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Combustion and emission characteristics of an electronically-controlled common-rail dual-fuel engine

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ABSTRACT

An experimental investigation was carried out to study the effect of injection timing, diesel injection pressure, substitution rate of natural gas as well as engine load on the combustion and emission characteristics of an electronically controlled common-rail diesel/natural gas dual fuel engine. The tests were conducted at a fixed engine speed of 1200 r/min, while other parameters were varied in reference to different study purposes. It can be concluded from the experimental results that maximum in-cylinder pressure and maximum heat release rate as well as the combustion noise are generally increased as injection timing advances and injection pressure increases, while decreases at higher substitution rate. Concerning the emission characteristics, THC and CO emissions could be improved by advancing injection timing and increasing diesel injection pressure with penalty on NOx emissions; in addition, THC emissions are significantly increased at higher load and higher substitution rate, while CO emissions reduce considerably with increasing load but tend to be less sensitive to substitution rate; NOx emissions can be mitigated by application of higher substitution rate and get worse as engine load increases.

1. Introduction

Currently, increasing concerns have been focused on the utilization of alternative fuels as a result of stringent emission standards and depletion of crude oil. Natural gas, with the advantages of abundant reserves and reduced exhaust emissions, is one of the most promising alternative fuel for internal combustion engines [1–3]. With the development of natural gas combustion technology, utilization of natural gas engines has also been extended to heavy-duty trucks and marine main impeller, where good power performance is in great demand. Towards this, the technique of dual fuel engines, one of which uses natural gas as a supplement for diesel, is widely employed with lower emissions than diesel engines and higher thermal efficiency than spark ignition natural gas engines [4,5].

For most commonly used dual fuel engines, natural gas is induced in the cylinder after homogenously mixing with air and diesel is injected directly into the cylinder before the top dead center of compression stroke, acting as the ignition source of natural gas/air mixture [6,7]. As natural gas has high octane number and low carbon content, they are adaptable to high compression ratio and produce less particulate emissions.

Many works on the combustion and emission characteristics of dual fuel engine as well as the effects of some influencing factors have been reported during the past decades. Gunea et al.[8] investigated the effects of pilot diesel quality and quantity on the ignition delay of dual fuel engine. It was found that both the quality and quantity of the pilot fuel have significant effects on the combustion process of gas fueled diesel engine, the auto-ignition of diesel is not deterred by the surrounding natural gas/air mixture and better performance can be achieved by the employment of high cetane number pilots. According to Zuo et al.[9] and Abd Alla et al.[10], mass substitution rates should

Abbreviations: APmax, crank angle of maximum in-cylinder pressure; ATDC, after top dead center; BTDC, before top dead center; CA, crank angle; CA0-10%, crank angle of 0–10% accumulated heat release rate; CA10–90%, crank angle of 10–90% accumulated heat release rate; CA50%, crank angle of 50% accumulated heat release rate; CO, carbon monoxide; EGR, exhaust gas recirculation; HC, hydrocarbon; H.R.R, heat release rate; n, engine speed; Pmax, maximum in-cylinder pressure; ROPR, rate of pressure rise; SRNG, substitution rate of natural gas; THC, total hydrocarbon.

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be lower than 90% in order to maintain regular burning, however, increased pilot amount not only leads to higher thermal efficiency and lower CO and HC emissions at the expense of earlier knocking, but also higher smoke and NOx emissions as a result of corresponding higher temperature and pressure; It was also found that higher thermal efficiency could be achieved at higher loads and power output at full load could be guaranteed by using electronic technology. Furthermore, Shen et al.[11], Ahmad-I et al.[12] and Papagiannakis [13] compared the performance of engine operating at diesel mode with that of dual fuel mode; the results suggested that the dual fuel mode results in lower exhaust temperature with certain sacrifice of brake power, in addition, the dual fuel combustion process could be improved by adjusting the injection timing to control the initiation of combustion after top dead center, decreasing intake air temperature as well as increasing its quantity and adopting electronically controlled fuel injection system. What's more, Selim [14] examined the effects of EGR rates on the combustion characteristics. Conclusions could be drawn from their investigations that the employment of 5% EGR rate contributes to improved thermal efficiency, combustion regularity as well as NOx emissions; in addition, the combustion noise benefits from increased EGR, compression ratio and intake charge pressure. The further effects of injection timing was also investigated in detail by some researchers [15–20]. It was found that advanced injection timing results in more complete combustion, higher cylinder temperature, better HC and CO emissions and deteriorated NOx emissions. In order to examine the effects of substitution rates and engine load, Krishnan et al.[21] conducted experiments on a single-cylinder engine and analyzed the heat release of combustion process with various substitution rates and engine loads; They found that brake specific fuel consumption decreases with natural gas substitution rate at high loads while exhibits an opposite trend at low loads; Papagiannakis et al.[13,22] measured the emissions in a wide range of diesel supplementary ratios; their results disclosed the effect of engine load and natural gas substitution rate on brake thermal efficiency and revealed the beneficial effect of the presence of natural gas on emissions.; Polk et al.[23] conducted an experimental analysis of the combustion process for a turbocharged dual-fuel engine; their hypothesis that the phasing and duration of dual-fuel combustion may be affected by natural gas substitution rate, in-cylinder conditions, therefore, influencing the emission characteristics and fuel economy directly was verified through experimental reults; Mittal et al.[24] studied the exhaust emissions of a turbocharged and intercooled dual-fuel engine for generator application at different loads and found that NOx emissions benefit more from dual-fuel operation at high loads.

As mentioned above, the influence of many operating parameters have been extensively studied by researchers worldwide, however, researches concerning the electronically controlled common-rail dual fuel engines are still in need as most of the previous researches were conducted on single-cylinder engines with outdated technologies. Moreover, investigations on the effects of diesel injection pressure, which is also an important influencing factor of the general performance of dual-fuel engine, were quite limited; besides, the only existing studies mentioned this point were carried out with diesel injection pressure lower than 1000 bar [25,26], study concerning conditions with diesel injection pressure higher than 1000 bar are required. The main object of this paper is to discuss the detailed effect of controlling factors such as injection timing, diesel injection pressure, substitution rate of natural gas and engine load on the combustion and emission parameters of an electronically controlled dual fuel engine with a common-rail diesel injection system through experimental investigation. Systematic experiments were carried out with various operating conditions and the effects of different parameters were analyzed in combination with in-cylinder pressure, ROPR(rate of pressure rise), heat release rate as well as emission values.

2. Experimental apparatus and experimental procedure

2.1. Experimental apparatus

The present study was conducted on a 6-cylinder, turbocharged intercooled, dual fuel engine, details of which are listed in Table 1. Diesel and natural gas were injected using an electronically controlled high-pressure common-rail fuel injection system and an electronically controlled gaseous fuel metering system respectively. An electric eddy current dynamometer(Xiangyi GW630) was coupled to the engine to measure the torque and an exhaust gas analyzer (Horiba MEXA-7200) was employed to obtain the CO, HC and NOx emissions, where CO was measured using non-dispersive infrared (NDIR) technology, HC was measured with flame ionization detector (FID), NOx was measured with a chemiluminescent detector (CLD). The in-cylinder pressure was obtained by piezoelectric pressure sensors (Kistler 6052C) at every 0.1 °CA. And the engine was also equipped with a Coriolis type mass flow meter (Micromotion CMF025) and a fuel meter (AVL 733S) to measure the fuel consumption of natural gas and diesel respectively. The schematic depiction of the test bed is shown in Fig. 1.

2.2. Experimental procedure

To get a full understanding of the combustion and emission characteristics of electronically-controlled common-rail dual-fuel engines, four set of experiments were performed. During the whole experimental process, the engine speed was kept constant at 1200 r/min, while the other parameters such as diesel injection timing, diesel rail pressure as well as engine load were changed according to the research

Table 1
Engine specifications.

Item	Specifications
Engine type	6-cylinder,4-stroke
Engine aspiration	Turbocharged, intercooled
Bore × stroke/mm	126 × 130
Displacement/L	9.72
Compression ratio	17
Valves per cylinder	2
Diesel fuel supply system	Electronically controlled high pressure common rail
Natural gas fuel supply system	Electronically controlled gaseous Fuel metering system
Combustion chamber	Bowl

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