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# Power generation from waste of IC engines

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ABSTRACT

Fuel consumption of IC engine could be improved significantly by harvesting waste thermal energy. Several methods for waste thermal energy recovery from internal combustion engine (ICE) have been studied by using supercharger or turbocharger and /or combined. This study presents an innovative approach on power generation from waste of IC engine based on coolant and exhaust. The waste energy harvesting system of coolant (weHS$^c$) is used to supply hot air at temperatures in the range of 60–70 °C directly into the engine cylinder, which would be useful to vaporize the fuel into the cylinder. The waste energy harvesting system of exhaust system (weHS$^{ex}$) has been developed with integrating fuzzy intelligent controlled Micro-Faucet emission gas recirculation (MiF-EGR) and thermoelectric generator (TEG). In this study the MiF-EGR (micro-facet exhaust gas recirculation) will be used to maintain the intake temperature 70 °C by keeping flow of the exhaust to the engine cylinder chamber and to increase the engine volumetric efficiency. The TEG produces electrical power from heat flow across a temperature gradient of exhaust and delivers DC electrical power to the vehicle electrical system which could reduce the load of the alternator by as much as 10%. The performance of weHS equipped engine has been investigated by using GT suite software for optimum engine speed of 4000 rpm. The result shows that specific fuel consumption of engine has improved by 3% due to reduction of HC formation into the engine combustion chamber causes significantly improved the emission. While, the brake power has been increased by 7% due to the fuel atomization and vaporization at engine intake temperature 70 °C.


**Contents**



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## 1. Introduction

Thermal management of IC engines is considered a serious problem as it develops high temperatures due to combustion of the fuel but needs to keep the temperature at a controllable level in order to operate the engine safely. Once the temperature in the combustion chamber has reached intolerable values the engine block and components may suffer damage. Therefore, it is essential to have a heat removal process which will maintain the engine at a safe operating condition. Heat losses to the atmosphere through the exhaust are unavoidable. The heat lost to the exhaust is determined by the temperature within the cylinder when exhaust begins. The large amount of energy from the stream of exhaust gases could potentially be used for waste heat recovery to increase the work output of the engine [4]. Hatazawa et al. [5] and [7], Stabler [6], Yang [9], Yu and Chau [8] stated that the waste heat produced from thermal combustion process generated gasoline could get as high as 30–40% is lost to the environment through exhaust pipe. Sam [23] reported that the engine energy distribution: shaft power 25–40%; heat rejection- coolant heat rejection 10–35%, exhaust enthalpy loss 20–45%, and engine external surface loss 2–10%. Conklin and Szybist [10] investigated that the percentage of fuel energy converted into useful work only 10.4% and also found that 27.7% energy lost through exhaust pipe. Dolz et al. [11] reported that the value of exhaust gases is 18.6% of total combustion energy. [12] stated that by installing heat exchanger exhaust energy can be saved up to 34%. Based on the above researches output it could be concluded that the engine waste energy can be turned into useful energy by using several techniques which are discussed in the following sections of this manuscript.

An accurate estimate of the heat transfer between cylinder gases and cylinder wall of a combustion engine is necessary for a precise calculation of power, efficiency and emissions during engine development [1]. Several models exist for evaluating the heat transfer coefficient, of which the correlations of [2] and [3] are the most widely used. The heat transfer involved in the intake system occurs when air or an air–fuel mixture enter into the manifold. The intake manifold is hotter than the air–fuel mixture because of its proximity to the engine components or the design of the manifold. The intake manifold can be designed to heat the air–fuel mixture so that the mixture can start to vaporize once it has entered the combustion chamber. One way of heating the manifold is to put it in close proximity with other hot components. The manifold will heat through convective heat transfer. Electricity and hot coolant flow are other ways in which the manifold can also be heated. After the manifold is heated the air–fuel mixture receives heat through convective heat transfer process [18]. Gu et al. [15] found that the engine cycle (Rankine Cycle) efficiency of several working fluids is very sensitive of evaporative pressure but insensitive to expander inlet temperature. Boretti [16] stated that in a given temperature gradient for optimizing the work output, the working fluid's evaporation enthalpy should be as high possible. Engine intake air temperature needs to increase to 60 °C by using hot spots at the intake manifold for 60% fuel vaporization, which helps the engine to do the complete burning of fresh air fuel mixture Willard [32]. Willard [32] has reported that in order to get the proper combustion it is necessary to make the fuel after injection: *atomization: the fuel droplets break into smaller droplets*; *vaporization: the small droplets of fuel vaporize in the chamber due to high temperatures.* About 90% of the fuel injected into the cylinder needs to be vaporized within 0.001 s after injection.

The maximum power, an engine can deliver, is limited by the amount of fuel that can be burned efficiently inside the engine cylinder . This in turn is limited by the amount of air that is introduced into each cylinder in each cycle [1]. So by introducing a greater amount of air into the cylinder, the opportunity for combustion increases, leading to increase in power of the engine. Different types of waste energy from exhaust can be captured using different energy harvesting materials. The most promising technologies in development include heat that can be captured and transformed into electrical power using thermoelectric and piezoelectric materials. Thermoelectric materials can capture some of this heat, and produce electricity. Thermocouple was first used by [20], to measure gun bore temperatures. Stobart et al. [13] explored the possibility of thermoelectric generator (TEG) in vehicles in which they found that the 1.3 kW output of thermoelectric device could potentially replace the alternator of small vehicle. By improving thermocouples, it would be possible to convert 3 to 5% of the waste heat into electricity which would be efficient enough to recharge a vehicle's 12 V battery. Therefore, the load on the engine is reduced thereby improving fuel efficiency by as much as 10%. However, a 10% efficient thermal electric generator can require at least 500 °C [21]. An increase of 20% of fuel efficiency can be easily achieved by converting about 10% of the engine waste heat into electricity [9,14]. TEG could be coupled with various other devices to maximize its potentiality. Yu and Chau [8] has proposed and implemented an automotive thermoelectric waste heat recovery system by adopting a Cuk converter and a maximum power point tracker (MPPT) controller as a tools for power conditioning and transfer.

## 2. Materials and methodology

This section has presented the engine heat transfer to the cylinder wall and variation of cylinder wall temperature with crank angle, the effect of heat transfer on the volumetric efficiency and emission such as CO, HC and $NO_x$. This section also presents the theoretical models of weHS$^c$ and the role of MiF-EGR on maintaining the emission and influences the performance of weHS$^c$ on engine power enhancement and finned type TEG performance on the conversation of waste heat energy of engine into electrical energy.

### 2.1. Thermodynamic analysis of internal combustion SI engine

Energy is supplied to the engine in the form of chemical energy of the fuel and producing useful power and losses as heat through exhaust and coolant. First Law of thermodynamics states that energy is conserved. Therefore, the energy balance equation for the engine can be represented as,

$$\dot{m}_f h_f + \dot{m}_a h_a = P_{brake} + \dot{Q}_c + \dot{Q}_{exh} + (\dot{m}_a + \dot{m}_f)\ h_e + \dot{Q}_{rad} \tag{1}$$

with

$$\dot{Q}_C = \dot{m}_c c_{pc} \Delta T \ \text{ and } \ \dot{Q}_{exh} = \dot{m}_{exh} c_{exh} \Delta T$$

where, $\dot{m}_a$ and $\dot{m}_f$ is the rate of flow of air and fuel to the engine as initial energy, $\dot{Q}_c$ and $\dot{Q}_{exh}$ is the heat transfer rate of the engine to the coolant and exhaust respectively, $h_e$ is the enthalpy of unburned gas mixture.

$$p_{brake} = \dot{m}_f h_f + \dot{m}_a h_a - \dot{Q}_c - \dot{Q}_{exh} - (\dot{m}_a + \dot{m}_f)\ h_e - \dot{Q}_{rad} - \dot{Q}_{fric} \tag{2}$$

Eq. (2) indicates that the $P_{brake}$ will be increased if % of $\dot{Q}_c$ and $\dot{Q}_{exh}$ can be recovered and can be reduced the unburned gas mixture of $(\dot{m}_a + \dot{m}_f)\ h_e$. Recover of waste heat energy can increase the brake power, improve the fuel consumption and reduce the $CO_2$ emission. This study presents waste energy harvesting system (weHS) for coolant and exhaust which could be potentially used to harvest % of waste energy. Heat transfer through a cylinder wall per unit surface area can be estimated by using the equation of Willard [32]:

$$\dot{q} = (T_g - T_c)/[(1/h_g) + (\Delta x/k) + (1/h_c)] \tag{3}$$

where, $T_g$ is average temperature of burn charge in the combustion