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Upgrading and dewatering of raw tropical peat by hydrothermal treatment

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ABSTRACT

In this study, hydrothermal upgrading and dewatering of raw tropical peat derived from Pontianak, West Kalimantan-Indonesia was evaluated at temperatures ranging from 150 to 380 °C, a maximum final pressure of 25.1 MPa and a residence time of 30 min. The moisture content of the raw peat was approximately 90 wt.%. Raw peat was hydrothermally upgraded without the addition of water in the laboratory scale. The yield of the solid products was between 53.0 and 99.7 wt.% and the effective calorific value of hydrothermally dewatered peat was between 17,290 and 29,209 kJ/kg following hydrothermal upgrading. In addition, the oxygen content in the solid product was varied from 38.4 to 15.6 wt.% after upgrading, while the carbon content from 55.2 to 77.8 wt.%. The hydrothermally upgraded peat fuel product also had an equilibrium moisture content of 2.3 wt.% and a maximum equilibrium moisture content of 17.6 wt.%. Upgraded peat is characteristically resistant to moisture adsorption at high humidity, which makes it promising for fuel based combustion. The change in the carbon-functional groups and their properties, as determined by FTIR and ^{13}C NMR, are discussed in terms of the hydrothermal upgrading and dewatering process.

1. Introduction

Recent increases in CO_2 emission due to the burning of fossil fuels and peat fires coupled with increases in energy costs have led to revived interest in the upgrading and conversion of several solid fuel resources. CO_2 emissions from peatland fires have been a major atmospheric pollutant in Indonesia. Anthropogenic activity is the primary reason for the injudicious utilization of Indonesian peat resources. Page et al. [1] estimated that between 0.81 and 2.57 Gt of carbon were released into the atmosphere in 1997 as the result of burning peat and vegetation in Indonesia. This value is equivalent to 13–40% of the mean annual global carbon emission from the burning of fossil fuels, and has contributed greatly to the largest annual increase in atmospheric CO_2 concentration detected since recording began in 1957 [1]. From 1997 to 2006, CO_2 emissions from peatland fires in Indonesia were several times greater than those resulting from peat decomposition in drained peatland areas, ranging from 1400 Mt/y to as much as 4300 Mt/y. If emissions from peatland drainage and degradation (including fires) are included, Indonesia is rated third in global CO_2 emissions, behind the USA and China. Without peatland emissions, Indonesia is rated 21st on this scale [2].

Indonesian peatlands and peat swamp forests cover 165,000–270,000 km^2 and contain carbon resources of approximately 46 Gt [3,4]. However, the effective utilization and conversion of raw tropical peat is an almost unexplored subject in Indonesia. The utilization of peat for energy as an immature fuel entails several problems, including the very high moisture content in natural peat deposits (80–90%) and the high oxygen content of the organic material (30–40%). These properties occur due to the colloidal bond between peat and water that exists under natural conditions and result in the formation of a pasty material [5,6]. These properties are also related to the rheology of peat itself, as well as its colloid chemistry properties [7,8]. Dewatering, drying, upgrading and/or compaction of this fuel resource are needed before it can be utilized on an economically feasible scale. Generally, the combustion of peat fuel requires the total moisture content of feed peat to be 40–50% [6]. During the gasification process, the maximum required moisture content of feed peat is approximately 40% [6]. Other liquefaction processes of peat require the moisture content of the feed peat to be around 35% [6]. Natural air drying, wet carbonization, compaction and mechanical dewatering have been studied as methods of reducing the moisture content of peat for several decades. However, reduction of the moisture content in peat currently requires large amounts of energy.

One common approach to the upgrading of tropical peat is dewatering and conversion by hydrothermal treatment. In this method, raw peat is directly transformed without pretreatment or drying, which leads to greatly reduced costs. However, few

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studies have been conducted to evaluate the hydrothermal treatment of raw tropical peat. Despite this lack of study, experiments imitating coalification by subjecting materials to heating with high pressure water were reported first by Bergius in 1913, who termed the method hydrothermal carbonization. This treatment method produces a black product and defined the type of reaction to be valid only up to a certain degree of coalification [9] and followed by others [10–13]. Recently, the production of oil by hydrothermal treatment of coal and biomass materials has generated a great deal of interest [14–18]. In the case of tropical peat and in particular, weakly, medium and highly decomposed peat, any process employing water as the medium would be very advantageous. Therefore, the present study was conducted to improve dewaterability during the upgrade of raw tropical peat. In addition, changes in the carbon-functional group of promising peat fuel products produced by hydrothermal treatment were evaluated.

2. Experimental

2.1. Materials

Raw tropical peat samples were obtained from open-drained, slashed and burned peatland areas in Mempawah City, which is 67 km north of Pontianak, West Kalimantan, Indonesia. The site is located in an equatorial secondary peat swamp forest that already contained an open and systematic drainage system. The peat in the study area is approximately 7–9 m thick and the water level is ⩽60 cm. The typical properties of raw tropical peat from the study site are shown in Table 1.

2.2. Apparatus and experimental procedure

The experiments were conducted in a 0.5 L batch-type reactor (Taiatsu Techno MA22) that was equipped with an automatic temperature controller and had a maximum pressure of 30 MPa and a maximum temperature of 400 °C (Fig. 1). The raw peat samples were introduced to the reactor without any pretreatment except milling. The amount of the raw peat added to the reactor was 300 g, corresponding to 40 g of moisture-free peat. The reactor was then pressurized with N_2 to 2.0 MPa at ambient temperature. Next, the raw peat was heated with agitation at 200 rpm while the reaction temperature was automatically adjusted from 150 to 380 °C at an average heating rate of 6.6 °C/min. Under supercritical conditions (380 °C), the charge was 230 g and the initial pressure was 0.1 MPa. After the desired reaction time of 30 min, the reactor was cooled immediately.

After cooling down, the gas products were released through a gasometer (Shinagawa DC-1) and the volume was determined by collection into a gas micro syringe (ITO MS-GANX00). The evolved gas composition was then determined by gas chromatography (GC) using a GC equipped with a thermal conductivity detector (Shimadzu GC-4C). The results of GC analysis are discussed elsewhere. The solid and liquid phases were then collected from the reactor and separated by filtration (ADVANTEC 5C) using a water aspirator. The total moisture content of the filtered solid products was then determined using a moisture content analyzer (Sartorius MA 150).

2.3. Analysis

The elemental composition of the raw peat and solid product was determined using an elemental analyzer (Yanaco CHN Corder MT-5 and MT-6). Additionally, proximate analysis (based on JIS M 8812), total sulfur analysis (based on JIS M 8819) and calorific analysis (based on JIS M 8814) were conducted separately. The gross calorific value (CV) measured using the bomb calorimetric method and the effective calorific value (ECV) of the sample at constant pressure were based on JIS M 8814, which is followed by ISO 1928. The equilibrium moisture content of the dried solid product was further analyzed while keeping their moisture contents constant according to JIS M 8811. Briefly, an aliquot of the sample was placed inside a desiccator containing saturated salt solution and measured rapidly using a moisture content analyzer (Sartorius MA 150). The primary components and the chemical structure of the raw peat and the solid product were further analyzed by Fourier transform infrared spectroscopy (FTIR) (JASCO 670 Plus) using the Diffuse Reflectance Infrared Fourier Transform Spectroscopy (DRIFTS) technique and the JASCO IR Mentor Pro 6.5 software for spectral analysis. The cross polarization/magic angle spinning (CP/MAS) ^{13}C NMR spectrum of raw peat and the solid product was measured using a solid state spectrometer (JEOL CMX-300). The measurement conditions were as follows: spinning speed in excess of 12 kHz, contact time of 2 ms, pulse repetition time of 7 s and scan number of 10,000. Chemical shifts are in ppm referenced to hexamethylbenzene. The curve fitting analysis of the spectrum was conducted using the Grams/AI 32 Ver. 8.0 software (Galactic Industries Corp., USA).

Table 1
Proximate and ultimate analysis, yield of solid products and calorific value of Pontianak tropical peat and hydrothermally upgraded peat.

Properties	Raw	Treated temperatures (°C)							
		150 °C	200 °C	250 °C	270 °C	300 °C	330 °C	350 °C	380 °C
Proximate analysis (wt.%)									
Moisture (a.r)	86.8	–	–	–	–	–	–	–	–
Equilibrium moisture (X) (a.r)	27.3	17.6	11.6	7.8	5.7	5.4	3.9	3.8	2.3
Volatile matter (d.a.f)	62.4	58.5	56.7	51.0	48.5	44.9	41.4	38.5	34.1
Fixed carbon (d.a.f)	37.6	41.5	43.3	49.0	51.5	55.1	58.6	61.5	65.9
Ash (d.b)	0.4	0.6	0.6	0.5	0.4	0.5	0.4	0.5	0.5
Ultimate analysis (wt.%) (d.a.f)									
C	55.2	57.8	59.8	64.8	67.7	70.4	72.8	74.6	77.8
H	5.0	4.8	4.8	4.7	4.7	4.7	4.7	4.6	4.6
N	1.3	1.2	1.3	1.4	1.6	1.7	1.8	1.8	1.9
O (diff.)	38.4	36.1	34.0	28.9	25.8	23.1	20.7	19.0	15.6
S	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Yield of solid products (Y) (wt.%) (d.b)	–	99.7	94.4	93.8	71.1	65.2	59.2	58.1	53.0
Calorific value (CV) (kJ kg^{-1}) (d.b)	22,037	22,556	23,474	25,587	26,720	27,711	28,877	29,753	30,953
Effective calorific value (ECV) (kJ kg^{-1})[a]	14,561	17,290	19,544	22,465	24,102	25,126	26,706	27,569	29,209
Total calorific value (TCV) (kJ)[b]	14,561	15,211	15,179	16,618	13,210	12,575	11,944	12,098	11,531

d.b = dry basis; a.r = as received basis; d.a.f = dry ash free basis; diff. = differences.

[a] ECV = $[CV - (212.2 \times H_{(d.b)}) - 0.8 \times (O_{(d.b)} + N_{(d.b)})] \times (1 - 0.01X) - 24.43X$.

[b] TCV = ECV $\times$ 0.727 $(Y/100)/[1 - (X/100)]$.