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ASPECTS OF USING BIOLOGICALLY REGENERATIVE FUELS IN INTERNAL COMBUSTION ENGINES

SUMMARY

The work describes some biologically regenerative fuels and comments on the possibility of their application. Regarding the European conditions, the most acceptable biologically regenerative fuel has proven to be the one based on rape. The characteristics significant for the combustion have been compared to the conventional (fossil) fuels. Also, the impact of biologically regenerative fuels on the emission of harmful exhaust gases has been described, and a favourable influence on the emission of carbon dioxide (CO_2) and other harmful exhaust gases has been determined.

1. INTRODUCTION

Numerous ecological problems (ozone holes, warming of the Earth's atmosphere, acid rain, etc.) are considered to be the main villain for the majority of changes in climate, and recently they are also claimed to be the cause of the growing number of natural disasters.

In order to save the environment as much as possible, it is necessary to undertake at once drastic measures which are mostly known but nobody is willing to follow them completely. The basic problem in undertaking measures for environmental protection is their high, i.e. very high price. Moreover, the ecologically adverse effects are often caused by the waste of energy, "dirty technology" or by processes which are considered as simplification of human work or luxury (which is something that few would like to live without).

Today, carbon dioxide is considered to be the main cause of global warming of the Earth atmosphere (see Fig. 1 and Fig. 2). This is usually called the "greenhouse effect".

This is precisely the reason for the conclusion accepted at the 1995 United Nations Conference on Climate held in Berlin that comprehensive measures re-

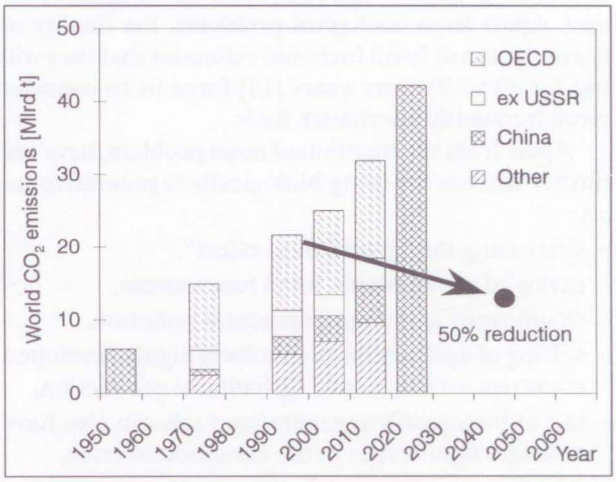

Figure 1 - Development of worldwide CO_2 emissions

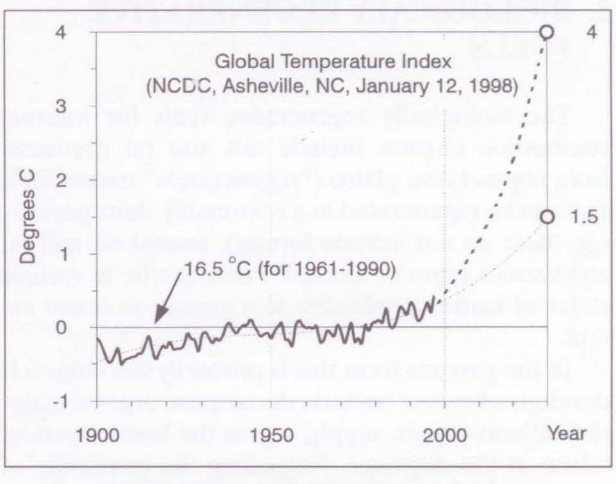

Figure 2 - Global temperature growth

garding drastic reduction of carbon dioxide (CO_2) emissions need to be implemented with the aim of reducing the world production of carbon dioxide by 50%, thus reducing it to the level recorded in 1987.

Carbon dioxide is generated in various ways, and one of them is the fuel combustion in internal combustion engines. Since it would be hard to imagine the today's world without these engines, the problem of reducing the generation of carbon dioxide (CO_2) refers to a great extent to the engine manufacturers and their users.

Various studies [1, 2] contain estimates that the internal combustion engines produce about 15 to 20% of the total world emission of carbon dioxide (CO_2).

Apart from carbon dioxide (CO_2), the emission of harmful exhaust gases poses also a significant problem, which is for the moment mainly solved by increasingly strict legislative regulations limiting these emissions.

One of the possible measures for damping the ecological problems is the use of fuels that present a lesser burden to the environment. This means, first of all, a better CO_2 balance, and reduced exhaust gases emission. Apart from ecological problems, the finality of the resources of fossil fuels and estimates that they will last for 40 to 50 more years [14] force us to consider more frequently alternative fuels.

Apart from the mentioned main problem, here are further reasons for using biologically regenerative fuels:

- decreasing the "greenhouse effect",
- saving of unrenewable fossil fuel sources,
- significantly lower environmental pollution,
- solving of agricultural problems in highly developed countries with excessive agricultural production,
- use of biologically regenerative fuels can also have strategic significance in the condition of crisis.

2. BIOLOGICALY REGENERATIVE FUELS

The biologically regenerative fuels for internal combustion engines include oils and fat produced from regenerative plants ("regenerative" means fuels that can be regenerated in a reasonably short period - e.g. these do not include forests), animal oil and fat and various types of alcohol. Fuels can be in various states of matter, applicable to a greater or lesser extent.

In the gaseous form this is primarily the biogas. It develops wherever bacteria decompose organic material without oxygen supply, e.g. in the lower layers of refuse at the disposals. Regarding the possibility of generation and exploitation, biogas is relatively seldom used as propulsive fuel, and it is usually used for heating.

As liquids, these are primarily alcohols and vegetable oil fuels.

Alcohols are mainly used to run Otto engines and have reached the peak of their exploitation in Brasil where sugar-cane is used for their production. For the production of alcohol as vegetable oil in Europe only sugar-beet could be exploited, which is very inconvenient from the energy point of view, since the ratio of energy required for the production of alcohol and the energy content of the obtained fuel is 1.2:1 [3]. When producing alcohol from sugar-cane this ratio is approximately 1:1.

Further possibility is the production of methanol through hydrolysis of raw and residual materials containing cellulose. Considering the price and the well known purpose of raw materials containing cellulose, only waste of the wood processing industry can be regarded as potential raw materials for such production.

Vegetable oil fuels are produced from seeds or from the fruits of the plants. The best plants for obtaining oil are those whose fruits contain most oil i.e. fat, and these include peanuts, rape[1], flaxseed, sunflower seeds, soy beans, palm trees, coconut palms. With today's production technology of vegetables and their fuels, vegetable oil fuels have the best ratio of the invested energy starting from their growing and the energetic value of the obtained fuel which is about 1:2.3 [3].

Regarding climatic conditions in Europe, the energy balance and the balance of carbon dioxide in the production of fuels from vegetable fruits is significantly in favour of the vegetable oil fuels than in other types of fuels. Therefore, the best applicable fuel is the rape-seed oil fuel and it will be considered later in more detail.

Apart from vegetable oils, waste fat composed of old, i.e. used frying fat and oils can be exploited. In that case a treatment by dehydration and cleaning is necessary. Animal fats from meat processing can be used in a similar manner.

3. THE USE OF VEGETABLE OIL FUELS

Considering the characteristics of vegetable fuels, two approaches are possible: either adapt the engine to the fuel or adapt the fuel to the engine. Since there is a large number of the already existing engines, attempts are mainly made to adapt fuels to the engine, thus exploiting the already existing engines . This, of course, increases the price of fuels as well.

Solving the problem by making modifications on the engine has up to now usually ended in the research or prototype engines which managed to prove that such engines can operate very well on raw oils, where a 10 - 20% increase in the fuel consumption does not cause the increase of harmful exhaust gases.

The first attempts to use vegetable oil fuels have started at the beginning of the eighties of 20th century, and raw oils of more or less all the plants have been used as fuels. Out of all of these vegetable oils, the rape-seed oil has proven the most suitable.

There are five possibilities for using rape-seed oil and rape-seed oil based products as Diesel engine fuels:

- use of pure (raw) rape-seed oil,
- adding of pure (raw) rape-seed oil to the standard Diesel fuel,
- adding raw rape-seed oil to the raw oil in oil refineries,
- transesterification of the rape-seed oil,
- adding the transesterified rape-seed oil to the standard Diesel fuel.

The attempts made up to now to use raw rape-seed oil as fuel for Diesel engines in farming machinery and passenger cars have proven that unburned fuel parts deposit faster on the walls of the piston and the cylinder, on the piston-rings and injectors themselves. The coking of the deposit occurs and causes deterioration of the engine performance, disturbances of engine operation, and constant worsening of the exhaust gases emissions. In order to insure proper operation, the intervals between two scheduled overhauls need to be substantially shortened, and the susceptible parts need to be cleaned, which increases the engine maintenance requirements. It was found that due to poor fuel atomisation, the rape-seed oil comes into contact with the lubrication oil, thus diluting it, which more or less always ended up with heavy engine failures. When using pure rape-seed oil as fuel, the cold start is difficult already at a temperature of 20 °C, and at a temperature of 0 °C the cold start is impossible, whereas at temperatures of -10°C the rape-seed oil becomes a viscous substance similar to margarine which renders it completely unusable as fuel [4]. The control of deposited impurities in the fuel tanks has shown that fungi grow which later spread over the whole fuel feeding system. Porsche has done researches and found out that rape-seed oil can be used only in slow running direct injection Diesel engines of high operating volume.

There have also been attempts to add 10 to 30% of pure (raw) rape-seed oil to the standard Diesel fuel. By adding rape-seed oil no major changes have been measured in the emission of unburned hydrocarbons and particulates in relation to the Diesel fuel emission. The emission of carbon monoxide (CO) increased with the proportion of the added rape-seed oil, and the emission of nitrogen oxide (NO_X) was slightly lower and in this case faster coking was observed. It was concluded that already a 10% proportion of rape-seed oil in fuel results in faster depositing of impurities at the fuel filter so that it needs to be replaced more frequently. Also, the formation of fungi was observed in the fuel supply system.

The next possible method of using rape-seed oil as fuel is to add it to the crude oil in refineries during the production of Diesel fuel. By adding rape-seed oil to crude oil in the proportion of 30%, a reduction of emission of carbon monoxide and hydrocarbons was recorded, whereas the emission of nitrogen oxides was slightly increased. A significant disadvantage of such fuel is the reduced ability for cold start depending on the proportion of rape-seed oil. In order to allow starting the engine in winter conditions, rape-seed oil has to be added in limited amounts of only several percent.

By transesterification of rape-seed oil the viscosity is reduced, thus significantly improving the possibility for cold start. Also, due to the changes in features essential for combustion, the coking is reduced. On the other hand, it should be considered that the transesterified rape-seed oil dissolves certain types of elastomers and varnish.

Adding transesterified rape-seed oil to the standard Diesel fuel is another possibility. The transesterified rape-seed oil and Diesel fuel can be mixed in all ratios without any harmful effects to the properties of the resulting fuel. This type is not used very often, due to inconvenient regulations on taxes for mineral fuels, especially in the West-European countries.

4. PRODUCTION OF RAPE-SEED OIL METHYL ESTER

Upon picking and cleaning the rape fruits, rape oil is produced. At today's level of agricultural development, one hectare of cultivated land yields about 3 tonnes of rape fruits. With the average of 40 to 42% fat content in the rape, 1.2 – 1.3 tonnes of oil per hectare are obtained.

By pressing the rape fruits and by refining the obtained liquid, raw rape oil is obtained. The main content of this oil are the triglycerides of various chain lengths. The highest proportion in the fatty acids in the raw rape oil belongs to oleic acid (about 60%), linoleic acid (about 20%) and linolenic acid (about 8%). Then follows the process of refining by which the majority of impurities from the raw oil are eliminated. The refining means removing the residual slime, deacidification, bleaching and deodorisation, thus obtaining the "refined rape-seed oil" at the quality level of edible oil products.

Long chains with double links in rape oil unsaturated fatty acids have low thermal stability[2] resulting in the increased emission of unburned hydrocarbons and coking on the engine components [6]. In operation both of these effects are adverse and need to be avoided as much as possible. This is achieved by transesterification (alcoholysis) of the rape-seed oil. The transesterification reduces substantially the viscosity and brings it almost to the level of Diesel fuel. It has thus become an indispensable part in the production procedure.

In transesterification methyl alcohol[3] is added to the refined rape-seed oil (it is therefore called methyl ester). In order to speed up the transesterification process, the so-called basic catalysts are added. Upon reaction, the resulting glycerine is removed and then the catalyst. The rest of the methanol is eliminated by distillation.

The last step in producing rape-seed oil methyl ester (RME) is the final purification of the fuel and vacuum drying of the fuel eliminating the possible residual water in the fuel.

The fuel obtained in this manner may be further subjected to the process of enhancing the fuel properties for operation in winter conditions.

5. RME VS DIESEL

Ecological advantages of rape-seed oil methyl ester (RME) in relation to the standard Diesel fuel, result primarily from the better balance of carbon dioxide. The basis for producing RME is the fruit of a plant, and it is well known that plants use a certain amount of carbon dioxide for their growth. In growing the plants, various farming machines are used that produce carbon dioxide. During the production process, and in the combustion of RME, carbon dioxide is also generated. A similar situation is also with the Diesel fuel since its production and combustion generate carbon dioxide as well. However, the difference lies in that further cultivation of rape uses up a part of carbon dioxide from the atmosphere, that was produced by the combustion of RME, whereas the Diesel fuel produced carbon dioxide only accumulates in the atmosphere. By growing rape, processing it into fuel, by combustion of this fuel and by growing rape again, an almost closed and ecologically friendly chain of generation and consumption of carbon dioxide is formed.

In considering the balance of carbon dioxide an obvious advantage of methyl ester as engine fuel can be noted. Even very precise estimation shows that the production and use of methyl ester reduces the carbon dioxide emissions to the level of only 40 – 50% of emissions resulting from the production and combustion of Diesel fuels from oil [4, 6]. If only combustion is considered, the situation is even better: methyl ester as fuel produces only 20 to 25% of carbon dioxide in relation to the fuel obtained from oil [4]. Some even claim that the total amount of carbon dioxide caused by production and combustion of rape-seed oil methyl ester is re-absorbed from the atmosphere by plants [3, 7]. However, this is possible only with the use of rape oil and not rape-seed oil methyl ester.

In relation to the conventional fuel, rape-seed oil methyl ester can be quickly and completely biologically degradable. Complete biodegradability makes it extremely suitable for application in ecologically sensitive areas such as e.g. national parks or water supply areas.

Rape oil and rape-seed oil methyl or ethyl ester have a very low sulphur content (maximally up to 0.02% mass). Thus the amount of sulphur dioxide produced by its combustion is negligible, which reduces the formation of acid rains [4].

It is well known that the reserves of fossil fuels are huge, but still limited. Unlike fossil fuels, the source for the production of rape-seed oil methyl ester is renewable, i.e. sufficient rape needs to be planted and processed into fuel for further production of rape-seed oil methyl ester.

Speaking about production, it should be noted that the production of RME is quite simple, so that it is even possible on farms, proved already by several examples in Austria and Germany.

The use of RME has also a positive effect on the reduction of the agricultural excess output (in Western Europe), which was discussed in the first section.

Apart from the mentioned advantages, the application of RME also shows certain drawbacks.

Regarding present and future requirements RME cannot be the only alternative fuel. According to the estimates of experts, RME is considered to be able to meet 20-30% of the overall requirements under optimal conditions.

Due to heavier fertilisation of the agricultural land where rape is grown, nitrogen suboxide is generated and it evaporates, thus resulting in acid rain.

Considering the very well developed and established production system of mineral fertilisers, RME is for the moment a much more expensive fuel.

Also, the lubrication oil becomes diluted during operation, so that it needs to be changed more often and additives are needed to enhance the properties.

The aggressiveness of RME towards elastomers usually used for the production of ducts and seals in the fuel feeding system, require the use of better quality materials that are resistant to RME (mainly fluoridated caoutchouc).

The glycerine obtained as a by-product of the RME production process is regarded by some as a disadvantage, but it can be used in the chemical industry and cosmetics.

5.1 Characteristics of Rape-seed Oil Methyl Ester

Table 1 presents the most important combustion characteristics of the conventional Diesel fuel and of rape-seed oil methyl ester

In RME operation, the specific fuel consumption (G/kWh) increases by approximately 14% due to the 14% reduced calorific value.

Table 1 - Fuel Characteristics

Characteristics	Unit	Diesel	RME
C	% mass	86.5	76.5
H	% mass	13	12.3
O	% mass	0	11.0
S	% mass	0.05	0.002
N	% mass	0.015	0.1
Ashes	% mass	0.01	0.02
Stechiometric volume of air	kg air/kg fuel	14.4	12.8
Density (15 °C)	kg/m^3	835	878
Calorific value	MJ/kg	42.50	37.10
Volumetric calorific value	kJ/m^3	3536	3265
Calorific value of the mix (0°C, 1 bar)	kJ/m^3	3813	3775
Beginning of evaporation	°C	~ 180	~ 320
End of evaporation	°C	~ 350	~ 360
Cetane number		50	~ 48
Kinematic viscosity 20 °C	mm^2/s	6.65	7.07
40 °C	mm^2/s	2.31	4.35
100 °C	mm^2/s	0.8	1.78
CFPP	°C	+5 ÷ -24	-12
Flash point (depends on the methanol content)	°C	70 ÷ 90	110 ÷ 140

5.2 Exhaust Emission

The diagram in Figure 3 presents the relative emissions in operation using Diesel fuel and rape-seed oil methyl ester with and without a catalyst [15].

Due to 11% oxygen content when RME is used, the emission of carbon monoxide is reduced by approximately 80%.

The reduction in the emission of hydrocarbons in RME-operated engines by 7 - 8% should not be considered a significant advantage, since the incompletely burned compounds of hydrocarbon are deposited on the particulates. This reduces the emission of hydrocarbons, and increases the emission of particulates. By the use of oxidation catalyst the emission of hydrocarbons is reduced by 60 to 65%.

In RME-fed engine the emission of nitrogen oxides increases by about 17%. By analysing the nitrogen oxide concentrations regarding operating points, a significant increase of the concentration of nitrogen oxide in the exhaust gases at higher and full engine loads was determined.

In RME operated engines, the emission of particulates increases by 65%, since RME shows greater evaporation at higher temperatures. By using the oxidation catalytic device in Diesel fuels, the emission is reduced by almost 50%, and in RME + catalyst the emission of particulates is reduced by about 70% due to the high proportion of (deposited) hydrocarbons contained by particulates.

In spite of the significantly higher emission of particulates in RME-fed engines, there is about 55% less soot in the exhaust gases.

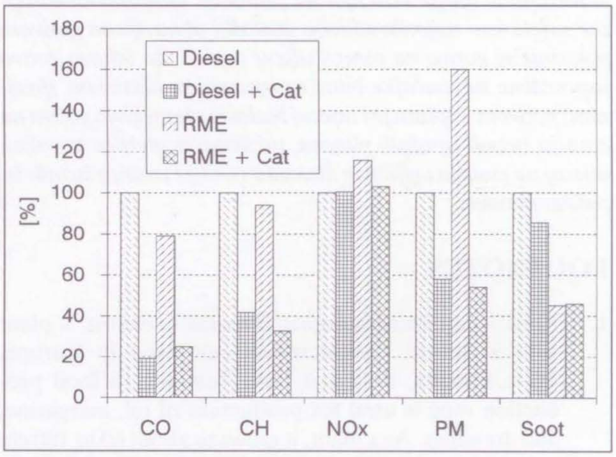

Figure 3 - Relative exhaust emission of Diesel, Diesel+Catalyst, RME, RME+Catalyst

6. CONCLUSION

For the purpose of producing biologically regenerative fuels, growing of rape is preferred in Europe. Because of certain problems in using raw rape oil as fuel, rape-seed oil methyl ester should be used. This choice has been confirmed by a relatively big number of mutually independent research done with RME operated Diesel engines, which showed a favourable influence on the exhaust gases emission.

The measurements have shown that at 14% higher specific fuel consumption with RME-operated engines compared to Diesel fuel, the emission of carbon monoxide and hydrocarbons is reduced and there is significantly less soot in the exhaust gases. Contrary to these advantages, a higher emission of nitrogen oxides and particulates has been noted. The problem of higher emissions can be reduced by using the oxidation catalyst resulting in a smaller particulates emission than in Diesel fuels.

Based on the long-term research and known results, the rape-seed oil methyl ester can already be found in everyday application in several places, and it can also be found under the commercial name Bio-Diesel.

Although RME cannot cover all the needs for fuel, its more favourable CO_2 balance, reduced exhaust gases emissions, and complete and fast biological degradability, are reasons why it should be used in the ecologically sensitive areas, and depending on the production possibilities, its use should be recommended in all the other circumstances as well.

SAŽETAK

ASPEKTI UPORABE BIOLOŠKI OBNOVLJIVIH GORIVA ZA MOTORE S UNUTRAŠNJIM IZGARANJEM

U radu su opisana pojedina biološki obnovljiva goriva te je komentirana mogućnost njihove primjene. Obzirom na europske uvjete kao najprihvatljivije, biološki obnovljivim gorivom pokazuje se gorivo na osnovi uljane repice. Za takovo gorivo uspoređene su značajke bitne za izgaranje s klasičnim (fosilnim) gorivom. Opisan je i utjecaj biološki obnovljivih goriva na emisiju štetnih ispušnih plinova, pri čemu je utvrđen povoljan utjecaj na emisiju ugljičnog dioksida (CO_2) i emisiju štetnih ispušnih plinova.

FOOTNOTES

1. Rape – *lat. Brassica napus, Brassica camestris,* a plant with a flower. Commercially cultivated in Europe, USA, Canada, Asia and New Zealand. In food production rape is used for production of oil, margarine, and dressings. As a plant, it grows to about 60 to 180 cm height, it has a yellow flower, about 1.5 cm in size. Depending on the type, it is a one or two-year plant.11.
2. resistance to compound decomposition related to temperature increase
3. methyl alcohol, methanol, CH_3OH, also ethyl alcohol CH_3CH_2OH can be used

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