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Full Length Article

Effect of adding 2-ethylhexyl nitrate cetane improver on the autoignition properties of ethanol–diesel fuel blend – Investigation at various ambient gas temperatures

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ABSTRACT

One of the alternative fuels considered for powering piston internal combustion engines is ethanol. In some countries, ethanol has been successfully used for many years as a self-contained fuel in positive-ignition engines after relatively minor technical modifications. Due, among other things, to a very low cetane number, this fuel cannot be used in pure form in diesel engines. Consideration is being given to fuels that are blends of diesel fuel with some ethanol fraction. Diesel fuel containing up to 15% (v/v) of ethanol is sometimes referred to as e-diesel or oxygenated diesel. However, it is necessary to improve the autoignition properties of such a blend. Improvement of the autoignition properties of an ethanol–diesel fuel blend (EDB) can be accomplished by introducing an additive that improves the propensity for autoignition. One such additive may be 2-ethylhexyl nitrate (2-EHN), which is commonly used to improve the autoignition properties of diesel fuels. This study determined the effect of the addition of 2-EHN (up to 10,000 ppm [m/m]) on the autoignition properties of an EDB with an ethanol fraction of 15% (v/v). The study was carried out by using a device with a constant volume combustion chamber, which additionally enabled determination of the effect of the ambient gas temperature (in the range 550–650 °C) on the period of ignition delay and the period of combustion delay, as well as the derived cetane number. The average and maximum pressure rise rates in the combustion chamber were also analysed. Studies have shown that, with an increase of the 2-EHN fraction in an EDB, the periods of ignition and combustion delay decrease, and the increase in the temperature of ambient gas into which the fuel is injected shortens these periods to a varying extent.

1. Introduction

Diesel fuel with the addition of esters of plant oils has long been used to power diesel engines. There are a number of studies on the properties of such blends – for example, in [1–5]. In addition, there has been interest in the use of organic oxygen compounds in diesel engines, particularly alcohols. However, such fuels are characterized by a low propensity for autoignition and have poor lubricating properties, as pointed out, for example, in [6–12]. The use of this type of fuel in a pure form would require significant engine design modifications. Due to their lubricity and autoignition properties, the blends of oxygen compounds with diesel fuel are of more practical importance, as noted in [6–9,13,14].

One of the alcohols considered as a possible additive to diesel fuel is ethanol. This is due, among other things, to the fact that this alcohol can be produced from raw materials of plant origin and therefore can be considered as a fully renewable fuel. It is also important that dehydrated ethanol exhibits a relatively good solubility in diesel fuel [9,15–19].

A number of publications on the possibilities of adding ethanol to diesel fuel explicitly indicate that with an increase of the ethanol fraction, the autoignition properties of diesel fuel deteriorate, which is a consequence of ethanol's low propensity for autoignition [6,10,15,16,20–26]. This is reflected in the declining CN (Cetane Number) value with an increased ethanol fraction in diesel fuel, as indicated by, for example, [6,9,15,23,26]. Low CN values are unfavourable because they prolong ignition delay. A long ignition delay period is disadvantageous because during this period prior to autoignition a large amount of fuel accumulates in the combustion chamber, which causes an increase in peak combustion pressures [20,27,28]. Operation of the engine becomes noisy, and the load of the elements of the piston-crank system increases, which accelerates engine wear and increases NO_X (Nitrogen Oxide) emissions. The impacts of the CN on the parameters of the diesel engine were presented, for example, in

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Nomenclature

EDB	ethanol–diesel fuel blend
2-EHN	2-ethylhexyl nitrate
CN	cetane number
NO_X	nitrogen oxides
THC	total hydrocarbons
HC	hydrocarbons
CO	carbon monoxide
DCN	derived cetane number
CVCC	constant volume combustion chamber
ID	ignition delay (period), ms
CD	combustion delay (period), ms
APRR	average pressure rise rate, MPa/s
MPRR	maximum pressure rise rate, MPa/s
CFPP	cold filter plugging point, °C
WSD	wear scar diameter, µm
HPLC	high performance liquid chromatography
PNA	polynuclear aromatic hydrocarbons
FAME	fatty acid methyl esters
p_0	chamber static pressure (gauge), MPa
MPR	maximum pressure rise, MPa
Δp_{ch}	maximum pressure rise (MPR) – the difference between chamber maximum pressure and chamber static pressure, MPa
t_{ch}	chamber wall temperature, °C
t_{co}	injector nozzle coolant jacket temperature, °C
p_{inj}	injection pressure, MPa
p_{ch}	gauge pressure in the chamber, MPa
T_a	initial ambient gas temperature inside combustion chamber, °C
t_{inj}	injection period (determined by the length of the electronic signal that opens the injector), ms,
NTC	negative temperature coefficient
WFCh	Worldwide Fuel Charter
$\Delta(ID)_A$	absolute measurement uncertainty of ID, ms
$\Delta(ID)_R$	relative measurement uncertainty of ID, %
$\Delta(CD)_A$	absolute measurement uncertainty of CD, ms
$\Delta(CD)_R$	relative measurement uncertainty of CD, %
$\Delta(MPR)_A$	absolute measurement uncertainty of MPR, MPa
$\Delta(MPR)_R$	relative measurement uncertainty of MPR, %
$\Delta(APRR)_A$	absolute measurement uncertainty of APRR, MPa/ms
$\Delta(APRR)_R$	relative measurement uncertainty of APRR, %
$\Delta(MPRR)_A$	absolute measurement uncertainty of MPRR, MPa/ms
$\Delta(MPRR)_R$	relative measurement uncertainty of MPRR, %
$\Delta(DCN)_A$	absolute measurement uncertainty of DCN
$\Delta(DCN)_R$	relative measurement uncertainty of MPRR, %

[29–39].

Engine tests carried out by Kidoguchi et al. [29] demonstrated that, among other effects, an increase of the CN of fuel results in a decrease in the peak cylinder pressure and in the heat release rate in the premixed combustion phase. The recorded pressure courses in the cylinder also indicate a reduction in the average pressure rise rate. In addition, with an increase in the CN, the concentration of NO_X in the exhaust gas is clearly reduced, especially in the range of higher load operations of the engine. In turn, for lower load operations of the engine and for the smallest of the analysed CN values, a clear increase in the THC (Total Hydrocarbons) concentration in the exhaust gases is observed. Engine tests carried out by İçingür and Altiparmak [30] show that as the CN increases, the ignition delay period is significantly shorter, which results in lower values of the average pressure rise rates in the cylinder and lower values of combustion peak pressure. The authors also noted that, with the CN increase, the NO_X concentration in the exhaust gas is reduced. However, their studies also show that the increase in the CN entails some decrease in the brake power and torque of the engine, as well as an increase in exhaust smoke. Engine tests carried out by Ahmed and Chaichan [36] indicate that with the increase of the CN, the energy and ecological parameters of the engine clearly improve. The authors of the aforementioned work noted that an increase of the CN (tests for the CN in the range from 48.5 to 55.0) resulted in a reduction of the specific fuel consumption, NO_X, HC (Hydrocarbons) and CO (Carbon Monoxide) concentrations in the exhaust gases, as well as reduced noise emissions. At the same time, with the increase of the CN, the authors noted an increase in the engine brake power and brake thermal efficiency.

Due to the significant impact of the CN and changes to the length of the ignition delay period, it is important to properly shape the autoignition properties of the fuel. This is often related to the necessity to increase the CN in accordance to the standard requirements for fuel. One of the ways to achieve this may be the use of an additive to improve the autoignition properties. A commonly used additive that improves a fuel's autoignition propensity is 2-ethylhexyl nitrate (2-EHN). It is mainly used to improve the autoignition properties of diesel fuels. When 2-EHN is added to a diesel fuel, the radicals generated from the improver facilitate an additional initiation pathway with a rate much higher than the initiation rate by oxygen. A faster initiation rate leads to a quicker generation of hydrocarbon radicals. This leads to a shortened ignition delay period, resulting in an increase in the CN. The course of the free-radical reaction using 2-EHN as a CN improver was presented in detail by Ghosh [40].

The issues related to the properties of 2-EHN, its impact on the physicochemical parameters and autoignition properties of various fuels, as well as the effect of this additive on the parameters of a diesel engine were the subject of studies included in, for example, [40–56]. Some of these studies concern the influence of 2-EHN on the properties of an ethanol–diesel fuel blend (EDB), which is directly related to the subject of this study. In their engine tests, Liu et al. [47] used, besides diesel fuel, three fuel blends composed of diesel fuel, dehydrated ethanol and octanol as an emulsifier. The fractions of ethanol and emulsifier were 30% (v/v) and 3% (v/v), respectively. One of the blends did not contain 2-EHN, while the other two contained 0.3% (v/v) and 0.6% (v/v) additions of 2-EHN, respectively. The research carried out by the authors showed that along with the increase in the fraction of 2-EHN, the ignition delay period shortens, resulting in a reduction of the heat release rate in the premixed combustion phase. The presented data also showed that the increase in the fraction of 2-EHN resulted in an increase in the peak combustion pressure at lower engine loads, while for higher engine loads, the peak combustion pressure in the cylinder remained relatively unchanged. The increase in the fraction of 2-EHN also resulted in the reduction of NO_X, HC and CO in the exhaust gas, but at the same time resulted in a higher exhaust smoke. Ciniviz et al. [55] conducted a study in which they investigated the effect of the 2-EHN additive on the performance of a diesel engine powered by an EDB with an ethanol fraction of 10% by volume. The fractions of 2-EHN used in the EDB were 2, 4 and 6% by volume. The conducted investigations showed that with the increase of the 2-EHN fraction, the CN of the EDB is increased. In general, the studies also showed that the addition of 2-EHN to the EDB resulted in a reduction of NO_X and CO in the exhaust gases but negatively affected the brake power and the specific fuel consumption.

Previous studies regarding how the 2-EHN additive affects the parameters of a diesel engine powered by an EDB were mainly focused on engine performance and exhaust emissions. However, it is also important to determine the effect of 2-EHN on the autoignition properties of such a blend, because the ignition delay period has a key effect on the engine parameters.