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Physical and Chemical Properties of Water Hyacinth (*Eichhornia crassipes*) as a Sustainable Biofuel Feedstock

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Abstract. Physical and chemical characterizations of water hyacinth (*Eichhornia crassipes*) plants as an alternative energy source have been conducted. The samples were originated from Sengguruh, Kepanjen, and Selorejo Dams, Ngantang, district of Malang, East Java, Indonesia. The Scanning Electron Microscopy-Energy Dispersive X-ray (SEM-EDX) test was performed for the chemical element content analysis of water hyacinth biomass and the proximate test was performed for physical characteristics investigation. The results indicated that chemical elements of water hyacinth are C, O, Na, Mg, Al, Zr, Cl, K, Ca, Si, Ti, and Fe revealing dominant elements, i.e., oxygen and carbon for 49.50% and 14.46%, respectively. The proximate analysis revealed that its moisture, volatile matter, fixed carbon, and ash content were 4.9, 61.2, 13.8, 20.1 (wt.%), respectively. This biomass has gross calorific value (GCV) that tested with an adiabatic bomb calorimeter of 14.46 MJ/kg. Since the water hyacinth biomass has a relatively high volatile content and a low heating value, it is reasonable that water hyacinth might suitably for co-combustion with coal to increase the coal's reactivity during the combustion process.

Keywords: water hyacinth, chemical properties, physical properties, biofuel, alternative energy

1. Introduction

The energy demand in Indonesia is estimated to increase by 7.2% per year within the period 2011-2030 [1]. The supply of fossil energy sources has been taking the majority part fulfilling such demand. Referring the ratio of the availability of fossil energy reserves to the elevating energy demand, it is estimated that coal, natural gas, and petroleum will be exhausted within 70, 37, and 12 years, respectively [2]. Thus, alternative energy sources are needed for the substitution or replacement of the fossil-based energy [3]. One of the alternative sources that abundant and environmentally friendly is the biomass-derived source of energy [4,5]. Water hyacinth (WH), the aquatic biomass with its expansive growth and therefore as a troublesome weed in the environment of Indonesian waters, is critical to be studied for its possibility as an alternative energy source.

WH has attracted global attention for its uncontrolled behavior and rapid spread which causes a disturbance in navigation, irrigation, and power generation [6]. In Indonesia, WH proliferates in swamps, reservoirs, lakes, and rivers. In Rawa Pening lake, 1900 ha of its total area of 2700 ha is covered with WH. 10000 ha out of 13000 ha of Tempe lake filled with WH [7]. WH also covers 26% (12 km^2)

of Kerinci lake surface [8]. 100 ha of the total of 650 ha of Selorejo Dam are clogged with spreading WH. As a result, boat transportation is disrupted, and farmers suffer losses due to their crop failure since the pests of rats hiding in WH are hard to eradicate. In addition, the surrounding people who rely on their living from fishing in the Dam are also disturbed [9]. Furthermore, in the Citarum river, the growth of WH interferes with water transport and causes the extinction of some species of fish [10]. Though the fast and invasive growth of WH is an ominous threat, it promises great potential for energy sources. Therefore, evaluating the prospects of WH as a raw material for fuel is critical to address both the problem of a WH's excessive amount and the exploring alternative renewable energy sources.

The utilization of WH as a fuel should be based on a vivid understanding of its properties: physical properties (e.g., moisture content, volatile, fixed carbon, and ash) and chemical properties. Both properties are often referred as physicochemical properties. Physicochemical properties are essential parameters for solid fuel raw materials [11] as they affect their characteristics during the thermal conversion process, either pyrolysis or combustion.

Physicochemical properties are the primary reference for proper furnace design for efficient combustion processes. The previous study revealed that WH has moisture, volatile matter, fixed carbon and ash content of 9.95, 56.30, 17.40, and 16.35 (wt%), respectively [12]. Water content is an essential physical property that affects combustion characteristics; because it requires a certain amount of energy to release before the combustion process can occur. As a consequence, the temperature in the combustion chamber will decrease and affect the overall efficiency [13]. Hence, this parameter must be known entirely as a basis for adjusting the appropriate temperature control system that ensuring the combustion process can smoothly continue in the combustion chamber. Volatile also affects the thermal characteristic of biomass fuels. The quantity of volatile release and its rate affect the temperature profile and its stability in the combustion chamber. Chemical contents of biomass are crucial parameters as well because they specify the quantity of energy contained in the fuel. In addition, the inorganic elements in the fuel affect the formation of slag deposits, ash, aerosols, and corrosion of boiler components [14]. Liu *et al.* [15] and Huang et al. [16] have presented the chemical composition of WH biomass, in which both kinds of literature showed the differences in the content of C, H, O, N and S. Since the biomass physicochemical properties were highly influenced by the environment where it grows, therefore, its physicochemical properties may be varied by different place and conditions. For the goal's of the effective thermal conversion process, these parameters should be known in detail, and therefore this research finds its place. This study examines thoroughly the potential of WH as a fuel which includes its chemical properties, physical properties (moisture content, volatile content, fixed carbon, ash), and calorific value.

2. Methods

2.1 Material
The WH utilized in this research was originated from the Sengguruh and Selorejo Dams, district of Malang, East Java, Indonesia. The sample is thoroughly cleaned, cut, and dried using an oven at 80-90°C for 6 hours. Eventually, the processes of pulverizing and filtering were applied to the dried WH to a mesh size of 60. It was then packed into an insulated bottle.

2.2 Chemical composition test
The WH biomass was tested using Energy-dispersive X-ray (EDX) spectrometry to specify the content of chemical elements. The scanning electron microscope (SEM) image was taken using FEI Inspect S50 equipment fitted out with the capability of X-ray microanalysis (AMETEK EDAX ^{TSL}). The sample was gold coated to decrease the influence of surface-electron-charging, which may distort the image.

2.3 Proximate and heating value test
The proximate analysis was performed according to ASTM D 3173-17, ASTM D 3175-17, ASTM D 3172-13, and ASTM D 3174-12, respectively to determine its content of moisture, volatile matter, fixed

carbon, and ash. Adiabatic bomb calorimeters were applied to determine the calorific value of biomass following the ASTM D 5865-13 standard. The 0.5 gram-sample were used for 10 minutes with 99.5% pure oxygen.

3. Results and Discussion

3.1 Chemical properties
The SEM and EDX spectrograms of WH are shown in Figure 1. Table 1 reveals the chemical element measurement mean score of WH with SEM-EDX test. Those chemical substances including carbon (C), oxygen (O), sodium (Na), magnesium (Mg), aluminum (Al), zirconium (Zr), chlorine (Cl), potassium (K), calcium (Ca), silicon (Si), titanium (Ti), and ferrum (Fe).

Table 1. The chemical composition of WH. Error represents the relative standard error of the mean score in 4 times measurement.

Chemical elements	Composition (wt%)
C	14.4± 6.81
O	49.5± 6.71
Na	0.58± 0.40
Mg	1.96± 1.04
Al	2.32± 1.71
Zr	2.24± 1.33
Cl	5.58± 1.94
K	8.26± 2.62
Ca	4.73± 0.63
Si	5.33± 4.52
Ti	0.27± 0.27
Fe	4.71± 4.32

The results of SEM-EDX indicated that carbon (C) and oxygen (O) dominate the chemical substances in WH. The carbon element (C) in WH contributes as generating calorific value while the oxygen (O) of its biomass supply a part of oxygen required for combustion, even though the more oxygen substance may decrease the higher heating value (HHV) [17]. The composition of C and O in WH is comparable with the *Isochrysis galbana* [5], which its elemental analysis was performed under the similar method.

Almost all of the chlorine (Cl) evaporated during combustion and accumulated into compounds; they were hydrochloride (HCl), chlorine (Cl_2), and alkaline chloride. The latter condensed and bound to fly ash particles when the temperature of flue gas decreases. The remaining untighten chlorin (Cl) which was not constrained into fly ash, bound with hydrogen (H) element form hydrochloride (HCl) compound and later will be discharged as exhaust gas [4].

Other chemical elements than C, O, and Cl in WH are the contributor in the formation of final combustion residue (ash). The elements which configure that residue are categorized into major (>1%) and minor (1-0.1%) ash-forming elements [5]. Major ash-forming elements in WH are Mg, Al, Zr, K, Ca, Si, and Fe, while minor ash-forming elements are Na and Ti. As listed in Table 1, standard error of mean for the Si, Ti, and Fe was too large because of the four measurements performed; not all measurements produce a score. Potassium (K) is the largest inorganic element in WH, i.e., 8.26 (wt%). It is biomass mainly existing in KCl formation. As the increasing temperature during the thermal process, most of the KCl evaporates into gas or turned into other compounds [18].

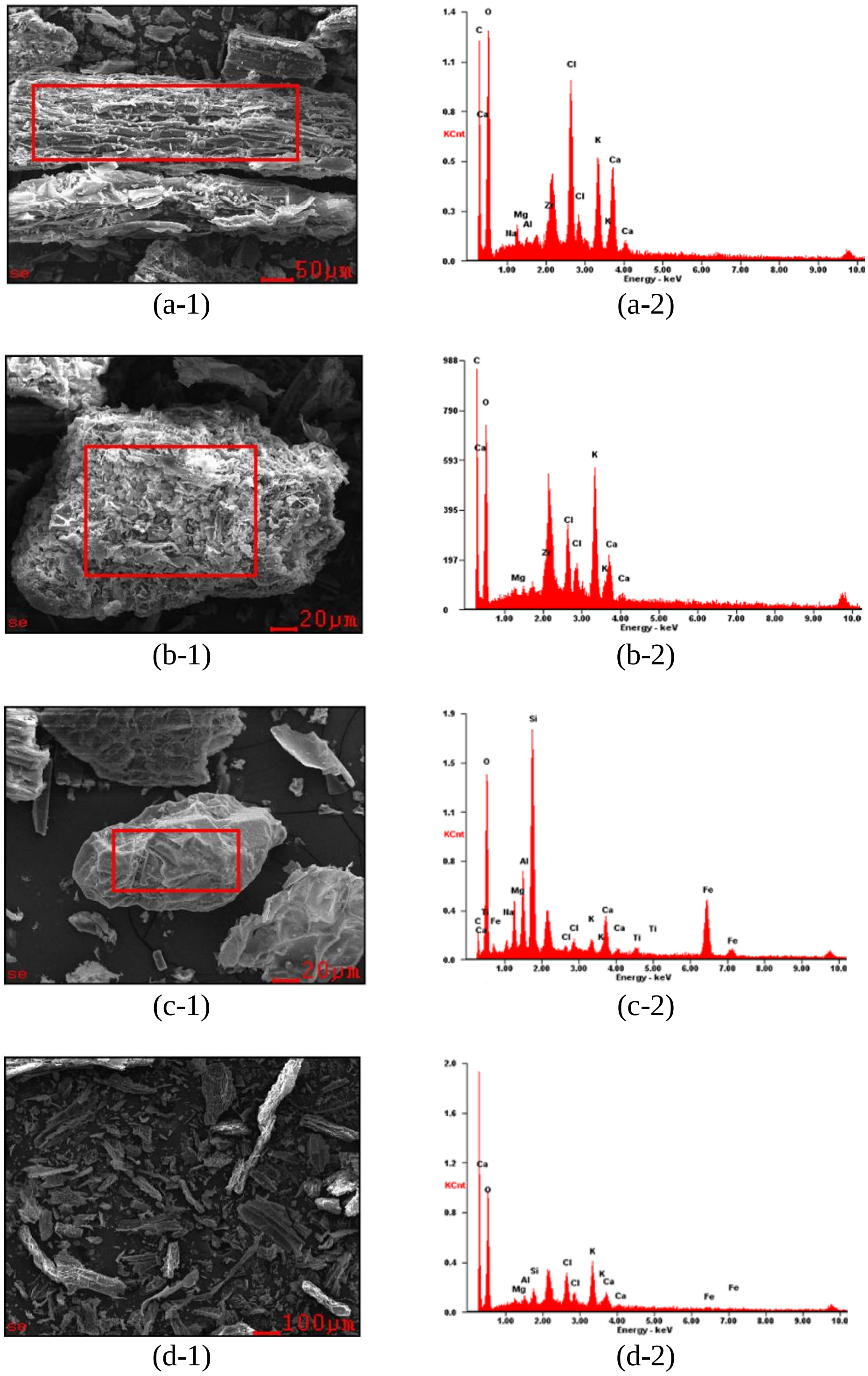

Figure 1. SEM photograph and EDX spectograms of WH on 4 obervatory locations: (a-1)-(d-1) are SEM photograph, while (a-2)-(d-2) are related EDX spectrograms.

3.2 Physical properties
Proximate results of WH biomass sample are shown in Table 2. Table 2 indicates that the content of *volatile matter* (VM) on WH is predominant with the value of 61.2 (wt%, AR). VM is the most flammable biomass component [19]. A low value of VM indicates that biomass is hard to burn or will affect into its low reactivity, and vice versa. Meaning that the higher the VM, the more susceptible the biomass to burn and the higher its reactivity. Therefore, the high VM content of WH infers that this biomass is reactive during the combustion process [4,5].

Table 2. The proximate test result of WH

Parameter	Unit	ar*	db**
Moisture	wt%	4.9	---
Volatile matter	wt%	61.2	64.4
Fixed carbon	wt%	13.8	14.5
Ash	wt%	20.1	21.1
GCV	kcal/kg	3455	3633

*ar: as received, **db: dry basis

Ash (A) becomes the second largest content with the value of 20.1 (wt%, AR). This high ash content is influenced by the inorganic elements which are non-flammable part of biomass [17,20]. These elements are derived from mineral fractions of biomass origin. The ash content of biomass fuel is tightly related to accuracy choice of combustion technology and gas cleaning method [21]. In the combustion system, the residual handling method and overall operating cost are strongly determined by the ash fuel content. Thus, fuel with the minuscule content of ash is highly desirable [5].

The highest third content of WH is fixed carbon (FC) with the value of 13.8 (wt%, AR). The ratio of VM/FC is the fundamental parameter to adjudging the biomass reactivity. The higher the ratio, the easier biomass was to be burnt, and vice versa. Biomass commonly has the ration of VM/FC >4.0 [22]. In this study, the ration of VM/FC of WH biomass is 4.4. Therefore, the combustion of WH will predominantly occur through the oxidation of gas phase from volatile species.

Lastly, WH has the moisture content of 4.9 (wt%). This value is relatively diminutive compared with its volatile content. It is considered as favorable since the smaller the water content, the smaller energy used for evaporation process during thermal conversion. Table 2 displays that the value of gross calorific value (GCV) of WH is 3.455 kcal/kg or 14.46 MJ/kg. This value is lower than the GCV of cotton residue [23], *Nannochloropsis oculata* [4] and *Isochrysis galbana* [5], but it is comparable with bagasse, paddy straw, and rice husk char [24].

4. Conclusion
The essential characteristics of WH as a future biofuel have been investigated. The analysis of its chemical element reveals that this biomass is predominantly with O element. The largest inorganic element is potassium that shall evaporate during the thermal process. The high volatile matter content of this biomass serves its potentially reactive during the combustion process. Therefore, WH may possibly become the coal mixture to increase coal's reactivity during the combustion process.

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