Simulation of a Mining Truck Diesel Engine Fueled with Blended Oxygenated Fuel

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Abstract
Aiming at the combustion, emission and mining truck engine adaption for oxygenated fuel, a numerical model for diesel and B20D10 oxygenated fuel was established with CFD software. The impact of fuel supply advance angle and maximum fuel supply amount were calculated as well. Result shows that compared with diesel, the application of B20D10 oxygenated fuel leads to a lower temperature in the engine cylinder, the NOx generation timing is later and soot emissions is significantly reduced. Power performance of the mining truck engine increases and soot emissions decrease as the fuel supply advance angle increases, yet mechanical loads and NOx emissions deteriorate. The power decline problem of diesel applied with oxygenated fuel could be solved by increasing maximum fuel supply amount. As maximum fuel supply amount increases by 10%, the maximum power of diesel engine applied with oxygenated fuel increases by 4% compared with the engine applied with diesel, and the soot emissions also decrease by 40%.
Key words: MINING TRUCK, DIESEL ENGINE, OXYGENATED FUEL, COMBUSTION, EXHAUSTS EMISSION

1. Introduction

With the worldwide energy shortage and environmental pollution becoming increasingly prominent, alternative fuels for vehicles have become a hot spot of new energy research [1-3].Among them, the molecules of oxygenated fuels contains oxygen atoms, which supplies oxygen function from the combustion process in diesel engines can increase the concentration of oxygen gas mixture, shorten combustion duration, improves thermal efficiency [4-8].According to its own characteristics of oxygenated fuels, blending oxygenated fuels with diesel as alternative fuels for vehicles is an effective measure to deal with energy shortage problem. At present, domestic and foreign scholars mainly research combustion and emission characteristics of oxygenated alternative fuels through bench test, which is of great cost and long periods [9-12].With the development of computer technology and diesel engine combustion models, numerical simulation has been widely used in diesel engine cylinder combustion and its working process simulation [13-16]. However, these researches mainly focus on numerical simulations of combustion and emission characteristics of the engine, there is yet no study on the adaptation of oxygenated fuels for diesel engines.

To solve this problem, a three-dimensional numerical model was established to simulation the mixture formation, combustion, and emission process of diesel and B20D10 (70% diesel + 20% biodiesel + 10% DMC) fuels applied to a certain mining truck diesel engine based on CFD software and the impact of oxygenated fuel on combustion was also analyzed. The results have some significance for the study of alternative fuels for diesel engines.

2. Modeling and Simulation of Disel Engine Working Process

2.1. Mathematical Models

The working process of spray mixture formation and combustion within the cylinder diesel engine is very complicated. It is a typical two-phase flow interaction process which has a non-homogeneous environment, strong turbulence and unsteady characteristics. For the mass, momentum and energy and other basic equation to enclose, mathematical model for cylinder working process needs to be calculated. As used herein, the selection of the mathematical models are shown in Table 1

Table 1. Mathematical Models

Type	Model
Turbulence Model	k-ε
Evaporation Model	Dukowicz
Ignition Model	Diesel_MIL
Combustion Model	Eddy Breakup
Emission Model	Zeldovich

2.2. Initial Conditions

The numerical simulation model is established based on a 12-cylinder turbocharged diesel engine with the bore of 150mm. Main parameters of the diesel engine combustion chamber are shown in Table 2.

Table 2. Main parameters of the diesel engine combustion chamber

Items	Value
Bore/mm	150
Maximum diameter of the combustion chamber/mm	150
Combustion chamber volume/mm^3	3 233.33
Nozzle number	8
Compression ratio	13.5

In order to reduce the computation time, the simulation results are from 60 °CA before TDC to 60 °CA after TDC. Calculation time step is set to 0.5 °CA within 20 °CA range before and after TDC, the rest step is set to 1 °CA. The fan-shaped body circumferentially opposite to the border is defined as a circle; the remaining boundary is defined as the solid wall boundary. Boundary conditions were set as shown in Table 3

Table 3. Boundary conditions set

Items	Value
Cylinder wall temperature/K	375.15
Piston surface temperature/K	475.15
Bottom surface of the cylinder head temperature /K	450.15
Fuel temperature/K	323

Diesel engine combustion system using axial symmetry arrangement, in order to improve computational efficiency, select 1/8 fan-shaped area of the combustion chamber as the calculation according to the injector holes (8 holes). Three-dimensional grids for combustor is shown in Figure 1, the initial meshing for calculate have 10060 units.

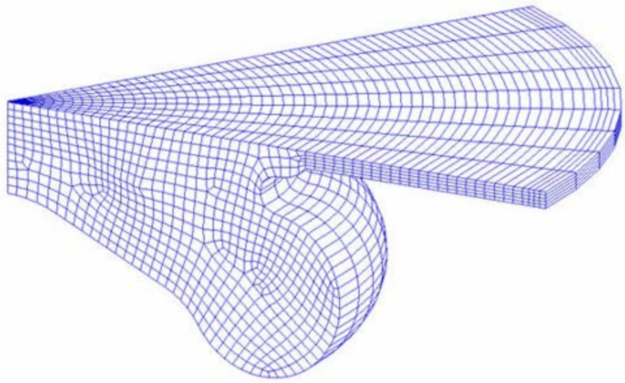

Figure 1. Three-Dimensional Grid for Combustor

2.3. Numerical Model Validation

To verify the accuracy of the model, the external characteristic of engine with the speed of 2000 r/min is calculated, test result of the diesel cylinder pressure in contrast with the simulation result is shown in Figure 2.

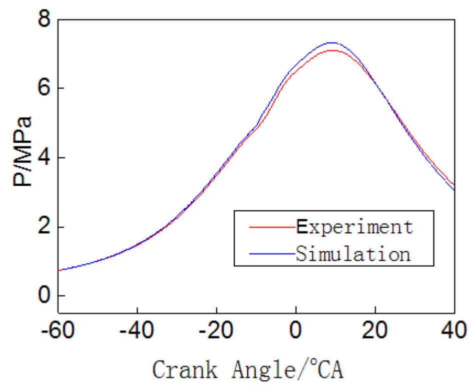

Figure 2. Comparison of Cylinder Pressure Test and Simulation Results

As shown in Figure 2, the simulation results and experimental results are basically the same; the error is less than 3%. The main reason account for the error is a single-step shell model used in the simulation, heat transfers faster than the actual speed, causing the maximum explosion pressure higher than the experimental values. Overall, the simulation results are in good agreement with the experimental results.

3. Combustion and Emission Characteristics Analysis of Oxygenated Fuel

As For the external characteristic with the speed of 2000 r/min, combustion and emission characteristics of diesel fuel and oxygenated fuels were analyzed.

3.1. Combustion Analysis

The formation of mixed gas and concentration distribution simulation results of each course in the cylinder is shown in Figure 3, and the diesel injection timing crank angle is corresponding to 704 °CA. It can be seen that diesel and oxygenated fuel during spraying are all experienced spray, wall interaction and evaporation processes. However, due to the viscosity decrease for oxygenated fuel, the initial particle size distribution is finer than that of diesel, and penetration distance of oxygenated fuel is smaller compared with diesel.

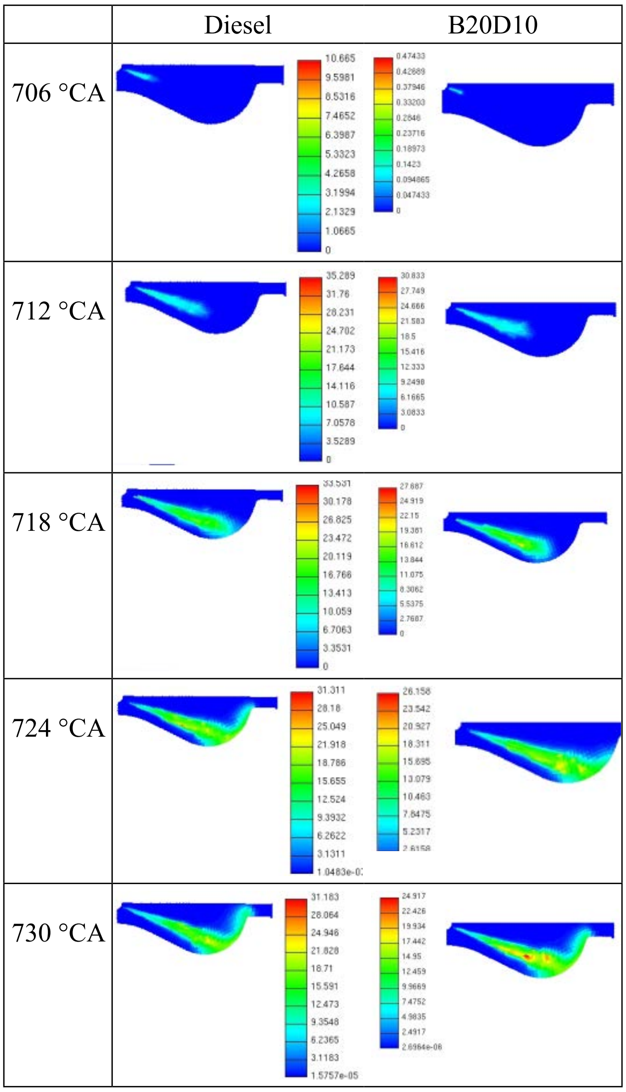

Figure 3. Concentration Distribution of mixed gas

The cylinder temperature distribution of maximum load with the speed of 2000 r/min is shown in Figure 4. It can be seen that: a) After the fuel injection, local area temperature is drop which dues to fuel evaporation process that absorbs heat, resulting in a decline of the local temperature. b) First ignition in cylinder occurs at the edge portion of the spray, because this part of the mixed gas was first evaporated, and the concentration is of more appropriate, which ignition delay is the shortest. c) Combustion temperature of oxygenated fuel is lower than that of diesel. It is because the LHV of oxygenated diesel fuel is less than that of diesel; therefore, temperature is lower for applying oxygenated fuel as quality is the same.

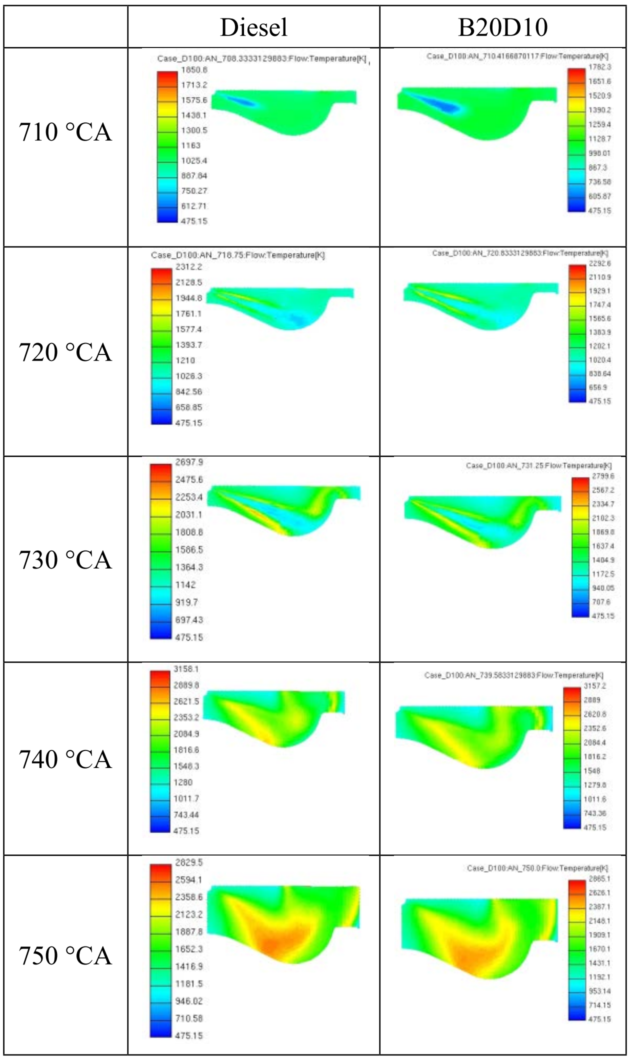

Figure. 4. Temperature Distribution in Cylinder

3.2. Emission Analysis

NOx formation process in-cylinder is shown in Figure 5. It can be seen that: There is basically no NOx generation before 740 °CA, and only in the late combustion, cylinder temperature is higher when there is the emergence of NOx emissions. It is because combustion temperature of oxygenated fuel is lower, therefore, its NOx emissions is lower compared with diesel fuel.

Soot formation process in-cylinder is shown in Figure 6. It can be seen that: After the fuel injection, in the high air-fuel ratio of the area there is soot formation, and as the temperature rises, this part of soot will be oxidation by air Soot generation is lower for oxygenated fuel compared with diesel, which mainly because there is oxygen-containing component within oxygenated fuel itself, the ratio of the concentration is lower than diesel, thus soot formation is more difficult.

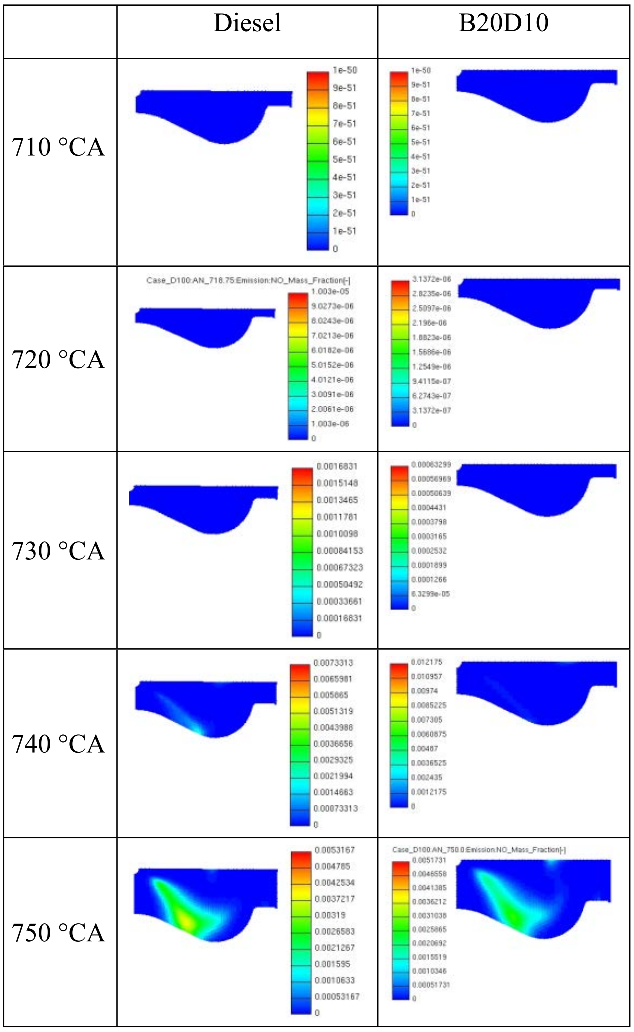

Figure 5. NOx Formation Process In-Cylinder

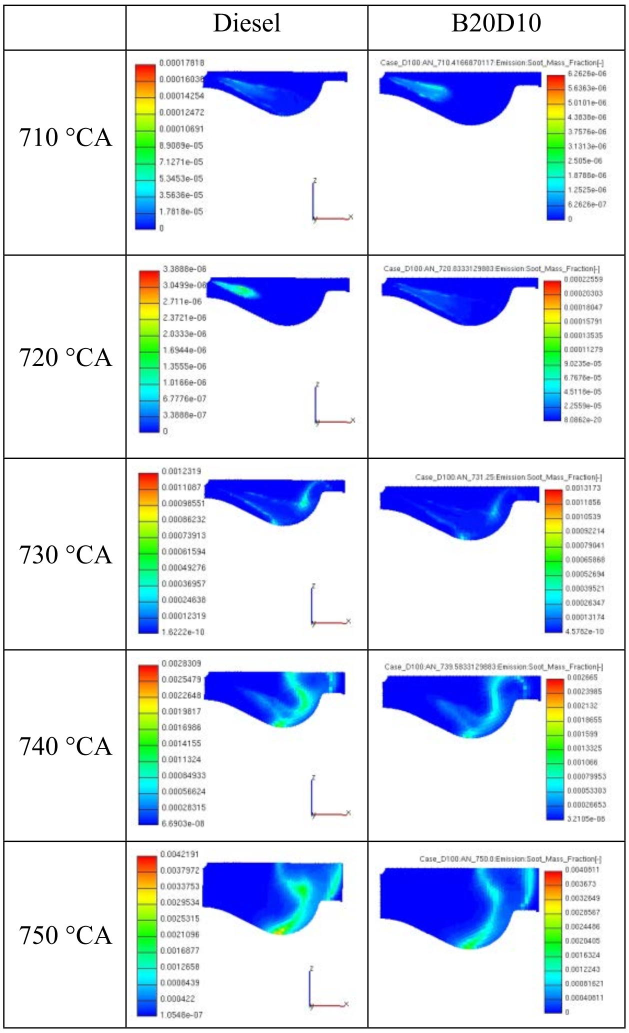

Figure 6. Soot Formation Process In-Cylinder

4. Calculation and Analysis of Engine Fuel Injection Timing and Fuel Supply Adjustment

In order to improve fuel adaptability, when fueled with oxygenated fuel, injection timing should be adjusted in diesel engines. But for the bench test, fuel injection timing adjustment it is very difficult, and the precision is difficult to ensure. Therefore, using of oxygenated fuel numerical model established for injection timing simulation and adjustment, vary injection timing and fuel injection quantity adjustment for oxygenated fuel can be easily adjusted, thus the performance can also be analyzed.

4.1. Adjustment of Fuel Injection Timing

Choose external characteristics condition with engine speed of 1400 r/min for calculation, the injection timing for the original machine is 19 °CA BTDC, fuel injection amount is 207 mg/cycle. Analyze the diesel engine combustion and emissions characteristics applying with oxygenated fuel with injection timing ranging from -25 °CA ~ -10 °CA. Figure 7 shows the in-cylinder pressure and heat release rate variation with the injection advance angle.

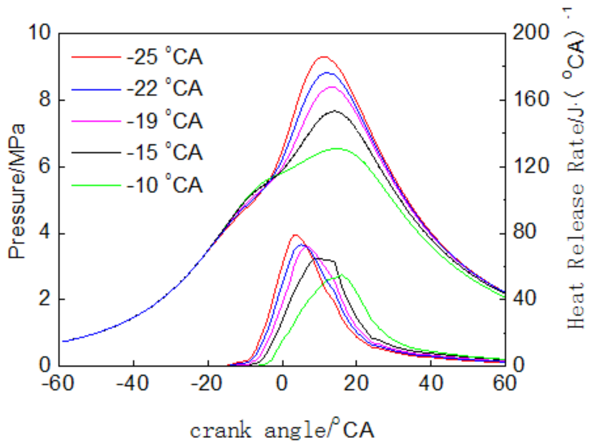

Figure 7. In-Cylinder Pressure and Heat Release Rate Variation with the Injection Advance Angle

The results show that injection timing has a greater impact on the performance of diesel engines: a) When original machines injection advance angle of -19 °CA were increased to -22 °CA and -25 °CA, the peak cylinder pressure increased from 8.28 MPa to 8.83 MPa and 9.30 MPa, respectively, an increase of 6.64% and 12.32 %. This is because when increasing the fuel injection advance angle, ignition delay period is extended, and accumulated amount of fuel increased, resulting in the rising of initial heat release rate and increasing mechanical load of diesel engine. b) When the injection advance angle was reduced to -15 °CA and -10 °CA, the peak pressure decreased by 7.37% and 21.01%, peak pressure crank angle postponed. c) When the original machines injection advance angle of -19 °CA were increased to -22 °CA and -25 °CA, the instantaneous peak heat release rate from the 71.79 J/°CA increased to 73.20 J/°CA and 79.01 J/°CA, rising by 1.96% and 10.06%. d) When the injection advance angle is reduced to -15 °CA and - 10 °CA, instantaneous peak heat release rate decreased by 9.35% and 23.01%, the corresponding crank angle postponed.

A variation of torque with diesel fuel injection advance angle is shown in Figure 8. It can be seen that: a) When injection advance angle is -22 °CA and -25 °CA, maximum torque increased by 3.05% and 6.10% compared with to original machine. b) When injection advance angle decreased by -10 °CA and -15 °CA, maximum torque dropped by 3.39% and 10.04%. c) With the injection advance angle decreases, the combustion duration prolonged and the power has been lost.

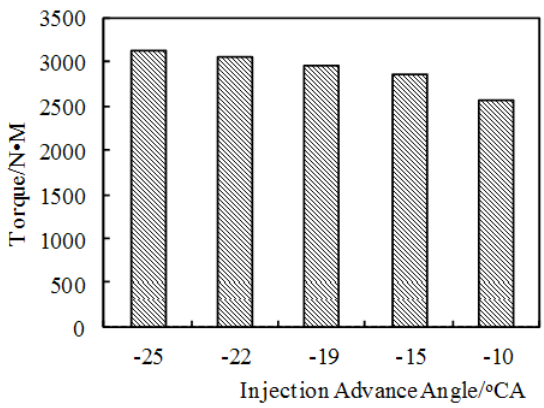

Figure 8. Engine Torque Variation with the Injection Advance Angle

Figure 9 is the variation of the concentration of NOx and soot emissions with the injection advance angle, it can be seen that: a) With the injection advance angle increases, NOx emissions increased, while gradually reducing soot emissions, showing a trade-off relationship. This is because with injection timing advances, ignition delay period increased, providing more time for fuel to mix and evaporate uniformly, the mixed gas combustion temperature increases after ignition, thus generating more NOx. Meanwhile, the scope of local concentrated area decreases, reducing soot generation region, this trade-off relationship of NOx and soot emissions leads to the difficulty to reduce emissions of them both simultaneously b) When the injection advance angle decreases from -22 °CA to -10 °CA, the concentration of NOx emissions drops from 1191×10^{-6} to 650×10^{-6}, soot concentration increased from 1005×10^{-6} to 1370×10^{-6}.

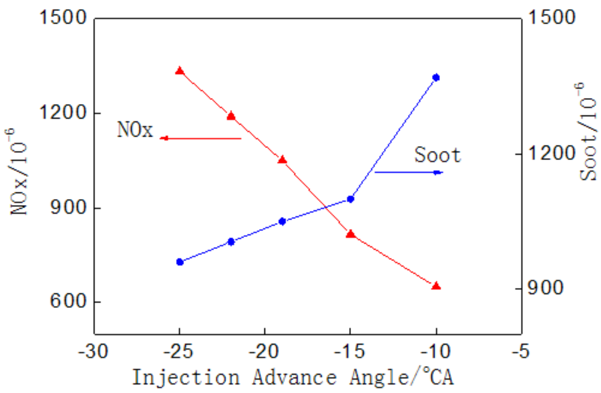

Figure 9. Emissions of NOx and Soot Variation with the Injection Advance Angle

It can be seen from the analysis above: a) For vehicle diesel engine fueled with Oxygenated Fuel, there is an optimal injection advance angle under certain working condition. b) The optimum injection advance angle depending on the selected composite indicator of diesel power, mechanical load and emissions. c) When injection advance angle increases, power of diesel engine increases and soot emission reduces, while mechanical load and diesel NOx emissions to deteriorate. Therefore, injection advance angle should be within the range from -15 °CA to -25 °CA. To ensure power, economy and reducing emissions of soot injection advance angle may remain unchanged (BTDC 19 °CA) or slightly ahead.

4.2. Adjustment of fuel injection amount

When blending with oxygenated fuel, due to the decreasing of low calorific value, the engine power decreases as the same amount of fuel injection, and the power loss could be compensate by increasing fuel injection amount. Choose external characteristics condition with engine speed of 2000 r/min for calculation, the power recovery of diesel engine and emissions performance are analyzed when maximum injection increases of 5% and 10% respectively.

The diesel engine torque recovery with fuel injection increase is shown in Figure 10, and dash line indicates maximum torque of original engine fueled with diesel fuel. It can be seen that: when the maximum fuel injection amount increased by 10%, diesel engine torque has reached 2 650 N • m, increased by about 4 percent than the original engine fueled with diesel fuel (2 536 N • m), which fully meet the demand for diesel power performance.

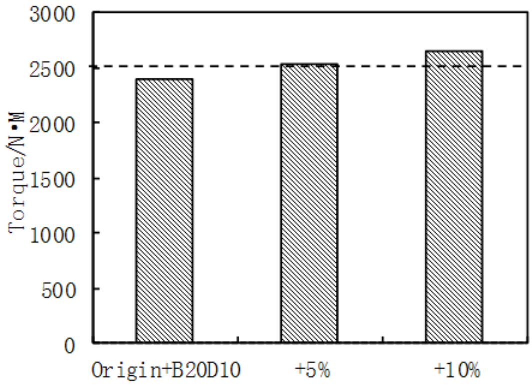

Figure 10. Changes of Engine torque with maximum fuel injection amount

Figure 11 is the variation of NOx and soot emissions with the injection amount, it can be seen that: a) NOx emissions increases significantly with the maximum amount of fuel injection, yet less soot emissions increase. This is mainly due to the NOx generation is effected by the combustion temperature, while the amount of fuel injection increases, there will be a corresponding increase in-cylinder combustion temperature, thus increase the NOx emissions. 2) Soot emissions are mainly related to the concentration of the mixed gas, oxygenated fuel contains oxygen itself, thus the sensitivity of soot to mixed gas concentration decreased, so there is not much soot increasing. c) As maximum injection amount increased by 10%, soot emissions increased by about 8%, but soot emissions is still decreased by 40% than the original engine fueled with diesel(figure dash). Thus, by increasing the maximum fuel injection amount, the power declining problem of oxygenated fuel could be solved, while ensuring the effect of reducing soot emissions.

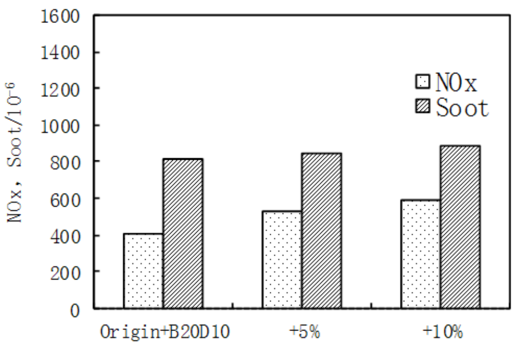

Figure 11. Change of NOx and Soot Emissions with maximum fuel injection amount

5. Conclusion

Through the establishment of the numerical simulation model to simulate the full load condition of the diesel and oxygenated fuel applied to a certain type of diesel engine, mixed gas formation, combustion and emission processes are discussed in this paper. The main conclusions are as follows:

1) A numerical combustion simulation model of diesel and Oxygenated fuel is established, the maximum error of pressure curve with experimental value is 3%.

2) Compared with diesel, the application of B20D10 oxygenated fuel leads to a lower temperature in the engine cylinder, the NOx generation timing is later and soot emissions is significantly reduced .

3) Power performance of the engine increases and soot emissions decrease as the fuel supply advance angle increases, yet mechanical loads and NOx emissions deteriorate. To ensure power, economy and reducing emissions of soot injection advance angle may remain unchanged (BTDC 19 °CA) or slightly ahead.

4) The power decline problem of diesel applied with oxygenated fuel could be solved by increasing maximum fuel supply amount. As maximum fuel supply amount increases by 10%, the maximum power of diesel engine applied with oxygenated fuel increases by 4% compared with the engine applied with diesel, and the soot emissions also decrease by 40%.

Conflict of Interest

The author confirms that this article content has no conflict of interest.

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