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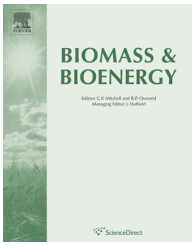

Ignition and combustion behaviour of vegetable oils after injection in a constant volume combustion chamber

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ABSTRACT

The ignition and combustion behaviour of vegetable oils to be used as fuel in combustion engines was researched using a constant volume combustion chamber. The chosen vegetable oils were characterised using the two structure indices average number of carbon atoms AC and average number of double bonds ADB. The structure indices were derived from the composition of the analysed fatty acids. The performance of these two structure indices in estimating differences in fuel properties, such as density, net calorific value, elementary composition and surface tension, was shown. The structure indices were also used to explain ignition and combustion behaviour. Differences in ignition and combustion behaviour were primarily recognised in the ignition delay and the first phase of combustion (premixed combustion). No differences were observed between the vegetable oils in subsequent phases of combustion. The longer the ignition delay, the higher the share was of premixed combustion. Models for the prediction of the ignition delay were developed using ADB. The ignition delay rises with increasing ADB. Differences in AC had no significant impact on the ignition delay. Hence, vegetable oils with a high ignition quality are characterised by a low amount of double bonds. The developed models can be used for estimation of the ignition quality and combustion behaviour of unknown vegetable oils.

1. Introduction

The usage of pure rapeseed oil as an alternative diesel fuel in agricultural machinery was demonstrated in various fleet tests in Europe [1–4]. The requirements for pure vegetable oils as fuel in vegetable oil compatible combustion engines are defined in the standards DIN 51605 [5] (rapeseed oil fuel) and DIN SPEC 51623 [6] (vegetable oil fuel). The CEN Workshop Agreement CWA 16379 [7] was implemented by the European Committee for Standardization. Although there are existing

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Abbreviations and symbols

AC	average number of carbon atoms
ADB	average number of double bonds
$\mathrm{AFR_a}$	actual air-fuel ratio
$\mathrm{AFR_S}$	stoichiometric air-fuel ratio
CA	camelina oil
CC	coconut oil
CN	cetane number
CR	corn oil
CVCC	constant volume combustion chamber
d	relative density
DCN	derived cetane number
E_A	apparent activation energy
EOI	end of injection
FAME	fatty acid methyl esters
HO	high oleic sunflower oil
IV	iodine value
JA	jatropha oil
LI	linseed oil
M	molar mass
M1	mixture 1
M2	mixture 2
m_Air	mass of air
m_Fuel	mass of fuel
$\overline{M}_\mathrm{VO}$	average molar mass of the vegetable oils
$N_{\mathrm{C},i}$	number of carbon atoms of the fatty acid i
NCV	net calorific value
$N_{\mathrm{DB},i}$	number of double bonds of the fatty acid i
PA	palm oil
p_C	pressure in the combustion chamber
R	universal gas constant
R^2_adj	adjusted coefficient of determination
RA	rapeseed oil
RMSE	root mean square error
SO	soybean oil
SOI	start of injection
SU	sunflower oil
SV	saponification value
T_C	temperature in the combustion chamber
V_C	volume in the combustion chamber
VO	vegetable oil
w_C	mass fraction of carbon
w_H	mass fraction of hydrogen
w_i	mass fraction of the fatty acid i
w_O	mass fraction of oxygen
x	mole fraction
λ	relative air-fuel ratio
ν	kinematic viscosity
ρ	density
σ	surface tension
τ_id	ignition delay
Φ	equivalence ratio

fuel quality standards for vegetable oils, there is still a lack of information on fuel properties, especially concerning ignition and combustion behaviour.

In contrast to diesel fuel, which is a mixture of many different hydrocarbon compounds, vegetable oils are triacylglycerides with a low amount of minor components (e.g., free fatty acids, lecithin). The triacylglycerides differ in the type of fatty acids bonded to the glyceride. The fatty acids that occur most frequently in vegetable oils can be differentiated by their carbon chain length and the number of double bonds [8]. The composition of the fatty acids causes differences in the physical and chemical properties of vegetable oils. Indices such as the iodine value, which is a measure of double bonds, or the saponification value, an indicator for the relative average molecular mass, are used to obtain information on the structure of vegetable oils [9]. In DIN 51605 and DIN SPEC 51623, only the iodine value is used as a structural index, and in CWA 16379 no structural index is listed. The relevance of the iodine value as a structure index is questioned and seems to be too general for a correlation of chemical and physical properties [9].

The ignition performance of fuels is of crucial importance for compression ignition engines as insufficient ignition quality can lead to higher emissions [10]. In DIN 51605 and DIN SPEC 51623, requirements for ignition performance are defined and an adapted test method based on EN 15195 [11] is suggested for use. The cetane number (CN) is a widely used (e.g., EN 590 [12]) measure for ignition performance and is determined in a CFR engine according to EN ISO 5165 [13]. Without modifications, however, this method is not applicable for use with vegetable oils [14]. Therefore, the ignition performance of vegetable oils should be determined using an apparatus in which the fuel is injected into a heated and pressurised constant volume combustion chamber (CVCC) [5,6]. In addition to EN 15195, EN 16144 [15] also describes a method based on a CVCC. In both methods, the ignition delay (time between start of injection and start of combustion) is measured and a derived cetane number (DCN) is calculated using an equation included in the standards; however, both methods also contain statements noting that they should be used with caution for alternative fuels due to the lack of prior empirical studies. According to the national standards DIN 51605 and DIN SPEC 51623, an adapted method based on EN 15195 shall be used for the determination of a DCN. The main adaptions are a defined initial combustion chamber pressure of 2.2 MPa, an initial combustion chamber temperature of 803 K and a fuel temperature of 348 K. Furthermore, the ignition delays of reference fuels with known CNs must be measured to find a calibration curve. The vegetable oil DCNs are determined by comparing the ignition delay with the calibration curve. Due to missing data on the precision and reproducibility of this adapted test method, the DCN cannot be used for legal disputes [5,6]. No requirements concerning the ignition performance were included in CWA 16379 because of the uncertainties of the test methods.

CVCC devices were already used to study the ignition behaviour of fatty acid esters [16–19]. With the increasing double bonds and decreasing chain length of the fatty acids, a