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Ecological efficiency in CHP: Biodiesel case

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ABSTRACT

This paper evaluates and quantifies the environmental impact resulting from the combination of biodiesel fuel (pure or blended with diesel), and diesel combustion in thermoelectric power plants that utilize combined cycle technology (CC). In regions without natural gas, the option was to utilize diesel fuel; the consequence would be a greater emission of pollutants. Biodiesel is a renewable fuel which has been considerably interesting in Brazil power matrix in recent years. The concept of ecological efficiency, largely evaluates the environmental impact caused by CO_2, SO_2, NO_x and particle matter (PM) emissions. The pollution resulting from biodiesel and diesel combustion is analyzed, separately considering CO_2, SO_2, NO_x and particulate matter gas emissions, and comparing them international standards currently used regarding air quality. It can be concluded that it is possible to calculate the qualitative environmental factor, and the ecological effect, from a thermoelectric power plant utilizing central heat power (CHP) of combined cycle. The ecological efficiency for pure biodiesel fuel (B100) is 98.16%; for biodiesel blended with conventional diesel fuel, B20 (20% biodiesel and 80% diesel) is 93.19%. Finally, ecological efficiency for conventional diesel is 92.18%, as long as a thermal efficiency of 55% for thermoelectric power plants occurs.

1. Introduction

In the last three decades the world has been confronting an energy crises caused by the decrease of fossil resources, the increase of environmental problems and the cost of derivates. This situation resulted in a search for alternatives and renewable fuels, which can not be only sustainable, but also environmentally friendly and techno-economically competitive.

Thermoelectric power plants which utilize both natural gas and diesel as fuels, can cause problems to the environment; their generated components cause damage to the human life, animals and plants. The main components generated from their combustion are carbon oxides (CO and CO_2), sulphur oxides (SO_2 and SO_3) nitrous oxides (NO and NO_2, denoted by NO_x). There are other components that cause the same damage during combustion; particle matter (PM) – among other pollutants – shows a higher level of risk to the environment that can change soil temperature and influence plant growth. CO_2 emission is directly linked to the greenhouse effect. The negative consequences of SO_2 can be seen in acid rain formation (with a NO_x contribution). There are other hazardous components present in the combustion of any fuel matter, such as heavy metals, dioxins, etc., which are harmful to the environment even in small concentrations [1].

A comparative analysis of biodiesel and diesel combustion pollution, in a thermoelectric power plant, utilizing combined cycle technology is performed, and an examination of each CO_2, SO_2, NO_x and PM emissions is made, comparing international air quality patterns, according to [2]. The methodology proposed analyzes thermoelectric power plant efficiency from an ecological standpoint, for the concentrations from the emitted gases (CO_2, SO_2, NO_x and PM). The ecological efficiency parameter (ε), was proposed by [1] for steam cycles using charcoal, and was extended by [3], for plants using a combined cycle and natural gas, internal combustion engines, and advanced cycles using biomass as fuel. The pollutant indicator, with which ecological efficiency (ε) is obtained, is a specific parameter to evaluate the environmental impact of thermoelectric power plant gas emissions, considering the combustion of 1 kg of fuel not the amount of exhaust gases released by the generated power unit [1,4]. For that reason, this parameter works directly with emission factor of pollutant.

Biodiesel, bio-fuels and bio-oils processed from biological materials such as vegetable oils, recycled cooking oils, animal fat, plant and forest waste products, are fuels that can be blended with petroleum oil distillates to be used in transportation engines, space heating and industrial processes to offset increasing energy demand. Biodiesel has diesel-like properties, but does not contain undesirable constituents, such as sulphur, nitrogen and polycyclic

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aromatic compounds. The product, in its purest form, is derived from transesterification of pure vegetable oils such as soybean, rapeseed and cottonseed oils, although post-consumer waste vegetable oils can also be used [5].

There is very little information about biodiesel utilization in gas turbine engines; however it is relevant to comment here on the investigation by [6] at the Japan Central Research Institute of Electric Power Industries on the combustion of palm methyl ester – PME (biodiesel), as an alternative fuel for gas turbines. Their results show that combustion characteristic of PME are similar to those of diesel fuel. Furthermore, it was indicated that NO_x emissions can be reduced by using PME instead of diesel fuel for gas turbines [6,7].

Briefly, the main purpose of this work is to calculate the ecological efficiency in CHP which uses biodiesel as fuel for gas turbines. In thus regard, a thorough search was made about emission factors from diesel burning and biodiesel mainly in Joule Brayton cycles. Data provided by [6] were very helpful at the end of the paper.

2. Pollutant emissions

In the Kyoto Protocol, Brazil committed not to increase its carbonic gas emissions, but the decision to solve the energy crisis by building a series of gas thermopowered combustors. The recent demand for gas and diesel generators as an energy alternative only serves to increase the greenhouse effect. Countries are concerned about global heating and the pollution; Denmark, for instance, are extinguishing thermopower installations. Opposing the decision of other powerful nations, Brazil's Thermopower Priority Plan (TPP) proposes the installation of tens of thermopower plants. It is said that the environmental impact of thermopower plants refers to the gaseous pollutant emissions to the atmosphere, the use of cooling water for steam condensation, among others, the disposal of oil and chemical reagents, electromagnetical emissions and ashy infected waters. In 20 year's time, Brazil would launch 87 million tons of additional carbons into the atmosphere [8].

Environmental impact studies of thermopower plants must be made, taking into consideration the following pollutants [9]: nitrogen oxides (NO_x), carbon monoxide (CO_2), sulphur dioxide (SO_2), particulate matter (PM), volatile organic compounds (VOC) and total organic compounds (TOC-hydrocarbons).

2.1. Emission standards

Air quality and pollution emission standards are determined by the effects of the pollutants on human beings, animals, plants and materials, as a result of the release of the pollutants into the atmosphere. Fuel oil, charcoal and natural gas, burning in thermoelectric power plants for producing energy, are considered to be the largest sources of SO_X, NO_x, CO_2, C_xH_x and particulate matter, which are directly related to the quality and type of fuel used. In Brazil, little attention has been given to this subject. The CONAMA 008/90 Resolution (National Environmental Council), establishes maximum SO_2 and total particle emission limits (emission standards) for external combustion processes in fixed sources. For the other fuels, the decision on maximum emission limits is being made by the Environment State Agencies. This resolution ranges only the sulphur oxides and particulate, without mentioning NO_x emissions. Table 1 presents Brazilian air pollutant emission standards, according to the CONAMA 008/90 Resolution.

Table 1
Pollutant emission standards (CONAMA 008/90 Resolution).

Classes	Power (MW)	SO_2 (g/million kcal)	Total particulate (g/million kcal)	
			Fuel oil	Charcoal
I	<70	2000	120	–
II	<70	5000	350	1500
III	>70	2000	120	800

The international data use due to the fact that the Brazilian NO_x emission standards are non-existent, and for the other pollutants these standards are very low. Thus, the standards of the European community, Austria and Japan are taken as they are more rigorous. However, it must be acknowledge that when we adopt the international standards we forget that they are based upon continuous pollutant gas monitoring mechanisms, depending upon the operation and type of the industrial plant. According to the CONAMA (National Environment Council) Resolution n 3, June 28, 1990, the value permitted for particulate matter (PM) concentration is 150 $\mu g/m^3$, but in some countries carbon taxes have been adopted, penalizing those who release high CO_2 concentrations, stimulating its reduction and establishing its maximum emission limit.

2.2. The equivalent carbon dioxide

The coefficient for equivalent carbon dioxide $(CO_2)_e$, (a hypothetical pollutant concentrations factor), is determined by Eq. (1) [1,4]. For the calculation of this coefficient, the maximum value allowed for the CO_2 concentration is divided by the corresponding air quality standard for NO_x, SO_2 and PM in 1 h. The expression for $(CO_2)_e$ is:

$$(CO_{2)_e} = (CO_2) + 80\ (SO_2) + 50\ (NO_x) + 67\ (PM) \quad (1)$$

In Eq. (1), $(SO_2)_e = 80(SO_2)$ is the sulphuric dioxide equivalent in (CO_2), $(NO_x)_e = 50(NO_x)$ is the nitrogen dioxide equivalent in (CO_2) and the particulate matter equivalent in (CO_2) is (PM)e = 67 (PM). The best fuel from an ecological standpoint is that which presents a minimum amount of $(CO_2)_e$ released from its burning process. In order to quantify this environmental impact, the pollutant indicator (Π_g) is defined by

$$\prod\nolimits_g = \frac{(CO_2)_e}{Q_i}, \quad (2)$$

where $(CO_2)_e$ is taken in kg/kg (kg/kg of fuel), Q_i is the fuel low heating value (LHV), expressed in MJ/kg, and Πg is expressed in kg/MJ.

2.3. Ecological efficiency

The ecological efficiency is defined as an indicator which allows the evaluation of thermoelectric power plant performance, according to pollutants emission, by comparing hypothetically integrated pollutants emission (CO_2 equivalent emissions), to existing air quality standards. Conversion efficiency is also considered a determining factor for specific emissions; it is expressed by a fraction. Eq. (3) can be used for the determination of ecological efficiency [1,4,8,10]:

$$\varepsilon = \left[\frac{0204\,n}{n + \prod_g} ln\left(135 - \prod\nolimits_g\right)\right]^{0,5} \quad (3)$$

where ε comprises, in a single coefficient, the aspects that define the thermoelectric unit environment impact intensity: fuel composition, combustion technology, pollutant indicator and thermodynamic efficiency. "ε" is directly proportional to thermoelectric power plant efficiency (η), inversely proportional to Π_g, the pollutant indicator value and also alternates between 0 and 1, similar to the thermoelectric efficiency. The situation is considered to be ecologically unsatisfactory when $\varepsilon = 0$; however, $\varepsilon = 1$ indicates an

Table 2
Fuel virtual characteristics.

Fuel	S (%)	CO_2 (kg/kg fuel)	Q_i (MJ/kgf)	Π_g (kg/MJ)	ε
Hydrogen	–	0	10.742	0	1
Sulphur	100	1400	10.450	134	0

ideal situation for standards of energy efficiency. For a better comprehension of this parameter, according to the fuel classification about two virtual fuels (hydrogen and sulphur), pure hydrogen would have no impact in the environment (if one considers that all the hydrogen reacts like water, ignoring the possible formation of NO_x due to high temperatures in the combustion equipments), while sulphur would cause 100% of impact; see Table 2 for details.

2.4. The case of carbon in biodiesel

CO_2 is different comparing to other pollutant agents. The emissions generated by biodiesel during the combustion in internal combustion engines, or boilers, are recyclable through vegetable photosynthesis. CO_2 is released into the atmosphere when biodiesel is burned and it is recycled by growing plants, which are later processed into the fuel. Hence, biodiesel also helps to mitigate global warming [11].

Using biomass (vegetal oils), for energy generation also releases CO_2. However, this biomass is derived from plants that consumed the same amount of the gas during their growth that will be returned to the atmosphere after its final use. The main reason for the use of bio-fuels is to decrease emissions of gaseous pollutants to the atmosphere (mainly CO_2 emissions), purposing the goals of the Kyoto Protocol. As already indicated, using biodiesel equals decreased global emissions.

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 conventional diesel. Therefore, using B100 (biodiesel pure form) results in 0.635 ton of CO_2 by m^3 biodiesel.

Using the 1998 biodiesel life cycle study, Table 3 and Fig. 1 summarizes CO_2 flow from the total life cycles of biodiesel, petroleum diesel and total CO_2 released at the tailpipe for each fuel. The combustion of fuel is the main source of CO_2 for both petroleum and biodiesel life cycle. For petroleum diesel, CO_2 emitted from the tailpipe represents 86.54% of the total CO_2 emitted across the entire life cycle of the fuel. Most remaining CO_2 comes from emissions at the oil refinery, which contribute 9.6% of the total CO_2 emissions. For biodiesel, 84.43% of CO_2 emissions occur at the tailpipe. The remaining CO_2 comes almost equally from soybean agriculture, soybean crushing, and soy oil conversion to biodiesel [11].

The American study applies perfectly to the situation in Brazil, since that the biodiesel that will be used in Brazilian thermoelectric power stations is produced by transesterification with methanol and soybean oil, the same components of biodiesel studied in the analysis of the American biodiesel life cycle.

3. Methodology

Efficiency values of thermoelectric plant ecology in Brazil, estimated for biodiesel (pure and blended with diesel) and diesel and the characteristics of these fuels are examined next.

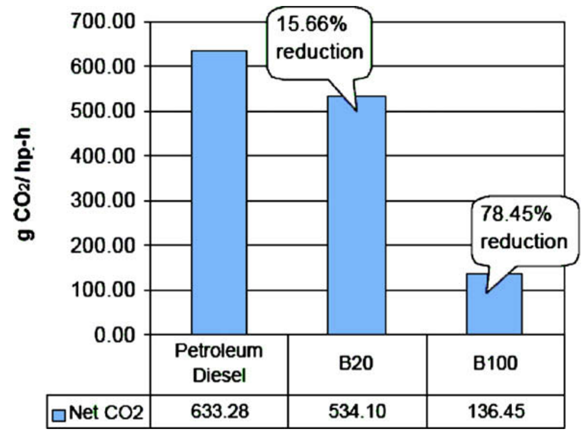

Fig. 1. Comparison of net CO_2 life cycle emissions for petroleum diesel and biodiesel blends [11]. 1hp-h = 0.745 kW-h.

3.1. Diesel

In Brazil, diesel fuel consumption is attributed to the transport sector, which represents 80% in the energy matrix. From this total, 94% is destined for the road transport system. Compared to American and European consumption, Brazilian oil diesel shows a high sulphur level. Since January 1998, the national diesel fuel has 0.5% sulphur content at the most [12]. When diesel fuel is used, the main pollutants are carbon dioxide, sulphur oxides and particulate material.

The traditional chemical formula for petroleum diesel is $C_{12}H_{26}$, with its density being 0.864 ton/m^3 [13]. The combustion reaction for normalized air excess α follows:

$$1\ C_{12}H_{26} + 18.5\ \alpha O_2 + 69.56\ \alpha N_2 \rightarrow 12\ CO_2 + 13\ H_2O + 69.56\ \alpha N_2 + 18.5\ (\alpha - 1)O_2 \quad (4)$$

Adopting diesel burning with 100% air excess (typical excess air ratio in gas turbine combustion), after the stoichiometric balance, a percentage in the mass of each compound resulting from this reaction is: 10.058% CO_2, 4.458% H_2O, 74.206% N_2 and 11.278% O_2 (Table 4). On the other hand, from its combustion reaction, the result is: 528 g CO_2 for 170 g (molecular mass). Taking into account the diesel density, the result is: 528 tons of CO_2 for 196.76 m^3 of oil diesel, or: 2.683 tons of CO_2 for m^3 of oil diesel [14].

Applying the mass percentage of each compound, it is possible to compose an equation for the specific heat (Cp) of the exhaustion gases, in the case of diesel combustion [15]. Fig. 2 shows the values in function of the temperature

$$Cp_D = 1.0039562 + \frac{3.39987 \times T}{10^5} + \frac{3.02996 \times T^2}{10^7} - \frac{1.3168 \times T^3}{10^{10}} \quad (5)$$

3.2. Biodiesel (methyl ester)

Chemically, biodiesel is composed of monoalkyl esters of long chains, and fatty acids derived from renewable feed stock like

Table 3
Tailpipe contribution to total life cycle CO_2 for petroleum diesel and biodiesel (g CO_2/hp-h) [11]. 1hp-h = 0.745 kW-h.

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%

Table 4
Combustion products (mass percentage).

Products (%)	Diesel	B5	B20	B50	B100
CO_2	10.058	10.088	10.177	10.355	10.652
H_2O	4.458	4.453	4.438	4.408	4.358
N_2	74.206	74.185	74.121	73.992	73.778
O_2	11.278	11.274	11.265	11.245	11.212

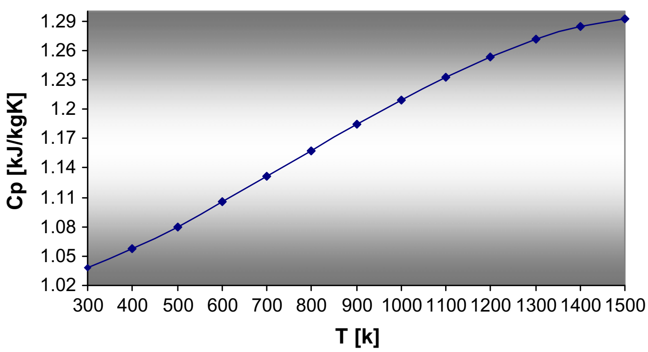

Fig. 2. Diesel specific heat in function of the temperature.

vegetable oils and animal fats. It is produced by transesterification, in which oil or fat is reacted with a monohydric alcohol in the presence of a catalyst. The biodiesel is used in compression ignition engines (diesel engines) or heating boilers. In general, biodiesel fuel has the same, or similar, properties as conventional diesel fuel and it can be blended in any percentage with diesel fuel.

Biodiesel presents a slightly lower heating value (LHV) in comparison to diesel fuel (37.42 MJ/kg, instead of 42.3 MJ/kg). Its kinematic viscosity, in general, varies between 3 and 6 mm^2/s; this parameter does differ little from the values corresponding to diesel fuel. Its density is approximately 880 kg/m^3 at 15 °C and its flash point is approximately 164 °C, which is higher than the value for diesel fuel, whose flash point is approximately 76 °C. The flash point makes biodiesel safer to manipulate and to transport [16,17]. Biodiesel has a cetane number slightly higher than diesel fuel; it has a high lubricating power. When added to regular diesel fuel in amounts of 1–2%, it can convert fuels with poor lubricating properties, such as modern ultra-low-sulphur diesel fuel, into an acceptable fuel [18].

Biodiesel shows a wide variety of advantages over its fossil origin partner (diesel fuel). Today, biodiesel is becoming a serious competitor in the energy market, which ecological benefits that represents must also be considered. Biodiesel is composed of a wide variety of fatty acids.

The molecular composition of PME (palm biodiesel), is $C_{19}H_{38}O_2$ [6]. Its combustion reaction for normalized air excess α follows:

$$C_{19}H_{38}O_2 + 27.5\ \alpha O_2 + 103,4\ \alpha N_2 = 19\ CO_2 + 19\ H_2O + 103,4\ \alpha N_2 + 27.5\ (\alpha - 1)O_2 \qquad (6)$$

Again, considering combustion with 100% air excess, the mass percentage of each compound resulting from this reaction is: 10.652% CO_2, 4.358% H_2O, 73.778% N_2 and 11.212% O_2 (see Table 4). Taking into account density of palm methyl ester, 0.88 ton/m^3 [17], the result is: 836 tons of CO_2 by 338.64 m^3 of biodiesel, which means 2.469 tons of CO_2 by m^3 of biodiesel [14].

As in the previous cases, it is possible to obtain an equation for the *Cp* of the biodiesel exhaust gases. Fig. 3 presents the values of *Cp* as functions of temperature

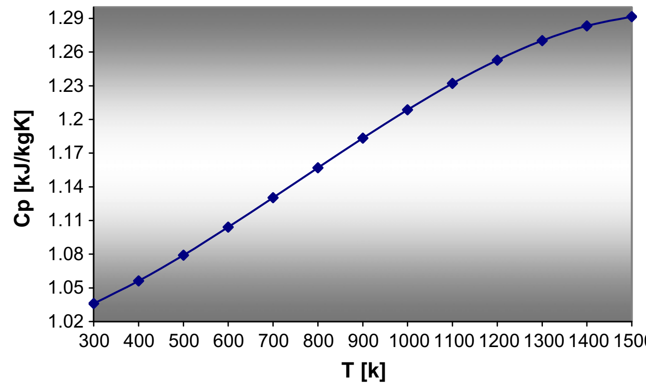

Fig. 3. Biodiesel specific heat in function of the temperature.

$$Cp_{\text{Biodiesel}} = 0.999949 + \frac{4.34391 \times T}{10^5} + \frac{2.94462 \times T^2}{10^7} - \frac{1.29221 \times T^3}{10^{10}} \qquad (7)$$

3.3. Biodiesel and diesel emissions

Biodiesel is basically composed of methyl or ethyl esters, containing several alkyl groups with C15–C17 hydrocarbon chains, collectively known as fatty acid alkyl esters [5]. The use of biofuels can play a vital role in helping developed and developing countries to reduce the environmental impact of fossil fuels. The main goal for the use of bio-fuels is to decrease emissions of gaseous pollutants to the atmosphere, mainly CO_2 emissions. As already indicated, the use of biodiesel includes a decrease in global emissions.

A 100% sulphur dioxide reduction is reasonable; taking into account that biodiesel, by its vegetal origin, does not contain sulphur. For example, CO emissions for biodiesel combustion in diesel engines are 40–50% lower than emissions from conventional diesel fuel; this is due to the presence of oxygen molecules, mainly in the methyl or ethyl ester in biodiesel, helping to achieve complete combustion. On the other hand, CO and THC emissions levels for gas turbines fueled with biodiesel (PME), are less than 2 ppm in all cases, for both fuels (diesel and biodiesel). In others words, fuel combustion efficiency was nearly 100% for all cases. (Fluctuation of CO or THC was not observed for all cases, for more details, see the Fig. 4 elaborated by [6].)

According to [6] the emissions about of the combustion performances of a palm methyl ester – PME (biodiesel) and diesel using an experimental apparatus for combustion experiment with a gas turbine were investigated. In the combustion experiment, no differences were observed in the ignition characteristics of both fuels. In the PME, the region of the luminous flame was smaller and less bright than in the diesel fuel. In addition, no soot accumulation is observed; PME has oxygen but no aromatic ring in the molecule. It can also be seen that, over the entire range of excess air ratios, the NO_x emission level for PME is lower than for diesel fuel; on the other hand, it was found that, for both fuels, NO_x emission levels increase with decreased atomizing pressure and fuel kinematic viscosity [6]. For details, see Fig. 4.

The emission values in gas turbines (in laboratory scale) for NO_x level is 36 ppm (12% O_2) for diesel and 27 ppm (12% O_2) for PME (biodiesel); the decreased percentage of diesel to biodiesel is 25% [6]. The same percent ratio will be applied for NO_x emissions in gas turbines for thermoelectric power plants.

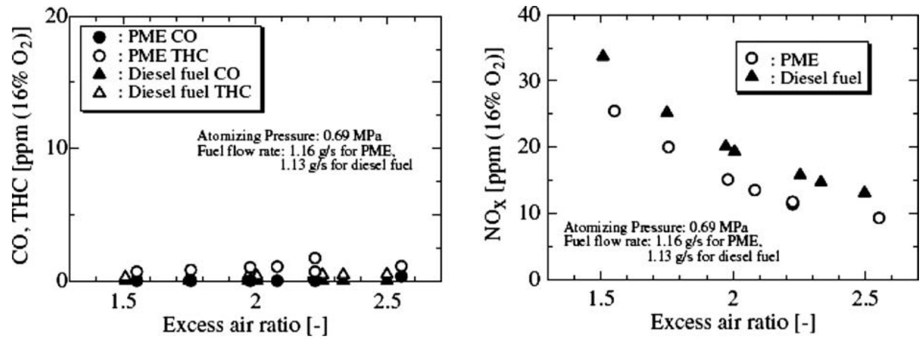

Fig. 4. CO and THC mole fraction as a function of excess air ratio; NO_x emissions as a function of excess air ratio [6].

Table 5
Comparison of results of pollutant emissions between fuels analyzed in CHP.

Pollutant emission kg/kg of fuel	Diesel	Biodiesel B5	Biodiesel B20	Biodiesel B50	Natural gas[a]	Biodiesel B100	Diesel/B100
$(CO_2)_e$	4.126	3.581	3.445	3.159	2.769	0.853	4.8 times
PM	1389×10^{-6}	1340×10^{-6}	1194×10^{-6}	903×10^{-6}	304×10^{-6}	417×10^{-6}	3.3 times
NO_x	2777×10^{-6}	2743×10^{-6}	2638×10^{-6}	2430×10^{-6}	856×10^{-6}	2083×10^{-6}	1.3 times
SO_2	9861×10^{-6}	9368×10^{-6}	7888×10^{-6}	4930×10^{-6}	25.32×10^{-6}	–	–
CO_2	3.1058	2.9807	2.6093	1.8705	2.7038	0.6568	4.7 times
Total (kg/kg of fuel)	3.1100	2.9942	2.6211	1.8788	2.7049	0.6593	4.7 times

[A] [8,19].

4. Ecological efficiency calculation

Table 5 shows a comparison between the fuels analyzed (biodiesel, pure and blended, diesel fuel and natural gas), for a thermoelectric power plant. In Fig. 5 shows the ecological efficiency values for the two fuels analyzed and, finally, Fig. 6 shows the ecological efficiency values in the function of thermoelectric power plant efficiency. The values for emissions of natural gas in gas turbines were obtained in [8,19].

5. Results and conclusion

In relations to CO_2 emissions (according to the fuel type in tons of CO_2 for m^3), it is observed that biodiesel (B100), emits fewer CO_2 emissions into the atmosphere, and the one that releases is diesel fuel. Biodiesel presents a similar situation in relation to diesel fuel. In fact, biodiesel emits similar quantities of CO_2 as does conventional fuel, but, as most of it being from renewable carbon stocks the fraction is not counted towards the greenhouse gas emissions from the fuel. However, biodiesel has more oxygen molecules than diesel fuel. Therefore, the combustion process is more complete

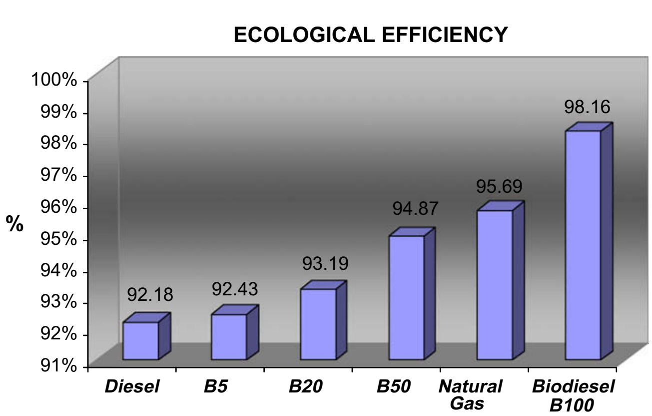

Fig. 5. Diesel, biodiesel B100 and biodiesel B20 ecological efficiency.

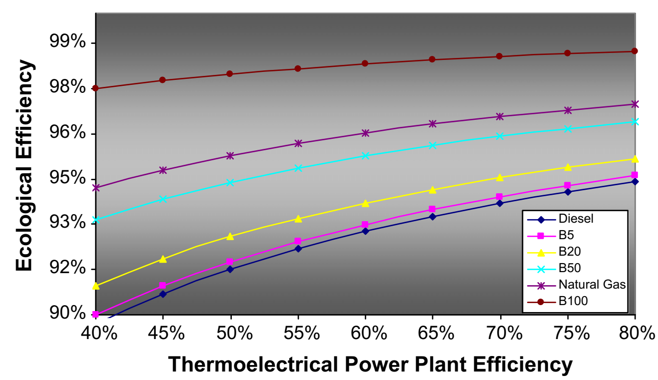

Fig. 6. Ecological efficiency variation in function of thermoelectric power plant efficiency. (Ecological efficiency of natural gas was obtained by [8]).

and, consequently, there is a reduction in CO emissions. The CO_2 released by petroleum diesel was fixed in the atmosphere during the earth's formative years, whereas the CO_2 released by biodiesel is continuously fixed by plants and may be recycled by the next crops generation. Therefore, the main advantage of biodiesel is that CO_2 emissions can be considered recycled by growing plants. Now the emission levels using this type of bio-fuel are 78.45% lower in comparison to diesel fuel. The calculated parameter is 0.578 tons of CO_2/m^3 of biodiesel (B100).

Thus, it can be concluded for the air quality standards adopted in this study, the use of biodiesel (pure or blended, B100, B50 or B5) can be noted as a renewable fuel, as well as the use of the combined cycle (CC) represents an excellent option on the ecological point of view.

The emission levels of a thermoelectric power plant using biodiesel (B100) and a thermal plant using diesel are, respectively: 417×10^{-6} and $1\,389 \times 10^{-6}$ kg/kg of fuel for the PM; 0.00 and $9\,861 \times 10^{-6}$ kg/kg of fuel for the SO2; 0.657 and 3.1059 kg/kg of fuel for the CO2; $2\,083 \times 10^{-6}$ and $2\,777 \times 10^{-6}$ kg/kg for the NO_x. Total emissions for a diesel thermoelectric power plant, in comparison with a biodiesel (B100) plant, are respectively 4.7 times, based in kg/kg of fuel. In terms of ecological efficiency, the characteristics of a thermoelectric power plant utilizing biodiesel (B100) and a plant using diesel are 98.16% and 92.18% respectively.

At present, the most promising blend is the mixture of 20% biodiesel and 80% diesel, by volume (commonly known as B20 blend). Regardless of the source and the process involved to produce biodiesel, the neat product, or B100, is required to meet ASTM D 6751 specifications to ensure its acceptable performance as a blending stock, as well as on engines. Hence, the emission levels of a thermoelectric power plant using biodiesel (B20) and a thermal plant are 1194×10^{-6} kg/kg of fuel for the particulate matter; 7888×10^{-6} kg/kg of fuel for the SO_2; 2.6093 kg/kg of fuel for the CO_2; 2639×10^{-6} kg/kg for the NO_x. In terms of ecological efficiency, the characteristic of a thermoelectric power plant utilizing biodiesel (B20) is 93.08%. The study shows that the use of biodiesel pure (B100), and B20 as alternative fuel is preferable to diesel, presenting higher values of ecological efficiency. Seen from the above findings, PME (biodiesel) is a promising alternative fuel for gas turbines.

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