Torrefaction study for energy upgrading on Indonesian biomass as low emission solid fuel

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Abstract. Torrefaction is a pyrolysis process with low heating rate and temperature lower than 300°C in an inert condition which transforms biomass into a low emission solid fuel with relatively high energy. Through the torrefaction process biomass can be altered so that the end product is easy to grind and simple in the supply chain. The research was aimed at designing torrefaction reactor and upgrading energy content of some Indonesian biomass. The biomass used consist of empty fruit bunches of oil palm (EFB), cassava peel solid waste, and cocopeat (waste of coconut fiber). These biomass were formed into briquette and pellet form and were torrified with 300°C temperature during 1.5 hours without air. The results of terrified biomass and non-torrefied biomass were compared after burning on the stove in term of energy content and air emission quality. The result shows that energy content of biomass have increased by 1.1 up to 1.36 times. Meanwhile emission air resulted from its combustion was met with Indonesian emission regulation.

1. Introduction

Depletion of oil reserves and global warming are problems faced by the world today. Many of the possible solutions are already in place, but they have not been widely adopted [1,2]. The best possible solution is to reduce the world’s dependence on non-renewable resources and to improve overall conservation efforts [3]. Biomass is one of good alternative energy sources over fossil fuel. It is renewable and it is generally commonly available [4]. Biomass uses also can be a solution on dependence on fossil or petroleum energy and fluctuations price of petroleum energy which became an obstacle for the development of industry [5,6]. Biofuels can help reduce carbon emissions, greenhouse gas build up and dependence on fossil fuels. Biofuels are commonly used to power vehicles and cooking stoves [7].

The problem of biomass when used for fuel or solid fuel are low energy density and low heating value, low fixed carbon content, high moisture content which can reach 50% , high volatile matter content, easiness to absorbs moisture (hygroscopic), low ash content, high alkali metal content (Na, K), low Chloride content compared to herbaceous biomass, less air for stoichiometric combustion, low combustion efficiency and smoking during combustion, wide variations in sizes, shapes and types (difficulties on handling and storage), and too bulky, not economical to transport over long distances.
Technology barriers to their utilization as energy sources is one of the main constrains of empowering biofuels [9].

Torrefaction is a pyrolysis process with temperature of 200-300°C near atmospheric pressure, absence of oxygen or air, low heating rate with residence time of 30 minutes up to 2 hours [10,11].

Currently available torrefaction technologies are basically designed and tested for woody biomass so further research is required to address on utilization of the agricultural biomass with technically and economically viable. Indonesia is the biggest producer of biomass such as oil palm empty fruit bunches (EFB), cocopeat, cassava peel waste [12]. The opportunity to develop non-fossil energy renewable is quite large this is due to: 1) the availability of a variety of renewable energy resources, 2) economic growth the better which will increase the demand in energy, 3) purchasing power of private investment in industrial development, and 4) the potential market for national, regional and international levels which are still open [13,14,15].

This preliminary research was aimed at designing bench scale of torrefaction reactor in upgrading energy content of some Indonesian biomass such as empty fruit bunches (EFB) of oil palm, cassava peel solid waste, and cocopeat or waste from coconut fiber. This study also was addressed to know emission quality of torrefied biomass and non-torrefied biomass. It is hope that combustion of biomass characteristics before and after torrefaction, its emission quality data can be recommendations for further study or scale up biomass torrefaction reactor

2. Materials and Methods

2.1. Torrefaction reactor

The bench scale torrefaction unit is shown schematically in Figure 1. The length, wide, and height of the reactor were 100 cm, 80 cm, and 100 cm respectively. Meanwhile the capacity of torrefaction process is 10 kg. The reactor was made from stainless steel, and it is equipped with the heater of 3000 Watt. The reactor was also was equipped with thermometer control (0-400°C) to observe biomass temperature during torrefaction. During the torrefaction process, absence of oxygen or air was controlled by a blade at the back of the reactor.

![Figure 1. Bench scale biomass torrefaction reactor](image-url)
2.2. **Materials**

Biomass waste such as empty fruit bunches (EFB) of oil palm trees, cassava peel waste, and cocopeat or waste from coconut fiber were used as solid fuel in this experiments. Tapioca starch with concentration of 5% from biomass mixture was used as binding agent for making cocopeat pellet and cassava peel briquette, and EFB briquette. To make appropriate rheological properties of mixture of pellet when pelletizing it was added waste cooking oil with concentration 5% of mixture.

2.3. **Pellet and briquette making**

Cocopeat pellet, EFB briquette, and cassava peel briquette were produced by the following steps. Firstly biomass were grinded with 2 horse power (hp) milling unit and continued by sortation of biomass to purge foreign materials and to produce raw materials, and to make uniform size. The mesh used for sortation was 60. Drying biomass was done in order to get the level of dryness biomass with of 14% maximum (wet basis) and to obtain the quality of good structures pellet as well as to produce low emission pellet or briquette (Lee et al, 2010; Amin et al, 2014). Agitation of mixing started by the addition of grinded biomass (90%), tapioca starch (5%), and waste cooking oil (5%) respectively for 10 minutes. Briquetting or Pelletizing was intended to form a biomass fuel in the form of briquettes (3m diameter) and pellets (2 cm long and 8 mm diameter). Making briquettes and pellets were done by manually press machine and pelletizer (10 hp). Finally briquette and pellet were then cooled to evaporate moisture of their surface.

2.4. **Torrefaction**

Torrefaction took place without air access and the temperature in the reactor was gradually increased to 300 °C. The temperature in the reactor was read from the display on the reactor's control unit. After fitting and sealing the reactor windows, and reaching the temperature of 300°C, 5 kilograms (kg) biomass was torrefied during 1.5 hours. Samples were taken inside torrefaction reactor unit and it was stopped when the color of the pellet or briquette was changed into dark shiny color [17].

2.5. **Analysis and emission test**

In general, testing of biomass before torrefaction and torrified biomass were to determine some parameters such as volatile matter (%), moisture content (%), ash content (%), fixed carbon (%), density (kg/m^3), energy content (kJ/kg) of biomass, briquette and pellet (before and after torrefaction), and air emissions quality of combustion pellet and briquette (CO, O_2, HC, and CO_2) during combustion on the stove.

2.6. **Combustion**

To know the pellet and briquette properties and combustion performance, experiments were carried out by burning such torrefied biomass on the stove. A half (0.5) kilogram pellet an briquette put in stove or bed furnace. Observation was conducted for combustion time which start from flame appear until coals from pellet or briquettes disappeared. The same experiments also were revealed by non-torrefied pellet and briquettes.

3. **Results and Discussion**

3.1. **Torrefaction reactor performance**

To test the performance of torrefaction reactor, torrefaction of biomass pellet and briquette was conducted at 300°C without air. This observation was carried out to know optimum torrefaction time of biomass. These works were based on observations each interval time in 15 minutes, 30 minutes, 45 minutes, 60 minutes, 75 minutes, 90 minutes, 105 minutes and 120 minutes. Indicators used of quality biomass was glossy color of biomass [16,17]. In 90th minute observation, biomass looks black and shiny and when it reached 120 minutes biomass started to burn and turn into coal. Thus, the length of the torrefaction process done for 90 minutes is the optimum time for biomass torrefaction.
Based on the optimum time the experimental research on some biomass and measurements will be done during 90 minutes or 1.5 hours. Figure 2 shows torrefied pellet and briquettes.

![Non-torrefied, Torrefied pellet, Briquette](image)

**Figure 2.** Non-torrefied and torrefied pellet/briquette

The use of torrefied wood or agricultural biomass in commercial industry is still in development, even though torrefaction is not a new process. Several companies are developing commercial torrefaction equipment based on one method obtained. For instance it is used a cylindrical reactor equipment with a device for removal of the liquid products and measurement of the gaseous products [18]. It would be better torrefaction process should also used others method in order to have optimum energy and minimum operational cost. The technologies under current development use a variety of combinations of temperature and residence time for processing woody biomass into torrefied wood [19]. For this research, a temperature used about 250°C with reaction times around 1 hour is recommended for torrefaction. However, at same operating conditions, mass and energy yields will vary for different biomass, as the polymeric composition and reactivity may differ. Consequently, each biomass will have its own set of operating conditions to achieve the same product quality. It would be better also for a good design and operation to use a biomass with pellet form and further understanding for optimisation of the process is required.

### 3.2. Chemical composition and energy

Table 1 shows the characteristics of torrefied biomass and non-torrefied biomass obtained in the performed experiments as well as the ash and the moisture contents, volatile matter, ash content, density, fixed carbon, and caloric value of the torrefied biomass and non-torrefied biomass.
Table 1. Chemical and energy of torrefied biomass

| PARAMETERS      | Biomass                      | Non-torrefied cocopeat pellet*) | Torrefied cocopeat pellet*) | Non-torrefied EFB briquette | Torrefied EFB briquette | Non-torrefied Cassava peel briquette | Torrifed Cassava peel briquette |
|-----------------|------------------------------|---------------------------------|-----------------------------|-----------------------------|-------------------------|---------------------------------------|-------------------------------|
| Moisture (%)    | Non-torrefied                 | 8.490                           | 6.745                       | 1.668                       | 1.643                   | 9.943                                 | 1.299                         |
|                 | Torrefied                    | 73.283                          | 48.996                      | 75.997                      | 54.210                  | 67.767                               | 54.83                         |
| Volatile matter (%) | Ash content (%)               | 10.565                          | 13.996                      | 6.527                       | 7.782                   | 9.512                                 | 7.751                         |
| Density (kg/m³) | Non-torrefied                 | 19.451                          | 37.996                      | 17.746                      | 37.697                  | 22.721                               | 37.376                         |
| Fixed carbon (%) | Calorific value (cal/g)      | 4083                            | 5565                        | 4289                        | 4555                    | 4494                                  | 5610                          |
| Energy ratio    | Non-torrefied                 | 1.36                            | 1.1                         | 1.25                        |                         |                                       |                               |

*) Alamsyah et al. [17]

The results in Table 1 above shows that there is an increasing calorific values for the three types of torrefied biomass. The increase of calorific value of torrefied biomass were 1.36 times for torrefied cocopeat pellet, 1.1 times for torrefied EFB briquettes, and 1.25 times for torrefied cassava peel briquette. This is due to the loss of substances such as cellulose, lignin, and volatile matter, and relatively smaller loss of calorie value. This increase is quite significant, especially for torrefied cocopeat pellet and cassava peel briquette so torrefaction process is expected to be a promising alternative to increase the added value of biomass as a renewable energy or solid fuel.

The type of biomass influenced the product characteristics. The torrefied cassava peel briquette and torrefied EFB briquette gave lower moisture content than torrefied cocopeat pellet. On the other hand the content of volatile matter which is owned cassava peel and briquettes EFB smaller than the same substance found in cocopeat pellet.

From the perspective of the agro-based industry logging and timber industry, literature indicates that raw material for torrefaction can vary in size and can include thin and thick chips, briquette, pellet, and even larger wood chunks. Bjorck [20] employed wood pellets of similar sizes. It was Cylindrical pellets that has 20 mm in length, and 16 mm and 6 mm diameter respectively and it was selected for torrefaction process. The energy densification resulted range from 0.85 up to 1. It can be shown that the characteristics of torrefied biomass will be depend on the pretreatment before process. Such torrefaction results it depend on the equipment design, and considering characteristics such as pre-drying, processing temperature and reaction time; it appears that performance of the torrefaction process may be vary and also types of woods, biomass, and their form [21]. However, research studies to support implementation commercial industry have been done partially. Research carried out are still complete yet and therefore need to be complementary to an integrated manner so that the result will be more efficient and maximum.

3.3. Combustion and emission test

Figure 3 shows the result of torrefied biomass combustion using stove. This figure shows the beginning of the combustion with full of flame (1), the middle combustion with half full of flame (2) and the end of combustion with full of coal (3). Table 2 shows biomass combustion time of torrefied pellet and briquette biomass.
The results show that the biomass obtained from the process torrefaction have greater energy. This is advantageous because the stored energy becomes greater than the non-torrefied biomass; then the experiments shows that the best combustion time in term of flame time until the coal disappear was shown by torrefied cocopeat pellet for 120 minutes, followed by torrefied cassava peel briquettes for 75 minutes, and torrefied EFB briquettes for 70 minutes.

The emissions test was done to find out whether the exhaust gases produced from the burning of torrefied biomass fulfill the requirements according the national regulations. Biomass pellet or briquettes combustion either torrefied or non torrefied ones were presented in Figure 4, 5, and 6. Based on the emission regulation specified in the Decree of the Minister of Environment of Republic of Indonesia No. KEP-13 / MENLH3 / 1965, all results of exhaust gas quality parameters from torrefied biomass meet the requirements. Thus, torrefaction treatment of exhaust emissions aspects is better and superior than non-torrefied biomass. From this table, are also found in combustion exhaust emissions test based on biomass feedstock on the stove in of a small quantity (0.5 kg) for all experiments either torrefied biomass and non-torrefied biomass. It is still need to do experiments with the large quantity of torrefied biomass to know whether the emission of hazardous gases in the pellet combustion such as production dangerous gas (especially CO) and the concentrations levels should be in safe limit.

### Table 2. Biomass combustion time

| PARAMETERS            | Biomass                          |
|-----------------------|----------------------------------|
|                       | Non-torrefied cocopeat pellet    | Torrefied cocopeat pellet | Non-torrefied EFB Briquettes | Torrefied EFB Briquettes | Non-torrefied Cassava skin briquette | Non-torrefied Cassava skin briquette |
| Weight (kg)           | 0.5                              | 0.5                        | 0.5                          | 0.5                        | 0.5                              | 0.5                          |
| Flame and coals time after burned (min) | 20                               | 120                        | 35                           | 70                         | 30                              | 75                           |
**Figure 4.** Emission quality of torrefied cocopeat pellet
(Standard gas limit  CO: 4.5 %,  HC: 1200 %, CO$_2$: 20 %)

**Figure 5.** Emission quality of cassava peel briquette
(Standard gas limit  CO: 4.5 %,  HC: 1200 %, CO$_2$: 20 %)
However, little attention has been paid to the influence of torrefaction of biomass processing for solid fuel. A series of experiments were performed to examine the characteristics of the torrefaction process, the properties of torrefaction products, and the effects of torrefaction on gas composition, cold gas efficiency and gasification efficiency. The results showed that during the torrefaction process the moisture content of biomass were reduced, and the wood fiber structure of the material was destroyed. Torrefaction is one of attractive option of upgrading biomass energy and the combustion result of terrified biomass give low emission [11]. From the observation of the smoke is concluded that there is only very little smoke. This findings was similar to those conducted by Azhar and Rustamaji [22] which indicates that the process torrefaction of bamboo have eliminated most of the volatile on bamboo. On the other hand observations of the burning briquettes can be concluded that the ash formed showed in a very small amount [22].

4. Conclusion
Energy of biomass can be upgraded and used as a fuel by torrefaction process. It was shown by the energy ratio of caloric value of biomass pellet after torrefaction. For cassava peel briquette, caloric value increase from 4494 cal/g to 5610 (or energy ratio was 1.25), for EFB briquette caloric value increase from 4289 to 4555 cal/g (or energy ratio was 1.1), and for cocopeat pellet caloric value increase from 4083 to 5565 cal/g (or energy ratio was 1.36).

Cocopeat pellet treated with torrefaction process reveals flame and coals time after burned is longer when combustion which means the energy stored in the biomass pellet was greater and pellet shape of biomass has greater influence on combustion. Meanwhile emission air resulted from its combustion of all torrefied bioamass (pellet and briquette) were met with Indonesian emission regulation standard. For a good design and operation of a biomass torrefaction reactor plant, further experiments for optimization of the process is required. It is suggested that future work should focus on biomass in Indonesia for optimum torrefaction conditions, as well as investigations of the combustion behaviour of these fuels.

Acknowledgement
The authors would like to acknowledge Center for Agro-Based Industry (CABI), Ministry of Industry for supporting budget in this research, Local Department of highway traffic (DLLAJR) and Bogor for air emission quality test.
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