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Review Article

ALTERNATIVE FUELS FOR DIESEL ENGINES

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ABSTRACT
This paper presents the development and genesis of the use of alternative fuels in internal combustion ignition engines. Based on the analysis of the literature, this article shows various alternative fuels used in Poland and all over the world. Furthermore, this article describes the research directions for alternative fuels use in road transport powered by diesel engines.

Keywords: biofuel, diesel engine, eco-fuels.

INTRODUCTION

The increase in the emission of pollutants into the environment coming from road transport, depletion of natural resources, and economic considerations are the main reasons for the development of alternative fuels to power internal combustion engines. Fuel consumption by modern road vehicles is an interesting parameter for all users and producers. [18]. In order to meet the energy needs, there has been increased interest in alternative fuels, such as biodiesel, methanol, ethanol, biogas, hydrogen and gas to ensure adequate replacement of diesel fuel for internal combustion engines [2]. Vegetable oils were applied for the first time as power by Rudolf Diesel – in the engine he constructed [6]. Vegetable oils are a very promising alternative to diesel fuel because they are renewable and have similar properties [2]. Vegetable oils offer almost the same power with a slightly lower thermal efficiency when used in SI engines [21]. The interest in alternative fuels were noted again during the great oil crisis in the 1970's all over the world and this interest lasts until now, for economic and environmental reasons.

This paper presents the development of the use of alternative fuels in internal combustion engines. A careful analysis of the literature allowed us to present the main trends in the development of alternative fuels in the country and all over the world. This article describes the research directions in the use of alternative fuels in transport vehicles powered by diesel engines.

PHYSICO-CHEMICAL CHARACTERIZATION OF ALTERNATIVE FUELS

Research of alternative fuels based on biocomponents to power diesel engines focus mainly on identifying their impact on the environment [11]. Alternative fuels can be divided into the following categories:

- alcohols: methyl and ethyl,
- bioethanol,
- biogas,
- alkyl esters of fatty acids (FAME, FAEE),
- CNG gas (Compressed Natural Gas),
- vegetable oils (biodiesel),
- hydrogen.

In Europe and Poland, because of the climate and agronomic reasons, rapeseed oil methyl esters and their mixtures with diesel fuel [5] are most commonly used as liquid biofuels. Biofuel or motor fuel biocomponents will constitute 7.55% of the total fuel market in 2014 [8, 9]. Despite significant advantages, in the papers [1, 4] the drawbacks of biofuels and their negative impact on the sustainability and viability of the internal combustion engine, and the environment, are presented.

In Europe, the basic raw material for the production of biofuels is rapeseed. Basic biofuel used to power diesel engines are esters of fatty acids (FAME, FAEE). Esters of pure vegetable oils have good solubility in diesel fuel. This feature allows to create commercial mixtures of biofuels such as B10, B20. Due to high viscosity, low freezing point, water content and organic acids using pure rapeseed oil is not desirable. It may lead to seizure or damage of injection equipment and engine. The fuel in the supply system is also the only lubricating medium. The amount of hydrocarbons containing carboxyl group determines the lubricity of the fuel, what makes them chemisorbed on a clean metal surface [5]. Ethyl and methyl esters differ in products of incomplete combustion. In the process of incomplete combustion of the methyl esters, toxic substances, such as formaldehyde and radicals, are exuded, which do not occur in the case of incomplete combustion of the ethyl esters [23]. Exhaust gasses of diesel engines powered by RME contain three times more free methyl radicals than exhaust gasses of engines powered by REE [17]. The comparison of some properties of ON diesel oil, vegetable oil OR, and rapeseed oil methyl ester RME is presented in Table 1.

Subjecting the oil to esterification allows to break heavy molecular structure of tri-glycerides. The reduction of particle size is accompanied by the reduction in viscosity – which substantially simplifies and improves the fuel injection spray [8]. In this process, the reaction of esters neutralization occurs. The unquestionable advantage of esters of rapeseed oil is very low sulphur content translated into a reduction of particulate emissions [8]. The disadvantage is hygroscopy, which favors the proliferation of bacteria and fungi which translates into low chemical stability of the fuel. In Polish climatic conditions, the use of pure ester as a fuel without the additive depressant decreasing the pour point causes a lot of problems, especially in the conditions of autumn – winter [24]. Another problem associated with the esters are the adverse effects on the structure of the plurality of polymers (for example, rubber, some of the seals, coatings, etc.). Important from the operation point of view is the property of sediment dissolution resulting from diesel engines power. Diluted sludge can cause clogging of filters, and damage to the injectors. For this reason a number of engine manufacturers make restrictions on the use of biofuels and in case of their use they demand more frequent servicing. These prob-

Table 1. Comparison of selected physical and chemical properties of fuels ON, OR and RME [23]

No.	Parameter	Unit	ON Diesel	OR Rapeseed oil	RME Rapeseed oil methyl ester
1	Viscosity T_0 = 40 °C	mm²/s	2–4.50	20	4.32
2	Mass calorific value	MJ/kg	42–43	36–38	36–38
3	Cetane number	–	Min 51	40–50	50–55
4	Theoretical air consumption	kg/kg	14.4–14.6	12.2–13	13.4–13.8
5	Density T_0 = 15 °C	kg/dm³	0.8–0.845	0.90	0.88
6	Surface tension T_0 = 20 °C	N/m	24×10^{-3}	36×10^{-3}	–
7	The cloud point	°C	-12	18	-9
8	Cold filter plugging point	°C	-31 (IZ 40)	9	(-9) – (-11)
9	Freezing point	°C	-40	4	-15
10	The sulfur content	%	0.001	0.0002	0.0002
11	Carbon residue	%	0.01	0.17–0.5	0.5
12	Ignition point	°C	>55	200–300	130
13	Initial boiling point	°C	175	300	300
14	Average elemental composition	% m/m	86.4	77.6	76.8
	C	% m/m	13.4	11.7	12.1
	H	% m/m	–	10.5	11.0

lems, however, did not stop the development of biofuels. The authors in [8] indicate that the use of B100 fuel and CE (camelina esters) is accompanied by higher specific fuel consumption than in case of diesel. However, the authors of [9] confirm that the emission of nitrogen oxides is higher when the engine is fueled with biofuels than with diesel engine. Emission of hydrocarbons for fuel B100, CE and HE is on the same level, particulate emissions are highest for CE [9]. Reduction of CO and THC value during powering by esters of vegetable oils is related to the oxygen content chemically bonded in the molecules of esters. Motor power supply with B100 bioester very positively influenced the smoke opacity. According to the authors [11], at low and medium engine rotational speed of the engine crankshaft, the smoke opacity was more than three times lower on average, and at the high rotational speeds was lower by tens of percent, compared to smoke opacity of diesel-powered engine. Less clear is the effect of the application of bioester concerning the emissions of hydrocarbons and nitrogen oxides [11]. However, taking into account the fact that in real conditions the test engine works more time in the field of small and medium speeds than large ones [16], the impact of bioester on the emission of hydrocarbons is favorable and unfavorable in case of nitrogen oxides.

In [10], the authors draw attention to the mechanisms responsible for blocking by a mixture of biodiesel the fuel distributor or fuel filter of the vehicle. These mechanisms are complex and vary depending on the following factors [10]:

- FAME source and type of treatment used for their production,
- characteristics of the solvency of the base oil,
- the level of impurities and contaminants in the fuel,
- fuel storage and working conditions.

The authors [10] state that the increase in the tendency to block the filter of FAME blended mixtures is likely due to complex interactions of trace constituents present in various types of FAME and is also strongly dependent on the storage temperature, storage time, and the properties of the base oil. Filter blocking issues have been seen in a field trial using experimental B20 and B13 blends HVO7 fuel, where the FAME portions of the blends were produced using a 50:50 RME: SME mix. Residues from the blocked filters were confirmed to be a good match with sterile glucosides using IR analysis, and saturated monoglycerides were also found in some filter samples using GC analysis.

A further study attempting to assess the individual contribution of various trace components in FAME towards an increase in FBT, showed that there was no effect on FBT due to the addition of 0.3% by mass monoglyceride to B20, made from distilled RME. The presence of sterile glucosides and water in combination had the most significant detrimental effect to FBT in B20 RME blends. This effect was identified at a constant MG level of 0.3% by mass.

Ethanol has been considered an important alternative fuel for internal combustion engines for a long time, because it solves a number of problems of traditional crude based fuels such as emission of greenhouse gases and particulates. As a fuel for diesel engines, it suffers from a very low cetane number (around 5…8, while diesel is typically higher than 51), and consequently a high auto-ignition temperature (around 640 K while diesel is around 500 K). Ethanol has a heating value of about 60% of diesel. Igniting ethanol in a 4-stroke compression engine either requires use of a higher compression ratio, use of glow plugs or a catalyst [15]. Despite this, ethanol has successfully been used for example in Sweden as an alternative to diesel in bus fleets [20].

Diesel fuel-alcohol blends (known by a number of names – including E-diesel, M-diesel, Oxy-diesel and diesohol) also can be used as fuel in diesel engines [13, 19]. Generally, ethanol can be blended with diesel without engine modifications [12]. Because ethanol is highly hygroscopic, additives must be used in order to ensure solubility of anhydrous ethanol in diesel fuel under a wide range of conditions. Miscibility is limited, especially at lower temperatures. The addition of ethanol to diesel fuel can reduce lubricity and create potential wear problems in sensitive fuel pump and injectors designs. Ethanol possesses also a lower viscosity and calorific value, with the latter imposing minor changes to the fuel delivery system in order to allow injection of larger quantities of fuel, what is likely to be required for engine performance and for fuel injector/pump durability. Because ethanol has a very low cetane number it reduces the cetane level of the diesel-ethanol blend.

However, a major drawback in ethanol-diesel fuel blends is that ethanol is immiscible in diesel over a wide range of temperatures and water content due to their difference in chemical structure and characteristics [12]. These can result in fuel instability due to phase separation. Prevention of separation can be accomplished in two ways: by adding an emulsifier, which acts in order to suspend small droplets of ethanol within the diesel fuel, or by adding a co-solvent, which acts as a bridging agent through molecular compatibility and bonding to produce a homogenous blend [12]. Emulsification usually requires heating and blending steps to generate the final blend, whereas co-solvents allow fuels to be "splash blended", thus simplifying the blending process [7]. Blends of diesel and bioethanol can be used as fuel for compression ignition engines, but with limited scope, primarily due to the reduced mingle capability of ethanol with diesel, as well to the worse ignition properties of the mixture.

Promising results have been obtained for utilitarian bi-fuel (with initiating dose ON) diesel engines fueled, especially CNG [22]. Biogas is a renewable alternative fuel currently used to produce electricity and heat. Using it as fuel should strive to bring these properties, which , is unfortunately complicated by the widespread use of biogas. To meet the expectations associated with the ecological and economical operation of vehicle a number of modifications of standard engine is required. These include the change of shape of the piston crown and the engine head as well as a change of the fuel supply system. Additionally, the catalyst choice and special fuel tanks are required. Both manufacturers of new engines as well as users of many older vehicles will be able to take some advantage of natural gas application which in turn may lead to an increase in the number of new and adopted vehicles fuelled with this fuel.

Despite the many drawbacks, the technology of CNG fueling is becoming increasingly popular amongst the crowd of consumers, individual and fleet users, and public transport, as an economic and ecological fuel. The low price of CNG fuel and available technology of vehicle conversion play a dominant role.

CONCLUSIONS

Modern pro-ecological attitude associated with environmental protection against increased toxic exhaust emissions and over-exploitation of natural resources have forced to look for innovative liquid fuels. For efficient use of different fuels in existing engines, fuel or power systems of internal combustion engines modifications are applied. As demonstrated in the paper, the problem is to produce fuel similar to a classic one, whose properties can be used as best as possible, withdrawing from the available raw material.

Experience from the test stand and the operation show that the power of internal combustion engines with alternative fuels is a complex and long-term process and possible use of renewable natural resources are among the most environmentally friendly. It is stated that you cannot clearly determine which fuel is the best. In case of small motors it can be quite different fuels than for tractors' engines or trucks and buses. Climatic conditions of exploited vehicles are of great importance when using biofuel. Advantageous effects of RME on exhaust emissions from older diesel engines have been confirmed in many previous studies. However, in case of modern diesel engines, the influence of RME seems to be less recognized.

The main scientific problems relating to alternative fuels include: accurate knowledge of physical, chemical, thermodynamic, supplies and logistics processes. Issues mentioned in the article, the problems associated with the use and production of alternative fuels show that research on the development of alternative fuels is a complex and constantly current research field.

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