25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-1049
COMBUSTION OF *ACACIA DEALBATA* PELLETS IN A 20 KW DOMESTIC BOILER

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Abstract.
The main purpose of this work was the study of combustion of invasive Acacia dealbata pellets, and the three mixtures of Acacia dealbata and Pinus Pinaster pellets, for different percentages of the two species, in a domestic pellets boiler. The samples of Acacia dealbata species were collected in the region of Viseu, and later cut into smaller sizes, so that they could be manageable subsequently. A solar dryer was used to dry the raw material until it had a moisture content of, approximately, 20%. During the drying process, that value was monitored. After drying, Acacia samples were milled in a Retsch SM100, knives type cutting mill. Then, Acacia dealbata and the three mixtures pellets, were produced using a laboratory pelletizer, with an average diameter of 6.66 mm. The process was carried out with temperature and pressure monitoring. The pellet combustion process was carried out for three different thermal loads, 'load 1', 'load 3' and 'load 5', which corresponded to the designations of the boiler manufacturer for the reduced, medium and high power, respectively. The results obtained, for the different types of pellets produced, were compared with the results obtained for commercial Pinus Pinaster pellets, certified by ENplus standard. The thermal efficiency of the boiler was determined, its dependence on excess air evaluated and the emission of combustion gases (O_2, CO_2, CO, NO_X) resulting from the combustion, under the referred different loads. With the increase of the thermal power of the boiler, it was possible to verify an increase in thermal efficiency. Concerning CO and NO_X emissions, the combustion of the pellets of Acacia dealbata represented the highest values.

Keywords: *Acacia dealbata, pellets, boiler, thermal efficiency*

1. INTRODUCTION

Since always, man has used the different sources of energy according to his needs (Cerqueira et al., 2010). Before the industrial revolution, the population density was reduced, and to produce energy it was necessary to resort to human or animal power. After the revolution, and with the appearance of the thermal engines, the production of energy became easier (Fakhri et al., 2015). With the increase of the population, with the improvement of the quality of life and with the industrialization, the increase of the demand and the consumption of energy was quite significant (Lee et al., 2007).

The energy sources can be divided into renewable and non-renewable. The predominant sources of energy are those of fossil origin, which represent about 83% of man's total energy consumption (Fakhri et al., 2015). Due the high emissions of these sources, the priority of the population today is to reduce carbon emissions by around 80%, replacing their use with renewable energy sources (Saidur et al., 2011).

Renewable energy sources are considered "clean" energies and are constantly being renewed; among these sources is significant to emphasize the importance of biomass, a carbon neutral resource. The cleaning of forests and the use of excess biomass present in these, for energy production, allows a reduction in the chance of occurrence forest fires (Magalhães, 2006).

Obtaining pellets, a solid and biological fuel, is possible by compaction of biomass (Dias et al., 2012).

The study of invasive *Acacia dealbata* was made once the resources of this species are high so then can be a great energy potential. The objective of this paper is to study the influence of the use of pellets of an invasive species, *Acacia dealbata*, and pellets resulting from the mixtures of *Acacia dealbata* and *Pinus Pinaster*, on the thermal efficiency of a domestic boiler. The results obtained were compared with those obtained with commercial *Pinus Pinaster* pellets.

2. MATERIALS AND EXPERIMENTS

2.1 Sample preparation

Initially, the capture of *Acacia* was made in a forest in the region of Viseu, to be later dried in a solar dryer. The moisture content of the material was monitored, and when it reached about 20%, the samples were removed from the solar dryer. The drying process was carried out during the autumn and winter, being that the last drying cycles were carried out during spring. After the material was dried, the samples were milled in a *Retsch SM100*, knives type cutting mill. The *Pinus Pinaster* species used in the mixtures of the two species, was acquired through an industrial unit to produce wood derivatives. Pellets with an average diameter of 6.66 mm were produced using an industrial pelletizer.

2.2 Pellets characterization

According to the standard EN 17225-2:2014, 20 samples of each type of pellets were selected and their dimensions were measured with the aid of a digital caliper. The pellet mass was determined using a laboratory analytical balance, *Precisa 6200*. The density of the pellets was determined by the ratio of pellet mass and volume, being that volume calculated by the formula used to calculate the volume of cylinders.

The pellet samples were dried in a *Venticell* oven at a temperature of 105±2 ºC, until constant mass. The moisture content of the *Acacia dealbata*, the three mixtures of the two species, and *Pinus Pinaster* pellets was determined according to EN 18134-2:2016.

The moisture content of the material, wet basis (wb), was determined according to Eq. (1).

$$MC_{wb}\ (\%) = \frac{\mathrm{m_w} - \mathrm{m_d}}{\mathrm{m_w}} \times 100 \quad (1)$$

where m_w represents the initial wet mass and m_d the dry mass.

The characteristics of the pellets used in the tests and their uncertainties (Ferreira et al., 2014) are shown in Tab. 1.

Table 1. Pellets characteristics.

	Pinus pinaster	*Acacia dealbata*	25% *Acacia dealbata*/75% *Pinus Pinaster*	50% *Acacia dealbata*/50% *Pinus Pinaster*	75% *Acacia dealbata*/25% *Pinus Pinaster*	Uncertainty (%)
Diameter (mm)	6.20	6.66	6.68	6.65	6.63	0.16
Length (mm)	21.13	28.06	26.93	26.38	28.21	0.05
Mass (g)	0.73	1.02	1.02	0.99	1.07	0.01
Particle density (kg/m^3)	1143.41	1035.69	1077.27	1077.62	1098.72	0.01
Moisture content (% wb)	8.37	6.21	6.90	6.61	5.65	0.26
Mechanical durability (%)	98.79	91.76	96.05	94.23	93.63	0.03

Durability is the main parameter that defines the physical quality of pellets. Tests of mechanical durability were made for three samples of each type of pellets, using a tumbling device defined by ASAE S269.5 (2012). A rectangular container made of aluminum or stainless steel was required for its determination. Thereby, a 500 g sample was manually sieved with a 3.35 mm round hole sieve and then tumbled for 500 rotations during 10 min (Temmerman et al., 2006). The sample was sieved again and the pellets remaining in the sieve were weighed; the mechanical durability was subsequently determined. The calculation of the durability of the pellets was done by Eq. (2).

$$\% \text{ Durability} = \frac{m_{\text{pellets final}}}{m_{\text{pellets initial}}} \times 100 \qquad (2)$$

By observing Tab. 1, some differences are possible to be identified between the different type of pellets. The main differences between pellets are the mass, density and mechanical durability. It is possible to observe that the diameter and length of the pellets is quite similar, being the length 90% of the knife adjustment. The moisture content for the different type of pellets is below 10%, which is in accordance with the standard. For durability, and for this to be in accordance with the standard, the value would have to be higher than 98%, which only occurs in *Pinus Pinaster* pellets.

Regarding to Lower Heating Value (LHV), its determination was made by the National Laboratory of Energy and Geology (LNEG), in Lisbon, Portugal.

2.3 Experimental setup

The boiler used for the combustion of the pellets of the two species was a domestic boiler of the brand *Metlor*, model *Aqualux*, with a nominal thermal power of 20 kW, Fig. 1.

Figure 1. Boiler used in the experimental work.

The boiler is composed by a container with a capacity of 35 kg of pellets, being that the pellets must be introduced manually, by a top-feed system, carried out by a screw.

The ignition of the pellets is performed through an electric resistance. For combustion, the air passes through orifices in a removable basket, which with the electric resistance allows it to occur.

The boiler has 5 operating modes, called loads, which correspond to 5 different way of operation for the screw, which adjusts the fuel to the desired power.

Inside the combustion chamber there are pipes through which the water circulates, which in turn is heated through a heat exchange between the combustion gases and the water. The combustion products are drained through a duct connected to a ventilation system.

Through Fig. 2 the experimental installation of the boiler can be observed.

The temperatures T1, T2 and T3, represent the water temperature at the inlet, the water temperature at the outlet and the combustion gases temperature, respectively. All of them were measured by 3 mm K type thermocouples.

The composition of the exhaust gases, O_2, CO_2, CO and NO_X, was analyzed through a *Testo 350* model analyzer.

The efficiency of the boiler was determined using Eq. (3):

$$\eta = \frac{\dot{Q}_{output}}{\dot{Q}_{input}} = \frac{\dot{m}_{H_2O} \times c_{H_2O} \times (T_2 - T_1)}{\dot{m}_{pellets} \times LHV_{pellets}} \qquad (3)$$

where, $\dot{m}_{H_2O}$ represents the mass flow rate of water in (kg/s), c_{H_2O} is the specific heat of water (kJ/ kg.K), T_2 and T_1 represent the water inlet and outlet temperature (ºC), $\dot{m}_{pellets}$ the fuel mass flow rate (kg/s) and $LHV_{pellets}$ the lower calorific value of the pellets in (kJ/kg). The mass flow rate of the pellets is the mass of pellets consumed, for the require time interval.

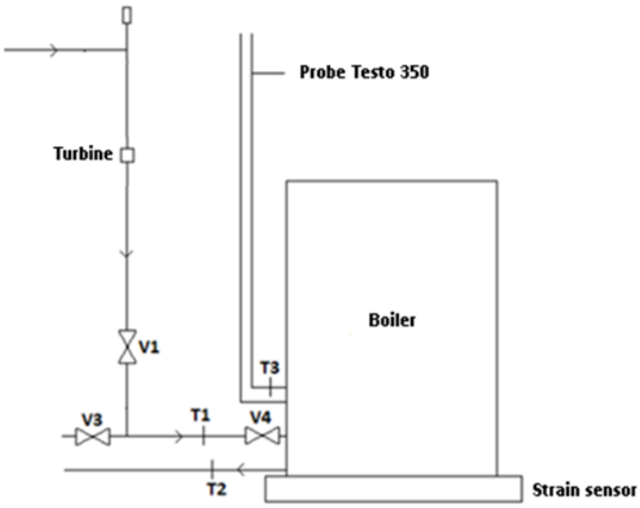

Figure 2. Experimental set-up – Adapted from Ferreira (2013).

The average uncertainty values for the experimental measurements, for Pine pellets at reduced load, associated to the process of measuring the critical variables for this study were determined according to Coleman and Steele (2009) and are presented in Tab. 2.

Table 2. Variable measurement uncertainties.

Variable	U (%)	Variable	U (%)
O_2 emission	0.2000	Water mass flow rate	2.2400
CO emission	0.0284	Water inlet temperature	3.93
NO emission	0.0005	Water outlet temperature	3.05
CO_2 emission	0.3880	Pellets mass flow rate	0.0051
Exhaust gases temperature	1.3000	-	-

3. RESULTS AND DISCUSSION

Several tests were performed for Pine, *Acacia* and the three mixtures pellets, in the different loads, “reduced”, “medium” and “high”.

Due to the differences in the physical characteristics of the different type of pellets, there were differences in feed rate for the different cases.

The influence of the pellets mass flow rate on thermal efficiency was studied for the three loads and are shown in Tab. 3 and Fig. 3.

Table 3. Thermal efficiency (%) for the three different loads.

	Pinus pinaster	*Acacia dealbata*	25% *Acacia dealbata*/75% *Pinus Pinaster*	50% *Acacia dealbata*/50% *Pinus Pinaster*	75% *Acacia dealbata*/25% *Pinus Pinaster*
Reduced load	55.50	51.22	54.91	54.41	53.44
Medium load	61.12	55.12	58.48	56.99	55.53
High load	64.49	57.12	60.41	59.16	58.70

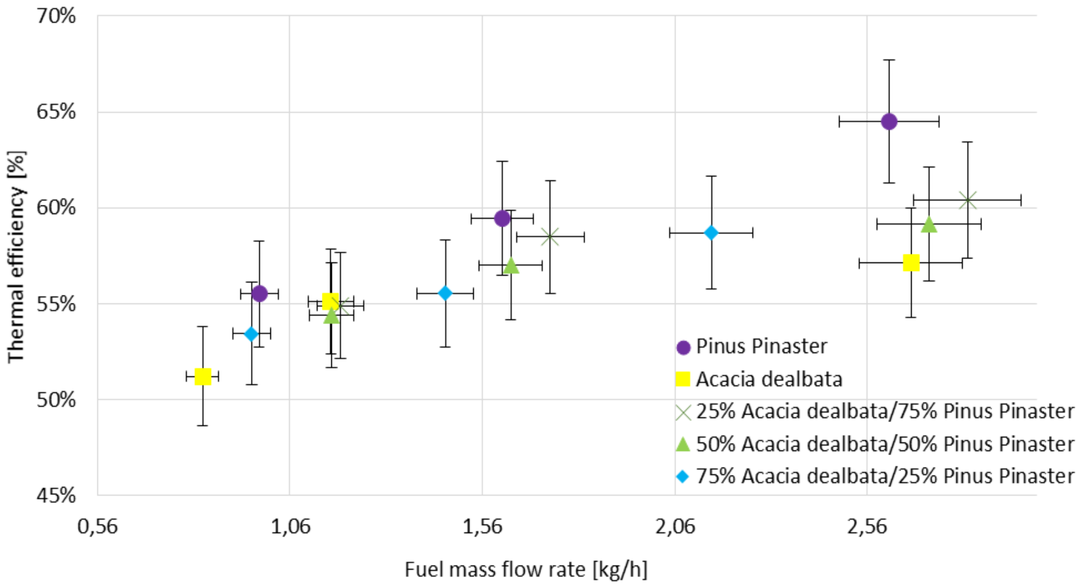

Figure 3. Thermal efficiency as a function of fuel mass flow rate.

From the presented results it can be verify that, with the increase of the fuel mass flow rate, there is an increase in the thermal efficiency of the boiler. For the three loads, the thermal efficiency is higher for *Pinus Pinaster* pellets. The higher thermal efficiency of the boiler was obtained for the Pine pellets, at high load.

The European standard EN 14785:2006 establishes that the thermal efficiency values should not be less than 70 and 75% for reduced and high loads respectively; verifying the values obtained in the tests performed for all types of pellets, none of these are in accordance with the standard.

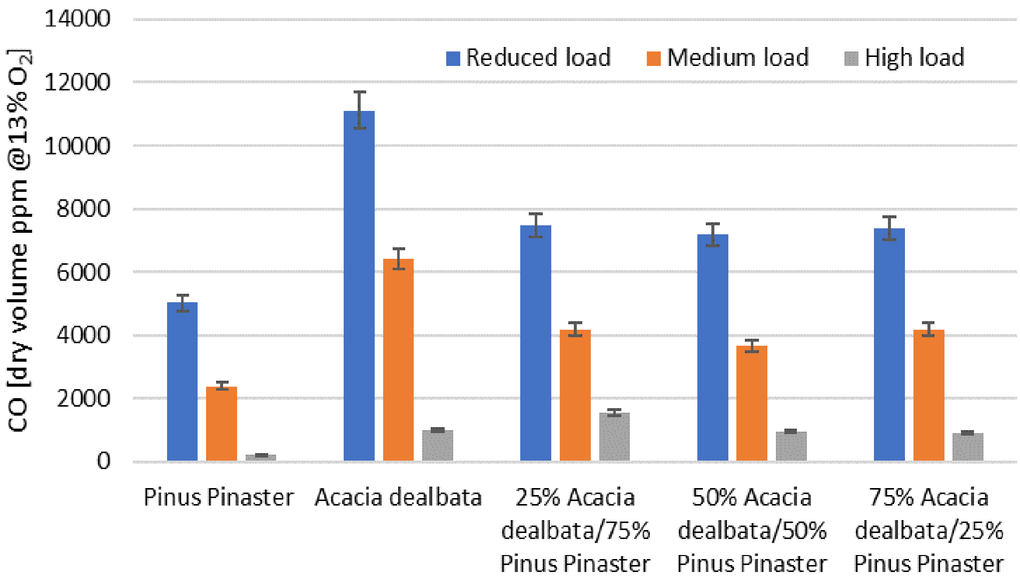

Figure 4. CO emissions for the different type of pellets.

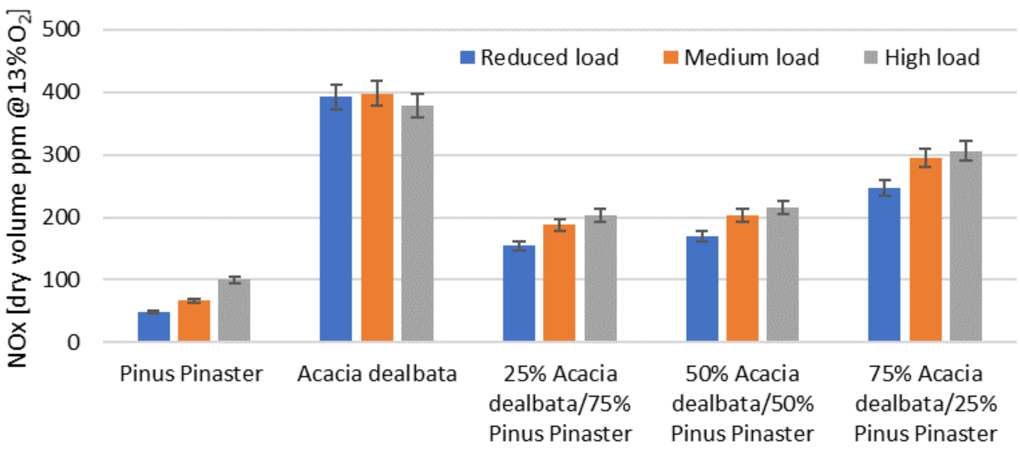

Figure 5. NO_X emissions for the different type of pellets.

In the above figures, Fig. 4 and Fig. 5, CO and NO_X emissions, for the different type of pellets, for the three loads, reduced, medium and high can be observed. The emissions shown were corrected to 13% of oxygen in the combustion gases.

CO emissions for smaller loads are higher than for larger loads. Although the CO emissions are lower for higher loads, the excess air in the combustion chamber remains too high considering the pellet mass flow rate consumed.

The European standard EN 14785:2006 set limits on CO emissions of 600 ppm (at 13% O_2) for reduced load and 400 ppm (at 13% O_2) for high load. From Fig. 4, for reduced load, none of the different type of pellets are according to the values established by the standard; for high load, only *Pinus Pinaster* pellets present a value below 400 ppm (at 13% O_2).

In the case of NO_X the lowest emissions correspond to Pine pellets, with *Acacia* being the species that represented the highest emission values.

The nitrogen oxides (NO_X) include NO, NO_2 and N_2O, being the first one the main source of nitrogen oxides. NO formation during the combustion is mainly due to three mechanisms: 'thermal NO' - with high temperatures, dissociation of the atmospheric nitrogen and oxygen takes place; 'fuel NO' - due to the elemental nitrogen content of the fuel; and 'prompt NO' - due to the fast reaction at the flame front (Liu et al., 2013). In face of high excess air values and moderate combustion temperatures registered, well below typical small domestic boilers 1300°C (Verma et al., 2012), and the amount of nitrogen in the acacia pellets, the 'fuel NO' mechanism is the major cause for NO formation (Rabaçal et al., 2013). Thus, the significant difference in NOx emissions is a consequence of the inherent nitrogen content of the species; the high NO_X emissions of *Acacia dealbata* pellets may be a result of a high nitrogen content, compared to the *Pinus pinaster*.

4. CONCLUSIONS

The present paper aimed at evaluating the influence of the invasive species *Acacia dealbata* and the three mixtures of different percentages of *Acacia dealbata* and *Pinus Pinaster* as a fuel in a domestic pellet boiler. The results obtained for *Acacia* and for the mixtures were compared with the results obtained in the tests for *Pinus Pinaster* commercial pellets. Thermal efficiency of the boiler and the emissions of pollutants from combustion, were evaluated for all the different types of pellets.

Pinus Pinaster pellets obtained the highest thermal efficiency value; the maximum value of thermal efficiency obtained was of 70%, for high load. An increase in the fuel mass flow rate leads to an increase in the boiler thermal efficiency.

Concerning CO and NO_X emissions, CO emissions decrease with increasing fuel mass flow, and this value was extremely high for *Acacia dealbata* in the reduced load. In the case of NO_X emissions, *Acacia* pellets presented always higher values. The maximum value of CO obtained was, for *Acacia* pellets, for a reduced load, of 11310 ppm, much higher than the 600 ppm limit that the European standard sets. The minimum value was for *Pinus Pinaster* pellets, with a value of 211 ppm. For NO_X emissions, the minimum value was obtained for Pine, 47 ppm, and the maximum for *Acacia*, 401 ppm. In general terms, the thermal efficiency of the boiler presented better values for *Pinus Pinaster* pellets. With the increase of *Acacia dealbata* percentage in the mixtures, a decrease in thermal efficiency values of the boiler was observed.

5. ACKNOWLEDGEMENTS

This work was partially supported by the SAICT-POL/23394/2016 grant from the Portuguese Foundation for Science and Technology (FCT). The tests were carried out in the laboratory facilities of ESTGV/IPV.

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