THE APPLICATION OF FURNITURE MANUFACTURING RESIDUES IN WOOD PELLETS: ASSESSMENT OF THE COMBUSTION EFFICIENCY

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Abstract

The European Union aims to fulfill 20% of the primary energy consumption with renewable energy sources, by 2020. Biomass has a great potential for domestic and industrial heating applications and these are amongst the most promising uses for biomass as they combine high efficiency and ease of use. Pellets are a good method for biomass distribution due to its quality standards and energy density which make them attractive to distribution and handling.

In addition to the traditional use of sawdust as a raw material, there has been a growing interest in the incorporation of residues from industry processing such as the furniture sector.

This paper reports the application of pellets made of residues from the furniture industry as a fuel source in domestic heating applications. Pellets were characterized according to their chemical and physical composition. They were subsequently burned in an automatic boiler rated at 15 kW. A probe in the exhaust chimney was used to continuously analyze the flue gases. In addition, the ashes chemical composition was also analyzed.

The results show that these pellets have a good thermal efficiency in domestic boilers, releasing however large emissions of NO_x, originated from the high concentration of nitrogen in its chemical composition. The ash analysis confirms the slagging and fouling prediction, and these problems were verified in the grate, chamber combustion and heat exchanger.

In conclusion, these pellets can be explored for industrial applications, with better control of its chemical composition. For domestic boilers however, these can cause serious ash problems.

1- INTRODUCTION

The global wood pellet market has reached 15 Mton in the year 2011 [1]. In Portugal, the use of pellets is increasing and more than 600 Mton were produced in 2010 [1]. The use of different raw materials, capable of producing biomass fuel for heating, has been studied [2–5]. Portugal, with more than one third of its area covered by forest, has a great potential to reduce its dependence on fossil fuels [5]. Carpentry, sawmill, panels and veneers and main furniture industries are the principal applications for the genus Pinus and Eucalyptus, and high quantities of residues are produced by these industries (600.2 dry kton/year) [6].

In addition to the traditional use of sawdust as a raw material, there has been a growing interest in the incorporation of residues from the processing industry, such as the furniture sector. However, these alternative sources may pose problems regarding their adequacy to meet the fuel standards for emissions and efficiency.

Furniture wastes have several applications in the market, as medium-density fiberboard (MDF) or particleboard. These residues contain small concentrations of formaldehyde and other compounds that can cause problems to human health. This has been studied through combustion gaseous emissions and chemical composition [7].

The furniture waste combustion was studied by M. Rabaçal et al. [8] in a domestic pellet boiler (22 kW), revealing high levels of NO_x emissions, and in fuel nitrogen content comparing with other fuels (pine and peach stones). No other complications were detected in this study of pellets from furniture wastes. Previous studies carried out by J. Dias et al. [2] have shown this problem regarding the NO_x emissions, and also concluded that increasing excess air contributes to raise these emissions. Yorulmaz et al. [7], focusing on pellets obtained by furniture waste, such as MDF, revealed that treatment of wood with additives and glues, appears to change the thermal oxidation and the oxidation mechanisms. The combustion of wood pellets from residues derived from the furniture manufacturing industry (FRWP) has not been studied with detail regarding ash related problems. Recently, various indexes applied to slagging and fouling problems in coal combustion have been introduced to predict the same problems of biomass pellets [9], [10].

This investigation is a good opportunity to promote the study of the FRWP combustion, analyzing the environmental impact of emissions and understanding the behavior of its ashes and possible problems.

2- MATERIALS AND METHODS

In this study the aim was to characterize pellets obtained from furniture waste according to their chemical composition, heat value, combustion gas emissions and ash characteristics. They were subsequently tested in a purposely built facility that includes an automatic boiler rated at 15 kW coupled with a thermal dissipation loop. A probe in the exhaust chimney was used to continuously analyze the flue gases in terms of CO, CO_2, O_2 and NO_x.

Figure 1 shows schematically the main components of the experimental facility: weighting scale, boiler, gas analyzer and data acquisition system.

The boiler is of mono-bloc type, which means that it includes the burner, combustion chamber and heat exchanger integrated into a single structure. The boiler has 5 power levels and can adjust the ratio of air inlet and pellets feeding. This parameter can be controlled within the range from -50 to +50. In the operating conditions the boiler was programed at -35 which represents higher air/fuel ratio.

The cooling system is built around a cross flow air/water heat exchanger that includes a fan to improve air circulation. The power dissipation is up to 44 kW, for an ambient temperature of 30 ºC. A multi gas analyzer was used for continuous monitoring the combustion gaseous emissions: O2, CO2, CO and NOx. Finally, a data acquisition system is used to collect the data and convert the voltage signal in to the units required for thermocouples, gas analyzer and scale.

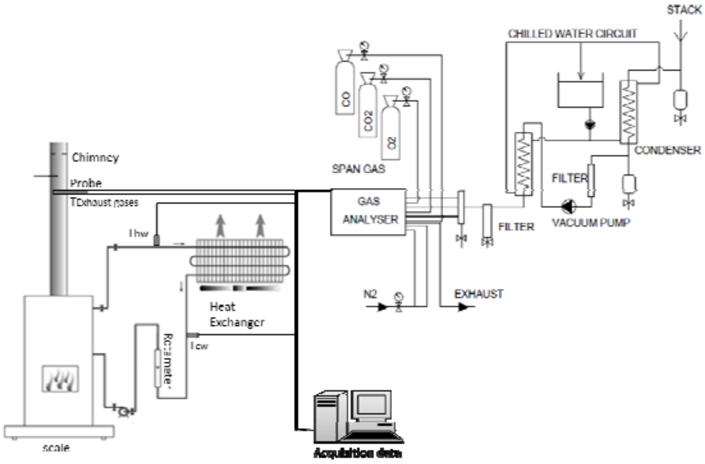

Figure 1. Experimental facility for biomass combustion

3- RESULTS AND DISCUSSION

The experiments were carried out to determining the environmental impact in the atmosphere, by analyzing the gaseous emissions. However, another important issue was the analysis of the ash impact (slagging, fouling) on several parts of the boiler, in continuous operation (6 hours).

3.1- Pellets properties

Pellets were produced from furniture manufacturing residues. Table 1 summarizes its physical and chemical characteristics and the limits defined by the ENplus quality standards [11].

Parameter	Units	ENplus-A1	ENplus-A2	B	Analyses method	FRWP
Diameter	mm	6 (+1) or 8 (+1)			EN 16127	6
Moisture	% wt, ar	< 10			EN 14774-1/2	**2.7**
Ash	% wt, db	< 0.7	< 1.5	< 3.0	EN 14775	**0.8**
LHV	MJ/kg	16.5<Q<19	16.3<Q<19	16.0<Q<19	EN 14918	**16.6**
Bulk density	kg/m^3	> 600			EN 15103	-
Nitrogen	% wt, db	< 0.3	< 0.5	< 1.0	EN 15104	**3.78**
Sulphur	% wt, db	< 0.03		< 0.04	EN 15289	**0.12**

Table 1. ENplus limit values for the classes A1, A2 and B and properties of the pellets

The FRWP exceeded the legal limit for the ENplus in respect to the ash, N and S levels. The ash value is not representative for the class A, and the N and S values exceed all the class limits. Even for industrial proposes (class B) these pellets are not applicable.

3.2- Environmental and thermal analysis

The boiler was operated at an intermediate power (level 3). The NO_x emissions in the various tests reflect the excess nitrogen in the pellets combustion. In addition to these factors that affect public health, pellets with such emission levels do not meet the legal limits imposed by the Portuguese legislation [12]

Table 2 details the results obtained from the flue gases analysis.

Parameter	**FRWP** (mg/Nm^3@ 11% de O_2)	**Legal limit** (mg/Nm^3@ 11% de O_2)
CO	198	500
NO_x	1,171	650
SO_2	6.15	500
PM	14.3	150
VOC	10.7	200

Table 2. Values of the exhausted gases and legal limits of Portuguese legislation [12].

3.3- Ash analysis

The ash analysis to the FRWP was separated in two distinct results: from the boiler grate (bottom ashes - slagging); from the heat exchanger and the walls of the combustion chamber (fly ashes - surface fouling). The results of the ash components are show in Table 3.

Parameters	**Bottom ashes ***	**Fly ashes ***	**Parameters**	**Bottom ashes ***	**Fly ashes ***
Al_2O_3 (%)	11.6	5.76	NiO (%)	0.067	0.06
BaO (%)	0.57	0.5	P_2O_5 (%)	2.62	2.65
CaO (%)	26.2	26	PbO (%)	0.028	0.055
Cl (%)	0.11	0.82	Rb_2O (%)	0.026	0.03
Cr_2O_3 (%)	0.14	0.2	SO_3 (%)	3.92	7.03
CuO (%)	0.23	0.12	SiO_2 (%)	16	15.5
Fe_2O_3 (%)	5.84	5.38	SrO (%)	0.19	0.15
K_2O (%)	6.6	6.8	TiO_2 (%)	17.2	19.5
MgO (%)	4.44	4.73	ZnO (%)	0.059	0.21
MnO (%)	1.34	1.06	ZrO_2 (%)	0.042	0.035
Na_2O (%)	2.89	3.46	-	-	-

*wt% ashes, analyzed with X-Ray Fluorescence

Table 3. Mass fraction for the bottom and fly ashes of the furniture pellets.

Figure 2 shows the major diferences in these ashes paths, highlighted by circles arround the bars. The Cl and S are corrosive to the internal componentes of the boilers, and the fly ashes have a higher content. The paths between the walls of the chamber combustion to chimney are affected. The Cl has a corrosive effect on metal surfaces in furnaces and boilers, and combine with other elements like HCl and particulate (KCl, NaCl, $ZnCl_2$) emissions [13]. The presence of Ca and Mg usually increase the ash melting point, while K and Na have an opposite effect [14]. The bottom ashes present a higher quantity of Al when comparing with the fly ashes. This component, being amphoteric, can react both with acid and base. According to F. Biedermann [13] aluminum silicates may also significantly decrease the ash melting point, which is typical of FRWP ashes. Elements like Na and K have low melting points. Therefore, the higher its percentage in the ashes, the higher the likelihood of fusion in ash elements. The total alkalis (K_2O+ Na_2O) higher than 0.4 represent a high tendency to fouling formation [10]. This and others indexes (Ratio acid/base, Silica percentage, alkali index, etc) were initially used to assess the likelihood of ash problems in coal. Recent studies show that the application of these empirical formulations can confirm the same problems in biomass combustion.

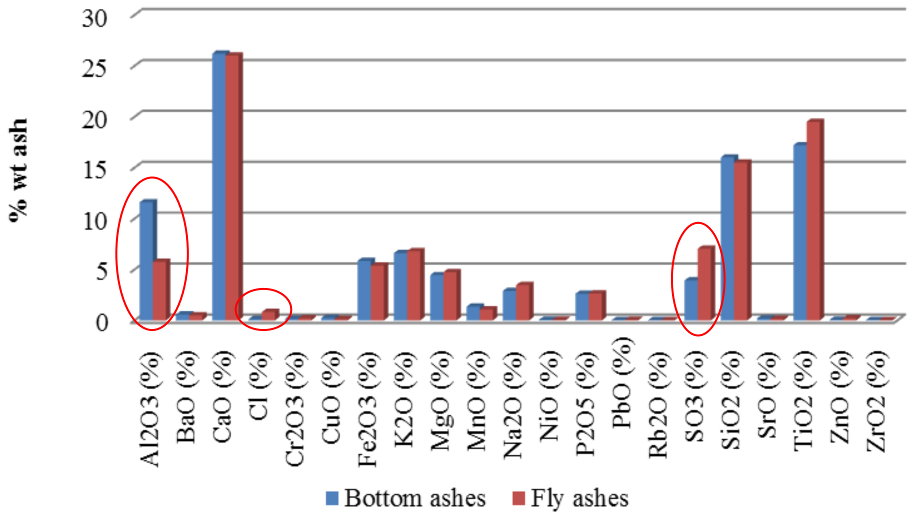

Figure 2. Mass fraction differences between bottom and fly ashes.

Ashes cause serious problems in combustion systems, of solid fuels, particularly causing shorter life periods in heating equipment. The ashes formed in the combustion of these pellets had a significant impact, causing fouling and slagging. Slagging problems appeared only after 1 day of continuous operation. Figure 3 illustrates some of these problems.

a)  b)  c) 

Figure 3. Ash problems in the boiler by the FRWP: a) fouling in the heat exchanger; b) slagging and obstruction of the air inlets of the grate; and c) slagging of the ash fusion.

The slag formed in the boiler grate blocks the primary air inlet, impairing the combustion and eventually extinguishing the flame. The fouling in the heat exchanger decreases the useful heat to inadequate levels, increasing the power demand and the maintenance costs.
Accordind to recent studies [9], [10], the influence of biomass ash can be predicted by the use of empirical parameters for slagging and fouling tendencies, as shown in Table 4. The ashes of FRWP revealed some problems, developing slags at the grate and fouling in the internal components. The results show that most indices point to slagging and fouling problems. Only in the Alkali index (AI) the tendency of ash problems is slight. In this formula the ash quantity in pellets has a large impact. These pellets present a low ash quantity in their initial proprieties (0.8 %). The bottom and fly ashes have differences in silica/aluminium indexes. However the two are representative of slagging tendency. The base/acid ($R_{a/b}$) ratio and total alkalis (TA) also suggest a slagging and fouling tendency that is shown in Figure 3.

Index/Formula	Slagging and Fouling tendency	Bottom ashes	Fly ashes
$AI = \frac{Kg\ (Na_2O + K_2O)}{GJ\ (Biomassa)}$	>0.34 certain	0.04	0.05
	0.34>AI>0.17 probable		
$R_{b/a} = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2}$	>1 high	1.03	1.14
	0.5< $R_{a/b}$ <1 medium		
	<0.5 low		
$TA = Na_2O + K_2O$	>0.4 high	9.49	10.26
	0.3>TA>0.4 medium		
	<0.3 low		
$\%\ Si = \frac{SiO_2 \times 100}{SiO_2 + Fe_2O_3 + MgO}$	>78% low	60.88	60.52
	<66.1% high		
$Si/Al = \frac{SiO_2}{Al_2O_3}$	0.31 < Si/Al <3 medium to severe	1.38	2.69

Table 4. Results for Slagging and Fouling indexes in FRWP ashes.

4- CONCLUSIONS

From this work the final conclusion can be drawn:

- The pellets composition does not comply the legal limits imposed by ENplus as the sulphur and nitrogen levels exceed the limits for classes A1, A2, and B.
- The high level of nitrogen in the chemical analysis promotes the high emissions levels of nitrogen oxides (NO_x).
- Regarding the emissions levels, the NO_x value exceeds the legal limits for biomass combustion, although the other parameters are within the acceptable limits.
- The mass fraction differences between bottom and fly ashes are not significant in most metal oxides. However differences like aluminium (bottom ashes), chlorine and sulphur (fly ashes) can cause problems in the long term use.
- These pellets show serious fouling e slagging problems, which may compromise the long term thermal efficiency and durability of the equipment.
- The fouling and slagging indexes confirm the problems observed. These indexes can be a good indication for future ash analysis.

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