Combustion characteristics of densified bio-char produced from Gayo Arabica coffee-pulp: Effect of binder

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Abstract. Increasing number of coffee-by-products highlights its potential as source of renewable energy. The use of coffee pulp as a raw material for bio-briquettes is considered as an effective way to minimize their wastage as landfill. This study aims to examine the combustion characteristics of bio-briquettes produced from Gayo Arabica coffee-pulp which was carbonized through a slow pyrolysis process and densified at a pressure of 150 kg/cm\textsuperscript{2}. Prior to densification process, the raw material was sun-dried, pyrolyzed, ground and sieved to mesh 20. A mixture was then made by adding starch binder at 20, 30 and 40 wt.\% followed by molding and drying processes. Characterization of the briquette employs a number of techniques including DSC, bomb calorimeter and proximate analyses as well as combustion test. The results show that the amount of starch-binder significantly affects the rate of combustion and the flame duration. However, no significant change is found in term of calorific value, moisture and ash content.

1. Introduction
Coffee is the second largest commodity with its annual production increased from 140 to 152 million 60 kg bags since 2010 \cite{1,2}. Processing coffee berries yields residual about 30 - 50% of its total weight depending on the type of processing \cite{3}. The main residues obtained after removing coffee beans with dry or wet process are coffee pulp and husk. An effective way is required to utilize this residual since disposing into the environment can bring serious problems to environment. In principle, this biomass waste can be directly used as fuel, however the combustion process cannot be maximized due to several factors, including low density, non-competitive calorific value per unit volume, higher moisture contains and produces smoke \cite{4}. On the other hand, the use of biomass to replace fossil fuels benefits in lowering emissions of green-house gases. Using biomass materials in their original form is not feasible and faces some challenges such as high moisture content, irregular shape and sizes, and low bulk density. Thus, briquetting is one of the most common strategies used for enhancing fuel quality and helps in establishing more effective fuel distribution, storage and utilization.

Densification of materials into pellets, briquettes, or cubes is one of solution to overcome the challenges in biomass utilization. Densification of biomass helps in reducing the costs of transportation, handling, and storage. Uniformity in shape and size makes densified products easy to handle and store using the standard equipment. In general, pressure-assisted densification method can...
be classified into three types: extruding, pelleting, and briquetting [5]. Evaluation on densification process is performed by measuring related-physical properties of the final product. This study aims to find-out the characteristics of densified bio-chars produced by slow-pyrolysis of Gayo Arabica coffee pulp. The main objective is to examine the characteristics of bio-briquettes produced through the cold-forming process as well as finding the effect of binder content on the combustion characteristics of briquette.

2. Methods

2.1. Bio-char preparation and densification
Wet-processing residue of Arabica coffee was collected from Bener Meriah District of Aceh Province, Indonesia. Initially, coffee pulp was sun-dried for three days and fed to pyrolysis reactor carbonization. Resulting char was ground and sieved to mesh 20. Starch was added as binder at 20, 30 and 40 wt. %, then each sample was denoted as CS80B20, CS70B30 and CS60B40, respectively. Cold-forming process of briquettes employs a home-made briquetting machine at a pressure of 150 kg/cm² with a constant weight of mixture of 120 g for all samples. Resulting briquette has diameter of 45 mm and 60 mm height. Briquette was then naturally dried for five days. Figure 1 shows a photograph of densified bio-char produced from Arabica coffee pulp after drying. All dried briquettes have final diameter of 49 mm and height of 75, 70 and 53 mm respectively for CS80B20, CS70B30 and CS60B40. The difference in height obtained in this briquetting process is due the constant weight of mixture and pressure applied. The more binder is added, the less biochar contained in the mixture which consequently reduced the final length of briquette.

![Figure 1. Images of densified biochar after drying.](image)

2.2. Testing procedures
Investigation on physical and chemical properties of densified bio-char produced from Arabica coffee pulp employs a number of techniques including Differential Scanning Calorimeter (DSC) and bomb calorimeter analyses. DSC is a thermo-analytical technique to find out the difference in the amount of heat required to increase the temperature of sample. DSC helps in defining required amount of heat flow and temperature for the sample during exothermic or endothermic reaction. Bomb calorimeter is used to find-out the caloric value of each sample of briquettes. Ignition time, flame duration and rate of combustion of the briquette were also tested at atmospheric pressure. Combustion test was performed on stainless steel wire mesh placed on a stainless steel dish. Prior to testing, sample was weighted and dipped in kerosene. Ignition is started by using a lighter and temperature was monitored by using infrared thermometer. To analyse the content of moisture, ash, volatile matter and fixed carbon, proximate analysis was carried out following ASTM D1762-84 procedure as described in literature [6].
3. Results and discussion
Assessment on quality of densified biochar was carried-out using bomb calorimeter and proximate analysis method. Proximate analysis results including caloric values, moisture, volatile matter (VM), fixed carbon (FC) and ash content is summarized in Table 1 for all samples. In general, no significant difference is observed in term of caloric value of each sample. The highest caloric value is 19523 J/g obtained from CS80B20 briquette. Caloric number changes slightly when more binder was added on the mixture. Effect of binder content can be observed from the changes in VM and FC where adding more binder increases VM content as well as decrease the amount of FC. There is no significant changes in moisture and ash content from all sample tested in this analysis.

Table 1. Caloric values and proximate analysis results of densified bio-chars.

| Sample code | Moisture (%) | Volatiles (%) | Fixed Carbon (%) | Ash (%) | Caloric value (J/g) |
|-------------|--------------|---------------|------------------|--------|-------------------|
| CS80B20     | 9.59         | 22.68         | 59.32            | 8.41   | 19523             |
| CS70B30     | 10.37        | 31.37         | 48.63            | 9.63   | 18539             |
| CS60B40     | 11.67        | 33.47         | 45.00            | 9.86   | 18622             |

Table 2. Combustion test results.

| Sample code | Ignition time (s) | Flame duration (min) | Rate of combustion (g/s) |
|-------------|-------------------|----------------------|--------------------------|
| CS80B20     | 550               | 81                   | 0.97                     |
| CS70B30     | 627               | 135                  | 0.59                     |
| CS60B40     | 687               | 207                  | 0.41                     |

Temperature of flame recorded during combustion test is plotted in Figure 2. Temperature was recorded starting from the first time combustion takes place until flame is off. These curves indicate a significant effect of binder on the combustion characteristic of densified-biochar. At any tests, maximum temperature recorded is in between 450 to 488°C and ignition temperature is 273°C. This data is comparable to combustion test results of briquettes reported in the literature [7][8] where flame duration is ranging from 80 to 200 min depending on the type of raw material.

Figure 3 illustrates DSC thermograms of three densified biochar samples burning under air at heating rate of 20 ml/min. The earlier peaks are associated with degradation of thermally unstable organic constituents below 200°C. Dehydration process formed an endothermic region on DSC curve until around 150°C, and beyond this temperature positive heat flows that indicate exothermic processes took place. This is in a good agreement with those reported in the literature [9]. The highest heat flows and their temperatures were 18.34 mW and 474°C obtained from CS80B20 sample. This suggests that the burning characteristic of carbonized coffee-pulp briquette is affected by amount of starch added during densification process.
4. Conclusion
Gayo Arabica coffee-pulp has been carbonized under slow-pyrolysis process and used as raw material for bio-briquettes. Varying amount of starch-binder results in a slight change in calorific value of the coffee-pulp briquette where the maximum value is 19523 J/g. Increasing the amount of binder slows-down the rate of combustion and prolongs the flame duration. However, no significant change was observed on the temperature of combustion upon increasing the binder content.

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