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Performance and emissions of diesel-gasoline-ethanol blends in a light duty compression ignition engine

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ABSTRACT

An approach to reduce CO_2 emissions while simultaneously keeping the soot emissions down from compression ignition (CI) engines is to blend in short chained oxygenates into the fuel. In this work, two oxygenated fuel blends consisting of diesel, gasoline and ethanol (EtOH) in the ratio of 68:17:15 and 58:14:30 have been utilized and studied in a single cylinder light duty (LD) CI engine in terms of efficiency and emissions. The reasons of utilizing gasoline in the fuel blend is due to the emulsifying properties it has while increasing the total octane rating of the fuel to be able to run the engine with a higher fraction of premixed flame. When performing the experiments, the control parameters were set as close as possible to the original equipment manufacturer (OEM) EU5 calibration of the multi-cylinder engine to study the possibility of using such blends in close to stock LD CI engines. With the oxygenates, in particular the fuel with the higher concentration of EtOH achieved an indicated net efficiency of ~51% inf comparison to ~47% for diesel at 8 bar BMEP. The NO_X emissions increased slightly for the double injection strategy at 13 bar BMEP from ~13.5 g/kW h to ~14.5 g/kW h when going from diesel fuel to the higher ethanol blend. However utilizing single injection strategy at lower loads reduces the NO_X. Highest soot mass measured for diesel was ~0.46 g/kW h in contrast to ~0.1 g/kW h for the oxygenates. Also, soot production when running the engine on the ethanol containing fuels was not significantly affected by EGR utilization as in the case of diesel. Considering particle size distribution, the particles are reduced both in terms of mean diameter and quantity. At 1500 rpm and 2 bar BMEP an increase of over ~300% in THC and CO was measured, however, increasing the speed and load to above 2000 rpm and 8 bar BMEP respectively, made the difference negligible due to high in-cylinder temperatures contributing to better fuel oxidation. Despite having lower cetane numbers, higher combustion stability was observed for the oxygenates fuels.

1. Introduction

As a result of combustion of fossil fuels, the concentration of anthropological CO_2 emissions are increasing [1]. One of the biggest contributors to the CO_2 emissions is the combustion engine, which is used worldwide as a source of mechanical work [2]. The compression ignition (CI) engine is widely used since it offers a high efficiency, however, the high levels of soot and NO_X emissions are two of the major drawbacks of this engine type, mainly due to the fuel utilized in combination with the combustion process [3]. Also, expensive exhaust after treatment systems (EATS) are necessary to, at least partially, eliminate these emissions. In general, the EATS used to clean the exhaust gases must be maintained [4]. One of the ways to reduce the formation of soot already in the combustion chamber is to replace a portion of the diesel with another, non-sooting, fuel. A fuel which has this advantage is EtOH [5].

The problem with diesel-EtOH blends is the miscibility. Since diesel consists of non-polar long chains of hydrocarbons, it is hard to mix EtOH into diesel in larger quantities than ~5 vol% without separation since EtOH is a short and polar molecule [6,7]. A way to avoid the issue of separation, is to use an emulsifier. Such a substance could for example be gasoline, which must be used in relatively high concentrations depending on the desired EtOH content. In general, more EtOH can be mixed into the blend if the aromatic content of the gasoline is higher [8].

A number of works has been conducted investigating diesel-gasoline blends, termed dieseline, however, these are blends often consisting of a very high fraction of gasoline. Furthermore, this binary blend has been investigated mainly as an fuel option for either partially premixed combustion (PPC) or homogeneous charge compression ignition (HCCI) and not for the conventional diesel combustion (CDC) strategy [9–13].

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Nomenclature

Definitions/Abbreviations

η_C	combustion efficiency
η_{NIE}	net indicated efficiency
η_T	thermal efficiency
λ	lambda, $\frac{(A/F)}{(A/F)_S}$
ATDC	after top dead center
BMEP	brake mean effective pressure
BTDC	before top dead center
CA10	the crank angle at which 10% of the charge has been consumed.
CA50	the crank angle at which 50% of the charge has been consumed.
CA90	the crank angle at which 90% of the charge has been consumed.
CA	crank angle
CAD	crank angle degree, same as CA
CI	compression ignition
DGE15	diesel, gasoline and EtOH blend in 68:17:15 ratio.
DGE30	diesel, gasoline and EtOH blend in 56:14:30 ratio.
EATS	exhaust after treatment system
EGR	exhaust gas recirculation
FID	flame ionization detector
FSN	filtered smoke number
$IMEP_N$	net indicated mean effective pressure
ISEC	indicated specific energy consumption
ISFC	indicated specific fuel consumption
NEDC	new european driving cycle
NO_X	nitrous oxides, NO_X=NO + NO_2
OEM	original equipment manufacturer
PM	particulate matter
PN	particle number
PRR_{MAX}	maximum pressure rise rate
RCCI	reactivity controlled compression ignition
RON	research octane number
SI	spark ignition
THC	total hydrocarbons

Reactivity controlled compression ignition (RCCI), has also been studied with diesel DI, and port fuel injected gasoline and ethanol. While being able to run RCCI in the whole engine map with reduced soot and NO_X, the gross indicated efficiency was measured to 48.2% [14,15]. However, the drawback of RCCI, is the structural complexity of the required fueling system.

Chen et. al. (2013) performed experiments using a diesel-gasoline blend in the ratio of (7:3) resulting in lower CO and soot, while NO_X was higher. Due to the chemical composition of gasoline and ignition delay, the charge is more premixed when the combustion is initiated and, therefore, less soot is produced. However, since the PRR_{MAX} is increased the NO_X are also elevated [16].

Diesehol, a blend of diesel and alcohol, generally EtOH, has seen rigorous testing. As for the dieseline case, the soot emissions are always reduced when blending EtOH and diesel, since the EtOH component does not produce particulate matter (PM) in a similar manner as diesel, and also has the same tendency as gasoline in terms of high RON rating which increases the ignition delay [17]. Since the ignition delay is prolonged, the combustion speed and peak pressure will increase which leads to elevated NO_X emissions, given that the combustion phasing is set constant [18]. However, if the maximum pressure rise rate (PRR_{MAX}) is kept under control, the EtOH component cool down the charge and reduce the NO_X formation [19,20]. Diesehol emits a higher amount of CO and total hydrocarbons (THC) since the combustion process is generally degraded due to the cooling effect of alcohol due to its high heat of vaporization [21]. Regarding the efficiency, both dieseline and diesehol show a higher efficiency than regular diesel [9,11,17].

As far as the authors' knowledge goes, earlier studies on the ternary fuel blend consisting of diesel, gasoline and EtOH have not been conducted, making this study unique in the choice of fuel blends. A study, somewhat related to this work, was conducted by Labeckas et. al. (2009) utilizing a ternary fuel blend consisting of rapeseed oil, gasoline and EtOH. The experiments conducted used a constant SOI for all the fuels which makes it possible to examine the combustion characteristics, however, performance and efficiency becomes less comparable between the fuels [22]. Moreover, the fraction of gasoline and EtOH were low; 7.5 vol% of each component.

The motivation behind this work is to examine the possibility of increasing the renewable fraction in the CI engine fuel, which is done by adding EtOH into diesel. Utilizing gasoline as an emulsifier will further decrease the cetane number enabling a combustion with a higher portion of premixed flame increasing the efficiency. The performance, emissions and combustion characteristics will be compared with conventional diesel fuel. Furthermore, the single cylinder engine used in this study resembles an OEM engine which would suggest that the fuels tested in this study could potentially run in lightly modified conventional light duty (LD) diesel engine. Considering the EtOH being produced from sugar cane, these fuel blends could potentially lower the well-to-wheel CO_2 emissions for DGE15 and DGE30 with 5% and 14% respectively [23].

2. Method

2.1. Experimental setup

The experimental engine used in this work is a single cylinder, EU5 standard, engine. The geometry is based on the Fiat/GM JTD 1.9 litre engine, however, with custom manufactured block and crank shaft. The cylinder head, originating from the stock engine, is modified to run only one cylinder. The engine specification and the experimental setup schematic can be observed in Table 1 and Fig. 1 respectively.

To allow full flexibility of the coolant, lubrication and fuel delivery controls, these are decoupled from the auxiliary system. A in-house compressor supplies the engine with air pressure, which is accurately controlled by a throttle. The exhaust back pressure and exhaust gas recycling (EGR) are both regulated using valves and the intake air is heated with a 1.5 kW heat element. A National Instrument based engine management system was developed and used to control all engine parameters. An AVL 733, using a gravimetric balance, measures the fuel mass flow to the engine.

A Kistler 6025B piezo-quartz transducer was used to measure the in-cylinder pressure every 0.2 CAD and the pressure measurements where

Table 1
Engine specifications.

Displaced volume [cm^3]	478
Stroke [mm]	90.4
Bore [mm]	82
Connecting rod length [mm]	145
Geometrical r_c [–]	16.5:1
Number of valves [–]	4
Swirl ratio [–]	2.1
Intake valve close [–]	152° CAD BTDC
Diesel Injection System [–]	Common rail, 1800 bar
Diesel Injector [–]	Solenoid 7 hole microsac