Production of high quality empty fruit bunch pellet by water washing and torrefaction

Supachita Krerkkaiwan1*, Duangkamol Boonbumrung1

1 The Joint Graduate School of Energy and Environment (JGSEE) and Center of Excellence on Energy Technology and Environment, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand.

*E-mail: supachita.kre@kmutt.ac.th, supachita.k@gmail.com

Abstract. EFB pellet is the high potential biomass for combustion process due to the relatively high heating value and the high availability in the Southern of Thailand. However, the containing of high unwanted minerals, especially K and Cl is the main drawback of EFB pellet which causing the ash fouling or/and slagging during the combustion. In this study, the high quality EFB pellets (low K, low Cl, high heating value) were produced by applying the water washing and torrefaction methods. For water washing treatment, the effect of water and acetic acid solution on the mineral content of EFB pellet was studied. In addition, the effect of torrefaction temperature (250, 280 and 300 ºC) on the quality of EFB pellet was investigated. Results revealed that the ash content of the washed EFB decreased from 5.3 % to 3.0 % and 0.7 % by washing with tap water and acetic acid solution, respectively. Comparing with the raw EFB pellet, K and Cl in ash were significantly reduced by washing about 60 % and 88 %, respectively. Heating value of the EFB and washed EFB pellet were increased after torrefaction with the higher temperature. The water washed EFB pellet and torrefied at 300 ºC gave the highest heating value about 24.3 MJ/kg. It was 33% increased HHV when comparing with raw EFB pellet.

Keywords: empty fruit bunch, torrefaction, water washing, EFB pellet

1. Introduction
Oil palm empty fruit bunch (EFB) is the largest solid waste derived from palm oil mill. In Thailand, about 4 Mton of EFB is approximately generated and about 2.2 Mton is the remaining EFB which has not been used [1]. Utilization of EFB as the solid fuel for heat and power production is the promising option because of the relatively high heating value of EFB (about 18 MJ/kg dry). However, EFB contains the high content of unwanted minerals, especially K and Cl that causing the ash fouling and slagging problems during the combustion. Removal of K and Cl in EFB is required before using. Water washing is selected to remove K and Cl in EFB because it is the simple and effective method [2, 3]. Some researches [4,5] studied the combination pretreatment process of biomass by washing and torrefaction. Chen et al. applied the water washing and torrefaction to upgrade the cotton stalk for bio-oil production. It revealed that the bio-oil derived from the treated biomass had the very low water and oxygen content and the solid product contained the very low ash content [4]. Zhang et al. also reported that the good quality of bio-oil derived from the pyrolysis of rice husk can be obtained after pretreatment by acid
leaching and torrefaction. However, no literature mentioned about the pretreatment of EFB in order to produce the high quality EFB pellet by using the combination process of water washing and torrefaction. Hence, this study aims to produce the high quality EFB pellet in terms of low K, Cl content, high heating value and high grindability by applying the water washing and torrefaction pretreatment. The characteristics of the EFB pellet before and after treatment by water washing and torrefaction have been analysed and discussed.

2. Materials and Method

2.1. Biomass sample
Empty fruit bunch (EFB), the solid waste from palm oil production plant in the Southern of Thailand, was ground by using the hammer mill and sieved into the particle size less than 6 mm. The shredded EFB was dried by sunlight for 48 hr before using in the further experiments. The proximate, ultimate analysis and heating value of raw EFB is shown in Table 1.

| Properties                      | Value |
|---------------------------------|-------|
| Moisture content (wt%)          | 7.7   |
| Proximate analysis (wt%, dry basis) |       |
| volatile matter                 | 79.2  |
| fixed carbon                    | 14.8  |
| ash                             | 6.0   |
| Ultimate analysis (wt%, dry basis) |       |
| Carbon (C)                      | 46.0  |
| Hydrogen (H)                    | 6.9   |
| Nitrogen (N)                    | 1.3   |
| Sulfur (S)                      | 0.15  |
| Oxygen (O)*                     | 45.7  |
| Higher heating value (HHV, MJ/kg)| 18.8  |

* by difference

2.2. Water washing, pelletization and torrefaction experiment
Water washing experiment was carried out in the 100 L-tank stirrer and the picture of washing process inside tank is shown in Fig. 1. For each batch, 4 kg of shredded EFB was loaded into the tank then filled with washing solution (water or acetic acid) for 80 L. Condition of washing is summarized in Table 2. After washing, the washed EFB was dried by sunlight at least 48 hr or until the moisture content was about 15 wt%. The raw EFB and washed EFB were made into the pellet form with 8 mm-diameter by using the flat die pellet machine. Raw EFB and washed EFB pellet are presented in Fig. 2. Torrefaction of the pellet is carried out in a lab-scaled fixed bed reactor using 3 cm-O.D. of quartz reactor. About 10 g of EFB pellet was placed in a quartz sample basket and purged with a 100 mL/min of inert-N₂ for 1 hr. Start heating the furnace from room temperature to the desired temperature; 250, 280 and 300 ºC and holding for 30 min. The torrefied EFB pellet was weighted and characterized by bomb calorimeter, CHNOS analyzer and TGA. For the mineral analysis, the ashing at 575 ºC following the ASTM E1755 of EFB pellet was done. The ash was collected and further analysis the mineral in ash by using the X-ray fluorescence (XRF) technique.
3. Result and discussion

3.1 Characterization of the washed EFB pellet

Characteristics of the raw and washed EFB pellet are summarized in Table 3. Comparing with raw EFB pellet, the highlighted result is the decrease of ash and Cl content. Ash content decreased from 5.3 wt% to 3.0 and 0.7 wt% in cases of water and acid washing, respectively. While, Cl content of the EFB pellet was removed from 0.68 wt% to 0.04 and 0.02 wt% in cases of water and acid washing, respectively. The EFB pellet was also compared to the standard of wood pellet (ENplus grade B [4]). It was observed that moisture content, heating value, fine particle, mechanical durability and Cl content of the washed EFB pellet achieved the wood pellet standard. It implies that washed EFB pellet could be applied for the solid fuel as good as wood pellet.

Table 3 Characteristics of the raw and washed EFB pellet

| Properties                     | raw pellet | water washed pellet | acid washed pellet | EN PlusB wood pellet |
|--------------------------------|------------|---------------------|--------------------|---------------------|
| Moisture (wt%)                 | 9.7        | 6.2                 | 10.8               | <10                 |
| Proximate analysis (wt%, dry basis) |            |                     |                    |                     |
| volatile matter                | 80.1       | 90.3                | 92.1               |                     |
| fixed carbon                   | 14.6       | 6.7                 | 7.1                |                     |
| ash                            | 5.3        | 3.0                 | 0.7                | <2.0                |
| Ultimate analysis (wt%, dry basis) |            |                     |                    |                     |
| Carbon (C)                     | 48.6       | 48.4                | 50.0               |                     |
| Hydrogen (H)                   | 7.1        | 6.7                 | 6.9                |                     |
| Nitrogen (N)                   | 1.0        | 0.8                 | 0.8                |                     |
Table 4 shows the ash analysis of the raw and washed EFB pellet. It can be seen that K and Cl are the major element in the EFB ash. After washing, K and Cl were effectively removed. To compare the K and Cl content before and after washing, the K and Cl content in EFB pellet was recalculated and presented in Table 5. It revealed that after washing, K in EFB was removed about 77.3 % and 94.9 % in cases of water and acid washing, respectively. Cl in EFB was removed over 93.4 % and 98.3 % for water and acid washing, respectively. This confirm the very efficient washing process.

| Element | raw pellet | water washed pellet | acid washed pellet |
|---------|------------|---------------------|-------------------|
| Mg      | 3.7        | 5.0                 | 2.9               |
| Al      | 0.0        | 1.2                 | 1.1               |
| Si      | 8.3        | 23.9                | 29.7              |
| P       | 2.5        | 4.1                 | 5.9               |
| S       | 1.5        | 4.0                 | 4.9               |
| Cl      | 12.0       | 1.4                 | 1.6               |
| K       | 63.3       | 25.4                | 24.3              |
| Ca      | 7.4        | 24.7                | 17.9              |
| Mn      | 0.2        | 0.3                 | 0.2               |
| Fe      | 1.1        | 10.0                | 11.6              |

Unit: wt% of 100 g dry ash

Table 5 K and Cl content of the raw and washed EFB pellet by XRF technique

| Element | raw pellet | water washed pellet | acid washed pellet |
|---------|------------|---------------------|-------------------|
| Ash     | 5.3        | 3.0                 | 0.7               |
| Cl      | 0.63       | 0.04                | 0.01              |
| K       | 3.35       | 0.76                | 0.17              |

Unit: wt% of 100 g dry EFB sample

3.2 Characterization of the torrefied EFB pellet

For the co-combustion between coal and biomass, the difference properties of coal and biomass is the main problem for the operation that could not blend the biomass with the high portion. Torrefaction of biomass is the one solution that can upgrade the biomass quality and can be blend with coal efficiently. The characteristics of the torrefied EFB pellet at different condition is summarized in Table 6. Consider in mass yield, it was found that mass yield decreased significantly when the torrefaction temperature increased from 250 to 300 °C. Washed pellets show the slightly higher mass yield than that of the unwashed pellet. It was also observed that the torrefied EFB pellet at higher temperature had the higher in carbon content but lower in oxygen content leading to the higher HHV and energy density. The torrefied washed EFB pellet at 300 °C had the highest HHV as high as 24.3 MJ/kg. This is comparative to the HHV of sub-bituminous coal [6]. Consider in the energy density, it was found that the torrefied washed EFB pellet had the higher energy density than that of the torrefied unwashed pellet, except at...
high torrefaction temperature. It was probably due to the washed pellet had the loose-pack particle than that the unwashed pellet. Even though, torrefied washed pellet had the K content slightly higher than the torrefied unwashed pellet but the K content is still lower than the raw EFB pellet. This result shows that the washed EFB pellet had both low alkali content and high heating value that is the very good properties for heat and power production.

| Properties                      | Temp. | unwashed pellet | water washed pellet | acid washed pellet |
|---------------------------------|-------|----------------|---------------------|-------------------|
| Mass yield (wt%)                | 250   | 65.9           | 71.0                | 67.7              |
|                                 | 280   | 42.0           | 55.6                | 59.6              |
|                                 | 300   | 37.1           | 41.8                | 42.1              |
| Carbon (C)                      | Raw EFB | 48.6           | 48.4                | 50.0              |
|                                 | 250   | 51.0           | 53.3                | 53.3              |
|                                 | 280   | 58.7           | 55.8                | 56.7              |
|                                 | 300   | 60.0           | 62.6                | 61.9              |
| Oxygen (O)                      | Raw EFB | 43.3           | 44.1                | 42.3              |
|                                 | 250   | 42.3           | 39.8                | 39.8              |
|                                 | 280   | 35.3           | 37.6                | 36.6              |
|                                 | 300   | 34.2           | 31.2                | 31.7              |
| Higher Heating Value (MJ/kg)    | Raw EFB | 18.3           | 19.1                | 19.1              |
|                                 | 250   | 19.9           | 20.4                | 20.2              |
|                                 | 280   | 22.7           | 21.6                | 20.9              |
|                                 | 300   | 23.4           | 24.3                | 24.3              |
| Energy density (MJ/m$^3$)       | Raw EFB | 8.75           | 9.03                | 8.98              |
|                                 | 250   | 12.74          | 19.39               | 20.17             |
|                                 | 280   | 19.39          | 14.64               | 21.84             |
|                                 | 300   | 20.17          | 15.43               | 18.41             |
| K content (wt%, dry sample)     | Raw EFB | 3.4            | 0.8                 | 0.2               |
|                                 | 250   | 4.3            | 0.8                 | 0.6               |
|                                 | 280   | 6.9            | 0.9                 | 1.0               |
|                                 | 300   | 8.1            | 1.4                 | 1.1               |

4. Conclusion
In this study, the high quality EFB pellet (low K, low Cl and high heating value) was produced by integrating the washing and torrefaction pretreatment process. Washing treatment is the very simple and practical method to remove unwanted elements (K and Cl) efficiently over 94.9 % and 98.3 % for K and Cl, respectively. However, the washing slightly affected the bulk density and mechanical durability of the EFB pellet. In addition, torrefaction could improve the high heating value and energy density of the EFB pellet. The high quality EFB pellet can produce with the low K content as low as 0.2 wt% and heating value as high as 24.3 MJ/kg. This EFB pellet could be utilized in the co-combustion with coal with high blending ratio.
Acknowledgements

This work is under the project “Effect of water washing pretreatment on the quality of agricultural biomass pellet” funded by the national research council of Thailand (NRCT) FY 2018.

References

[1] Department of alternative energy and development and efficiency (DEDE), ministry of energy Thailand, “Biomass potential in Thailand 2012” report.
[2] Piyali Das, et al., “Influence of pretreatment for deashing of sugarcane bagasse on pyrolysis products” Biomass and Bioenergy (27), 2004, Page 445-457.
[3] Pak Yiu Lam et al., “Leaching Characteristics of Inorganic Constituents from oil palm residues by water” Industrial & Engineering Chemistry Research (53), 2014, Page 11822 – 11827.
[4] Dengyu Chen et al., “Combined pretreatment with torrefaction and washing using torrefaction liquid products to yield upgraded biomass and pyrolysis products” Bioresource Technology 228 (2017) 62–68.
[5] Shuping Zhang et al., “Effects of torrefaction and organic-acid leaching pretreatment on the pyrolysis behavior of rice husk” Energy 149 (2018) 804-813.
[6] N.F. Mohamad, et al., “Characteristics of Bituminous Coal, Sub-Bituminous Coal and Bottom Ash from a Coal-Fired Power Plant” Proceedings of the 2013 IEEE Business Engineering and Industrial Applications Colloquium (BEIAC).