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Characterization of carbon materials and differences from activated carbon particle (ACP) and coal briquettes product (CBP) derived from coconut shell via rotary kiln

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ABSTRACT

Biomass carbon production is currently a large industrial source of energy conversion. This study describes the conversion process of coconut shells, using a rotary kiln, into activated carbon particles (ACP) and coal briquettes product (CBP). The ACP and CBP samples were analyzed and characterized through x-ray fluorecence (XR-F), heating value (HV), pore size distribution, and scanning electron microscopy (SEM). The results showed high thermal values in the reactor core at a controlled temperature of between 0 and 800 °C within 25 min per round. The characteristics of ACP and CBP derived from coconut shells revealed high potential of necessary composition by XR-F. The analysis of ACP and CBP showed that the resulting product could be a potential source of renewable solid fuel with a heating value of 33.45 and 27.45 MJ kg^{-1}, respectively. The pore size distribution of ACP and CBP showed that the cumulative pore volume of ACP was higher than CBP. SEM patterns revealed amorphous nature of the carbons feature in ACP including stacked features in CBP and the existence of carbon-rich large molecules. These analyses of contents of the resultant ACP and CBP indicated that there is a high possibility of this product being viable power sources.

1. Introduction and overview

1.1. Biomass and bioenergy in Thailand

Thailand is an agricultural country. After the harvest, there will be a significant amount of agricultural waste or residue left, which could be used as biomass energy. Biomass is produced from this industrial-agricultural waste, such as rice husk, bagasse fiber, coconut shell and palm shell. Thus, agricultural residues is an attractive feedstock for producing biomass energy in the form of solid and liquid fuel. One such method holding the greatest promise for industrial application is pyroprocess, which can be used for the efficient conversion of biomass into fuels suitable both for internal combustion engines and heat generation. Usually, industrial sectors use fossil fuels, including crude oil, diesel, liquid gas, and coal because of their high heating value, convenient utilization and transportation, and low cost. For the last decade, the price of petroleum has fluctuated in accordance to demands in the global market. As a result, the industrial sector has turned to biomass fuel to replace petroleum in order to reduce production costs and to eliminate waste [1]. Currently, industrial plants and power plants have increased their demand for biomass and as a result, prices have increased dramatically, while biomass fuel shortages are becoming more common in many areas. Therefore, factories and power plants using biomass have to stop operation due to lack of sufficient biomass fuel.

1.2. Rotary kiln

The rotary kiln is a pyroprocessing device used to raise the raw materials (biomass, or in this case, coconut shells) to a high temperature. The kiln is a cylindrical vessel, inclined slightly on a horizontal axis, which is rotated slowly around its axis. The key component of the

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system, the rotary kiln, is a refractory-lined cylinder that rotates at a horizontal angle of 5–10 degrees or less and at a speed of 1–5 rotation per minute (rpm) [2]. Operators may also use auxiliary heating systems to heat the kiln to the desired temperature. Coconut shells to be processed are fed into the upper end of the cylinder. As the kiln rotates, the material gradually moves down to the lower end, and may undergo a certain amount of stirring and mixing. Hot gases pass along the kiln.

The kiln is a rotating cylinder with an average inner diameter of 1 m and a total length of 10 m. Under standard process conditions, the heat input by the fuel is in the range of 30 and 40 MW. The heat transfer process inside the kiln is complex. Heat radiation between flame, particles, inner kiln surface and predominating heat transfer type constitutes over 90% of the total heat transferred to the biomass [2,3]. The length of the flame determines the radiated heat transfer distribution over the kiln length. To avoid temperature peaks inside the kiln, and hence a highly uneven axial temperature profile, a long flame is desired [4–6]. In addition to the heat radiation, heat is transferred via convective heat transfer between the flue gases, biomass and inner kiln surface [5–9].

1.3. Coconut shell

The coconut tree belongs to the Palmae Family is scientifically known as *Cocos nucifera* L. [10] , and is a source the multipurpose product known as the coconut. The tree is originally from Southeast Asia, whence it spread to South America, Africa and the rest of the Asian mainland. Coconut trees flourish in tropical and rainforest climate, especially along the coastlines where it enjoys plentiful sunlight, as well as water and high humidity [11]. In addition to the edible insides, coconut shells are known to be valuable raw materials for the production of activated carbon, a vital material that provides high surface area (1,000 m^2/g) [12] for adsorption/absorption of different gases, liquids, emulsions and fine suspensions. A comparison of the properties of various residual plant in Thailand including coconut shell from proximate analysis is presented in Table 1. Table 1 also shows heating value of biomasses in Thailand. Table 2 shows the ultimate analysis of biomasses in Thailand [13].

1.4. Activated carbon

Generally, activated carbon is prepared by carbonizing and activating organic substances. Raw materials, such as, coconut shells, peat, lignite, coal, cellulose residues, and petroleum coke may be carbonized and activated at high temperature with or without the addition of inorganic salts in a stream of activating gases, such as steam or carbon dioxide. Activated carbon usually increases the cost of the treatment process. This drawback has stimulated interest in finding more cost-effective raw materials for the production of activated carbon [14,15]. Consequently, a wide variety of agricultural by-products and wastes have been investigated as cellulosic precursors for the production of activated carbon in addition to hard wood and bituminous coal. These precursors include: coconut shell and various types of wood [16,17]. Coal is also a readily available and a reasonably cheap raw material. The quality of activated carbon obtained depends on the type of coal used and its initial processing prior to carbonization and activation. It is a normal procedure to grind the coal and reconstitute it into a form suitable for processing [18]. An alternative method is to grind the coal and utilize its volatile content to fuse the powder together in the form of a briquette.

Activated carbon manufacture is generally considered a three-stage process consisting of pre-activation, activation and post-activation [19]:

- Pre-activation is concerned with quality checking and correct sizing and screening of material prior to activation [20]. At this point, the material can be called kiln-feed.
- Activation is the process by which charcoal raw material kiln-feed is turned into activated carbon. This process subjects the kiln-feed, in this case coconut shells, to high temperatures and steam within specially designed activation kilns.
- Finally, post-activation consists of quality checking the parameters of kiln output material.

1.5. Coal briquette

The coal briquette is a type of solid fuel prepared by compacting pulverized coal, biomass, binder (tapioca flour), and sulphur fixation agent [21]. The high pressure involved in the process ensures that the coal and the biomass particles are sandwiched and adhere together to ensure that there is no separation during transportation, storage and combustion. During combustion, the cocombustion of the coal and the biomass gives a better combustion performance and reduces pollutant emission i.e. bio-coal briquette has a favourable ignition, has better thermal efficiency, and emits less dust [22,23]. Since the biomass component of the briquette combusts at a lower temperature than the coal, this ensures that the volatile matter in the coal, which would otherwise be liberated as smoke a low combustion temperature, will combust completely.

The complete combustion of the volatiles reduces smoke and contributes to the total heat released by the fuel. An important area of application of biomass fuel in the form of briquettes is in heating applications such as cooking, boiling and air heating that heavily rely on the smokeless combustion of fossil fuels in urban areas and semi-urban areas of developing countries [24]. Thus biomass briquettes seem to be a sustainable renewable energy option for heating applications in developing countries where potential feedstocks are produced annually in abundance in the rural areas [25,26]. Most Korean and Japanese barbeque restaurants in Thailand use these briquettes due to the fact that it produces less smoke, gives high heat and ignite much longer than typical carbon. The 1st grade of briquette was produced in this research and certified by the laboratory of the Center of Fuels and Energy from Biomass, Chulalongkorn University.

Table 1
Proximate analysis and heating value of biomasses in Thailand [1,7].

Proximate analysis and Heating value	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Higher Heating Value (KJ/kg)	Lower Heating Value (KJ/kg)
Rice Husk	12.00	12.65	56.46	18.88	14.75	13.51
Rice Straw	10.00	10.39	60.70	18.90	13.65	12.33
Bagasse	50.73	1.43	41.98	5.86	9.24	7.37
Cane Trash	9.20	6.10	67.80	16.90	16.79	15.47
Palm Fiber	38.50	4.42	42.68	14.39	13.13	11.40
Corncob	40.00	0.90	45.42	13.68	11.29	9.62
Tapioca Rhizome	59.40	1.50	31.00	8.10	7.45	5.49
Eucalyptus Bark	60.00	2.44	28.00	9.56	6.81	4.91
Coconut Shell	12.56	5.85	62.96	18.63	16.87	10.08