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Research Article

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Numerical study of fuel injection on combustion and emission characteristic of marine diesel/methanol dual-fuel engine

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Abstract The combustion and emission characteristics of marine diesel/methanol dual fuel engine were numerically simulated by combining chemical kinetics and computational fluid dynamics. The results show that with the increase of methanol substitution rate, the peak in-cylinder pressure and peak heat release rate under dual fuel mode increase. NOx and soot emissions under dual fuel mode are lower than those under diesel mode, but HC and CO emissions are higher than those under diesel mode. The advance of injection timing and the increase of injection pressure will increase the in-cylinder pressure and heat release rate, and NOx emissions will also increase, but soot, HC and CO emissions will decrease.

Keywords marine, dual-fuel engine, Injection strategy, combustion, emission

1. Introduction

Marine transportation accounts for 80 % -90 % of global trade transportation, which is the most important mode of international trade transportation. With the development of economy and the increase of international trade, the number of global shipping vessels has increased. Since most ships use diesel-based marine fuel oil-operated engines, this trend will increase the demand for shipping fuel [1]. With the increase in the number of shipping vessels, the problems of air pollution and greenhouse gas emissions caused by engines using traditional fossil fuels cannot be ignored. The main emissions include carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HC), particulate matter (PM) and sulfur oxides (SOx). NOx and SOx emitted by ships account for more than 20 % of global emissions, and carbon dioxide emissions account for 6 % of global emissions [2]. Atmospheric pollutants will not only cause damage to the ecological environment, but also affect human life and health. In order to cope with the environmental problems caused by air pollutants and greenhouse gas emissions, various countries or organizations have proposed stricter emission regulations. In 2018, the International Maritime Organization (IMO) announced a preliminary strategy for greenhouse gas emission reduction in the shipping industry. Based on the carbon emissions in 2008, the carbon emission intensity will be reduced by at least 40 % in 2030 and 70 % in 2050.

Diesel engine is one of the most commonly used power plants on ships. It usually uses traditional fossil fuels, so the emission of pollutants in exhaust gas is very high. At present, carbon capture technology can be used to collect CO2 emitted by ships and store it in many ways to avoid its emission to the atmosphere. Secondly, the use of alternative fuels can reduce CO2 emissions from the source, achieving very low shipping greenhouse gas emissions and ultimately zero [3-5]. Methanol is one of the simplest alcohols, at room temperature and pressure is a colorless liquid, easily soluble in water and most organic solvents, easy to store, transport, filling. Compared with diesel, methanol contains only one carbon atom, high oxygen content, no carbon-carbon bond, and is not easy to produce soot during combustion. And its octane number is high, antiknock performance is good.

The atomization, evaporation, diffusion and mixing of fuel are all related to fuel injection. Avinash Kumar Agar wal et al. [6] studied the effects of diesel injection timing, injection pressure and methanol substitution rate on e ngine performance and emissions, Compared with the diesel mode, the efficiency of the dual fuel mode increases, except for the higher substitution rate, and the NOx decreases with the increase of the methanol substitution rate, but with the advance of injection time, the injection pressure of diesel increases, HC, CO and smoke decrease, and NOx emissions increase. Yangyang Li et al. [7] compared the difference between diesel single injection and double injection, experiments show that compared with single injection, the engine runs more smoothly in double injection, both the heat release rate and the maximum in-cylinder temperature decrease, the cyclic variation of the mean indicated pressure increases, HC emissions decreased, while CO, NOx and PM emissions increased. In order to explore the effect of pilot injection strategy on combustion and emission characteristics of marine diesel/methanol dual fuel engine, Base on chemical reaction kinetics and computational fluid dynamics, the numerical study of marine diesel /methanol dual fuel engine is carried out.

2. Numerical model and validation

A geometric model was established based on a six-cylinder water-cooled turbocharged marine diesel/methanol engine produced by Zi chai Company, the main parameters of the engine are shown in Table 1. Because the 6-hole injector is installed at the central axis of the cylinder, and the circumferential direction of each injection hole is evenly distributed, in order to improve the calculation efficiency, the three-dimensional modeling of the 1/6 combustion chamber area is carried out, the calculation time starts when the intake valve is closed and ends when the exhaust valve is open. The geometric model is imported into CONVERGE software, the basic grid is set to 2 mm, the velocity field and temperature field are encrypted by two-level adaptive encryption, the nozzle and oil beam are encrypted by two-level fixed encryption, and the boundary is encrypted by one-level fixed encryption. The computational grid at the top dead center is shown in Figure 1.

Table 1: Main engine parameters

Parameter	Value
Bore × Stroke (mm)	170 × 200
Compression ratio	14.5
Rated power	450 kw @ 1500 r/min
IVC	-140 °CA ATDC
EVO	115 °CA ATDC
Nozzle number	6

CONVERGE software uses RANS simulation combined with its detailed chemical kinetic model SAGE, reasonable chemical reaction mechanism and adaptive mesh technology (AMR) to accurately simulate in-cylinder combustion. A simplified diesel / methanol chemical reaction kinetics mechanism was adopted [8]. The RNG κ-ε turbulence model [9], the KH-RT model [10], the Extended Zeldovich NOx model [11] and the Hiroyasu Soot model [12] were used in the turbulent model, the spray breakup model, the NOx emission model and the soot emission model, respectively.

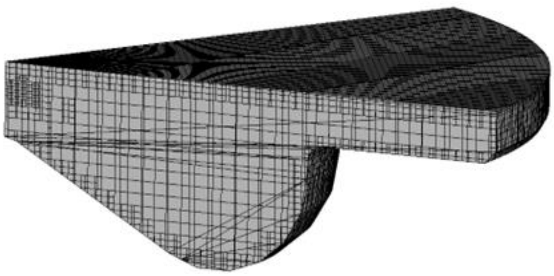

Figure 1: Computational mesh at TDC

In order to verify the reliability of the three-dimensional model for predicting the combustion and emission of diesel / methanol engine, the cylinder pressure of 1191 r / min and 1805 N·m is verified. The verification results are shown in Figure 2 compares the cylinder pressure of the simulation results with the experimental results. It can be seen that the peak phases of the cylinder pressure and heat release rate curves of the simulation data and the experimental data are relatively consistent. It can be considered that the established calculation model is reliable enough to be used in this simulation process.

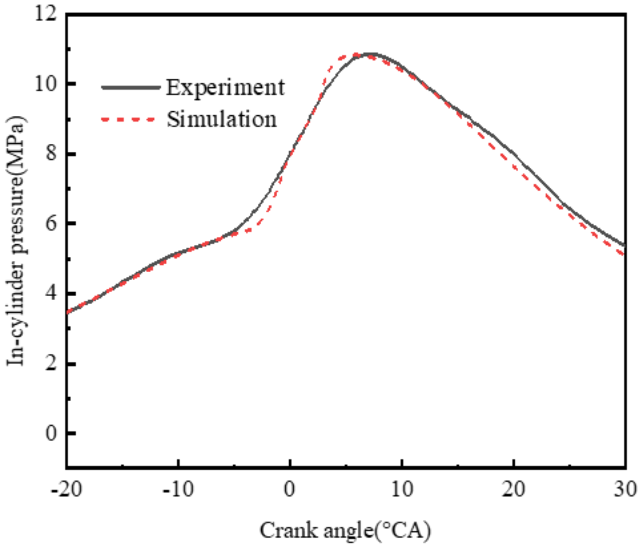

Figure 2: Comparison of experimental and simulated values of in-cylinder pressure

The substitution rate is the ratio of methanol energy to total energy and is given by the following equation:

$$MSR = \frac{m_M \times LHV_m}{m_D \times LHV_D + m_M \times LHV_m} \times 100$$

where , m_D are m_M the mass flow rate of diesel and methanol respectively, LHV_D and LHV_m are the lower heating value of diesel and methanol separately.

3. Results & Discussion

3.1 Effect of MSR on combustion and emission characteristics

At 1191r/min, 1805N·m, SOI (start of injection of diesel fuel) is -6 CA ATDC, the trend of in-cylinder pressure and heat release rate at different MSR is given in figure 3. It can be seen from the figure that as the MSR increases, the in-cylinder pressure increases and the peak heat release rate increases. Because methanol is an oxygenated fuel and burns fast, the peak heat release rate increases with the increase of MSR. Secondly, methanol has an inhibitory effect on the ignition of diesel, and the ignition delay becomes longer. Methanol, diesel and air are mixed more evenly, and the proportion of premixed combustion increases.

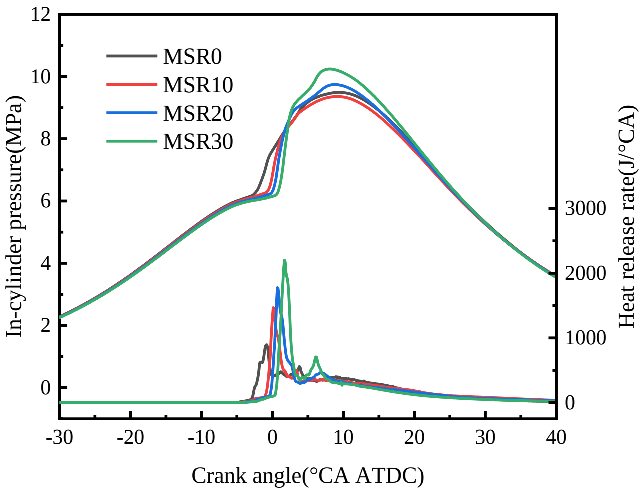

Figure 3: The effect of MSR on in-cylinder pressure and HRR

Figure 4 shows the trend of NOx and soot emissions at different MSR. It can be seen from the figure that the NOx and soot emissions of MSR0 are lower than those of methanol fuel, and soot decreases with the increase of

MSR. Because methanol is an oxygenated fuel, the formation of soot is reduced. Secondly, as the MSR increases, the amount of diesel participating in the combustion decreases, and as the premixed combustion ratio increases, the in-cylinder temperature contributes to the reduction of soot. For NOx emissions, the high gasification latent heat of methanol will reduce the intake air temperature, reduce the local high temperature area in the cylinder, and the addition of methanol will increase the oxygen concentration of the local mixture, which is conducive to the formation of NOx, NOx emissions depend on the competition between the two.

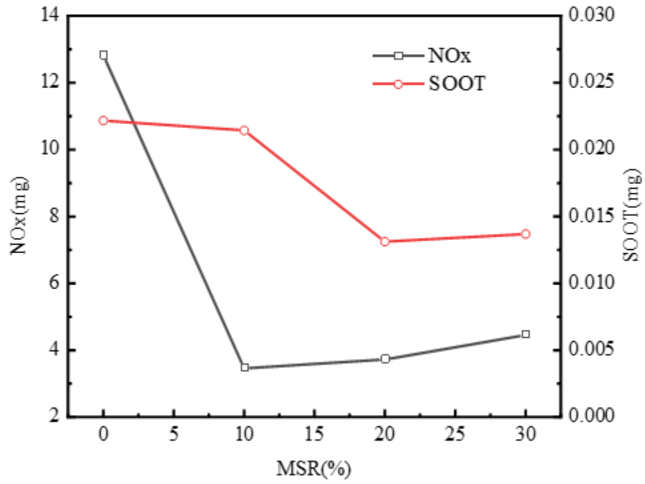

Figure 4: The effect of MSR on NOx and soot emissions

Figure 5 shows the trend of HC and CO emissions at different MSR. It can be seen from the figure that when MSR is 0, HC and CO are almost not produced, and CO and HC emissions increase with the increase of MSR. Because with the increase of the MSR, the unburned HC increases, the methanol enters the combustion chamber by premixing, and the wall cold shock effect increases, while the incomplete combustion and the quenching layer of the cylinder wall will increase CO.

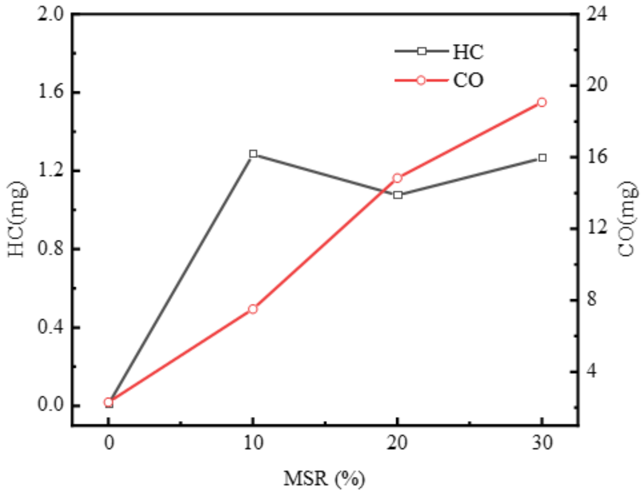

Figure 5: The effect of MSR on HC and CO emissions

3.2 Effect of diesel injection pressure on combustion and emission characteristics

Figure 6 shows the variation trends of in-cylinder pressure and heat release rate under different injection pressures at 1191r / min, 1805N · m, MSR of 30 % and SOI of − 5 CA ATDC. It can be seen from the figure that as the injection pressure increases, the peak pressure in the cylinder and the peak heat release rate increase, and the peak heat release rate moves forward. This is because the higher injection pressure reduces the injection pulse width, reduces the diameter of the fuel droplets, improves the atomization effect, improves the degree of oil and gas mixing, and increases the proportion of diesel premixed combustion.

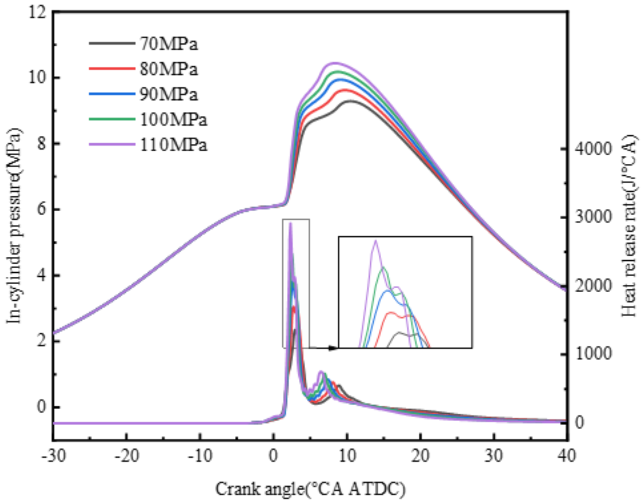

Figure 6: The effect of diesel injection pressure on in-cylinder pressure and HRR

Figure 7 shows the variation trend of NOx and soot under different injection pressures. It can be seen from the figure that with the increase of injection pressure, NOx emissions gradually increase and soot emissions gradually decrease. As the injection pressure increases, the fuel, methanol and air are more evenly mixed, the combustion speed is accelerated, the combustion efficiency is improved, and the temperature in the cylinder increases, resulting in an increase in NOx production. At the same time, the higher injection pressure reduces the local anoxic area and the higher in-cylinder temperature reduces the soot generation.

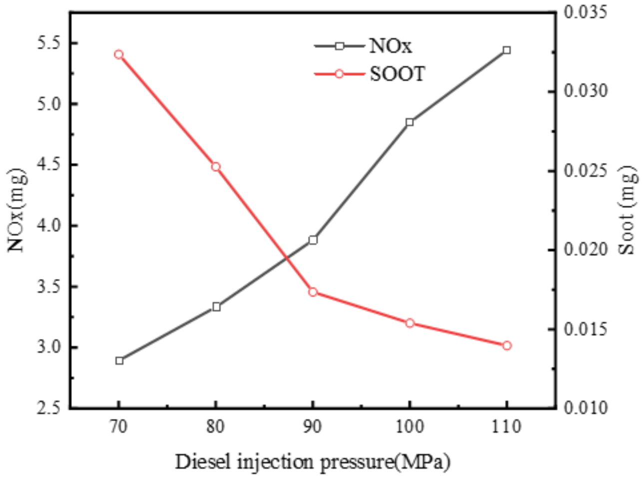

Figure 7: The effect of diesel injection pressure on NOx and soot emissions

Figure 8 shows the trend of HC and CO emissions under different injection pressures. It can be seen from the diagram that both decrease with the increase of the injection pressure, because with the increase of the injection pressure, the diesel atomization is more sufficient, and the local over-concentration area is avoided. Secondly, the momentum of fuel injection increases with the increase of injection pressure, and the effect of entrainment is beneficial to the increase of the mixing rate of oil vapor and methanol and the decrease of local equivalence ratio.

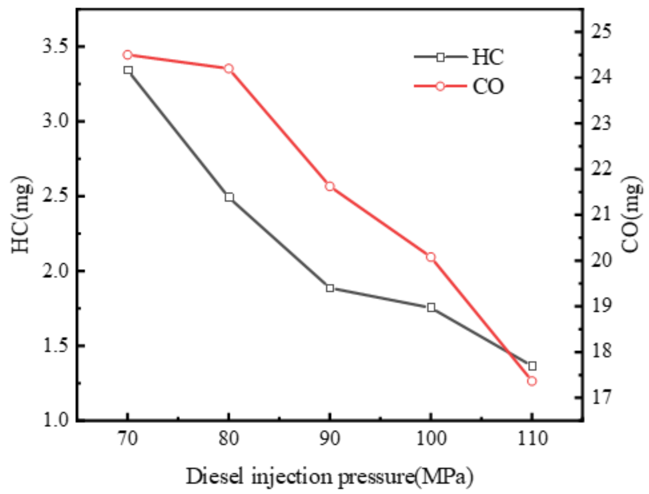

Figure 8: The effect of diesel injection pressure on HC and CO emissions

3.3 Effect of SOI on combustion and emission characteristics

Figure 9 shows the in-cylinder pressure and heat release rate at different SOI when the MSR is 30 % at different injection speeds of 1191r / min and 1805N · m. It can be seen from the figure that as the fuel injection time advances, the in-cylinder pressure increases, the peak heat release rate increases, and the combustion phase advances. The change of SOI will affect the ambient temperature and pressure of diesel injection, thus affecting the mixing time of diesel, and then affecting the equivalent ratio distribution in the cylinder, thus affecting the whole combustion process. With the advance of the SOI, the fuel mixing is more uniform, the proportion of premixed combustion increases, the local high equivalence ratio is reduced, and the equal volume of combustion is improved.

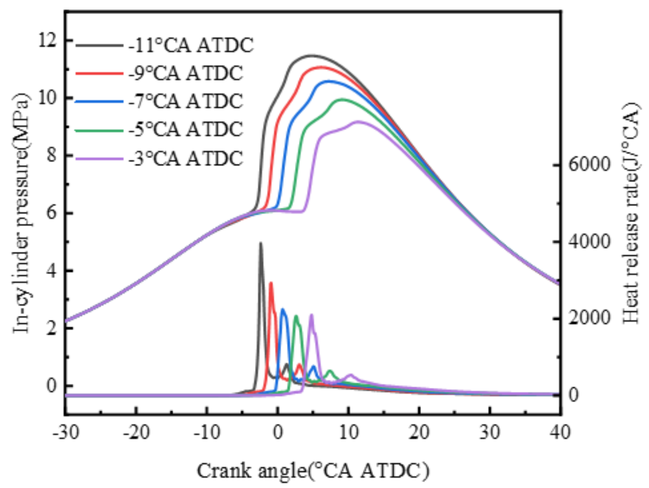

Figure 9: The effect of SOI on in-cylinder pressure and HRR

Figure 10 shows the variation trend of NOx and soot at different SOI. It can be seen from the figure that as the SOI is delayed, the NOx emission decreases and the soot emission increases. Because with the delay of SOI, the decrease of in-cylinder temperature inhibits the generation of NOx, but because of the delay of SOI, the fuel atomization is not good, and the uneven mixing with the air leads to the increase of the high equivalence ratio area and the increase of soot emission.

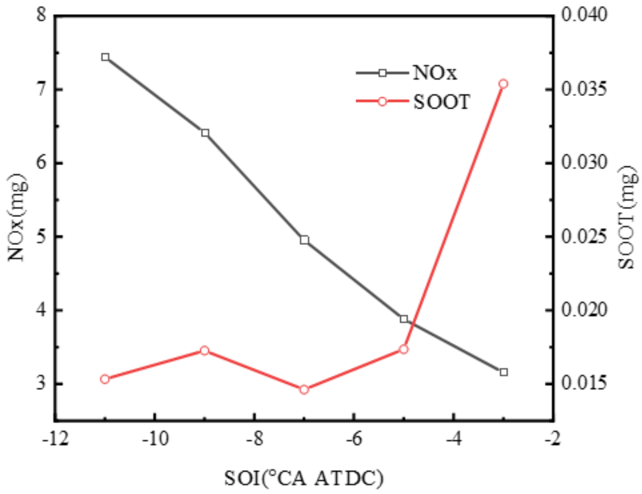

Figure 10: The effect of SOI on NOx and soot emissions

Figure 11 shows the trend of HC and CO emissions at different SOI. It can be seen from the figure that with the delay of the SOI, HC decreases slightly and then increases, while CO continues to increase. Because with the delay of the SOI, the mixing uniformity of fuel and air becomes worse, the local high equivalence ratio increases, and the CO continues to increase. For HC emissions, with a slight delay in the injection time, the fuel entering the cylinder clearance decreases, but the SOI continues to be delayed, because the temperature in the cylinder is low, the unevenness of fuel mixing increases, and HC emissions continue to increase.

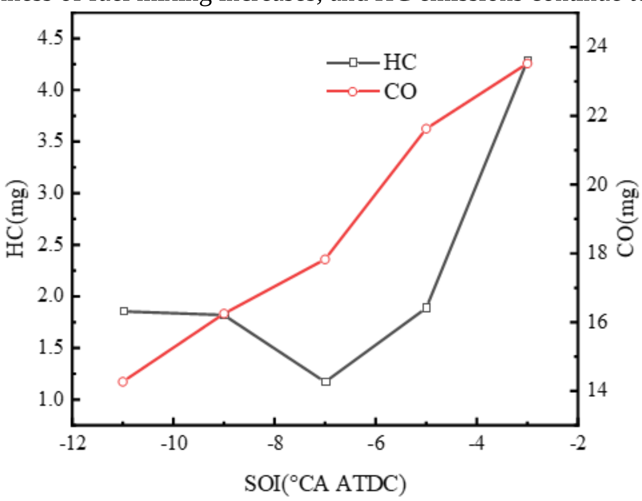

Figure 11: The effect of SOI on NOx and soot emissions

4. Conclusion

The fuel injection parameters of marine diesel / methanol dual fuel engine are numerically studied. The main conclusions are as follows.

With the increase of methanol substitution rate, the peak values of in-cylinder pressure and heat release rate increase. The NOx emission in the dual fuel mode is lower than that in the pure diesel mode. Soot emissions decrease with the increase of substitution rate, but HC and CO emissions increase.

With the increase of diesel injection pressure, the peak values of in-cylinder pressure and heat release rate increase, NOx emissions increase, but HC, CO and soot emissions decrease.

With the delay of diesel injection timing, the peak values of in-cylinder pressure and heat release rate decrease, and NOx emission decreases, but soot, HC and CO increase.

References

[1]. Wang Y, Cao Q, Liu L, et al. (2022). A review of low and zero carbon fuel technologies: Achieving ship carbon reduction targets[J]. Sustainable Energy Technologies and Assessments, 54: 102762.

[2]. Sun W, Jiang M, Guo L, et al. (2023). Numerical study of injection strategies for marine methanol/diesel direct dual fuel stratification engine[J]. Journal of Cleaner Production, 421: 138505.

[3]. Bilgili L. (2023). A systematic review on the acceptance of alternative marine fuels[J]. Renewable and Sustainable Energy Reviews, 182: 113367.

[4]. Chiong M C, Kang H S, Shaharuddin N M R, et al. (2023). Challenges and opportunities of marine propulsion with alternative fuels[J]. Renewable and Sustainable Energy Reviews, 149: 111397.

[5]. Rony Z I, Mofijur M, Hasan M M, et al. (2023). Alternative fuels to reduce greenhouse gas emissions from marine transport and promote UN sustainable development goals[J]. Fuel, 2 338: 127220.

[6]. Agarwal A K, Kumar V, Jena A, et al. (2022). Fuel injection strategy optimisation and experimental performance and emissions evaluation of diesel displacement by port fuel injected methanol in a retrofitted mid-size genset engine prototype[J]. Energy, 248: 123593.

[7]. Li Y, Chen H, Zhang C, et al. (2021). Effects of diesel pre-injection on the combustion and emission characteristics of a common-rail diesel engine fueled with diesel-methanol dual-fuel[J]. Fuel, 290: 119824.

[8]. Y. Chang, M. Jia, Y. Li, M. Xie, (2015). Application of the optimized decoupling methodology for the construction of a skeletal primary reference fuel mechanism focusing on engine-relevant conditions, Front. Mech. Eng. 1 .1–14.

[9]. Han Z, Reitz RD. (1995). Turbulence Modeling of Internal combustion Engines Using RNG k-ε Models [J]. Combustion Science and Technology,106: 267–295.

[10]. Ricart LM, Reltz RD, Dec JE. (1995). Comparisons of Diesel Spray Liquid Penetration and Vapor Fuel Distributions With In-Cylinder Optical Measurements [J]. Journal of Engineering for Gas Turbines and Power, 122: 588.

[11]. Heywood, JohnB. (1988). Internal combustion engine fundamentals [M].

[12]. Hiroyasu H, Kadota T. (1976). Models for combustion and formation of nitric oxide and soot in direct injection diesel engines[J]. SAE transactions, 513-526.