PROCEEDINGS OF THE INSTITUTE OF VEHICLES 2(116)/2018

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BIOETHANOL AS A FUEL COMPONENT FOR SPARK-IGNITION ENGINES

1. Introduction

The growing interest in alternative fuels for diesel engines is caused by a number of factors that include:

- concern over the shrinkage of existing ores of crude oil which is the basic raw material for the production of conventional fuels. National governments aim to ensure the highest energy safety and the vision that the resources of raw materials presently used seriously undermines that safety;
- commitment to seek more cost-effective energy raw materials or such that could be produced on own account;
- concerns regarding the protection of environment against pollution emitted when using mining raw materials.

The carbon dioxide emission hazardous for the environment is the underlying reason for stirring interest in fuels that do not contain mining coal, such as hydrogen and renewable fuels with a period of one year of carbon circulation in fuel production and usage processes.

Among biofuels that motivate interest are fuels containing bioethanol. Fuels with bioethanol can be used for fuelling spark-ignition and self-ignition engines. This article addresses spark-ignition engines fuelled with bioethanol fuel [1, 2].

2. Characteristics of bioethanol

Bioethanol is dehydrated (containing less than 1% volume of water) ethyl alcohol produced with the use of biomass or biodegradable part of waste. In room temperature it is a colourless, flammable liquid of a characteristic odour and acrid taste. In the presence of air it burns with a poorly visible, bluish flame. Table no. 1 shows physical and chemical properties of bioethanol [3].

The production of bioethanol comprises the process of fermenting plants containing monosaccharides (glucose, xylose) or disaccharides (sucrose, lactose) and thereafter the distillation of the resulting liquid. In Poland raw materials that contain the said disaccharides include whey and molasses. Whey is a by-product in the dairy industry. It contains lactose of approx. 4-5% which can be used for the production of bioethanol. Molasses is a by-product in sugar plants and contains approx. 50% of sucrose [4].

Bioethanol in the industry is commonly produced from raw materials containing polysaccharides, i.e. starch and cellulose. These raw materials however require preliminary processing, as a result of which polysaccharides are distributed into fermentable saccharides [5].

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Table 1. Physical and chemical properties of bioethanol [3]

Property	**Description**
Vapour density	Vapours of bioethanol like petrol have a higher density than air; hence they cumulate low above the ground. Ethanol and its fuel mixtures should be handled and stored taking special precautions, as in case of petrol.
Solubility in water	Bioethanol has strong hygroscopic properties. A larger quantity of water may result in the detachment of phases in a mixture of ethanol and petrol. For this reason the presence of water in all containers and equipment for handling and storing ethanol must be limited to minimum.
Calorific value	Bioethanol has a lower calorific value by approx. 30% than petrol. This means that a greater quantity of ethanol or its mixture with petrol is needed to achieve the same volume of energy as that produced by petrol alone.
Flame visibility	The flame of combusted bioethanol is less visible than the flame of petrol; however it is easily visible in daylight.
Density	Bioethanol and its mixtures with petrol have a greater density than petrol.
Electrical conductivity	Bioethanol and its mixtures demonstrate higher electrical conductivity as compared to petrol. This property is a disadvantage when using ethanol due to the possible corrosion of certain materials exposed to contact with ethanol.
Stoichiometric ratio	Bioethanol particles contain atoms of oxygen; therefore, the stoichiometric ratio of ethanol in a mixture with air is lower than the stoichiometric ration of petrol in a mixture with air.
Toxicity	Pure bioethanol is small quantities is not toxic and does not have carcinogenic potential. However, fuel ethanol and its mixtures with petrol are considered toxic and carcinogenic because they contain hydrocarbons, i.e. petrol.
Flammability	depending on the type of bioethanol mixture, vapours in the tank may reach the flammability limit. The greatest risk occurs in low ambient temperatures.

The commonly used sources of starch include rye, triticale, corn and potatoes. These contain from 20% of starch (potatoes) up to 60% (grains).

In North America the main raw material used for the production of bioethanol is corn. The remnants of corn are used as feed for breeding animals. In Europe so far bioethanol was produced mainly from edible plants such as grains, sugarcane, corn and sugar beets.

The production of bioethanol from starch is limited due to a narrow raw material assortment, which is in the first place used for human and animal nourishment. For this reason research is conducted on the use of cellulose lignin for the production of bioethanol. For example, bioethanol can be produced from corn straw, wheat straw and other farming, forestry or household waste. Bioethanol of cellulose-lignin origin is expected to be the obligatory component in the future requirements concerning fuels from renewable sources [5].

There are two basic technologies of producing ethanol from cellulose-lignin:

- biotechnological,
- chemical.

In the first technology the cellulose-lignin material undergoes hydrolysis with the use of enzymes originating from genetically modified microorganisms. The results of hydrolysis comprise 5, 6-carbon monosaccharides, which are then subjected to fermentation and distillation. In the chemical method gasification is conducted, whereby cellulose-lignin material is transformed into a gas carbon oxide and hydrogen. Thereafter, the products of gasification are used in the synthesis of biofuel by way of classical chemical catalysis or bioethanol biosynthesis, followed by distillation [6].

Edible ethanol and bioethanol used as fuel are produced in the course of similar production processes. A minimum of 2% of hydrocarbon substances (e.g. petrol) are added to bioethanol intended as fuel to make it inedible [3].

Canada-based Iogen Corporation is a producer of bioethanol using one of the most known processes of transforming cellulose and hemicellulose (Figure 1). Plant biomass is the raw material used in this process, thus the resulting ethanol is referred to as bioethanol. The aforesaid biomass is composed chiefly of straw, corn stem and grass. The production process starts with chopping and grinding the plants. The crushed material undergoes thermal processing in the presence of steam and sulphur acid solution of 0.5-2%. The reactor has a temperature of 180 - 250°C. The thermal processing phase continues from 1 to 5 minutes, followed by a sudden reduction of pressure. The materials thus prepared are combined with enzymes that are to disintegrate hemicellulose and cellulose into monosaccharides. Then, to separate sediment from the saccharide solution, the product of hydrolysis is filtered. Lignin as a by-product of filtration is used for the production of water vapour and from it – electrical energy. The solution of saccharides is inserted into the fermenting unit where in the presence of yeast saccharides are fermented into ethanol. As a result of two-phase cascade distillation process pure ethyl alcohol is achieved from an ethanol solution [7].

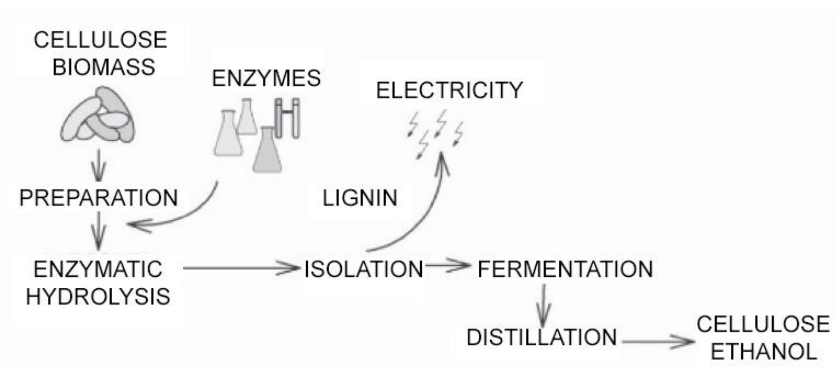

Fig. 1. Ethyl alcohol production process by Iogen Corporation [6]

BlueFire Ethanol Inc. (USA) is also a producer of bioethanol. Non-organic acids used by it hydrolyse particles of cellulose and hemicellulose to monosaccharides. For this purpose sulphur acid is often used which is then eliminated with the use of chromatographic methods. The ion exchange technology allows for separating superfluous substances generated in the hydrolysis process without the need to dilute the solution of saccharides. Small remnants of the sulphur acid in the mixture are removed in the reaction with calcium, whereby gypsum not soluble in water and easily removed is formed. The mixture of 5, 6-carbon saccharides goes through fermentation and distillation with traditional methods. The resulting product is used as a 2nd generation fuel [4].

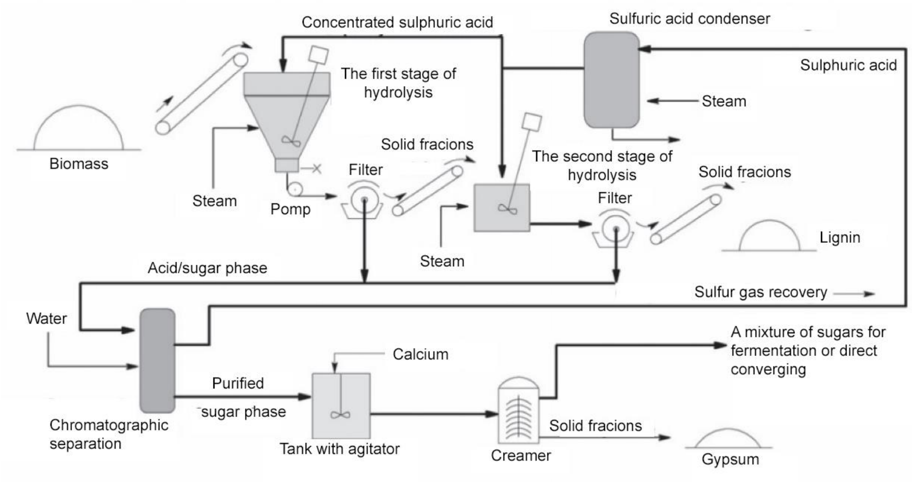

Fig. 2. Ethanol production process by BlueFire Ethanol Inc. based on sulphur acid for hydrolysis of plant biomass [6].

3. LO95 & LO95 E10 petrol and E20 & E85 ethanol fuels

To fuel spark-ignition engines bioethanol can be used as [1]:

- a petrol additive with volume content up to 5% of bioethanol, in this case the mixture is not treated as biofuel;
- a petrol additive with volume content up to 10% of bioethanol – in some West European countries (e.g. Germany, France) such mixture is not treated as biofuel and known as E10 fuel, considered standard petrol;
- a petrol additive with volume content greater than 5% (or 10%) – in this case the mixture is a biofuel. For example E20 fuel contains max. 20% of ethanol and min. 80% of petrol;
- a petrol additive with volume content of 70-85% - a biofuel known as E85 used for fuelling modified spark-ignition engines;
- bioethanol with premium additives – a biofuel known as E10.

Pure bioethanol and E85 biofuel are not fit for fuelling spark-ignition engines adapted for petrol. Therefore, changes must be made in the fuel and steering system to allow for fuelling the spark-ignition engine with those fuels. E85 biofuel is very popular – among others – in the US. For marketing purposes it must meet the requirements of ASTMD5798 of the American Society of Tests and Materials. Also, bioethanol used for fuel production must fulfil the requirements of ASTMD4806. According to these standards bioethanol content in E85 fuel should be adapted seasonally to weather conditions to improve the conditions of cold engine start-up and engine's operation after warming up. Bioethanol content may range from 51% to 83% (V/V). As in case of petrol, the volatility of E85 should also be adapted due to geographical location and the season. This is achieved by adding lightweight hydrocarbons to fuels used in low temperatures [3]. The ASTM D5798 standard does not specify particular quantities of anti-corrosion and dispersing additives in fuels with bioethanol component. The producers of bioethanol apply anti-corrosion additives in a quantity defined for bioethanol used for producing E10 fuel. Such quantity of the additive exceeds the required amount for E85 fuel [3].

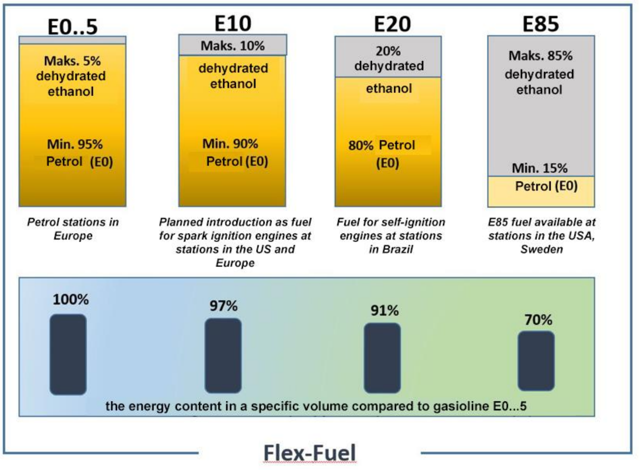

Fig. 3. Example ethanol fuels together with a comparison of energy content [8]

Bioethanol characterises with approx. 35% lower calorific value than petrol and for this reason to achieve a comparable energy level 1.5 to 1.8 times more alcohol is needed than petrol in combustion. The consumption of ethanol fuel by a particular vehicle will be greater than that of petrol. Figure 3 provides a comparison of energy contained in a tank of a given volume for fuels with different bioethanol content. Moreover, the air mass ratio in a stoichiometric mixture for bioethanol is 9 and 14.7 for petrol. Consequently, to achieve complete combustion of bioethanol a smaller volume of air is necessary than for petrol [9]. Table no. 2 presents a comparison of physical & chemical properties of E5 petrol and E20 ethanol fuel.

Differences between the fuels in question are considerable in terms of the elementary and chemical composition, knocking resistance and calorific value. With a greater octane rating and therefore higher resistance to knocking of ethanol fuel the engine’s effective power can be increased by greater compression, greater ignition timing angle and higher charging pressure. The above correlations prove that by fuelling a spark-ignition engine with bioethanol fuel the engine’s effective power can be boosted. However, to achieve it changes in the construction of the engine and the fuel system and greater fuel consumption are necessary [1].

Table 2. Comparison of the properties of E20 fuel and E5 petrol

Properties	**LO95**	**LO95 E10**	**E20**	**E85**	**Testing method according to**
1.Research octane number RON	96,2	95	98,6	97	PN-EN ISO 5164
2. Motor octane number MON	85,5	85	88,5	-	PN-EN ISO 5163
3. Lead content mg/l	< 2,5	5	< 2,5	-	PN-EN 237
4. Density at 15°C, kg/m3	749,2	733,9	758,0	782,2	PN-EN ISO 12185
5. Sulphur content mg/kg	7,5	<3	6,0	<3	PN-EN 20846
6. Induction period, minute	> 360	>480	> 360	>480	PN-ISO 7536
7. Content of resins mg/100ml:	< 1	1 (1.3)	< 1	1 (0,9)	PN-EN ISO 6246
8. Group composition according to FIA, %(V/V): - paraffin-naphthalene - olefins - aromas	48,7 10,9 31,5	- 18 35	38,9 8,8 25,1	- - -	PN-EN 15553
9. Petrol content, %(V/V)	0,89	1	0,71	-	PN-EN 238
10. Oxygen content, %(m/m)	2,5	3,84	9,1	30,29	PN-EN 1601
11. Content of oxygen compounds, %(V/V):					
-- ethanol	4,7	10,2	23,8	85,8	
-- ETBE	4,2	-	3,4	-	
13. Vapour pressure (DVPE), kPa	56,0	61,0	56,3	34,1	PN-EN 13016-1

A very important issue from the point of view of fuel systems in spark-ignition engines is distillation. Both bioethanol and E85 fuel are almost single-fraction in terms of the boiling point. The range of boiling points of bioethanol fuel is approx. 5°C and temperature values are lower than the boiling point of most hydrocarbons contained in petrol. Consequently, a spark-ignition engine fuelled with bioethanol fuel may encounter problems with start-up when it is cold and with operation in warm conditions [1].

4. Fuelling a spark-ignition engine with an ethanol-component fuel

Bioethanol – owing to its physical & chemical properties – causes problems when used for fuelling spark-ignition engines. One of its problematic properties is hygroscopy and full miscibility with water. The presence of water in the fuel system in diesel engines leads to corrosion of the elements of the system and engine made of cast-iron, copper, brass and aluminium. Such materials should be avoided or covered with protective agents. In winter water present in the fuel may freeze and as a result block the fuel system and prevent engine start-up. When the diesel engine is working, part of fuel transferred to the combustion chamber may drip into the lubricant grease. In the presence of bioethanol and the accompanying water in the motor oil substances of acidic range are produced. Non-combusted bioethanol in motor oil may react with oxygen, thus developing acetic acid. The presence of acetic acid and water in the lubricant grease creates conditions for the occurrence of corrosive processes affecting engine elements made of soft metals. One of these elements are - e.g. slide bearing sockets [9, 10, 11].

Bio-components such bioethanol often manifest degrading action towards certain construction materials used in the fuel system. Frequently exposed are sealing, fuel tanks, fuel pipes and some elements of fuel injectors and pumps. Vehicles fuelled with fuel of a bioethanol component greater than 10% (V/V) should have these elements made of materials resistant to the bioethanol effect, e.g. sealing made of fluorocarbon elastomers [9].

Fig. 4. Impact of bioethanol fuel on elastomers [9]

Pure bioethanol demonstrates very low vapour pressure; however, when mixed with petrol it brings a non-additive increment of the parameter. It is not obvious then that upon mixing two components (fuel bioethanol and engine petrol) compliant with the requirements of their specifications, the resulting product will also fulfil those requirements. Fuel with a petty bioethanol add of approx. 20% (V/V) may exceed the maximum vapour pressure (c.a. 60 kPa), thus failing to meet the specification. This is particularly important in summer when such situation may lead to vapour locks in the fuel system, bringing the engine to a stop. On the other hand, with high bioethanol content in E85 fuel it is possible that the fuel may not achieve minimum vapour pressure. This in turn could obstruct the start-up of a cold engine [12].

The enthalpy of vaporisation for bioethanol is twice higher than for petrol (table 2). For this reason the air flow in which fuel is de-vaporised is cooled to a greater extent. While low temperature in the inlet system and the combustion chamber before the stroke improves the efficiency of cylinder filling, it makes de-vaporisation of heavier petrol fractions that settle on the combustion chamber walls more difficult. Higher heat of bioethanol de-vaporisation combined with its greater quantity in a cycle cause that the engine head is exposed to greater changes of temperature in subsequent engine strokes [10].

In low temperatures fuel with high bioethanol content may prevent proper engine operation due to a considerable difference in volatility of bioethanol and engine petrol [11].

During fermentation of bioethanol sulphates are produced. While these compounds dissolve in bioethanol, there is likelihood that they may dissipate when mixing bioethanol with engine petrol. Undissolved sulphates in fuel lead to fuel filter and injectors blocking and may cause the development of sediments on inlet valves and combustion chambers [9].

Unburned bioethanol which moved to the motor oil does not mix completely with it. Such situation increases the risk of faster wear of the engine's elements. Particularly exposed are elements that require High Temperature High Shear Rate viscosity. Because of its solubility characteristics, bioethanol can remove particles of grease from the metal's surface, thus reducing the thickness of oil film between the contacting surfaces. In engines with direct fuel injection the oil film may be washed out by unburned ethanol from cylinder sleeves. The lack of oil film on the sleeves results in a more intensive process of their abrasive wear [13].

5. Conclusions

- Ethyl alcohol is produced from plants containing saccharides. Because of environmental protection, biomass and biodegradable part of waste are the most suitable raw materials for its production.
- The production of bioethanol is a complicated and multi-phase process.
- Pure bioethanol is not fit for fuelling conventional spark-ignition engines.
- In Europe bioethanol is added to engine petrol in a quantity of no more than 10% (V/V). Such quantity of bioethanol in petrol does not change considerably the latter's properties.
- Mixtures of petrol with more than 10% (V/V) of bioethanol are known as bioethanol fuels.
- There are spark-ignition engines (Flex-Fuel) specially adapted to ethanol fuelling.

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Abstract

This article presents the general characteristics of bioethanol and method how it is obtained. Two exemplary bioethanol production processes used in industry were discussed. Next, a comparison was made between the physico-chemical properties of bioethanol and motor gasoline, which were important for supplying the spark ignition engines. The second part of the article discusses the ways of using bioethanol to supply the spark ignition engine and describes selected mixtures of bioethanol and gasoline. The final part of the article lists the basic advantages and problems in the use of bioethanol to supply the spark ignition engine.

Keywords: bioethanol, spark ignition engine, Flex-fuel, E85

BIOETANOL JAKO KOMPONENT PALIW DO SILNIKÓW O ZAPŁONIE ISKROWYM

Streszczenie

W tym artykule przedstawiono ogólną charakterystykę bioetanolu oraz sposób jego otrzymywania. Omówiono dwa przykładowe procesy produkcyjne bioetanolu stosowane w przemyśle. Następnie dokonano porównania właściwości fizyko-chemicznych bioetanolu oraz benzyny silnikowej istotnych ze względu na zasilanie silnika z ZI. W drugiej części artykułu omówiono sposoby zastosowania bioetanolu do zasilania silnika z ZI oraz scharakteryzowano wybrane mieszaniny bioetanolu z benzyną. W końcowej części artykułu wymieniono podstawowe zalety i problemy w zastosowaniu bioetanolu do zasilania silnika z ZI.

Słowa kluczowe: bioetanol, silnik z zapłonem iskrowym, Flex-fuel, E85