The effects of temperature, residence time and particle size on a charcoal produced from coconut shell

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Abstract. Coconut shell charcoal is an important product obtained from coconut shells, which are widely used as domestic and industrial fuel. Wastes of coconut residues (shells, husks and coir) from processing of coconut milk and oil industries are widely generated everywhere all over the world. They have the potential of use as a fuel in renewable energy for different applications. In this study, the production of charcoal from coconut shell through the process of pyrolysis was conducted to determine the influence of particle size, temperature and residence time on the charcoal weight loss. Pyrolysis is a thermochemical conversion method which converts biomass into more valuable products in form of solid (charcoal, bio-char and activated carbon), liquid (oil) and gas in the absence of oxygen. The process was carried out under various process conditions of temperature (300 °C, 400 °C, and 500 °C), residence time (15 minutes, 30 minutes, and 60 minutes), and particle size (5.0 mm and 25.0 mm). It was found that for both the temperature and the residence time, the weight loss from the coconut shell increase linearly with increase in temperature and residence time. The particle size has influence in percentage weight loss. The resulting charcoal obtained can be utilized as an alternative energy resource for different applications.

1. Introduction

Presently fossil fuels are sources of conventional energy and energy demand is increasing due to ever increasing population [1]. Current fossil fuels reserves are insufficient to overcome the increasing demands of energy. It is predicted that energy sources will be scared in near future if their use continues at the same pace. Therefore, renewable energy sources such as biomass, wind, solar, and hydro are appeared as alternative source to fulfill the increasing demands of energy and cut greenhouse gases discharge into environment [2, 3].

Biomass is a clean and renewable energy source that available in abundantly in nature from a variety of sources. It has the advantage of being nearly carbon neutral and the potential to replace conventional fossil fuels in the energy marketplace [4]. The use of biomass is increasing in developing countries because most of their economies largely depend on agriculture. Agricultural residues are the most potential and common biomass worldwide considering their abundant availability, but they are not fully utilized in harnessing energy. There are several barriers to be overcome for technological advancement and commercialization to progress. One of such is the conversion of high-quality fuel from biomass through thermal conversion like carbonization for energy utilization. In carbonization of biomass, charcoal is the main solid product generated from slow pyrolysis. It is a process where...
biomass is heated to obtain solid residues with increasing element content of carbon by pyrolysis in the absence or controlled presence of oxygen. The properties of charcoal are controlled by the type of raw material used and the manufacturing process [5, 6]. Pyrolysis is a thermochemical conversion process which converts biomass into more valuable products such as charcoal, bio-char, activated carbon (solid), oil (liquid), and gases in the absence of oxygen [7, 8].

Charcoal, a valuable product of biomass is an energy dense fuel which has a wide market acceptance and that can easily be transported. It has been employed in domestic roles for many years, in the manufacture of several industrial chemicals like carbon tetrachloride, sodium cyanide, and carbon disulfide, as an activated carbon and other high carbon products like carbon electrode [9]. Charcoal acts as a major player in the global carbon market as a result of rich, clean, and simple production technology which offers significant advantages over raw biomass fuels because the process of carbonization reduces the particulate emissions, and reduces the risk of developing health and environmental hazards [10-12]. The major charcoal production is the conventional method where the biomass is allowed to be heated for several days. There are many methods of charcoal production, but the charcoal piles, earth kilns/pit kilns, and pit methods are the most widely used methods of charcoal production. In the traditional kilns, there are large heat losses during long period of operation and it does not have good insulation. To sustain the pyrolysis process, a major fraction of biomass is used as fuel for burning. Depending on the type of raw material and the conditions produced, commercial charcoal contains almost 75% of carbon, 20% of volatile, and 5% of ash [12].

Again, the operating conditions in making charcoal are not well recognized in the production processes because charcoal making is a traditional industry across the world. The methods are inefficient due to long process time, poor process control, low char yield, energy loss and environmental pollution problems due to the release of gases into the atmosphere [12]. Whereas, in emerging technology of thermochemical conversion method of pyrolysis, the process parameters like residence time, heating rate, and temperature are controlled sophisticatedly.

Coconut (Cocos nucifera L.) is an important and useful perennial product from agriculture, which is grown throughout the year when compared with other fruits [13]. Among ninety-two countries worldwide produce almost ten million hectares of coconut product where the world's largest coconut producer (Indonesia) account for almost 75% of the production, followed by Philippines, and India [14]. Coconut biomass is generated as a waste from the processing of coconut in the coconut milk, and coconut oil industry everywhere in the world. These wastes are in the form of shells, husks, and coir which have the potential to utilize as a fuel in renewable energy for different applications. The shell of coconut is gotten from coconut milk, water, and oil processing industries as a by-product. It is produced in abundance everywhere as a biomass waste throughout the tropical countries worldwide [15]. As a result of coconut economic importance and potentials like in the health benefits, its demand increases, this leads to the growth of coconut oils and milk market. Coconut shells are attractive biomass fuel and are also a good source of charcoal production that can be utilized and serve as a potential source of carbon [14]. Thus, its utilization has always been a major challenge for scientific applications. The coconut shells generated from oil and the milk industry poses a risk to health as well as environmental issues if left discarded without proper utilization. Handling the waste of coconut shells is quite complicated. Incineration may lead to various environmental and health-related problems because it is flammable and has a strong odor. These coconut shells can be better utilized to convert into charcoal as a fuel for different applications. The aim of this study is to investigate the effect of different parameters on charcoal production using coconut shells as a potential feedstock for various applications prior it use for commercial application.

2. Materials and method

2.1. Materials and sample preparation
The feedstock used in this study was coconut shells and the tools include: Machete, oven, granulator, sieve, porcelain dish and pyrolysis reactor. The coconut shells were chosen for current study, mainly
because of its abundance availability, suitability for thermochemical processes, and ease of operation, low initial moisture content, less feedstock preparation effort, high density, and energy content. Coconut shells were obtained from a coconut seller in a grocery store nearby the Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia. The outer fibrous portion of the coconut shell was removed with a machete. The moisture content of the coconut shells, which is the key factor for thermal conversion, was determined according to the procedure given by ASTM E871-82 standard procedure [16]. The sample was dried in an oven at 105 °C for 24 hours in order to determine the initial moisture content of the feedstock. The sample was crushed using Granululator and sieved to a particle size of 25.0 mm and 5.0 mm by using a sieve. Figure 1 (a) and (b) show the sample of the coconut shells before the pyrolysis process.

**Figure 1.** Prepared coconut shells (a) 25.0 mm and (b) 5.0 mm particle size.

The study was conducted at biomass research laboratory, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia. The process was carried out under various process conditions as shown in table 1. These values were chosen as they were within the range of pyrolysis process (carbonization) as suggested by Prabir, [7]. The feedstock (coconut shells) was weigh to 100 g for each experiment and sample was heated gradually at different specific temperature and residence time in a pyrolysis reactor (figure 2).

| Parameter                  | Process conditions |
|----------------------------|--------------------|
| Temperature (°C)           | 300                |
|                            | 400                |
|                            | 500                |
| Residence time (minutes)   | 15                 |
|                            | 30                 |
|                            | 60                 |
| Particle size (mm)         | 5                  |
|                            | 25                 |

2.2. Experimental setup
The experiment was carried out using an electrical-powered downdraft pyrolysis reactor (figure 2). A nitrogen gas was connected with a rotameter to the reactor. The condensable and non-condensable gases pass through a 0 °C salty ice cooling system. The non-condensable gases further pass through gas cleaning system and the gas compositions were analysed via Emerson X-stream X2GP Online Gas Analyser, which records the concentrations of the major syngas components (CO, CO₂, CH₄ and H₂) in
a computer. At the end of the process, the reactor was switched off and allowed to cool to collect the produced charcoal.

![Experimental setup](image)

**Figure 2.** Experimental setup.

As the feedstock (100 g) was loaded to the pyrolysis reactor, the temperature was raised from 100 °C to desired temperature and residence time. Nitrogen gas (flow rate of 20 mL/minute) was used to obtain the inert condition and sweep away the volatile vapors. While the breakdown of the coconut shells structure continues at a specific temperature, the vapor gives off as condensable vapors and the non-condensable gases, which include carbon monoxide, hydrogen, methane, and carbon dioxide gas. The heating process was stopped at the desired temperature and residence time. The charcoal was collected at and placed in a desiccator to avoid moisture gain or loss. The gas was condensed by a condenser with an ice cooling system to collect the liquid that contain bio-oil and water bio-oil. The results were saved and the process was proceeds to the next step.

### 3. Results and discussion

This section reports the results and discussion of the analysis carried out. The pyrolysis of coconut shells were carried out as per standard test procedure. Temperature of 400°C was chosen to study the effect of pyrolysis parameter on the charcoal weight loss because it was the optimum and relatively highest temperature of pyrolysis for the production of charcoal as described by Basu [7].

#### 3.1. Effect of residence time on the charcoal weight loss

Figure 3 shows the effect of residence time on percentage of weight loss of coconut shells charcoal at a constant temperature of 400 °C. It shows the higher the residence time of the pyrolysis process the higher the weight loss from the coconut shells. Figure 4(a), shows that feedstock partially pyrolyzed, and weight reduction was 48.88%. Some of the feedstock has not undergone complete process due to the short residence time, which was 15 minutes. Eventually increasing the residence time from 35 to 45 minutes as shown by figure 4(b) and figure 4(c), respectively, it slightly changes the weight loss of the coconut shells charcoal from 65.15% to 65.3%. This could be due to nearly completion of carbonization stage. Residence time of the product in the reactor is an important factor [7]. Duration of
carbonization process has a significant effect on the development of the carbon’s porous networks. The time should be sufficient to eliminate all the moisture and most of the volatile components in order to allow the formation of pores[17].

Figure 3. Effect of residence time on the weight loss at 400 °C pyrolysis temperature.

Figure 4. Coconut shells charcoal at 400 °C pyrolysis temperature at (a) 15 minutes residence time, (b) 30 minutes residence time, and (c) 45 minutes residence time.

3.2. Effect of temperature on the charcoal weight loss
Figure 5 shows the effect of temperature on percentage of weight loss of coconut shells charcoal at a constant residence time of 30 minutes. At 300 °C as shown in figure 6(a), the percentage of the weight loss is lower when compared to 400 °C in figure 6(b) and 500 °C in figure 6(c). This could be as a result of the temperature difference. This shows the process has not completed at low temperature. When the reactor temperature was 400 °C and 500 °C, the percentage weight loss indicates an increase of weight loss from 63.9% to 71.33%. This indicates that the carbonization has nearly reached the maximum pyrolysis temperature. Reaction temperature plays an important role in slow pyrolysis thermal decomposition process. It is necessary to bring the biomass particles to an optimum temperature and minimize their exposure to higher temperatures that favor other product. Feedstock
particle is heated at a definite rate from ambient to a maximum pyrolysis temperature. The feedstock is held in the reactor until the operation is over. The pyrolysis temperature affects both composition and yield of the product [7, 18].

Figure 5. Effect of temperature on the weight loss at 30 minutes residence time and 25 mm particle size.

Figure 6. Coconut shells charcoal at (a) 300 °C, (b) 400 °C, and (c) 500 °C pyrolysis temperature with 30 minutes residence time and 25 mm particle size.

3.3. Effect of particle size on the charcoal weight loss
The effect of particle size on the charcoal weight loss can be seen clearly from figures 3 and 5. It shows that the weight loss from figure 3 is higher than that of figure 5 at the same temperature and residence time which are 65.15% and 63.9%, respectively. This shows that the heat transfer in smaller particles is uniform. Particle size greatly affects the heating rate of solid fuel. It is an important parameter which controls the rates of drying and primary pyrolysis process during biomass decomposition. The composition, size, shape, and physical structure of the biomass affect the heating rate of pyrolysis product. Fine particles have a uniform heating rate due to negligible extra particle and intra particle heat transfer resistance, this causes the drying and primary pyrolysis occur more or less uniformly throughout the particles. As a result, it enables the primary volatiles and moisture leave the
particle with minor interaction between each other and limits the extent of the secondary reactions inside the particle [7, 19].

4. Conclusion
This study sets out to determine the effect of pyrolysis process conditions (temperature, residence time, and particle size) on the charcoal weight loss. It can be concluded that, higher the residence time and the temperature of the pyrolysis process, the higher the weight loss from the coconut shells. The particle size has influence also on the percentage weight loss based on this study. The results obtained can highlight the use of optimum conditions for charcoal production in terms of its production behaviour and the process efficiencies by knowing how it interacts at various operating conditions. This is important in designing a reactor system for its production. This process can greatly reduce the issue of waste disposal and emission of greenhouse gases, thereby reducing the environmental health issues as the coconut shells cannot be disposed rather it can be pyrolyzed.

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