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Alcohol–diesel fuel combustion in the compression ignition engine

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HIGHLIGHTS

- Metanol and E85 as alternative fuels for the dual fuel engine.
- Increase in THC, CO exhaust toxic emission were observed in the methanol/E85–diesel fueled engine.
- Reduction in both NO_x and soot emissions were observed in the methanol/E85–diesel fueled engine.
- Heat release rate analysis of the dual fuel engine powered by diesel–methanol and diesel–E85.
- Two characteristic peaks in the HRR clearly emphasize premixed and diffusion combustion.

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ABSTRACT

Shortage of fossil fuels requires from scientists to undertake investigation focused on applying alternative, renewable based fuels to a reciprocating engine. Among others, alcohols: methanol and ethanol are proposed as satisfactory fuels, that would be applied either as single fuels or blended with gasoline o diesel fuel. The paper describes impact of both methanol and E85 (85% ethanol and 15% gasoline) as additional fuels added to a diesel fueled engine on its combustion characteristics and exhaust toxic emission. These fuels were added by injection into an intake manifold in amounts expressed by their energy percentage of 20%, 50%, 75% and 90% with respect to total diesel fuel–methanol or diesel fuel–E85 blends. The tests in a compression ignition engine contained analysis of heat release rate and combustion parameters as well as analysis of exhaust toxic emission NO_x, THC, CO and soot. It was observed that with increase in methanol or E85 peak combustion temperature decreases as well as temperature of the mixture at the end of compression stroke that affects combustion duration. For methanol or E85 two characteristic peaks in the heat release rate profile were observed. The first peak represents burning the diesel fuel and the second burning methanol or E85. Hence, diesel fuel injection timing should be corrected, if alcohols, even in small amounts, are applied. Furthermore, as advantage, slight increase in brake efficiency was observed. Next, radical reduction in soot, particularly at 50% alcohol (methanol or E85) addition was also managed as important advantage. On the other hand, increase by 16% in NO_x emission was observed, while 20% methanol or E85 were added. Summing up, addition of methanol or E85 to the diesel fueled engine is justified, however, it significantly changes entire combustion process. Especially, intensive research should be undertaken on reducing higher NO_x emission.

1. Introduction

Diesel engines are widely used all over the world due to their relatively high fuel efficiency and durability. The existing CI (compression ignition) engines operate with conventional diesel fuel derived from crude oil. It is well known that the world petroleum resources are limited and production of diesel fuel is day-by-day becoming more expensive.

The extensive use of fossil fuels is accused for a long-term environmental threat in the form of climatic changes and the gradual increase in the average global temperature [1], which is strictly associated with the CO_2 concentration in ambient air. The European Parliament passed Directive 2009/28/EC on the promotion of the use of energy from renewable sources. This provision requires EU member states to use 10% of renewable fuels in transport by 2020. Biofuels made from agricultural products reduce the dependence on crude oil import and support local agricultural

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industries as well as enhance farming incomes [2]. Among others, diesel engines are the main emitters of respiratory suspended particles and nitrogen oxides (NO_x). They both are harmful to human health, and to the environment, and are targets for reduction. Furthermore, NO_x can also cause smog, while reacting with hydrocarbon compounds at the sunlight [3].

It is known that alcohols used in the diesel engine are source of volatile hydrocarbons which could be harmful to humans and could enhance the formation of photochemical smog [4]. Several studies have shown that concentration of fine particles in the ambient air is adversely associated with health effects [5]. Hence, by improving the performance and reducing emissions from these engines, it will contribute to both increase in fuel economy and decrease in environmental pollution. The available methods of PM and NO_x reduction include engine modifications as well as after-treatment of exhaust gases [6–9]. However, after-treatment technologies including an oxidation catalyst, a diesel particulate filter (DPF) and a NO_x reduction catalyst often do not lead to simultaneous reduction in both PM (particulate matter) and NO_x. A way to succor these measures is to combine combustion products from an oxygenate additive to basic fuel with a diesel oxidation catalyst [10].

In recent years, alcohol based fuels have received much attention as fuels to diesel engines [11,12]. Among alcohol fuels, ethanol and methanol have been examined in detail as either additives to or blends with diesel fuel. Some of the disadvantages of alcohol fuels in comparison to diesel fuel are the following: low lubricity, decreasing environment temperature due to high latent heat of vaporization and remarkably higher auto-ignition temperature. Lower heating value (LHV) of methanol is lower in comparison to diesel fuel, hence, to obtain the same engine performance, higher amounts of methanol should be provided. Its relatively low air–fuel (A/F) stoichiometric ratio, high oxygen content and high H/C ratio may be beneficial at improving the combustion process and reducing both soot and smoke [12]. Methanol has higher heat of vaporization, therefore it absorbs heat from surroundings when it vaporizes, hence, it cools the cylinder charge and therefore can reduce NO_x emissions from combustion [12]. As a result of cooling effect on the charge, cylinder temperature decreases, that might contribute to reduction in nitrogen oxides during combustion. Additionally, methanol has poor autoignition characteristics due to both its low cetane number, high latent heat of vaporization and high ignition temperature. Therefore, it characterizes longer ignition delay [12]. On the other hand, among all alcohols, ethanol features itself better combustion characteristics due to its lower heat of vaporization and lower auto-ignition temperature [13]. There is a growing interest all over the world on applying alcohols as substitutes for diesel fuel as: oxygenated fuels contain additional oxygen that participates in combustion, enhances the premixed combustion phase and improves the diffusive combustion phase [14].

Usage of alternative fuels produced from fossil-free resources in CI engines is suggested as one of the most attractive methods for improving their performance and emissions. These fuels include alcohols (such as ethanol and methanol), ethers, vegetable oils, animal fats, bio-diesel and gaseous fuels (hydrogen, natural gas, liquefied petroleum gas) [3].

Among these fuels, methanol is a low cost, being non-sooting fuel, and high oxygen content, even though it features low cetane rating and poor solubility in diesel fuel. The pros and cons of methanol as a CI engine fuel will be discussed in the next section. Results reported in numerous published papers concerning the effect of using alcohols in CI engines on the exhaust emissions and engine performances are very prospective [4,9,12,13,15–17]. Several alternative methanol-like fuels may be applied to diesel engines as fuel additives at relatively low cost.

Several attempts have been done to supply diesel engines with various alcohols. Currently, research efforts have been focused on partial replacement of the diesel fuel by alcohol, either premixed with the diesel fuel or separately injected into the intake manifold. Both methods can be readily applied to diesel engines. However, blending alcohol with diesel fuel leads to some difficulties. At first, it requires additives for stabilizing the mixed fuel. Secondly, there is a limitation on the amount of alcohol which can be premixed with diesel fuel for stable operation. Fortunately, there is no need for significant modification of the engine [12,18]. Probably, the easiest method to deliver methanol is simply inject it into the engine manifold with aid of low-pressure fuel injectors as is typical in gasoline injection systems. This method makes it possible to provide alcohol/diesel fuel ratio in wide range. Moreover, it allows change in this alcohol/diesel fuel ratio at various operating conditions, whereas the alcohol blended diesel fuel can only provide work at fixed alcohol/diesel fuel ratio [9,19].

As mentioned, in most cases, methanol is used as the additional fuel [20]. However, another mixture of 85% ethanol and 15% gasoline (E85) is currently in use to power internal combustion engines. This fuel is considered as a prospective alternative fuel for internal combustion engines. E85 is a mixture of ethanol and gasoline. Single ethanol combustion in a diesel engine has great potential to achieve highly efficient combustion with low exhaust emissions such as systems with both homogenous charge compression ignition and stratified charge compression ignition [7,21].

As mentioned, alcohol fuels have low cetane number, what do not make them as competitive fuels to CI engines, hence investigation in this field has not been intensively stimulated. Alcohol fuels cannot be directly used in typical diesel engines without their modifications, however, there are possibilities of using alcohols as blends with esters or diesel fuel [10].

Both E85 and methanol can be classified as oxygenated fuels. Oxygenated fuels contain oxygen, hence makes them helpful in reducing PM emissions. There are no PM emissions from diesel engines when the mass of oxygen in the fuels is more than approximately 30% [22]. Due to higher octane rating of alcohol, engine knocking is not a problem, thus the fuel can be burned at higher compression ratio. The problem appears in mixing ethanol with diesel fuel, water content in the ethanol causes phase separation.

From the classical theory of ignition by Semenov [23] it is known that the ignition event is characterized by the initial period in which pre-flame chemical reactions play crucial role. The so-called chemical delay is reckoned from the beginning of these reactions. The physical phenomena which may occur in the diesel engine during so-called physical ignition delay are as follows: disintegration of the fuel jet into separate droplets, heating and evaporating the droplets, and finally diffusing fuel vapors into air. The rate of combustion of liquid fuel is defined by rate of its evaporation and mixing vapors with air [24]. The rate of these physical and chemical phenomena, which occur at the initiation of ignition process depends on temperature. With increase in methanol or E85 in fuel mixture, temperature at the beginning of the compression stroke decreases. Thus, as mentioned, it reduces the charge temperature, hence it lengthens the ignition delay. Furthermore, lower partial pressure of oxygen (lower oxygen content) can also increase ignition delay. Finally, this premixed air–alcohol charge may remarkably influence on the pre-ignition reactions concerning diesel fuel injected into this environment [25].

Gasoline is also used to improve operating parameters of the diesel engine. There are works in which gasoline is used there for improving engine performance and reducing the toxicity of exhaust gases. Sahin and Durgun [26] recommended gasoline fumigation for improving engine performance and reducing NO_x emission in existing diesel engines. Some studies of the dual-fuel

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