

Suitability of aquatic biomass from Lake Toba (North Sumatra, Indonesia) for energy generation by combustion process

A Brunerová^{1,*}, H Roubík², D Herák³

¹Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, CZ 165 00 Prague, Czech Republic

²Department of Sustainable Technologies, Faculty of Tropical Agri Sciences, Czech University of Life Sciences Prague, Czech Republic

³Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences Prague, Czech Republic

* brunerova@tf.czu.cz

Abstract. Several aquatic plant species were identified as aquatic pollution of Lake Toba, North Sumatra (Indonesia); specifically, water hyacinth *Eichhornia crassipes* and aquatic weeds *Hydrilla verticillata* and *Myriophyllum spicatum* due to their high biomass yield which causes impenetrable mats at the bottom and surface of the lake. That complicates other vegetation growth and utilization of water areas for fishing or recreation. In attempt to clean the lake and prevent plants expansion, great amount of plants populations are removed from water but subsequent efficient utilization of such aquatic biomass is not ensured. Present research investigated energy potential of aquatic biomass originated from mentioned aquatic plants from Lake Toba and its possible utilization for energy production by direct combustion. Performed chemical analysis contained from determination of moisture, ash and volatile matter contents and calorific values. Evaluation of results proved highest suitability and energy potential of *Eichhornia crassipes* with gross calorific value (GCV) 16.31 MJ·kg⁻¹, followed by *Hydrilla verticillata* with GCV 15.24 MJ·kg⁻¹. Samples of *Myriophyllum spicatum* exhibited unsatisfactory results due to its low GCV (11.27 MJ·kg⁻¹) in combination with high ash content (36.99%) which indicates complications during combustion, thus, low energy production efficiency and overall unsuitability for combustion purposes.

1. Introduction

Agricultural sector in Republic of Indonesia is characterized by production of abundant amount of various agricultural residues [1]; it corresponds to approximately 146.7 million tons of such residues produced every year [2]. Such residues represent waste biomass with great potential for energy generation by combustion methods and can be used as a source of clean and renewable energy [1; 3]. Nevertheless, not only large-scale manufactures producing agricultural residues are source of suitable biomass for energy production; various kinds of waste biomass with no other purposes can be also found in Indonesia, namely, herbaceous, wood, fruit or aquatic biomass [3].

Aquatic biomass includes biological wastes originated from aquatic plant species; most of them provide benefits for environment during their lives, however, some specific species represent serious issues due to their profuse vegetation and invasive behaviour [4, 5]. Several aquatic weed species wildly growing in water areas in Indonesia were considered as



undesirable members of local ecosystem by previous studies [6, 7, 8] that identified as local aquatic pollution mainly water hyacinth *Eichhornia crassipes* and aquatic weeds *Hydrilla verticillata* and *Myriophyllum spicatum*.

There was monitored and evaluated presence of mentioned plants populations, which are considered as an aquatic pollution, in the water areas of Lake Toba (see in Figure 1), the largest lake (surface area 800 km²) in tropical Asia located in the middle of North Sumatra [5, 8, 9]. Lake Toba, represents frequently visited tourist destination and is considered as a natural wonder, therefore there is an effort to eliminate the population of undesirable aquatic weed species [10]. Mentioned aquatic plant species are characterized by extremely high biomass yield which forms desirable thick impenetrable mats at the bottom and surface (large floating islands of plants) of the lake [10, 11] which exclude other vegetation growing and complicate utilization of water areas (activities such as fishing, irrigation, energy generation or recreation) [12]. To prevent all mentioned negative impacts of identified aquatic plant species, the existing plants populations are removed from water by manual or mechanical harvesting (heavy machinery) in attempt to clean the lake and prevent further plants reproduction [8, 13]. Identical harvesting techniques were also documented in case of aquatic pollution of Lake Rawa Pening, Central Java [14] and Lake Tempe, South Sulawesi [15].



Figure 1. Aquatic pollution of Lake Toba: a) *Eichhornia crassipes*, b) *Hydrilla verticillata*, c) *Myriophyllum spicatum* (manual harvesting) [Authors data]

Such a harvested aquatic biomass is occasionally utilized as cheap fertilizer or livestock feed by small scale farmers but majority is left without subsequent effective utilization [14, 16, 17]. Nowadays, investigations focused on effective utilization of aquatic biomass were performed, mainly focused on biofuels production. Specifically, a transformation of present aquatic plants species into the liquid biofuel (bioethanol) and gaseous biofuel (biogas) was investigated directly in Indonesia [18, 19]. Investigations focused on production of solid biofuel (in form of briquettes) were performed with satisfactory results in Nigeria [20], Kenya [21] and Zimbabwe [22] where the aquatic pollution of water areas is also widespread. Mentioned studies proved potential of investigated aquatic plant for biofuel production within testing of mechanical and chemical quality of produced briquette samples.

Main aim of present study was to monitor and evaluate the energy potential of aquatic waste biomass originated from Lake Toba, Indonesia. Especially wildly growing aquatic plant species *Eichhornia crassipes*, *Hydrilla verticillata* and *Myriophyllum spicatum*. Experimental investigation was focused on potential of mentioned aquatic plant species for direct combustion and subsequent energy generation.

2. Materials and Methods

Whole experimental investigation was performed within mechanical and chemical analysis of selected investigated materials describing their suitability for energy generation by direct combustion, as well as evaluation of observed results was conducted to technical mandatory standard which describes all processes of specific measurements and tests in detail and states required levels of specific biofuels quality indicators. Namely, following standards were used in the present research: EN ISO 17225-1 (2015), EN 15234-1 (2011), ISO 16559 (2014), ISO 18134-2 (2017), EN ISO 18122 (2015), EN ISO 18123 (2015), EN 14918 (2010) and ISO 1928 (2010).

2.1. Materials and samples

Wildly growing aquatic plant species originating from water areas of Lake Toba, North Sumatra, (Indonesia) were used as investigated biological materials for experimental measurements of present study; namely, *Eichhornia crassipes*, *Hydrilla verticillata* and *Myriophyllum spicatum* (expressed in Figure 2). Whole bodies of mentioned plants were harvested manually from water areas and collected during summer season from August to September 2016 in district of Laguboti, Regency of Toba Samosir and in surroundings of Samosir Island, Regency of Samosir.

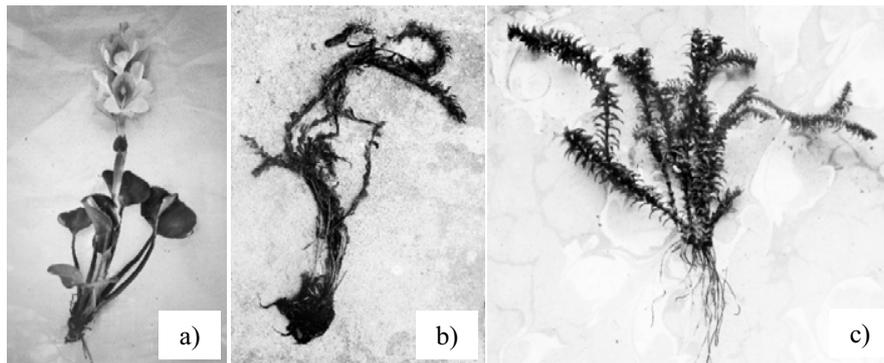


Figure 2. Investigated aquatic plants: a) *E. crassipes*, b) *H. verticillata*, c) *M. spicatum* [Authors data]

2.2. Experimental methodology

Primarily, raw samples were subjected to determination of initial moisture content directly after harvesting by using of laboratory oven Daihan Labtech, type LDO-080F (New Delhi, India). Secondary, previously dried materials were grinded into fine powder (<0.1 mm) and used for determination of ash and volatile matter contents by using of thermo gravimetric analyser LECO, type TGA 701 (Saint Joseph, United States). Subsequently, a gross calorific value determination was performed by using of isoperibol calorimeter LECO, type AC 600 (Saint Joseph, United States) and net calorific value was calculated using appropriate formulas according to standard ISO 1928 (2010).

3. Results and discussion

Presence of investigated aquatic plants species and aquatic pollution was proved in case of Lake Toba by initial visual evaluation of target area. A great amount of vegetation growing in Lake Toba in the form of floating macrophytes (*E. crassipes*) and submerged macrophytes (*M. spicatum* and *H. verticillata*) was observed.

Chemical analysis of selected aquatic plants performed by experimental testing exhibited result values of main chemical quality indicators which are resulting in the issue of plants suitability for energy production by direct combustion. Detail values of specific tested materials parameters are noted in Table 1 and statistical analysis of obtained result values is expressed in Table 2 (see below).

Initial moisture content of all investigated samples exhibited extremely high values. Such results were expected if considered the taxonomic classification of plants. However, low amount of dry matter content (12.2% in average) could be considered as a limitation due to higher demand on biomass quantity collection. Recommended moisture content of feedstock material for solid biofuel production is <10% [23], therefore, proper preparation (drying) of raw material before utilization for combustion purposes would be necessary. However, body structure of selected aquatic plants is easily dryable, thus, solar power can be used for that purpose.

Table 1. Indicators of investigated aquatic plants chemical quality

	GCV (MJ·kg ⁻¹)	SD (MJ·kg ⁻¹)	NCV (MJ·kg ⁻¹)	SD (MJ·kg ⁻¹)	AC (%)	SD (%)	MC (%)	SD (%)	VMC (%)	SD (%)
<i>E. crassipes</i>	16.31	0.10	15.09	0.09	11.60	0.29	85.3	0.02	87.41	1.20
<i>H. verticillata</i>	15.24	0.42	13.93	0.38	15.53	1.11	88.5	0.02	80.41	4.30
<i>M. spicatum</i>	11.27	0.15	10.58	0.14	36.99	0.15	89.6	0.02	58.36	0.79

(GCV – gross calorific value, NCV – net calorific value, SD – standard deviation, AC – ash content, MC – moisture content, VMC – volatile matter content)

Table 2. Statistical analyses of measured data

	GCV		NCV		AC	
	t _{rat} (–)	t _{crit} (–)	t _{rat} (–)	t _{crit} (–)	t _{rat} (–)	t _{crit} (–)
<i>E. crassipes</i>	4.29	0.96	5.08	0.96	5.94	0.96
<i>H. verticillata</i>						
<i>E. crassipes</i>	48.73	0.96	46.65	0.96	5.47	0.96
<i>M. spicatum</i>						
<i>H. verticillata</i>	15.40	0.96	14.18	0.96	7.66	0.96
<i>M. spicatum</i>						

(GCV – gross calorific value, NCV – net calorific value, AC – ash content)

Statistical analysis using standard two tailed paired t-test (Table 2) between determined data for investigated aquatic plants showed that compared result values of GCV, NCV and ash content are significantly different from each other. The significance of the analysis results was based on values of t_{crit} being lower than t_{rat} values with level of significance 0.05.

Evaluation of ash content result values indicated low level of present parameter; such results are undesirable because they indicate complication during combustion of materials, thus, related lower combustion efficiency and lower energy potential. Ash content is primarily related to kind of biomass; wood biomass always exhibited lower ash content in compare with other kinds [24]. Considering herbaceous biomass, a rice husks representing one of major agriculture residues in Asia, also exhibited high result values of ash content equal approximately 20% [25]. Ash content can be also influenced by contamination of biomass by external particles. In case of investigated aquatic plants, it could have been caused by sand or soil impurities contamination.

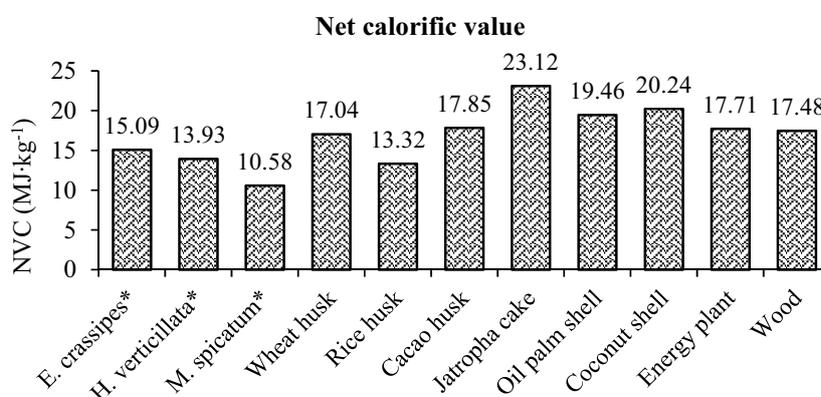


Figure 3. Energy potential of various kinds agriculture residues [*Authors data; 25–30]

Mentioned relation between high ash content and low combustion efficiency was directly proved by result values of calorific values. Focused on the energy potential, *E. crassipes* sample exhibited highest level of net calorific value, followed by *H. Verticillata* samples and lowest level was achieved by samples of *M. spicatum* (extremely high ash content). Comparison of obtained result values with other kinds of waste biomass commonly used for energy production (expressed in Figure 3) describes that investigated materials exhibited lower level of energy potential, nevertheless, *E. crassipes* and *H. verticillata* exhibited satisfactory level, but level of net calorific value of *M. Spicatum* was very low and represented unsatisfactory result. Overall evaluation of obtained result values of chemical quality indicators proved suitability of *E. crassipes* and *H. verticillata* for combustion purposes with subsequent energy production. Samples of *M. spicatum* exhibited unsatisfactory results due to its extremely high ash content in combination with low net calorific value which in adequate combustion properties of material, thus, it would represent low quality biofuel.

4. Conclusion

Summarizing of all observed findings related to chemical composition and energy potential of investigated aquatic plants, the utilization of *Eichhornia crassipes* and *Hydrilla verticillata* for energy production by combustion can be recommended. In general, energy potential (calorific values) of investigated aquatic plants occurred at lower level in comparison with other biomass types. Such a limitation can be improved for example by transformation of biomass into solid biofuel which increases calorific values of final products. Although, several limitations were identified within selected plants energy potential, it is also important to consider that utilization of such waste biomass is an important step of proper waste management within the actual effort to clean water areas of Lake Toba. This fact must be considered as positive aspect of such materials utilization for energy production, as well as, low financial demands for the acquisition of such materials. Extensive aquatic plants populations already exist and after harvesting becoming aquatic waste biomass; potential renewable source of energy with no financial demands for its cultivation.

Acknowledgment

Appreciation belongs to research team members Surya Ningsi Hutauruk and Herti Novalia Hutapea from Institut Teknologi Del for assistance due to data collection and participation at

the conference NICTE 2017. The research was supported by Internal Grant Agency of the FE, CULS Prague, grant number 2017:31140/1312/3112 and by the Internal Grant Agency of the CULS Prague, grant number 20173005 (31140/1313/3108).

References

- [1] Singh R and Setiawan A D, 2013, Biomass energy policies and strategies: Harvesting potential in India and Indonesia. *Renewable and Sustainable Energy Reviews* 22 pp 332–345
- [2] Abdullah K, 2002, Biomass energy potentials and utilization in Indonesia. *IPB and Indonesian Renewable Energy Society [IRES]*, Bogor
- [3] Kuvarakul T, Pradidina A, Anggraeni D and Saraswati H, 2015, Renewable Energy Guideline on Biomass and Biogas Power Project Development in Indonesia, p 204.
- [4] Scheffer M, 1998, Ecology of shallow lakes *Population and community biology* series 22
- [5] Smart R M and Doyle R D, 1995, Ecological theory and management of submersed aquatic plant communities *Aquatic Plant Control Research Program* (Vicksburg: U.S. Army Engineer Waterways Experiment Station)
- [6] Pancho J V and Soerjani M, 1978, Aquatic Weeds of Southeast Asia. *BIOTROP, Indonesia: Bogor* p 130.
- [7] Nasution Z, 2003, Land and Forest Management in the Lake Toba Catchment Area. *Universiti Sains Malaysia*.
- [8] Nasution M I T, Awal S M S and Permana D M, 2016, The Methods of Preventing Water Hyacinth as Aquatic Pollution in Lake Toba Caused by Agricultural Waste *International Journal of Environmental Science and Development* vol. 7(8) pp 630–633
- [9] Gopal B and Ghosh D, 2009, Lakes and Reservoirs of Asia. *Encyclopedia of Inland Waters* pp 501–512 (Boston: Elsevier)
- [10] Langeland K A, 1990, Hydrilla: A continuing problem in Florida waters *University of Florida Circular* No. 884 (Gainesville: University of Florida)
- [11] Rahman I A, Saad B, Shaidan S and Sya Rizal E S, 2005, Adsorption characteristics of malachite green on activated carbon derived from rice husks produced by chemical–thermal process., *Bioresource Technology* 96 pp 1578–1583.
- [12] Kannan R R, Rajasimman M, Rajamohan N and Sivaprakash A B, 2010, Equilibrium and kinetic studies on sorption of malachite green using Hydrilla Verticillata biomass. *International Journal of Environmental Research* vol 4(4) pp 817–824.
- [13] Tjitrosemiteo S, 1994, Integrated management of paddy and aquatic weeds in Asia. In: Proceedings of the International Seminar “*Biological Control and Integrated Management of Paddy and Aquatic Weeds in Asia*” J., Asian and Pacific Council., Tsukuba, Japan
- [14] Little E C S, 1968, Handbook of utilization of aquatic plants. *Plant Production and Protection Division* Rome, FAO, p 123.
- [15] Ali M S S, Majika A and Salman D, 2017, Food Consumption and Production in Tempe Lake, South Sulawesi, Indonesia. *Journal of Asian Rural Studies* vol. 1(1) pp 43–52.
- [16] Ling S W, 1960, Control of aquatic vegetation. In: *Third International Inland Fisheries Training Centre* Rome, FAO p 12.
- [17] Bagnall L O, 1971, Processed aquatic plants for animal nutrition. *Annu.Res.Rep.Inst.Food Agric.Sci.Univ.Fla.* vol 49
- [18] Aswathy U S, Rajeev K, Sukumaran G, Devi L, Rajasree K P, Singhanian R R and

- Pandey A, 2010, Bio-ethanol from water hyacinth biomass: an evaluation of enzymatic saccharification strategy *Bioresource Technology* vol. 101, pp 925–930.
- [19] Annachhatre A P and Khanna P, 1987, Methane recovery from water hyacinth through whole-cell immobilization technology *Biotechnology and Bioengineering* vol. 29 pp 805–818.
- [20] Ighodalo O A, Zoukumor K, Egbon C, Okoh S and Odu K, 2011, Processing Water Hyacinth into Biomass Briquettes for Cooking Purposes. *Journal of Emerging Trends in Engineering and Applied Sciences* 2(2) pp 305–307
- [21] Rodrigues A J, Omondi M, Hayombe P O, Akuno W, Kerich D and Maobe I, 2014, Converting Water Hyacinth to Briquettes: A Beach Community Based Approach. vol 4531 pp 358–378.
- [22] Munjeri K, Ziuku S, Maganga H, Siachingoma B and Ndlovu S, 2016, On the potential of water hyacinth as a biomass briquette for heating applications. *International Journal of Energy and Environmental Engineering* vol 7(1) pp 37–43.
- [23] Kaliyan N and Morey R V, 2009, Factors affecting strength and durability of densified biomass products. *Biomass and Bioenergy* vol. 33(3) pp. 337–359.
- [24] Johansson L S, Leckner B, Gustavsson L, Cooper D, Tullin C and Potter A, 2004, Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. *Atmospheric Environment* 38(25) pp 4183–4195.
- [25] Brunerová A, Malat'ák J, Müller M, Valášek P and Roubík H, 2017, Tropical waste biomass potential for solid biofuels production. *Agronomy Research* 15(2) pp 359–368.
- [26] Brunerová A, Brožek M and Müller M, 2017, Utilization of waste biomass from post-harvest lines in the form of briquettes for energy production. *Agronomy Research* vol 15 pp 344–358.
- [27] Mahlia T M I, Abdulmuin M Z, Alamsyah T M I and Mukhlis D, 2001, An alternative energy source from palm wastes industry for Malaysia and Indonesia. *Energy Conversion and Management* vol 42(18) pp 2109–2118.
- [28] Özyuguran A and Yaman S, 2017, Prediction of Calorific Value of Biomass from Proximate Analysis. *Energy Procedia* vol 107 pp 130–136.
- [29] Brunerová A, Müller M and Brožek M, 2017, Potential of wild growing Japanese Knotweed (*Reynoutria Japonica*) for briquette production. In: *Engineering For Rural Development*. Jelgava: Latvia, pp 561–568.
- [30] Malat'ák J, Bradna J and Velebil J, 2016, Combustion of briquettes from oversize fraction of compost from wood waste and other biomass residues. *Agronomy Research* 14 pp 525–532.