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Separate and combined effects of hydrogen and nitrogen additions on diesel engine combustion

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ABSTRACT

Shortage of non-renewable energies, increase in fossil fuel prices and stricter emissions regulations due to high NOx and soot emissions emitted from combustion of heavy diesel fuels by compression ignition engines, has led consumers to use renewable, cleaner and cheap fuels. An investigation has been computationally carried out to explore the influences of hydrogen and nitrogen addition on engine performance such as indicated power and indicated specific energy consumption and amounts of pollutant emissions like NOx, soot, and CO in an HSDI (High-Speed Direct Injection) diesel engine. Optimized submodels, such as turbulence model, spray model, combustion model and emissions models have selected for the main CFD code. Meanwhile, HF (Homogeneity Factor) has been employed for analysing in-cylinder air-fuel mixing quality under various addition conditions. After validations with experimental data of diesel combustion with a single addition of 4% hydrogen and combined addition of 6% hydrogen + 6% nitrogen, investigations have conducted for modeling mixing and combustion processes with additions of hydrogen and nitrogen by ranges of 2–8% (v/v). Results showed that a single addition of H_2 increased NOx and decreased CO and soot and improved ISEC and IP. In the case of nitrogen addition, NOx decreased, both CO and soot emission increased and ISEC and IP considerably ruined compared with NDC operation. Based on the results obtained for simultaneous addition of N_2 (8% of v/v) and H_2 (8% of v/v), NOx and soot emissions decreased by 11.5% and 42.5% respectively, and ISEC and IP improved 25.7% and 13%, respectively. But amount of CO emissions had an increase of 52% should be paid necessary attention as a main disadvantage.

Introduction

Lower fuel consumption, high thermal efficiency, and more power density and durability have made diesel engines more applicable than spark ignition and gas engines [1]. Over the past several years, due to a high level of the pollutant emissions such as NOx, soot and CO produced by diesel engines lots of efforts have been made to make the combustion of compression ignition engines cleaner. Many types of research have been carried out to improve engine performance while decreasing amount of pollutant emissions in diesel engines. Usage of high injection pressure [2,3], changing the injection profile [4,5], applying the split and multiple

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injections [6,7], changing the fuel spray angle and the number of injection holes [8,9], recirculating the part of the exhaust gas into the combustion chamber (EGR) [10], varying the swirl ratio [11] and changing the combustion chamber geometry [12] are the common used strategies that their positive and adverse effects have discussed in many papers.

Shortage of non-renewable energies and increase in fuel prices such as diesel and gasoline causes the development of a new study field which deals with the investigation the effects of biofuels and fuel additives on the diesel engines parameters. Many researchers have studied the effects of various fuels and fuel additives such as natural gas [13,14], syngas [15], Iso-Butanol [16,17], propane [18] and hydrogen gas [19,20] on engine performance and amounts of output emissions. In their study, Chun et al. have investigated the influence of H_2 gas addition on the emissions formation and performance of a diesel engine [21]. They have indicated that substitution of H_2 gas for diesel fuel have made the premixed burn fraction larger and also the amounts of Nitrogen Oxides (NOx) and Particulate Matter (PM) have decreased simultaneously. In their experimental study, Karagöz et al. [22] injected H_2 fuel into intake manifold using LPG-CNG injector, while diesel fuel was injected directly into a cylinder using high-pressure injection system that is controlled by an engine control unit. They examined the influence of various hydrogen energy fractions 0% (pure diesel), 22%, and 53% of total fuel energy (hydrogen + diesel fuel) on smoke, NOx, CO, UHC emissions, performance (BSFC and brake thermal efficiency), and combustion characteristics (in-cylinder pressure and heat release rate) in a diesel engine at 1100 RPM constant speed. Their results showed that by increasing hydrogen energy fraction CO and smoke emissions considerably decreased. However, UHC slightly increased, and also NOx emissions have grown by increasing the percentage of hydrogen energy portion. They also included that peak of in-cylinder pressure rose by 7.8% and 36.2% with 22% and 53% hydrogen energy fraction addition in comparison to neat diesel combustion. Furthermore, a 25.77% growth in peak heat release rate acquired with 22% hydrogen energy portion.

Talibi et al. [23] have provided a discussion of the effects of hydrogen gas fuel addition on combustion characteristics, emissions formation and engine performance in a naturally aspirated high-speed direct injection compression ignition engine. They have reported that with fixed diesel fuel injection periods and increasing hydrogen gas addition, particulates, CO, and UHC emissions have decreased. However, NOx emissions have increased by increasing H_2 due to increase in diesel-hydrogen co-combustion temperature. Deb et al. [24] have studied the effects of various hydrogen energy fractions on combustion, performance, and emissions formation in a single cylinder, dual fuel direct injection diesel engine at 1500 RPM engine speed and 5.2 kW consistent indicated power. The hydrogen energy fraction was varied from 0% (neat diesel combustion), 11%, 17%, 30% and 42%. According to their obtained results, increasing hydrogen energy fraction accompanied with improvement of brake thermal efficiency of the engine and reduction in brake specific energy consumption. They have also indicated that, by increasing hydrogen energy fraction CO, CO_2 and smoke emissions have decreased and due to increase in combustion temperature of dual fuel combustion process, NOx emissions have increased. Furthermore, they have observed a sharp increase in peak in-cylinder pressure and rate of heat release with the increasing hydrogen energy fraction.

In other research, Sandalci and Karagöz [25] experimentally have explored the effects of hydrogen addition on combustion characteristics, emissions formation, and performance of a diesel engine. They have varied hydrogen gas energy fraction from 0% (pure diesel fuel combustion), 16%, 36% and 46% at 1300 RPM constant engine speed and 5.1 kW of constant indicated power. According to their experimental results, by increasing the hydrogen gas fuel, energy fraction indicated thermal efficiency have decreased, and isfc (indicated specific fuel consumption) have increased simultaneously. Regarding emissions formation, they showed that CO, CO_2 and smoke emissions decreased by increasing H_2 gas energy fraction. However, NOx emissions have not changed at 16% hydrogen energy portion. Furthermore, they have shown that peak of in-cylinder pressure and rate of heat release have increased with the increasing H_2 energy fraction. In their paper, Yang et al. [26] carried out multidimensional computations on the effects of H_2 gas addition on combustion characteristics and emissions formation of Cummins ISM370 diesel engine at 70% load. Their numerical results have shown that by increasing the percentage of H_2 gas addition, the cylinder pressure and rate of heat release first increased and then decreased. Regarding emissions formation, NO emissions have increased, while PM emissions decreased. They have also indicated that both the pressure and heat release rate has reached the maximum value at the addition of 17% H_2.

Zho, Cheung, and Leung [27] conducted an experimental study on the influence of hydrogen energy fractions on combustion characteristics, performance, regulated and unregulated emissions of a diesel engine by varying energy fraction from 10%, 20%, 30%, and 40% of the total fuel. They have reported that, at 90% load and more than 30% hydrogen addition, due to the drastic increase in peak heat release rate, shortened ignition delay, and combustion duration, abnormal combustion have occurred. They have indicated that CO/CO_2 and seven kinds of unregulated emissions can considerably reduce. Furthermore, more than 30% of hydrogen addition can reduce the UHC emissions at low to medium loads. They have also shown that the percentage reduction of NOx emissions is engine load dependent, being positive at low loads and negative at high loads. Jheng and co-workers [28] have investigated the effects of a conventional diesel engine through the addition of H_2 mixture, generated through water electrolysis. In their work, three different diesel-hydrogen blend ratios 0% (neat diesel combustion), 0.6% and 1.2% used. Experimental tests were carried out at the idling condition under constant speed from the low to high engine load with different amount of hydrogen gas fuel mixture. Their experimental results have shown an improvement in Brake Thermal Efficiency (BTE) and Brake Specific Fuel Consumption (BSFC) with an increasing amount of H_2. Furthermore, increasing the amount of H_2 gas mixture have reduced the carbon dioxide and carbon monoxide emissions simultaneously and also at high load operation, the reduction of emissions was the most significant. However, the unburnt hydrocarbon emissions have been increased 4.94% and 13.1%

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