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Biodiesel CO_2 emissions: A comparison with the main fuels in the Brazilian market

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ABSTRACT

The use of biodiesel is increasing as an attractive fuel due to the depleting fossil fuel resources and environmental degradation. This paper presents results of an investigation on the potentials of biodiesel as an alternative fuel and main substitute of diesel oil, comparing the CO_2 emissions of the main fuels in the Brazilian market with those of biodiesel, in pure form or blended in different proportions with diesel oil (2%, 5%, and 20%, called B2, B5, and B20, respectively). The results of the study are shown in ton CO_2 per m^3 and ton CO_2 per year of fuel. The fuels were analyzed considering their chemical composition, stoichiometric combustion parameters and mean consumption for a single vehicle. The fuels studied were: gasoline, diesel oil, anhydrous ethyl alcohol (anhydrous ethanol), and biodiesel from used frying oil and from soybean oil. For the case of biodiesel, its complete life cycle and the closed carbon cycle (photosynthesis) were considered. With data provided by the Brazilian Association of Automotive Vehicle Manufacturers (ANFAVEA) for the number of vehicles produced in Brazil, the emissions of CO_2 for the national fleet in 2007 were obtained per type of fuel. With data provided by the Brazilian Department of Transit (DENATRAN) concerning the number of diesel vehicles in the last five years in Brazil, the total CO_2 emissions and the percentage that they would decrease in the case of use of pure biodiesel, B100, or several mixtures, B2, B5 and B20, were calculated. Estimates of CO_2 emissions for a future scenario considering the mixtures B5 and B20 are also included in this article.

1. Introduction

In the last three decades, the world has been confronted with energy crises due to the decrease of fossil resources and the increase of environment constraints and prices of oil. This situation brought as consequence the search for alternative and renewable fuels, which need to be not only sustainable, but also environment friendly and techno-economically competitive. The biofuels like ethanol, vegetable oil, biomass, biogas, synthetics fuel, and biodiesel, among others, are becoming of high interest to the developed countries. Some of these fuels can be burned in direct form; however, others need some kind of modification to replace the conventional diesel fuel: gasification or digestion when dealing with biomass, and transesterification when dealing with biodiesel.

The growth of mobility demand in the world was followed by the growth of transportation by road and, consequently, by the increase of greenhouse gas emissions produced from fossil fuel combustion. During the last ten years, it was recognized that greenhouse gases, CO_2 in particular, represent a high threat for future generations, causing global warming and climatic changes. The energy consumption of the transportation sector represented, in 1998, 28% of the total CO_2. According to the European Commission [1], if nothing is

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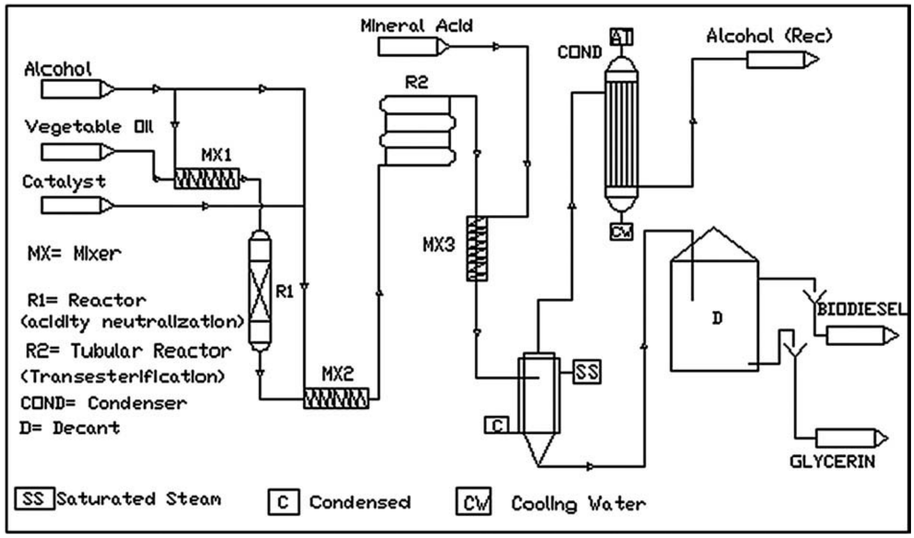

Fig. 1 – Biodiesel fuel production scheme. Adapted from [2].

made to change the road transportation tendency, the CO_2 emissions in this segment will increase approximately 50% until 2010, in comparison to 1990, reaching 1113 million tons of CO_2 per year. Once again, road transportation is the main responsible for this situation, since it represents 84% of the CO_2 emissions in comparison with air transportation, which is responsible for 13% [3,4].

This work consists of the first study about biodiesel engine benefits in Brazil regarding CO_2 emissions, in comparison to other Brazilian fuels. Biodiesel is one of the main alternative fuels to replace the conventional diesel fuel. A comparison in respect to CO_2 emissions is made with the main current Brazilian fuels in the market. The biodiesel emissions were considered for the fuel in pure form and blended in different proportions with conventional diesel oil. The results show a reduction in the CO_2 emissions levels to the atmosphere in the case of replacing the conventional fuel by biodiesel. To conduct the study, data of the National Association Manufacturers of Automotive Vehicles [5] and the National Department of Transit [6], collected for the last five years, were used in the case of the Brazilian road transportation system.

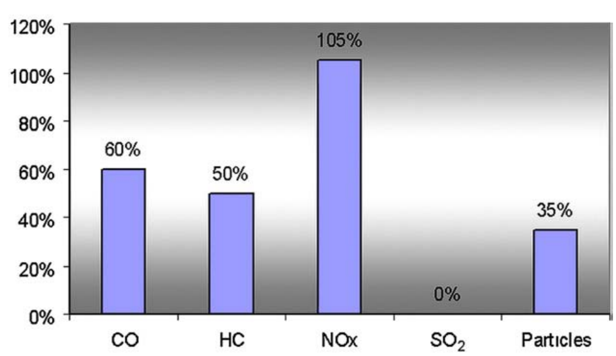

Fig. 2 – Gaseous emissions of biodiesel combustion in an internal combustion engine. The value of 100% is considered the emission level of the diesel engine [7].

2. Literature review

2.1. *Biodiesel fuel production*

Chemical biodiesel is composed of monoalkyl esters of long chain fatty acids derived from renewable feed stock, like animal fats and vegetal oils [8,9]. According to Larosa [2], a biodiesel industrial plant that utilizes methanol in the transesterification process needs to carry out the following steps: reactants preparation, and transesterification, separation and purification of the obtained phases. Fig. 1 shows a diagram of such production scheme.

The reactants are prepared in the first step. Oils and fats mix with part of an alcohol (methanol, ethanol, propanol, butanol, and amil-alcohol) in the static mixer MX1, flowing to the fixed bed reactor R1. In this reactor, esterification of the free fat acids takes place in order to eliminate a possible initial acidity of the vegetal oil. The product flows out of R1 and mix with the remaining alcohol in the static reactor MX2, under a catalyst chosen for each project. KOH or NaOH are the most usual bases in this process.

The resulting mixture from MX2 is taken to the transesterification region. The temperature is increased to the reaction

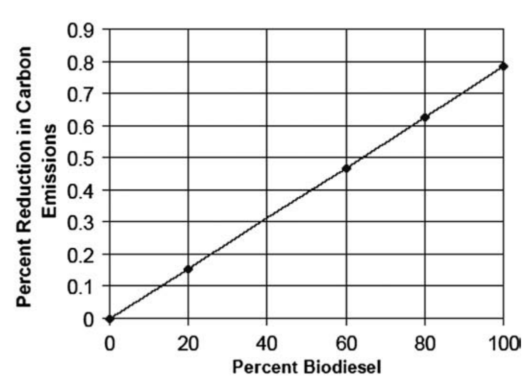

Fig. 3 – Effect of biodiesel blend level on CO_2 emissions [10].

Table 1 – Exhaust gas concentrations in internal combustion engines (volume percentage) [11]

Component	Maximum content by volume (%)		Observation
	Gasoline	Diesel	
Nitrogen	74–77	76–78	Non toxic
Oxygen	0.3–0.8	2.0–18.0	Non toxic
Steam	3.0–5.5	0.5–4.0	Non toxic
Carbon dioxide	5.0–12.0	1.0–10.0	Non toxic
Carbon monoxide	0.1–10.0	0.01–0.5	Toxic
Nitrogen oxide	0.1–0.5	0.001–0.4	Toxic
Hydrocarbons	0.2–3.0	0.009–0.5	Toxic
Aldehydes	0–0.2	0.001–0.009	Toxic
Sulphur dioxide	0–0.002	0–0.03	Toxic
Soot (g/m^3)	0–0.04	0.01–1.1	Toxic

temperature until arriving in the tubular reactor R2, where, with adequate reaction conditions, the triglycerides from the vegetal oil are transformed into two immiscible phases, one which is aqueous (glycerin) and the other which is organic (biodiesel). Once the transesterification reaction is concluded, the mixture follows to a third region, where phase separation and purification occur, to obtain a product with adequate quality. Before this step, it is recommended that the catalyst be neutralized with a mineral acid; this takes place in mixer MX3. Following, the product is taken to a flash chamber to eliminate the excess of alcohol used in the beginning of the process, which is recovered in a condenser. The mixture then flows from the bottom of the flash chamber, consisting of two immiscible phases free of catalyst and alcohol. This product flows to a decanter where the ester and glycerin phases are obtained. These phases are then submitted to distinct steps of purification, depending on the grade of purity desired to sell the products and sub-products in the market [8,10,12].

2.2. *Biodiesel emissions*

The biodiesel is the only renewable alternative fuel that can be used directly in any diesel engine without the need of conducting some type of modification. As its properties are similar to those of the diesel fuel derived from petroleum, both can be blended in any proportion without any inconvenience. The more common blend is 20% biodiesel with 80% diesel; this blend is designated by “B20”. “B100” means 100% biodiesel.

The use of biofuels in ignition compression engines can play a vital role in helping the developed and developing countries to reduce the environmental impact of fossil fuels. The main target for the use of biofuels is to decrease the emissions of gaseous pollutants to the atmosphere, mainly CO_2 emissions. As already indicated, the use of biodiesel takes with itself a global emission decrease. Fig. 2 shows the emissions of the main polluting agents. In the case of biodiesel combustion, the emissions are very low (with the exception of NO_x).

A 100% sulphur dioxide reduction is reasonable taking into account that biodiesel, by its vegetal origin, does not contain sulphur. The CO emissions for biodiesel combustion in diesel engines are 40 to 50% lower than those for conventional diesel; this happens due to the presence of oxygen molecules in the biodiesel, mainly in the methyl or ethyl ester, helping to obtain complete combustion. The particulate matter emissions (PM) are decreased to 35 to 45% in comparison with operation with diesel [14]. A decrease of unburned hydrocarbons due to complete combustion also takes place, because the chains of carbon–hydrogen and oxygen in the esters help the formation of CO_2 and water, unlike to what occurs with diesel fuel [15,10].

The case of CO_2 is different compared to other pollutant agents. The emissions generated by biodiesel during combustion in internal combustion engines or boilers are “recyclable” through vegetable photosynthesis. The CO_2 is released into the atmosphere when the biodiesel is burned and it is recycled by the growing plants, which are later processed into the fuel. Hence, biodiesel also helps to mitigate global warming [16]. Fig. 3 shows the effect of biodiesel blend levels on CO_2 emissions.

The NO_x emissions increase in 5%. It is evident that with biodiesel, due to improved combustion, the temperatures in the combustion chamber are expected to be higher, leading to formation of higher quantities of NO_x in biodiesel-fuelled engines. However, the biodiesel lower sulphur content allows the uses of NO_x control technologies that cannot be otherwise used with conventional diesel. Hence biodiesel fuel NO_x emissions can be effectively managed and eliminated by engine optimisation [8].

2.3. *Toxicity in internal combustion engines*

The main toxic compounds in the exhaust gases of internal combustion engines are carbon monoxide and nitrogen oxides. Carbon monoxide appears in the exhaustion gases as

Table 2 – Typical soy bean oil methyl ester [13]

Fatty acid	Weight (%)	Mol. wt. (g)	Formula
Palmitic (A)	12	270.46	$C_{15}H_{31}CO_2CH_3$
Stearic (B)	5	298.52	$C_{17}H_{35}CO_2CH_3$
Oleic (C)	25	296.5	$C_{17}H_{33}CO_2CH_3$
Linoleic (D)	52	294.48	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)7CO_2CH_3$
Linolenic (E)	6	292.46	$CH_3(CH_2CH{=}CH)_3(CH_2)7\ CO_2CH_3$

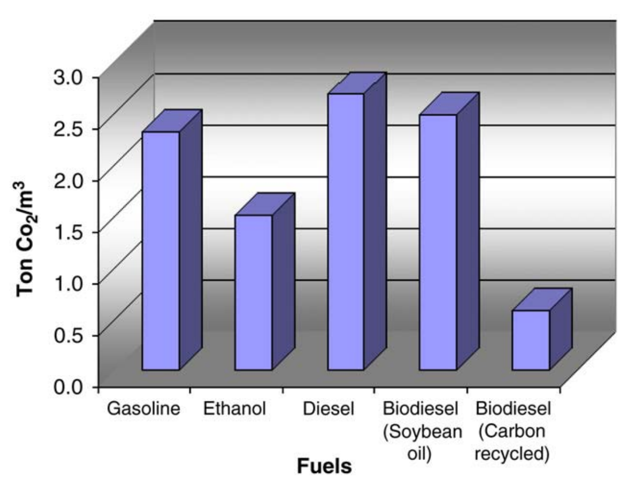

Fig. 4 – CO_2 emissions in respect to the fuel used.

Table 3 – Tailpipe contribution to total life cycle CO_2 for petroleum diesel and biodiesel (g CO_2/bhp-h) [15]

Fuel	Total life cycle fossil CO_2	Total life cycle biomass CO_2	Total life cycle CO_2	Tailpipe fossil CO_2	Tailpipe biomass CO_2	Total tailpipe CO_2	% of Total CO_2 from tailpipe
Petroleum Diesel	633.28	0.00	633.28	548.02	0.00	548.02	86.54%
B100	136.45	543.34	679.78	30.62	543.34	573.96	84.43%

result of fuel incomplete combustion; the reason is insufficient oxygen in the combustion chamber or fuel particles that are not burned properly. Table 1 shows the main emissions of an internal combustion engine.

The substances that compose the exhaust gases can be classified in several groups. Nitrogen, oxygen, hydrogen, steam and carbon dioxide belong to the non toxic group of substances. The toxic group of substances includes carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (C_xH_y), aldehydes (R_xCHO), soot, sulphur dioxide (SO_2), sulphydric acid and solid particles. The poly-aromatic hydrocarbons (PAH) are carcinogenic substances and form a special group [17].

A small vehicle releases to the atmosphere, in average, between 0.6 and 1.7 kg/h of CO; a truck releases between 1.5 and 2.8 kg/h CO. In general, when 1 kg of diesel fuel is burned, it releases between 80 and 100 g of toxic compounds, specifically: 20 to 30 g of CO, 20 to 40 g of NO_x, 4 to 10 g of HC (hydrocarbons), 10 to 30 g of SO_x, 0.8 to 1 g of aldehydes, and 3 to 5 g of soot. When 1 kg of gasoline is burned, it releases approximately 300 g of toxic compounds, specifically: 225 g of CO, 55 g of NO_x, 20 g of HC, 1.5 to 2 g of SO_x, 0.8 to 1 g of aldehydes, 1 to 1.5 g of soot [11]. Particulate material (PM) emissions of diesel fuel for automotive vehicles are 13.2 kg/m^3; in the case of gasoline for automotives vehicles, the PM emissions are 1.44 kg/m^3 [18].

3. Methodology

The emission factors for CO_2 were calculated for the fuels commonly used in the Brazilian market, including the biodiesel (pure and mixed with conventional diesel fuel). Following, the average amount of CO_2 emitted by an automobile per year was computed for the fuels. Using data reported by [5] and [6], the CO_2 emissions by the diesel and the gasoline vehicle fleet in Brazil and the reduction of such emissions in the case of the use of biodiesel (pure or a mixture) were calculated. Projections were made for the future 10 and 15 years for the automotive vehicles in Brazil regarding their CO_2 emissions.

3.1. *CO_2 emissions according to the fuel*

The amounts of CO_2 emitted to the atmosphere are starting to constitute in an important parameter to be determined in combustion processes, because this gas is the main responsible for the greenhouse effect [19]. The European Union agreed in reducing its CO_2 emissions by 8% in the period 2008–2012, in reference to 1990 values [20]. The calculations of the emissions factors for the studied fuels are given in the following.

3.1.1. *Gasoline*

The chemical formula of gasoline is C_8H_{18} (octane) and its density is 0.75 t/m^3 [21]. Observing its stoichiometric combustion reaction with air, Eq. (1), the result is: 352 g of CO_2 per 114 g of gasoline. Taking into account the gasoline density, the result is: 352 ton CO_2 per 152 m^3 gasoline, which means 2.316 ton CO_2 per m^3 gasoline.

$$1C_8H_{18} + 12.5O_2 + 47N_2 \rightarrow 8CO_2 + 9H_2O + 47N_2 \quad (1)$$

3.1.2. *Ethanol*

The chemical formula for anhydrous ethyl alcohol is C_2H_5OH and its density is 0.79 t/m^3 [22]. From its stoichiometric combustion reaction with air, Eq. (2), the result is: 88 g of CO_2 per 46 g de alcohol, which, considering the alcohol density,

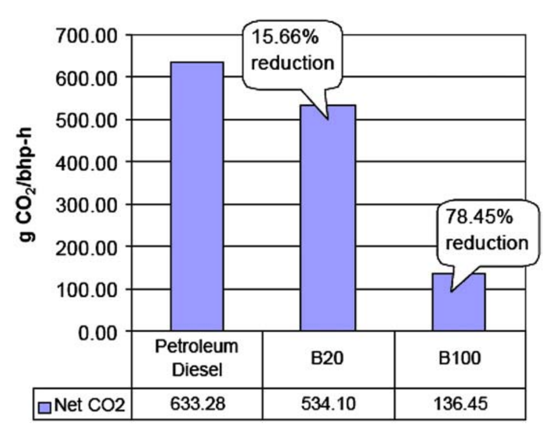

Fig. 5 – Comparison of net CO_2 life cycle emissions for petroleum diesel and biodiesel blends [16].

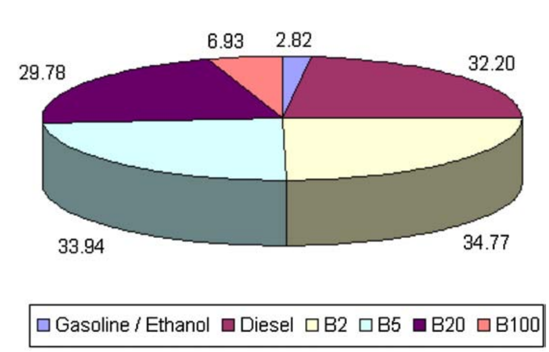

Fig. 6 – Vehicle emissions in ton CO_2 per year. Gasoline/ethanol (20% ethanol and 80% gasoline), B2 (2% biodiesel and 98% diesel).

Table 4 – Produced Brazilian vehicles for the last five years [6]

Type of vehicle	Dec/2002	Jan/2008	Difference
Truck	1,544,190	1,853,746	309,556
Truck tractor	211,603	306,713	95,110
Small bus	156,228	216,065	59,837
Bus	295,509	377,252	81,743
Total	2,207,530	2,753,776	546,246

Table 5 – Number of produced Brazilian vehicles by type fuel in 2007 [5]

Vehicles	Jan	Apr	Ago	Oct	Dec	Total
Gasoline	63,627	65,760	69,695	71,974	39,835	769,913
Flex fuel	126,481	136,700	183,260	198,075	162,125	1,933,902
Ethanol	0	0	3	0	0	3
Diesel	15,184	21,160	26,050	26,378	18,812	267,000
Total	205,292	204,073	279,008	296,427	220,772	2,970,818

gives: 88 ton CO_2 per 58.23 m^3 alcohol, meaning 1.511 ton CO_2 per m^3 alcohol.

$$1C_2H_5OH + 3O_2 + 11.28N_2 \rightarrow 2CO_2 + 3H_2O + 11.28N_2 \quad (2)$$

3.1.3. *Diesel*

The traditional chemical formula for the petroleum diesel is $C_{12}H_{26}$ and its density is 0.864 t/m^3 [23], which result in: 528 g of CO_2 by 170 g of diesel, Eq. (3). Taking into account the density of the diesel fuel, the following is obtained: 528 ton CO_2 per 196.76 m^3 diesel, i.e., 2.683 ton CO_2 per m^3 diesel.

$$1C_{12}H_{26} + 18.5O_2 + 69.56N_2 \rightarrow 12CO_2 + 13H_2O + 69.56N_2 \quad (3)$$

3.1.4. *Biodiesel (soybean)*

The density of the biodiesel made from soybean by transesterification with methanol is 0.878 t/m^3 [14]. The average molecular weight of soybean oil methyl ester is 292.2 g/gmol. This was calculated using the average fatty acid distribution for soybean methyl esters presented in Table 2 [13]. This table also shows the molecular weight and chemical formula for each of the component esters; each component was designated by a different character. From the stoichiometric combustion reaction with air, the emission rates of CO_2 are: 282.45 g of CO_2 by 100 g biodiesel, Eq. (4). Taking into account the fuel density, the following is obtained: 282.45 ton CO_2 per 113.88 m^3 of biodiesel, i.e., 2.48 ton CO_2 per m^3 soybean oil methyl esters (biodiesel).

$$0.04437A + 0.01675B + 0.08432C + 0.1766D + 0.0205E + 9.037O_2 + 33.98N_2 \rightarrow 6.42CO_2 + 5.92H_2O + 33.98N_2 \quad (4)$$

3.1.5. *Biodiesel (used frying oils)*

According to Mittelbach and Tritthart [24], a biodiesel from used frying oils has the following mass composition: 77.4% C, 12% H, 11.2% O, and 0.03% S, which gives 283.8 g of CO_2 per 100 g of biodiesel. Considering the biodiesel density, the result is: 283.8 ton CO_2 per 113.88 m^3 of biodiesel, i.e., 2.492 ton CO_2 per m^3 of biodiesel, Eq. (5).

$$6.45C + 12H + 0.00094S + 9.45O_2 + 35.54N_2 \rightarrow 6.45CO_2 + 6H_2O + 0.00094SO_2 + 35.54N_2 \quad (5)$$

Biomass-derived fuels decrease the net atmospheric carbon in two ways: first, they participate in the relatively rapid biological cycling of carbon to the atmosphere (via engine tailpipe emissions) and from the atmosphere (via photosynthesis). Second, they substitute fossil fuels. Fossil fuel combustion releases carbon that took millions of years to be removed from the atmosphere. Combustion of biomass fuels participates in a process that allows CO_2 to be rapidly recycled to fuel [16].

A 1998 biodiesel life cycle study, jointly sponsored by the US Department of Energy and the US Department of Agriculture, concluded that biodiesel decreases net CO_2 emissions by 78.45% compared to mineral diesel. This is due to the biodiesel closed carbon cycle. Sheehan et al. [16] and Peterson et al. [25] also reported that CO_2 emissions are significantly lower with biodiesel. Therefore, considering this aspect, in the case of the use of B100 (biodiesel pure form), the result is: 0.578 ton CO_2 per m^3 with biodiesel. Fig. 4 shows a summary of the CO_2 emissions according the fuel used.

Table 3 presents the CO_2 emissions corresponding to the Brazilian vehicles produced in 2007, according the fuel type. Fig. 5 presents a comparison of the net CO_2 life cycle emissions for petroleum diesel and biodiesel blends. For the petroleum diesel, the CO_2 emitted at the tailpipe represents 86.5% of the total CO_2 emitted across the entire life cycle of the fuel. Most of the remaining CO_2 comes from emissions at oil refineries, which contribute to 9.6% of the total CO_2 emissions. For biodiesel, 84.4% of the CO_2 emissions occur at the tailpipe. The

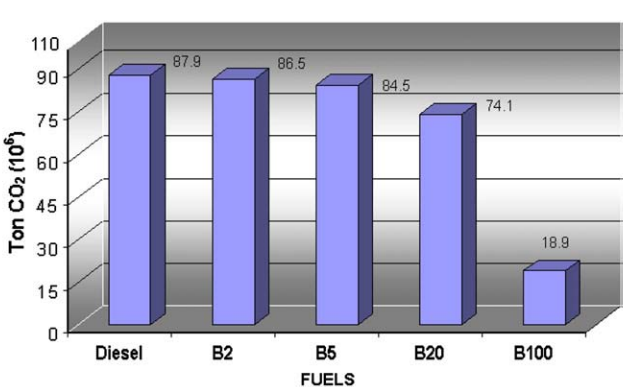

Fig. 7 – CO_2 emissions by fuel type, for the last five years, for the Brazilian diesel fleet.

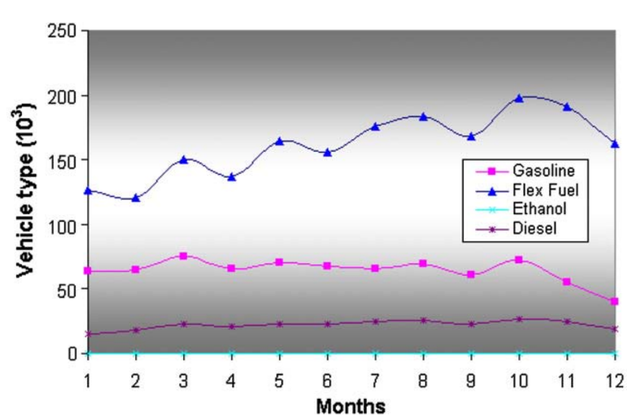

Fig. 8 – Number of vehicles by type fuel — 2007 [5].

Table 6 – CO_2 emissions of the Brazilian vehicles that was produced in 2007 according the fuel type

Vehicles to	No. of vehicles	ton CO_2/m^3 by vehicle	ton CO_2 per year
Gasoline	769,913	2.155	2,170,814.0
Flex fuel [a]	1,933,902	2.155/1.511	4,986,009.4
Alcohol	3	1.511	6.1
Diesel	267,000	2.683	8,597,877.4
Total vehicles	2,970,818		15,754,706.9

[a] Considering that 70% of the times this vehicles use gasoline and, 30% of the time use alcohol.

remaining CO_2 comes almost equally from soybean agriculture, soybean crushing, and soy oil conversion to biodiesel [16].

The case of producing biodiesel by transesterification utilizing soybean oil, methanol and a catalyst base applies perfectly to the Brazilian scenario. The stoichiometric calculations and projections corresponding to this case were considered in this paper.

3.2. *Vehicle CO_2 emissions*

In anhydrous form, ethyl alcohol is miscible in gasoline. Therefore, it is possible to use it in mixtures with gasoline in automobiles as anti-detonation agent, and also to decrease gasoline consumption. The percentage of anhydrous ethanol in the Brazilian gasoline has varied throughout the years, between 20 and 25% in volumetric basis [19].

In order to obtain the vehicle emissions in tons of CO_2 per year, the case of a gasoline vehicle that runs 20,000 km/year was considered. This is the average distance run by a Brazilian gasoline car per year. These parameters were obtained considering the data on commercialisation and sales of national fuels in Brazil [26], and the data on the number of the gasoline/alcohol vehicles in Brazil [6]. The average Brazilian car uses gasoline (75% gasoline and 25% ethanol — called Gasoline C). A mean consumption of 15 km/l (15,000 km/m^3) was considered [19]. Taking into account all these parameters and the stoichiometric calculations of the previous section, a gasoline/alcohol vehicle will release 2.820 ton CO_2 per year.

Also in order to obtain the vehicle emissions in tons of CO_2 per year, the case of a diesel vehicle that runs 60,000 km/year was considered. This parameter was obtained considering the

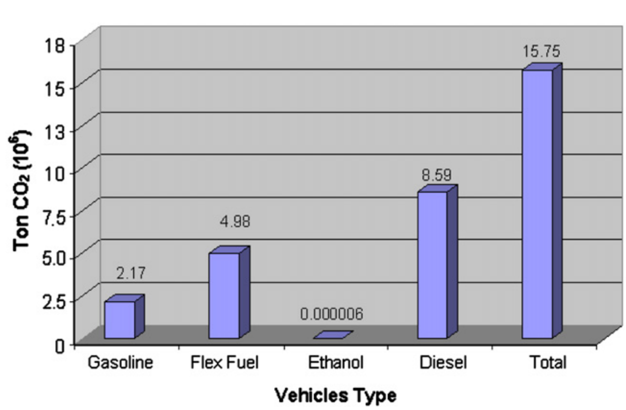

Fig. 9 – CO_2 Emissions for the produced Brazilian vehicles by the fuel type in 2007 [5].

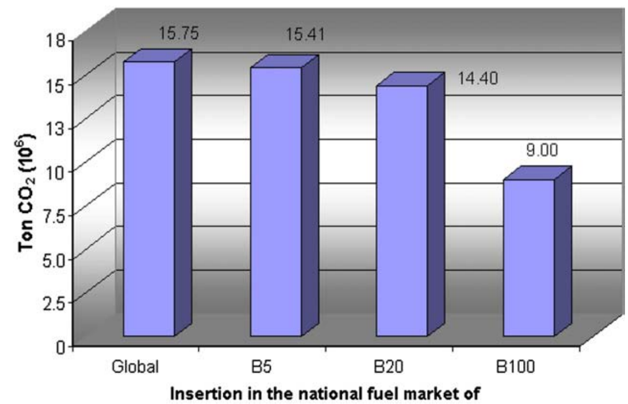

Fig. 10 – Decrease of the CO_2 emissions for produced Brazilian vehicles in 2007, if the diesel by biodiesel (B5, B20 e B100) were replaced in the energetic fuel matrix.

average distance run by a Brazilian diesel vehicle per year, also considering the data of ANP [26], and the number of diesel vehicles in Brazil, given by DENATRAN [6]. A mean consumption of 5 km/l (5000 km/m^3) was considered. Taking into account all these parameters and the stoichiometric calculations of the previous section, a diesel vehicle will release 32.202 ton CO_2 per year. Fig. 6 shows the CO_2 emissions in ton CO_2/year for the fuels analysed above. For biodiesel, a reduction of 78.45% in the CO_2 emissions (carbon recycled) was considered.

4. Results

4.1. *CO_2 emissions for the last five years in the Brazilian diesel fleets*

The national diesel fleets for the last five years are those given in Table 4 [5]. Considering that the Brazilian diesel fleets run 60,000 km/year (Brazilian average for diesel vehicles, including large and small trucks, buses and microbuses; this value was explained in the previous section) using diesel at 5 km/l (5000 km/m^3) mean consumption for the last five years (Dec/2002–Jan/2008), the CO_2 emissions would reach 87.95 Mton CO_2 for the five years. On the other hand, if the diesel fuel were blended with biodiesel in different percentages (2% — B2; 5% — B5; 20% — B20; 100% — B100), a decrease in the CO_2 emissions would clearly occur. Fig. 7 compares the CO_2 emissions in tons, when 100% diesel fuel is used and when blends with biodiesel are used, for data corresponding to the last five years. A decrease of CO_2 emissions is clearly observed as the percentage of biodiesel increases.

Table 7 – Projections for the diesel vehicular fleets in Brazil

Years	2010	2015	2020	2025
No. of vehicles (10^6)	1.135	1.710	2.285	2.860
ton CO_2 (10^6) — Diesel	365.6	826.2	1471.9	2302.8
ton CO_2 (10^6) — B5	351.3	793.8	1414.2	2212.5
ton CO_2 (10^6) — B20	308.2	696.6	1241.0	1941.5

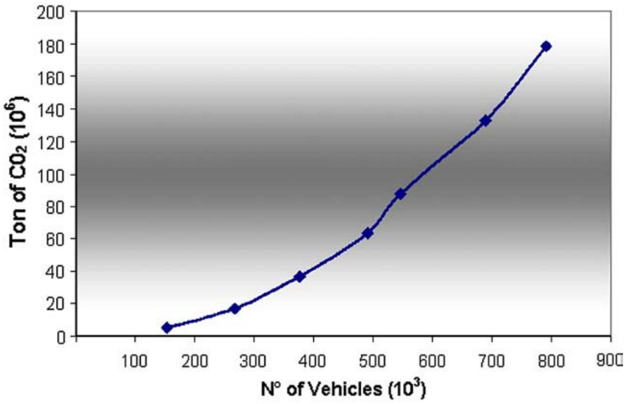

Fig. 11 – Mton of CO_2 vs number of diesel vehicular fleets in Brazil.

The benefits that may occur with the insertion of biodiesel fuel in the Brazilian fuel market, for the CO_2 emissions from the vehicles produced in Brazil, are discussed. The data about the number of Brazilian vehicles produced in 2007 (by fuel type) were provided by DENATRAN [6], and they are shown in Table 5 and Fig. 8. Working in the same way than in the previous cases, considering that all the vehicular gasoline/alcohol fleet runs 20,000 km/year and the vehicular diesel fleet runs 60,000 km/year with 5-km/l (5000 km/m^3) mean consumption fuel, the CO_2 emissions for all Brazilian fleet of vehicles in a year (2007) is 15.75 Mton CO_2. Table 6 and Fig. 9 show in detail the values in Mton of CO_2 per year for the analyzed fuels. In case of the implementation of a federal law obliging the blend of 2%, 5% or 20% of biodiesel in the diesel fuel in the country, the total CO_2 emissions would be reduced to 15.41 Mton CO_2 in the case of using B5. In the case of B20 the reduction would be to 14.40 Mton CO_2. Finally, in the case of B100 the reduction would be to 9.00 Mton CO_2, as shown in Fig. 10.

5. Conclusions

It was shown that the fuel that less releases CO_2 to the atmosphere is ethyl alcohol; on the contrary, the fuel that releases highest CO_2 emission to the atmosphere is diesel fuel. Due to the oxygenated nature of biodiesel, where more oxygen is available for burning, this fuel produces decreased rates of unburned hydrocarbon and CO emissions in the exhaust. The main advantage is that CO_2 emissions, in the case of use of biodiesel, can be regarded as carbon credit as it is a biofuel, produced by photosynthesis. Therefore, the emission levels using this kind of biofuel are 78.45% lower in comparison with those of diesel fuel. The real parameter considering the biodiesel life cycle is 0.578 ton CO_2/m^3 (B100).

The Brazilian diesel vehicular fleet for the last five years (December 2002–January 2008), including trucks, tractors, small buses and buses increased by 546,246 vehicles, which released to the atmosphere an extra of 87.95 Mton CO_2. If this diesel fleet had used B2 in the last five years, the CO_2 emissions would have decreased 1.6%. With B5, the CO_2 emissions would have decreased 3.9%, and with B20, the CO_2 emissions would have decreased 15.7%.

The production of national vehicles in 2007 totalized 2,970,818 vehicles, being the majority constituted of *flex fuel* vehicles, those that use hydrated ethanol or gasoline, or both. The number of vehicles decreased in the following order: gasoline, diesel and ethyl alcohol vehicles. These vehicles released, in 2007, 15.75 Mton CO_2. Brazil has approximately 186 millions of habitants, according to the Statistical and Geography Brazilian Institute; therefore, this represents 0.084 ton CO_2/hab. If the Brazilian fuel energetic matrix begins to use a blend with biodiesel, for example B20 for the diesel engine, the CO_2 emissions, considering the rest of vehicles (flex fuel, gasoline and alcohol), would totalize 14.40 Mton of CO_2, which mean 8.56% less. This low reduction occurs because most of vehicles produced in Brazil are *flex fuel*. For this reason, there is interest of the developed countries in replacing not only diesel by biodiesel fuel, but also gasoline by other biofuels. This is in accordance with the intention announced in January 2007, by the president of the United States, of replacing 20% of the consumed gasoline by biofuels too [27].

The increase of the Brazilian diesel fleet from 2000 to 2007 was approximately 115,000 vehicles per year [6]. Considering this growth rate, by 2015 the country will have 1,710,000 diesel vehicles, and, by 2025, 2,860,000 diesel vehicles. The amounts of CO_2 expected to be released by the national diesel fleet will be 826.2 Mton in 2015, and 2302.8 Mton in 2025. Table 7 and Fig. 11 show details regarding these projections.

With B5, the projections on reduction of CO_2 are 351.3, 793.8, 1414.2 and 2202.5 Mton for 2010, 2015, 2020 and 2025 years, respectively. With B20, the projections on reduction are 308.2, 696.6, 1241.0 and 1941.5 Mton for the same years, respectively. Fig. 12 shows the reductions on emissions.

Finally, it has been evidenced in 2007 that Brazil has become self sufficient in petroleum, and this happened in a moment of strong world demand, in which the price of a barrel attained a historical peak of USD 125 in June 2008. The environmental gains of using biodiesel are clearly evident, as demonstrated in this paper. It is expected that the Brazilian

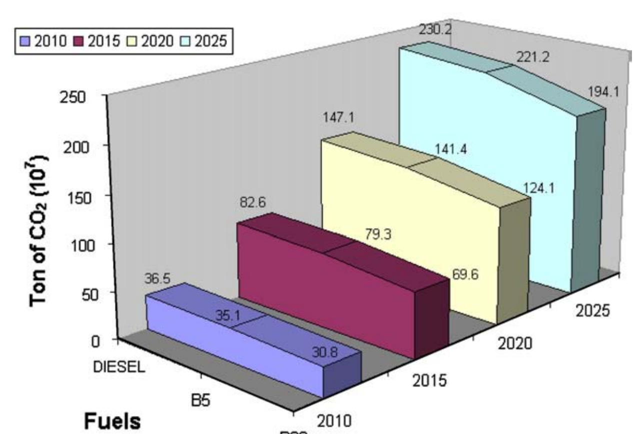

Fig. 12 – Projections on CO_2 reduction between the years 2010 and 2025.

self-sufficiency in petroleum and the production of biodiesel can alleviate the current fuel prices.

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