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A PRELIMINARY STUDY OF APPLICATION OF SMART THERMAL INSULATION COATING ON IMPROVING THERMAL EFFICIENCY IN A MARINE LOW-SPEED DIESEL ENGINE

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ABSTRACT

The performance of heat insulation by "Smart Thermal Insulation Coating (Smart TIC)" in the combustion chamber walls were studied in a marine low-speed diesel engine. Different with the adiabatic engine that features constant high temperature on combustion chamber walls and low volumetric efficiency, the Smart TIC with low heat conductivity and low heat capacity materials leads to "Temperature Swing" on the combustion chamber walls, reducing the heat transfer loss while increasing the volumetric efficiency. The simulation results show that the Smart TIC with thermal conductivity of 0.1 W/(mK), heat capacitance of 20 J/(kg*K) and thicknesses of 0.1 mm can increase the indicated thermal efficiency by 3.55% with slightly increase of NOx emissions.

Keywords: Smart Thermal Insulation Coating, low-heat-conductivity and low-heat-capacity materials, volumetric efficiency, thermal efficiency, NO_x emissions.

1. INTRODUCTION

With superior durability, reliability and fuel economy, diesel engines are widely used in modern industry and transportation. Future regulations for better fuel efficiency are driving diesel manufactures to optimize the combustion system of diesel engines. For in-cylinder heat losses, approximately 14-19% of the injected fuel energy dissipate to the surrounding combustion chamber walls [1]. Thus, reducing the in-cylinder heat loss is an effective way to improve thermal efficiency.

Many researches have been done since the 1980s to reduce heat loss from the working gas to the walls of the combustion chamber. The idea is applying a low-heat-conductivity and high-heat-capacity material such as ceramic to the combustion chamber wall. By this way, adiabatic effect can be achieved by reducing the heat transfer loss from the combustion chamber to the cooling water [2]. However, the high-heat-capacity materials would keep the combustion chamber wall at high temperature all the times even the intake and exhaust strokes. The high wall temperatures would reduce the volumetric efficiency and facilitated the engine's knock.

Therefore, a low-heat-conductivity and low-heat-capacity material with suitable thicknesses as a new Smart TIC can overcome the drawbacks of Conventional Thermal Insulation Coating (Conventional TIC). The temperature of Smart TICs can change with the temperature of the working gas in the cylinder. In the intake stroke, the low temperature of Smart TICs can increase the volumetric efficiency of engine, while in the combustion and expansion stoke, the high temperature of Smart TICs can decrease the heat transfer loss. Kosaka et al. [3] and Andrie et al. [4] applied low heat capacitance thermal barrier coatings to a small-bore diesel and natural gas engines achieve improved thermal efficiency.

In the past, the research of thermal insulation coating was based on small-bore diesel engines, and there was no discussion on marine diesel engines. In the present paper, the application of Smart TIC on the marine diesel engines is discussed. Firstly, the wall

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temperature curve is simulated in ANSYS. Then, the effect of thicknesses of Smart TICs on in-cylinder temperature, in-cylinder pressure, NOx emissions, the volumetric efficiency and thermal efficiency was simulated in the CONVERGE^{TM}. Finally, the results are discussed and analyzed.

2. METHODOLOGY

2.1 TEST ENGINE

A two-stroke low-speed marine diesel engine was selected in this study, which has 6 cylinders. The test engine layout is shown in Fig. 1. The Table 1. lists the main engine parameters at full load.

Table 1. Engine specifications.

Engine type	Six cylinder, two-stroke, direct injection, uniflow scavenging
Bore × Stroke [mm]	340×1600
Compression ratio	19.8
Engine speed [rpm]	157
Power [kW]	4896
Injector	2×4-hole
Nozzle hole diameter[mm]	0.71

2.2 NUMERICAL MODEL AND VALIDATION

A simple thermodynamic analysis was established to evaluate the temperature fluctuation of Smart TIC. Fig. 2 shows the model for calculating the temperature of Smart TIC, which simplifies the Smart TIC and combustion chamber wall to plates.

Table 2. The boundary conditions in ANSYS.

Gas temperature:	Experimental results
Aluminum wall temperature:	470K
Cooling water temperature:	350K
Heat transfer coefficient:	Woschni model

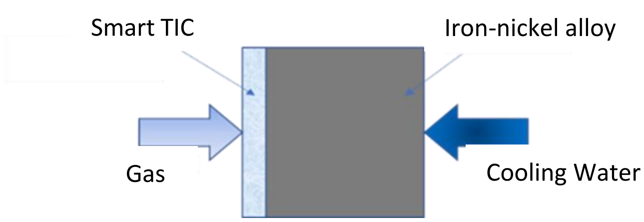

Fig. 1. Calculation model for Smart TIC.

The Table 2 shows the boundary conditions of the Smart TIC model in ANSYS [3][5][6]. Heat conductivity and heat capacity of the Smart TIC was set to be 0.1 W/(mK) and 20 J/(kg*K), respectively. The surface temperatures of the Smart TICs under three thicknesses were calculated, which were used as boundary conditions for the engine simulations in CONVERGE^{TM} software package, a commercial 3D CFD.

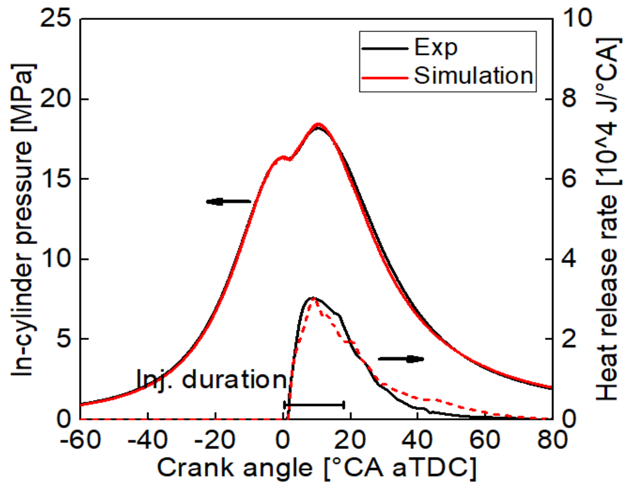

Fig. 2. Model validation for in-cylinder pressure and AHRR at full load.

Renormalization Group (RNG) k-ε turbulence model and Kelvin-Helmholtz and Rayleigh-Taylor (KH-RT) hybrid model be used to simulate the turbulent flow, spray droplet break-up. Details about the model construction and validation can be found in [5]. The CFD simulations was calibrated by the experimental results to predict the complex behaviors in the cylinder as accurately as possible. The size of the base grid was 4 mm for the 340 mm engine. As Fig. 2 shows, the simulation predicted pressure trace and AHRR trace in good agreement with the experimental results. Therefore, the simulations in this work can predict the experiment results precisely.

3. RESULTS AND DISCUSSION

Fig. 3 shows the comparison of wall temperature among the Smart TICs under three different thicknesses, the base engine and the Conventional TIC. Since the heat capacity decreases with the thickness decreasing, the 0.1 mm Smart TIC has the largest temperature fluctuation.

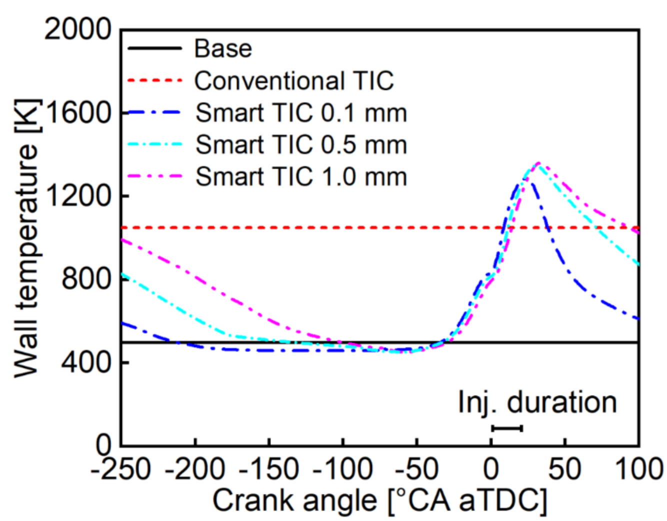

Fig. 3. Temperature comparison of Smart TICs in 0.1 mm, 0.5 mm, 1.0 mm, base engine and Conventional TIC.

The Fig. 4 shows the effect of Smart TIC thickness on in-cylinder pressure and normalized HRR. As can be seen, the in-cylinder peak pressure of Smart TICs is higher than that of base engine. The in-cylinder peak pressure decreases with the Smart TIC thickness increasing. This can be attributed to that the 0.1 mm Smart TIC has higher volumetric efficiency, as shown in Fig. 5. The highest volumetric efficiency of the 0.1 mm Smart TIC can be attributed to lowest temperature at the intake stroke.

The Fig. 6 shows the effect of Smart TICs thickness on in-cylinder averaged temperature. The in-cylinder temperature of Smart TICs is lower than Conventional TIC, while higher than that of base engine.

The Fig. 7 shows the effect of the accumulated heat transfer evolution normalized by the fuel injection quantity among Smart TICs, base engine and Conventional TIC. Because the temperature of Conventional TIC continues to be high, it has minimal heat transfer loss. And obviously, all Smart TICs have lower heat transfer loss than that of the base engine. This can be attributed to the high in-cylinder temperature in the combustion processes.

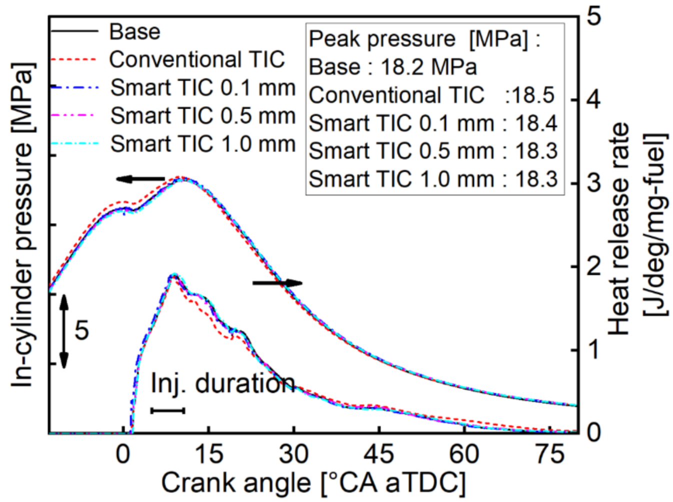

Fig. 4. Effect of Smart TIC thickness on the in-cylinder pressure and normalized HRR.

Fig. 8 shows thermal efficiency improvement rate of Smart TICs and Conventional TIC. As shown, compared to the base engine, the combustion chamber wall coated with 0.1 mm Smart TIC can improve thermal efficiency by 3.55%. The engine with Smart TICs has a higher volumetric efficiency at intake stroke, and lower heat transfer losses during combustion strokes, resulting in the increased thermal efficiency more obvious than Conventional TIC.

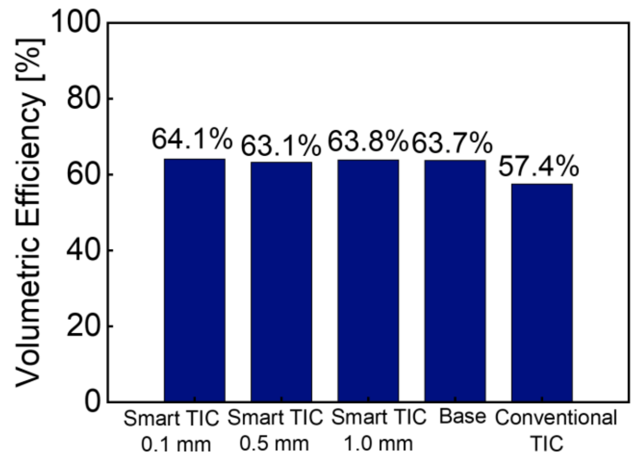

Fig. 5. Comparison of volumetric efficiency.

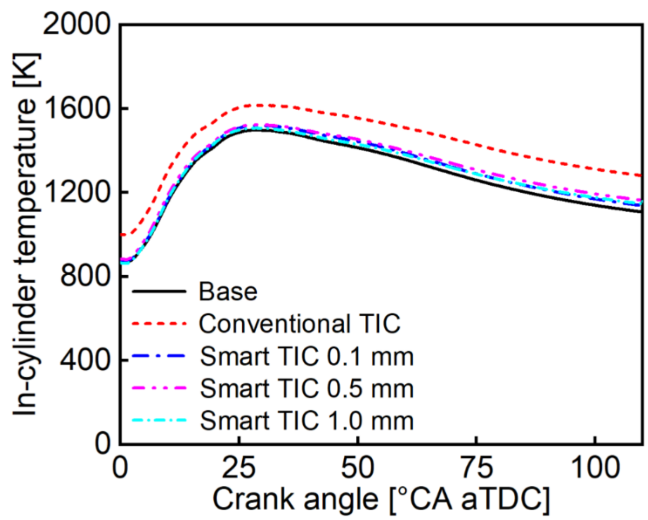

Fig. 6. Comparison of the in-cylinder averaged temperature.

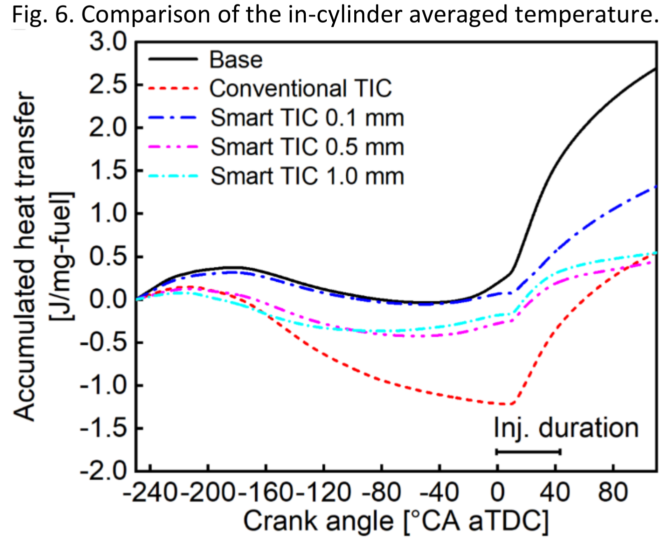

Fig. 7. Comparison of the normalized accumulated heat transfer evolution among Smart TICs, base engine and Conventional TIC.

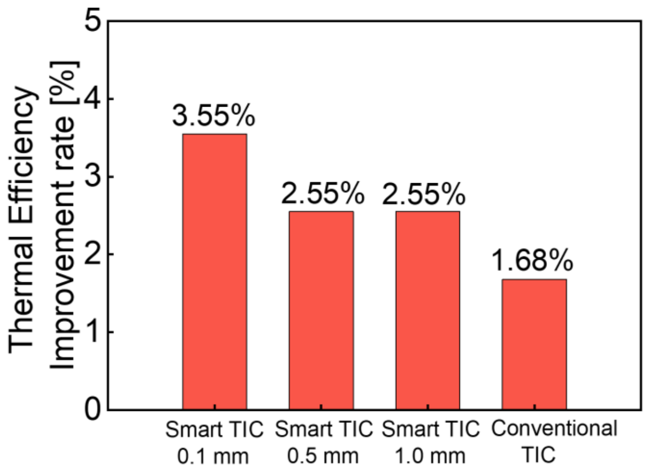

Fig. 8. Comparison of thermal efficiency.

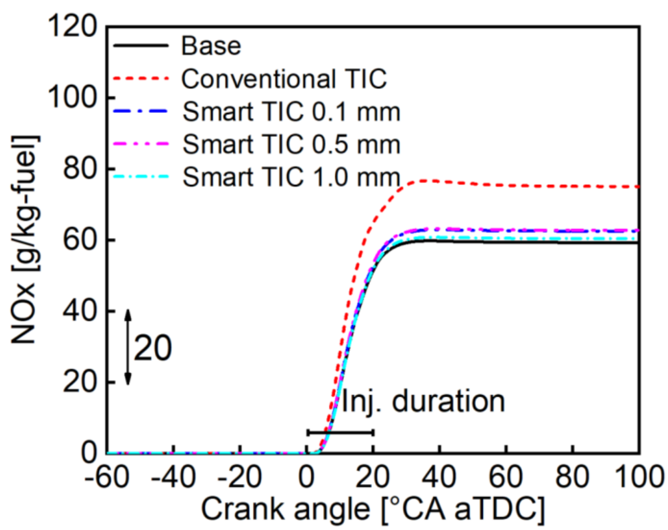

Fig. 9. Comparison of the in-cylinder NOx evolutions.

Fig. 9 shows the comparison of the in-cylinder NOx formation among Smart TICs, base engine and Conventional TIC. As known, the temperature is critical for NO_x formation. Since the Smart TICs have higher in-cylinder temperature than that of base engine, the NO_x emissions are lightly higher. Contrast to Conventional TIC, the Smart TIC increases thermal efficiency with a slight increase in emissions, which is acceptable.

4. CONCLUSION

In this work, a new Smart Thermal Insulation Coating with thermal conductivity of 0.1 W/(mK) and heat Capacitance of 20 J/(kg*K) have been investigated for used in a two-stroke low-speed marine diesel engine. The major conclusions are the following:

(1). The surface temperature of combustion chamber wall with Smart TIC follows the transient gas temperature, and the temperature fluctuation increases with the thickness of the coat increasing.

(2). The Smart TIC with low heat conductivity and low heat capacity materials leads to "Temperature Swing" on the combustion chamber walls, reducing the heat transfer loss while increasing the volumetric efficiency.

(3). Smart TIC thickness affects the volumetric efficiency and thermal efficiency of the engine. The smaller the thickness of Smart TIC, the greater the increase in thermal efficiency.

ACKNOWLEDGEMENT

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