Influence of Combustion Process on the Carbonyl Emission of Diesel Engine

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Abstract. The bench test of diesel engine is conducted fueled with biodiesel, diesel and blending fuel, the changes of cylinder pressure with crank angle is also measured, combined with the measurement results of carbonyl emissions, the theoretical relationship between combustion process and carbonyl formation is analyzed. The results show that, combustion intermediates such as C7, C5, CO and C2H2 are produced in the fuel oxidation process during the premixed combustion phase. The diffusion combustion period extend with the increase of load, and it is the main stage of re-oxidation and decomposition for the intermediate products, the cylinder temperature and pressure increase with the increase of load, while the ignition delay period is shortened, the probability of oxidation and conversion for carbonyl pollutants improve because of the extended residence time in the high-temperature and high pressure region, the high exhaust temperature in high load is conducive to the re-oxidation of carbonyl emission.

Introduction

The total hydrocarbon emissions of the diesel engine include the hydrocarbon, alkanes, olefins, carbonyl groups, phenols, esters and other organic substances, carbonyl pollutants are intermediate oxidation products of combustion, because of the wall quenching effect, piston leakage and the adsorption effect of lubricant film and so on, it's easy to accumulate the carbonyl pollutants in the clearance between the piston top shore and the quenching layer[1-3]. Although carbonyl pollutants account for a relatively small proportion of the total emissions, the harm to human body is relatively large, although the vehicle emissions regulations of all countries are still not setting the limits of carbonyl group emissions, it is necessary to investigate the formation process of the diesel engine carbonyl pollutants, revealing carbonyl pollutants formation mechanism, and the effect of conventional pollutants emissions.

This article, adopting biodiesel, diesel and its blending oil to conduct diesel engine bench test, has measured in-cylinder of combustion pressure changers with the crank angle , and combining with the calculation results of heat release law, has analyzed the key thermodynamic parameters of combustion pressure, combustion temperature, heat release rate and ignition delay, and has explored the theoretical relationship between the combustion process and carbonyl pollutant formation in-cylinder.

Measuring equipment and research proposal

Measuring equipment

186FA Four-stroke air-cooled diesel engine with compression ratio of 19, displacement of 0.42L，rated speed at 3600 r/min and rated power at 6kW is used as the test engine.Measuring equipment include engine combustion analyzer and cylinder pressure sensor. The dynamometer data is obtained through an acquisition system which consists of a cylinder pressure sensor, a crank angle signal generator, a charge amplifier, and an A/D converter. The cylinder pressure sensor is installed on top

of the engine cylinder head while the crank angle signal generator is installed at the end of the engine flywheel.

Research proposal

$0^{\#}$ diesel and biodiesel made of cooking oil waste by Kate New Energy Changzhou are used as the testing samples. BD100, BD50 and BD0 indicate three different blended oil with different mixing proportions. BD50 indicates a blended oil with 50:50 mixing proportion between biodiesel and diesel in terms of volume.Test Conditions：Engine rated speed at 3600r/min，engine load at 10%, 50% and 100% respectively, engine combustion pressure of BD100, BD50 and BD0 respectively.

Calculation of heat release

The research methods of combustion process inside the engine cylinder include the measurement of combustion pressure inside the engine cylinder, calculation based on exothermic law, analysis of combustion temperature, analysis of rate of heat release and the analysis of other variations of key parameters[4-6].Law of conservation of energy, equation of state and law of conservation of mass are used in the exothermic law calculation. The working process inside the engine cylinder is subdivided into five subsequent phases: air intake, compression, combustion, expansion and emissions. The engine is assumed to work in an ideal condition.

Carbonyl emission measurement results

Carbonyls are detected and measured using derivatization technology, integrated with highly performing liquid chromatography. 2,4-Dinitrophenylhydrazine is used for the sample collection while the highly performing liquid chromatography is used for the quantitative analysis of carbonyls emissions.Figure 1 illustrates the carbonyls emissions of engine with each blended oil at different engine loads. As shown, the carbonyls emissions of engine operating at both 10% and 50% load with different blended oil do not show much variation. The results shows an average amount of 20mg/m^3. Meanwhile, the carbonyls emissions of engine with pure biodiesel shows a decreasing trend at a steady state. At 100% engine load, the carbonyls emissions of engine with pure diesel is the highest, amounts at approximately 45mg/m^3，followed by BD50 with decreasing trend，and pure biodiesel at approximately 16mg/m^3.

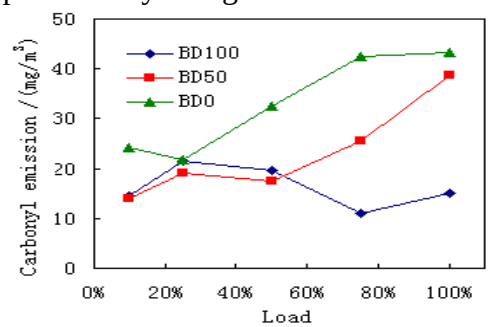


Fig 1 The emission trends of the total carbonyl compounds of three kinds of fuels

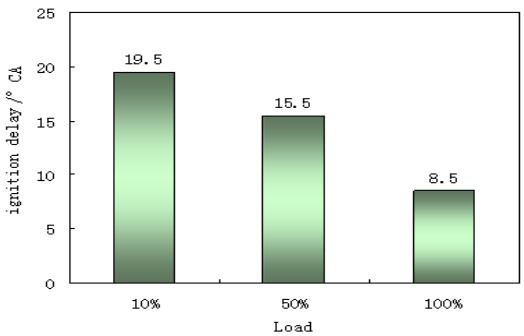


Fig 2 The change of ignition delay period with the loads

Analysis and discussions

Ignition delay

The crank angle during the valve opening is set as the starting point of ignition delay while the crank angle during the drastic increasing of pressure is set as the ignition starting point. Figure 2 shows the variations of ignition delay of biodiesel engine with rotating speed of 3600r/min at increasing loads. As shown, the ignition delay of engine is decreasing with increasing load. The ignition delay is shorten by an approximate amount of 11°CA when the load increases from 10% to 100%. Ignition delay would greatly affect the premixed combustion process inside the engine cylinder[7]. During the premixed combustion period, it could result in the production of air/fuel vapor mixture at the edge of

the fuel bundle. At the same time, formaldehyde, carbon monoxide, ethylene, and other combustion intermediates will be produced in the fuel oxidation process.

Law of heat release

The combustion process in a diesel engine can be divided into premixed combustion period and diffusion combustion period. Figure 3 illustrates the heat release rate of diesel engine operating at 3600 r/min with different load and different crank angles. As shown, heat release rate increases with increasing engine load. At 10% and 100% engine load, heat release rate is measured at 13.5 J/°CA and 20.1 J/°CA respectively. Meanwhile, ignition point is shifted 11°CA earlier when the engine load increases from 10% to 100%.

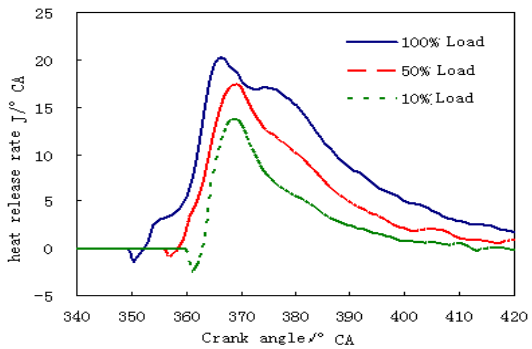


Fig 3 The change of heat release rate with the crank angle

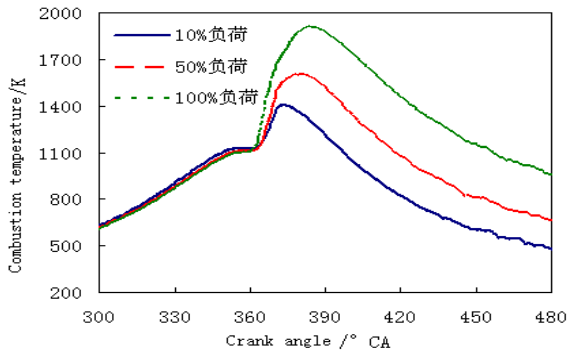


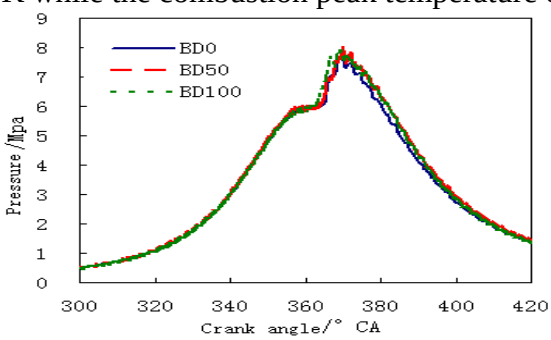
Fig 4 The change of combustion temperature with the crank angle

Combustion temperature

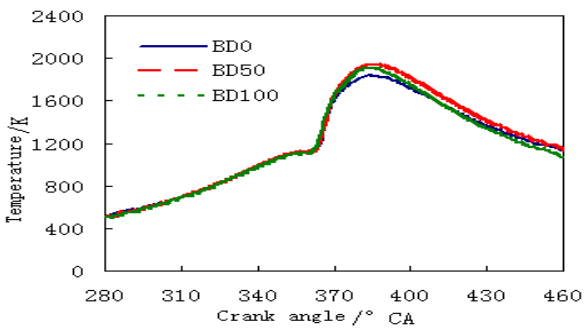
Figure 4 shows the combustion temperature of diesel engine operating at 3600r/min with different load and different crank angles. As shown, combustion temperature increases with increasing engine load. Combustion temperature is increased by approximately 36% when the engine load increases from 10% to 100%. Carbonyls can be eliminated in the subsequent oxidation process [8]. When the engine operates at low load, a large amount of aldehydes will be formed at the quenching layer of the combustion chamber. While the engine load increases, the retention time of carbonyls in the high temperature and pressure zone will be prolonged and thus, the oxidation and conversion rate will increase as well.

Mixing proportion

Compared to diesel, biodiesel contains approximately 10% oxygen, which would serve as the oxidizing agent for higher combustion efficiency and higher oxidation rate of carbonyls intermediate[9].Figure 5 illustrates the combustion temperature and pressure inside the engine cylinder on 100% load at different crank angles. As shown, the combustion peak pressure for both BD50 and BD100 are quite similar while the combustion peak pressure of pure diesel is the lowest among the three. Under such condition, the combustion peak temperature of pure biodiesel reaches 1908K while the combustion peak temperature of diesel reaches 1842K.



1）pressure



2）temperature

Fig 5 Cylinder temperature and pressure of the different blending ratio biodiesel under 100% loads

Conclusion

1. The length of ignition delay period would affect the production of carbonyls intermediate during the premixed combustion period. During the premixed combustion period, the oxidation process of fuel is the main phase where carbonyls intermediates oxidation products are formed. Meanwhile, diffusion combustion period is when the intermediates are once again oxidized and decomposed.

2. Carbonyls are chemically active. When the engine operates at high load, carbonyls in the emissions would easily be oxidized alongside with the hydrocarbon fuels. As the load increases, the retention time of carbonyls in the high temperature and high pressure zone will be prolonged; thus, the oxidation and conversion rate will increase as well.

Acknowledgements

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