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A case study on compatibility of automotive exhaust thermoelectric generation system, catalytic converter and muffler

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ABSTRACT

The power generation of an exhaust TEG (thermoelectric generator) depends on heat energy and thermoelectric conversion efficiency. However, there are compatibility problems among TEG, CC (catalytic converter) and muf (muffler). The present work tried to vary the installation position of TEG and propose three different cases. Case 1: TEG is located at the end of the exhaust system; case 2: TEG is located between CC and muf; case 3: TEG is located upstream of CC and muf. Simulation and experiment were developed to compare thermal uniformity and pressure drop characteristics over the three operating cases. From the simulation and experiment, heat exchanger in case 2 obtained more uniform flow distribution, higher surface temperature and lower back pressure than in other cases. At the same time, the CC and muf could keep normal working in case 2, providing a theoretical and experimental basis for the exhaust gas waste heat recovery system.

1. Introduction

In recent years, because of the forecast limitations in oil supply and increasingly stringent vehicle exhaust gas emission regulations such as Euro 6, new energy technologies are being developed to improve fuel efficiency and reduce emission; examples include hybrid vehicles as well as those powered by fuel cells and hydrogen [1]. For gasoline engine, about 40% of the primary gasoline energy is discharged as waste heat in exhaust gas [2]. Historically, several types of heat exchangers and different heat transfer enhancement measures such as ribbing, grooving and protrusions have been investigated since the first automobile thermoelectric generator (TEG) was built in 1963 [3]. Chung et al. investigated a thermoelectric energy generation system which used a thermoelectric module (TEM) generator. The main feature of their study was the use of high temperatures (up to 200 °C) to ensure TEG reliability, especially for diesel engines, whose exhaust gases are at temperatures from 200 °C to 300 °C at the outlet of the catalyst filter [4]. Thacher et al. employed a rectangular, 1018 carbon steel compact heat exchanger with offset strip fins for a 5.3 L V8 gasoline engine [5]. With the same requirements for exhaust heat exchanger in vehicle waste heat recovery by a Rankine cycle, a shell and tube counter flow heat exchanger was used with exhaust gases in tubes and working fluids in shell [6].

However, there are compatibility problems among TEG, CC (catalytic converter) and muf (muffler). Both TEG and CC need heat to keep normal working in the vehicle exhaust system. The pressure drop directly affects the back pressure of the

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engine exhaust gas, and then the intake and exhaust system of the engine is also affected, which may reduce the engine power. The interaction between them when they are both installed in the automobile exhaust system would cause improper working [7]. The present work tried to vary the installation position of TEG and propose three different cases. Case 1: TEG is located at the end of the exhaust system; case 2: TEG is located between catalytic converter (CC) and muffler (muf); case 3: TEG is located upstream of catalytic converter (CC) and muffler (muf).

A test bench was developed to compare thermal uniformity and pressure drop characteristics over the three operating cases, which provided a theoretical and experimental basis for the exhaust gas waste heat recovery system.

2. Modeling

Fig. 1 presents a plate-shaped heat exchanger of the TEG: diameters of the intake manifold and the exhaust manifold of the heat exchanger are both 36 mm. There are two small fins set at the entrance for diverting the flow, so that the high-temperature exhaust gas is diffused in the entire lateral area rather than concentrating in the central region; many small fins are disorderly set in the internal structure for disturbing the flow, so that the exhaust gas can be fully in contact with the metal walls of the heat exchanger and stays longer in the cavity of the heat exchanger, which can increase the heat that airflow transfers to the fins. Thereby the energy of the high-temperature exhaust gas can be absorbed effectively.

The catalytic converter, whose depth is 200 mm and thickness is 5 mm, is a cylindrical shell with a 50 mm radius. The muffler, whose depth is 150 mm and thickness is 5 mm, is an elliptic cylindrical shell with a 43 mm and 70 mm radius.

3. Simulation

3.1. Boundary

A 2.0-L naturally aspirated engine was used as a study object. Its performance data are listed in Table 1. According to the relevant parameters, the engine exhaust velocity reaches 20 m/s when the engine rotation speed is 2800 r/min and the gas inlet temperature is about 350 °C, which is measured by a thermocouple. So the gas inlet temperature is set to 350 °C and the inlet flow velocity can be set to 20 m/s. The exit faces the atmosphere, so the pressure at the exit is approximately standard atmosphere pressure, and the back pressure at the exit can be set to 0. Additionally, the coefficient of convective heat transfer between the outer surface of the exchanger and the air is set to 20 W/m^2 K. The coefficient of the convective heat transfer among the outer surface of the CC, the muf and air is set to 15.2 W/m^2 K.

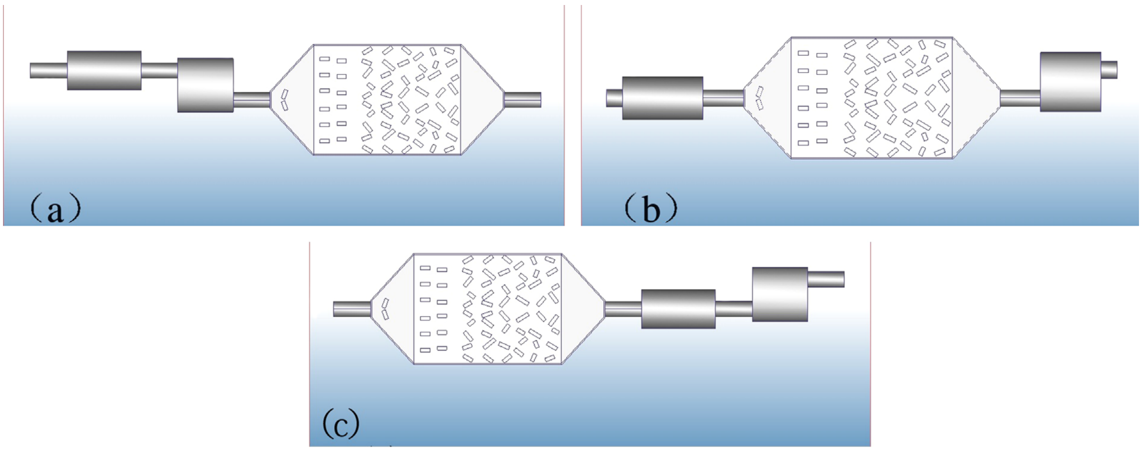

Fig. 1. Structures of three cases: (a) case 1, (b) case 2, and (c) case 3.

Table 1
The engine performance parameters.

Parameter	Value	Parameter	Value
Cylinder number	4	Governed power (kW)	108
Valves per cylinder	4	Governed speed (rpm)	6000
Displacement	1997 ml	Peak torque/speed	200 N m/4000 rpm
Bore/stroke (mm)	85/88 mm	Power of pump	0.18 kW
Firing order	1-3-4-2	Cooling mode	Water cooling
Radiator size	$547 \times 415 \times 50$ mm^3	Number of fan shift	1