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Use of Soybean Oil in Energy Generation

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1. Introduction

This chapter deals with the possibility of using soybean oil in energy generation. The environmental, energetic and social-economic aspects are discussed. The steps for obtaining biodiesel from soybean oil are presented as well as the characterization of soybean oil and soybean biodiesel. Results for performance and emissions of using soybean oil and soybean biodiesel in a stationary engine are also presented.

Vegetable oils are obtained predominantly from grains of different plant species. The oil extraction can be made by physical process (pressing) or chemical (solvent). The solvent extraction produces better results, but the more traditional way is physical extraction, which uses mechanical and hydraulic presses to crush the grains. A mixed extraction (mechanical/solvent) can also be done. Selecting the type of extraction depends on two factors: the productive capacity and oil content.

Soybean (*Glycine max* (L.) Merrill) is a very versatile grain that gives rise to products widely used by agro-chemical industry and food industry. Besides is a raw material for extraction of oil for biofuel production. Soybean has about 25% of oil content in grain.

In the agribusiness world, soybean production is, among the economic activities in recent decades, the most prominent. This can be attributed to several factors, such as structuring of a large international market related to trade in products of soybean, oilseed consolidation as an important source of vegetable protein and increased development and delivery of technologies that made possible the expansion of soy exploration for various regions of the world. The largest producers of soybeans are: United States, Brazil, Argentina, China and India.

One possible use of vegetable oil is in the power generation engines. The vegetable oil can be used directly in diesel engines, preferably mixed with diesel. It may also undergo a chemical reaction (transesterification), yielding biodiesel and glycerol. In literature, several works are related to the use of vegetable oil and biodiesel for power generation, as evidenced below.

A review of the use of vegetable oils as fuel in compression ignition (CI) engines is presented (Hossain & Davies, 2010). The review shows that a number of plant oils can be used satisfactorily in CI engines, without transesterification, by preheating the oil and/or modifying the engine parameters. As regards life-cycle energy and greenhouse gas emission analyses, these reveal considerable advantages of raw plant oils over fossil diesel and biodiesel.

It is pointed out (Grau et al., 2010) that straight vegetable oil can be used directly in diesel engines with minor modifications. It is proposed a small-scale production system for self-supply in agricultural machinery.

It is emphasized (Misra & Murthy, 2010) that the ever increasing fossil fuel usage and cost, environmental concern has forced the world to look for alternatives. Straight vegetable oils in compression ignition engine are a ready solution available, however, with certain limitations and with some advantages.

It is presented (Sidibé et al., 2010) a literature review on the use of crude filtered vegetable oil as a fuel in diesel engines. It is emphasized the potential and merits of this renewable fuel. Typically, straight vegetable oils produced locally on a small scale, have proven to be easy to produce with very little environmental impact. However, as their physico-chemical characteristics differ from those of diesel oil, their use in diesel engines can lead to a certain number of technical problems over time.

A review on the utilization of used cooking oil biodiesel is presented (Enweremadu & Rutto, 2010). There were no noticeable differences between used cooking oil biodiesel and fresh oil biodiesel as their engine performances, combustion and emissions characteristics bear a close resemblance.

A review on biodiesel production, combustion, emissions and performance is shown (Basha et al., 2009). A vast majority of the scientists reported that short-term engine tests using vegetable oils as fuels were very promising, but the long-term test results showed higher carbon built up, and lubricating oil contamination, resulting in engine failure. It was reported that the combustion characteristics of biodiesel are similar as diesel. The engine power output was found to be equivalent to that of diesel fuel.

An overview of political, economic and environmental impacts of biofuels is presented (Demirbas, 2009a). Biofuels provide the prospect of new economic opportunities for people in rural areas in oil importer and developing countries. Renewable energy sources that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Biofuels are expected to reduce dependence on imported petroleum with associated political and economic vulnerability, reduce greenhouse gas emissions and other pollutants, and revitalize the economy by increasing demand and prices for agricultural products.

It is emphasized (Sharma & Singh, 2009) that Biodiesel, a renewable source of energy seems to be an ideal solution for global energy demands.

The soy, which cultivation is widespread in the world, can be used to produce vegetable oil in order to be used as fuel, according some following examples.

It is pointed out (Liu et al., 2008) that Soybean (*Glycine max* (L.) Merrill), one of the most important crops in China, has been known to man for over 5000 years. The largest production areas in China are in the Northeast China's three provinces, where soybean is spring seeded and grown as a full-season crop.

A study about large-scale bioenergy production from soybeans in Argentina is presented (van Dam et al., 2009), showing the potential and economic feasibility for national and international markets.

Inedible vegetable oils and their derivatives can, also, be used as alternative diesel fuels in compression ignition engines (No, 2011).

The advantages of using vegetable oil as fuel are evidenced in the literature (Alonso et al. 2008; Misra & Murthy, 2010) as described below.

One of the main advantages of vegetable oils is its life cycle, as it is a closed cycle. Crops take CO_2 via photosynthesis from the atmosphere. Oil is extracted from these crops which can be used directly as fuel or, after the pertinent transformations, a fuel can be obtained which, when burned, generates CO_2 that can be absorbed by the plants.

Environmental advantages of vegetable oils are: minor influence on the greenhouse effect when used instead of fossil fuels; biodegradability; lower sulfur and aromatic content; at lower percentages of vegetable oil blends with diesel have shown better results than the fossil diesel in terms of engine performance and exhaust emissions.

Energetic advantages of vegetable oils are: renewable energy source; reduction of the dependence on fossil fuels; positive energy balance; the fuel production technology is simple and proven; heating values of various vegetable oils are nearly 90% to those of diesel fuel; higher flash point allows it to be stored at high temperatures without any fire hazard; additional oxygen molecule in its chemical structure helps in combustion process.

Social-economic advantages of vegetable oils are: use of marginal land for energy purposes; maintains employment and income levels in rural areas; avoids population migrations; encourages job creation in various agro-industries; contributes to the creation of new jobs; straight vegetable oils are available normally in rural area where its usage is advantageous especially in smaller engines in agricultural sector; improve the living conditions of the rural people and offer greater income opportunities through enhanced rural employment; plant leafs and cake can be used as organic manure which can be source of additional income farmers; selected crops can be grown on arid and semi-arid lands which are presently not cultivable; having carbon credit value (Kyoto protocol).

The main disadvantages of vegetable oils, compared to diesel fuel, are higher viscosity, lower volatility, and the reactivity of unsaturated hydrocarbon chains. The problems meet in long term engine use (Misra & Murthy, 2010). The land required for commercial production is vast.

Many countries have potential to produce biodiesel from vegetable oil. The top 10 countries in terms of absolute potential are: Malaysia, Indonesia, Argentina, USA, Brazil, Netherlands, Germany, Philippines, Belgium and Span (Sharma & Singh, 2009).

Some reasons for sufficiently strengthen the program for the use of biofuels are: the variation in prices for oil, which in recent years has fluctuated between $ 40 and 150 per barrel, the political and social pressure in order to reduce the emission of gases that cause global warming, the development of the market for carbon credits, the need to strengthen the agriculture industry and the possibility of strengthening the energy matrix, reducing dependence on foreign energy sources and giving relief to the trade balance with clear effects on the macroeconomics of the country.

The possibility to produce hydrocarbons from different raw material to replace the diesel makes the definition of biodiesel a complex and legal nature. Many documents of an academic nature define biodiesel as a monoalkyl ester of vegetable oil or animal fat, but official documents and international standards are more specific, defining the process by which one can obtain the ester and the characteristics that it must have to be considered biodiesel.

The regulations for biodiesel have been developed in different countries where its use is permitted. In the U.S. the standard for biodiesel is set by the technical standard ASTM D 6751, the European Union is related with the standard EN 14214 and in Brazil is set in the ANP (National Petroleum Agency) No. 07 from 19.03.2008.

Biodiesel can be produced from different oilseeds, according to the design of the plant, market conditions and availability of raw material in the region. Each oilseed production has a different culture method and a different destination. The disposal of oils for biodiesel production must take into account beyond the capacity of oil production, market competitiveness in relation to the cost of oil and the price of a barrel of fuel. Biodiesel can be obtained, too, from used cooking oil, animal fats and algae.

Just as vegetable oil, the use of biodiesel as fuel in partial or total replacement to diesel has many advantages that have been highlighted in the literature (Demirbas, 2009b; Pereira et al., 2007).

Environmental advantages of biodiesel are: greenhouse gas reductions; biodegradability; higher combustion efficiency; improved land and water use; carbon sequestration; lower sulfur content; lower aromatic content; less toxicity.

Energetic advantages of biodiesel are: supply reliability; higher flash point; reducing use of fossil fuels; ready availability; renewability.

Social-economic advantages of biodiesel are: sustainability; fuel diversity; increased number of rural manufacturing jobs; increased income taxes; increased investments in plant and equipment; agricultural development; international competitiveness; reducing the dependency on imported petroleum.

2. Theoretical foundations

All vegetable oils consist primarily of triglycerides. The triglycerides have a three-carbon backbone with a long hydrocarbon chain attached to each of the carbons. These chains are attached through an oxygen atom and a carbonyl carbon, which is a carbon atom that is double-bonded to second oxygen. The differences between oils from different sources relate to the length of the fatty acid chains attached to the backbone and the number of carbon–carbon double bonds on the chain. Most fatty acid chains from plant based oils are 18 carbons long with between zero and three double bonds. Fatty acid chains without double bonds are said to be saturated and those with double bonds are unsaturated (Misra & Murthy, 2010).

In general, vegetable oils are made especially of fatty acids with chains between 12 and 24 carbons: Lauric (C12:0); Myristic (C14:0); Palmitic (C16:0); Palmitoleic (C16:1); Stearic (C18:0); Oleic (C18:1); Linoleic (C18:2); Linolenic (C18:3); Arachidic (C20:0); Gadoleic (C20:1); Behenic (C22:0); Erucic (C22:1); Lignoceric (C24:0). The proportions of the fatty acid composition can be determined by gas chromatography method.

Triglycerides are hydrocarbons with physical and chemical characteristics that can be classified as liquid fuels in the majority.

Vegetable oils have a high heating value, near the heating value of conventional diesel fuel, which makes them an important energy resource.

To improve the properties of vegetable oils and in order to use them as substitutes for diesel fuel, triglycerides are converted into esters (biodiesel) by transesterification process, modifying the composition of molecules and changing the characteristics of the fluids. The composition of the resulting esters has approximately the same proportion of fatty acids present in oils before the transformation process.

Biodiesel is known as monoalkyl, such as methyl and ethyl, esters of fatty acids. Biodiesel can be produced from a number of sources, including recycled waste vegetable oil, oil crops and algae oil. Biodiesels play an important role in meeting future fuel requirements in view of their nature (less toxic), and have an edge over conventional diesel as they are obtained from renewable sources (Demirbas, 2009b).

The transesterification process is used to transform triglycerides into esters, or biodiesel. In the process of transesterification, the triglycerides found in different kinds of oils and fats react with alcohol, usually methanol or ethanol to produce esters and glycerin. For the reaction to occur it is necessary to use a catalyst. Processes performed the supercritical conditions of methanol transesterification can be conducted without the catalyst. (Demirbas, 2003; Saka & Kusdiana, 2001)

In the transesterification process, a triglyceride molecule reacts with an alcohol molecule causing the separation of one of the fatty acids of the triglyceride, producing a diglyceride and an ester. This diglyceride reacts with a second molecule of alcohol that takes another fatty acid, forming a second ester and a monoglyceride. Finally a third molecule of alcohol reacts with the monoglyceride, forming the third ester and a molecule of glycerin. The reactions occurring are reversible, and the stoichiometric ratio is three moles of alcohol for each mole of oil being processed. The reaction can be carried out with concentrations of alcohol in excess, as this reduces time and increases the conversion efficiency of the process. (Lang et al., 2001)

The transesterification process using methanol and base catalyst is the most commonly used to produce biodiesel. The catalysts commonly used are sodium hydroxide (NaOH) or potassium hydroxide (KOH). The catalyst is diluted in alcohol and then added the oil. The product is the ester (biodiesel) and crude glycerin. The glycerin is separated from the ester by decanting or centrifuging.

Repeated washing processes are performed by adding acidified water in the reaction products. This mixture is stirred lightly and serves to remove residual glycerine soap, catalyst and serves as a neutralizing agent of the fuel. The washing process is repeated until the biodiesel becomes clear. The main drawbacks of the process are the presence of water on some of the reagents and the high level of free fatty acids in the raw material. In both cases, the transesterification reaction is replaced by a saponification reaction.

The transesterification process can also be developed using acid catalysts and no homogeneous catalysts. In the case of acid catalysts, the process times are longer, but do not have drawbacks with the water content and free fatty acids. In the case of no homogeneous catalysts, these bring benefits in: reducing the washing process; product separation and reuse of catalysts.

Methanol and ethanol are produced on an industrial scale and their use in transesterification reactions has been reported.

The biodiesel used in several countries of Europe and in the United States is a mixture of methyl esters. Methanol is usually obtained from non-renewable fossil fuels, but can also be obtained by distillation of wood; this route, however, produces smaller quantities. The technology of biodiesel production using methanol is fully understood, however, this route has the disadvantage that methanol is extremely toxic.

The transesterification using ethanol is more difficult because the use of alcohol, even if anhydrous, involves problems in the separation of glycerin from the reaction medium. However, the use of ethanol is advantageous, since it is produced on a large scale in

countries like Brazil and the United States, being from a renewable source of energy, resulting in environmental gains could generate carbon credits. As for the difficulties in the separation of phases in reactions employing ethanol in biodiesel synthesis, they can be bypassed by adjustments in reaction conditions.

3. Soybean oil and soybean biodiesel obtaining and characterization procedures

The fuel blends used were prepared at the Thermo-sciences Laboratory of Mechanical Engineering Department at Fluminense Federal University (UFF).

It was used Oxx as the nomenclature to designate mixtures of soybean oil with diesel, being xx the percentage by volume of vegetable oil added to diesel. The following mixtures were used: O5; O10; O15 and O20, besides pure diesel (O0).

It was used Bxx as the nomenclature to designate mixtures of biodiesel with diesel, being xx the percentage by volume of biodiesel added to diesel. The following mixtures were used: B5; B10; B15; B20; B50 and B75, besides pure diesel (B0) and pure biodiesel (B100).

Diesel fuel used is from the Laboratory of Distributed Power Generation at Fluminense Federal University. This fuel is used as reference for the tests.

The soybean oil used in the tests was obtained in the food market and the biodiesel used was produced at the Thermo-sciences Laboratory of Mechanical Engineering Department at Fluminense Federal University.

Refined oils are free of substances inhibiting the transesterification process. They have low amount of free fatty acids, less than 0.5%. The beta-carotene and phosphatides of the raw material are eliminated in the process of bleaching and degumming the oil. Thus the processing of these oils for conversion to biodiesel is a process that does not present major technical difficulties. The process is performed at atmospheric pressure.

3.1 Basic procedures for biodiesel obtaining

A guide for biodiesel obtaining from refined oils is given as follows.

Raw material:

- 100 mL of refined vegetable oil (commercial oil, whose acidity is less than 0.5%, degummed, microfiltered, deodorized and bleached);
- 25 mL of anhydrous methyl alcohol;
- 1 g of potassium hydroxide;

Steps:

1. Put 100 mL of vegetable oil in a glass container and lead to heating to a temperature of 45°C;
2. Place the container on the balance. Tare, and put 1g of KOH in it and close the container to avoid hydration of the reagent;
3. Measure a volume of 25 mL of anhydrous methyl alcohol using a test tube (methanol is toxic and must be handled with care in appropriate place);
4. Mixing the methanol with KOH to achieve a uniform solution of methoxide;
5. Add the methoxide to the solution of vegetable oil and stir for a period of two hours;
6. Turn off the mixer and check whether it produces a phase separation, it can be seen that a fluid dark (glycerin) deposits at the bottom of the container;

7. After checking the reaction, put the fluid in the decanting funnel, allow the glycerin settle for a period exceeding 30 minutes. Separate the glycerin and ester (biodiesel) produced in clean containers;
8. Wash the decanting funnel to remove the glycerin stuck on the walls and then fill with the ester obtained;
9. Perform the washing process of ester, adding 30 mL of water, preferably hot (50-60°C), inside the funnel, stirring to ensure the contact of two fluids;
10. Decant the water and remove it from the funnel;
11. Perform the washing process three more times to ensure complete removal of the glycerin;
12. Perform the drying process putting the ester in an oven, heating up to 110 ° C for 10 minutes
13. Cool and bottle the product (biodiesel)

3.2 Characterization of soybean oil and soybean biodiesel and stationary engine tests

The properties of soybean oil, soybean biodiesel and diesel were determined at the Thermosciences Laboratory and Rheology Laboratory of Fluminense Federal University. The heating values were determined at the Laboratory of fuels at the National University of Colombia. The characterization tests followed the standards, as detailed in Table 1.

The tests conducted in the stationary engine were made at constant speed of 3600 rpm and variable power in the Fluminense Federal University

For each fuel tested, a test was performed and repeated. Performance data and emissions were measured continuously during the test and the series of data were analyzed to obtain values representative of engine performance

PROPERTY	STANDARD
Viscosity	ASTM D 445 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids
Density	ASTM D 4052 Density and Relative Density of Liquids by Digital Density Meter.
Flash point	ASTM D 93 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
Cloud point	ASTM D2500 Test Method for Cloud Point of Petroleum Products
Pour point	ASTM D97 Test Method for Pour Point of Petroleum Products
Copper strip corrosion	ASTM D130 Test Method for Copper strip corrosion of Petroleum Products
Heat of combustion	ASTM 240 Test Method for heat of combustion of Petroleum Products.

Table 1. Technical standards associated with the characterization tests

The stationary engine used (Figure 1) is formed by an engine, a generator and a control panel, with the possibility of producing electricity at 115V and 230V. The generator has a control system to regulate the motor rotation. The characteristics of the diesel engine are: 3600rpm; four-stroke; direct injection; one cylinder; air cooling system; 0.211L displacement

volume; 2.0kW maximum output; 1.8kW nominal power; 2.5L fuel capacity and 47 kg weight.

The engine was modified in order to have a fuel consumption control by gravity, changing the original fuel tank by a remote tank, being possible to be placed on a balance

The electrical load was simulated on a load bank, where 150W power lamps were activated to modify the load (Figure 1). The measurements of instantaneous power, current frequency, voltage and electrical current were made using a measuring device (CCK 4300) manufactured by CCK Automation Ltda (São Paulo, Brazil).

Emissions were measured using the gas analyzer Greenline 8000 built by Eurotron Instrument S.A. The equipment has measurement system of gas concentration by non-dispersive infrared (NDIR) and electrochemical method, in addition to measuring temperature, pressure and temperature of gases. The equipment has RS232 communication system for data acquisition and algorithms for calculating the efficiency indicators for different fuels. The resolution and the error limits of the equipment for measured gases are: electrochemical CO, 1 ppm and $\pm$ 10 ppm; NDIR CO_2, 0.01% and $\pm$ 0.3%; electrochemical NO, 1 ppm and $\pm$ 5 ppm; electrochemical NO_2, 1 ppm and $\pm$ 5 ppm and calculated NOx, 1 ppm. The SO_2 measurements were made by the method of molecular absorption spectroscopy (Tulcan, 2009)

Fig. 1. Stationary engine and control panel (operating).

4. Energy generation using soybean oil and soybean biodiesel

The yield of the process of producing biodiesel from soybean was 0.91L of biodiesel per 1L of used oil.

Table 2 shows the properties of diesel, soybean oil and soybean biodiesel, obtained in accordance with the standards shown in Table 1.

The expanded uncertainty of measurements are: density = ± 0.00008 kg/L; viscosity = ± 0.006 mm²/s; flash point = ± 2.1 °C; cloud point = ± 1.5°C and pour point = ± 1.8°C (Santo Filho, 2010a; Abreu, 2010).

The weight composition of fatty acids found in soybean oil was: C16:0=11.6%, C16:1=0.1%, C18:0=3.2%, C18:1=20.4%; C18:2=59.7% and C18:3=5%.

Based on the physicochemical characterization performed in the soybean oil and soybean biodiesel, some correlations were determined.

PROPERTY	DIESEL	SOYBEAN OIL	SOYBEAN BIODIESEL
Density kg/L (20 °C)	0.85519	0.92037	0.88230
Viscosity mm²/s (40 °C)	4.689	30.787	4.161
Flash point °C	82	332	150
Cloud point °C	2	-2	0
Pour point °C	-12	-14	-6
Copper strip corrosion	1a	1b	1a
Higher heating value kJ/kg	42800	-	41685

Table 2. Properties of diesel, soybean oil and soybean biodiesel.

The equation that best describes the behavior of flash point for blending diesel-soybean biodiesel is (Tulcan, 2009):

$$FP(mixture) = \left[\left(FP(a) - FP(d) \right).(\%mixture)^{\left(\frac{FP(a)}{FP(d)} \right)} \right] + FP(d) \tag{1}$$

where: FP (a) is the flash point of the additive (biodiesel) and FP (d) is the flash point of diesel.

The best fitting function representing the behavior of soybean oil density is, as follows (Santo Filho et al., 2010b):

$$\rho = -0.00069T + 0.93420 \tag{2}$$

where: ρ is the density of soyben oil (kg/L) and T is the temperature (^{0}C).

The best fitting function representing the behavior of soybean biodiesel density is, as follows (Santo Filho et al., 2010c):

$$\rho = -0.00073T + 0.89691 \tag{3}$$

where: ρ is the density of soyben biodiesel (kg/L) and T is the temperature (^{0}C).

The behavior of soybean oil viscosity is, as follows (Santo Filho, 2010a):

$$\nu = (0.1115)e^{(953.1562/(T+129.5732))} \tag{4}$$

where: the viscosity of soyben oil is given in mm²/s and the temperature (T) is in (⁰C).
The behavior of soybean biodiesel viscosity is, as follows (Santo Filho, 2010a):

$$\nu = (0.1246)e^{(609.1440/(T+133.6409))} \tag{5}$$

where: the viscosity of soyben biodiesel is given in mm²/s and the temperature (T) is in ⁰C.
Figures 2-7 show the values of specific fuel consumption (SFC) and emissions of NO, NO_x, CO, CO_2 and SO_2 for diesel, soybean biodiesel and mixtures of diesel-soybean oil and diesel-soybean biodiesel. The reported values represent the average for four values of load (400W, 700W, 1000W and 1300W).

Figure 2 shows the behavior of SFC for diesel-soybean oil mixtures and diesel-soybean biodiesel blends. The specific fuel consumption is lower for mixtures of 5% soybean oil than that for diesel. For this percentage, the oil has an oxygenating effect which improves engine performance, with an average of 1.9% decrease from the SFC. For larger percentages of mixture, the SFC increases, indicating a drop in engine performance. This is a consequence of lower heating value of soybean oil and of the increasing of the difficulties to burn fuel in the combustion chamber, requiring more fuel. For mixtures of 20% soybean oil, the increase in SFC is 4.5%. In the case of diesel-soybean biodiesel blends, a slight decrease in the SFC can be observed for smaller proportions of the mixture (5% to 10% soybean biodiesel). This decrease is due to the oxygenating capacity of biodiesel. For larger values of the mixture (15% to 100% soybean biodiesel), the SFC increases. This increase in SFC is due to the lower heating value of biodiesel, requiring more fuel. As the mixing ratio increases, the specific fuel consumption increases. The SFC hits an increase of 14% for the use of pure biodiesel compared to diesel.

Figures 3 and 4 present the average values of NO and NO_x emissions for different mixing ratios of soybean oil with diesel and soybean biodiesel with diesel. The NO and NO_x emissions increase with the use of blends up to 10% of soybean oil in diesel. From this amount of mixture, the NO and NO_x emissions decrease reflecting a decrease in the temperature of combustion chamber. However, the values are still higher than the emissions of diesel. For diesel-soybean biodiesel blends, the production of NO and NO_x is higher for blends superior to 5% than for diesel. Emissions of NO and NO_x grow rapidly for blends above 15% of soybean biodiesel. For mixtures between 20% and 75% soybean biodiesel, the emission levels of NO are an average of 200 ppm. For pure biodiesel the emission levels fall, this is a consequence of the low temperature in the combustion chamber due to the lower heating value of fuel.

Figure 5 shows the mean values of CO for soybean oil and soybean biodiesel blended in diesel. It may be noted that in proportions of up to 5% of soybean oil, the mixtures have an advantage in relation to diesel. For higher proportions, the CO emission increases to a level of 405 ppm for the mixture with 20% of soybean oil, 18% higher than the levels achieved by diesel emissions. The increase in the amount of CO shows a less efficient combustion. In the case of diesel-soybean biodiesel blends, it can be observed that the emission of CO for mixtures was lower than for diesel. The CO emission decreases by increasing the proportion of soybean biodiesel in the blend. In the case of pure biodiesel, the reduction in CO emission was 21% compared with diesel.
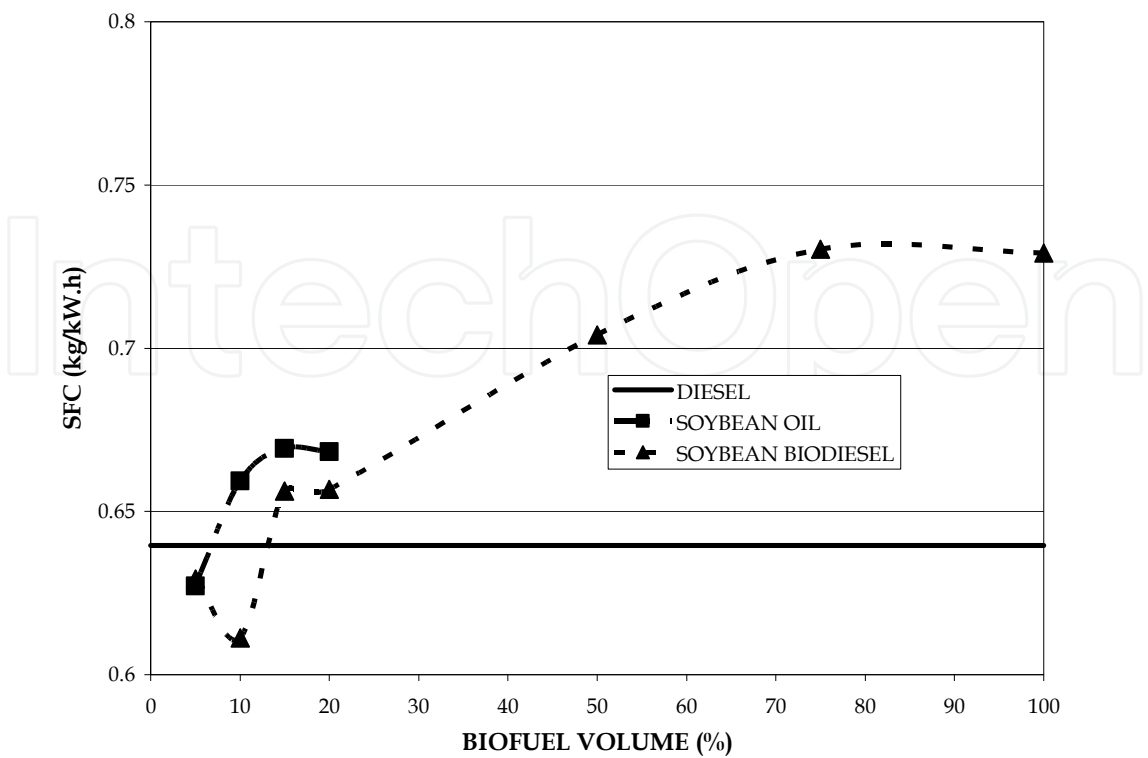
Fig. 2. Mean values of SFC for soybean biodiesel and soybean oil blended in diesel.
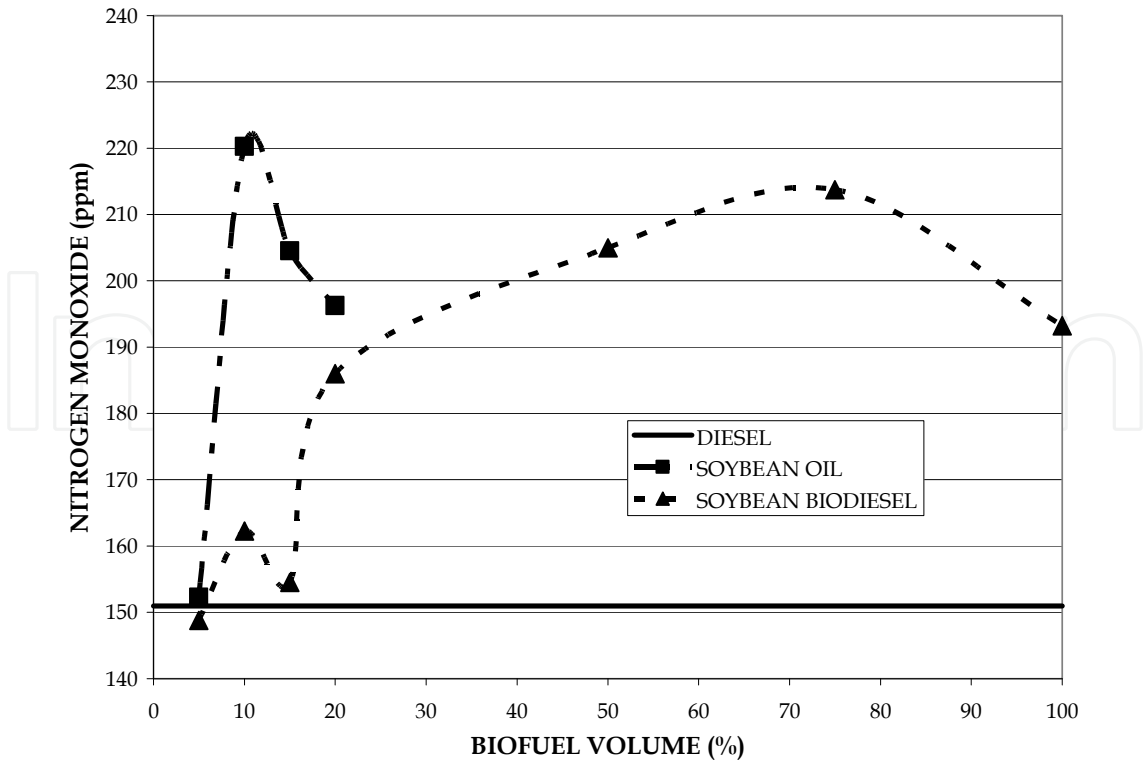

Fig. 3. Mean values of NO for soybean biodiesel and soybean oil blended in diesel.
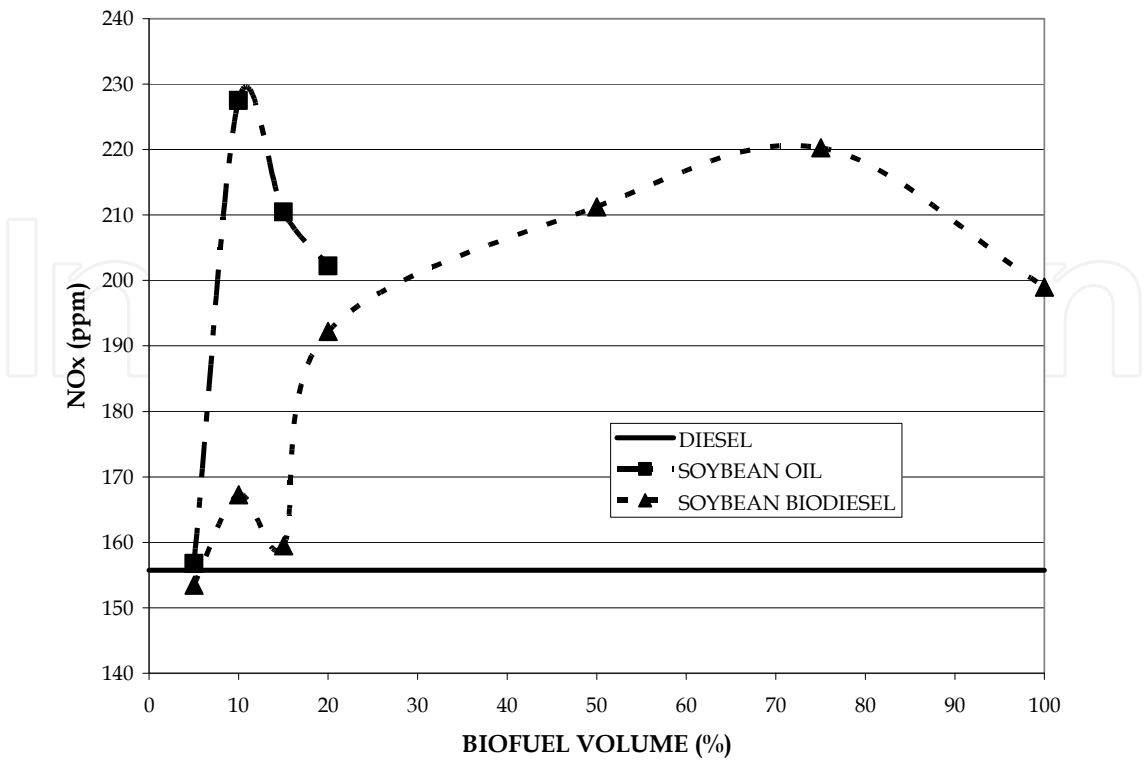
Fig. 4. Mean values of NO_x for soybean biodiesel and soybean oil blended in diesel.
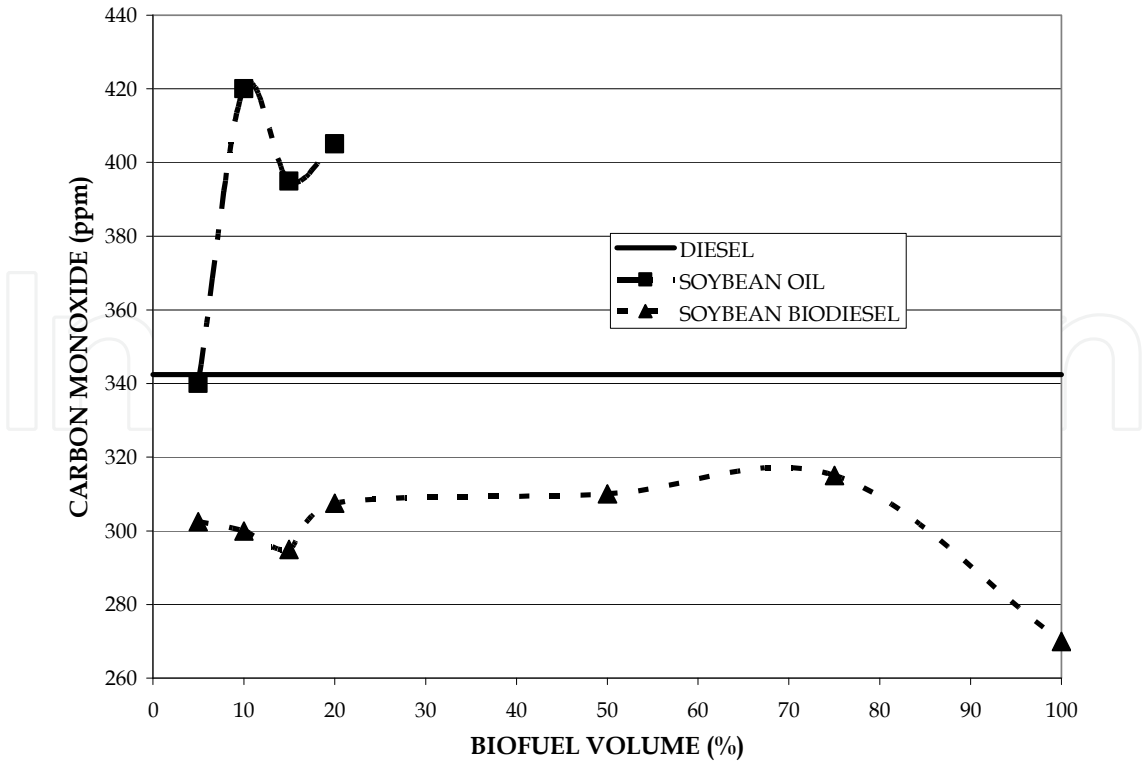

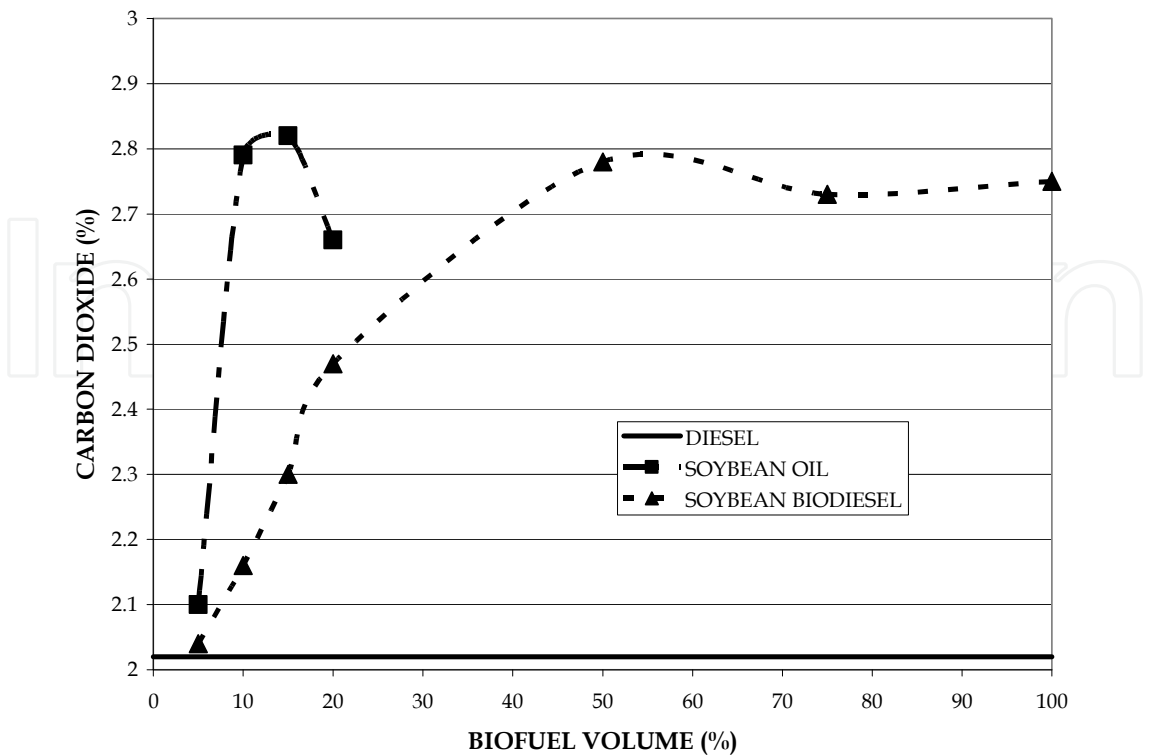Fig. 5. Mean values of CO for soybean biodiesel and soybean oil blended in diesel.

Fig. 6. Mean values of CO_2 for soybean biodiesel and soybean oil blended in diesel.

Figure 6 shows the CO_2 average emissions for soybean oil and soybean biodiesel blended in diesel. It can be observed that the percentages of CO_2 emissions for the mixtures are always higher than for diesel. Compared with diesel, a mixture of 15% of soybean oil increases the production of CO_2 by 40% and the mixture of 20% of soybean oil by 31%. The production of CO_2 increases with the addition of soybean biodiesel reaching a value of 2.77% to 50% soybean biodiesel, representing an increase of 37% compared to diesel. From this value a slight reduction in CO_2 occurs.

Figure 7 shows average results of the SO_2 emission obtained by the method of molecular absorption spectroscopy. In the figure it can be observed that, in some cases, the addition of soybean oil increases the production of SO_2. The production of SO_2 is caused by oxidation of sulfur in the fuel. Although the addition of soybean oil reduces the presence of sulfur in fuel, the cause of production of sulfur oxides may be due to rising temperatures in the combustion chamber and the consequent degradation of lubricating oils in the engine and volatilization of no burning fuel inside the combustion chamber. For fuel mixtures in proportions greater than 10% of soybean oil, the levels of SO_2 emissions begin to decrease. For mixtures of 15% to 20% of soybean oil, the levels of SO_2 emissions are lower than for diesel. In the case of 20% soybean oil, the reduction of SO_2 is 69%. For diesel-soybean biodiesel blends, the emission of sulfur dioxide, in some cases, is higher than for diesel, as also happened in the case of mixtures with soybean oil. Moreover, one can observe that the emission of SO_2 decreases for fuel mixtures in proportions greater than 50% of soybean biodiesel. In the case of 100% soybean biodiesel, the reduction of SO_2 is 71%. The presence of SO_2 in the burning of pure biodiesel can be due to burning of lubricating oil and residual diesel into the combustion chamber.
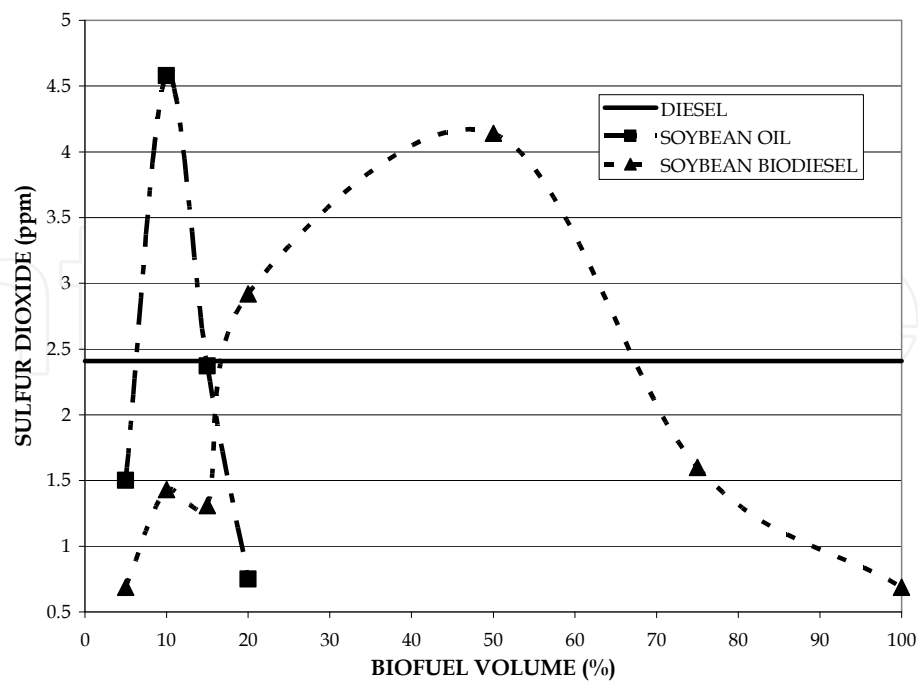
Fig. 7. Mean values of SO$_2$ for soybean biodiesel and soybean oil blended in diesel.

Figures 8 to 13 show the emission behavior as a function of load in the stationary engine for mixtures of 20% soybean oil and 20% soybean biodiesel with diesel.
The behavior of the SFC is similar in the cases of diesel and the mixtures 20% soybean oil-diesel and 20% soybean biodiesel-diesel. As shown in Figure 8 the value of SCF for the fuels studied decreases with increasing load.
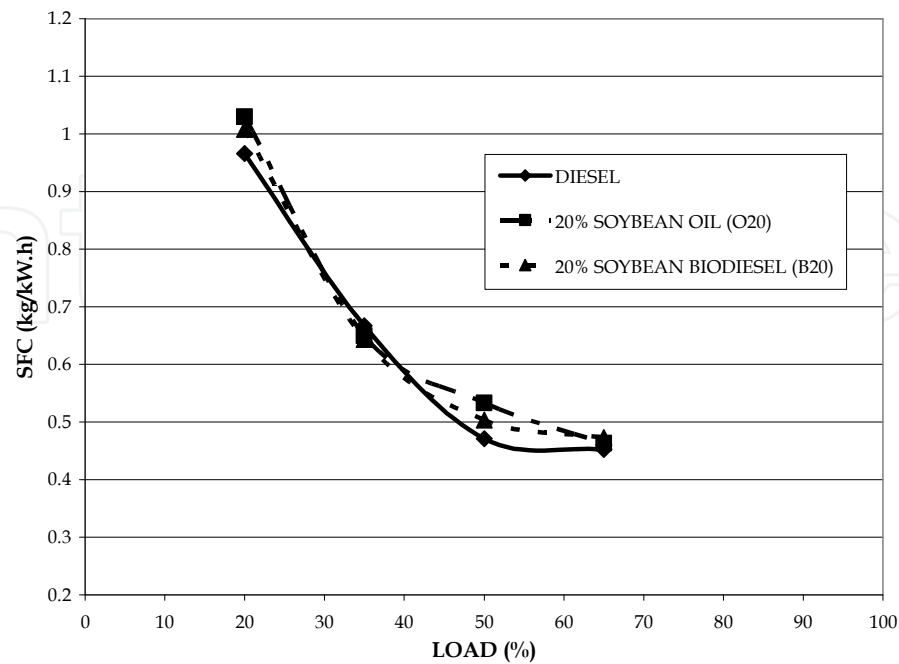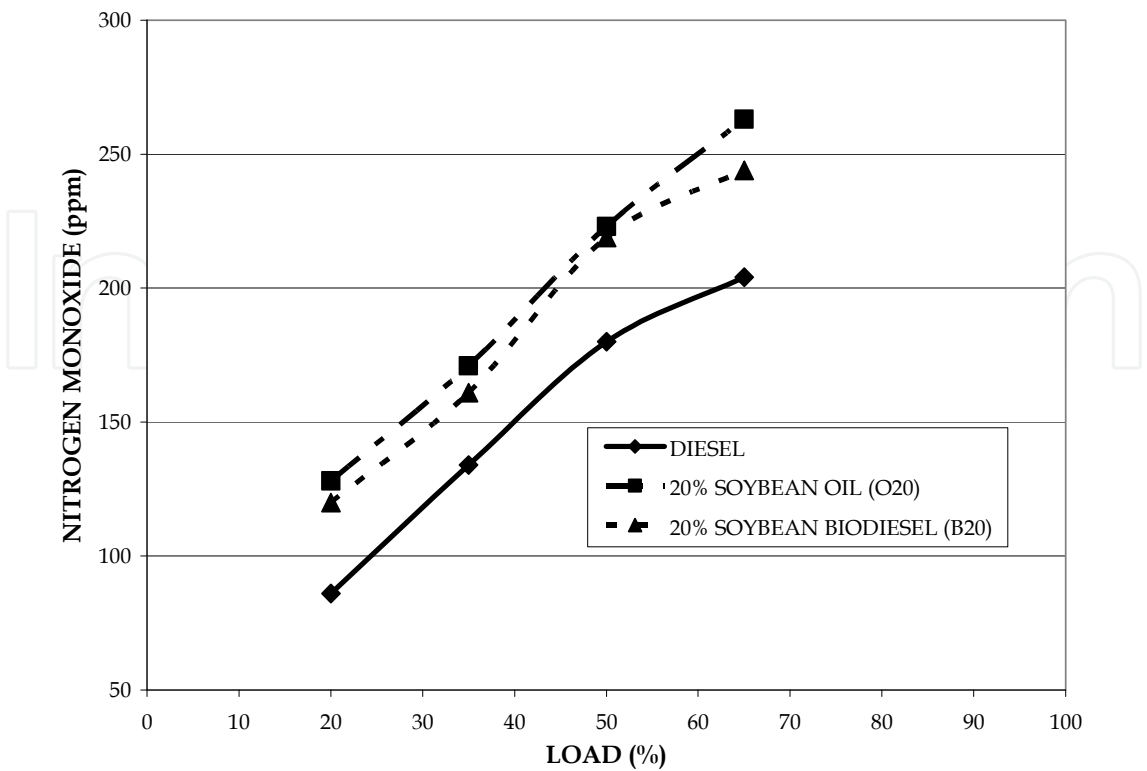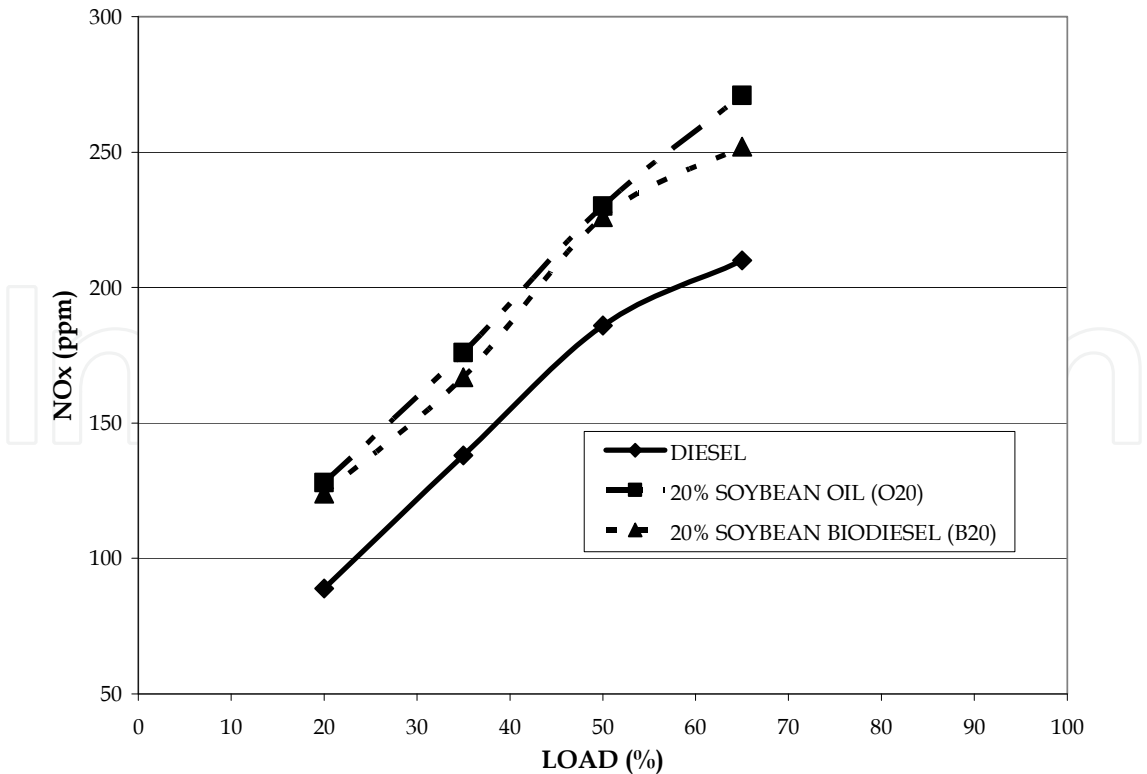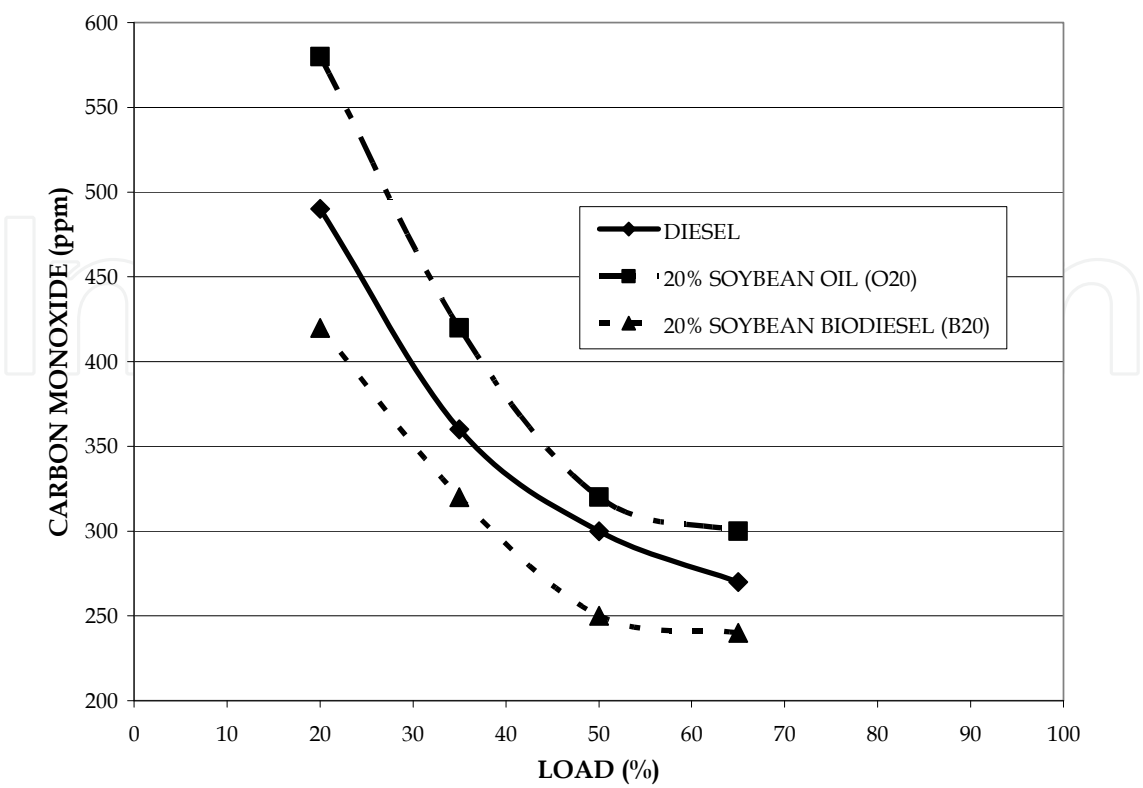

Fig. 8. Values of SFC for 20% soybean biodiesel and 20% soybean oil blended in diesel.

Fig. 9. Values of NO for 20% soybean biodiesel and 20% soybean oil blended in diesel.

Fig. 10. Values of NO_x for 20% soybean biodiesel and 20% soybean oil blended in diesel.

Fig. 11. Values of CO for 20% soybean biodiesel and 20% soybean oil blended in diesel.
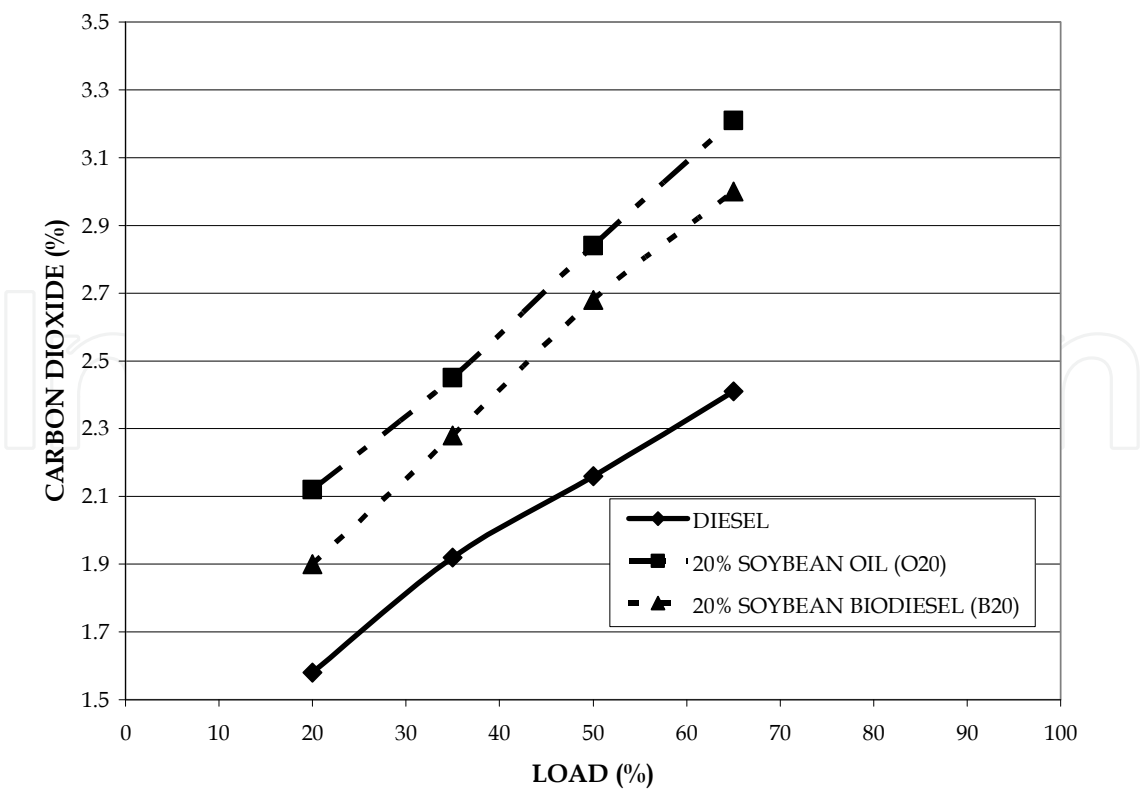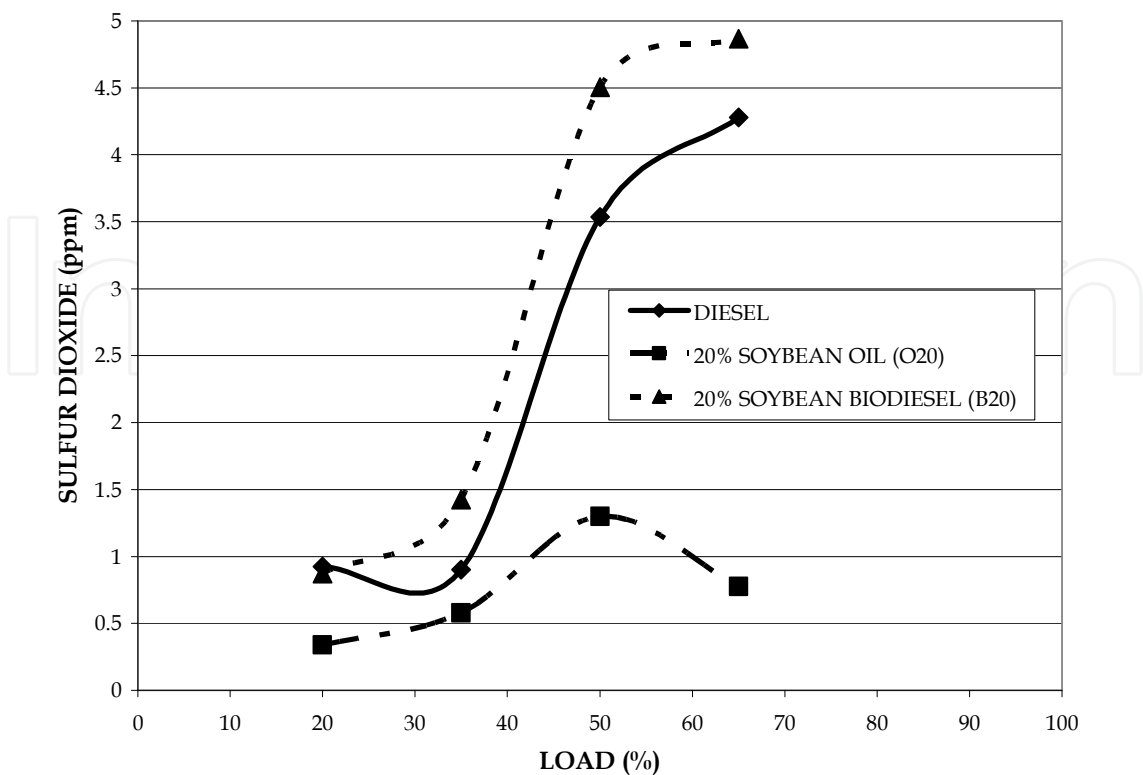

Fig. 12. Values of CO_2 for 20% soybean biodiesel and 20% soybean oil blended in diesel.

Fig. 13. Values of SO_2 for 20% soybean biodiesel and 20% soybean oil blended in diesel.

The Figures 9 and 10 show that the emission of NO and NO_x, for mixtures of 20% soybean oil-diesel and 20% soybean biodiesel-diesel, are higher than those of diesel at all loads studied, probably due to increased temperature in the combustion chamber.

In Figure 11 it can be observed that the CO emissions decrease with increasing load for all fuels tested, showing a better combustion in these cases. The lower values of CO occur with the 20% blend of soybean biodiesel (B20).

As shown in Figure 12, as the load increases the amount of CO_2 emissions increases for all fuels studied.

The emissions of SO_2 with the load are shown in Figure 13. The lowest emissions occur at lower loads.

5. Conclusion

Soybean oil and soybean biodiesel can be added to diesel fuel to be burned in combustion engines. These compounds have an oxygenate capacity that is useful to improve engine performance, but this ability only gives you an edge when the mix ratio is 5% for vegetable oil and 10% for biodiesel. The gains made in reducing the SFC using the oxygenating additives affect about 2% in the case of 5% soybean oil blended with diesel and about 4.5% for 10% soybean biodiesel blended with diesel. Using a larger proportion of mixture generates increases in SFC by 9% on average when pure biodiesel is used, and 3% when mixture of 20% soybean oil is used.

The emission of NO and NO_x increases with the addition of oxygenated components (vegetable oil and biodiesel). The use of 20% soybean oil blended with diesel (O20) increases

the NO emission by 30%. But the use of pure soybean biodiesel (B100) promotes an increase in NO emission by 28%.

The addition of soybean oil in diesel reduces emissions of CO only for mixtures of up to 5% soybean oil. In the case of biodiesel addition in diesel, CO emissions decrease with the mixture reaching a 21% reduction, when pure soybean biodiesel (B100) is used.

The addition of soybean oil and soybean biodiesel in diesel increases the emission of CO_2 which however is compensated by the absorption of CO_2 by the plants (raw material for production of vegetable oil and biodiesel).

The addition of soybean oil and soybean biodiesel in diesel reduces the sulfur content in fuel and consequently reduces the emission of sulfur dioxide.

Soybean oil can be successfully applied in CI engine blending with diesel up to 20% of soybean oil. Soybean oil can also be converted in biodiesel and applied in CI engines neat or blended with diesel in any proportion. Concerning the exhaust emissions it is better use soybean biodiesel or blends of soybean biodesel with diesel instead of blends of soybeans oil with diesel.

The possibility of using soybean oil in power generation, leads to the concept of energy farms soybeans that can be an opportunity for farmers who can not meet the quality standards required for selling the soybeans to food industry.

6. Acknowledgment

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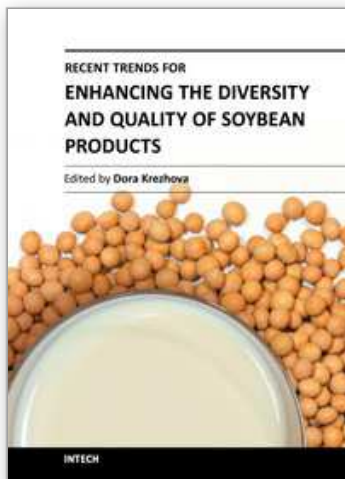
Recent Trends for Enhancing the Diversity and Quality of Soybean Products

Edited by Prof. Dora Krezhova

This book presents new aspects and technologies for the applicability of soybean and soybean products in industry (human food, livestock feed, oil and biodiesel production, textile, medicine) as well as for future uses of some soybean sub-products. The contributions are organized in two sections considering soybean in aspects of food, nutrition and health and modern processing technologies. Each of the sections covers a wide range of topics. The authors are from many countries all over the world and this clearly shows that the soybean research and applications are of global significance.

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