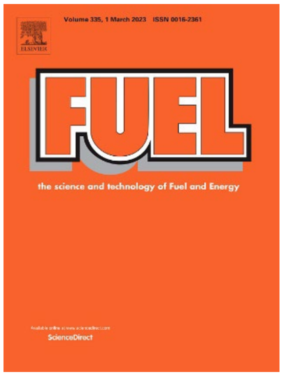

Influence of ashes in the use of forest biomass as source of energy.

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Influence of ashes in the use of forest biomass as source of energy

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Abstract. One of the main challenges using biofuels, such as pellets or wood chips in domestic boilers, is the slagging and fouling risks associated to the process, which could damage the boiler and limit its efficiency. The prediction of sintering and slagging in biomass combustion is essential to establish biofuel quality standards, and minimize their harmful effects. In this work, we analysed the chemical composition of 40 woodchips samples from different genera and origins in order to predict slagging. We studied two indexes of deposition (%B and the NaK/B) in order to limit sintering of biomass ashes. In addition, a new threshold classification was proposed for ratio-slag viscosity index. These indexes were validated with two different tests: a qualitative test, and a quantitative test (*Bioslag*). Our results showed that the species chosen did not have an impact in slagging and sintering. However, biomass with high concentrations of SiO_2 and tree bark showed high risk of slagging. On the other hand, high CaO concentrations showed a low slagging risk. The results obtained from the validation tests showed similar results to the ones obtained from the indexes. It can be concluded that the %B and NaK/B indexes show good potential and should be considered as tools for predicting slagging in woody and herbaceous biomass.

Keywords. Biomass; sintering; slagging indexes; biofuels

1. Introduction

Human Population is growing at a high rate, and it is estimated that by 2050 it will increase to 9 billion [1]. As a consequence, by 2040 global energy demand will grow by more than a quarter, and therefore, oil and gas demand will continue to rise [2]. In fact, to this day, fossil fuel supply still dominates global energy supply [3]. The Sustainable Development Goals, which were adopted by the United Nations in 2015, established three priority objectives: guarantee affordable and universal access to modern energy services, increase the share of renewable energy and double the global rate of improvement in energy efficacy [4]. Countries like China, India, the United States and The Russian Federation have set targets to increase the use of renewable energy and reduce carbon emissions [5]. The European Union has also set a renewable energy target of 32% by 2030 [6]. It is estimated that the share of renewable energy will grow from 15% in 2015 to 63% in 2050 [5]. In addition to the environmental benefits provided by using renewable energies, there are several advantages such as a decrease in external energy dependence, promotion of regional consultancy and engineering services, and creation of employment [7]. This could benefit countries like Spain and Portugal, which are highly dependent on energy from abroad – they import more than 70 % of all energy they consume [8].

As any other type of renewable energy, the use of biomass as a clean, environmental friendly energy source has increased as a result of fossil fuels depletion [9], and the environmental and health problems caused by fossil fuels burning [10]. Biomass also has a high energy potential similar to other more conventional energy sources [11]. Plant biomass used as biofuels include pellets, wood chips and firewood, which are usually directly burned in home appliances such as stoves [1].

One of the main problems using raw materials such as pellets or wood chips as biofuels in domestic boilers, is the slagging and fouling risks associated to these biomass fuels, which potentially could damage the boiler and limit its combustion efficiency [12]. Slagging is a process in which agglomeration of ash occurs, and sintering takes place in boiler sections that are directly exposed to flame radiation due to high contents of alkali, sulphur (S) and silica contents of the biomass [13,14]. Ash content is also an indicator of biomass quality, the higher the ash content, the lower the lower heating values (LHV) [15]. Fuels with high silica content can result in the formation of silicates [16], leading to ash deposition which can cause problems at moderate and high temperatures [17,18]. These ash deposits can delay heat transfer, cause mechanical failure and corrosion in the combustion equipment [19].

The prediction of sintering and slag formation in biomass combustion is essential to establish biofuel quality standards and to minimize their detrimental effects [18]. There are several methods for predicting bed agglomeration. Skrifvars et al. [20], compared three different techniques to predict bed agglomeration in ten different types of biomasses, and their results showed significant differences predicting bed agglomeration temperatures depending on the technique used. Llorente et al [18], also compared different methods for predicting sintering of biomass ash in combustion and they determined that ash sintering behaviours prediction differed not only depending on the technique used but also on the type of biomass and their content in alkali element. Fuel indexes, based on the detection of chemical elements, are one of the most promising approaches for predicting slagging [21]. These indexes are created from chemical fuel analyses, checked at real scale combustion labs and evaluated to assess their applicability [22] However, most of these indexes have been developed to study carbon ashes, and therefore their applicability must be validated according to biomass fuels [20]. Biomass has a higher level of humidity, a lower calorific value and a higher concentration of chlorine (Cl), potassium (K), sodium (Na) and sulphur (S) than carbon. The main problem with these elements is that they play a key role in the behaviour of ashes during combustion as they react with alkali metals to form potassium chloride (KCl) and sodium chloride (NaCl) which can be easily volatilized during combustion generating deposition problems [23–25].

In this work, we analysed the performance of 40 different biomass types during the process of combustion in order to predict slagging. Ash sintering is considered to be the initial step during the process of fouling and slagging. Two indexes of deposition and thresholds for these indexes were studied in order to limit sintering of the biomass ashes. Validation of these indexes was carried out. Additionally, these indexes were compared with other similar ones. Results of this paper can serve as theorical guidance for the research and development of combustion technologies for the blends of different types of biomass.

2. Methods

2.1 Selection of samples and chemical composition

The chemical composition of 40 woodchips samples was analysed. These samples were obtained from two different companies -one that produces biofuels from different biomass sources and one that utilizes biofuels from different biomass sources-, and also from urban gardens pruning. Most of the samples comprised species from the genera *Pinus, Eucalyptus*, *Betula, Populus* and *Quercus* (Table 1).

Samples were analysed at Centro de Apoyo Científico y Tecnológico a la Investigación (CACTI). Carbon, hydrogen, nitrogen and sulphur concentrations were determined with a Carlo Erba 1108 Elemental Analyser. Elements such as cadmium, iron, calcium, magnesium and silicon were determined with an inductively coupled plasma mass spectrometry (ICP-MS) instrument and with an atomic absorption spectroscopy instrument.

2.2 Slagging indexes

Two deposition indexes were used to predict slagging and fouling. These indexes are based in the chemical composition of the biomass. The indexes used were:

Alkali index (modified according to Vega, 2011 [26]):

$$NaK/B = (Na_2O+K_2O) / (CaO+MgO+Na_2O+K_2O) \quad (1)$$

and Ash fusibility index [27]:

$$\%B = B/B+A \quad (2)$$

where $B = CaO + MgO + Fe_2O_3 + Na_2O + K_2O$ and $A = SiO_2 + Al_2O_3 + TiO_2$

Thresholds were used to predict the sintering risk of the different samples studied (Table 2). These thresholds were slightly modified by some authors [28–31], after they were tested at the laboratory showing they fit better to the fuel behaviour.

Furthermore, the results obtained with these indexes were compared with other relevant indexes (Table 2).

- SR ratio-slag viscosity index [27]:

$$S_R = \frac{SiO_2}{SiO_2+Fe_2O_5+CaO+MgO} * 100 \ (3)$$

- Sintering index [18]:

$$\frac{CaMg}{NaK} = \frac{(CaO+MgO)}{(Na_2O+K_2O)} \ (4)$$

- SiO_2 content [32]

  At SiO_2 > 20-25%, slagging problems have been found.

2.3 Statistical analyses

IBM SPSS Statistics (SPSS, Inc., and IBM Company 1989) was used to performed statistical analyses in order to determine if there were significant differences between species in relation to the %B index. The coefficient of determination (R^2) was calculated to study the relation between SiO_2 and the %B index. The results of the indices and the ash chemical composition are mean values ± standard deviation from three independent experiments. Pearson´s correlation was used to calculate the correlation between the compounds that form the ashes. Pearson´s coefficient of determination was used to study the relation between S_R and the %B index.

2.4 Validation of results

To validate the results obtained by the slagging indexes, two tests were used, first a visual qualitative test (visual sintering test), and second a quantitative test (*Bioslag*) [33]. These tests are experimental methods based in the granulometry of ash deposits which are obtained through combustion. For each of our samples, an amount of between 100 g and 200 g (Table 1) was deposited in a crucible and introduced into a Therm Concept oven. Samples were gradually heated by increasing 10 ºC from 10 ºC until reaching a temperature of 250 ºC, and maintained at such temperature for four hours to eliminate all the volatile matter. The process was repeated until 1100 ºC was reached and maintained at such temperature for six hours. A Eurotherm 3500 was used to regulate the temperature and samples were then weighed again.

The qualitative visual test was carried out recording the degree of difficulty of separating ash particles from the crucible using a laboratory spatula. The observed results were divided into three groups depending on the sintering level (Table 2).

For the quantitative test (*Bioslag*), a CISA RP-03 shaker was used at 200 revolutions per minute (rpm) to sieve the ash recovered after combustion. Two potency levels were used for one minute each: a power 3 (P3) potency, and a power 6 (P6) potency. Three sieves with different apertures were used: 2mm, 1mm and a <1mm. The samples obtained weighted again, as well as the crucible with the ash residue.

Ultimately, a hardness index was applied in order to determine the probability of hard sintering [30] (Table 2):

$$\%D_1 = [(ac\%1\_P6) / (ac\%1\_P3)] * \text{hardness coefficient} \quad (3)$$

where: ac%1_P6= accumulated weight of the samples for the P6 potency, ac%1_P3= accumulated weight of the samples for the P3 potency

hardness coefficient: if in the granulometric test the texture of the slag is soft, the coefficient is equal to 0.5. If this texture is hard, the coefficient is 2.

3. Results and Discussion

3.1 Chemical composition

Chemical composition of the ash samples is shown in Figure 1. Ash forming elements are usually presented as oxides: Al_2O_3; SiO_2; CaO; Fe_2O_3; MgO; MnO_2; P_2O_5 [34]. These results are characterized by the high variation in some of the inorganic compounds, mainly in SiO_2 and CaO. High levels of SiO_2 are observed in some of the samples. This can be due to the different origins and sources of the biomass from areas where contamination is more frequent, for example sandy areas, as in agreement with Nunes et al. and Vassilev et al. [35,36]. Öhman et al. [32] concluded that the Si content correlated well with the sintering tendencies in the burners. There can also be observed high levels of CaO in some of the samples, which could be as a result of the presence of tree bark, as in concordance with some authors [37,38]. Presence of S and Cl, which play a role in deposit formation and corrosion [39], was not found in our samples. This could be due to the fact that S and Cl content is generally very low in woody species as in agreement with other studies [39,40]. Figure 2 shows the distribution of the measured element concentrations in the ashes. The mean, standard deviation, median, maximum, and minimum concentrations of the elements are summarized in Figure 2. The elements with the highest percentage present are CaO (42.01%), K_2O (25.65 %) and SiO_2 (10.30%). Low vapour pressure compounds, such as alkaline earth elements (Ca and Mg), alkaline oxides, phosphates and silicates, do not easily volatilize [41]. The ash chemical composition affects the viscosity and the sintering behaviour of fly ash. SiO_2 positively affects the viscosity, whereas CaO or Na_2O modify the silicate network structure decreasing the viscosity [42,43]. When analysing the CaO data, samples 2 and 7, with very a low concentration of this compound, should be considered as samples that might produce slagging. In addition, when observing the SiO_2 values, samples 7,17,23,25 and 26, since they have a higher concentration of this compound, might also produce slagging. Furthermore, it has been reported that melting temperature decreases at high K_2O concentrations [44,45]. Therefore, samples with high percentages of K_2O and SiO_2 will show lower ash melting points, which would eventually lead to slagging [46].

Potassium lowers the melting point of ash [47,48]. Potassium reacts in presence of silicon to form potassium silicates, contributing to slagging as they stick together with silicon [48,49]. High CaO content melting point of about 2570-2580 °C [50], increases the melting temperature of the sample. Besides, the building of potassium silicates is prevented, which show low ash melting temperatures.

Pearson´s correlation coefficients were calculated to explore the correlations between the different elements in the ash (significant for $P \leqslant 0.01$). Significant correlations were found between elements, such as Fe_2O_3 and Na_2O (R=0.789), P_2O_5 and TiO_5 (R=0.458), P_2O_5 and Na_2O (R=0.450) and Al_2O_3 and SiO_2 (R=0.523). Chandrasekaran et al.,[41] determined that due to the low levels of these concentrations, the correlations are likely to be as a results of using wood harvested from similar locations.

3.2 Slagging indexes

Results from the slagging indexes and the risk level associated (Figure 3) suggest that there is a high risk of slagging in samples with high SiO_2 content (contaminated samples), and those with presence of tree bark. These findings are in agreement with other studies [35,38]. Therefore, the species chosen as biofuel will not have any influence in slagging. However, there is a significant relationship between the SiO_2 concentration and the %B index (Pearson´s correlation R^2=-0.935, p=0.01). As seen in Figure 4, the highest the amount of SiO_2 present in the biofuels, the highest the risk of slagging, which is concordant with previous studies [13,51,52]. Thus, our results show the importance of choosing biomass sources with low SiO_2 concentrations (i.e. non contaminated biomass) to avoid slagging. Results show that there are not significant differences between amongst species in relation to the %B index (p>0.05). For this reason, these indexes show good potential and should be considered as tools for predicting slagging in woody and herbaceous biomass used as biofuels. None of the species studied here shows a predisposition to sintering, sample 7, from *Pinus*, with a higher SiO_2 content, shows contamination by traces. But the rest of the *Pinus* samples do not show this predisposition to sintering. Therefore, the species analysed here are presented as viable options with a low probability of producing sintered compounds over pellets of mixtures with barley straws [53] or other pellets such as those produced with other materials such as algae [54][55]. Results from the visual qualitative test show none or little sintering for those ash samples from species with no contamination (Figure 5, A). However, samples with high contents of SiO_2 (contaminated samples due to traces of soil) and CaO (samples with tree bark traces), show medium to high sintering (Figures 5, B). The qualitative test, therefore, supports results from the slagging indexes previously studied

Results from the quantitative Bioslag test (Figure 3) show that samples with high levels of SiO_2 present a higher weight percentage of sintering products falling under the category of hard sintering. The Bioslag test supports results from the slagging indexes previously studied. Samples with low risk of slagging (%B index >0.7) do not exceed 25% of the ash total weight (Figure 6, C), which is in agreement with previous studies, such as Vega and Somoza [26,28], who found a relationship between risk of slagging and total ash weight. The Kruskal-Wallis test for a Bioslag and the %B index obtained a value of $p = 0.470$ ($p > 0.05$) showing no differences significantly. The Kruskal-Wallis test for a Bioslag and the NaK/B index obtained a value of $p = 0.340$ ($p > 0.05$) showing no differences significantly. Regarding the new proposed index %D1 (Figure 3), we did not observe hard sintering for values >0.7%. A relationship between %B and %D1 can be observed. Those samples with hard sintering (%B<0.7) also show a hardness coefficient of %D1>0.7% (Figure 6, D).

Figure 7 shows the indexes used to make the comparisons and the sintering level classification according to SiO_2 >20-25%. Pearson´s correlation was studied, and a high relation between SiO_2 (%) and the S_R index was observed (R =0.983). There is also a significant relationship between the S_R index and the %B index (R=-0.954) (Pearson´s correlation, p=0.01). Despite the fact that the statistical tests performed show high correlation, this is not in agreement with the classification values established by Pronobis, [27]. Based on the high statistical relationship, a new classification is proposed in order to make this tool more useful. The proposed classification is as follows: <30 no risk (green), ≥ 30 medium risk (yellow), ≥ 70 high risk (orange). With this new classification, the index is more similar to the Sintering Type, ac% _1P, % D1, % B indixes, and results would match for all the cases that presented slagging, except for sample 23.Also, with this new classification, our data would match 100% with the index proposed by Öhman et al.[32]. A priori, the S_R index, with the new classification, would have better precision, as highlighted by sample 7, than the % B and NaK/B indexes. The S_R values have been represented along with the ac%_1P and% D_1 indexes (Figure 6, down). They all show similar behaviour, with a similar pattern for HS values. Results from the sintering index show low correlation with the %B index and with SiO_2. However, the S_R index, which does not take into account the presence of Si in the sample, seems unreliable for the ash analysis carried out.

3.3 General discussion

A high number of biomass resources remain largely unused due to the sintering risk produced by the combustion ashes. In general terms, there is little information available on the behaviour of some species used as biofuels. Our study shows that the amount of ashes present in the biomass is one of the main factors that could potentially limit their use for energy generation. Currently, there is no single efficient method to assess biomass behaviour, as well as the slagging and sintering risks associated. The ash composition information is of great value. Compounds like CaO, Si_2O or K_2O give valuable details about which samples have the greatest potential for slagging. Choosing samples with a higher percentage of CaO and lower Si_2O would reduce the probability of this problem occurring. The %B and NaK/B indexes used in this work showed good potential for the detection of slagging. The results obtained, which were validated, with two different tests, show that these indexes could be used by companies- those producing biofuels, and those using biofuels-as tools to predict and mitigate. Furthermore, a new classification for the S_R index was proposed. This new classification seems promising according to the samples studied, as it shows greater precision than other indexes such as the ac%_1P and % D_1. However, further studies should be performed before using these novels methods at large-scale. As future recommendations, it would be interesting to provide companies with a tool that allows the correct management and optimization of resources. As well as improve the standardization of these mathematical indices and qualitative and quantitative tests to improve the correct management of biomass. The results of this article can serve as a theoretical guide for the research and development of combustion technologies for the mixtures of different types of biomass, optimizing the use of biomass resources.

4. Conclusions

Two slagging indexes, %B and NaK/B, were used to study the behaviour of biomass ashes. The results showed that the species chosen will not have an impact in slagging and sintering. However, biomass with high concentrations of SiO_2 and tree bark will show a high risk of slagging. Also, low CaO concentrations will indicate a higher probability of slag being produced. Therefore, the origin of the biomass is a factor to take into consideration. A new modified threshold for the S_R index has been proposed, with promising results. Modified thresholds proposed by other authors were used as they showed the fit better with the ash behaviour. The indexes were validated with a qualitative visual test and with the *Bioslag*, a quantitative test. Regarding the new proposed index %D_1, there were no observations of hard sintering for values >0.7%. Therefore, a relationship between %B and %D_1 can be observed. Samples with hard sintering (%B<0.7) also show a hardness coefficient of %D_1>0.7%. Nevertheless, it is important to take into consideration that the %D_1 test is a new index and could eventually evolve and be modified.

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Figure captions

Figure 1. Chemical composition of the ash samples (%).

Figure 2. Variation in ash compound concentrations, with Mean, Standard Deviation, Minimum, and Maximum Concentrations.

Figure 3. Results obtained from the *Bioslag* and %D_1 tests (ac%_1P= accumulated weight (g); %D_1=hardness coefficient for the 1mm sieve).

Figure 4. Relationship between SiO_2 levels and %B.

Figure 5. Results from the qualitative test for samples 1, 2 and 3 (Pinus, no contaminated) (A). Results from the qualitative test for samples 5 and 6 (Eucalyptus, high content of CaO due to the presence of tree bark) (B). Results from the qualitative test for sample 7 (Pinus with high content of SiO2 due to contamination from soil) (C).

Figure 6. Scatter plot of ac%_1P with relation to %B. Samples that show hard sintering have a %B<0.7 and an ac%_1P>0.25% (A). Scatter plot showing the relationship of the hardness

coefficient (%D1) and %B regarding the sintering type (B). Scatter plot of the ac_1P with relation to SR (C). Scatter plot of the %D1 with relation to SR (D).

Figure 7. Results obtained from the Sintering index and SR.

Tables

Table 1. Samples analysed

Table 2. Sintering risk according to the indexes values obtained

Tables

Table 1. Samples analysed

Samples	Genera	Weight ±0.01 (g)	Source	Notes
1	*Pinus*	111.47	Company producing biofuels from biomass	
2	*Pinus*	104.81	Company producing biofuels from biomass	
3	*Pinus*	105.52	Company producing biofuels from biomass	
4	Unknown genera. Recycled industrial wood	109.33	Company producing biofuels from biomass	
5	*Eucalyptus*	116.93	Company producing biofuels from biomass	Contains tree bark
6	*Eucalyptus*	100.91	Company producing biofuels from biomass	Contains tree bark

7	*Pinus*	100.00	Company producing biofuels from biomass	Very contaminated with soil traces
8	*Eucalyptus*	198.69	Company producing biofuels from biomass	Contains tree bark
9	*Eucalyptus*	164.76	Company producing biofuels from biomass	Contains tree bark
10	*Betula*	109.10	Company using biofuels from biomass	>16mm
11	*Betula*	111.40	Company using biofuels from biomass	<16mm
12	*Betula*	120.60	Company using biofuels from biomass	>8mm
13	*Betula*	47.20	Company using biofuels from biomass	<8mm
14	*Pinus*	80.40	Company using biofuels from biomass	>16mm
15	*Pinus*	100.50	Company using biofuels from biomass	<16mm
16	*Pinus*	110.50	Company using biofuels from biomass	>8mm
17	*Pinus*	84.30	Company using biofuels from biomass	<8mm Contaminated with soil

18	*Populus*	85.80	Company using biofuels from biomass	>16mm
19	*Populus*	99.30	Company using biofuels from biomass	<16mm
20	*Populus*	108.30	Company using biofuels from biomass	>8mm
21	*Populus*	91.10	Company using biofuels from biomass	<8mm
22	*Quercus*	94.60	Company using biofuels from biomass	>16mm
23	*Quercus*	163.20	Company using biofuels from biomass	<16mm
24	*Quercus*	139.70	Company using biofuels from biomass	>8mm
25	*Quercus*	137.40	Company using biofuels from biomass	<8mm Contaminated with soil
26	Unknown genera. Mixture of conifers and angiosperms	114.90	Company using biofuels from biomass	
27	Unknown genera. Mixture of conifers and angiosperms	104.40	Company using biofuels from biomass	
28	Unknown genera. Mixture of conifers and angiosperms	115.50	Company using biofuels from biomass	
29	Unknown genera. Mixture of conifers and angiosperms	115.50	Company using biofuels from biomass	

30	Unknown genera. Mixture of conifers and angiosperms	105.50	Company using biofuels from biomass	
31	Unknown genera. Mixture of conifers and angiosperms	123.30	Company using biofuels from biomass	
32	Unknown genera. Mixture of conifers and angiosperms	115.60	Company using biofuels from biomass	
33	Unknown genera. Mixture of conifers and angiosperms	102.70	Company using biofuels from biomass	
34	Unknown genera. Mixture of conifers and angiosperms	106.10	Company using biofuels from biomass	
35	*Ligustrum*	109.20	Pruning of urban gardens	
36	*Platanus*	101.20	Pruning of urban gardens	
37	*Quercus*	111.80	Pruning of urban gardens	
38	Unknown genera	124.50	Pruning of urban gardens	
39	Unknown genera	137.70	Pruning of urban gardens	
40	Unknown genera	120.70	Pruning of urban gardens	

Table 2. Sintering risk according to the indexes values obtained

Indexes	**Low**	**Medium**	**High**	**Very high**
%B	>0.70	0.70-0.50	0.50-0.30	<0.30
NaK/B	<0.3	0.30-0.50	>0.50	
S_R	>72	72≥SR>65	≤65	
ac%_	1P<25%	1P>25%		
Group	Weak Sintering (WS)	Hard Sintering (HS)	Completed Melted (M)	
Sintering Type	Particles can be easily disintegrated	Particles are difficult to disintegrate	Particles are completely melted and cannot be disintegrated	
Characterization	**WS**	**HS**		
Sintering index	>2	<2		
Group	**WS**	**HS**		
SiO_2*%*	<20	>20-25		
Group	**WS**	**HS**		
%D_1	<0.70	>0.70		

Notes. Low: the risk of sintering is improbable; medium: the risk of sintering is possible, but still low; high: the risk of sintering is high: very high: biofuels with very low quality composed by mostly recycled and synthetic products.

Figures

Figure 1. Chemical composition of the ash samples (%).

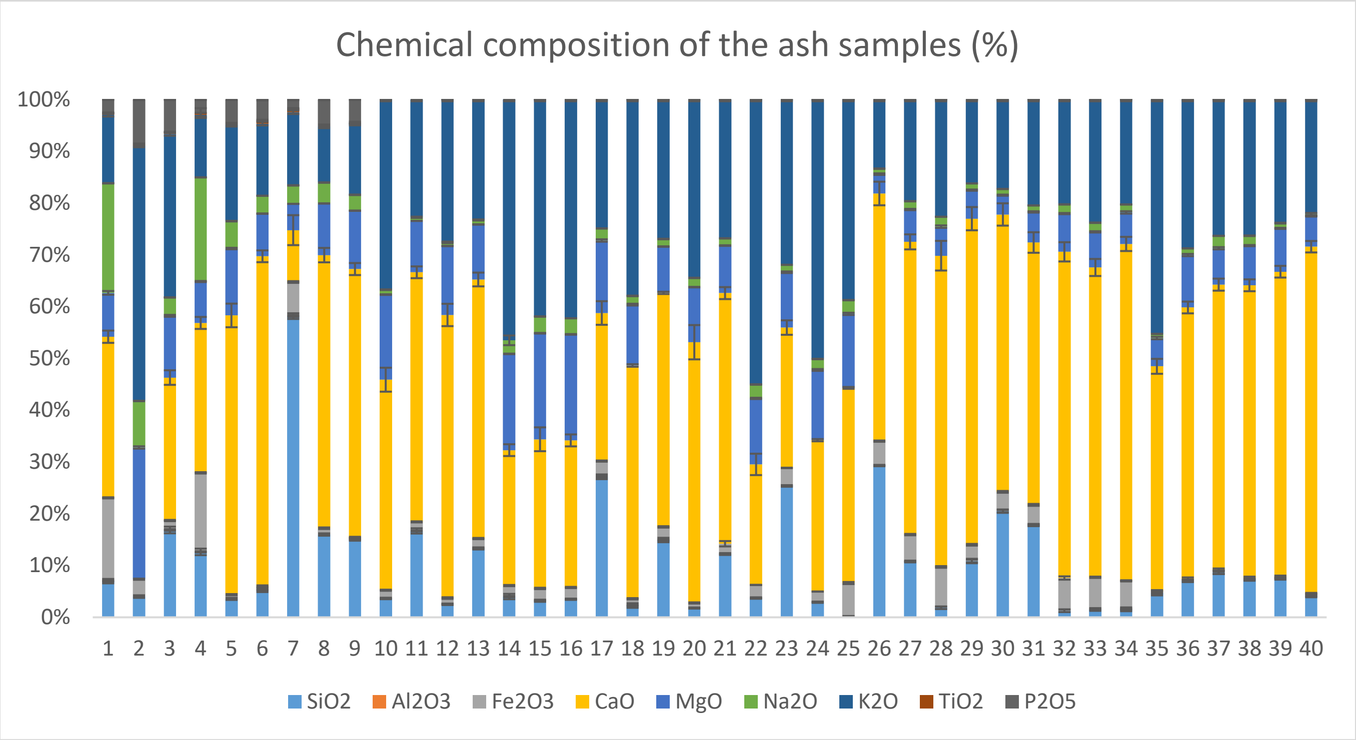
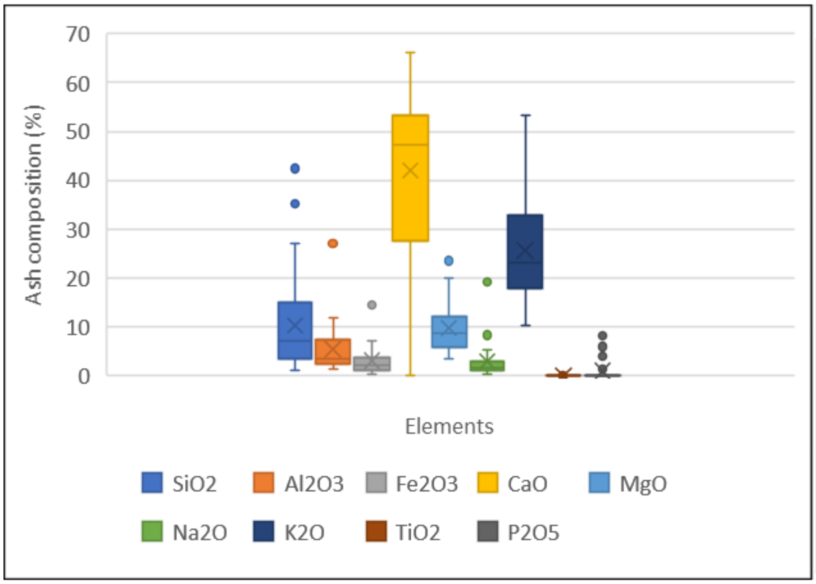


Figure 2. Variation in ash compound concentrations, with Mean, Standard Deviation, Minimum, and Maximum Concentrations.



	Mean	SD	Max.	Min.	Med.
SiO_2	10.3	9.65	42.4	1.12	6.99
Al_2O_3	5.44	4.71	27	1.36	3.51
Fe_2O_3	3.01	3.23	15.2	0.25	2.13
CaO	42.01	15.31	66.17	0	47.36
MgO	9.69	4.69	23.5	3.46	8.75
Na_2O	2.9	4.12	20	0.4	1.61
K_2O	25.65	11.49	53.3	10.24	23
TiO_2	0.05	0.14	0.6	0	0
P_2O_5	0.96	2.03	8.1	0	0

Figure 3. Results obtained from the *Bioslag* and %D_1 tests (ac%_1P= accumulated weight (g); %D_1=hardness coefficient for the 1mm sieve).

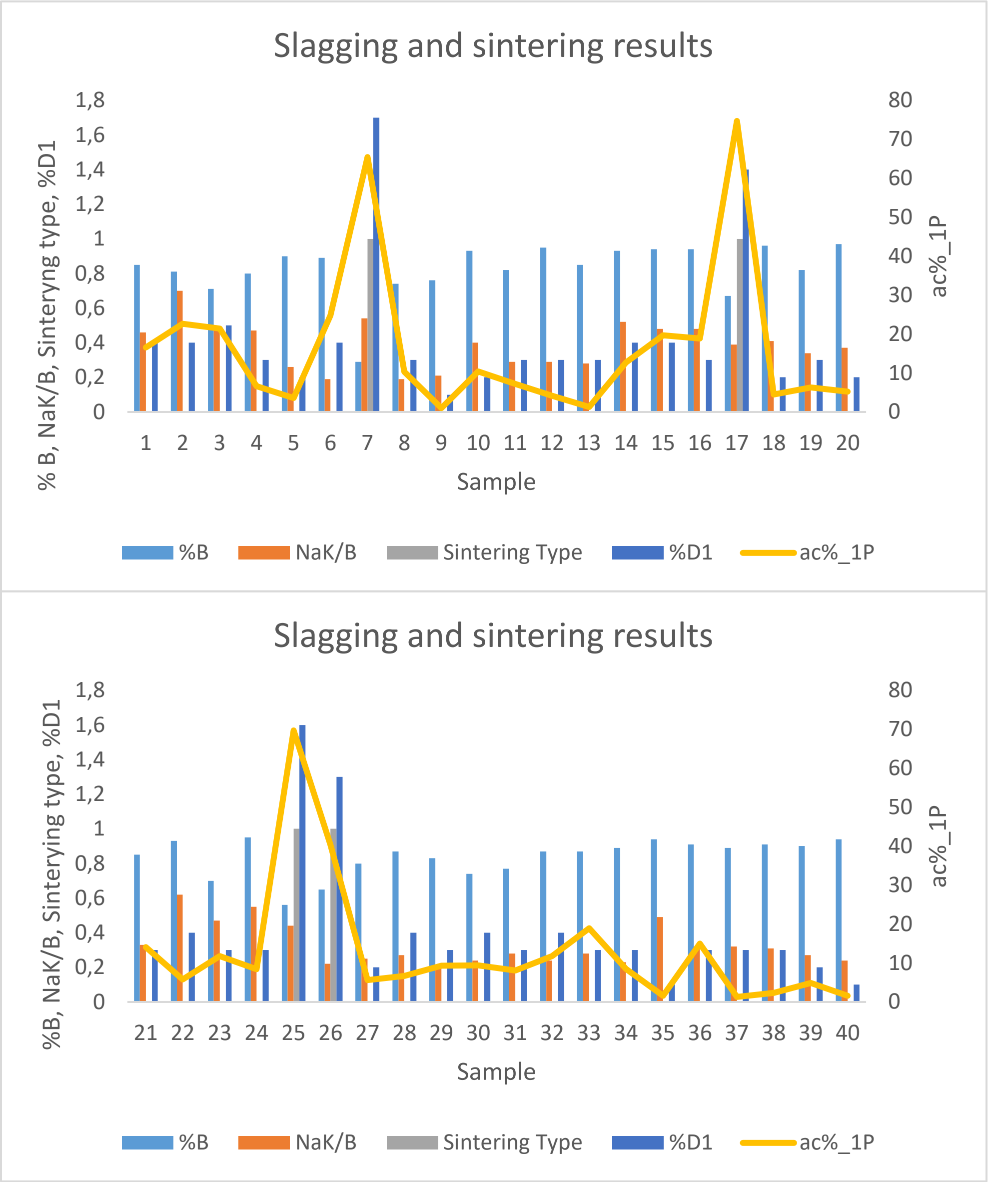
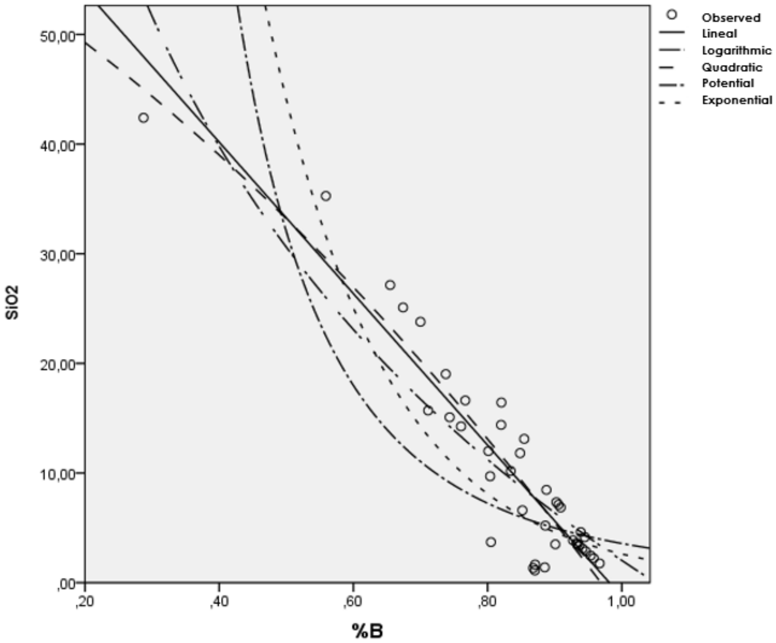


Figure 4. Relationship between SiO_2 levels and %B



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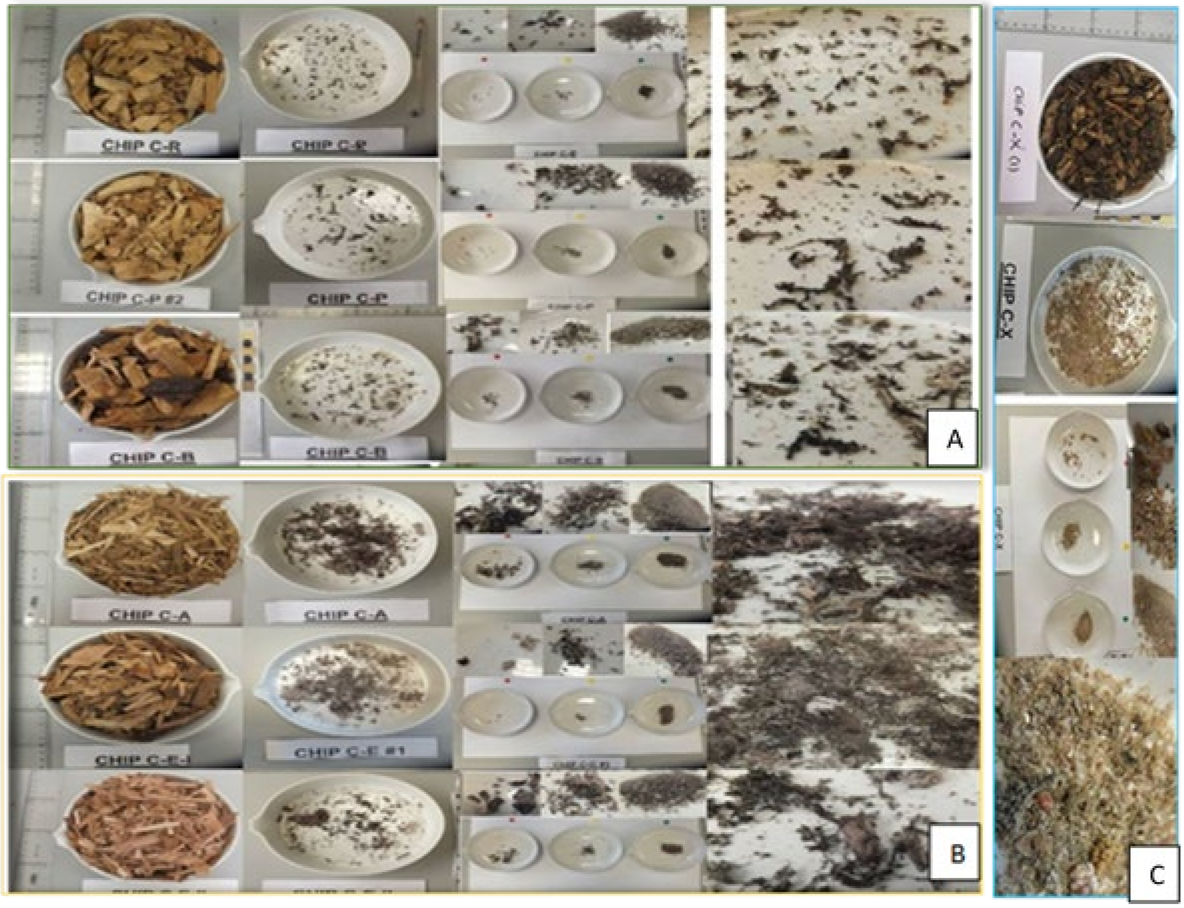

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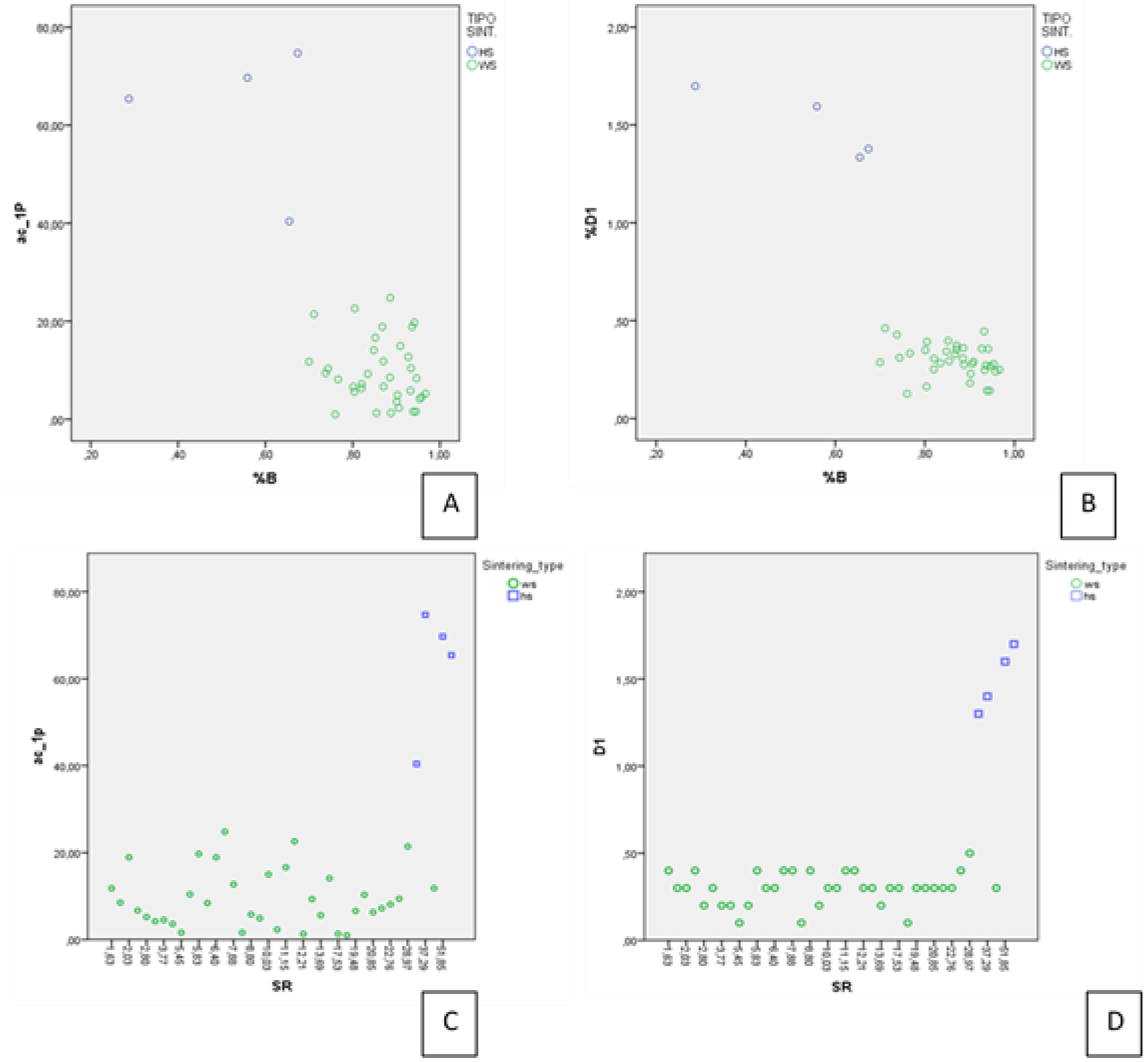
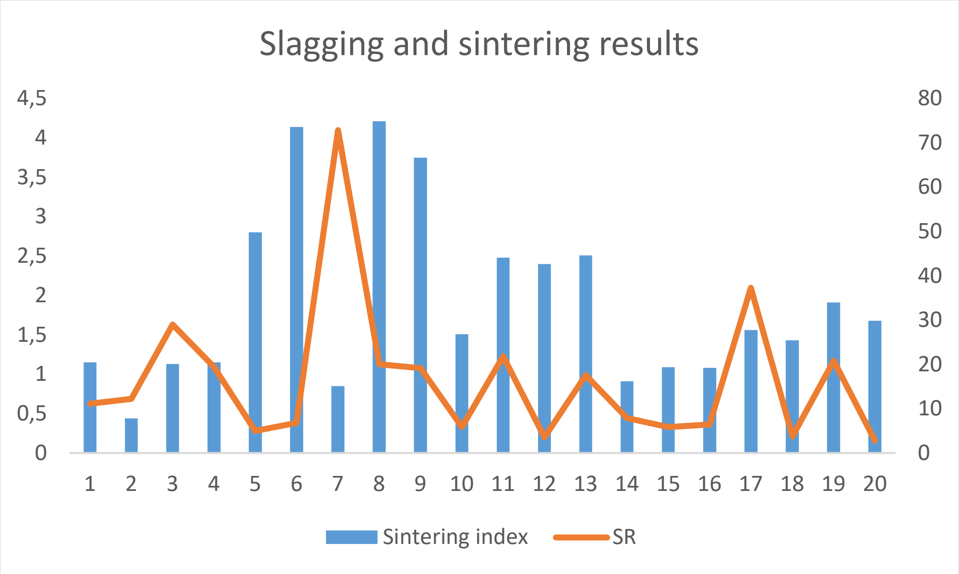
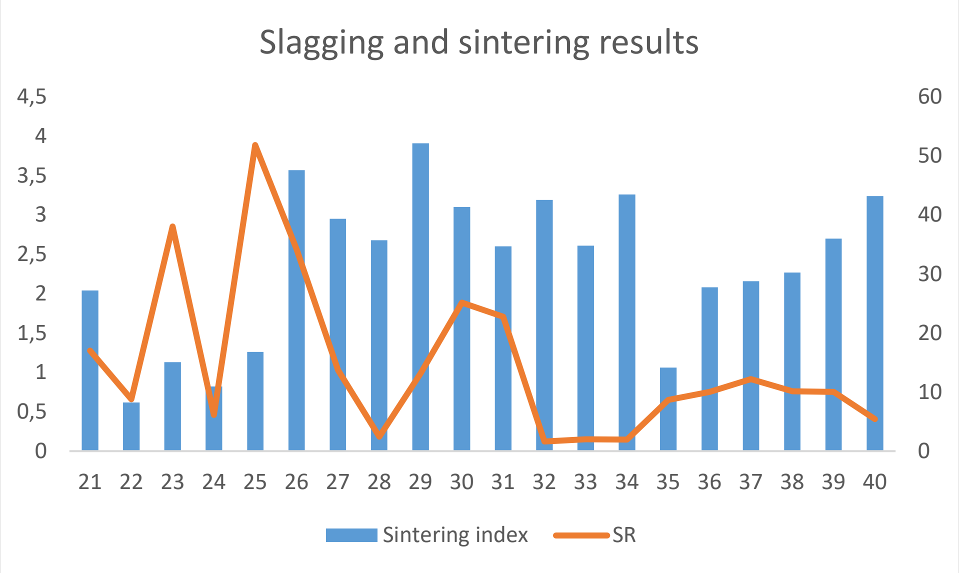


Figure 7. Results obtained from the Sintering index and SR.


Slagging and sintering results
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sintering index
SR


Slagging and sintering results
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
60
50
40
30
20
10
0
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Sintering index
SR