Conversion of Spent Tea Waste for Solid Carbon Fuel via Hydrothermal Carbonization Process

Abstract–The aim of this research was to study effect hydrothermal carbonization (HTC) processes constraints like reaction temperature and contact time of the hydrochar produced via conversion of spent waste tea (SWT), at that time rid the environment of the pollutant SWT, then hydrochar produced by HTC process. At the range of temperatures, the SWT feed amount was 5 g, 2 MPa N_2 pressure, by a constant contact time of 45 min, with various temperatures of 150, 175, and 200°C, respectively. At the range of residence times the 5g of SWT, 2 MPa N_2 pressure, at constant temperature at 200°C (finest degree it was found), and the various of the contact duration at 30, 45, and 60 minutes, respectively. The characterization process was carried out via physical properties, higher heating values (HHVs), proximate and ultimate analysis, energy recovery (ER), and energy yield (EY). The results showed that the SWT was reached carbon contents and the highest HHV. The conversion of SWT by the HTC process could be used as a solid carbon fuel for energy generation and to rid the environment of pollutant materials.

Keywords: waste spent tea, HTC, high heating value, high heating value improvement

1. INTRODUCTION

The optimal utilization of agricultural waste as an energy source for decentralized power generation and heating applications can help rural communities meet escalating energy demands. Forests, agricultural produce, residential garbage, animals, food processing, industrial activity, and other sources all produce different kinds of biowastes [1]. Tea drink is the most popular beverage after water, consumed by more than two-thirds of the total population globally [2]. Tea is one of the items consumed globally and contributes significantly to reusable garbage. Tea is a dried leaf-infused beverage made from the leaves of Camellia sinensis L. It is the world's second-best-selling non-alcoholic beverage [3]. Excessive use of fossil fuels has largely contributed to global warming and the looming energy crisis, which requires the promotion and development of alternative energy sources to achieve green energy or energy neutrality. Recently, scientific researchers were able to develop pioneering units to increase production efficiency through scientific research, like thermochemical conversion processes which included (hydrothermal carbonization, pyrolysis, microwave processes [4]. Over 90% of tea is wasted after ingestion [5]. Tea leaf brewing waste is a lignocellulosic biomass waste generated during the tea-brewing process. Tea brewing trash can be generated in either residential or industrial procedures [6]. Tea trash, such as trimmed branches, seed shells, and tea remnants, include a of lignin, cellulose, hemicellulose, and other organic components, which are conducive to the formation of a heating value and large surface area during hydrothermal carbonization process [7]. Tea waste can be turned into solid carbon fuel or activated carbon using a variety of thermochemical techniques, including pyrolysis, hydrothermal carbonization, and microwave processes [8]. Chemical agents have also been widely employed to increase surface properties, surface functional groups, and new structures in biochar or activated carbon.

The HTC method produces a large amount of treated water with significant dissolved organic molecules, minerals, and nutrients. Processed water contains around 15% of the feedstock's energy, 20–50% of biomass organics, and high levels of phosphorus and nitrogen [9]. Converting waste biomass to energy has a huge impact on solid waste management [10]. Thermochemical conversion processes are characterized by being quick, easy, and low-cost processes, designed with minimal equipment, and result in solid carbon fuel [11]. Hydrochar is a solid carbonaceous material obtained by thermochemical carbonization of biomass in an oxygen-non environment [12].

This research objectives were to prepare and characterize SWT, and determine the suitability it undergo the hydrothermal carbonization HTC process to produce solid carbon fuel under effect of reaction temperatures, residence times, and rid the environment of pollutant materials.

MATERIALS AND METHODS

2.1 **Spent waste tea preparation**. The spent waste tea (SWT) sample used in this work was collected from the Household waste resulting from daily consumption of tea. The experiments were done of dried SWT samples to 105°C at 2 h [13]. Then, it was manually crushed, saves into powdered to obtained a similar form and the small size.

2.2 **HTC processes of SWT**. The SWT samples were putted in the crucibles and heated at 105 °C in an oven for 2 hours to eliminate residual status, and then ground in a grout and pestle to produce the same powder. On one hand, hydrochar with a temperature range of 5 g SWT feed quantity, 2 MPa N2 pressure, contact period of 45 min, and a variety of temperature at 150, 175, and 200°C were labeled (HTC@45min-150°C, HTC@45min-175°C, and HTC@45min-200°C, respectively). In this run was found the best temperature was 200°C, and has highest calorific value was reached at 14.77 kJ/kg, as shown in Table 1. On the other hand, hydrochar yield with a range of contact time feed amount 5 g of SWT, 2 MPa N2 pressure, at a constant temperature at 200 °C optimum temperature it was originated the previous run, and the difference of the contact time at 30, 45, and 60 minutes were labeled (HTC@200°C-30min, HTC@200°C-45min, and HTC@200°C-60min), respectively. Furthermore, throughout this run, the best residence time was 75 minutes, and the greatest HHV was 14.95 kJ/kg, as shown in Table 1. HTC runs were performed with a 100 ml batch reactor autoclave stainless steel, and the reactions occurred under N2 gas pressure. The reactor operated without a mixer, and a 1.0 kW jacket electric heating power source heated the autoclave reactor. The reactor automatically cooled to room temperature after the reaction takes place. For subsequent analysis, the hydrochars generated were dried at 105°C for 2 hours and milled into fine powder [14]. At least six times all experiments were repeated.

2.3. **Analysis methods**. The raw material spent waste tea (SWT) was prepared and characterized according to the details as in next sections. The HHV according to (ASTM E711) using a Bomb calorimeter [15]. The amount of solid yield was calculated by dividing the yield by the feed [16]. Promotion the SWT property as a fuel by energy properties was investigated via equations from one to five [17]. The CHN-O elemental contents (weight percent) of element components were measured with an analytical instrument element (Flash EA 1112). The volatile matter was evaluated using the ASTM E872–82 [18]**.** The ash content was investigated in an electric muffle furnace, and the ash % was estimated using D1102-84 [19]**.** The estimated value of fixed carbon (FC) was calculated by adding ash and volatile matter and removing 100% [20]. The enhancement of SWT qualities as a fuel by energy characteristics was investigated.

$$Hydrochar\ yield\ (\%) = \frac{Hydrochar\ weight}{SWT\ weight} \times 100 \qquad (1)$$

$$Fuel\ ratio = \frac{Fixed\ carbon}{Volatile\ matter} \qquad (2)$$

$$\%\ HHV\ improvement = \frac{HHV\ of\ hydrochar - HHV\ of\ SWT}{HHV\ of\ SWT} \times 100 \qquad (3)$$

$$Energy\ recovery = \frac{HHV\ of\ hydrochar}{HHV\ of\ SWT} \qquad (4)$$

$$Energy\ yield = Hydrochar\ yield \times Energy\ recovery \qquad (5)$$

3 RESULTS AND DISCUSSION

3.1 **Hydrochar yield of SWT**. The solid yield was calculated as Eq. (1). The HTC processes of SWT by a range of temperature and residence times were investigated to enhance the hydrochar produced. Table 1 and Fig. 1 show the solid formed by hydrochar at (a) different temperatures and (b) different contact times. The HTC process of SWT was initially initiated by using 5 g of SWT, setting the residence duration at 45 minutes, and varying the reaction temperatures at 150, 175, and 200°C, as indicated in Table 1 and Fig. 1a. The hydrochar fluctuates from one batch to the next due to temperature fluctuations during the process. Increasing the temperature degree to 200 °C has been demonstrated to decrease the hydrochar production. HTC@45min-150°C yielded 3.65 g - 71.2%, followed by HTC@45min-175°C yielded 3.22 g - 64.4%, and HTC@45min-200°C yielded 3.11 g – 62.2 %. The highest hydrochar was 3.65 g – 71.2% at 150°C, and 45 min [21]. At last, under the effect of the residence times, the HTC technic of SWT was during added 5g of SWT, constant temperature at 200°C (best temperature was found) with different ranges of residence time of 30min, 45min, and 60 min as shown in Table 1 and Fig. 1b [14]. The hydrochar was close each other due to the changes of residence times. Rising the residence time reached to 60 min has been detailed to decrease hydrochar yield. The arrangement hydrochar yield highest to lowest was HTC@200°C, 30 min = 3.18 g – 63.6%, HTC@200°C, 30 min = 3.2 g – 64%, and HTC@200°C, 45 min = 3.22 g – 64.4 %. The highest hydrochar was 3.22 g – 64.4% at 45 min and 200°C. The solid yield percentage of hydrochar indicated that the SWT was rich in carbon compounds, organic complexes which shown a slightly lowest weight loss of about 37.8%, at 200°C reaction temperature and 45 min residence time. In comparison, the maximum weight loss was 36.4 % at 60 minutes of contact time and 200 degrees Celsius.

Table 1. Hydrochar yield, and calorific value of the SWT, hydrochar yield at different temperatures, and various contact times

	SWT	**hydrochar@ 45 min, different temperatures, °C**			**hydrochar@ 200 °C, various residence times, min**		
		150	**175**	**200**	**30**	**45**	**60**
Hydrochar yield, g	-	3.56	3.22	3.11	3.20	3.22	3.18
Hydrochar yield, %	-	71.2	64.4	62.2	64	64.4	63.6
HHV, kJ/kg	4.2	6.21	6.51	6.88	5.95	6.51	6.95
HHV improvement	-	47.85	55.00	63.81	41.66	55.00	56.90
Energy recovery (ER)	-	105.21	99.82	104.52	90.66	99.82	105.74
Energy yield (EY)	-	74.91	64.28	65.01	58.02	64.28	67.25

As a result, the hydrochar yield produced has a constsnt temperature of 200°C and residence durations of 30, 45, and 60 minutes, as seen in Table 1 and Fig. 2b. The yield % was obtained using equation one. The solidyield of hydrochar varies according on its residence period. Rising contact time has been shown to increase the fraction of hydrochar at 45 minutes, then decrease till 60 minutes. From highest to lowest hydrochar yield, HTC@200°C-45min = 3.2 g - 64.4%, HTC@200°C-30min = 3.20 g - 6.4%, and HTC@200°C-60min = 3.18 g - 63.6%. The maximum hydrofuel yield was 3.22 g (64.4%) after 45 minutes at 200°C. The consequences revealed a considerable ratio of hydrochar production, showing that the SWT was high in carbon-based and carbon components, with the lowest weight loss of 35.6% at 45 minutes and 200 degrees Celsius. In comparison, the lowest weight loss was 36.4% during a residence duration of 60 minutes and a temperature of 200 degrees Celsius [22]. Hydrochar yields decrease with rising temperatures and contact time, owing of higher hydrolysis response of organic materials at highest temperature in SWT. The result finding illustrates the efficiency of the decarboxylation procedure and the reaction of the SWT to the thermochemical conversion approach used by the HTC process [23].

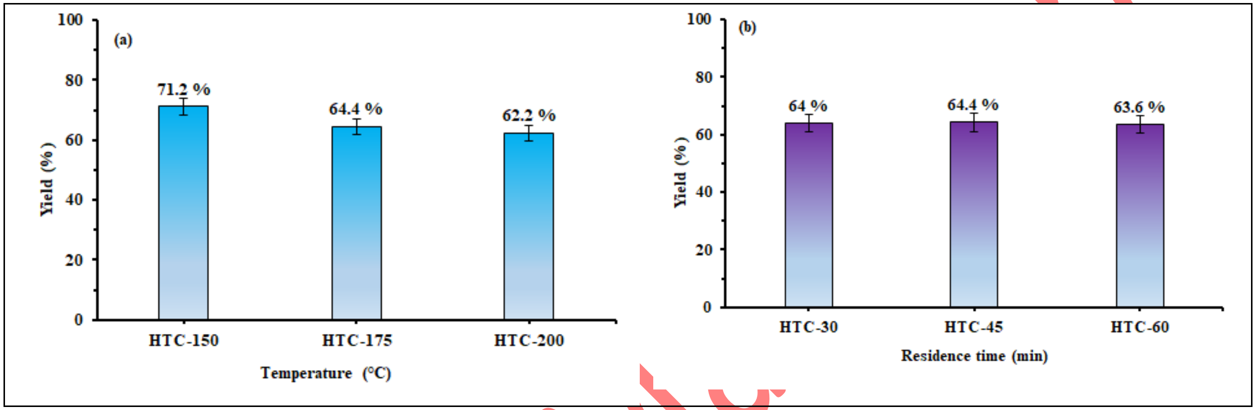

Fig. 1. Hydrochar produced of the SWT via HTC processes, (a) hydrochar produced at different temperatures, (b) hydrochar produced at different residence times

3.2. **HHV values**. HHV of solid carbon fuel hydrochar yield at differenr temperatures and contact periods is detailed as in Table 1 and Fig. 2. Fig. 2a shows the HHV of SWT and hydrochars at various temperatures, whereas Figure 2b shows the HHV of SWT and hydrochars at varied resident residence periods. As a result, the temperature had a negative impact on [24]. The HHV of the SWT was 2.4 kJ/kg [25]. HTC@60 min - 200°C = 6.88, HTC@60 min - 175°C = 6.5, and HTC@60 min -150°C = 6.2 kJ/kg were the greatest and lowest HHV values, respectively. The greatest HHV was HTC@60 minutes - 200°C = 6.88 [26]. While the lowest HHV was HTC@60 min - 150°C = 6.2 kJ/kg. The reaction of duration time of 60 min was appropriate for all reaction temperatures, increasing the HHV. Hydrochar formed at different reaction temperatures was enhanced. Fuels' combustibility was determined by scheming the HHV of the fuel burned [27].

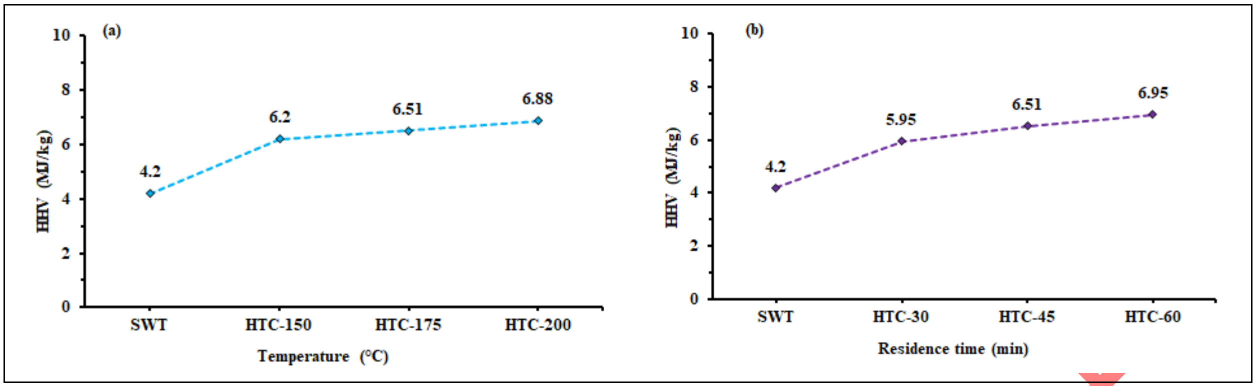

Fig. 2. HHV of SWT and hydrochar, (a) hydrochar produced at various temperatures, (b) hydrochar produced at different residence times.

The high heating value of hydrochar at range residence duration was sorted greatest to lowest was HTC@200°C - 60 min = 6.95, HTC@200°C - 45 min = 6.51, and HTC@200°C - 30 min = 5.95. As a result, these findings indicate that the optimal HTC residence time to production of alternative solid carbon fuel hydrochar is approximately 760 minutes [28]. The reaction temperature of 200°C was adequate for the full reaction residence time, boosting the HHV yield. This study found that SWT-derived hydrochar exhibited a considerable increase in HHV when compared to the raw material SWT. The duration time reaction directly influenced the HHV [29]. The results showed that the HHV has been enhanced [30].

3.3. **HHV improvement**. The percentage of HHV improvement hydrochar yield at different temperatures and contact times were detailed in Table 1, Fig. ~~4~~ 3. Figure ~~4a~~ 3a shows the percentage of HHV improvement hydrochars produced at various temperatures, and Fig. ~~4b~~ 3b shows the percentage of HHV improvement hydrochars produced at different resident residence times [31]. The resultant percentage of HHV improvement was consistent with upgraded fuel characteristics. HTC@200°C - 60 min showed the highest percentage of HHV improvement (65.9%). As a consequence, the percentage of HHV enhancement via diverse residence times was superior to various reaction temperatures [32]. The highest percentage of HHV improvement was HTC@60 min - 200°C = 45. The results percentage of HHV improvement was compatible with upgrade fuel properties [25]. The results of HHV improvement were indicated that these results were suitable to develop of the fuel properties [33].

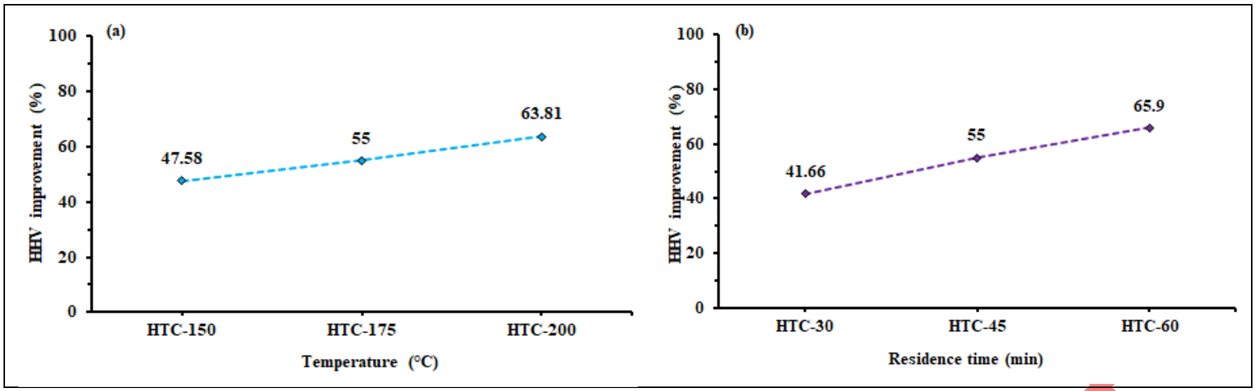

Fig. 3. HHV improvement of hydrochars (a) hydrochar produced at various temperatures, (b) hydrochar produced at different residence times.

3.4. **Proximate and ultimate analysis**. Table was detailed the proximate and ultimate analysis of SWT, hydrochars. The proximate analysis is an appraisal of the relative quantities of fixed carbon (FC) volatile matter (VM), and (Ash), while the ultimate analysis evaluates the relative content of individual rudiments such as C, H, N, S, and O [34]. The results demonstrate that the SWT has low volatile metals (40.60%), low ash (25.2%), and a high carbon content (29.69%). Perhaps reactions in HTC processes, such as decarboxylation and dehydration, will occur in a short time [35].

Table 2. The proximate, fuel ratio, and ultimate analysis of SWT and optimum hydrochars

Characterizations		**SWT**	**HTC@45 min - 200°C**	**HTC@200°C - 60 min**
Proximate analysis	VM%	41.60	40.11	39.45
	Ash%	25.20	28.31	27.75
	FC%	28.69	31.58	32.80
Fuel ratio	FC/VM	0.68	0.78	0.83
Ultimate analysis	C %	38.16	41.22	41.15
	H %	8.15	6.12	6.22
	N%	4.32	3.72	3.15
	O%	49.37	48.94	49.48

3.5. **Upgrading the SWT properties as a solid Fuel**. Figure 4 depicts the fuel ratio FR (FC/VM) of SWT and hydrochar produced across a range of contact times. The highest fixed carbon percentage of the hydrochar generates a less angry flame and supports stable combustions; nevertheless, the high VM concentration of hydrochar causes unstable combustion due to poor heat balance burning [36]. The fuel ratio of hydrochar increased as the reaction temperature rose. This could be owing to a considerable fall in VM at higher treatment temperatures, whilst the upsurge in FR can be interpreted as an enhancement in fuel properties through hydrothermal treatment. Given the product hydrochar yield and energy-related qualities connected with the produced high-quality fuel, it is reasonable to conclude that the attributes of hydrochar were improved during HTC [37]. The FR of SWT to hydrochar yield was raised from 0.68 SWT to 0.78 HTC@200°C for 45 minutes and 0.83 HTC@60 minutes at 200°C. The highest FR was 0.83, which resulted in a 22.06% rise at 200°C for 60 minutes. This research indicates that SWT's hydrothermal treatment has a strong energy recovery potential. The FR of hydrochar displayed a diverging trend in changing indices FR grew until the treatment temperature reached 200°C, 60 minutes, and then declined to more than 200°C, 45 minutes [38]. This finding was consistent with the results of the proximal analysis. A residence time of 60 minutes may be adequate for all reaction temperatures, increasing the ash content while decreasing the VM contents of the fuel.

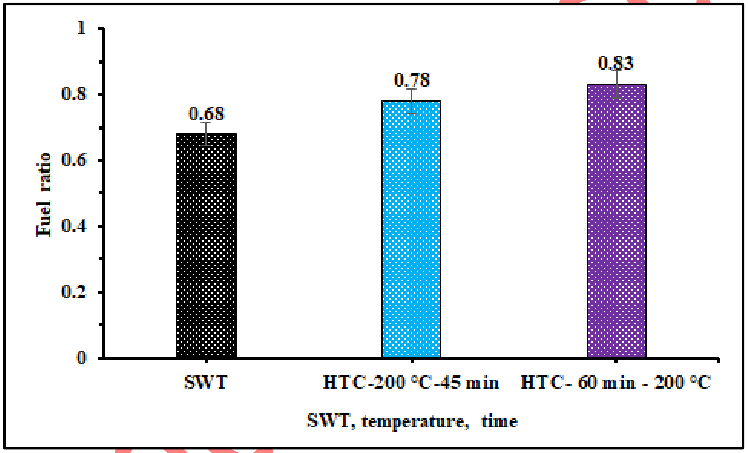

Fig. 4. Fuel ratio of SWT, HTC@200°C- 45 min, and HTC@60min - 200°C.

Furthermore, to assess the HTC technic efficiency, the enhanced energy of the solid carbon fuel product was evaluated after it was produced by the HTC method [39]. As a result, the HTC technic was evaluated by fuel ratio, which was affected by the decreased product yield and increased heating value [40]. The ER achieved a maximum of 105.74 % at 200°C for 60 minutes. This was caused by the HTC process because the dehydration and decarboxylation reactions higher the temperature [41]. According to Kambo and Dutta's observations, the SWT's ER generally decreased as the reaction temperature increased [42]. However, after HHV enhancement, HTC@200 achieved a score of 105.21 %, whereas HTC@60 scored 105.74 %. Based on the findings, it can be inferred that HTC can improve the fuel characteristics of hydrochar from the SWT [35].

3.6. **Energy recovery**. The recovered energy (ER) was calculated after the hydrochar was formed to determine and compare the hydrochar's burn efficiency. Table 1 and Figure 5 depict the

ER of hydrochar formed at different temperatures and residence durations. Figure 5a illustrates the EY of hydrochar created at different temperatures, while Figure 5b shows the energy recovered from hydrochar produced at different residence times. This finding implies that the HTC therapy of SWT was quite detrimental in terms of ER potential. SWT's maximum ER potential was 33.43 of HTC at 200°C for 75 minutes [43]. HTC was treated at a temperature of 200 degrees Celsius. ER and EY enhanced the mixture hydrochar product yield and calorific value. The HTC technique enhanced the hydrochar combustion efficiency compared to SWT. As can be seen, the composition of hydrochar varies with HTC reaction temperature and residence time [44]. The reaction temperature of 200°C was adequate for all reaction residence times, resulting in a higher ER of the hydrochar. HTC treatment at higher temperatures improves hydrochar formation and ER [45].

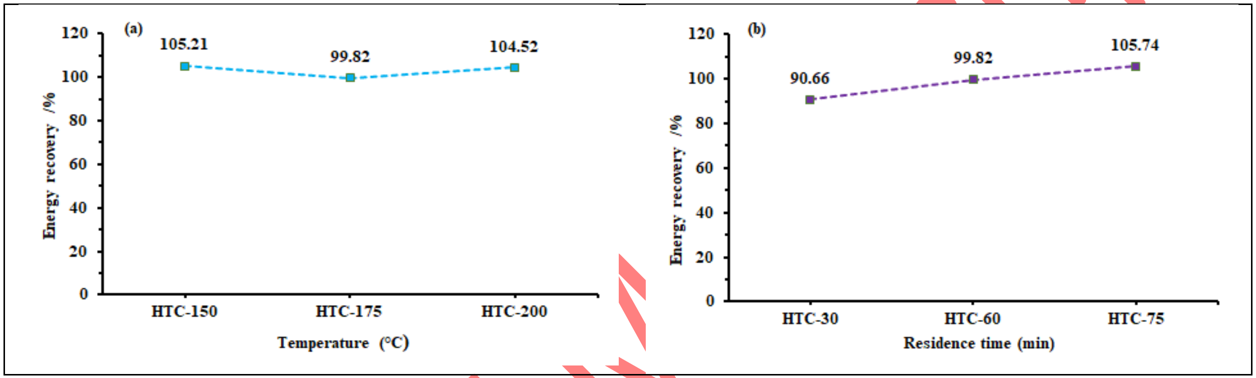

Fig. 5. Energy recovery of hydrovhar (a) hydrochar produced at various temperatures, (b) hydrochaer produced at different residence times.

3.7. **Energy Yield**. The EY of hydrochar during the HTC process of SWT is illustrated as in Table 1 and Fig. 6. Figure 6a shows EY of solid carbon produced at several temperatures, and Fig. 6b shows EY of solid carbon fuel produced at different contact times [46]. With the increase in temperature degree the EY of hydrochar increased rapidly and then increased slightly, while EY at residence times were slightly increased. The EY (104.52%) of hydrochar produced at 200°C and 60 min. While the EY of hydrochar produced at different residence times was 67.25 of HTC 75 min was the highest in the condition of HTC residence time, which increased by 6.12% [47]. The percentage of increase were in reaction temperature was better than in residence time. After the HTC process, the EY change was not obvious because the reactions reached relative equilibrium. The results showed that the EY of hydrochar could be improved during the HTC process [48].

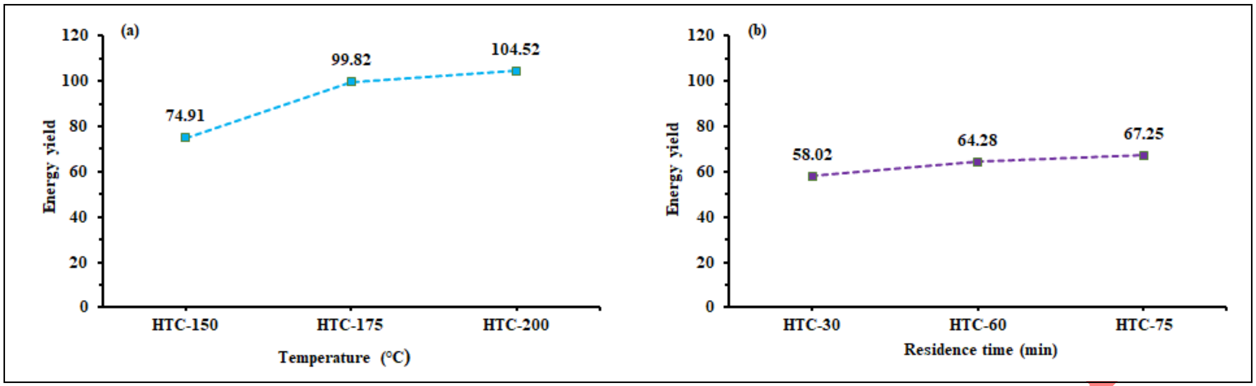

Fig. 6. Energy yield of hydrovhar (a) hydrochar produced at various temperatures, (b) hydrochaer produced at different residence times.

CONCLUSIONS

In study addressed the manufacturing of hydrochar and its energy characteristics using SWT's HTC technology. HTC treatment enhanced reaction temperature, improved HHV, and reduced SWT combustion stage in air combustion. The results showed that temperature had an effect on solid yield up to 200°C, beyond which it dropped. While the effect of duration time on solid product was favorable, it was discovered that the solid product grew as the contact time increased, indicating that the impact of residence time was most effective for the longest time attained (60 minutes). The carbon content measurement revealed that the best hydrochar was achieved at 200°C for 60 min. The solid result can be used as a fuel for combustion due to the efficiency with which the hydrochar fuel is burned. The researchers did not previously specify that the HTC process must incorporate feed volume, pressure, temperature, and duration. At the start of the experiment, fill the reactor with water and manually mix it in the absence of a mixer, followed by pressure, temperature, and contact duration. The results showed that the HHV of the SWT was increased from 4.2 to 6.95 kJ/kg hydrochar, resulting in a 72.88% recovery, suggesting that the hydrochar produced was converted to an excellent solid carbon fuel. This increase in HHV supports the utilization of SWT converted during HTC process to provide solid fuel for energy production. The large amounts of SWT accumulated as greenhouse waste can be convert by HTC technic for solid carbon fuel production.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest requiring the disclosure in this article.

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