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Thermoelectric Energy Conversion by Rankine Bottoming Cycle Technique: An Approach towards Waste Heat Recovery from IC Engine

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Abstract

Now a days, the worldwide problem regarding rapid economy development and also shortage of energy, the exhausted waste heat from internal combustion engine and environmental pollution has been more emphasized heavily. In an IC engine, approximately, 30 to 40% of the total heat supplied to the engine in the form of fuel is converted into useful mechanical work; out the remaining heat is rejected to the atmosphere through exhaust gases and engine cooling systems, so it is required to utilized waste heat into useful work. The utilization of this waste heat not only conserves fuel but also reduces the amount of waste heat and greenhouse gases harmed to surrounding atmosphere. The study shows the availability of waste heat from internal combustion engine. Possible methods to recover this waste heat from internal combustion engine discussed, in current study, is through the Rankine bottoming cycle operating by low grade waste heat exhausted from diesel powered internal combustion engine.

Keywords : Rankine bottoming cycle; waste heat recovery from IC Engine; waste heat; Thermoelectric energy.

Introduction

Waste heat is the heat, which is generated in a process by combustion of fuel or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful work and economic purpose. This rejected heat depends in part on the temperature of the waste heat gases and mass flow rate of exhaust gas. For example, consider internal combustion engine approximately 30 to 40% is converted into useful mechanical work. The remaining heat is rejected to the atmosphere through exhaust gases and engine cooling systems.[1] It means approximately 60 to 70% energy losses as a waste heat through exhaust (30% as engine cooling system and 30 to 40% to atmosphere through exhaust gas). Exhaust gases immediately leaving the engine can have temperatures as high as 850-1150°F. Consequently, these gases have high heat content, carrying away as flue gas exhaust emission.

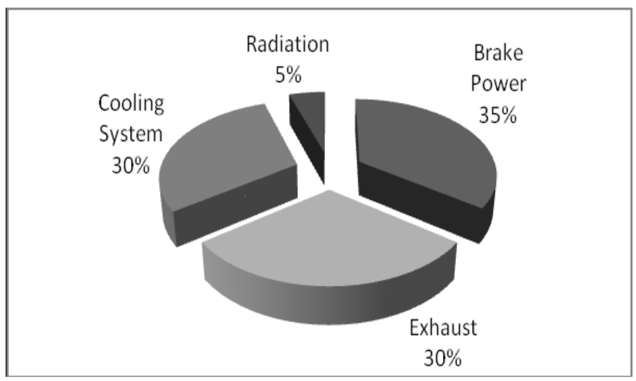

Fig. Total Fuel Energy Content in I. C. Engine

Mr. Johnson found that for a 3.0 l engine with a maximum output power of 120 kW, the total waste heat released can vary approximate from 25 kW to as much as 400 kW across the range of usual engine operation. This is suggested that for a typical and driving cycle, the average heating power available from waste heat is about 25 kW, compared to 0.8–3.9 kW of cooling capacity provided by typical passenger car Vapour Compression Refrigeration unit.[2] 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

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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 a heavy duty diesel engines, one of the most promising technical solutions for exhaust gas waste heat utilization appears to be the use of a useful work. On other hand 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. The common technologies used for waste heat recovery from engine include thermo- electrical devices, organic Rankine cycle or turbocharger system. In this paper, we approach towards recovering the waste heat rejected by small scale generator set though exhaust. This rejected heat could be utilized to operate any other suitable low energy operated thermal cycle on account of improvement in the efficiency of diesel generator. By maximizing the potential energy of exhaust gases, engine efficiency and net power may be improved.

Recent Development of Thermoelectric Generation

[TEG] in automotive industry. Thermo-Electric Generation could be coupled with various devices to maximize its potential. Yu and Chau [3] has proposed and implemented an automotive thermoelectric waste heat recovery system by adopting a Cuk converter and a maximum power point tracker(MPPT) controller into its proposed system as tools for power conditioning and transfer. The other exciting development of TEG is the combination of thermoelectric and photovoltaic (PV) systems which can be called as a hybrid system. Zhang and Chau [4] proposed the TE-PV system coupled with MPPT controller to achieve maximum power output. They reported that the power improvement is recorded from 8% to 10% when the hot-side temperature of the TEG is heated from 100 ℃ to 250 ℃ and the irradiance of PV generator (PVG) is fixed at 1000W/m^2 Also, when the irradiance of the PVG is controlled from 200W/m^2 to 1000 W/m^2 and the hot-side temperature of the TEG is fixed at 250 ℃, the power improvement as much as 4.8% to 17.9% can be achieved. As a result the potential use of the system open sup many possibilities for engine efficiency.

Heat recovery through Rankine bottoming cycle. The low-grade temperature heat from the exhaust can not be efficiently converted to electrical power by using conventional methods as seen in industrial waste heat recovery systems. In this section, a study on converting these low-grade temperature heat sources using Rankine cycle is discussed. There are many other thermodynamic cycles proposed to generate electricity from exhaust heat. These are Kalina, supercritical Rankine, organic Rankine, trilateral flash and Goswami cycles. Interestingly, Kalina and organic Rankine cycles have been compared in many studies in the past few years. DiPippo [5] reported that even though there have been claims of upto 50% of more power output for the same input for Kalina cycles as opposed to organic Rankine cycles, data from actual operations only show a difference of about 3% in favour of Kalina cycle as compared to organic Rankine cycle under similar conditions. Vaja and Gambarotta [6] mentioned that a 12% increase in the overall efficiency with respect to the engine with no bottoming. They added Organic Rankine Cycle(ORC) can recover only a small fraction of the released heat by the engine through the cooling water. Rankine bottoming cycle is a derivative of the Rankine cycle. Because of the low-grade heat sources, the efficiency of the cycle depends on the selected working fluids and operating conditions of the system.

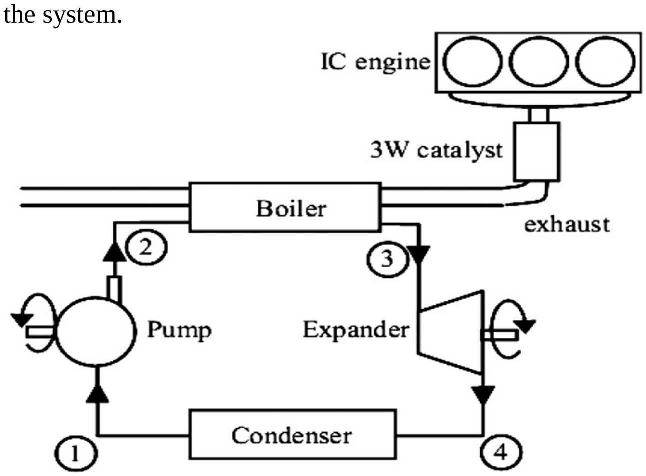

Fig. Layout of the waste heat recovery Rankine bottoming cycle.

Chen et al. [7] reviewed 35 different types of working fluid under different operating conditions. It may be noted that the best working fluids with the highest efficiency cycles may not be the same for other operating conditions and different working fluids. Duparchy et al. [8] have studied a Rankine bottoming cycle system implemented in a hybrid vehicle.

Working Fluids

Rankine bottoming cycle system consists of a wet, dry or isentropic fluid as the working fluid, a pump to circulate the working fluid (increase in pressure), an evaporator/boiler to absorb exhausted

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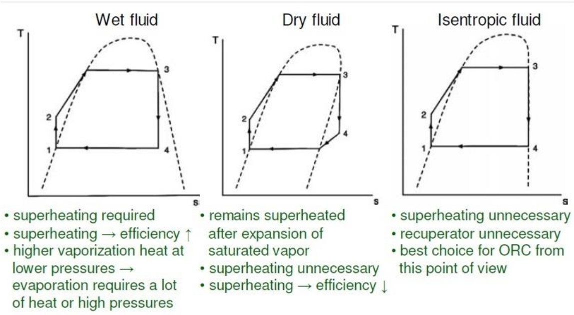
heat energy, an expansion machine (expander) to release power by bringing the fluid to a lower pressure level (organic vapor expands in the turbine to produce mechanical energy), a condenser to release the heat from the fluid and liquidize the fluid before starting the whole cycle again. The T-s diagram of working fluids can have positive slope of saturation curve, negative slope or vertical slope. Accordingly, these fluids are called wet, dry and isentropic fluids(shown in figure).



An organic Rankine cycle(ORC) utilizes organic fluid (i.e., dry or isentropic) instead of water as the working fluid. It could be said that the efficiency of the cycle is greatly dependent on the selection of the working fluid. An organic Rankine cycle generally uses isentropic organic fluids due to their low heat of vaporization and they do not need to be superheated to increase their recovery efficiencies as needed for wet working fluid (water). For an organic Rankine cycle, it is strongly suggested to use isentropic or dry fluids to avoid liquid droplet impingement in the turbine blades during the expansion process.

Summary. Selective summary of waste heat recovery (WHR) literatures using Rankine bottoming cycles shows in a tabular form as given below.

Description of technique used in the study	**Accomplishment**	**Reference**
A specific thermodynamic analysis is examined to study the performance of a stationary internal combustion engine with an ORC system.	Achieved 12% increase in efficiency using Rankine cycles from exhaust gas and engine coolant. The latter only recorded a small fraction of overall improvement.	[6]
An ORC technique was used with high-efficiency, low emissions dual fuel low temperature combustion engine to examine the potential exhaust WHR.	7% of improvement of fuel economy was achieved. Average emissions of NOx and CO2 were also reducedby18%.	[9]
Examined system concepts and control methods for exhaust WHR in hybrid vehicles through computer simulation.	Potential fuel economy efficiencies between 6–31% can be achieved. Dynamic system controls need to be investigated and developed.	[10]
A study on WHR from dual- cycle system for power generation was presented. The system uses TEG and ORC technique to maximize WHR.	Shows an overall improvement mainly due to ORC that produces most of the energy improvement. Only small fraction of energy generated through TEG but may be useful for parasitic heat loss i.e., fans and power steering pumps.	[11]
Potential exergy from WHR of exhaust andcoolantfor2.0l Honda Stream SI engine that utilize ORC technique was studied. Changes were made on the engine to produce maximum waste heat energy.	Successfully showed an increase in thermal efficiency from 28.9% to 32.7% at a constant speed.	[12]

Conclusion

From the above study, it has been identified that a major part of energy could be saved through the use of waste heat recovery technologies. Waste heat recovery promotes capturing and reusing the waste heat obtained from internal combustion engine

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after fuel combustion and using it for heating or generating mechanical or electrical energy. It would also help to recognize the improvement in performance and controls harmful emissions of the engine if such technologies were adopted by the automotive manufacturers. Rankine bottoming cycle is a suitable cycle of recovery of waste heat from any internal combustion engine which results an improvement of approximate 12% to 15% in performance without addition any external heat or work. The another advantage of using bottoming cycle is reduction in pollutant concentration exhausted from engine due to combustion of fossil fuel. This paper concluded the useful way could be implemented with the help of organic Rankine cycle (ORC) along with suitable working fluid usually water. The working fluid operated at different conditions i.e wet, dry saturated and superheated state, result of which is higher heat absorption capacity at different operation conditions and reduction in CO_2 and NO_x emissions. This will finally effect the green house effect and reduction in ozone layer depletion.

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