

# Characterization of Biomass Woodchips as Fuel for Industrial Boilers

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**Abstract**—This study aims to evaluate the implications of the use of maritime pine non-debarked wood chips as an alternative solid fuel in industrial boilers in Portugal, highlighting the energy properties and chemical composition of the ash produced. Several samples have been collected from different sources, on which an approximate analysis is carried out to determine the volatile matter content, fixed carbon content, ash content and higher heating value (HHV). The chemical composition of the ash samples is determined by the SEM – scanning electron microscope – method. Then, empirical indices are used to assess the behaviour of the ash and its tendency to create slagging and fouling deposits in industrial boilers during the combustion process. From the presented results it is clear that the use of maritime pine non-debarked wood chips can contribute significantly to the formation of slagging and fouling phenomena in industrial boilers. These phenomena will be responsible for increasing the number of technical stoppages of the equipment and for the increase in maintenance costs.

**Index Terms**—wood chips, biomass energy, chemical composition, ash, boilers.

## I. INTRODUCTION

The search for alternative sources for the production of thermal energy with less environmental impact has caused biomass to occupy a very important role compared with other forms of renewable energy [1]. Biomass thereby has great importance in the production of thermal energy; this biomass mainly comes direct from the forest and forestry operations in all its forms, namely that processed into wood chips after the cutting of the trees [2].

These wood chips are used directly as fuel in thermal energy production in combustion. In this process of thermochemical conversion, organic elements present in the fuel suffer total or partial oxidation, transforming the chemical energy into heat [3].

Combustion systems have very important environmental issues that must be considered, with emphasis on the production of ash that is a solid residue of the process and does not participate in the reactions. Several studies make reference that, in the biomass of forest origin, the ash content represents the percentage of mineral compounds that can be found in the fuel. This ash content is directly influenced by such factors as: the environmental conditions during growth, the species, the part of the tree used (bark, leaves, logs) and age. The main chemical elements that can be found in biomass ash are K, Ca, P, Si, Al, Fe, Ti, Na and Mg [4].

These elements can form on the thermal exchange surfaces of the large slagging areas of industrial boilers and can lead to malfunctioning and a reduction in heat transfer efficiency. In addition, depositions can generate fouling areas and corrosion that accelerate the wear of the heat transfer surfaces and even the boiler structure [5].

Slag formation potential depends on the fusion capacity of the chemical elements present in the ash. Alternatively, fouling starts with the sintering process, resulting in much harder deposits which are more difficult to remove over time [6].

From an energy point of view, the selection of the biomass form to produce energy is almost always made considering only the energy content of the fuel. In contrast, the effect of the biomass forest ash in the combustion process in boilers is still understudied and the probability of generating slagging and fouling can derail its use, mainly due to the significant increase in maintenance costs of the equipment [7].

This motive itself justifies a novel analysis that allows the definition of how far a material with high energy potential can be used as fuel, but also considering the analysis of the ash. In this way, the main objective of this research is to evaluate possible implications for industrial boilers in Portugal of maritime pine (*Pinus pinaster*) wood chips, the forest biomass form with the highest potential to be used as fuel, considering its energy properties and the chemical composition of the ash.

## II. MATERIALS AND METHODS

### A. Sampling and Samples preparation

The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations. In this study, five different non-debarked maritime pine wood-chip samples used as fuel in industrial boilers were analysed. Sampling and the preparation of the samples was conducted in order to be representative of the combustion process in the different boilers, with several samples collected directly from the grate

covering the entire combustion surface. The samples collected in each boiler were mixed and homogenized before chemical analysis in order to represent the average value.

Figures 1 and 2 present some examples of the samples that were collected in the boilers.



Fig. 1. Vitrified sample of ash collected in an industrial boiler.



Fig. 2. Sample of “petrified” ash collected in an industrial boiler. It is possible to identify several layers with different chemical compositions.

### B. Characterization of the collected samples

The proximate analysis to determine moisture (%ar), ash (%db), fixed carbon (%db) and volatile matter (%db) was undertaken following standards EN14774-2, EN14775 and EN15148. High heating value (HHV) was achieved with a Parr 6400 calorimeter.

### C. Chemical composition of the ash

The ash samples collected were analysed using a Phenom ProX desktop scanning electron microscope (SEM), where the sample structures were physically examined and their elemental compositions determined.

Figure 3 shows an example of the obtained results. These results were later converted into oxide percentages.

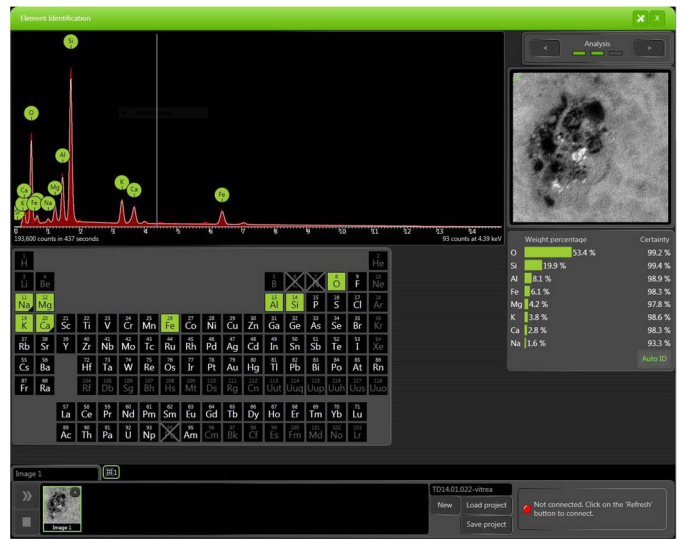


Fig. 3. Example of the obtained SEM results.

### D. Slag and fouling indexes of ash in industrial boilers

In this study, several empirical indexes were used to evaluate the behaviour of the ash and its tendency to generate slagging and fouling deposits on the inner walls of the boilers, furnaces and tubing during combustion. These indexes were originally developed for fossil fuels, but have also been used for biomass fuel analysis in several recent studies [8–11].

The indexes used are described by the following equations:

1) Slagging Index (B/A): is the base-acid relation used to measure the slagging occurrence tendency caused by the fuel ash (Equation 1):

$$(B/A) = \frac{(Fe_2O_3 + CaO + MgO + K_2O + Na_2O)}{(SiO_2 + TiO_2 + Al_2O_3)}$$

Equation 1 was developed for fossil fuels with low phosphorus (P) content. In a later study, and following the methodology previously presented, the P content was also considered in the relation presented in Equation 2 [12]:

$$(B/A) + P = \frac{(Fe_2O_3 + CaO + MgO + K_2O + Na_2O + P_2O_5)}{(SiO_2 + TiO_2 + Al_2O_3)}$$

where a relation  $B/A < 0.5$  indicates a low propensity for slagging;  $0.5 < B/A < 1.0$  indicates medium propensity for slagging;  $B/A = 1.0$  indicates high propensity for slagging and  $B/A > 1.75$  indicates severe propensity for slagging.

2) Fouling Index (FI): represents the propensity for fouling formation in industrial boilers and is represented in Equation 3:

$$FI = \frac{(Fe_2O_3 + CaO + MgO + K_2O + Na_2O)}{(SiO_2 + TiO_2 + Al_2O_3)} \times (Na_2O + K_2O)$$

where  $FI < 0.6$  indicates a low propensity for fouling;  $0.6 < FI < 40$  indicates a high propensity for fouling and  $FI > 40$  indicates a severe propensity for fouling [13, 14].

3) Alkali Index (AI): expresses the quantity of alkali oxides in the fuel per unit of energy (kg/GJ), and is represented in Equation 4 [15–17]:

$$AI = (1 \times 10^6 \times \text{Ash\%} \times (\text{K}_2\text{O} + \text{Na}_2\text{O}\%)) / (\text{HHV} (\text{kJ/kg}))$$

where  $AI < 0.17$  indicates low propensity for slagging and fouling;  $0.17 < AI < 0.34$  indicates a high propensity for slagging and fouling and  $AI > 0.34$  indicates severe propensity for slagging and fouling.

### III. RESULTS AND DISCUSSION

#### A. Energy characterization of the biomass

In Table I the results of the energy characterization of the biomass samples are presented.

TABLE I  
PROXIMATE ANALYSIS AND HHV FOR MARITIME PINE NON-DEBARKED WOOD-CHIP SAMPLES.

Samples	1	2	3	4	5
Moisture (%)	43.30	47.80	28.50	39.70	49.10
Volatile matter (%)	76.90	77.80	79.30	80.60	77.70
Fixed carbon (%)	21.60	20.90	20.10	19.00	20.60
Ash (%)	1.53	1.25	1.82	1.76	1.70
HHV	11.90	11.10	14.80	12.60	10.82

As can be seen in Table I, the percentage of volatile matter is above 70%, and is as expected for these biomass forms and desirable in the direct combustion process [18]. The obtained values for fixed carbon varied between 19% and 21.6%, also assumed to be normal for this type of biomass [19].

Concerning the ash content, it is possible to verify that the obtained values varied between 1.73% and 1.92%, which can be considered high when compared with other forms of biomass also used as fuel in industrial boilers. Bark tends to contribute to higher ash content compared to debarked wood, as has been shown in previous studies, because higher nutrient and contamination content accumulates [20–23].

HHV varied between 10.82 MJ/kg and 12.60 MJ/kg. This variation in the obtained values is accepted because there are differences between the moisture content of the samples that varied respectively between 28.50% and 49.10%, provoking the difference in HHV. These values are in accordance with the results presented in several previous studies [24, 25].

#### B. Chemical composition of the ash

The chemical composition of the ash of the studied samples is characterized by the variation in some of the inorganic compounds that are presented in Table II as mineral oxides.

TABLE II  
CHEMICAL COMPOSITION OF THE ASH.

Oxides (%)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
SiO <sub>2</sub>	42.57	45.63	19.65	10.91	24.60
Al <sub>2</sub> O <sub>3</sub>	15.30	10.96	11.16	18.33	12.66
CaO	3.92	9.23	3.64	1.82	7.56
P <sub>2</sub> O <sub>5</sub>	0.96	0.91	1.23	1.03	1.15
Fe <sub>2</sub> O <sub>3</sub>	8.72	13.23	41.43	30.45	7.29
K <sub>2</sub> O	4.58	8.79	9.23	10.30	6.56
MgO	6.96	6.30	8.23	8.62	12.44
TiO <sub>2</sub>	1.21	0.98	1.34	1.50	1.12
Na <sub>2</sub> O	3.17	3.56	3.56	4.71	4.21
MnO	0.00	0.00	0.00	0.00	1.15

As can be verified, the differences are mainly in SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub>, which can be justified by the different origins and sources of the biomass, namely mainland regions or littoral areas where contamination with sandy materials is more frequent.

#### C. Ash tendency for slagging and fouling in industrial boilers

It is possible to verify that there was no difference in the occurrence tendency of slagging in industrial boilers compared to the indexes with and without phosphorus oxide (Table III).

As can be observed in Table III, with the exception of Sample 1, all the remaining samples present a high tendency for slagging and fouling. This difference may be justified by the origin of the fuel used. This fuel may have originated in mainland areas, far away from the sandy littoral regions and have less SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> contamination.

TABLE III  
QUANTITATIVE AND QUALITATIVE ANALYSIS OF ASH SLAGGING AND FOULING.

Samples	1	2	3	4	5
<b>Quantitative analysis</b>					
Slagging index	0.46	0.71	2.06	1.82	0.99
Slagging index + P	0.48	0.73	2.09	1.85	1.02
Fouling index	3.59	8.82	26.29	27.30	10.68
Alkali index	0.11	0.20	0.19	0.21	0.19
<b>Qualitative analysis</b>					
Slagging index	Low	Medium	Severe	Severe	Medium
Slagging index + P	Low	Medium	Severe	Severe	High
Fouling index	High	High	High	High	High
Alkali index	NP	P	P	P	P

Where: NP – Not Probable; P – Probable; VP – Very Probable

#### IV. CONCLUSIONS

As can be seen in the results, the general tendency pointed to a high probability of slagging and fouling when non-debarked maritime pine wood chips are used as fuel. The exception presented in Sample 1 can be explained by the different origin of the biomass and also by the different relation between the bark and the wood core diameter that will dilute the mineral elements content, which is more abundant in the bark, in a larger quantity of wood. Thus, it is possible to conclude that the continuous utilization of non-debarked maritime pine wood chips will cause slagging and fouling phenomena in boilers and tubing that will contribute to increasing maintenance technical stoppages, as well as increasing maintenance costs associated with equipment operation. In this way it is predictable that the utilization of non-debarked wood in wood chip production will significantly reduce the ash content of the fuel, but will also reduce the quantity of chemical elements that contribute to the occurrence of slagging and fouling phenomena in industrial boilers.

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