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Experimental investigation of improving diesel combustion and engine performance by ethanol fumigation-heat release and flammability analysis

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ABSTRACT

The effects of ethanol fumigation (EF) on combustion, smoke index K and nitrogen oxides (NO_x) emission and performance parameters of a turbocharged IDI automotive diesel engine have been examined experimentally. Also, evaluations based on heat release and flammability analysis have been done. Experiments were performed at three diesel fuel delivery rates (FDRs), three different engine speeds and various EF ratios (EFRs). Ethanol was introduced into intake air by a carburetor, which main nozzle section is adjustable, given approximately 2%, 4%, 6%, 8%, 10% and 12% (by vol.) ethanol ratios. Experimental results show that smoke index K reduces for up to 4–8% EFRs but then it begins to increase. EF tests results showed that NO_x emission takes lower values than that of neat diesel fuel (NDF). NO_x emission decreases approximately 8.5%, 9.79% and 11.02% for 1/1, 3/4 and 1/2 FDRs respectively, at the selected engine speeds. For ethanol ratios higher than 8–10%, engine performance parameters improve for 1/1 and 3/4 FDRs but they deteriorate for 1/2 FDR at selected engine speeds. In heat release rate diagram two distinct peaks are observed for high ethanol additions. The first peak occurs before top dead center (TDC) and the second peak takes place after TDC. On the other hand, the first peak becomes larger, but the second peak diminishes as ethanol percentage increases. That is, premixed combustion of ethanol–air improves engine performance and also it increases in-cylinder pressure. However, total fuel cost of EF becomes higher than NDF because actual ethanol price is six times of diesel fuel in Turkey.

1. Introduction

Diesel engine is one of the most efficient types heat engines and it is widely used as a prime mover for many applications. The most important process that determines the performance of diesel engine is its combustion process [1]. For this reason, researchers and engine producers have aimed to enhance the combustion process ever since they invented. Engine efficiency and exhaust emissions could be improved mainly by enhancing engine combustion process. Consequently, for improving diesel engine combustion and performance; constructive advancements have recently been done and also studies on the fuels have been continued. Using new injection systems or enhancing the injection process, improving the combustion chamber geometry, increasing the number and dimensions of valves and widespread using of turbocharging systems can be listed as examples for structural developments. On the other hand, fuel studies can be grouped mainly as, methods of economical using of existing classical fuels and studies of using various alternative fuels [2–4].

Ethanol as a promising renewable oxygenated fuel has been used in both of spark ignition engine and diesel engine. Therefore recently various studies on the using of ethanol either in the spark ignition engine as well as in the diesel engine have been done [3,4]. As ethanol has high octane number, it is appropriate for using as ethanol–gasoline blends in spark ignition engine. But ethanol cannot be used by mixing with diesel fuel directly in compression ignition engine because encountering various difficulties. The main difficulties are: (a) Cetan number of ethanol is extremely low; but in spite of this high cetane number such as (45 ± 55) fuels are preferred in the diesel engines. Because, high cetane number fuels auto-ignite easily and give small ignition delay [5,6]. (b) Diesel fuel has good lubrication quality, whereas lubrication quality of ethanol is lower. Therefore, adding ethanol to diesel fuel may cause some wear problems in the injection system [5,7]. (c) Ethanol has lower

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Nomenclature

b_e, bsfc	brake specific fuel consumption (kg/kW h)	LHV	lower heating value (kJ/kg)
CA	crank angle (degree)	LFL	lower flammability limit
CGP	in-cylinder gas pressure	N_e	effective power (kW)
EF	ethanol fumigation	NDF	neat diesel fuel
fum	fumigation	TDC	top dead center
FDR	fuel delivery rate	x_e, x_d	volumetric percentage of ethanol and diesel fuel, respectively
HRR	heat release rate		

heating value than that of diesel fuel. As a result, much amount of fuel requires to obtain a specified power when ethanol added to diesel fuel [8]. (d) Ethanol exposes miscibility problem with diesel fuel. To solve this problem, it is required to use various surfactants or co solvents. Also, its blends are not stable and ethanol draws more water and causes phase separation problem [5,8,9].

Although replacing diesel fuel entirely by ethanol is very difficult, an increasing interest has recently emerged related to using of ethanol–diesel fuel blends at various percentages or applying different techniques in diesel engines such as dual fuel operation. Broadly speaking, these techniques can be divided into three categories. (1) Ethanol–diesel fuel blends: Up to 25% ethanol is mixed with diesel fuel in the fuel tank, (2) Dual injection: Two separate injection system are required for ethanol and diesel fuel. In this technique, ethanol can be used at the levels of 90% of diesel fuel demand. (3) Ethanol fumigation (EF): Ethanol is introduced into the intake air charge either by an injector or a carburetor. Here, ethanol can be used at the level of up to 50% of diesel fuel demand [5,8,10]. The simplest and the most attractive one of these techniques is EF for diesel engines. In this method, ethanol is introduced into the intake air flow by a simple carburetor or injected into the intake air stream by a separate injection system. A carburetor, an injector or a vaporizer, along with a separate fuel tank, lines and a control system are required for this technique. However, when a simple carburetor is used; minor modifications must be done on the engine intake system. Thus, this technique can be applied more easily and cheaply.

Many studies on EF and fumigation of other light fuels such as methanol, gasoline, and diesel fuel, in direct injection (DI) diesel engines can be found in the literature [5,7,10–17]. In the above listed studies, it is stated that engine performance and exhaust emissions have been somewhat improved. Also, by inspecting of the relevant literature it can be seen that by applying fumigation technique and by using above-mentioned fuels NO_x and soot emissions decreases substantially. Some studies on the EF and their main results can be summarized as follows. Abu-Qudais et al. [5] carried out an experimental study to evaluate the effects of EF and ethanol–diesel fuel blends on engine performance and exhaust emissions of a single cylinder DI diesel engine. In this study, it was aim to determine optimum ethanol percentages for EF and ethanol–diesel fuel blend techniques. It has been found that 20% EF and 15% ethanol–diesel fuel blend give the best increment ratios of engine performance and best decrement ratios of exhaust emissions. For 20% EF; brake thermal efficiency increased at the levels of 7.5% and also, a reduction of 51% in soot mass concentration was obtained.

However, carbon monoxide (CO) and hydro carbon (HC) increased at the levels of 55% and 36%, respectively. By using 15% ethanol–diesel fuel blend; brake thermal efficiency increased at the level of 3.6% and also, soot mass concentration decreased approximately 32%. However, concentrations of CO and HC increased at the levels of 43.3% and 34%, respectively [5]. A numerical study was performed to investigate the effects of EF on the DI diesel engine cycle and performance characteristics [10]. Here, the effects of 2.5–20% EF were investigated. They found that by increasing EF; nitric oxide (NO) concentration and brake specific fuel consumption (bsfc) decreased and, CO, effective power, effective efficiency increased. Another EF study was carried out recently by using a small capacity DI diesel engine [16]. They reported that EF improved engine performance and decreased NO_x, CO, carbon dioxide concentrations and exhaust temperature in a DI diesel engine. However, EF increased unburned hydrocarbon emission for all of the selected loads.

The above brief review shows that EF gives promising results for engine performance parameters and exhaust emissions in DI diesel engines. On the other hand, gasoline [11,12,18], methanol [13,14] and dimethyl ether [19] have also been used by applying fumigation technique in DI diesel engines. Similarly, in the recent studies it also be reported that engine performance and exhaust emissions have been improved and NO_x and smoke emissions have been decreased significantly by applying of fumigation technique [2,11–14,19].

From the above literature survey it is clear that many studies on the effects of fumigation of various light fuels such as ethanol, methanol and gasoline in DI diesel engines have been done [5,11,14]. But in spite of this, there are few parametric and experimental alternative fuel studies in indirect injection (IDI) automotive diesel engines [20–23]. Actually, IDI diesel engines are not used commonly nowadays. However, these engines are proposed for use in auxiliary power unit applications for civil and possible military operations [22]. Because of their higher speeds, DI diesel engines with common-rail fuel injection system have been used widespreadly. Instead of this, by obtaining any probable enhancement in IDI diesel engine, their using could become widespread and by this way using of a cheaper engine with lower injection pressure could be realized. For these reasons, in the present study the effects of EF on an IDI turbocharged automotive diesel engine performance and smoke index K and NO_x emission were investigated experimentally. Here, fuel cost analysis has also been conducted and various EF results were compared with that of NDF.

2. Experimental system and test procedure

2.1. Engine and experimental set-up

EF investigation was carried out in a 4 cylinder, 4-stoke, water cooled, pre-chamber automotive diesel engine (XLD 418 T, Ford). Main technical specifications of the engine are given in Table 1 and schematic view of the test system used in the experiments was presented in Fig. 1a. This test system was produced by Cussons. Here; loading was done by a water brake and brake moment (loading force) was measured electronically. The fuel consumption was determined by mass.

NO_x emission was measured by using a NO_x gas analyzer (MEXA-720, Horiba) which employs a zirconia ceramic sensor. The main specifications of this NO_x gas analyzer are given in