www.rericjournal.ait.ac.th

Organic Waste Conversion by Torrefaction Pretreatment

Saifone Harnchanaphol*, Kittisak Khuwaranyu#, and Duangkamol Ruen-ngam*, 1

ARTICLE INFO

Article history:
Received 22 August 2023
Received in revised form
18 December 2023
Accepted 02 January 2023

Keywords:
Calorific value
Mass yield
Organic waste
Pretreatment
Torrefaction

ABSTRACT

This research aimed to demonstrate the thermal pathway (torrefaction technology) to convert organic waste to be biochar/biocoal. Organic waste (cabbage) from Nonthaburi fresh market, Thailand was used as raw material. Torrefaction technology was processed in horizontal cylindrical batch reactor with Nitrogen gas purging during doing experiment. Temperature profile was preliminary checked to find out lag time. Amount of loaded weight and particle size of material were preliminary tested. Experimental conditions such as time and temperature were tested at 30 and 60 minutes, and range temperature of 220 to 300°C. Important property of product; calorific value of product in form of high heating value (HHV) and mass yield percentage were measured. The optimal conditions were evaluated with two parameters; increase of HHV compared to reference condition and % mass yield. Increase temperature was significant effect to increase HHV value of biochar. The optimal time and temperature for getting the highest heating value were 60 minutes and 280°C.

1. INTRODUCTION

Municipal solid waste (MSW) contains various types of waste. Waste from fresh market has a large fraction of organic matter, cover of vegetable. Organic waste can also be grouped as biomass. Due to limitation of landfill facility and landfill disposal can make GHGs (greenhouse gases), such as methane (CH_4), generated during the anaerobic decomposition of organic matter especially in Asian cities [1]-[5], therefore conversion to economics respect is the common way to manage organic waste [2], [3]. Ordinary organic waste has been used for producing biogas; however, purification process is expensive. Therefore, this research demonstrates alternative technology for utilizing organic waste for fuel. Nonthaburi province in Thailand was crowned city and well managed for sanitation landfill method since 2006 [7]. Organic waste, especially vegetables of around 1.5 tons per day, is collected from Nonthaburi city municipality fresh market. Nowadays renewable energy was hot issue because of coal shortage and biomass can be potential source of renewable energy.

Pyrolysis is well known as MSW conversion that operates in range temperature of 300-650°C. Milder condition as torrefaction/carbonization was thermochemical conversion route (200-300°C) without contact with oxygen for biomass conversion [6]. Torrefaction alters the chemical structure of biomass hydrocarbon to increase its carbon content while reducing its oxygen. Torrefaction also increases the density of biomass to make the biomass hygroscopic [6]. Thermal pretreatment has been used as a potential method for biomass conversion [7], [8]-[12]. Limitation of organic waste for torrefaction technology is its high moisture content around 93% by wet basis that cannot be used as biomass, therefore the water was necessary to remove. Drying by sunlight and open air were ordinary drying method and earlier research used simultaneous drying and torrefaction [13]. Earlier research has proposed that organic waste can be produced to be biochar with high calorific value (inform of high heating value, HHV). Because of high capital for using thermal oven drying therefore mechanic drying such as squeezing machine was used for organic waste treatment. Moreover, the use of torrefaction for converting organic waste has not appeared.

The study aimed to improve the high heating value (HHV) and mass yield of organic waste by using squeezing, drying and torrefaction process.

2. METHODOLOGY

2.1 Raw Material and Preparation

Organic waste samples were obtained from Nonthaburi fresh market, Mueng Nonthaburi district, Nonthaburi province of Thailand. Characteristics of organic waste and sample section. Systematic selection was used for material selection. Characteristics of cabbage demonstrated in Saengpeng's paper (2022) [13]. Only cabbage was used in this experiment because the cover

*Rattanakosin College for Sustainable Energy and Environment (RCSEE), Rajamangala University of Technology Rattanakosin, Salaya Phutthamonthon, Nakhonpathom, 73170, Thailand.

#Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University, Amphore Muang, Nakhonpathom, 73000, Thailand.

1Corresponding author:
Email: duangkamol.rue@rmutr.ac.th

of cabbage had the largest amount with 56.25% compared to other types. A sample photo of the cabbage cover is as shown in Figure 1. Because of cellulosic content in organic waste results to be biofuel, organic waste can be fuel in many forms; gas from fermentation or oil from extraction and solid from pretreatment by thermal pathway.

2.2 Experimental Procedure

Organic waste cover of cabbage sample was preliminarily pretreated by squeezing, then dried for moisture removal and maintained moisture at about 20% by Universal oven (Memmert Universal Oven UF55, Germany). From then on dried-organic waste was named biomass. Biomass was weighed in range of 10 to 60 grams per sample and placed homogeneously in batch reactor. Torrefaction reactor is made of stainless steel with diameter 36 mm and length 150 mm as shown in the experimental setup in Figure 2. Nitrogen gas (N_2) was purged during the experiment for removing air and flow rate was controlled at 100 ml/min. Temperature profile was preliminary checked to find out lag time. Experimental conditions were conducted by varying size, weight of loaded biomass, time and temperature as shown in Table 1. Setting value (SV) and present value (PV) were set according to the program of retention time and temperature according to Table 1. The calorific value was measured by a bomb calorimeter. The weight of the torrefied biomass, herein biochar, was measured by a 3-decimal weight machine.

Fig. 1. Cabbage cover.

Fig. 2. Experimental setup (a) Torrefaction system (b) Reactor.

Table 1. Experimental conditions.

Parameters	Conditions
Biomass weight (grams)	10, 20, 30, 60
Particle size (μm)	1) 212 2) 850 3) Original mixture (763)
Time (minutes)	1) 30 2) 60
Temperature (°C)	220, 240, 260, 280 and 300

2.3 *Calorific Value (high heating value, HHV) analysis*

Calorific value of torrefied biomass was demonstrated in form of high heating value (HHV). The HHV was analyzed by a bomb calorimeter, Parr®, USA in accordance with ASTM E 711 Method [14].

2.4 *Calculation*

High heating value (HHV) comparison, mass yield percentage and enhnaced conversion factor (ECF) were calculated according to Equations (1), (2) and (3).

HHV comparison was calculated as percentage deviation of HHV at each torrefied condition (HHV torrefied) which was based on HHV at reference condition (HHV ref.).

$$\%\, HHV\ comparison = \left(\frac{HHV\ torrefied - HHV\ ref}{HHV\ ref}\right) \times 100 \quad (1)$$

Mass yield was calculated according to Equation (2).

$$Mass\ yield\ (\%) = \left(\frac{weight\ torrefied}{weight\ of\ raw\ material}\right) \times 100 \quad (2)$$

Enhanced conversion factor (ECF) was calculated by HHV ratio (HHVtorrefied/HHVraw material) divided by mass yield in Equation (2).

$$Enhance\ conversion\ factor\ (ECF) = \frac{HHV\ ratio}{Mass\ yield} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 *Temperature Profile*

Temperature profile was preliminary tested for lag time determination. This experiment was done by loading 30 g biomass. At a temperature of 250°C had longer time to reach desired temperature compared to empty reactor or had lag time around 33 minutes as shown in Figure 3.

Heating rate of biomass depended on loaded biomass weight. Results of heating rate were 9.78, 9.80, 8.19 and 8.13°C/min for 0, 10, 20 and 30 grams, respectively. Empty load was not significantly different compared to 10 grams of biomass. The heating rate at 30 grams biomass was lower than empty loading by around 16%. The lag time for increase temperature to the certain value was around 33 minutes.

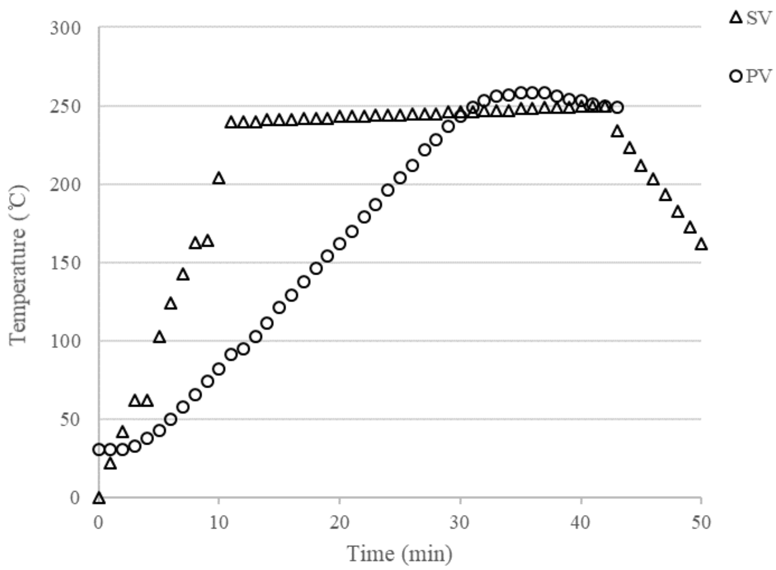


Fig. 3. Temperature profile at 250°C (SV = Setting value, PV = Present value).

3.2 *Effect of Biomass Particle Size*

This experiment was done by uploading biomass at 20 g then torrefied at 250°C 30 minutes. Dried biomass was sieved through standard mesh that can be divided in three sizes as shown in Table 2. Increase of HHV was calculated according to Equation (1) by using original mixture with using size 736 µm as reference. Homogeneous mixture was benefit in pretreatment process for increasing HHV by torrefaction. Reduction of biomass size increased HHV of product. The smallest size (212 µm) had the higher HHV compared to the largest size (850 µm). It might be because of the non-homogeneous of heat transfer inside the reactor. The particle size affected the torrefaction rate [15].

For economic considerations, reducing feed size process was not important for organic waste pretreatment because squeezing had already reduced size and HHV was not significantly difference.

3.3 *Effect of Biomass Weight*

This experiment was done at 250°C 30 minutes with the range of loaded biomass 10 to 60 grams. Effect of amount of biomass weight demonstrated in Figure 4. HHV comparison was calculated according to Equation

(1) using HHV of 10 grams biomass as reference. The grey bar in Figure 4 shows results of HHV comparison with scale on the left axis. Mass yield in percentage demonstrates in right axis shows dimension of white circle symbol that was calculated according to Equation (2).

Increasing the amount of loaded biomass from 10 to 30 gram increases HHV value and then dropped when loaded biomass to 60 grams; however, it was not a significant difference. It might be because of the non-homogeneous heat distribution inside the reactor. When increasing the loaded weight, compact bulk arrangement resulted in an autocatalytic composition pathway and a higher level of decomposition [10]ใ

Increasing the amount of biomass decreased the % mass yield. However, it was not significantly different and were found to be the same in other research [10], [16], [17]. Because compact arrangement has autocatalytic reaction. Water in the volatile matter played the role as catalyst in the biomass composition.

Above information for loaded biomass at 30 grams was further used in next section for time and temperature determination because such condition has the highest HHV.

Table 2. HHV of torrefied screened biomass.

Particle size (μm)	HHV (kcal/kg)	Increase of HHV compared to original biomass (%)
850	4876.1	3.61
Original biomass (763)	4706.1	0.00
212	4964.8	5.50

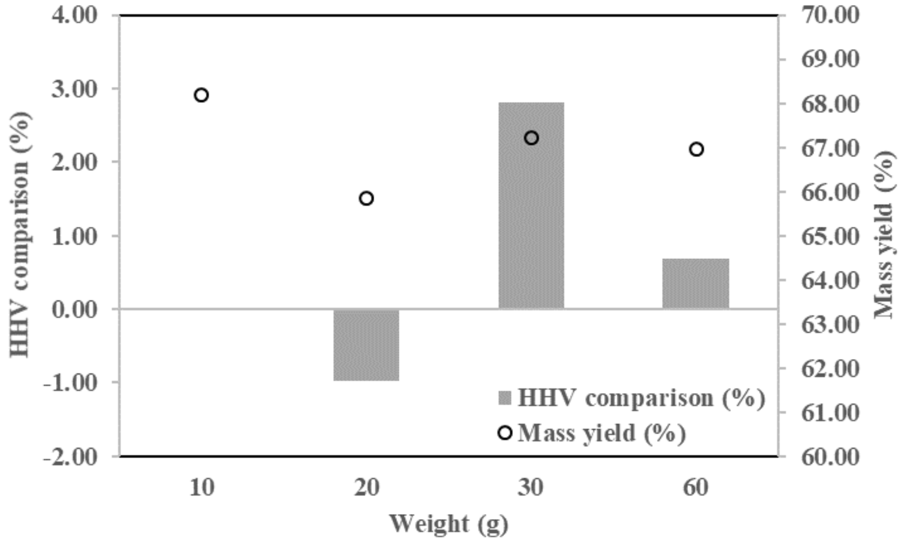
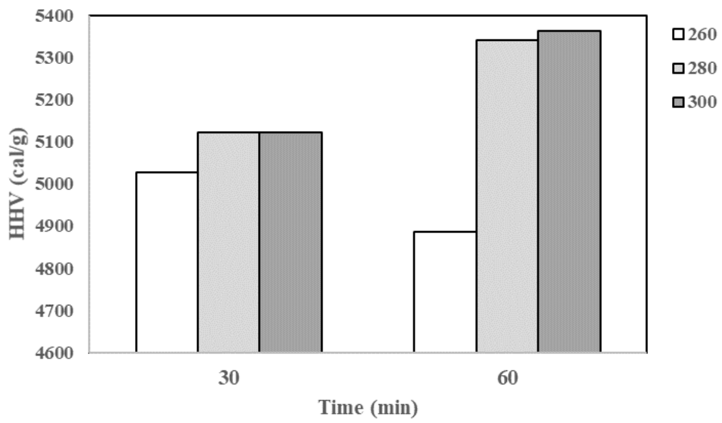


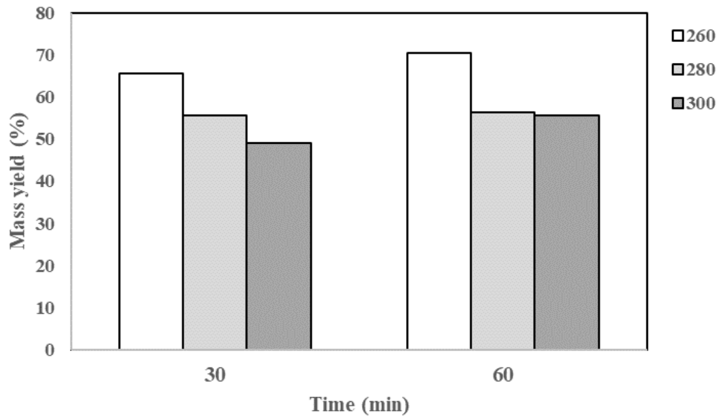
Fig. 4. Effect of loaded biomass weight at 250°C, 30 min.

3.4 Effect of Time

The heating value of the biomass can be defined by the setting time which refers to the time to reach the setting point. Results of time on HHV and %mass yield are demonstrated on Figure 5. Increasing the torrefying time increased the HHV. In the case of 280°C, the HHV increases around 4.31%, while at 300°C it increases to 4.74% as shown in Figure 5(a). This might be because the biomass was compacted homogeneously. However, with longer time, biomass could get degraded by heat. The percentage of mass yield was not different between 60 and 30 minutes at 280°C or increase around 1.28% whereas at 260°C and 300°C were around 7.5 and 13.33%, respectively. When the biomass was torrefied, the hemicellulose and other non-cellulosic matter started to decompose resulting in a damage surface [10], [18], [19].



(a) HHV



(b) %Mass yield

Fig. 5. Effect of time in range temperature of 260 to 300°C (a) HHV (b) Mass yield.

3.5 Effect of Temperature

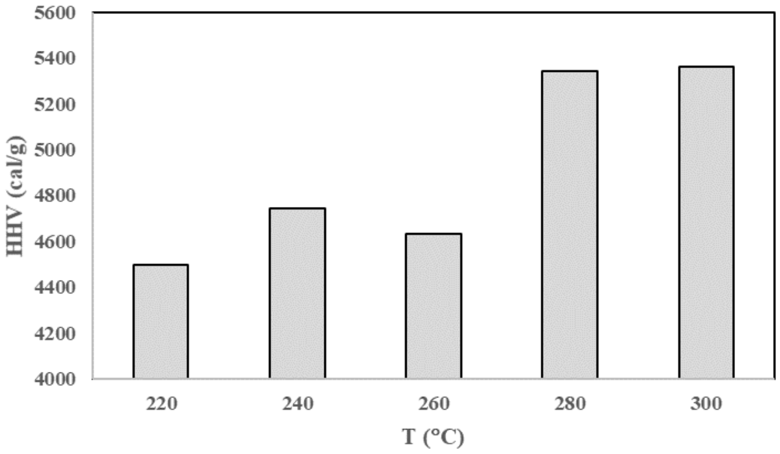
This section shows experimental results at 60 minutes. Increasing the reaction temperature increases HHV as shown in Figure 6 and biochar product as demonstrated in Figure 7. HHV increased around 15.25% with temperature from 260 to 280°C whereas in the range of 240 to 260°C, HHV decreased around 2.26%. Table 3 shows value of percentage increasing of HHV (cal/g) and mass yield (%) between biochar products from 20°C interval range of operating temperature. The HHV was high in the range of temperatures 280-300°C.

Figure 6(b) shows decreasing the reaction temperature results to a decrease in % mass yield. Mass yield reduced around 19.92% when temperature increased from 260 to 280°C. A temperature higher than 280°C resulted in a more degradation of biomass surface that matches with other research [10], [18], [19].

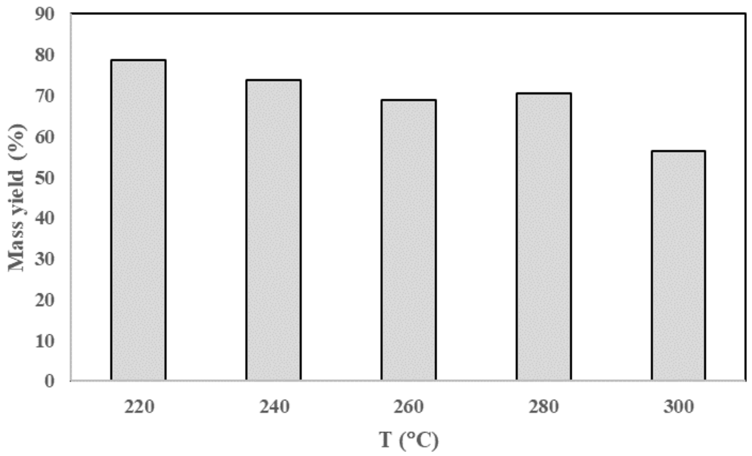
ECFs were calculated according to Equation (3). HHV ratios were calculated by HHV torrefied values in Figure 6(a) were divided by HHV raw material (4,030.81 cal/g). The results shown in Table 4 that increasing torrefying temperature increases enhanced conversion factor (ECF) that means improvement of calorific value of raw material.

3.6 Product Comparison (HHV comparisons)

The biochar from this experiment is in the same range of torrefied biomass (3,824-6,931 kcal/kg) and higher than biomass; sugarcane, soybean, corn, rice, sorghum and sunflower [20]. Removal of water by mechanic squeezing can enhance the HHV of organic waste when compared to simultaneous drying method [13]. That meant lower capital expense for pretreatment by squeezing.



(a) HHV



(b) %Mass yield

Fig. 6. Effect of temperature in range 220 to 300°C at 60 minutes on (a) HHV and (b) %mass yield.

Table 3. Comparison of HHV (cal/g) and mass yield (%) of biochar at operating temperatures with 20°C intervals.

T (°C)	Increase of HHV (%)	Increase of mass yield (%)
220	-	-
240	+5.38	-6.25
260	-2.26	-4.44
280	+15.25	-19.92
300	+0.42	-1.26

Table 4. Enhanced conversion factor (ECF) in range temperature of 220-300°C.

T (°C)	HHV torrefied (cal/g)	HHV ratio	Mass yield	Enhanced conversion factor (ECF)
220	4499.3	1.12	0.79	1.42
240	4741.5	1.19	0.74	1.61
260	4634.5	1.14	0.70	1.62
280	5341.2	1.34	0.56	2.37
300	5363.6	1.34	0.56	2.40

Fig. 7. Biochar product.

4. CONCLUSIONS

This experiment demonstrated suitable conditions for organic waste conversion to produce biochar. Laboratory scale of torrefaction technology was selected in this research. The optimal conditions were evaluated under three parameters: HHV, %mass yield and enhanced conversion factor. The optimal time and temperature were 60 minutes and 280°C for getting the highest heating value. The suitable time and temperature were in a wide range that usually depended on economic feasibility and agreement between renewable energy producer and buyer.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the Power Development Fund for sustainable community development from office the Energy Regulatory Commission, Ministry of Energy, Thailand for financial support for the preliminary results in previous research.

REFERENCES

[1] Ram LV. and B. Guilberto. 2022. Emissions of greenhouse gases from municipal solid waste management system in Ho Chi Minh city of Viet Nam. *Urban Science* 6: 78.

[2] Stocker T.F., Qin D., Plattner G.-K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex, P.M.V., 2013. IPCC, Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Midgley Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013.

[3] Gautam S.P., Bundela P.S., Pandey A.K., Awasthi M. K. , and Sarsaiya S., 2010. Composting of municipal solid waste of Jabalpur city. *Global Journal of Environmental Research* 4: 43–46.

[4] Thanomnim B. , Papong S., and Onbhuddha R. , 2022. The methodology to evaluate food waste generation with existing data in Thailand. *Thai Environmental Engineering Journal* 36: 1–9.

[5] UNEP (United Nations Environmental Programme). Waste Management in ASEAN Countries: Summary Report. 2017. https: / / www. unep. org/ resources/ report/ waste-management-asean-countries-summary-report

[6] Basu P., 2013. *Biomass Gasification, Pyrolysis and Torrefaction, Practical Design and Theory*, 2nd Edition. Elsevier., Inc.

[7] Salihu A. and M. Z. Alam, 2016. Pretreatment method of organic wastes for biogas production. *Journal of Applied Sciences* 16(3): 124–137.

[8] Nitipong S., Suwat N., and Paisan C., 2022. Thermal degradation of cassava rhizome in thermosyphon-fixed bed torrefaction reactor. *Processes* 8: 267. https://doi.org/10.3390/pr8030267.

[9] Nitipong S., Suwat N., and Paisan C., 2020. Thermal and torrefaction characteristics of a small scale rotating drum reactor. *Processes* 8: 489. https://doi:10.3390/pr8040489.

[10] Nitipong S. and S. Unchana. 2015. The effect of biomass bulk arrangements on the decomposition pathways in the torrefaction process. *Renewable Energy* 81: 679-684.

[11] Kamonwat N., Pongtanawat K., Wasawat K., Parinvadee C., Bunyarit P., Duangta K., and Prasert P., 2021. Upgrading properties of biochar fuel derived from cassava rhizome via torrefaction: Effect of sweeping gas atmospheres and its economic feasibility. *Case Studies in Thermal Engineering* 23: 100823.

[12] Chadatip L., Kamonwat N., Sanchai K., Anan J., Bunyarit P., 2022. Enhancing lignocellulosic energetic properties through torrefaction and hydrothermal carbonization processes. *Biomass Conversion and Biorefnery*. https://doi.org/10.1007/s13399-021-02132-2.

[13] Jakkrit S., Kittisak K., and Duangkamol R., 2022. Simultaneous drying and torrefaction pretreatment of organic waste for upgrading value, *International Energy Journal* 22: 157 – 166.

[14] ASTM International. (2004). Standard Test Method for Ash in Wood; ASTM E 711, ASTM International, Pennsylvania, USA.

[15] Peng H.J., Bi T.H., Sokhansanj S., and Lim C.J., 2012. A study of particle size effect on biomass

torrefaction and densification. *Energy and Fuels* 26: 3826-3839.

[16] William S.M., Michael J.A.J., Piroska S., Gabor V. and Birbala Z., 1992. Formation of charcoal from biomass in a sealed reactor. *Industrial and Engineering Chemistry Research* 31: 1162-1166.

[17] Medic D., Darr M., Shah A., Potter B., and Zimmerman J., 2012. Effects of torrefaction process parameters on biomass feedstock upgrading. *Fuel* 91: 147–154.

[18] Wei-Hsin C., Wen-Yi C., Ke-Miao L., and Ying-Pin H., 2011. An evaluation on improvement of pulverized biomass property for solid fuel through torrefaction. *Applied Energy* 88: 3636–3644.

[19] Wang L., Barta-Rajnai E., Skreiberg Ø., Khalil R., Czégény Z., Jakab E., Barta Z., and Grønl M., 2018. Effect of torrefaction on physiochemical characteristics and grindability of stem wood, stump and bark. *Applied Energy* 227: 137–148.

[20] Morato T., Vaezi M., and Kumar A., 2019. Assessment of energy production potential from agricultural residues in Bolivia. *Renewable and Sustainable Energy Reviews* 102: 14-23.