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Investigation of emission characteristics affected by new cooling system in a diesel engine †

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Abstract

In a typical cooling system of automotive engine, a mechanical water pump is used to control the flow rate of coolant. However, this traditional cooling system is not suitable for a high efficiency performance in terms of fuel economy and exhaust emission. Therefore, it is necessary to develop a new technology for engine cooling systems. These days, the electronic water pump is spotlighted as the new cooling system of an engine. The new cooling system can provide more flexible control of the coolant flow rate and the engine temperature, which used to be strongly relied on the engine driving conditions such as load and speed. In this study, an engine experiment was carried out on a New European Drive Cycle (NEDC) with a 2.7L diesel engine. The electric water pump operated by BLDC motor and the electronic valve were installed in the cooling system to control the coolant flow rate and temperature. This paper explains that the exhaust emissions were reduced with an increase in the engine temperature and a decrease in the coolant flow. From this experiment, we found that increasing coolant temperature had a significant effect on reducing the emissions (e.g. THC and CO). Decreasing coolant flow also affected the reduction of emissions. In contrast, NOx emission was observed to increase in these conditions.

Keywords: Engine cooling system; Electric water pump; Fast warm up; Exhaust gas emission

1. Introduction

A typical automotive engine cooling system has three major components, namely, a mechanical water pump, cooling fans, and a wax-type thermostat. [1-5] These components are not independent of various engine driving conditions. The pump and fans are coupled with a crank shaft by belts, thereby being subject to the engine operating speed. [7-10] Furthermore, the mechanical cooling pump is not able to supply sufficient flow for cabin heating at idle condition because of its low efficiency. [11] With respect to the thermostat, its opening and closing relies only on thermal expansion of wax. This gives rise to some shortcoming such as high pressure drop, slow response time and hysteresis. For these reasons, a flexible control of engine temperature is in great difficulty with current cooling technology in our hands. Fortunately, technologies on electronic pumps and actuators have been considerably developed; hence, such difficulty could be easily solved by replacing the mechanically driven system with electronically controllable one. [11, 12]

Our strategy in this study was basically to employ electronic equipments that could control the coolant temperature and flow rate more flexibly. The strategy was expected to promote combustion performance in the aspect of fuel saving and emissions penalty. With such goal in mind, engine experiments were performed with a new cooling system containing an electric water pump (EWP) and electronic water valves. The experiment was also accomplished during warm-up period under the NEDC operating mode to explore how much the renovated cooling system could con-

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tribute to shortening the warm-up period. From this experiment, we found that increasing coolant temperature had a significant effect on reducing the exhaust emissions.

2. Experimental apparatus

The experimental set-up used in this study is shown in Fig. 1. It consisted of a cooler substituted for a radiator in real vehicles, an electric water pump, an electronic valve replaced with the wax-type thermostat, and an emission sampling system (Horiba MEXA-7100DEGR). The engine for this experiment was the 2.7L HSDI diesel engine. The specifications of the engine are summarized in Table 1.

Thermocouples were used to measure the coolant temperature, and the temperature data were sent to a control module to determine the valve opening ratio.

Table 1. Engine specification.

Cylinder array	In line 5
Swept volume	2696cc
Bore x Stroke	86.2mm x 92.4mm
Number of valves	20
Compression ratio	18 : 1
Rated power	125kW at 4000rpm
Rated torque	347Nm at 1800rpm

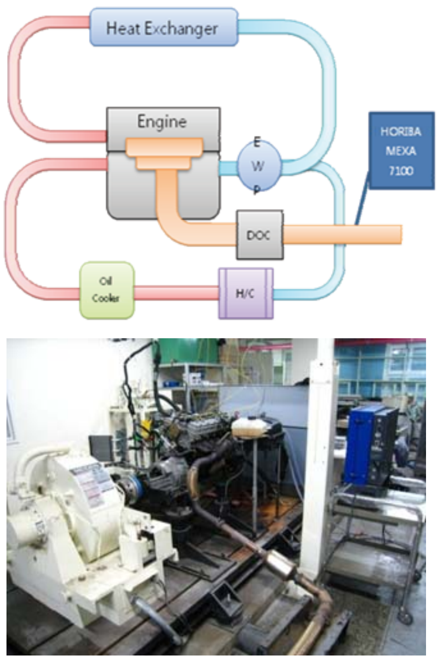

Fig. 1. Schematics of experimental set up.

A conventional water pump was operated electrically by connecting it with a BLDC motor. To select the capacity of BLDC motor, the driving torque of the water pump was measured. This motor had a uniform driving torque for all pump speed range.

3. Test procedure

3.1 Operating condition

For the dynamometer test, eight different engine conditions were selected based on the NEDC drive cycle. The list of Key Point and corresponding engine conditions are tabulated in Table 2.

In order to find the effect of coolant temperature, the experiment was carried out for each Key Points by increasing coolant temperature from 90 to 105℃. A cooler was used to change the coolant temperature and maintain it constant for this set of experiment.

For this case, an electric water pump was used to control the coolant flow rate. Through reducing the water pump speed, the flow was down to 60% of conventional flow, which was the minimum coolant flow rate as the best condition for safety issues. Beyond the flow rate, the engine temperature would be overheated.

3.2 Flow control system

During warm-up period, the engine temperature needs to be increased as fast as it could because combustion performance is not optimum. This transient period causes high exhaust emissions and high fuel consumption. Two methods were tested in this study.

By stopping the operation of the water pump, near zero flow condition could be achieved during the

Table 2. NEDC key point.

Key Point		1	2	3	4	5	6	7	8
Speed	rpm	750	1100	1200	1600	2000	1900	2200	2600
Torque	Nm	2	120	34	64	21	172	152	238
BMEP	bar	0.1	5.6	1.6	3.0	1.0	8.0	7.1	11.1

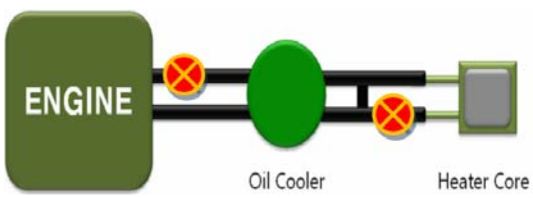

Fig. 2. Schematics of valve control.

warm-up period, and consequently the requiring time for the warm-up of opthe coolant could be significantly reduced.

In this case, the flow path was blocked during the warm-up period. Fig. 2 shows two electronic valves in the coolant pathway.

The coolant within the engine was trapped by closing the valve between the engine and the oil cooler during the warm-up period, which aided in reducing the period. The other valve located in near the heater core blocked the hot flow from wasting heat during the summer time when the heater core is not used.

4. Results and discussions

4.1 Effect of coolant temperature on overall engine performance

Fig. 3 shows the effects of coolant temperature on exhaust emissions and fuel consumption. The most significant fact was that emissions of THC and CO were reduced when the coolant temperature was higher than 85℃. Compared with data at 85℃, THC and CO at 105℃ were reduced by 10% and 4%, respectively. In addition, the BSFC was reduced by approximately 3%. However, NOx emission was observed to increase because higher coolant temperature contributed to raising combustion temperature.

4.2 Effect of coolant flow rate on exhaust emission

Fig. 4 shows the effect of coolant flow rate on exhaust emissions. To ensure engine safety, we kept coolant temperature constant at 90℃. The coolant flow rate was decreased down to 60% of conventional coolant flow rate.

Compared with THC and CO emission obtained from the conventional cooling system, THC and CO emissions were reduced by 12.5 and 26.1 ppm with de

creasing the coolant flow rate up to 60%. However, NOx emission was found to increase by 47.9 ppm using this strategy as it was expected. The decreases in THC and CO emissions as well as the increase in NOx emission correspond to approximately 20 %. It is believed that the low coolant flow rate made the cylinder temperature high. Consequently, the high metal temperature enhanced fuel evaporation and increased combustion temperature of a diesel engine.

An active control of the coolant flow rate with a EWP enables to control the engine temperature optimally. A fast engine warm-up achieved by reducing the coolant flow rate during the cold engine start warm-up period is beneficial to decrease harmful engine-out emissions and fuel consumption. Frequent change in operating conditions during driving with a conventional water pump causes unsteady conditions in terms of coolant flow rate and engine temperature. As a result of it, the combustion becomes unstable, which is a direct cause of high emissions and fuel consumption. The active coolant flow rate control also has an advantage of post cooling. Heavy-duty diesel truck drivers typically keep the engine running to prevent thermal soak after arriving their destination. It becomes an increase in emissions and fuel consumption. Therefore, the active coolant flow rate control is desirable, and the effect of zero-flow strategy on fast-

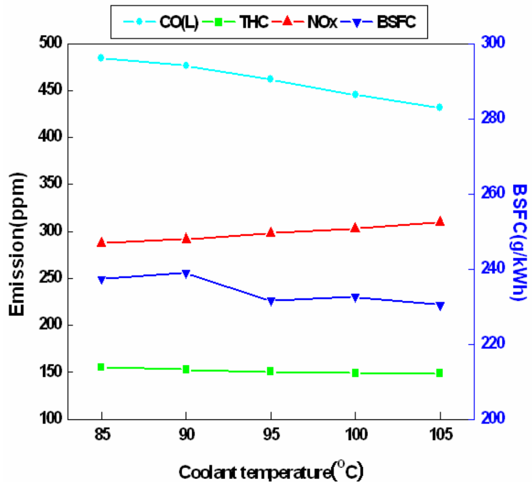

Fig. 3. Effect of coolant temperature on emission characteristics and BSFC.

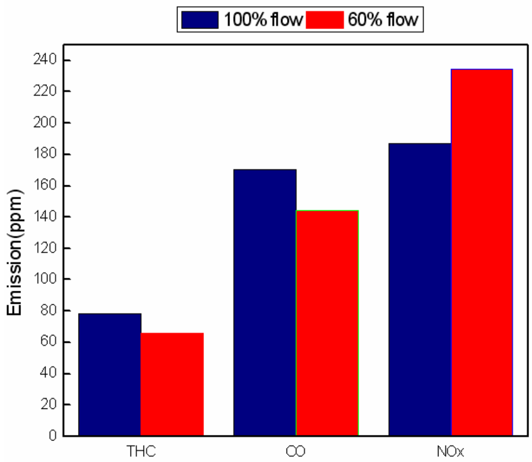

Fig. 4. Effect of water pump speed on exhaust emission.

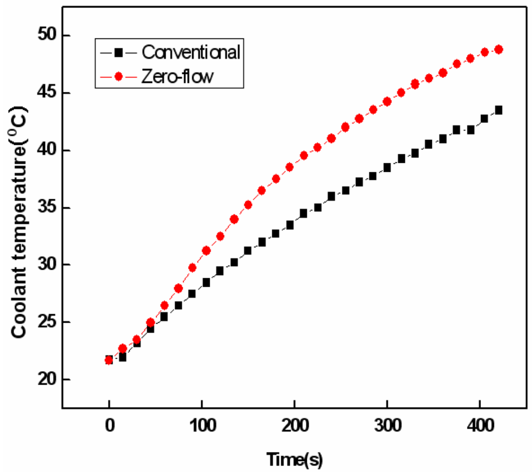

Fig. 5. Effect of the zero-flow strategy on an increase of coolant temperature.

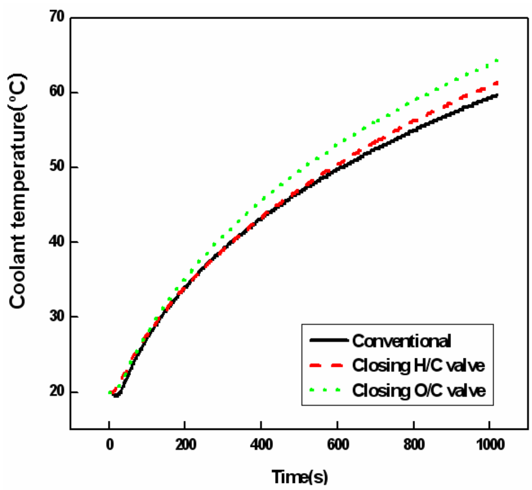

Fig. 6. Effect of valve-control strategy on an increase of coolant temperature.

warm up was discussed in the following section.

4.3 Effect of cooling strategy on fast-warm up

To reduce the warm-up period, zero-flow strategy was examined by stopping the water pump operation during the warm-up period. Fig. 5 shows an increase of the coolant temperature as a function of time. The zero-flow strategy helped the coolant temperature to increase quickly, thereby, shortening the warm-up period. It was observed that the warm-up time was shortened approximately by 30% with the strategy.

4.4 Effect of valve control on the coolant temperature

By controlling the coolant flow path, we could also shorten the warm-up period. The warm-up period of the system with adapting the valve control strategy was shorter than that of conventional system, which was shown in Fig. 6. When the valve between the engine and the oil cooler (i.e. H/C valve) was closed, the warm-up time was shortened approximately by 20 %.

5. Conclusions

In this study, an electric water pump and electronic valves were adapted for a new cooling strategy. The coolant temperature and flow rate were controlled using the electric water pump and electronic valves. The experimental results are summarized as follows:

- At partial load conditions of NEDC drive cycle, THC and CO were reduced by approximately 10 % and 4%, respectively.
- In the case of decreasing coolant flow, THC and CO were reduced down to 20% during NEDC drive cycle.
- The zero-flow warm-up strategy helped the engine temperature raise faster compared to the traditional strategy.
- Controlling the flow path also shortened the warm-up period. Significant reduction of the warm-up period was achieved by closing valve between the engine and the oil cooler.

In short, the emission characteristics of the new cooling concept were much improved more than that of traditional strategy. This new concept is expected to satisfy the stringent emission regulations in the near future.

Acknowledgment

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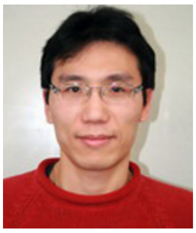

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