat of exhaust gas of engine can be used for generating mechanical work output. This can be developed directly by thermoelectric generator and indirectly by using Rankine cycle, Brayton cycle, Stirling cycle etc. Electricity generation is directly from heat source such as thermoelectric and piezoelectric generator. Efficiency of power generation is depends upon the temperature waste exhaust gas and mass flow rate of exhaust gas [5]

A. *Stirling Engine:*

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 [6]

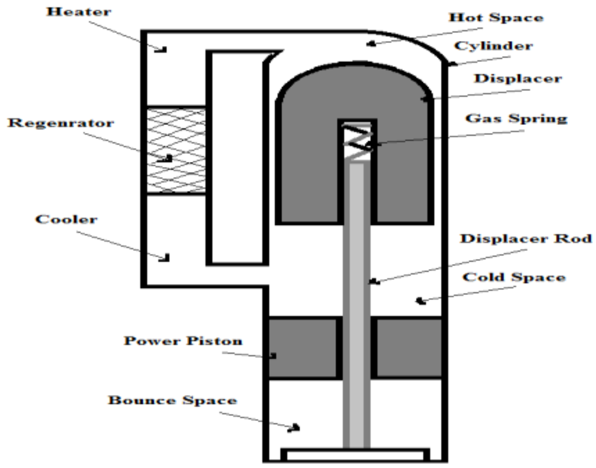

Fig. 2: Free Piston Type Stirling Engine

Heat of exhaust gas is used as a heat source for Stirling engine. 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 [7].Waste heat from engine exhaust or coolant can be used to run alternator by using stirling engine as a waste heat recovery device It is found that the temperature difference obtained between the radiator ends is approximately equal to 70 degree Celsius. With 70 degree temperature difference the power output from the Stirling engine is 950 Watts (assuming the volume ratio to be 5). The alternator consumes 600 Watts power to charge the 12 volt battery, so Stirling engine can be certainly used to run the alternator's rotor and produce current. [8]

B. *Organic Rankine Cycle:*

For recovering high amount of waste heat from source the temperature difference between source and sink should me maximum. This high-grade temperature heat can be converted into electricity. But for low-grade temperature heat from exhaust cannot be efficiently converted in to electricity by conventional methods. So for this heat recovery the Rankine cycle is used. This system is based on steam generation by using heat of exhaust gas to produce more power by expanding this steam in expander. A special case of low temperature energy generation systems uses certain organic fluids instead of water in so-called Organic Rankine Cycle (ORC). In recent years, interests in a Rankine bottoming cycle have prompted various automotive manufacturers to investigate its potentials. Many researchers reported that they achieved a decrease in fuel consumption up to or more than 10% for their passenger cars. For commercial trucks, Nelson (2008) reported that Cummins improves 10% of fuel consumption for their trucks by utilizing ORC.

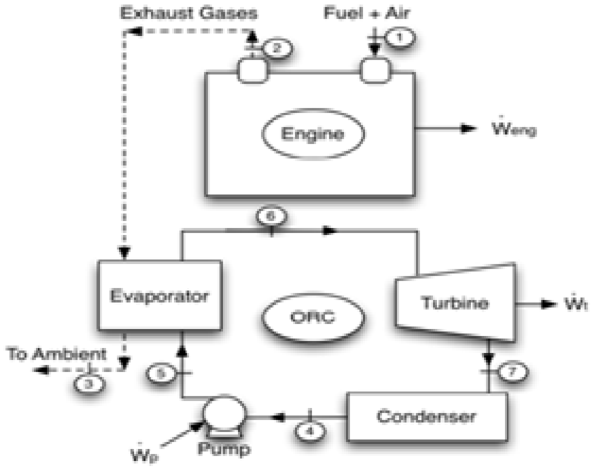

Fig. 3: WHR by using Organic Rankin Cycle

Waste heat recovery from Rankine cycle operated at low temperature difference using unconventional fluids (refrigerants, CO2, binary mixtures) is shown in fig. 3. At very low heat source temperature the trans-critical CO2 cycle produces highest net power output . By using Rankine cycle as a waste heat recovery system for stationary I.C engine to recover waste heat from exhaust gas and coolant it is found that efficiency increases by 12%. [9]. ORC technique can be used for dual fuel low temperature combustion engine which results in 18% reduction in CO2 and 7% improvement in fuel economy and emission. [10]

Waste heat recovery (WHR) system that operates on a Rankine cycle to recover energy from the coolant and exhaust systems to generate and supply a high temperature and high pressure working fluid to the stationary gas compression ignition engine.[11]

C. *Thermoelectric Generator:*

The Thermoelectric Generator is the solid state device that converts heat directly into electricity. Thermoelectric Generator does not contains any moving parts, so operation is very quite. But they have lower efficiency like traditional engines. 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 seebeck effect. Thermoelectric systems can be easily designed to operate with small heat sources and small temperature differences.

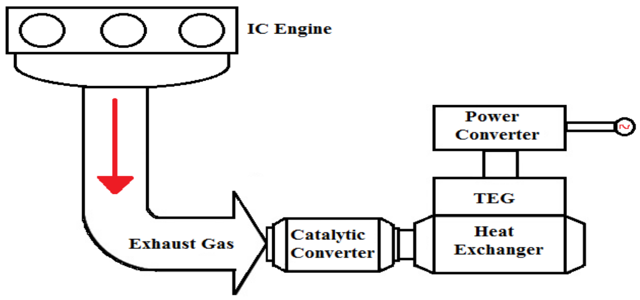

Fig. 4: Thermoelectric Generator and its Components

A thermoelectric produces electrical power from heat flow across a temperature gradient. The resulting voltage (V) is proportional to the temperature difference (ΔT) via the Seebeck coefficient α, ($V = \alpha\ \Delta T$). By connecting an electron conducting (n-type) and hole conducting (p-type) material in series, a net voltage is produced, that can be driven through a load. 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 recover 30-40% of the energy supplied by fuel depending on engine load [12].

D. *Refrigeration and Air Conditioning:*

Air conditioning is used for maintaining the comfort environment for human being. For running A/C system it requires power this can be given from engine, this means it consumes some amount of fuel for its working. It is the investigation is that waste heat of engine can be used to run A/C system of vehicle. This results in reduction in fuel economy of vehicle. To avoid this problem vapour Absorption System can be successfully used. In this system heat source is used as Exhaust gas or Coolant water. 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 [13].

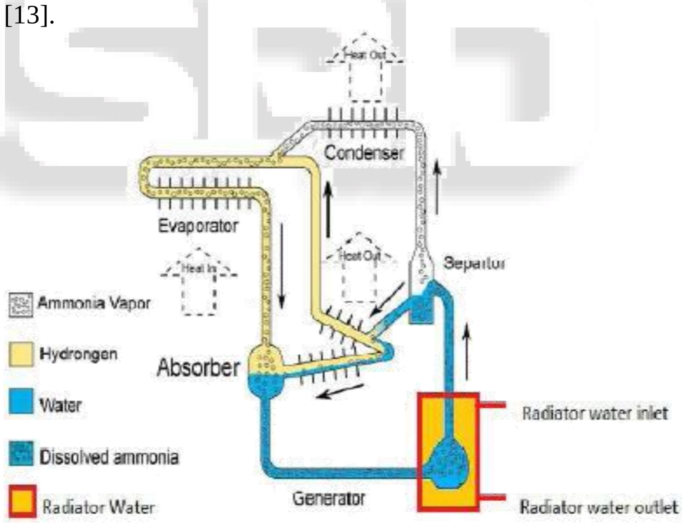

Fig. 5: Vapour Absorption System

The exhaust gases of the Genset have a very large amount of heat at about 700 ºC at full load and waste heat of coolant at about 120 º C can be exploited to run a central air conditioning plant based on vapour absorption chiller The central air conditioning plant can be run by tapping waste heat of the exhaust (14.5 TR) and coolant heat (15.5 TR) of 125 HP Genset. The energy cost may reduce approximately by 35 %. [14]. A prototype of an absorption refrigeration system for truck refrigeration using heat from the exhaust gas heat which can replace the conventional compression refrigeration system. [15]. for open cycle absorption cooling system the cooling potential in the exhaust gas is much greater than the required for cooling of the vehicles interior space. [16].

E. Mechanical Turbo Compounding:

Turbo charging is method used to boost the charge density. Compressor and turbine are coupled to a single shaft and turbine is driven by utilizing the waste heat of exhaust gases engine. Power developed is used to run the compressor which raises the inlet fluid density prior to entry to each engine cylinder. The turbocharger is a mechanism that increases the power output of the engine using a turbine. It is widely used to convert waste heat into power output and increase the efficiency of I.C engine.

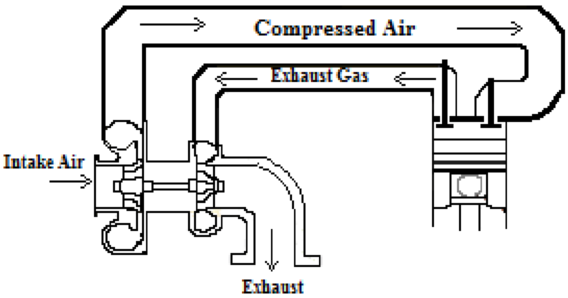

Fig. 6: Turbocharger

The main disadvantage is total heat from exhaust of engine cannot be recovered by using Turbocharger. [4]

F. Active Coolant Warm Up System:

In some cases if the temperature of oil or coolant is very low it will results in friction of engine parts, so to avoid this oil or coolant is warm up. For that warm up purpose the heat required is utilized form the waste heat of exhaust gas of engine. This can be achieved by using heat exchanger. This system is shown in fig.7

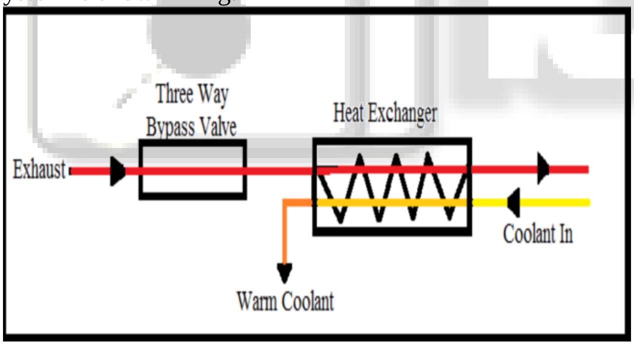

Fig. 7: Active coolant warm up system

A three way exhaust flap valve control the exhaust flow between an exhaust bypass and heat exchanger: during low coolant temperature exhaust gas warm up the coolant. Once the coolant reaches the threshold temperature the flap redirect the exhaust gas away from the heat exchanger through a bypass. [17]

G. Heat Wheel (Enthalpy Wheel):

The enthalpy wheel is a type of air-to-air rotating recovery device. Their primary use is in HVAC systems that operate on the principle of heat and moisture transfer between outside air and building's exhaust air. These devices have the ability to lower peak energy demand and total energy consumption. Their design meets current green building requirements and ASHRAE standards. This can be used very efficiently in air-conditioning system to recover waste heat.

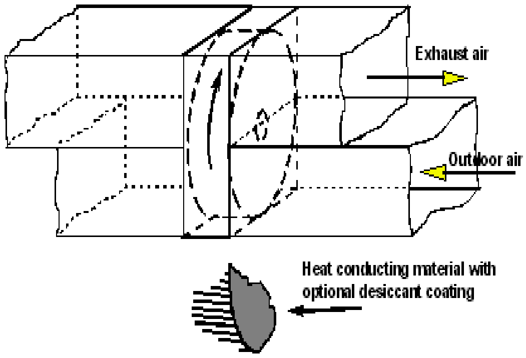

Fig. 8: Heat Wheel

An enthalpy wheel operates between two air supplies and serves as an intermediary device. Using a rotating mechanism, it can absorb or transfer sensible and latent heat. This device will be used for preheating the intake air of diesel engine with the help of waste heat of Exhaust gas of engine. By providing the preheated air for engine cylinder efficiency will be increases, fuel consumption decreases and finally it reduces the pollution [18].

VI. CONCLUSION

It has been observed that there is a large amount heat is waste from the engine. Approximately heat lost by exhaust as is same to useful work produced by engine. It is identified that there is large potential of energy saving through the use of waste heat recovery technologies. The recovery and utilization of waste heat not only conserves fuel but also reduces the greenhouse gases and waste heat by increasing efficiency of engine. This study shows the Benefits of waste heat recovery, Heat carried away by the exhaust gas, various possible methods for heat recovery.

This also shows that the new concept of Heat wheel may be used for exhaust gas heat recovery for intake air preheating of Diesel engine.

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