Alternative mixing scenarios and pretreatment manner to optimize wood fuel pellet

Dian Andriania and Tinton Dwi Atmaja b,*

a Research Centre for Biotechnology – Indonesian Institute of Sciences, Cibinong 16911, Indonesia
b Research Centre for Electrical Power and Mechatronics – Indonesian Institute of Sciences, Bandung 40135, Indonesia

Received 17 September 2012; accepted 25 October 2012

Abstract

Biomass potential to be a renewable fuel can be established by creating a good quality biomass pellet. This paper conducts a review for optimizing of the highest ranked potential sources of wood pellet using several different manners and scenarios. Optimization can be used before the pelletizing process, using pretreatment manner such as steam explosion to increase the heat content or using pulverized pellet to impact the gasification progress. Wood pellet can also be mixed with other raw materials to produce mixed biomass pellet. Other raw materials are such as sawdust or wood shaving for increasing the energy saving or wood and cotton to increase the fuel potential. The reviewed manners and scenarios can be basis of optimizing the overall performance of the biomass pellet to meet the physical, mechanical, and chemical properties needed.

Keywords: pellet; pretreatment manner; mixed biomass; optimizing; review.

1. Introduction

Biomass pellets are global development topic emerged from the depletion of the fossil fuel and the global warming issue. The pellet are environmentally friendly, alternate a low production cost, and have a massive renewable resources all over the world. As bio-fuel, pellets are easily transported, stored, and sold to the consumer. European countries already demand a proper standardization in order to improve its position in the pellet global market in term of quality [1-2]. Research conducted by A. Sultana, et al. [3] shows that wood is the best sources for pelletization among other alternative biomass resources such as by switchgrass, straw, poultry litter and alfalfa pellets. Its superiority is due to its high bulk density, low friability, lower emission, and low deposit formation. Table 1 shows the ranking of pellets using PROMETHEE II without including qualitative criteria analysis [3].

The selection of best sources for wood pellets according to the wood species was conducted by C. Telmo et al. as to be detailed in Table 2 [4] for their HHV–LHV and moisture content (Mar). The study showed different calorific value of wood pellets from different species. Table 2, using Tukey–Kramer HSD test, shows that Bowthicamitida has the highest HHV (20,809.47 kJ/kg) and also highest LHV (17,907.85 kJ/kg). Other existing Higher Heating Values is in the Phyllis Database [5]; for softwood are ranging from 18,398 to 20,519 kJ/kg and for hardwood are ranging from 17,384 to 23,052 kJ/kg.

This paper tried to review some pretreatment processes for wood pellet and some scenario on the mixture of raw material to create proper mixed biomass pellet (MBP). The pretreatment process should be a steam explosion pretreatment and pulverize manner to the wood pellets [6-7]. The mixture of raw material would consider wood shaving, corn, cotton, and coal as alternative material to enhance the quality of wood pellets [1, 8]. It is managed that the properties of the pellets produced from those pretreatment manners and mixture processes can stand the standardization in the biomass pellet developing countries. As the comparison, European countries has develop various standard for their basic requirement, limit value and application mode to the [2]. Specified standards in Europe are such as French recommendations (for the use of pellets in stove and heating), German standards [9-10], the Austrian norm [11], and Italian standards (for A1 and A2 pellets) [12]. Pellet size, moisture content, heating value, and ash content are the quality parameters that appear most frequently in standards and recommendations. However,
pellet size (diameter, length and/or length/diameter ratio) is the only parameter that is appeared in all the norms [2].

2. Pretreatment manner

2.1. Steam explosion pretreatment

Steam explosion is performed to enhanced biomass fuel and wood pellet quality by increasing the heat content. Previously, steam explosion was mentioned to ethanol and wood pellet quality by increasing the heat content. The study conducted by A.K. Biswas et al. [6], using willow (Salix) chips, mentioned that steam pretreatment alter biomass fuel property significantly such as the fuel characteristic and ash release the pressure after 6 to 12 minutes observed residence time in the reactor.

The steam explosion pretreatment creates altered properties of the biomass fuel where the fixed carbon was increased while the volatile content was reduced [6]. This alteration of elemental condition creates another effect such as increased severity factor so the higher heating value was increased as well. Ash content and other mineral content also altered by steam explosion. Ash content has been decreased and the heavy metal elements (Ba, B, Co, Zn, and Cd) were significantly decreased. Considering ecological reason, the amount of heavy metal strongly recommended to be reduced.

The pellet produced after steam explosion pretreatment have a higher density and more durable pellets. During pelletization, particle per unit volume is increased and porosity of the pellet is decreased which results in increase of pellet density. Therefore, wood pellet from steam explosion pretreatment showed significant rise in pellet density even at lower applied pressure [6]. The study conducted by Bergström and co-workers [18] showed that pellet with finer particle size distribution had abrasive resistance of 98.8%. Higher amount of fines is considered to emerge more durable pellet and steam explosion pretreatment has been observed to produces higher amount of fines [6]. Compared with untreated pellet, it is concluded that steam explosion pretreatment enhances the durability of pellet almost to 100% durable pellets.

However, thermo chemical characteristics of the pellet had also altered where the char reactivity was reduced
corresponding to the increasing of the lignin and the reducing of both the hemicelluloses and celluloscs. From previous study, it can be found that lignin produces higher amount of char during pyrolysis as compared to hemicelluloses and cellulose [19]. Hence, higher lignin content in the char can decrease the reactivity due to softening, melting, and carbonization of lignin and partial blocking of the pores of the char [20].

2.2. Pulverised pretreatment

Applying different pyrolysis condition to original and pulverized pellet can observe the produced gas characteristic. A research conducted by A. Alevanau et al. [7] concluded that the flow rates of the produced gas are different for each form. Fig 2 shows the flow rates of the hydrogen and carbon dioxide for pulverized and original pellets under three different pyrolysis treatments 800°C, 900°C, and 950°C.

In the same amount of mass of the pulverized and original pellets, there is a slight different can be observed for duration (min) and rates (Mol/min). The time of heating of the pulverized pellet with 0.2–1.0 mm size is much lower than the heating time of the original pellets. Fig 2 also show that the release of the volatile from pulverized pellet is faster than the original pellet due to the loose spacing of the layer [7]. It is clearly states that original pellet should had been pulverized to achieve a lower process duration. The three pyrolysis treatments also show the efficiency of the process. It is showed that rapid pyrolysis condition may cause a faster pellets’ breakup [21-22]. The higher the temperature of the pyrolysis treatment, the faster is the pellets breakup.

3. Mixing scenario

3.1. Sawdust and wood shaving scenario

Common biomass material for wood pellet production (particularly sawdust) can also be mixed with other raw materials such as wood shaving to increase the energy saving and reduce production cost. A study conducted by A. Uasuf et al. [8] mixed coniferous (P. Elliotii and P. Taeda) sawdust and shavings to observe three specific costs and three energy consumptions. The mixing of the sawdust and the wood shavings was made in four scenarios as shown in Table 3 [8]. Figure 3 shows the specific production cost and the specific energy consumption of wood pellets for the different scenarios [8].

To compare the total production cost (€/p.a.), each scenario was observed for the annual capital costs, maintenance costs, and operating cost. The annual capital cost was considering the capital recovery factor, general construction, purchase, and installation. The maintenance cost was considering average service and maintenance cost including wear and tear of machinery part [23-24]. In the specific energy consumption, operating cost was considering the cost of raw material, heat cost for drying, electricity consumption cost, and personnel cost. Energy

![Figure 2. (a) Hydrogen flow rates for two forms of the pellets; (b) Carbon dioxide flow rates for two forms of the pellets [7]](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of raw material input</td>
<td>100% wet sawdust</td>
<td>50% wet sawdust; 50% wood shavings</td>
<td>100% wet sawdust</td>
<td>50% wet sawdust; 50% wood shavings</td>
</tr>
<tr>
<td>Pellets production rate</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Annual operating hours</td>
<td>7884</td>
<td>7884</td>
<td>7884</td>
<td>7884</td>
</tr>
<tr>
<td>Annual pellet production</td>
<td>23652</td>
<td>23652</td>
<td>47304</td>
<td>47304</td>
</tr>
</tbody>
</table>
consumption was detailed according to the energy source: electrical energy, heat energy, and diesel energy. The total electrical energy consumed corresponded to the electricity required by the hammer mill, dryer motor, pellet mill, cooler, and miscellaneous equipment. It is considered that not all electrical installations operate on full load at the same time was [23]. The total heat energy was corresponded to the total heat required to evaporate water from the raw material. The total diesel fuel energy consumed was corresponded to the high heating value (HHV) of diesel fuel [25] multiplied by the annual consumption of diesel fuel (liters/year).

3.2. Corn and cotton scenario

Other study was conducted to see the possible heating value from combination of wood with corn and cotton. Study conducted by V. Karkania et al. [1, 26] was combining 50% wood (25% pine, 25% fir) with 50% corn (sample 1) and 50% wood (25% pine, 25% fir) with 50% cotton (sample 2). The experiment was observing the LHV of the pyrolysis gas from the sample in the temperature of 400–750°C at atmospheric pressure in He (50 ml/min), with a heating rate 65-75°C/s [1]. Fig 4 shows the LHV of the pyrolysis gas of the biomass pellets (wood with corn and cotton) [1]. It shows that the gas lower heating value of the gas composition has been determined at 14–15 MJ m⁻³.

3.3. Coal scenario

Study conducted by V. Karkania et al. [1, 27] was also observed the potential of combining coal in certain percentage in to the mixed biomass pellets. The study was using Pinus Patula and Cypress sawdust and coal in proportions of 0%, 5%, 10%, 20%, and 30% v/v of coal. The sample were divide into two kind of mixtures, the first one was mixtures composed of granular coal and of wood pellets and the second one was pellets composed of pulverized wood and granular coal. All samples were cogasified with steam by using an electrical heated fluidized-bed reactor, operating in batches, at 850 °C [27].

Fig 5 shows the effect of the content of coal over the (% v/v) composition for the mixtures composed of granular coal and of wood pellets considering H₂, CO, CH₄ and CO₂ [1, 23]. It shows that the increasing of coal content has decrease the hydrogen product and increase the CH₄ value. The CO product was also decreasing until the minimum value of 20% of coal while the CO₂ product was increasing.
ash fusibility was observed in steam treated residue [6].

and heavy metal components of biomass, degradation in pretreatment shows promising in terms of reducing alkali pellet durability. However, even when the steam consideration. The produced pellets also having a higher metal content such as Ba, B, Co, Zn, and Cd for ecological

composition of the fuel to increase carbonization degree steam explosion pretreatment affects the elementary density, more durable, and reduce the heating time. The produced pellets. The steam explosion pretreatment and pulverizing manner were believed to increase the heat content of the fuel, reducing the ash content, have a higher density, more durable, and reduce the heating time. The steam explosion pretreatment affects the elementary composition of the fuel to increase carbonization degree and oxygenated compound removal. It also reduced heavy metal content such as Ba, B, Co, Zn, and Cd for ecological consideration. The produced pellets also having a higher density and grows a higher amount of fines to increase pellet durability. However, even when the steam pretreatment shows promising in terms of reducing alkali and heavy metal components of biomass, degradation in ash fusibility was observed in steam treated residue [6].

4. Result and discussion

Wood pellets are believed to be the better pellet rather than other alternatives such as switchgrass, straw, poultry litter or alfalfa pellets. The selection on the raw material of the pellet should have considered the best wood existed in the area should it produced optimal calories than the others. It is important as the heating value is appeared in most standards developed by countries with high biomass energy implementation.

Two pretreatment manners for wood pellet were observed in this paper to enhance the quality of the produced pellets. The steam explosion pretreatment and pulverizing manner were believed to increase the heat content of the fuel, reducing the ash content, have a higher density, more durable, and reduce the heating time. The steam explosion pretreatment affects the elementary composition of the fuel to increase carbonization degree and oxygenated compound removal. It also reduced heavy metal content such as Ba, B, Co, Zn, and Cd for ecological consideration. The produced pellets also having a higher density and grows a higher amount of fines to increase pellet durability. However, even when the steam pretreatment shows promising in terms of reducing alkali and heavy metal components of biomass, degradation in ash fusibility was observed in steam treated residue [6].

Figure 6. Effect of the content of coal over the (% v/v) composition for pellets composed of pulverized wood and granular coal: (a) H2, (b) CO, (c) CH4 and (d) CO2(Thek G, Obernberger I)

up until the maximum value of 20% of coal.

Fig 6 shows the effect of the content of coal over the (% v/v) composition for pellets composed of pulverized wood and granular coal considering H2, CO, CH4 and CO2 [1, 23]. It shows that there was a decreasing value of hydrogen and monoxide, and an increasing value of methane but no higher than 2.5%. The CO2 product was increasing up until the maximum value close to 20% of coal. The increasing methane was believed to be the process of consuming the hydrogen while the increasing of the carbon dioxide was because of the consuming of the carbon monoxide.

5. Conclusion

Wood as renewable source of energy is friendly to the environment and easily processed to be a promising bio-fuel pellet with competitive annual cost. Optimal pretreatment scenario on the wood pellet using steam explosion pretreatment and pulverizing manner were believed to increase the heat content of the fuel, reducing the ash content, reducing heavy metal content, have a higher density, more durable, and reducing the heating time. Mixing wood with other raw material could create

Other pretreatment is to physically pulverize the pellet and observe the rates and durations of char gasification under three different pyrolysis treatments 800°C, 900°C, and 950°C. The pulverized pellets show a faster pellet breakup corresponding to the higher the pyrolysis temperature. It is important to be acknowledged that the pulverized pellet have a lower heating time than original pellet without pretreatment. A further approach conducted by A. Alevanau et al. [7] using the shrinking core grain model (GM) [28] random pore model (RPM) [29-30] and volumetric model (VM) [31], said that To sustain elevated temperatures uniformly in the whole volume of an industrial size fixed bed reactor, one may have heat for endothermic reactions to be delivered by reasonably high flow rates of high temperature steam. Such condition would add more efficiency to the process.

Combining sawdust with wood shaving in four scenarios shows lower production cost and lower energy consumption. This reducing was believed to be caused due to the fact that wood shavings do not need to be dried before entering the pellet line. However, Mani [24] and Thek and Obernberger [23] was believe that personnel cost should have higher annual cost.

Other alternative for mixed biomass pellets is combining the wood with the corn (sample 1) and wood with cotton (sample 2). Accomplished study [1] was showing that the heating value of the gas emerged from the pyrolysis of both sample is about 14–15 MJ m−3 in temperature of 400–750°C. It can be concluded that energy content from both pellet sample is suitable for standardized energy consumption. Mixed biogas pellet containing coal in certain proportion produced different gas product according to the mixture process. The result obtained from the mixtures composed of granular coal and of wood pellets and the pellets composed of pulverized wood and granular coal has similar evolution for H2 and CO product but has a different behavior for CH4 and CO. So it is said that the different ways in the mixture of coal and wood could affect the evolution of CH4 and CO. The dissimilar evolution was caused by the different intimacy of the material contact of the two samples.
mixed biomass pellet with proper LHV, lower production cost, lower energy consumption, and alter the characteristic of produced gas such as $\text{H}_2$, $\text{CH}_4$, $\text{CO}$, and $\text{CO}_2$ to a more optimum characteristic.

Acknowledgements

The writers would like to thank all researchers in RC for Biotechnology and Research Centre for Electrical Power and Mechatronics. The writers would also like to thanks Prof. Dr. Bambang Prasetya and Dr. Wien Kusharyoto for all the support on the completion of this paper.

References


