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ENHANCEMENT OF PYROLYSIS YIELD DISTRIBUTION AND PARTICULATE EMISSION OF EMPTY FRUIT BUNCHES BY WASHING PRE-TREATMENT

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ABSTRACT
Empty fruit bunches (EFB) are treated with distilled water at different washing medium temperature. The effects on the yield distribution of pyrolysis products and its particulate emission released are studied via feedstock behaviours analysis and the effectiveness of washing pre-treatment. Room temperature washing medium is considered as the optimum washing medium condition of pre-treatment in order to provide better qualities of feedstock for pyrolysis work. The feedstock are possessed with minimal weight percentage of ash content, and acquired great amount of volatiles matter and energy value of 87.63 wt% and 18.04 MJ/kg, respectively. Furthermore, yield distribution of EFB pyrolysis products are enhanced to around 40.98 wt% of bio-char, 55.08 wt% of pyrolysis liquid and 3.93 wt% of gas. Particulate emissions of EFB feedstock are described accordingly by three combustion phases of pyrolysis process. The raw/untreated EFB was revealed to release higher amount of particulate emission along the pyrolysis activity as compared to the treated EFB feedstock.

Keywords: Empty fruit bunches, Washing pre-treatment, Distilled water, Ash, Pyrolysis, Yield distribution, Particulate matter.

Contribution/ Originality

The paper's primary contribution is finding that the properties of empty fruit bunches are improved by the employment of water washing pre-treatment. Better feedstock behaviours will promoting positive influence towards the yield distribution of pyrolysis products at minimal release of the particulate emission during burning activity.

1. INTRODUCTION

The syngas released by burning activity of biomass contains a number of impurities such as particles, sulphur, nitrogen, chlorine compounds, alkali and heavy metals. The culprits are generally considered as the main proxy of ash in the biomass [1]. These domains are differed by their sizes with diameter ranging from 1 nm to a few hundred nanometers. The impurities would

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convert into many molecular substance forms after undergoes thermal conversion process, such as dispersions of nanoparticles in a tar-liquid, on reactor surfaces, or embedded in a continuous biomass matrix. Therefore, there will be forming great limitation to utilize as main sources in power and energy production by creating several thermal energy problems such as combustion, maintenance and environmental issues [2].

Pyrolysis is the thermal conversion process of materials working in the absence of oxygen for complete and dynamic combustion. Via pyrolysis process, pyrolysis products, which are solid char, pyrolysis oil and gas, are common complex combination of fuel products obtained from the decomposition process of cellulose, hemicellulose and lignin component [3]; [4]; [5]. The yield distribution of fuel products are totally depending by their degradation rates and phases during pyrolysis process. Besides, secondary reactions caused by the ash constituents are also influenced the final yield distribution of pyrolysis products, and the release amounts of their particulate emission [6]; [7]; [8]. In order to minimize the particle emission form the combustion activity of biomass, several methods of reducing the detrimental effects has recently been studied and attempted. Previous studies had been proving that the employment of washing pre-treatment are capable of reducing the thermal conversion problems in such practical, effective and sustainable ways. Therefore, simple leaching methods was experimentally attempted by researchers such as Deng, et al. [9] and Davidsson, et al. [2] . Reducing the ash and its components in biomass were main approached in their research work as precursor to obtain better feedstock quality and minimize the release of particulate emission.

Work done by Deng, et al. [9] were practically studying the effect of water washing on fuel properties, pyrolysis and combustion characteristics of biomass fuels. Various type of alkaline metals were effectively removed either using room temperature or hot water washing medium. Fuel properties were enhanced especially their energy values due to the reduction of ash and its components. Therefore, volatiles were released greater for washed waste rather than the origin waste during the pyrolysis process due to the increment of devolatilization and reaction rate. Another proactive washing work was done by Davidsson, et al. [2] on the wheat straw, wood waste and cellulose at various conditions of washing pre-treatment, in order to observe the release rate of alkali compound by a surface ionization technique. Two major peaks of alkali emission were bounded along the temperature range between 100 to 1000^{O}C. By only rinsing the biomass with de-ionized water, alkali released has reduced to around 5-30% within the pyrolysis temperature range of 200-500^{O}C, while the emission reduced lower by more than 90% as the pyrolysis process continued further above 600^{O}C, respectively.

In this paper, a simple washing pre-treatment is employed on empty fruit bunches (EFB) in order to study the effects of pre-treatment on the yield distribution of pyrolysis products and its particulate matter released. The treatment was employed in such well-controlled temperature condition to optimize the water washing activity. All EFB feedstock were then pyrolyzed at fixed temperature in order to examine the influence of various feedstock conditions towards the yield product distribution and particle emission released.

2. MATERIALS AND METHODOLOGY

2.1. Material

EFBs were properly collected from a local palm oil mill in Nibong Tebal, Penang. Average size and weight of EFBs approximately around 600-700g are only used and prepared for the entire research work. Structural view of dried raw EFB is presented as in Figure 1. The EFBs were firstly dried in order to reduce their moisture content, which earlier measured approximately around 64 wt%. Moisture content of biomass must present to be less than 10 wt% in order to prevent the growth of fungus and microorganisms before packed and stored [4]; [10].

Figure-1. Structural view of dried raw EFB

Thermochemical behaviours of the EFB are preliminary determined by covering the proximate, ultimate and heating value analysis. Proximate analysis was studied basically for their moisture content, ash content, volatile matter and fixed carbon determination by referring to their standard test methods, which are ASTM E871-82, E872-82, E830-87 and by difference, respectively. Meanwhile, the ultimate analysis was covered the elemental composition determinations, which are carbon, hydrogen, nitrogen, sulphur and oxygen concentration of the biomass. The analysis was automatically determined by using the CHNS/O analyzer, Perkin Elmer 2400 series II Elemental Analyzer. The higher heating value (HHV) of the biomass was measured according to the standard test method, ASTM E711-87, which experimentally conducted by using the adiabatic oxygen bomb calorimeter, Parr 6200 bomb calorimeter.

2.2. Application of Washing Pre-Treatment

Treating biomass with various washing conditions would provide significant influence towards not only the feedstock properties but also the yield and quality behaviours of pyrolysis products. EFB was practically undergo leaching process by treating with different washing medium temperatures. By regulating the electric power of the water bath, two different temperatures are practically able to keep constant within time interval. EFBs are treated at room temperature (RT) and hot temperature (HT) washing medium of $30^{O}C$ and $90^{O}C$, respectively.

Minimum volume of washing medium approximately around 2.5L of distilled water was used which practically just enough to fully submerge over the 100g of whole EFB structure. For each pre-treatment, the biomass was soaked for at least 20 minutes.

Several analyses were also performed on treated EFB in order to study the effectiveness of washing pre-treatment. Initially, weight determinations of washed feedstock were carried out by using digital weighing balance, which corresponds to the initial mass of EFB used. In addition, the work were also determined the proximate, ultimate and heating value analysis. The method was referred accordingly to the standard test analysis, which similarly methods measured on the raw biomass earlier.

2.3. Determination of the Pyrolysis Products Yield and Particulate Matter Concentration Release

Both treated and untreated EFB were pyrolyzed at the terminal pyrolysis temperature of 400^{O}C under constant heating rate of 10^{O}C/min for at least 2 hours. The pyrolysis process was conducted by using the fixed bed reactor as designed in Figure 2, which mainly equipped with furnace and liquid collecting system. The feedstock was first manually chopped into smaller part before being tightly packed into the pyrolyzer. Chopped EFB was then loaded as pack as possible in order to limit the presence of air during pyrolysis process.

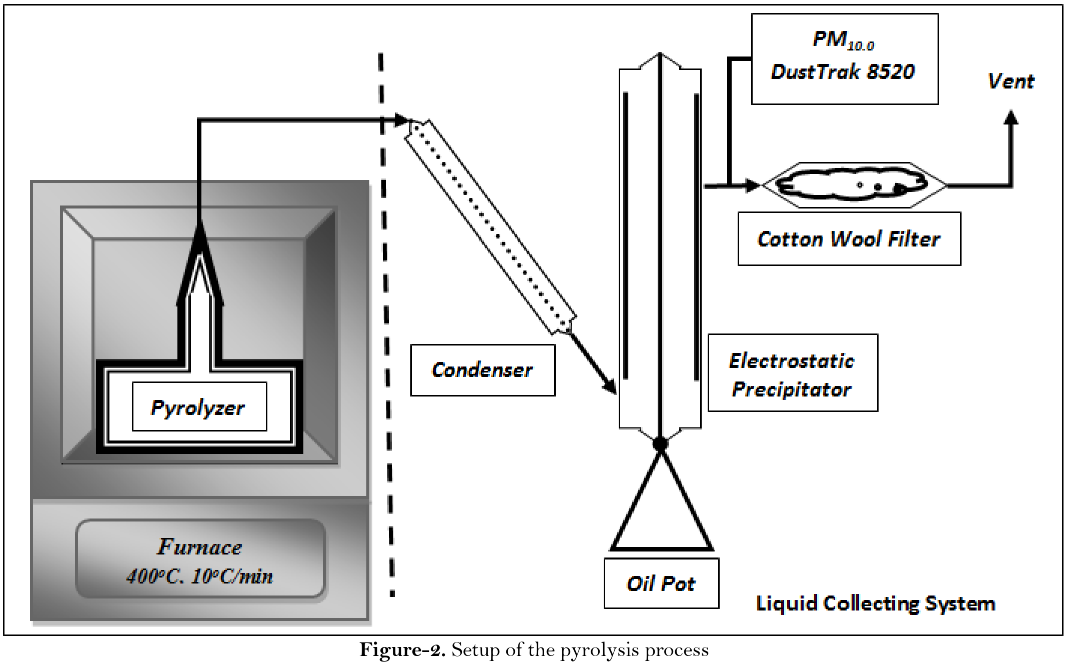

Figure-2. Setup of the pyrolysis process

Bio-char was obtained directly in the pyrolyzer at the end of pyrolysis process. Meanwhile, pyrolysis liquid was only obtained after the pyrolysis vapour being thoroughly condensed through the series of condenser, electrostatic precipitator (EP) and cotton wool filter. By chilling the condenser with continuous flow of tap water at 10^{O}C and inducing the EP with low current of

12kV power supply, the liquid was highly condensed and collected in the oil pot. Yield production of bio-char and pyrolysis liquid was measured by weighing products left in the pyrolyzer and oil pot, respectively, which corresponds to the initial mass of the waste feed. The gas yield was only determined by calculating the difference from the total yields of the collected solid bio-char and pyrolysis liquid.

The released of particulate matter during pyrolysis process were measured by using DustTrak Aerosol Monitor 8520. The DustTrak 8520 was attached parallel inside the pipe exist before letting flown out into the cotton wool filter. $PM_{10.0}$ measurement was used for the entire pyrolysis work, therefore specific inlet nozzle was selected for the aerosol measurement within $PM_{10.0}$ range [11]. The measurement was based on the two hours counting started as the heat suddenly became greater than the room temperature. In addition, few selection parameters of the DustTrak 8520 were programmed by using the TrakPro software, which are time constant and logging interval. In this study, time constant was fixed at 60.0s for the average counting updated of every second within time period provided, while the logging interval was set up for 120 minutes.

3. RESULTS AND DISCUSSION

Thermochemical behaviours of dried raw and treated EFB are presented as in Table 1. The volatile matter of raw EFB was approximately around 85.16 wt%, with ash content amounting to weight percentage of 4.07 wt%. An increment of volatile matter value was observed to around 87.63 wt% after the waste being treated by RT washing medium. However, the volatility of EFB was negatively responded towards HT washing medium by only amounting to around 83 wt%. Due to high weight percentage of volatile matter, the RT treated feedstock was favourable to produce greater amount of vapours and gases during pyrolysis process rather than the other feedstock, thus provided better mechanisms of condensation process for liquid collection [4]. As reported earlier, ash content of biomass was able to present lower than their origin value after treating with various technique or procedure of washing pre-treatment. Various washing conditions were surely caused significant influence in ash concentration by mainly due to the removal and diffusion of solid culprits and alkaline earth metals from the biomass [7]; [6]. By treating EFB either using room temperature or hot washing medium, both treatments has caused large percentage of ash reduction by amounting to approximately around 32.6 and 20.6%, respectively. Positive result on the ash reduction is surely contributed for better yield distribution of pyrolysis products with minimal release of particulate matter.

It can also be seen that the energy values of feedstock are increased slightly due to the employment of washing pre-treatment. The reduction of ash concentration would be main contributor for the increment of HHV value. As ash culprits removed or diffused by washing pre-treatment, entire hydrocarbon components are able to form strong bonding within the biomass matrix. Therefore, high energy would generate in conjunction to breakdown the hydrocarbon bonding structure. Energy loss might also occur due to the influence of HT washing medium, by which few hemicellulose and cellulose constituents might break apart or dissolve from the biomass matrix [9]. This assumption was quite relevant to be relating with the percentage of weight loss measured. Even leaching mechanisms would occur comprehensively between water molecules and biomass particles matrix, it was undeniable that few erodes were observed microscopically on the biomass surface morphology due to the application of HT washing medium. Forces, which induced by highly thermal water molecules, are believed causing for not only the removal of ash culprits but also extensive reduction of biomass lignocellulosic components.

Both treated and untreated EFB are majorly consisted of carbon and oxygen element, with low trace content of nitrogen and sulphur by only amounted to around 1-2 wt%. The releases of nitrogen and sulphur oxides during fuel burning are limited only at low concentration, as a precursor to provide sustainable and healthier environment. Furthermore, environmental concerns have extended to more significant harmful air pollutants, which are micro and hazardous air pollutants such as particulates and toxic chemical substances, that adversely affect human health such as cancer and asthma attacks [12]; [13]. Therefore, critical precaution on this environmental problems should be taken today for a viable world for coming generations.

Table-1. Properties of dried raw and treated EFB

Analysis	Proximate Analysis (mf wt%)				Higher Heating Value, HHV (MJ/kg)	Elemental Analysis (wt%)					Weight Loss (%)
	Moisture Content	Volatile Matter	Ash Content	Fixed Carbon		C	H	N	S	O	
Raw EFB	7.17	85.16	4.07	10.77	17.05	42.47	5.92	1.08	0.93	49.60	-
RT Treatment	5.84	87.63	2.74	9.61	18.04	47.55	6.66	1.85	0.41	43.53	6.66
HT Treatment	6.49	83.00	3.23	13.76	17.78	47.21	5.36	1.32	0.61	45.50	8.19

The yield distribution of EFB pyrolysis products ars presented as in Figure 3. As expected, the pyrolysis product distribution was totally differed well by the behaviour of the feedstock. By without having any employment of pre-treatment, untreated feedstock has possessed with 35.86 wt% of bio-char, 53.04 wt% of pyrolysis liquid and 11.09 wt% of gas yield. Clear distinction of yield distribution was distinguished by comparing with the treated EFB pyrolysis products. The distinction was majorly attributed by the difference degradation rate of biomass constituents. Alkaline metals, which highly bounded in biomass, would act dominantly as catalyst during pyrolysis process. Furthermore, it might also favourable for the secondary reactions to occur either in solid char or pyrolysis liquid. This phenomenon would lead majorly for extended decrement in solid char and pyrolysis liquid fractions, yet increases surprisingly in non-condensable gas yield distribution.

Since ash was present less in RT treatment feedstock, biomass constituents are allowed to degrade comprehensively in conjunction to promote great released in amount and quality of condensable gases. Yields distribution are enhanced by amounting around 40.98 wt% of bio-char, 55.08 wt% of pyrolysis liquid and 3.93 wt% of gas fractions. Bio-char was fully carbonize and rich with carbon. Pyrolysis liquid would present great due to high competency and capability of released gases molecule to thoroughly convert into liquid product during condensation activity. Rapid quenching of released gases compound has attributed for the collection of complex mixture in pyrolysis liquid such as water, carboxylic acid, sugars, phenolics and other oligomeric species [3]; [5]. Apparent of pyrolysis liquid has found that the RT treatment feedstock was the only homogenated liquid fuel, while the other feedstock liquid products are separated into two phases, which are tarry organic and watery aqueous phases. This phenomenon was surely attributed by the fraction of water compound which abundantly present in those non-homogenous liquid products. Sulaiman and Abdullah [6]; Das, et al. [7] and Abdullah, et al. [14] are decisively agreed that the secondary cracking reactions could reduce the total organics yield due to increment of water fraction production. Therefore, various numbers of critical upgrading techniques such as physical, chemical and catalytic were also been suggested, in conjunction to not only enhance the pyrolysis products behaviours but also as precursor for the production of sustainable bio-based products such as resins, briquettes and etc...

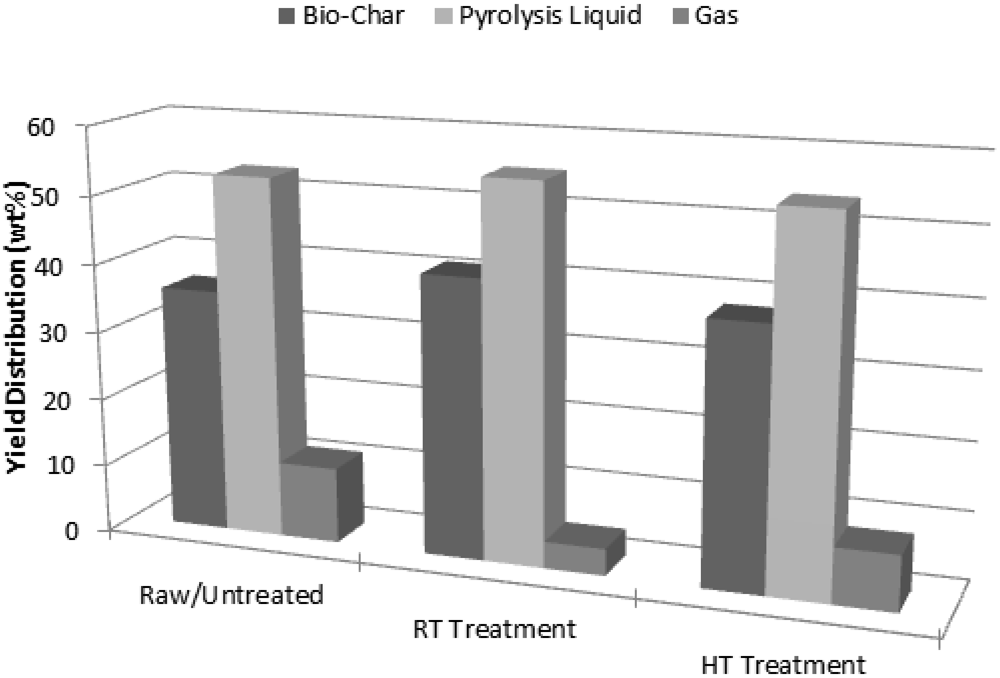

Figure-3. Yield distribution of treated and untreated EFB pyrolysis products

Figure 4 presents the mass concentration profile of particulate matter released during pyrolysis process. According to the figure, particulate emission behaviours are considerably be explained by three regime of burning phases, which are start-up, intermediate and burn-out phase [15]. The first regime is start-up burning phase (within first 12 minutes), typically showing high release of particulate emission clearly observed only by raw/untreated feedstock rather than the other feedstock. This situation was normally regarded to the interaction of ash constituents such as dirt, sand and inorganic matter with the conduction of heat supplied. Ashes interaction was started earlier rather than biomass matrix constituents since those culprits are thoroughly deposited on the outer surface of the waste. Therefore, those inorganic materials in such various types and sizes would evaporate, and flow together with the moisture and volatiles. This phenomenon would keep occurring until the ash components have emitted, or the needed temperature for the earlier decomposition stage of lignocellulosic components reached.

The intermediate phase starts when the heat approaching remarkably within the range of desired terminal temperature, which is approximately between time intervals of 1400-2400s. All feedstock were seemed to have major particulate emission along this time interval rather than other time periods. However, the raw/untreated feedstock was obviously occupied greater release of particulate matter along this time interval rather than the treated feedstock. At this range, heat was penetrated intensely into biomass matrix, by which hemicellulose and cellulose component are started to degrade comprehensively to form solid char and white smoke. Vapours and gases are thoroughly promoted due to great thermal conduction acquired. Besides, alkali metals, which highly bounded in hydrocarbon bond, would evaporate or undergo devolatilization simultaneously with biomass constituents during pyrolysis process. This phenomenon would describe that ashes are undergoing rapid volatilization or subsequent chemical transformation at higher temperature by releasing major part of its components [16]; [17]. Approaching to the end of biomass decomposition, both treated feedstock would consider by not releasing any such amount of particle emission. However, particulate emissions of the raw/untreated feedstock were consistently released even the pyrolysis process reaching ended. This situation might be related well with secondary reactions occurred in solid char or pyrolysis liquid. Therefore, it was necessary to avoid or prevent the reactions to be occurred in order to kept sustainability of bio-fuel production for longer period of any combustion activity.

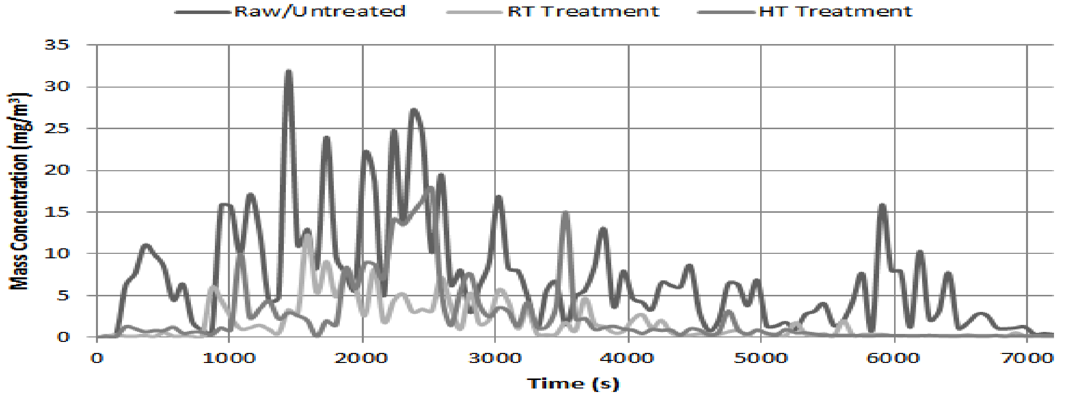

Figure-4. Profile of particulate matter released by EFB feedstock

4. CONCLUSION

Employment of washing pre-treatment on EFB was found as the practical, effective and sustainable upgrading technique in order to provide better yield distribution at low release of particulate emission. Employment of RT washing medium seemed sufficient enough to reduce the ash content and enhance the energy value of feedstock to 2.74 wt% and 18.04 MJ/kg, respectively. By the pre-treatment, the yield of pyrolysis products are optimally produced by amounting to 40.98 wt% of bio-char, 55.08 wt% of pyrolysis liquid and 3.93 wt% of gas fractions. Via pyrolysis process, major releases of EFB particulate matter are revealed within time interval of 1000 to 3000s. Particulate emissions by the RT treatment feedstock are consistently released at low in amount for every burning phases of pyrolysis process.

5. ACKNOWLEDGEMENT

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