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Full Length Article

Use of the constant volume combustion chamber to examine the properties of autoignition and derived cetane number of mixtures of diesel fuel and ethanol

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HIGHLIGHTS

- Ignition and combustion delay for some diesel-ethanol mixtures were measured.
- Tests of autoignition properties were conducted for different injection pressures.
- Derived cetane number (DCN) for ethanol-diesel mixtures is discussed.

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ABSTRACT

Due to increasing fuel consumption in various industries, especially in road transport, interest in increasing the market proportion of renewable fuels is growing. One of such fuels is ethanol. The raw materials for production of ethanol may include sugar beets, sugar cane, potatoes and many other plants containing starch. Ethanol can be used as a self-contained fuel in positive-ignition engines, which undergo relatively minor technical modifications. However, in diesel engines with compression ignitions, due to, e.g., a very low cetane number, this fuel cannot be used. Therefore, more attention is given to fuels consisting of mixtures of diesel fuel with certain proportions of ethanol. In this paper, the properties of autoignition mixtures of conventional diesel and ethanol, with ethanol content of up to 14% (v/v), were examined. A combustion chamber of constant volume was used in the study. The effect of injection pressure in the range of 80 MPa–140 MPa on the period of ignition delay and the period of combustion delay was determined in the study. In addition, for each mixture of diesel fuel and ethanol, the value of derived cetane number was examined. The studies have shown that with increasing proportions of ethanol, the ignition and combustion delays periods increase and the increase in fuel injection pressure in varying degrees shortens those periods. It was also shown that in the range of 14% ethanol, for every 2% increase in the proportion of ethanol, the derived cetane number of the mixture of diesel and ethanol is reduced by an average of 1.7 units.

1. Introduction

Rising prices of fuels derived from crude oil and the limitations resulting from the increasingly stringent standards for exhaust emissions have grown the interest in alternative fuels. At the same time, an unflagging interest in the use of compression ignition engines in industry and transport can be observed. For a long time, the use of diesel fuel with esters of plant oils to supply this type of engine has been common, but recently the interest in the use of common alcohols has increased. The advantage is the low cost of methanol production and reduction in opacity [1], but the disadvantage that significantly restricts the use in diesel engines is the low solubility in diesel fuel [2]. Moreover, world production of this alcohol is based on the use of synthesis gas, which in turn is created, inter alia, of coal and natural gas, and thus fossil fuels. Larger hopes are for the use of ethanol as an additive to diesel. This is due to the good solubility of dehydrated ethanol in diesel fuel, and because it can be produced from vegetable products, and thus can be considered a fully renewable fuel. The issue of miscibility

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DCN	derived cetane number
CO	carbon monoxide
NO_X	nitrogen oxides
CVCC	constant volume combustion chamber
CRU	combustion research unit
ID	ignition delay (period), ms
CD	combustion delay (period), ms
HPLC	high performance liquid chromatography
PNA	polynuclear aromatic hydrocarbons
FAME	fatty acid methyl esters
p_{inj}	injection pressure, MPa
t_{inj}	injection period (determined by the length of the electronic signal that opens the injector), ms
p_0	chamber static pressure (gauge), MPa
t_{ch}	chamber wall temperature, °C
Δp_{ch}	the difference between chamber maximum pressure and chamber static pressure, MPa
SW	the method of determination of ignition delay period (described in the operative procedures [26])
PW	the method of determination of ignition delay period (based on an analysis of the averaged course of pressure in the chamber and determining the actual start of fuel injection and the beginning of heat release after autoignition occurs)
ID_P	ignition delay (period), ms (based on actual start of injection fuel and start of combustion)
t_{co}	injector nozzle coolant jacket temperature, °C
p_{max}	maximum chamber pressure (gauge), MPa
ΔID	relative error of ignition delay (period), %
ΔID_P	relative error of ignition delay (period), % (based on actual start of injection fuel and start of combustion)
ΔCD	relative error of combustion delay (period), %
$\Delta\Delta p_{ch}$	relative error of the difference between chamber maximum pressure and chamber static pressure, %
ΔDCN	relative error of derived cetane number

of ethanol with diesel is more commonly presented, among others, in studies [3–5].

There are numerous studies on the use of mixtures of ethanol and diesel to power compression ignition engines, which show the advantages and some limitations resulting from such a solution. For example, in [6,7] it was proven that the use of a 20% addition of ethanol to diesel fuel resulted in a reduction of CO and NO_X emissions relative to the diesel fuel. Additionally, research on the operating parameters of the compression ignition engine under different engine speeds and loads generally indicates the possibility of reducing CO and NO_X [8] in certain engine operating conditions and opacity [8,9] when fed with a mixture of diesel fuel and ethanol, with respect to the diesel fuel supply.

Considering the possibility of using ethanol in a diesel engine, the addition of ethanol significantly alters the physicochemical and quality parameters of diesel fuel. Particular attention should be given to the tendency of autoignition and the connected period of ignition delay.

A long ignition delay period is disadvantageous because during this period, before igniting, a large amount of fuel accumulates in the combustion chamber, which causes an increase in peak combustion pressures [10,11]. Operation of the engine becomes noisy, the load of elements of the piston-crank system increases which accelerates engine wear, and increases nitrogen oxide emissions. Therefore, the ignition delay period should be shortened. For the duration of ignition delay period, factors such as: the autoignition ability of the fuel, the micro-structure and macro-structure parameters of the fuel spray and the air temperature at the time of the start of fuel injection have the greatest impact. The parameters associated with the fuel atomization process are mainly determined by the phenomena occurring in fuel injection systems [12,13].

Shorter ignition delay periods lead to lower resistance of fuel components to oxidation. The lowest oxidation resistance, and therefore the best autoignition properties, are achieved by hydrocarbons with straight saturated chains, i.e., paraffin hydrocarbons. The chain branching and increase in the number of carbon atoms in the side chains contributes to longer ignition delay periods. The ignition delay period of paraffinic, naphthenic and olefinic hydrocarbons decreases with an increasing number of carbon atoms in the molecule. Additionally, a higher fuel boiling temperature benefits the ignition delay period. However, its increase above a certain limit can prolong the period of ignition delay due to a reduction in fuel volatility [11].

Many publications on the possible use of ethanol addition to diesel clearly indicate that with an increase of the proportion of ethanol, the autoignition properties of diesel fuel deteriorate, which is a consequence of a low propensity to spontaneous combustion of ethanol [1–4,9,11,14–17]. This is reflected in the decreasing value of the cetane number with an increase of the proportion of ethanol in diesel fuel, which is indicated in the literature [2,4,8,17]. However, in those studies, results of experimental examinations of the cetane number for diesel fuel with specific additions of ethanol were not specified. This may be due to the complexity and cost of determining the cetane number for a tested engine. Because of this, it is difficult to find results in terms of cetane number for fuels that are not as popular as diesel or biodiesel. Moreover, the addition of ethanol results in a marked reduction in fuel viscosity [4,8] and its lubricity [4,17], which may result in damage to the injection system of the tested engine. The procedure for determining the cetane number by the motor method is described, among others, in standards [18] and [19].

An alternative method of determining the autoignition properties of fuel is the use of constant volume combustion chambers. To distinguish it from measurements using a test engine, when measured by the CVCC method, the concept of derived cetane number is used [10].

The study of derived cetane number uses the correlation between the period of ignition delay and the cetane number [10,20–23]. The standard procedure for determining the DCN is described, among others, in standards [24–28]. In the procedures included in [24,25,27,28], DCN is calculated on the basis of the measured ignition delay period. In those methods, the beginning of the ignition delay period is the start of the needle lift in a pintle injector, while the end of the period is the point where the pressure rapidly begins to increase in the combustion chamber. Fuel injection occurs to compressed and heated synthetic air. The injection parameters are determined during calibration using a reference fuel.

In the procedure included in [26], to calculate the DCN the ignition delay period and the so-called combustion delay period are used. The method to define this parameter is presented in part of the article on the research methodology. According to the requirements included in the standard [26], fuel injection is performed by a Common Rail injector with multi-hole atomizer.

A common feature of the test equipment used to determine the DCN according to the standard is to measure the ignition delay period under established conditions, i.e., at a predetermined fuel injec-