Preparation of biofuel pellets from water hyacinth and waste coffee grounds

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Abstract

This research dealt with the preparation of biomass fuel pellets from water hyacinth and spent coffee grounds with an aim to obtain the composite pellets with highest calorific value. The benefits of producing biomass fuel pellets in this work were to explore an alternative energy source from local renewable wastes and also reduce the water hyacinth, one of the world's worst aquatic weeds that contributed to the environmental pollution. The fuels were produced from dried biomass and formed into the cylindrical bar with diameter of 6 millimeters and typically 1-2 centimeters length using pelletizing machine. The effects of raw material composition and starch concentration used in binder on fuel properties were investigated. The composite pellets were produced using different mixing ratios of water hyacinth: coffee grounds of 100:0, 90:10, 80:20, 70:30, and 60:40 by weight. Cassava starch paste was used as binding agent using various concentrations of starches in the paste of 5%, 10%, 15%, and 20% (w/w). The properties of prepared pellets including calorific value, moisture, ash, volatile, and fixed carbon content were characterized. The results of this work presented the highest calorific value of fuel pellets that was equal to 17.19 MJ/kg with 5.61% moisture, 11.08% ash, 73.20% volatile matter, and 10.11% fixed carbon content found in the pellets with the composition of water hyacinth and coffee grounds as 60:40. Moreover, the starch content in the paste (5-20% w/w) was found to have no significantly effect on the fuel properties. The study also found that the pellets had moisture content, and the calorific value in the levels acceptable under wood pellet standard. This study demonstrated that water hyacinth weed mixed with waste coffee grounds were potential candidates to produce biofuel pellets.

Keywords: biomass wastes, solid biofuels, fuel pellets, water hyacinth, coffee grounds, alternative energy

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Received: October 14, 2020; Revised: October 30, 2020; Accepted: November 23, 2020

Introduction

Due to the continuous depletion of the limited fossil fuel reserves and the excessive emission of CO_2, investigations of clean alternative energy have been continuing widely. Bioenergy is one potential option to migrate the effects of fossil fuel use. Among renewable biofuels, lignocellulosic biomass has significant potential to be used as an alternative and sustainable energy source for biofuel production due to its availability, abundance and relatively low cost. Moreover, biomass is referred to as a carbon neutral fuel because there is no net addition of carbon dioxide in atmosphere unlike fossil fuel. The source of biomass can range from agricultural crop residues, forestry residues, weeds, industrial residues, and municipal wastes. Biomass wastes can be used in many useful applications (Bani-Hani, 2017; Jairuan, Pairintra & Sudaprasert, 2017; Lee et al., 2019). Converting biomass into a solid fuel through pelletization process appears to be another attractive solution in utilizing biomass wastes. Pelletizing is a technology to obtain dense, lower moisture and uniform biofuel solids with higher heating value compared to raw materials (Karwandy, 2007; Kaliyan, & Morey, 2009; Castellano, Gomez, Fernandez, Esteban, & Carrasco, 2015). Pellets can be used in many energy conversion units, including household stoves, boilers and power plants (Karwandy, 2007; Ungureanu, Vladut, Voicu, Dinca, & Zabava, 2018).

Water hyacinth is an aquatic weed waste, which causes severe environmental problems in Thailand and many countries (Figure 1). The fast growth of water hyacinth causes many problems such as restricting movement of water, blocking sunlight from penetrating the water surface and reaching native aquatic plants, and reducing oxygen contents in the water. The abundance of the rapidly growing water hyacinth weed shows both environmental challenges and opportunities for developing bioenergy. It is envisaged that water hyacinth is a potential biomass feedstock for the production of fuel pellets because of its rapidly growth yield and availability in large amount throughout the year (Hudakorn, & Sritrakul, 2020). Since the water hyacinth biomass has relatively low heating value compared to other biomass, so the pellets would need to be mixed with other biomass sources to improve the heating values (Munjeri, Ziuku, Maganga, Siachingoma, & Ndlovu, 2015; Sukarni et al., 2019). An alternative method is to mix water hyacinth with spent coffee grounds. Coffee ground is one of the waste biomasses that can be used as an alternative energy source. The global coffee beans consumption reached 10.5 million tons in 2018. Moreover, the coffee beans manufacturing generates 91% of waste biomass in the form of spent coffee grounds. The large amount of coffee residue produced all over the world and high calorific value of spent coffee grounds indicates its potential utilization as biofuel solid (Kristanto, & Wijaya, 2018; Elmously, Jager, Apfelbacher, Daschner, & Hornung, 2019; Nosek, Tun, & Juchelkova, 2020).

Figure 1 Water hyacinth in a river.

Although numerous studies related to the utilization of a variety of biomass waste for solid biofuels have been conducted by numerous published researches such as mangosteen peel briquettes (Asavrukulchai, Semsayan, Prapakdee, Piamsuansiri, & Choochart, 2011), water hyacinth (Munjeri, Ziuku, Maganga, Siachingoma, & Ndlovu, 2015), pineapple peel briquettes (Tantisatayakul, Saidam, Phusongsri, & Ngernruengroj, 2015), biosolid and wood waste pellets (Sukarta, Sastrawidana, & Ayuni, 2018), cow manure (Anatasya, Umiati, & Subagio, 2019), filter cake pellet (Pajampa, & Wongwuttanasatien, 2019), corncobs and oil palm trunk bark briquettes (Kpalo, Zainuddin, Manaf, & Roslan, 2020), the use of blends of water hyacinth and coffee grounds as feedstock for composite pellets have not been conducted yet.

This work aims to produce biofuel pellets made from blends of worst aquatic weed waste and food-industrial waste, using water hyacinth as its main composition, spent coffee grounds as minor ingredient, and starch paste as binding agent, to obtain with highest calorific value. The effects of raw material ingredients and starch concentration in the binder that enhances the calorific value of the biofuel pellets were investigated. Several parameters involved in these biomass pellets are calorific value, moisture, ash, volatile matter content, and fixed carbon were characterized.

Methodology

Raw materials

Water hyacinths were collected from rivers in Chachoengsao province of Thailand. Spent coffee grounds were received from Nailar Coffee Roasting Factory in Thailand. Agro-industrial wastes, low-quality cassava starch rejected was collected from starch manufacturers in Thailand.

Binder preparation

Aqueous slurry of cassava starch was made with tap water (5-20% w/w) and then heated over a water bath with stirring until a clear solution was obtained. The resultant starch paste was used as a binding agent in the pellet preparation.

Fuel pellet preparation

The preparation of fuel pellets was performed in six steps (Garcia-Maraver, & Carpio, 2015) : i) sun drying the fresh biomass raw materials for a week (for fresh water hyacinth, they were cut to approximately 1-2 centimeters size before drying), ii) grinding and screening to produce the biomass powder with a sieve size of 2 millimeters to ensure uniform grain size and ease of pelletization, iii) combining the biomass powder with known mass of raw material ingredients (water hyacinth and coffee grounds), iv) blending the mixed biomass with starch paste at a weight ratio of 2:1, v) forming cylinder-shaped agglomerate through pelletizing machine (Model SF-125, SEREN, China) (Figure 2), and vi) sun drying the obtained pellets for 6 days. Each experiment was performed in triplicate. The obtained pellets were kept in zip lock plastic bags to prevent moisture absorption before analysis. The pellet samples in this work were shown in (Figure 3).

Figure 2 Pelletizing machine.

Figure 3 Pellets produced from water hyacinth and coffee grounds (60:40).

Experimental method

Optimization experiment in this study was separated into 2 parts that are optimization of raw material mixing ratio and optimization of binder concentration.

Optimization of raw material mixing ratio

The fuel pellets was produced by water hyacinth and coffee grounds at the weight mixing ratios of 100:0, 90:10, 80:20, 70:30 and 60:40. The raw material mixture was added with the binder in a weight ratio of 1:1. The binder as starch paste used in this experiment was 5%

starch concentration (w/w). The fuel properties of the obtained pellets were analyzed to find the optimum ratio of ingredients providing the highest calorific value.

Optimization of binder concentration

The second part, fuel pellets was produced from the optimum raw material ratio selected from the first part of the experiments. The raw material mixture was added with the binder at the weight ratio of 1:1. The binders were prepared in four different starch concentrations of 5%, 10%, 15% and 20% in solution (w/w). The obtained pellets were characterized to study the effect of starch concentration in the binder used.

Characteristic analysis

The prepared pellets were characterized using analysis methods as shown in (Table 1) (Trangkaprasith, & Chavalparit, 2011). All the measurements were carried out in triplicate, and the results were averaged to obtain a mean value.

Table 1 Analysis methods for calorific value and proximate testing.

parameter	unit of measurement	analysis method
calorific value	MJ/kg	ASTM 5865, standard test method for gross calorific value of coal and coke
moisture content	% (w/w)	ASTM D3173, standard test methods for moisture in the analysis sample of coal and coke
ash content	% (w/w)	ASTM 3174, standard test methods for ash analysis of coal and coke
volatile matter content	% (w/w)	ASTM 3175, standard test methods for volatile matter in the analysis sample of coal and coke
fix carbon content	% (w/w)	ASTM D3172, a standard practice for proximate analysis of coal and coke (100 minus ash content, moisture content, and volatile matter)

Statistical analysis

Statistical analysis was conducted with Minitab 17 Statistical Software, using a 5% significant level. *P-values* below 0.05 were considered statistically significant (Williams et al., 2018).

Results and discussion

Optimization of raw material mixing ratio

In order to determine the differences in the quality of fuel pellets prepared by the addition of ground coffee in water hyacinth biomass with five compositions (mixing ratios of water hyacinth to coffee grounds of 100:0, 90:10, 80:20, 70:30, 60:40), the calorific value and proximate analysis of composite pellet samples were carried out and summary in (Table 2). The calorific values (heating values) of pellet sample were determined by using bomb calorimeter according ASTM 5865. (Figure 4) presents the calorific values of the pellet samples.

Table 2 Calorific values and proximate analysis of pellets produced with different mixing ratios of water hyacinth and coffee grounds.

the mixing ratios of water hyacinth: coffee grounds	moisture (%)	ash (%)	volatile matter (%)	fixed carbon (%)
100:0	$7.26^{a} \pm 0.13$	$15.89^{a} \pm 0.15$	$62.64^{e} \pm 0.61$	$14.21^{a} \pm 0.26$
90:10	$6.94^{b} \pm 0.15$	$15.70^{b} \pm 0.18$	$63.57^{d} \pm 0.54$	$13.79^{b} \pm 0.42$
80:20	$6.78^{c} \pm 0.09$	$13.82^{c} \pm 0.24$	$66.75^{c} \pm 0.42$	$12.65^{c} \pm 0.26$
70:30	$6.12^{d} \pm 0.16$	$12.56^{d} \pm 0.22$	$69.98^{b} \pm 0.59$	$11.34^{d} \pm 0.31$
60:40	$5.61^{e} \pm 0.15$	$11.08^{e} \pm 0.25$	$73.20^{a} \pm 0.83$	$10.11^{e} \pm 0.27$

Note: Mean with different letters indicate significant differences among columns for each sample ($p<0.05$).

A significant indicator of the quality of pellets is the calorific value (heating value), which measures of the energy content of the fuel. It is defined as the amount of heat generated when a mass of fuel is burned completely and the products of combustion are cooled (Sukarta, Sastrawidana, & Ayuni, 2018; Lunguleasa, Spirchez, & Zeleniuc, 2020). As shown in (Figure 4), the calorific value of the pellets was in the range of 13.80-17.19 MJ/kg. The highest calorific value in the amount of 17.19 MJ/kg was found at mixing ratio of 60:40, while the one prepared using mixing ratio of 100:0 (pure water hyacinth) had the lowest calorific value as 13.80 MJ/kg. It was found that the calorific value of pellets was increasing with the quantity of added coffee grounds. Therefore, the mixing ratio of water hyacinth and coffee grounds had significant effect on the calorific value of pellets ($p<0.05$). Results indicated that adding coffee grounds to pellet formulation improved heating value of pellets produced in this work. This is consistent with Solowiej, & Neugebauer (2016) in suggesting that coffee grounds can be good additive to biomass for raising their calorific value.

In this work, the water hyacinth was incorporated as the main constituent in the pellets and thus the ratio of water hyacinth: coffee grounds reach to 60:40. Therefore, the mixing ratio of 60:40 was found to give the highest heating value in this experiment. If the mixing ratios are increased (i.e., 50:50, 40:60), the calorific values will also increase and thus the mixing ratio of 0:100 (100% coffee grounds) should give the highest calorific value.

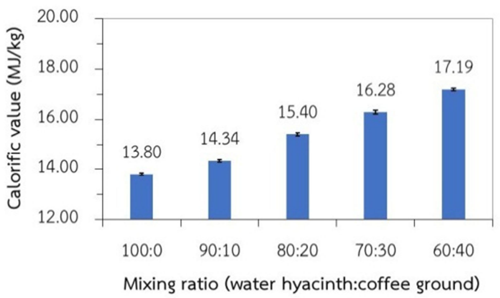

Figure 4 Calorific value of fuel pellets produced from water hyacinth mixed with coffee grounds at different mixing ratio.

The moisture content of the pellets in this experiment ranged from 5.61-7.26% that agrees with literature recommendation (5 to 12%) for good quality of solid fuels as reported by Chin, & Siddiqui (2000). The highest moisture content was found in pellets with the mixing ratio of 100:0, while the lowest moisture content was found in the sample having mixing ratio of 60:40. It was observed that moisture content decreased with increasing coffee ground proportion. The water content is an important characteristic that affects the combustion characteristics of the fuels. It related with the ignition first. The higher moisture content in pellets inhibits the combustion process and thus it makes harder the ignition first than less moisture content (Kristanto, & Wijaya, 2018; Moelyaningrum, Molassy, & Setyowati, 2019).

Ash is an inorganic constituent that remains as a residue after combustion of organic matter (Xayyasene, Thongsiya, Phengmeangkhune, Hunt, & Ngernyen, 2019). The ash content of biomass indicates slagging behavior. Biomass pellets with higher ash content is considered of poorer quality because it results in poorer combustion performance and increase routine cleansing required with boilers. Therefore, there is a need to have a low ash content so as to meet quality standards (Hytönen, & Nurmi, 2015). From (Table 2), the ash content of the pellets produced in this study ranged from 11.08% to 15.89%. The highest ash content of 15.89% was found at mixing ratio of 100:0 (pure water hyacinth), while the lowest ash content (11.08%) was found in the sample having mixing ratio of 60:40. Lower ash content was observed in pellet sample what have higher calorific values. The higher ash content gives the lower calorific value for the pellets. This is because ash does not generate energy. This was in agreement with the work of Xayyasene, Thongsiya, Phengmeangkhune, Hunt, & Ngernyen (2019).

Volatile matter (volatile ingredient) is the actual combustible matter in the fuel. High volatile matter content results in easing ignition and enhancing combustion (Lubwama, & Yiga, 2017). The volatile matter of the pellets prepared was in the range of 62.64-73.20% as shown in the (Table 2). The highest volatile matter content in amount of 73.20% was observed in pellets having mixing ratio of 60:40. On the other hand, the lowest volatile matter content equals to 62.64% which was found in pellets having mixing ratio of 100:0 (pure water hyacinth). Results indicated that adding coffee grounds to pellet formulation increased volatile matter content of the pellets. In addition, if the mixing ratios are increased (i.e., 50:50, 40:60), the volatile matter contents will also increase and thus the mixing ratio of 0:100 (100% coffee grounds) should give the highest volatile matter.

Fixed carbon is the carbon that remains after the volatile matter is released from the combustion process. It used as an estimate of the amount of coal that will be produced from the sample of a fuel material (Sukarta, Sastrawidana, & Ayuni, 2018). The fixed carbon content of the pellets produced was in the range of 10.11-14.21%. The highest level of carbon (fixed carbon) in the amount of 14.21% was found in the pellets with pure water hyacinth (mixing ratio of 100:0), while the lowest reached 10.11% in the pellets with the mixing ratio of 60:40. It was observed that the fixed carbon exhibited decrease as the quantity of added coffee grounds increased.

Results indicated that the composition in pellets can play vital role in the calorific value and the parameters of proximate analysis of the obtained pellets. Adding coffee grounds to pellet formulation increased heating value and volatile matter content, but it decreased moisture, ash and fixed carbon content. Therefore, the pellets produced from mixture of water hyacinth and coffee grounds pellets could be better biofuel than one from water hyacinth alone. The optimum mixing ratio of water hyacinth to coffee grounds in this study was 60:40.

Optimization of binder concentration

The fuel pellets prepared from different concentration of starch in binder of 5, 10, 15, and 20% at fixed mixing proportion of 60:40 (water hyacinth: coffee grounds) were investigated. From the (Table 3), the calorific values of pellets with different starch concentrations have small differences. There was no statistically significant difference between heating values of prepared pellets ($p>0.05$). This may be due to the small difference in starch concentration (5-20% w/w) used in this study. In addition, the binder prepared from starch concentration greater than 20% (w/w) was not used in this study because its high-viscosity make it difficult to prepare the well-mixed paste and use in pellet preparation. However, the results showed that the higher starch concentration used in the fuel preparation tend to reduce the calorific value of the obtained composite pellets. This was because the composite pellet (blends of water hyacinth and coffee grounds at 60:40) provide high calorific value (approximately 17 MJ/kg), while the cassava starch has low calorific value average as 15 MJ/kg (Handra, Kasim, & Santosa, 2018). Therefore, the calorific value of the obtained pellet could be reduced with further increase in the starch concentration used in the pellet preparation. Moreover, the physical properties of pellets, such as the moisture content, fixed carbon, volatile matter, and ash content, were within narrow ranges of 5.53-5.66%, 9.81-10.46%, 73.20-74.22%, and 10.59-11.08%, respectively.

Table 3 Calorific value and proximate analysis of water hyacinth and coffee grounds pellets with different starch concentration in the binder.

the starch concentration used as binder (% w/w)	moisture (%)	ash (%)	volatile matter (%)	fixed carbon (%)	calorific value (MJ/kg)
5	5.61±0.15	11.08±0.25	73.20±0.83	10.11±0.27	17.19±0.04
10	5.54±0.20	10.68±0.32	73.32±0.55	10.46±0.44	17.19±0.06
15	5.66±0.18	10.59±0.24	73.66±0.63	10.09±0.35	17.16±0.03
20	5.53±0.08	10.59±0.19	74.22±0.45	9.81±0.60	17.13±0.07

Properties of fuel pellets

The properties of fuel pellets prepared in this study were compared to the results of some previous researches with different biomass feedstocks and wood pellet standard EN 14961-1, as presented in (Table 4). It was shown that the properties including calorific value, fixed carbon, moisture, volatile matter and ash content of pellets produced in this work are in good agreement with solid biofuels prepared from various types of biomass. In addition, the pellets produced from water hyacinth and coffee grounds (with calorific value of 17.19 MJ/kg) was found to have higher calorific value than filter cake biomass fuels (11.71 MJ/kg), pineapple peel (13.90 MJ/kg), cow manure (16.36 MJ/kg), and corncobs and oil palm trunk bark (16.91 MJ/kg), but lower than mangosteen peel fuels (18.20 MJ/kg). The calorific value and moisture content of the pellets produced in this work are in the range of standard value of wood pellet, while the ash content is higher than standard.

Table 4 Properties of fuel pellets prepared from this work compare with other studies and wood pellet standard.

properties	biomass fuel pellets or briquettes made from different raw materials						wood pellet standard EN 14961-1
	corncob and oil palm trunk bark[1/]	pineapple peel[2/]	mangosteen peel[3/]	filter cake[4/]	cow manure[5/]	water hyacinth and coffee grounds (60:40)	
moisture (%)	9.24	17.80	5.65	5.33	4.48	5.61	≤10
volatile matter (%)	-	62.90	86.55	51.33	57.72	73.20	-
ash (%)	-	3.30	5.03	35.67	39.55	11.08	≤0.7
fixed carbon (%)	-	15.90	2.77	7.67	2.73	10.11	-
calorific value (MJ/kg)	16.91	13.90	18.20	11.71	16.36	17.19	≥16.5

Note: [1/] Kpalo, Zainuddin, Manaf, & Roslan (2020).

[2/] Tantisatayakul, Saidam, Phusongsri, & Ngernruengroj (2015).

[3/] Asavrukulchai, Semsayan, Prapakdee, Piamsuansiri, & Choochart (2011).

[4/] Pajampa, & Wongwuttanasatien (2019).

[5/] Anatasya, Umiati, & Subagio (2019).

Conclusion

In summary, the composite pellets were developed from blends of local aquatic weed as water hyacinth and waste coffee grounds using cassava starch paste as a binder agent. The solid fuel preparation by pelletization technique is simple and does not require heat input. The mixing ratio (raw material composition) was found to significantly affect the heating value and physical properties of the obtained pellets. The combination of different biomass materials by adding coffee grounds to water hyacinth can enhance the heating value of fuel pellets. The highest calorific value (17.19 MJ/kg) was produced by pellets made from 60:40 mixing ratio of water hyacinth and coffee grounds. However, starch concentration in the paste used as the binder in the pellet preparation had no significant effect on the fuel properties. Moreover, the pellet properties, including heating value and moisture content, were compared to wood pellets standard and agreed well within the wood pellet standard. However, high ash content of the pellets was a drawback. The results demonstrated that the fuel pellets produced from blends of water hyacinth and coffee grounds can be considered to be one of alternative fuels. It could offer an opportunity to mitigate aquatic environmental problems by utilizing and reducing the amount of water hyacinth, increase value of industrial waste and tackle problems of energy shortages.

Acknowledgement

This research was supported by the Faculty of Science and Technology, Rajabhat Rajanagarindra University.

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