18th Brazilian Congress of Thermal Sciences and Engineering
November 16-20, 2020 (Online)

ENC-2020-0483
CHARACTERIZATION OF DIESEL AND BIODIESEL BLENDS AND ESTIMATED SPRAYS CHARACTERISTICS PRODUCED BY THE INJECTOR OF DIESEL GENERATOR

Gabriel Baldin Nogueira, baldin.nogueira@unesp.br [1]
Claudia Gonçalves de Azevedo, claudia.azevedo@unesp.br [1]

[1]Universidade Estadual Paulista "Júlio de Mesquita Filho" – Campus Experimental de Rosana – Avenida dos Barrageiros, 1881, Primavera, SP, Brasil.

Abstract. *Growing concerns about electric energy prices and the search for emergency solutions in eventual cases of power failure arouse the interest of the scientific and industrial community for the use of generators in various segments of society such as industries, hotels, gas stations and hospitals. From the burning of diesel oil in internal combustion engines, generators can produce electricity at competitive prices, producing, however, a high amount of pollutants emissions. The biodiesel usage has presented a promising potential as an additive to the diesel oil, both for its renewable characteristic and the considerable reduction both for its renewable characteristic and for the considerable reduction that it causes in the levels of pollutant emissions produced by the diesel cycle engines. Thus, the present work aims to determine the main physical-chemical properties of diesel (S500) and soybean and bovine tallow biodiesel blends with different concentrations. Such properties will be used to determine the theoretical droplet diameters and theoretical spray cone angles produced by the injector of the system, such as the thermal power of the combustion system.*

Keywords: *Generators, diesel, biodiesel, energy efficiency*

1. INTRODUCTION

Growing concerns about electric energy prices and the search for emergency solutions in eventual cases of power failure arouses the interest of the scientific and industrial community for the use of generators in various segments of society such as industries, hotels, fuel stations and hospitals.

For industries with medium and high voltage power supply, the possibility of installing generator sets independent of the concessionaire's energy, due to the irregularity of the power supply, is a viable alternative since it allows the production to continue uninterrupted. This generation model is called Distributed Generation (GD).

According to the National Institute for Energy Efficiency (2013), the basic principle of DG consists to add small or medium-sized generation, from the use of alternative energy sources, based on different technologies in distribution and transmission systems. Due to the proximity of the load and generation, the distributed generation presents advantages for both consumers and transmission and distribution companies, since, it occurs the reduction of losses along the generation-load path, less investment in networks and also a smaller time for implementation (Santos; Santos, 2008).

Among the commonly technologies used for GD, diesel generators are usually employed by users who require a higher degree of reliability of electric power generation, since it is most robust in the scope of generation when compared with other technologies such as photovoltaic systems that can suffer intermittence and are easily affected by climatic variations.

From the burning of diesel oil in internal combustion engines, generators are able to produce electricity at competitive prices, producing, however, a high amount of pollutants emissions. In this context, the biodiesel has presented a promising potential as an additive to the diesel oil, both for its renewable characteristic and the considerable reduction that it causes in the levels of pollutant emissions produced by the diesel cycle engines.

Since biodiesel has physical and chemical characteristics similar to those of diesel, it can be used in diesel engines (compression ignition), without the need for adaptations in these engines (Tolmasquim, 2003). Because of such similarities, biodiesel can replace totally or partially in a blend, the diesel oil used in trucks, tractors, automobiles, generators, among others.

The fuel atomization is a very important process in diesel engines, since a larger surface area is produced, reducing the fuel vaporization time, resulting in better mixing and increasing the time available for complete combustion (Lefebvre, 1983).

Diesel injectors, are the best-known example of a plain orifice injector. In plain-orifice injectors the disintegration of the fuel jet into drops is promoted by an increase in the flow velocity, which increases the turbulence level in the issuing jet and the aerodynamic drag forces exerted by the surrounding medium, it is opposed by an increase in the fuel viscosity which delays the onset of atomization by resisting breakup of the ligaments (Lefebvre, 1989).

Since the liquid fuel atomization process plays a decisive role in several essential aspects of combustion, in the last decades the study of the biodiesel atomization and injection process has become one of the main research areas for the addition of portions of biodiesel to diesel.

Subramanian *et al*,. (2007) studied the injection and spray characteristics (SMD and cone angle) of a diesel engine with a nominal power of 7.4 kW for the use of different blends of karanja biodiesel (B10 and B20). The spray cone angle found for the mixtures (B10 and B20) was smaller than for diesel due to the higher density of biodiesel mixtures. However, the cone angle is greater than that of the diesel close to the TDC (Upper Neutral).

Faria *et al*., (2010) analyzed the effects of using pure castor and soy biodiesel and mixtures with diesel oil on the atomization quality in a combustion chamber of a diesel cycle engine using a common-rail injection system. The authors found that in all operational situations there is a tendency to increase the SMD as the biodiesel content in the mixture increases, however there was no variation in the cone angle as a function of the fuel used.

Lahane *et al.* (2015) carried out a comparative study of the effect of different biodiesel-diesel mixtures (B5, B10, B15, B20, B25, B50 and B100) on the injection, spraying, combustion, performance and emissions of a direct injection diesel engine at constant speed (1500 rpm). The authors concluded that the spray cone angle is smaller for biodiesel-diesel mixtures than for diesel due to the higher density of biodiesel-diesel mixtures than diesel, and that the Sauter Mean Diameter (SMD) is greater for the biodiesel-diesel blends than for diesel due to the higher density, viscosity and surface tension of biodiesel-diesel blends.

Since biodiesel can be used as an additive to diesel oil presenting both economic and environmental advantages, the present work aims to determine the main physico-chemical properties of diesel (S500) and soybean and bovine tallow biodiesel blends in different proportions. Such properties will be used to determine the theoretical droplet diameters and the theoretical cone angles of the sprays produced by the system injector.

2. MATERIALS AND METHODS

The spray characteristics are strongly affected by the physicochemical properties of the liquid that will be atomized. The most important properties are density, viscosity and surface tension (Lefebvre, 1989).

In order to determine the theoretical droplet diameter and theoretical spray cone angles for each blend analyzed, will be determined the properties for blends composed by oil-diesel (D) and soybean and bovine tallow biodiesel (B). The blends to be analyzed are shown in Table 1. The fuel blends were obtained taking into account the mass percentagens of each fuel resulting in 9 blends with 150mL (Figure 1).

Table 1. Blends fuel.

Sample	Percentage (%)
D100	100
D90 – B10	90 – 10
D80 – B20	80 – 20
D70 – B30	70 – 30
D60 – B40	60 – 40
D50 – B50	50 – 50
D40 – B60	40 – 60
D30 – B70	30 – 70
D20 – B80	20 – 80
D10 – B90	10 – 90
B100	100

Figure 1. Diesel and biodiesel blends.

2.1. Characterization of blends

In order to determine the blends densities was used the Gay-Lussac type pycnometer (Fig. 2a), to determine the blends dynamic viscosities was used the Ostwald Cannon Fenske viscometer (Fig. 2b) and to determination of the blends surface tensions was used the ring method (Fig. 2c).

a) Gay-Lussac pycnometer b) Ostwald Cannon Fenske viscometer c) Ring method

Figure 2. Equipment for fuel blends characterization.

2.2. Theoretical modeling of droplet diameters

Due to the random nature of the atomization process, the spray produced by an injector is composed of droplets with a great variability of diameters. Therefore, in order to characterize a spray with a single droplet diameter value, it is necessary to have some statistical function of the sizes of the measured droplets.

In combustion system the droplet size distribution is frequently characterized by its Sauter mean diameter (SMD), defined as the characteristic droplet diameter whose volume - surface area ratio is proportional to the volume - surface ratio of the entire spray (Lefebvre, 1989):

$$SMD = \frac{\sum N_i \cdot D_i^3}{\sum N_i \cdot D_i^2} \tag{1}$$

The models to be used in this study to determine the theoretical droplet diameters were proposed by Merrington and Richardson's (1947) and Tanasawa and Katoda (1955).

Merrington and Richardson's (1947) proposed a relationship to estimate the Sauter mean diameter (SMD) given by:

$$SMD = {500 \cdot d_0^{1,2} \cdot \upsilon_L^{0,2}} \Big/ {U_L} \tag{2}$$

being d_0 the discharge orifice diameter, m, υ_L the liquid kinematic viscosity, m^2/s and U_L the liquid velocity, m/s.

Tanasawa and Katoda (1955) proposed the following equation for to estimate the SMD:

$$SMD = 47 \cdot d_0 \cdot U_L^{-1} \cdot \left(\sigma \big/ \rho G \right)^{0,25} \cdot \left[1 + 331 \cdot \mu_L \Big/ \left(\rho_L \sigma d_0 \right)^{0,5} \right] \tag{3}$$

being d_0 the discharge orifice diameter, m, U_L the liquid velocity, m/s, σ the surface tension, kg/s^2, ρ_G the air density, kg/m^3, μ_L the liquid dynamic viscosity, kg.m/s, and ρ_L the liquid density, kg/m^3.

2.3. Theoretical modeling of spray cone angle

The spray cone angle depends of the injector characteristics, physical properties of the liquid (density, viscosity and surface tension) and environmental conditions (temperature and pressure). The spray cone angle is related to the penetration capability of the spray and, consequently, affects the mixture and vaporization processes, as well as the flame geometry.

The spray cone angle is defined as the angle formed by two straight lines drawn from the exit orifice to the outer periphery of the spray at a distance 60 d_0 downstream of the nozzle.

Among the several formulas to estimate the theoretical spray cone angle, the simplest equation is given by the jet mixing theory of Abramovich (1963):

$$\tan\theta = 0,13 \cdot \left(1 + \rho_A / \rho_L\right) \tag{4}$$

being θ the spray cone angle (°), ρ_A the air density, kg/m³ and ρ_L the liquid density, kg/m³.

Another equation presented in literature to determine the spray cone angle was proposed by Bracco *et al.* (1985):

$$\tan\theta = \left(2\pi / \sqrt{3A}\right) \cdot \left(\rho_A / \rho_L\right)^{0,5} \tag{5}$$

being θ the spray cone angle (°), A the relation relationship between the orifice length and orifice diameter, in this case, equal to 4.9, ρ_A the air density, kg/m³ and ρ_L the liquid density, kg/m³.

3. RESULTS AND DISCUSSION

The results obtained for the determination of the density for the different blends of diesel and biodiesel are presented in Figure 3 and Table 2.

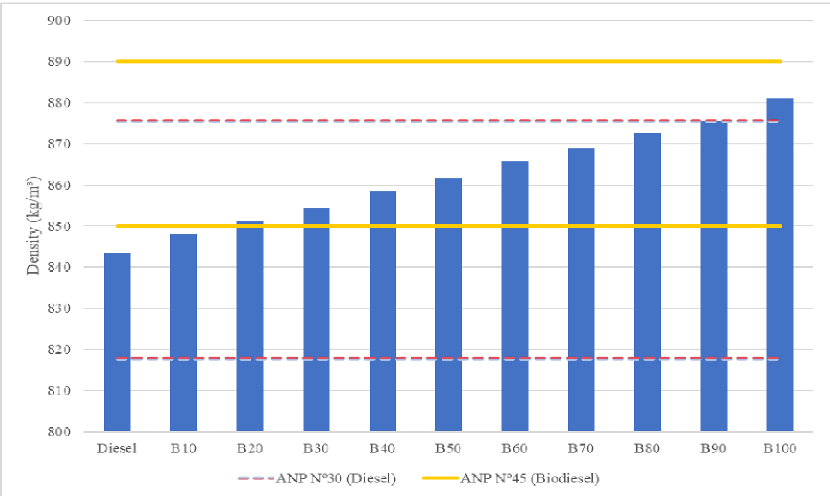

Figure 3. Density of the analyzed blends.

Table 2. Density of the blends.

Sample	Density (kg/m³)	Standard deviation (%)
D100	843.31	1.05
D90 – B10	848.05	1.79
D80 – B20	851.17	1.07
D70 – B30	854.19	0.59
D60 – B40	858.42	0.79
D50 – B50	861.55	1.15
D40 – B60	865.70	1.45
D30 – B70	868.77	1.40
D20 – B80	872.58	0.73
D10 – B90	875.51	1.39
B100	881.04	1.63

It is observed that the densisties of pure diesel and 100% biodiesel, do not obstruct the ANP resolution, that is, both fuels have acceptable rates for their commercialization and use. It appears that by increasing the percentage of biodiesel in fuel blends, there is an increase in density, as expected, given that biodiesel has a higher density than diesel.

It is observed that all the blends analyzed present density values within the values stipulated by ANP Nº45, which specifies the minimum and maximum values for the density of the commercial Diesel S500. Such results enable the use of blends in the motor-generator regarding this property. However, soybean and bovine tallow biodiesel (B100) showed values above the margin of the standard, even containing acceptable values for commercial biodiesel.

In general, the main effect of liquid density is the production of a more compact and penetrating spray, so that the influence of liquid density on the average droplet size is secondary (Lorenzetto and Lefebvre, 1977).

The results obtained for the determination of the viscosity the different blends of diesel and biodiesel are presented in Figure 4 and Table 3.

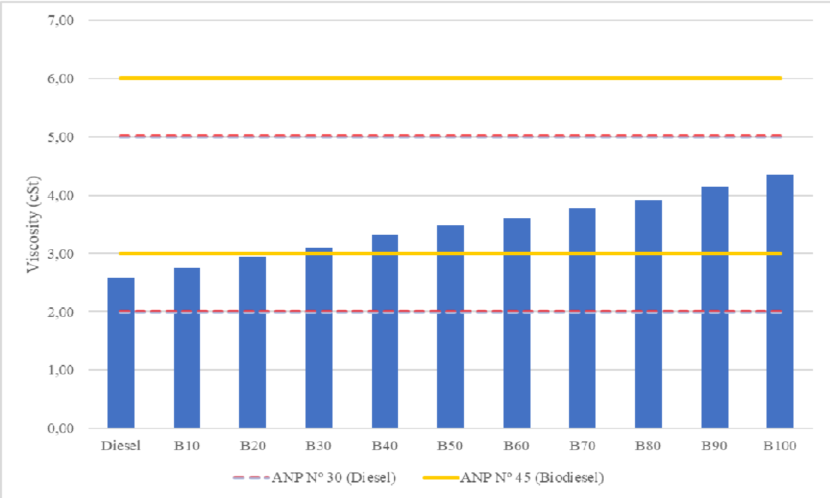

Figure 4. Viscosity of the analyzed blends.

Table 3. Viscosity of the blends.

Sample	Viscosity cinematic (cSt)	Standard deviation (%)
D100	2.59	0.036
D90 – B10	2.76	0.014
D80 – B20	2.94	0.026
D70 – B30	3.09	0.050
D60 – B40	3.32	0.025
D50 – B50	3.47	0.011
D40 – B60	3.60	0.024
D30 – B70	3.77	0.023
D20 – B80	3.91	0.019
D10 – B90	4.14	0.025
B100	4.34	0.013

It should be noted that viscosity is the main property that influences the atomization process.

According to Ejim *et al.*, (2007) viscosity values can represent up to 90% of the influence on the size of droplets generated, thus leaving the values of density and surface tension in the background for some theoretical models of droplet size. Viscosity directly influences the drop disintegration interval and the size of a spray droplet. By increasing the viscosity, there is an increase in the length of the undisturbed liquid sheet and in the penetration of the jet, the formation of waves is prevented, the turbulence is reduced, and, consequently, the production of spray with larger drops has to occur.

Lorenzetto and Lefebvre (1977) showed that any increase in viscosity causes an increase in the average diameter of the drops, which can be attributed to the increase in viscous forces, which tend to oppose the disintegration of the column of liquid in drops, both in the process primary as well as secondary atomization.

According to Shahir *et al.* (2014), the determination of viscosity values is important since there are minimum and maximum limits that a fuel can present to be used in an engine. For very low viscosities, leaks in the fuel system can occur mainly by the formation of very small droplets. For high viscosity, there may be, among others, greater formation of deposits in the engine, incomplete combustion, increased energy for pumping fuel and problems starting in cold climates.

The results obtained for the determination of the surface tension for the different blends of diesel and biodiesel using the ring method are presented in Table 4.

Table 4. Surface tension of the blends.

Sample	Surface tension (N/m)	Standard deviation (%)
D100	0.0340	0.0015
D90 – B10	0.0354	0.0006
D80 – B20	0.0358	0.0009
D70 – B30	0.0377	0.0004
D60 – B40	0.0384	0.0006
D50 – B50	0.0391	0.0005
D40 – B60	0.0397	0.0001
D30 – B70	0.0401	0.0002
D20 – B80	0.0405	0.0001
D10 – B90	0.0409	0.0005
B100	0.0416	0.0012

The National Agency of Petroleum and Biofuels does not stipulate in its resolution's limits or average values for the surface tension of diesel and biodiesel, thus there are no certain standards that can be used to compare this property.

It appears that an increase in the percentage of biodiesel in the mixtures leads to an increase in surface tension, since biodiesel has a higher surface tension than diesel.

The surface tension is an important property, since it represents the resistance force to the formation of a new surface area, so that a high surface tension represents a consolidating force, and, during the atomization process, it counteracts any distortion of the surface of the liquid (Lefebvre, 1989). When surface tension is increased, there is a delay in the formation of ligaments and drops, resulting in larger droplet sizes. The surface tension affects the spray cone angle, the droplet diameters and the operating pressure required for the atomizer.

It is verified that an increase in the biodiesel percentages in the blends with diesel leads to an increase in the densities, viscosities and surface tensions of the blends, since biodiesel presents the highest density, viscosity and surface tension. Higher densities, viscosities and surface tensions lead to a greater resistance of the fuel flow, which may hamper the atomization process.

Table 5 shows the estimated values for the theoretical droplet diameters and the spray cone angles.

Table 5. Theoretical droplet diameters and the spray cone angles.

Sample	Merrington and Richardson´s Model (μm)	Tanasawa and Katoda Model (μm)	Abramovich Model (º)	Bracco *et al.* Model (º)
D100	24.28	19.39	90.00	89.87
D90 – B10	24.66	20.09	90.00	89.87
D80 – B20	25.02	20.80	90.00	89.87
D70 – B30	25.32	21.40	90.00	89.87
D60 – B40	25.74	22.28	90.00	89.87
D50 – B50	26.03	22.88	90.00	89.87
D40 – B60	26.28	23.41	90.00	89.87
D30 – B70	26.57	24.08	90.00	89.87
D20 – B80	26.81	24.63	90.00	89.87
D10 – B90	27.17	25.53	90.00	89.87
B100	27.51	26.35	90.00	89.87

It is verified that an increase in the percentage of biodiesel leads to increase in the Sauter Mean Diameter, since blends with larger fractions of biodiesel present the higher densities, viscosities and surface tensions. It is known that the increase in density leads to an increase in droplet size since less interaction occurs with the atomizing air stream and a greater amount of air is required to obtain good atomization.

Likewise, increasing the viscosity causes an increase in droplet size, since increasing the viscosity causes an increase in undisturbed liquid sheet length and jet penetration, prevents wave formation, reduces the turbulence, and consequently, the production of spray with larger droplets.

It is also known that an increase in the surface tension also leads to an increase in droplet size, once occurs an increase in fluid resistance to a shear force and an increase in surface tension also leads to an increase in droplet size, once a high surface tension represents a consolidation force and during the atomization process counteracts any distortion of the surface of the liquid so that by increasing the surface tension there occurs a delay in the formation of ligaments and droplets resulting in larger sizes of drops.

It is verified that the theoretical diameters obtained by both models present close values. The difference between the obtained values for both models can be explained by the fact that the Tanasawa and Katoda Model take into account, in addition to viscosity, the density and the surface tension. Thus, the results obtained by the Tanasawa and Katoda Models are more accurate than those found by Merrington and Richardson's Model.

Regarding the theoretical cone angles the results obtained by both models are very close, since both models take into account only the liquid density. It is verified that the fraction of biodiesel in the blends does not change the spray cone angles obtained since the influence of the density under the cone angle is negligible.

4. CONCLUSIONS

In the present work, the main physical and chemical properties of different blends of S500 diesel and biodiesel from soy and bovine tallow were determined, which influence the formation of a spray and the cone angle: density, viscosity and surface tension.

For all the blends of diesel and biodiesel analyzed, it was found that there is an increase in density, viscosity and surface tension with the increase in the percentage of biodiesel in the blend, given that biodiesel has higher values of density, viscosity and surface tension than diesel.

The values obtained from the properties of the fuel blends were compared with resolutions No. 30 and No. 45 of the National Agency of Petroleum and Biofuels, which regulate the levels accepted for commercialization of fuels.

Regarding the density of the samples, it was observed that all blends have acceptable values for commercialization and use when compared according to resolution No. 30 (diesel), however regarding the viscosity only pure biodiesel did not satisfy the acceptable diesel resolution index, but comparing with its resolution No. 45 (biodiesel) has acceptable values.

Regarding the theoretical diameter obtained for each blend, it was found that by increasing the percentage of biodiesel in the blend, there was an increase in the Sauter Mean diameter (SMD), since blends with larger fractions biodiesel have the highest densities, viscosities and surface tensions.

Regarding the cone angle of the spray it was found that the fraction of biodiesel in the blends does not change the spray cone angles obtained, since the influence of the liquid density under the cone angle is insignificant.

5. ACKNOWLEDGEMENTS

São Paulo Research Foundation (FAPESP) - Grant #2017/25885-6

6. REFERENCES

Ejim, C. E.; Fleck, B. A.; AMIRFAZLI, A. Analytical study for atomization of biodiesels and their blends in a typical injector: Surface tension and viscosity effects. Fuel, v. 86, n. 10–11, p. 1534–1544, 2007.

Faria, M. D. C.; Pinto, R. R. DA C.; Valle, M. L. M., Efeito do Biodiesel na Atomização do Combustível em Motores Diesel de Injeção Direta, Artigo técnico, 2010.

Lahane, S.; Subramanian, K. A., 2015. "Effect of different percentages of biodieseldiesel blends on injection, spray, combustion, performance, and emission characteristics of a diesel engine". *Fuel*, Vol. 139, pp. 537–545, 2015.

Lefebvre, A.H., 1983, "Gas Turbine Combustion", Hemisphere, Washington, D.C.

Lefebvre, A., 1989. Atomization and Sprays, Taylor & Francis.

Lorenzetto, G., & Lefebvre, A. (1977). "Measurements of drop size on a plain-jet airblast atomizer". 12th Propulsion Conference.

Merrington, A. C., & Richardson, E. G, 1947. “The break-up of liquid jets”. *Proceedings of the Physical Society*, Vol. 59, No. 1, pp. 1–13.

Shahir, S. A., Masjuki, H. H., Kalam, M. A., Imran, A., Fattah, I. M. R., & Sanjid, A., 2014. “Feasibility of diesel–biodiesel–ethanol/bioethanol blend as existing CI engine fuel: An assessment of properties, material compatibility, safety and combustion”. *Renewable and Sustainable Energy Reviews*, Vol. 32, pp. 379–395.

Santos, F. A. C. M.; Santos, F. M. S. M., 2008. “Geração distribuída versus centralizada”. *Revista do Instituto Politécnico de Viseu*, Vol. 35, pp. 1–15.

Subramanian, K. A.; Lahane, S. Comparative evaluations of injection and spray characteristics of a diesel engine using karanja biodiesel–diesel blends. International journal of energy research, v. 31, n. August 2007, p. 135–147, 2007.

Tanasawa, Y., Toyoda, S., 1955. ‘‘On the atomization of liquid jet issuing from a cylindrical nozzle’’. *Technol. Rep. Tohoku Univ*., Vol. 19, No. 2, pp. 135–156.

Tolmasquim, M. T., 2003. Fontes Renováveis de Energia no Brasil. Rio de Janeiro: Interciência: CENERGIA.

Van Wylen, G.J. and Sonntag, R.E. Fundamentos da termodinâmica clássica. São Paulo: Edgard Blucher, 318 p, 1993.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.