Applied Energy xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Modeling on blend gasoline/diesel fuel combustion in a direct injection diesel engine ☆

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HIGHLIGHTS

- The effect of blend gasoline and diesel fuel was investigated numerically.
- The coupled KIVA4–CHEMKIN was used to simulate the combustion.
- Under high load, blend fuel could offer a better performance.
- Under low load, the engine fueled with pure diesel performed the best.

ARTICLE INFO

Article history:
Received 2 August 2014
Received in revised form 28 August 2014
Accepted 30 August 2014
Available online xxxx

Keywords:
KIVA4 code
Blend fuel
Diesel
Gasoline

ABSTRACT

Gasoline and diesel as fuels for internal combustion engines have been commonly available and used for decades. In this study, the performance and emission formation of a direct injection engine fueled with gasoline/diesel blend fuel are investigated numerically. Simulations are conducted on pure diesel and its blend fuels with 10%, 20%, 30% and 40% gasoline at an engine speed of 2800 rpm under 10%, 50% and 100% loads. A reduced PRF (primary reference fuel) mechanism which consists of 45 species and 142 reactions is used in coupled KIVA4–CHEMKIN code for detailed chemistry calculations. In this mechanism, gasoline and diesel are represented by iso-octane and n-heptane, respectively. Comparing the results among different blend conditions, it is found that the ignition delay time is extended by increasing the ratio of gasoline in blend fuels. However, this extended ignition delay has diverse effects on engine performance for different engine loads. At low load, pure diesel condition achieves a better performance; in contrast, a better performance could be realized by blend fuels at medium and high loads, though a slightly higher NO_x emission level.

1. Introduction

The compression ignition (CI) engine is one of the major power suppliers for vehicles nowadays. Usually, it has a higher energy conversion efficiency than that of a spark ignition (SI) engine due to its higher compression ratio [1]; therefore it has a more widely application area. After realizing the pollutants emitted from engines are detrimental to the health of humans and environment, efforts have gone into developing high efficiency and low emissions techniques. Both engine management including injection pressure, timing and rate, and alternative fuels could reduce the harmful emissions [2].

From the perspective of engine management, by advancing injection timing, premixed charge compression ignition (PCCI) mode will be realized; it could achieve low temperature combustion, hence reducing nitrogen oxides (NO_x) emissions in diesel engines [3]. This low temperature combustion is mainly because of a well-mixed air–fuel mixture caused by an extended ignition delay [4]. Another way to reduce combustion temperature is to increase exhaust gas recirculation (EGR) rate [5]. However, high EGR rate not only leads to a low level of NO_x emissions, but high levels of carbon monoxide (CO) and soot emissions [6]. Some studies have found that changing injection strategy appropriately could reduce CO and soot emissions in high EGR rate engines [6–8]. In addition to the engine management, appropriate use of blend fuels is also a promising way to control emissions. Blending conventional diesel with biodiesel could reduce CO and soot emissions, but increase NO_x emission [9]. To further reduce NO_x levels, EGR should be introduced [10].

☆ This paper is included in the Special Issue of Energy innovations for a sustainable world edited by Prof. S.k Chou, Prof. Umberto Desideri, Prof. Duu-Jong Lee and Prof. Yan.

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http://dx.doi.org/10.1016/j.apenergy.2014.08.105
0306-2619/

Please cite this article in press as: Li J et al. Modeling on blend gasoline/diesel fuel combustion in a direct injection diesel engine. Appl Energy (2014), http://dx.doi.org/10.1016/j.apenergy.2014.08.105

As for the fuel management, the conventional fuel gasoline with a low cetane number could be an ideal option to be blended with diesel for the long ignition delay, which might be inferred as being responsible for the air–fuel mixture process and finally affecting the combustion and emissions formations. Besides, both diesel and gasoline have been commonly available and used for decades; this makes them more practical for the applications in transportation.

Some studies have been carried out to investigate the effect of blend gasoline/diesel fuel on homogeneous charge compression ignition (HCCI), PCCI and conventional CI engines. Zhong et al. [11] conducted experiments on an HCCI engine. Pure gasoline and its blend fuels with 5%, 10%, 20% and 50% diesel by mass were used. They found that using gasoline/diesel blend fuel allowed a lower intake temperature compared to pure gasoline case. This is because diesel plays a flammable role in HCCI operation. Benajes et al. [12] studied the gasoline/diesel blends effect in a PCCI engine. Comparisons were made between pure diesel and its blend fuels with 25% and 50% gasoline. It was found that increasing the percentage of gasoline would extend ignition delay, and sufficient time was provided to form a local low equivalence ratio region, hence decreasing soot emissions. However, NO_x emissions were observed to increase slightly. Nonetheless, Collings and Weall [13] found that increased percentage of gasoline would reduce smoke emissions in a PCCI engine fueled with gasoline/diesel blend fuels.

Han et al. [14,15] experimentally studied the effect on NO_x, soot, CO and hydrocarbon (HC) emissions using pure diesel and its blend fuels with 20% and 40% gasoline by volume at a fixed load of 7.5 bar indicated mean effective pressure (IMEP) and a fixed speed of 1500 rpm on a modified diesel engine. To investigate the effect of intake oxygen concentration, EGR rate was varied from 30% to 50%. The results showed that the ignition delay was shorten by increasing intake oxygen concentration (i.e. decreasing EGR rate) for different fuels. The soot emission was less sensitive to the intake oxygen concentration when 40% gasoline was blended with diesel. However, NO_x emissions showed a similar trend with different fuels. HC emissions would increase with blended gasoline, but CO emissions were less affected by increasing the percentage of gasoline. Yu et al. [16] compared the combustion and emission characteristics between conventional diesel engine and the engine fueled with gasoline/diesel blend fuel. It was found that with blend fuel the thermal efficiency was higher than that of conventional diesel engine. Soot reduction was achieved by using blend fuel. Further reduction in NO_x emissions could be achieved by increasing EGR rate. To have a close look into the effect caused by blend gasoline/diesel fuel on evaporation process, Park et al. [17] conducted experiments in a CI engine. It was found that by increasing the fraction of gasoline, the fuel was atomized into smaller droplet size. Also with the extended ignition delay, a more homogeneous mixture was formed; therefore NO_x and soot emissions were reduced. In contrast, HC and CO emissions increased slightly. However, this enhanced atomization performance caused by blending gasoline will be lessen at high engine load.

However, all these studies on blend gasoline/diesel fuel are carried out by experimentation; few studies are based on numerical approach. In this study, coupled KIVA4–CHEMKIN code with reduced chemical reaction mechanism is used to investigate the effect of blend gasoline/diesel fuel on the performance and emission formations in a diesel engine. Simulations are run with pure diesel and its blend fuels with 10%, 20%, 30%, and 40% gasoline under 10%, 50% and 100% loads at a fixed engine speed of 2800 rpm in this study. In-cylinder pressure, heat release rate, NO and CO emissions are compared at different conditions to spot the effect of blend gasoline/diesel fuel.

2. Methodology

2.1. Experimental setup

The experimental results used in this work to validate the models were obtained on a four in-line cylinder diesel engine fueled with pure diesel (G0). Table 1 shows the specifications of this engine. More detailed descriptions could be found in Ref. [18]. The operating conditions for 10%, 50% and 100% loads under 2800 rpm are listed in Table 2; the parameters are determined by engine control unit.

2.2. KIVA4–CHEMKIN

With the advances in computational hardware, CFD (Computational Fluid Dynamics) has become an option to study the combustion characteristics and emission formation in internal combustion engines [19,20]. Compared to experimentation, which is limited by budget and consumes lots of time and materials, modeling study has shown its superiority. In addition, the results obtained by numerical simulation could be visualized by some technical means which would provide a more comprehensive understanding on the working process of engines.

In this study, a 3-dimensional computational code, KIVA4 [21] coupled with CHEMKIN [22] for detailed chemistry calculation, was used to simulate the combustion in the engine. A reduced PRF (primary reference fuels) reaction mechanism [23] which consists of 41 species and 130 reactions was applied to model the oxidation process of both iso-octane and n-heptane. Therefore, the chemical properties of gasoline and diesel are represented by iso-octane and n-heptane, respectively. To consider NO_x emissions, a reduced mechanism developed by the Gas Research Institute (GRI) [24] was implemented into the reduced PRF reaction mechanism; subsequently, the final reaction mechanism consists of 45 species and 142 reactions. In addition, the spray model in original KIVA4, Taylor Analogy Breakup, was substituted by Kelvin–Helmholtz and Rayleigh–Taylor hybrid model. Furthermore, RNG k-ε model was used to model the turbulent flow.

2.3. Grid generation

Since the injector has 6 holes as listed in Table 1, a 60° sector mesh with crevice was created in this study to ease the computa-

Table 1
Four in-line cylinder engine specification.

Bore (mm)	92
Stroke (mm)	93.8
Displacement (L)	2.494
Rated engine power (kW)	75
Rated engine speed (rpm)	3600
Intake valve close (CA ATDC)	−149
Exhaust valve open (CA ATDC)	150
Fuel injection system	Common rail injection
Holes of injector	6

Table 2
Operating conditions for 10%, 50% and 100% loads under 2800 rpm with pure diesel.

Engine speed (rpm)	2800		
Engine load (%)	10	50	100
Pressure at intake valve close (bar)	1.514	1.84	1.92
IMEP (bar)	3.06	7.44	12.29
Diesel fuel consumption (kg/h)	3.42	7.52	13.34
Air flow rate (kg/h)	291.95	333.08	333.80
Start of injection (CA ATDC)	−14.5	−13.1	−13.12

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