Numerical Study of a Turbo-charged Common-rail Diesel Engine Fueled with Various Biodiesel Blends

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Abstract

The combustion processes of various biodiesel blends in a turbo-charged common-rail diesel engine with exhaust gas recirculation (EGR) is studied numerically. This computational fluid dynamics (CFD) model enables comprehensive investigation of the physical phenomena such as the effect of tumbling motions on the mixing and combustion, the spatial distributions of various species, temperature, pressure, and pollutant formation of NOx inside the combustion chamber. The mean cylinder pressures predicted by the CFD model at various injection timings and EGR rates are validated against the experimental data of cylinder pressure with pure diesel. Finally, numerical study of engine combusting various blends of biodiesel fuel is conducted. The effects of blend ratio on combustion process and NOx emission are discussed.

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1. Introduction

With the excellent fuel efficiency and high torque output, diesel engines become popular for heavy duty vehicles [1]. However, diesel engines suffer from the formation of pollutants such as particulate matters (PM), NOx, CO\textsubscript{2}, CO and HC in exhaust [2]. It is found in recent studies that the use of biodiesel can reduce CO, HC, PM and CO\textsubscript{2} emissions [1]. Biodiesel has been widely used in diesel engines, mainly because biodiesel can be refined from a variety of alternative oils such as vegetable oil, animal oil and recycled oil [5]. However, owing to the lower energy density of biodiesel fuel than that of petrochemical refinery diesel, using biodiesel may cause a decrease in performance and increase in fuel consumption [2]. Moreover, due to the higher oxygen content in biodiesel fuel, it may result in an increase in NOx emission [2]. Recent development of the common rail fuel injection system and selective catalytic reduction system not only increases the engine output but also reduces the emission of exhaust pollutants [3, 6].

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In this study, a computational fluid dynamics (CFD) model of a 4-stroke Mitsubishi engine 4M42-4AT2 equipped with exhaust gas recirculation (EGR) system is built to investigate the effects of injection timing and various EGR ratios on the engine performance and exhaust emissions. In particular, the formations of NOx in the engine cylinder combusting various biodiesel blends are studied systematically. To justify the validity of our numerical simulations, the average cylinder pressures of the engine combusting pure diesel with various injection timings and EGR ratios are validated against the experimental results first. Then the model is used to study the behaviours of the cylinder pressure and NOx formation of the engine combusting various biodiesel blends.

2. Engine model

The detailed dimensions of the engine are obtained by measuring the parts after disassembling the whole engine. Dynamic mesh is used to account for the motions of the piston and inlet/outlet valves. The number of element is around one million and the number of nodes is around 900,000, as shown in Fig. 1. The injection, atomization, and evaporation of fuels are predicted by phenomenological models provided by ANSYS Fluent. Combustion process is simulated with a PDF model. Transient analysis is conducted with a step size of 0.01 crank-angle degree at 2000 rpm. Properties of the biodiesels such as densities, heating values and cetane numbers etc. are obtained from the CPC Corporation in Taiwan. The high heating values of various biodiesels are confirmed experimentally using a Parr 6200 bomb calorimeter in our labs.

3. Results

In the simulation, each thermodynamic cycle starts from crank angle 360° to 1080° that includes intake, compression, expansion, and exhaust processes respectively. The combustion top dead centre (TDC) is located at 720°. Due to the page limitation, we only present the case of running the engine at 2000 rpm under 25% loading in the subsequent discussion. To demonstrate the validity of our numerical simulations, three calculations (using pure diesel) with different injection timings (11, 15, 19° BTDC) are conducted. The numerical results are juxtaposed with the experimental data in Fig. 2. Other than slight difference in the peak amplitudes, the numerical results agree with the experimental results qualitatively. Interestingly, the double peaks in the cylinder pressures due to the coupling between ignition delay and expansion processes occurring in both numerical and experimental results (11° BTDC) can be clearly identified. Fig. 2 demonstrates the effect of various EGR ratios (0, 3, and 17.1%) on the cylinder pressures. Clearly, introducing EGR into the combustion chamber results in the reduction of the peak pressures [4]. Again, the consistency between numerical results and experimental data confirms the validity of our numerical calculations. Fig. 3 and Fig. 4 illustrate the effect of various biodiesel blend ratios (B100/B80/B60/B40/B20/D100) on the mean pressures and temperatures inside the combustion
chamber. As expected, both the cylinder pressures and temperatures decrease as the percentage of biodiesel increases. This can be attributed to the fact that the heating value of biodiesel is about 10% lower than that of pure diesel. More interestingly, Fig. 5 shows that while the peak cylinder temperature slightly drops the NOx concentration increases as the percentage of biodiesel increases. We have to remember that biodiesel contains roughly 11% of oxygen and this may provide an oxygen-rich fuel-air mixture which may facilitate the formation of NOx.
4. Conclusions

A CFD model for a turbo-charged common-rail diesel engine is constructed in this paper. Physical variables such as cylinder pressure, gas velocity, cylinder temperature and mass fraction of cylinder gas components can be easily obtained from the simulations. The CFD model is first validated against cylinder pressure measurements with pure diesel at various injection timings and various EGR ratios. The CFD model is then used to explore the effect of biodiesel blend ratios on the cylinder pressure, temperature and NOx formation. Simulation results indicate that as the percentage of biodiesel increases, even though the peak cylinder temperature slightly drops NOx emission in pollutant increases due to the higher oxygen content in the biodiesel fuel.

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References


Biography

Chia-Jui Chiang received the Ph.D. degree from the University of Michigan, Ann Arbor, in 2007. Currently, he is an Associate Professor in the Mechanical Engineering Department at the University of National Taiwan University Science and Technology, Taipei, Taiwan. His current research interests include modelling and control of advanced internal combustion engines, energy storage devices, and hybrid energy systems.