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Energy and exergy analysis on gasoline engine based on mapping characteristics experiment

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HIGHLIGHTS

- ▶ Exhaust gas energy has higher exergy efficiency than cooling water energy.
- ▶ The higher exhaust gas exergy efficiency appears in high-speed and high-load area.
- ▶ The higher cooling water exergy efficiency appears in low-speed and low-load area.
- ▶ Gasoline engine fuel efficiency can come up to 60% through waste heat recovery.

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ABSTRACT

In order to evaluate the energy utilization efficiency of gasoline engine and predict the recovery potential for waste heat energy, energy distribution and waste heat energy characteristics of a naturally aspirated gasoline engine have been studied by combining the methods of energy and exergy analysis. During the research processes, engine energy balance tests were conducted under mapping characteristics, and the parameters required for calculating the energy balance and exergy balance were measured. On this basis, waste heat recovery potential and gasoline engine total exergy efficiency were studied by using the method of exergy analysis. Research results show: at low-speed and low-load, waste heat energy mainly focuses on cooling water; at high-speed and high-load, exhaust gas energy is larger than cooling water energy not only in quantity, but also in exergy percentage and exergy efficiency; the highest exhaust gas exergy efficiency appears in high-speed and high-load area, while the highest cooling water exergy efficiency appears in low-speed and low-load area; theoretically, total fuel efficiency of this gasoline engine can be nearly improved by a time through waste heat recovery, and the maximum total fuel efficiency can reach 60%.

1. Introduction

Nowadays, energy saving and environmental protection have become an important development strategy in the world. As one of the most important power machineries, internal combustion engine (IC engine) plays an irreplaceable role in the society. However, it consumes more than 60% of fossil oil and produces lots of harmful gases at the same time, such as CO, HC. For this reason, IC engine is one of the main objects for energy saving and environmental protection. In the field of IC engine, lots of research focuses on how to improve the fuel utilization efficiency for the purpose of saving energy [1]. According to the existing research, there are two main ways to achieve this goal: one is to improve IC engine thermal efficiency while the other is to recover IC engine waste heat energy.

On one hand, to study the processes of energy conversion and transfer in IC engine is a useful means to improve IC engine thermal efficiency, and lots of scholars are engaged in this field [2–5]. For example, Yuksel and Ceviz have studied the thermal balance of a four stroke SI engine operating on hydrogen as a supplementary fuel [3]; Taymaz has carried on the experimental study of energy balance in low heat rejection diesel engine [4]. On the other hand, according to the research results of energy balance, the effective thermal efficiencies of most IC engines are between 20% and 40%. That is, more than 60% of fuel energy in IC engine is taken away by waste heat. As a result, waste heat recovery (WHR) is one of the most important ways to improve the fuel efficiency and to achieve the goal of energy conservation on IC engine [6]. To date, scientists and engineers have done lots of research on IC

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Nomenclature

Acronyms		$\dot{m}$	mass flow rate (kg/s)
WHR	waste heat recovery	P	power (W)
ORC	organic Rankine cycle	c_P	constant pressure heat capacity (J/kg K)
BMEP	brake mean effective pressure	T	temperature (K)
SFC	specific fuel consumption	Q	energy (J)
		η	efficiency (%)
Symbols		E_X	exergy (J)
H	enthalpy (J)		

engine waste heat recovery [7–12]. For example, Conklin and Szybist have proposed a six-stroke internal combustion engine cycle with water injection for in-cylinder exhaust heat recovery [7], and they have demonstrated that this concept has the potential to significantly increase engine efficiency and fuel economy; Wang et al. have studied the working fluid of organic Rankine cycle (ORC) for engine waste heat recovery [8], etc.

However, as most of research on IC engine energy balance only considered various kinds of energy distributions, and the research on waste heat recovery only considered the energy recovery efficiency, the studies may be more reasonable if the two kinds of research are combined under IC engine mapping characteristics. At the same time, there comes a question that what is the energy saving potential for IC engine waste heat recovery? To answer this question, IC engine waste heat energy characteristics should be analyzed firstly. In addition, energy balance and exergy balance under mapping characteristics are useful for evaluating the fuel utilization efficiency of IC engine especially for selecting the suitable operating conditions. Based on the above considerations, we have conducted the combined research on IC engine energy flow and waste heat energy characteristics by using the methods of energy analysis and exergy analysis based on mapping characteristics experiment. All the work can provide some helps for optimizing IC engine energy utilization efficiency and evaluating the recovery potential of waste heat energy.

2. Basic theory of engine energy balance

2.1. Energy balance system and equations

IC engine energy balance is also called as thermal balance, which is the research on IC engine energy distribution from the angle of system integration [13]. Usually, a commonly used method is to build an energy balance system includes all kinds of energy in IC engine [14]. Then, the allocation proportions of various kinds of energy in each subsystem can be studied. On this basis, IC engine energy utilization efficiency can be improved by optimizing its energy distribution. From the viewpoint of in-cylinder energy balance, fuel chemical energy can be divided into effective work, heat transfer loss, friction loss, exhaust gas energy and unburned product chemical energy. In these kinds of energy, the heat transfer loss is taken away by cooling water and the friction loss is taken away by cooling oil. Consequently, when the study is conducted by experiment measurement, the energy balance system based on the whole IC engine will be more convenient than that based on cylinder. Furthermore, IC engine energy balance can be effectively analyzed by combining the stable energy balance equation and the concept of control volume. Fig. 1 shows the control volume of IC engine energy balance system [14].

As can be seen from Fig. 1, there are two groups of energy in this control volume system. The energy flows into the control volume system includes fuel chemical energy and intake enthalpy. While the energy flows out of the control volume system consists of five parts, which are effective output power, exhaust gas energy, cooling water energy, unburned fuel energy and heat transfer on the surface of IC engine by convection and radiation. The stable energy balance equation gives the relationship among various kinds of energy, as follows [14]:

$$H_1 = P_e + (H_2 - H_3) + Q_1 + Q_2 + Q_3 \tag{1}$$

The calculation formulas for various kinds of energy in Formula (1) are described as follows:

H_1 is the fuel chemical energy, and its calculation formula is given as:

$$H_1 = \dot{m}_f \cdot H_L \tag{2}$$

where $\dot{m}_f$ is the mass flow rate of fuel and H_L is the low heat value of fuel.

P_e is the effective output power of IC engine.

H_2 is the exhaust gas enthalpy, whose calculation formula can be written as:

$$H_2 = (\dot{m}_f + \dot{m}_a) \cdot c_{P\_ex} \cdot T_{ex} \tag{3}$$

where $\dot{m}_a$ is the mass flow rate of intake gas; c_{P_ex} is the specific heat capacity of exhaust gas and T_{ex} is the temperature of exhaust gas.

H_3 is the intake gas enthalpy, which can be calculated according to the following formula:

$$H_3 = \dot{m}_a \cdot c_{P\_in} \cdot T_{in} \tag{4}$$

where c_{P_in} is the specific heat capacity of intake gas and T_{in} is the intake gas temperature.

Q_1 is the energy taken away by cooling water, which can be calculated as:

$$Q_1 = \dot{m}_w \cdot c_w \cdot (T_{2w} - T_{1w}) \tag{5}$$

where $\dot{m}_w$ is the mass flow rate of cooling water; c_w is the specific heat capacity of cooling water; T_{2w} and T_{1w} are the cooling water temperature at outlet and inlet, respectively.

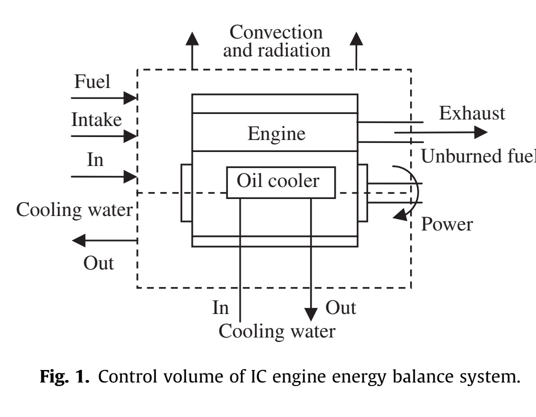

Fig. 1. Control volume of IC engine energy balance system.