

# Reducing Ash Related Operation Problems of Oil Palm Biomass for Combustion Applications using Leaching Techniques

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## Introduction

The major problem during combustion of lignocellulosic biomass is the generation of ash which reduces the efficiency of the process. A majority of agricultural by-products contain high amount of ash, and thus, is responsible for the lower combustion efficiency when used for bioenergy applications. Although representing only a minor proportion by weight, ash appears to be a major determinant in the combustion behaviour of lignocellulosic material. The usage of high ash content biomass for heat and electricity generation may lead to various ash-related problems. The main cause of these problems is the high alkaline content (e.g. K, Na, S and Cl) and consequently the low melting temperature (Bernhardt et al, 2011; Liu and Bi, 2011). These alkali and alkaline elements, foul heat transfer surfaces, participate in slag formation in grate-fired units and contribute to the formation of fluidized bed agglomerates. When the combustion temperature exceeds the melting point of ash, it resulted in unwanted deposits and corrosion in energy conversion systems. These ash forming elements may give rise to molten phases during combustion which produce sticky ash particles that adhere to heat transfer surfaces (Werklin et al, 2005). Besides, high ash content also tends to lower the heating values of the raw materials by virtue of not being a contributor to the fuel heating value (Jenkins et al, 1998). The result is an increase in operating and maintenance costs and reduced conversion efficiency of the combustion systems.

Due to the disadvantages attributed by the high content of ash in lignocellulosic biomass, a number of authors have explored several methods to remove ash forming elements from biomass prior to combustion (Dayton et al, 1999; Sears and Walker, 1999; Cui et al, 2010). Leaching methods have been proven effective in removing ash forming elements from coal and recently this method being introduced to the biomass. Leaching is the process of removing inorganic, organic contaminants or radionuclides elements prior to fuel

utilization. These elements are released from the biomass into the liquid phase under the influence of mineral dissolution and desorption. Most biological organic and inorganic substances occur in a mixture of different components in biomass. In order to separate the desired solute constituent and to remove an undesirable solute component from the biomass, normally the biomass is brought into direct contact with liquid. The biomass and liquid are in contact and the solute or solutes can diffuse from the solid into the solvent, resulting in separation of the components originally in the biomass.

The proper selection of ash forming elements leaching treatments needs to be evaluated on a case-by-case basis as it highly depends on the ash removal effectiveness of different treatment method, and the effect of these treatments leading to organic degradation of the lignocellulosic biomass. The following work aims at evaluating the effectiveness of leaching method on removing ash forming elements and to determine the effects of leaching agent (water and acetic acid) on ash melting of oil palm biomass. Ash melting temperature is one of the most important parameters which should be used to characterize the fuel as it affects the design of boiler (temperature control). Thus, how the ash sintering and molten indices relate to the ash melting temperature was discussed in this study.

## Leaching Process

Empty fruit bunch and oil palm trunk (oil palm biomass) were subjected to various leaching temperature and reaction time with water and acetic acid (1M) as extraction solution. Leaching was performed on the lignocellulosic biomass with three different reaction times (30 min, 60 min and 120 min) at room temperature ( $27 \pm 2$  °C). 10 g samples were weighed and

placed in a 200 ml conical flask. 100 ml of water/ acetic acid were earlier heated to the selected leaching temperature and poured into the conical flask which contained the weight samples. The mixture was gently stirred to ensure the sample was fully submerged in the extraction solution. Leaching was carried in a constant temperature by placing the conical flask in a water bath regulated at the selected leaching temperature. After the leaching, the solutions were filtered and washed with 100 ml distilled water. The leached samples were oven dried at 105 °C over 24 h for further evaluation.

### Ash Melting Characteristic at Different Combustion Temperature

During combustion, ash related operation problems are to be expected for the ash fusion classes 'molten' and 'strongly sintered', while 'loose' or 'slightly sintered' ash should cause no or less problems. The lignocellulosic biomass was prepared into ash. Low-temperature ash of the lignocellulosic biomass was prepared in crucibles holding approximately 10 g of samples each. The crucibles were placed in a muffle furnace heated to 550 °C and kept at this temperature for 6 hours. Low-temperature ash samples (0.2 g) were weighed in small ceramic crucibles and heated in a muffle furnace for two hours with the selected combustion temperature (700 °C, 800 °C, 900 °C and 1000 °C) for two hours. As shown in Table 1, the ash samples were classified into one of the four ash fusion classes of a classification scheme adapted from Tonn et al. (2012) and Steenari et al. (2009).

**Table 1.** Macroscopic and microscopic characteristics of ash fusion classes

Ash fusion class	Ash sintering characteristics
(1) Loose	Macroscopic: ash loose, no evidence of sintering Stereo microscope: intact organogenic structure, no or only few small molten vesicles visible.
(2) Slightly sintered	Macroscopic: ash slightly sintered, manual disintegration easy Stereo microscope: intact organogenic structure, its surfaces partly or completely sintered, larger molten vesicles visible
(3) Strongly sintered	Macroscopic: ash strongly sintered, manual disintegration difficult Stereo microscope: majority of ash molten, but organogenic structure till distinctly visible, structure of ash still porous

(4)  
Molten

Macroscopic: ash molten, manual disintegration not possible Stereo microscope: no or only few remnants of organogenic structure visible, ash compact with molten phase largely flown into the pores of the original structure.

(Source: Tonn, 2012; Steenari, 2009)

As tabulated in Table 2, increasing the combustion temperature from 700 °C to 1000 °C increased the sintering degree of the untreated lignocellulosic ash. Water and acetic acid leaching was sufficient to improve the classification of most of these biomass samples by at least one class. At 700 °C untreated OPT samples show no or slight sintering tendency. EFB sintered as a whole with certain hardness and even crushed it is not easy to become powder. The structure of the ashes still porous but molten formation was observed all over the material grain surface. When the combustion temperature increased to 800 °C, the sintering degree of the oil palm biomass increased as well. EFB ash was molten; ash particles closely connected into a solid structure and no sign of biomass ash debris. OPT was classified as "strongly sintered" under the ash fusion classes. The ash formed into a hard and dense sediment, thus, segregation was difficult. Combustion temperature at 900 °C further increased the sintering degree. EFB and OPT were overall melted, the sediments were tightly combined and disintegration was impossible. Ash from biomass made of untreated EFB and OPT tended to melt at least partly at 900 °C. EFB ash was molten at temperature as low as 700 °C. After water leaching treatment, OPT were classified loose or slightly sintered at temperature 1000 °C and could be considered safe for combustion.

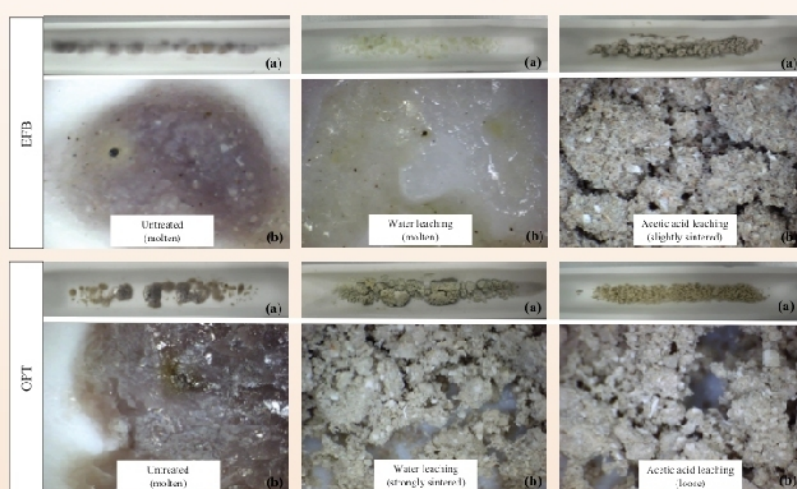
**Table 2.** Ash melting characteristics after water leaching and acetic acid leaching<sup>1</sup>

EFB				
700	Strongly sintered	loose	loose	
800	molten	Strongly sintered	loose	
900	molten	molten	loose	
1000	molten	molten	Slightly sintered	
OPT				
700	Strongly sintered	loose	loose	
800	Strongly sintered	loose	loose	
900	molten	Strongly sintered	loose	
1000	molten	Strongly sintered	loose	

(Source: Tonn, 2012; Steenari, 2009)

Figure 1 show the melting characteristic of ash at 1000 °C for untreated oil palm biomass and after the oil palm biomass were leached with water (25 °C for 120 mins) and acetic acid (25 °C for 120 mins). As the temperature increases to 1000 °C, the untreated EFB and OPT samples were completely melted, particles closely connected into a solid molten structure with smooth surface. Whereas, the leached biomass ash heated at 1000 °C fell into 'loose' or 'slightly sintered' classes except EFB treated with water leaching treatment as

shown in Figure 1. Acetic acid leaching treatment improve the ash melting classification of EFB to slightly sintered at 1000 °C but water leaching treated EFB was highly sintered and molten at 900 °C and 1000 °C (Figure 1), respectively. Even though the EFB showed significant decrease in ash content using water leaching method, the concentrations of alkali species is still sufficient to cause a reduction in ash melting temperatures when compared to the acetic acid leached EFB.



**Fig. 1.** Ash formation of EFB (top row) and OPT (bottom row) ash under combustion temperature at 1000°C  
(a) macroscopic view (b) microscopic view (40X)

## Conclusion

The extent of each elements removed using water as the leaching agent was associated with the amount of water-soluble elements; the higher the water soluble content, the higher the efficiency. Using the method established in this research, the selected oil palm biomass can be prepared for combustion with the assurance that ash forming elements have been reduced sufficiently to safeguard against ash production and slagging in biomass boiler. However, further process development and optimization required to confirm technical and economic feasibility. In general, when designing an industrial scale leaching facility,

several factors that may inhibit the feasibility of the leaching process include: (i) cost and energy for size reduction; (ii) water requirement; (iii) dewatering of the leached biomass; and (iv) treatment and disposal of the leachate. Further studies on the technical feasibility of the proposed lignocellulosic biomass leaching technique, including further modelling and scale-up, and the building of a pilot-scale plant are recommended to demonstrate the technical and economic potential for leaching process.

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