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Evaluation of the Tung's fruits as a possible source of sustainable energy

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ABSTRACT. Tung's fruits (*Aleurites fordii*) produce oil of great applicability in the market of painting and covering due to its drying characteristics. Tung's oil may be an alternative for the production of new biofuels. In this study, it was evaluated the energetic potential of the fruit, oil and biodiesel obtained from the Tung. The average yielding of the extracted seed oil was 50.6%, a value similar to those presented in literature. Moreover, its density presented a value of 931.5 g L^{-1} and its acid index, 4.5 mg KOH g^{-1}. In the last step of this study, biodiesel was produced by basic methyl route using potassium hydroxide. The specific mass of the produced biodiesel was 909.2 kg m^{-3} at 20°C; its acid index was 0.473 mg KOH g^{-1} and its flash point was 178°C. The values of heating values *in natura* and the low level of ashes in the residual biomass makes the Tung's fruits a promising renewable clean source of energy of second generation fuel.

Keywords: oilseed, biomass, heating value, biodiesel.

Avaliação das frutas do Tung como possível fonte de energia sustentável

RESUMO. O fruto de Tung (*Aleurites fordii*) produz óleo de grande aplicabilidade no mercado da pintura e da cobertura, pelas suas características de secagem. O óleo de Tung pode ser uma alternativa para a produção de novos biocombustíveis. Neste estudo, avaliou-se o potencial energético do fruto, óleo e biodiesel obtido a partir do tung. A média de produção do óleo extraído da semente foi de 50,6%, valor semelhante aos apresentados na literatura. Além disso, sua densidade apresentou um valor de 931,5 g L^{-1} e o seu índice de acidez, 4,5 mg de KOH g^{-1}. Na última etapa do presente trabalho, o biodiesel foi produzido por via metil básica usando hidróxido de potássio. A massa específica do biodiesel produzido foi de 909,2 kg m^{-3} a 20°C; seu índice de acidez foi 0,473 mg KOH g^{-1} e seu ponto de inflamação foi de 178°C. Os valores de aquecimento *in natura* e o baixo nível de cinzas na biomassa residual torna os frutos do tung uma promissora fonte de energia limpa e renovável de segunda geração de combustível.

Palavras-chave: oleaginosa, biomassa, poder calorífico, biodiesel.

Introduction

Countries like China, India and Brazil will probably face the infrastructure problems to maintain the long-term economic growth (ex. electric energy, fuel and environmental pollution) (Duailibe, 2010). One possible alternative that has been coming up in the last years is the production of second and third generation biofuel. Tung (*Aleurites fordii*) may be part of the second generation of biofuels, its cultivation is perennial and has a production life of nearly thirty years starting from three years after its plantation.

Tung oil tree is sourced from the Yang-Tzê valley, China (Peixoto, 1978), which shows a weather similar to the south of Brazil what could turn this tree farming an alternative to oil production. This oil is commonly used for drying purposes attributed to approximately 80% of α-eleostearic acid, a conjugated, trienoic fatty acid (Dyer et al., 2004). The oil content of Tung seeds have already been reported ranging between 21 and 41 wt. %. However, one of its most interesting characteristic is the content of uncommon fatty acids that differs of the others vegetable oils (Chen, Chen, Chang, & Chang, 2010). Dyer and Shockey, scientists from South Regional Research Center (SRRC), in New Orleans, Louisiana, in 2007 investigated how the Tung seed produces so many uncommon fatty acids. The researchers found that an enzyme (the diacyl glycerolacyl transferase type II or DGTA2) present in the Tung fruits play an important role on producing these fatty acids. Dyer reported that oil from seed is chemically similar to crude oil and it could provide renewable raw materials to replace some industrial materials and fuels (Twister, 2007).

The Tung oil is already spread in the market and it is often employed in paintings and coatings due to its easy polymerization in contact with air. For instance, Tung oil has already been used to wood varnish, conservation of ship hull, insulation for electrical wires, wall covering, stones and porous substrates (He, 2014).

In this research, it was investigated the energetic potential of the Tung's fruits, oil and biodiesel in order to evaluate its properties as a renewable source of energy.

Tung biodiesel is classified as second generation of energy source. In addition, Tung fruits shell and the waste obtained after oil extraction produce a large amount of biomass that can be transformed in energy after its pyrolysis, gasification, combustion and cofiring.

In Brazil, in accordance with the Synthesis Report released in 2014 the biomass represented 22.6% of thermoelectric source including the sugar cane bagasse with developed technology (Brasil, 2015).

Modern Technologies that improves the efficiency in the use of the biomass to convert heat in electric energy and environmental awareness has brought up public investments in energetic plants. Biomass and bioenergy may be easily stored, help to avoid fossil sources and the amount of CO2 released during combustion is the same absorbed by the plant; in other words, the production is sustainable (Schütte, 2004).

This research focused on the analysis of the energetic potential of the Tung fruit. Shang, Jiang, Lu, and Liangm (2010) showed that the composition of the Tung oil could vary in accordance with its origin. On the other hand, Tung biodiesel is still in process of analysis in the laboratory. It was determined the curves of the specific consumption and the thermic yielding for the Tung biodiesel and its blends. The evaluation of the total energetic potential of the Tung was determined through the measurement of the heat power of the crushed seeds, pericarp, oil, residual pie, seed coat and Tung biodiesel.

Material and method

Tung's fruits were harvested in the period between the beginnings of March until middle of April 2012 and kept in shadow until they were dried. The harvest was performed in the city of Cascavel, state of Paraná, Brazil. The regional soil is classified as Red Latosoleutroferric, and has a clayey texture. The weather is subtropical mesothermal super humid (Caviglione, Kiihl, Caramori, Oliveira, & Pugsley, 2000) and the average annual temperature is 19.6°C, with an average annual precipitation of 1971 mm and time of insolation estimated in 2462 hours per year.

In July of 2012, the fruits were peeled and the experiments were performed in September 2012. It was also acquired 18 liters gallon of commercial Tung's oil from Campestre Ind. and Com. of Vegetable Oil ltda from São Bernardo do Campo, state of São Paulo. This oil was used to synthesize biodiesel in March 2013.

The dry fruit physic characterization was performed manually by the separation and weighing of the shell (pericarp), the seed coat and the seeds. Then, it was determined the percentage of the mass relative to the total mass of fruits.

Seed's moisture was determined by the indirect destructive method using an oven with airflow. It was adopted the pattern procedure to dry the seeds using 105 ± 3°C for 24 hours (Luz & Laura, 2006). It was used a mass of 12.0 g of intact seeds; for the crushed seeds it was used a mass of 10.1 g. The moisture in dry basis (W_d) was determined by Equation 1:

$$Wd = \frac{Ma}{Md} \quad (1)$$

and in the humid basis (W_w) by the Equation 2:

$$Ww = \frac{Ma}{Md + Ma} \quad (2)$$

where:
the M_a is the mass of humidity and M_d is the mass of solid.

The extraction of oil was performed through soxhlet using hexane as solvent for four times varying the mass of the seeds in 29% in a period of 3 hours and 30 min to 5 hours and 30 min.

Due to its feasibility, it was used the transesterification methodology to produce the biodiesel from Tung's oil with basic homogeneous catalysis (Xie & Li, 2006). The solvent used was methanol rather than ethanol due to its highest yielding (Demirbas, 2005) and the proportion used followed the molar ratio of 9:1 oil/methanol in order to turn easier the stirring taking into account that the Tung's oil was very viscous. It was used potassium hydroxide as catalyst in a concentration of 0.5% of the oil mass. Pardo et al. (2012) observed that the molar ratio of oil and methanol 9:1 did not affect the yielding of biodiesel and that the minor concentration of potassium hydroxide helps on the phase separation process since it decreases the saponification.

Through the molar mass of the fatty acids that compose the Tung's oil and using Equation 3, it was possible to estimate the molar mass of the Tung's oil.

$$MM_{oil} = 3 \times \frac{\sum \%molar\ fatty\ acid\ \cdot MM_{fatty\ acid}}{\sum \%molar\ fatty\ acid} + 38.04 \quad (3)$$

The materials and equipment used in the process were: heating plate, beaker, stirrer, thermometer, phase separation funnel and oven.

Firstly, the beaker containing the Tung's oil, thermometer and magnetic stirrer was placed over a heating plate and the temperature was increased to 60°C. Next, the potassium hydroxide was dissolved in methanol and the time for the complete reaction was one hour and twenty minutes. After this, the solution was poured in a separatory funnel to give rise to both phases: biodiesel and glycerin. Biodiesel was washed with plenty of distilled water that was removed in the separatory funnel. Finally, biodiesel was taken into the oven in a temperature of 65°C for 72 hours to eliminate the water and methanol.

In order to prepare de biodiesel, it was used 2500.0 g of Tung's oil, 830.00 g of methanol, 14.40 g of KOH using a temperature of 60°C for 1 hour and 20 min. After the preparation, it was obtained 2280.0 g of Tung's biodiesel, and this biodiesel was used in the analysis and in the experiment with the power supplier.

The high heat value was obtained using an isothermal calorimeter (DDS - E2K Combustion Calorimeter) composed by a calorimetric vessel, an oxygen cylinder and two manometers (to control the pressure). The samples used had a mass lower than 0.5 g. The content of ashes present in the sample mass (%) was determined using the residuals ashes. In this procedure, it was used three samples to obtain the high heat value for the crushed seeds, the shells, the residual pie, seed coat and Tung's oil; this value was also obtained for one sample of commercial oil and two samples of biodiesel.

Relative's densities of Tung's oil and biodiesel were obtained using a pycnometer, analytical balance and distilled water for comparison. The measurements of the Tung's oil were performed at 25°C and for the Tung's biodiesel the temperature was 20°C. The density of water was 997.0 kg m^{-3} at 25°C and 998.2 kg m^{-3} at 20°C. It was also measured the water and fluid mass that fill the pycnometer.

The methodology used to calculate the acid index (Equation 4) consisted in adding 25 mL of ether/alcohol (2:1) in 2.000 g of the sample in an Erlenmeyer. After that, the solution was stirred and then, two drops of phenolphthalein was added. Sodium hydroxide 0.1 mol L^{-1} was used to titrate the solution.

$$AI = (5.61 \cdot Vf)/P \quad (4)$$

where:
V (mL) is the total volume of sodium hydroxide used in titration, f is the factor of the sodium hydroxide solution and P is the mass of the sample (g) (Figueiredo, Vieira, & D'Elia, 2015). It was used 1.7 mL of sodium hydroxide solution 0.1 mol L^{-1} for 2.0162 g of sample to obtain the acid index of Tung's biodiesel.

Viscosity was measured using a viscometer (Cannon-Fenske number 150 capillary) where the sample flowed through under gravity force and the time of the flux was measured by chronometer. Then, the value was calculated by multiplying the time of the flux in seconds by the constant of the viscometer for the bulb (0.035 cSt).

Flash point was determined by lighting a flame over a recipient that contains the sample of biodiesel and a thermometer. When a flash can be observed the temperature is recorded, and that temperature corresponds to the flash point.

The oxidative stability was obtained using the Rancimat (Metrohm, Rancimat 843) test using a sample of 3.000 g pre-heated at 110°C. The equipment developed the curve for the electric conductivity and the second derivative for the first point of inflection, which shows the induction time. A second point of inflection was calculated graphically by the intersection of two straight lines: the slope where there is an elevation on the curve and the other slope at the level of the curve (Laubli & Bruttel, 1986). Those two points indicated the oxidative induction time.

The specific consumption test and thermal yielding were performed for the Tung's biodiesel produced in the Unioeste laboratory and the diesel for comparison.

The power generator (Brando BD-6500CF) used in the test had a maximum power of 5.5 kVA and the load associated was composed of some resistors with nominal power of 1, 2, 3, 4 and 5 kW selected by electric switches on the panel control.

Fielder Logger modulus (Novus) used for recording and registering of analogical variables was set up for phase potential and current signals provided the active power, apparent power, reactive power, power factor and energy consumption. Fuel consumption was measured by a flow meter (Flowmate Oval M III LSF-41-LO), with a range of 1 to 100 L hour^{-1} and a temperature range of -20 to 80°C. Flow meter was inserted in the fuel fed system, and it was composed by gears in which every 1 mL of fuel corresponded to one complete spin of the gear. It generated a potential that varied in a range between 6.2 and 7.6 V that was recorded by the data acquirer every 250 ms through a digital channel that converted the signal. After each evaluation, the data was sent to the computer to be recorded and then was converted to L hour^{-1}.

The specific energy consumption was calculated in kg kW^{-1} hour^{-1} using the flux of mass per unit of time. The consumed thermal power of the engine was calculated using the value of specific energy consumption and the heat value of the fuel. The engine efficiency was determined by the relationship between the thermal power supplied by the fuel and the electric power generated.

The fuel consumption was calculated by the product of its specific mass and its flow. The value of density and heat value for the Diesel was 854 kg m^{-3} and 10540 kcal kg^{-1}, respectively, and 909.2 kg m^{-3} and 9149.1 kcal kg^{-1} for the Tung's biodiesel, respectively.

Results and discussion

The mass percentages obtained after separation of the Tung's parts were: 46.32 for the shell (pericarp), 24.83 for the seed coat and 28.85% for the seeds. The values calculated for the moisture are presented in Table 1.

Table 1. Mass of seeds (Ms), dry seeds (Md), moisture (Ma), moisture in wet basis (Wa) and in dry basis (Wd).

	Ms g^{-1}	Md g^{-1}	Ma g^{-1}	Wa %$^{-1}$	Wd %$^{-1}$
Crushed seeds	10.1025	9.7175	0.3850	3.81	3.96
Seeds	12.0529	11.5110	0.5419	4.50	4.71

Sharma et al. (2011) found a moisture index of 13.24% for the Tung's seeds when they were kept in plastic bags in a temperature of 5°C. Seeds samples were pre-heated to a temperature of 22-25°C with a relative humidity of 30-40%. All the seeds were harvested in March and kept in bags that allowed the air to pass in order to speed up the drying until September 2012, when they were evaluated.

In order to extract the oil from the seeds, they were crushed and placed inside the extractor and hexane was used as solvent to obtain the oil. The process of extraction was repeated four times and the results obtained are shown in Table 2.

The extraction average yielding was of 50.6 ± 1.4%, with a minimum of 49.3 and a maximum of 52.5%. Azam, Waris, and Nahar (2005) investigated methyl esters and fatty acids extracted from plenty of seeds that were not usually used to obtain oil and they reported that the percentage of oil extracted from Tung could reach 57%. So, the yielding obtained in this study (50.6 %) may be considered high when compared to the value obtained by Azam et al. (2005) and cited in Chen et al. (2010) when they used seeds provided by (Embrapa, Brazilian Agricultural Research Company) and obtained a value of 40.12% by crushing method and 41.30% by Soxhlet method.

Table 2. Mass of: seeds (M_s), hexane volume (HV), time of extraction (TE), oil mass (OM) and yielding (Y_d).

	M_S g^{-1}	HV mL^{-1}	TE hour^{-1}	OM g^{-1}	Y_d %$^{-1}$
Sample 1	26.98	140	3.5	13.29	49.3
Sample 2	29.93	130	4.0	15.74	52.5
Sample 3	34.82	130	5.5	17.54	50.4
Sample 4	30.44	140	4.0	15.28	50.2
Average					50.60
Standard					1.41

Relative average density of the Tung's oil obtained in this work was 931.5 kg m^{-3} at 25°C a common value for vegetable oils. Its acid index presented a value of 4.5 mg KOH g^{-1}. Chen et al. (2010), in Taiwan, worked with Tung's oil carefully stored in a dark plastic recipient and maintained it hermetically sealed, away from heat, and determined the following characteristics for oil: density of 941 kg m^{-3} at 15°C; acid index of 1.45 mg KOH g^{-1}. Lianhua, Pengmei, Wen, Zhongming, & Zhenhong (2010) worked with the etherification of Tung's oil with an acid index of 7 mg KOH g^{-1}. Difference among the values of acid index shows the need to be careful on the fruits storing since that may influence highly in this parameter. In fact, Chen et al. (2010) showed that their conditions were effective in maintaining the oil acidity low.

The density of Tung's biodiesel at 20°C was of 910.8 kg m^{-3} and its specific mass was 909.2 kg m^{-3} at 20°C a value little bit higher than the specification of 900 kg m^{-3} (Figueiredo et al., 2015).

The acid index of Tung's biodiesel was 0.473 mg KOH g^{-1} staying inside the specifications limit of 0.5 mg KOH g^{-1} (Figueiredo et al., 2015). This means there was a pre-treatment of the oil acidity on the esterification process as described by Lianhua et al. (2010).

Kinematic viscosity obtained was 11.62 mm s^{-2} a value much higher than the specifications limits of 3.0 and 6.0 mm s^{-2}, indicating the possibility of using the Tung's biodiesel in a blend with others low viscosity biodiesels. This high value was expected due to the high kinematic viscosity of the Tung's oil (107.2 mm s^{-2} at 40°C) that can be explained by the conjugated double bonds that may increase molecular interactions and the reactions of oxidation and polymerization (Chen et al., 2010).

Oxidative stability index provided by the Rancimat equipment was 0.09 hour, indicating, in this period of time, the presence of some volatile acids that may oxidize fast. Then, a linear behavior was observed until a new inflexion point have appeared close to the value of 7.8 hour. Specific antioxidants may increase the oxidative stability of the first induction point. The values of the crushed Tung's seeds are shown in Table 3.

Table 3. High heat value (HHV) and ashes level (AL) of the crushed seeds.

Seeds	Sample 1	Sample 2	Sample 3	Average	Standard Deviation
HHV MJ^{-1} kg^{-1}	29.34	29.29	29.45	29.36	0.08
HHV $kcal^{-1}$ kg^{-1}	7012.67	7000.72	7039.20	7017.45	19.69
AL $\%^{-1}$	1.73	1.80	1.87	1.80	0.07

Table 4 shows the results of HHV and AL for the three samples of shell dried at ambient temperature. Shell consisted of crushed and mixed epicarp, mesocarp and endocarp.

Table 4. HHV and AL of the Tung's pericarp.

Shell	Sample 1	Sample 2	Sample 3	Average	Standard Deviation
HHV MJ^{-1} kg^{-1}	19.00	19.68	19.16	19.28	0.36
HHV $kcal^{-1}$ kg^{-1}	4540.15	4704.11	4579.59	4607.95	85.58
AL $\%^{-1}$	0.64	0.61	0.71	0.66	0.05

Table 5 shows the results of HHV and AL obtained for three samples of pie as result from oil extraction of Tung's oil.

Table 5. HHV and AL of the residual pie.

Pie	Sample 1	Sample 2	Sample 3	Average	Standard Deviation
HHV MJ^{-1} kg^{-1}	20.73	20.13	20.40	20.42	0.30
HHV $kcal^{-1}$ kg^{-1}	4953.39	4810.23	4876.67	4880.10	71.64
AL $\%^{-1}$	2.35	2.07	2.30	2.24	0.15

Vale, Mendes, Amorim, and Dantas (2011) investigated the energetic potential of shells and pie from *Jatropha curcas* and the authors obtained for the percicarp a value of 3641 kcal kg^{-1} for HHV and 14.4% for AL; for the pie it was obtained a value of 5122 kcal kg^{-1} for HHV and 7.95% for AL. When those values are compared the Tung's shell shows clear advantages with due to its lower AL and higher combustion heat value; the Tung's residual pie has a lower value of AL, indicating high quality on thermal energy generation.

The values of HHV and AL for the seed coat are shown at Table 6.

Table 6. HHV and AL for seed coat.

Seed coat	Sample 1	Sample 2	Sample 3	Average	Standard Deviation
HHV MJ^{-1} kg^{-1}	15.09	14.85	15.14	15.03	0.16
HHV $kcal^{-1}$ kg^{-1}	3606.36	3549.00	3619.50	3591.62	37.49
AL $\%^{-1}$	5.91	5.65	5.85	5.80	0.13

Quirino, Vale, Andrade, Abreu, and Azevedo (2004) showed that the average heat value for 258 different species of woods was 4710 kcal kg^{-1}, a value similar to that obtained for Tung's pericarp; the seed coat have a value close to the corn that has an average heat value of 3570 kcal kg^{-1}.

A financial support is provided for companies that present high values of HHV and low values of AL. The reference values are 1850 kcal kg^{-1} for HHV and 1 to 8% for AL, depending on the biomass type. Based on these values, all parts of the Tung's fruit are good source of thermal energy and may be a good alternative to reduce its costs.

Three samples of oil was used to obtain an average heat value of the Tung's oil extracted in this work and its average value (38.53 MJ kg^{-1}) was close to the oil obtained commercially (38.15 MJ kg^{-1}).

The HHV of Tung's biodiesel was 9149 kcal kg^{-1} (usual value for vegetable oils) and 10540 kcal kg^{-1} for Diesel used as comparison (Table 7). This behavior is explained by the fact that the Diesel is a hydrocarbon of long chain. In other words, longer chains of hydrocarbon leads to higher internal energy.

Table 7. HHV of Tung's biodiesel.

	Sample 1	Sample 2	Sample 3	Average	Standard Deviation
HHV MJ^{-1} kg^{-1}	38.14	38.50	38.21	38.28	0.19
HHV $kcal^{-1}$ kg^{-1}	9115.68	9200.53	9131.21	9149.14	45.17

In order to calculate the values of specific consumption and heating energy, for the diesel it was used the values of 854 kg m^{-3} for specific mass and 10,540 kcal kg^{-1} for the heating value and for the Tung's biodiesel, 909 kg m^{-3} for specific mass and 9149 kcal kg^{-1} for Tung's biodiesel.

Data of fuel consumption were obtained by the average of the flow measured using a micro flowmeter and they are shown in Table 8.

Table 9 shows the mass average of fuel consumption for Tung's biodiesel and diesel obtained by the product of the specific mass and consumption in kg $hour^{-1}$.

Table 8. Fuel consumption data in L hour^{-1}.

Nominal power kW^{-1}	B10	B20	B50	B75	B100	Diesel
1	0.8335	0.8274	0.8027	0.8906	0.8812	0.9118
2	0.9877	0.9720	0.9762	1.1044	1.1073	1.1052
3	1.1726	1.1890	1.2199	1.3777	1.3575	1.3587
4	1.2651	1.2920	1.3369	1.4134	1.4639	1.4960
5	1.2341	1.2504	1.2201	1.3661	1.3809	1.4558

Table 9. Average of fuel consumption in kg hour^{-1}.

Nominal power kW^{-1}	B10	B20	B50	B75	B100	Diesel
1	0.8335	0.8274	0.8027	0.7974	0.8012	0.7787
2	0.9877	0.9720	0.9762	0.9889	1.0068	0.9438
3	1.1726	1.1890	1.2199	1.2336	1.2342	1.1603
4	1.2651	1.2920	1.3369	1.2656	1.3310	1.2776
5	1.2341	1.2504	1.2201	1.2232	1.2555	1.2433

The average power values calculated from the module of reading and recording data are shown in Table 10:

Table 10. Average of power values obtained by Fielder Logger (kW).

Nominal power	B10	B20	B50	B75	B100	Diesel
1	0.8708	0.8687	0.8651	0.8656	0.8627	0.8806
2	1.8483	1.8158	1.8023	1.8006	1.7810	1.8590
3	2.7464	2.7084	2.6773	2.6725	2.6417	2.7601
4	3.3082	3.2960	3.2491	3.0390	2.9840	3.3727
5	3.5093	3.5159	3.2578	3.0688	2.8978	3.5441

Table 11 shows the values of Tung's biodiesel and Diesel specific consumption as function of the load.

Table 11. Specific consumption of different Tung's biodiesel composition in kg kW^{-1} hour^{-1}.

Load kW^{-1}	B10	B20	B50	B75	B100	Diesel
1	0.9571	0.9525	0.9278	0.9213	0.9287	0.8843
2	0.5344	0.5353	0.5416	0.5492	0.5653	0.5077
3	0.4270	0.4390	0.4556	0.4616	0.4672	0.4204
4	0.3824	0.3920	0.4115	0.4164	0.4460	0.3788
5	0.3517	0.3556	0.3745	0.3986	0.4333	0.3508

Specific fuel consumption curves are the best parameter of comparison to show the engine efficiency when the fuel is converted in work. Figure 1 displays the specific consumption curves for the Tung's biodiesel and for the Diesel. The HHV of the Diesel was responsible for the lowest specific consumption.

The curves of the specific consumption present a quadratic tendency where the lowest value indicates the highest efficiency power of the engine. The values are high for the lowest demands of energy and get lower when the supplied power increases. It was verified that when the required energy is low the relative curve of Tung's biodiesel is closer to the Diesel curve. When the demand on energy increases, the curves start to differ from each other.

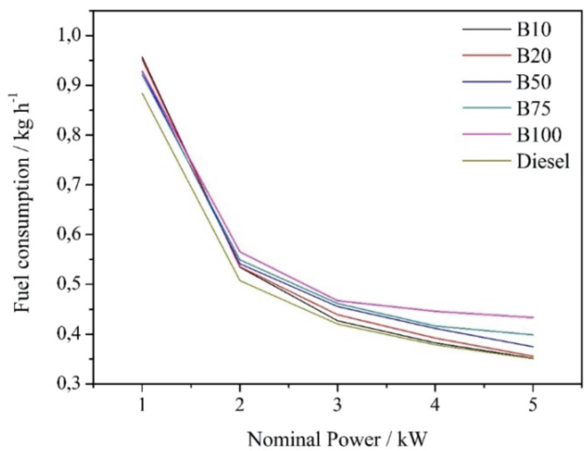

Figure 1. Specific consumption curves as function of nominal power.

Table 12 shows the thermal yielding as a function of the load for the Tung's biodiesel and for the Diesel. It is possible to observe that the performance of the engine is better for small load of Tung's biodiesel but an inversion occurs in approximately 70% of the nominal load. The performance of the Diesel is better. This behavior was a consequence of the higher specific mass of Tung's biodiesel that led to higher yielding in low load values.

Table 12. Fuels efficiency in %.

Load kW^{-1}	B10	B20	B50	B75	B100	Diesel
1	8.7	8.8	9.4	9.9	10.1	9.2
2	15.5	15.7	16.2	16.5	16.6	16.1
3	19.4	19.1	19.2	19.7	20.1	19.4
4	21.6	21.4	21.3	21.8	21.1	21.6
5	23.5	23.6	23.4	22.8	21.7	23.3

A comparison between the Tung's biodiesel and Diesel is shown in Figure 2.

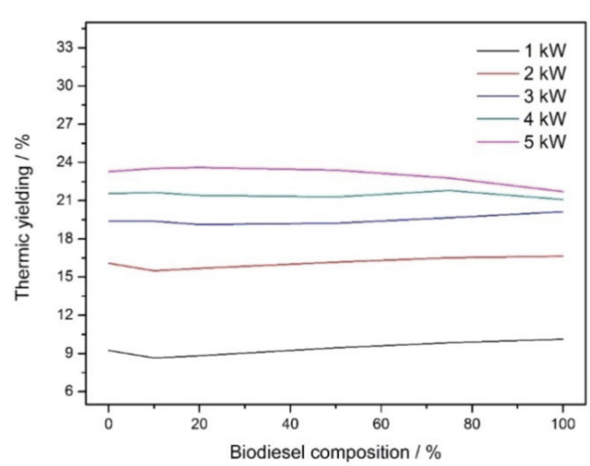

Figure 2. Thermic yielding curves.

From 70% of the nominal load forward the Tung's biodiesel has a worse performance than the Diesel due to its higher specific mass, lower heat value and higher kinematic viscosity. Those properties cause incomplete combustion and an increase on particles emissions.

Conclusion

The total average energetic power of the dry Tung's fruit as function of its capacity of generating thermal energy was 5051 kcal kg^{-1} presenting an average residual ashes level of 2.27%. The HHV obtained for the Tung's oil was 9209 kcal kg^{-1} and for the Tung's biodiesel was 9149 kcal kg^{-1}.

In the oil extraction from the Tung's seeds it was obtained the following results: yielding of 50.60% w w^{-1}; specific mass 934.4 kg m^{-3} at 25°C; acid index of 4.5 mg KOH g^{-1}.

Tung's biodiesel presented the following properties: specific mass of 909.2 kg m^{-3} at 20°C; acid index of 0.473 mg KOH g^{-1}; and kinematic viscosity of 11.62 mm² s^{-1}, indicating the possibility of use in biodiesel with lower viscosity and specific mass.

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