Feasibility of Analyzing Wood-Based Derivatives Combustion Emission Gas to Develop "Biomass Charcoal Briquettes"

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Feasibility of Analyzing Wood–Based Derivatives Combustion Emission Gas to Develop "Biomass Charcoal Briquettes"

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To enhance the utilization of wood–based derivatives and to reduce the gaseous emissions during combustion, this study used wood processing residues from Japanese cedar (JC) as a precursor, and prepared JC charcoal (JCC) in different carbonization temperatures. The combustion emission gas was analyzed by Continuous Emission Monitoring (CEM) based on the briquetting conditions, such as the JCC particle size, the mixing percent weight with charcoal and pulping byproduct lignosulfonate (JCC/LS, wt%), and the predetermined density of charcoal briquette (PD). The briquetting conditions with less gaseous emission was developed into "Biomass Charcoal Briquettes (BCB)" by cold pressing. The JCC yielded at the range of carbonization temperature of 300–600°C was 33.22–42.09%. The heating values of JC and various JCCs were 15.54 MJ/kg and 24.51–28.54 MJ/kg, respectively. The power consumption and CO_2 emission were the lowest at the carbonization temperature of 300°C. To develop BCB, the JCC particle size 100–200 mesh at 90/10 wt% and 0.6 g/cm³, 80/20 wt% and 0.6 g/cm³, 80/20 wt% and 0.8 g/cm³ and 80/20 wt% and 1.0 g/cm³ of JCC/LS and PD had less gaseous emission. The heating value of BCBs was 21.02–22.68 MJ/kg, which was higher than that of JC by 45.94%. The heating value of the BCB with the same mixing percent weight increased with the PD. The "BCB" increases the value–added of wood–based derivatives, and evaluates the combustion emission gas in the briquetting condition before briquetting preparation can serve as a reference for developing biomass energy.

Key words: Wood–Based Derivatives, Continuous Emission Monitoring (CEM), Combustion Emission Gas, Biomass Charcoal Briquettes (BCB), Heating Value

INTRODUCTION

The biomass energy is physically, chemically, and biologically transformed from biomass into solid, liquid, and gaseous energies with physical and chemical characteristics. The preparation techniques include biomass gasification, liquefaction, and pyrolysis (Demirbas, 2004). The biomass is transformed by pyrolysis into charcoal with high carbon content and a higher heating value, such as the fermentation residue – Sorghum Distillery Residue (Lin *et al*., 2021). The wood–based residues often processed with incineration or landfill. The produced gas by these processes is the part that influences the greenhouse effect (EPA, 2021a). The charcoal, transformed from the residues, can use as biomass energy, and the greenhouse gas can reduce possibly. The wood–based derivatives include wood processing residues and pulping byproduct. The average residues of Taiwan's lumber mills accounts for about 21.6% (86,000 m³) of the wood–based materials (EPA, 2021b). These wood–based derivatives are biomass and have a potential for renewable energy (Wamukonya and Jfnkins,

1995). In terms of the byproducts generated in the course of pulping and papermaking, the lignosulfonate (LS) is derived from the sulfite process or alkaline pulping. Its molecular structure comprises three basic structural units including hydroxybenzene propyl, guaiacyl, and syringyl. It is a good water–soluble anionic surfactant for containing such hydrophilic groups as a sulfonic group, carboxyl group, and phenolic hydroxyl group, and can used as a dye dispersant, boiler anti–scaling compositions, and aqueous solution thickening agent (Laurichesse and Avèrous, 2013).

The fossil fuels have used in the Industrial Revolution and the greenhouse gases have accumulated in the atmosphere, which influences the human being and environment. In general, the gas contaminations (emission contents, ppm), such as CO, SO_2, NO_X, and C_XH_Y, detected from Continuous Emission Monitoring (CEM) during the combustion at thermal power plants and waste incinerators (Lin *et al*., 2004; 2006; 2007a; 2007b; 2011; 2021). The elementary composition percentages of fuel can obtain from elemental analysis. In comparison to fossil fuel, biofuel has lower sulfur and nitrogen contents, which have lower emission of greenhouse gases (Liu, 2014). The biomass energy conversion technologies include direct firing and physical conversion. In physical conversion, the biomass residues crushed, screened and dried, and mixed with adhesive for molding. This produces solid fuel which is easy to transport and store. Reused derived fuel, wood pellet, and biomass charcoal briquettes (BCB) are some types

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of solid fuel (Kaliyan and Morey, 2008; Lin *et al.*, 2021). General solid fuel is used for combustion. The generated heat energy can be used as biomass energy. Combustion heat value can measure by using an adiabatic calorimeter (EPA, 2007). The heating value is the amount of heat released from the complete combustion of a substance, mostly represented by MJ/kg (ASTM D 2015, 2000).

This Japanese cedar (*Cryptomeria japonica*) wood processing residues pyrolyzed at different carbonization temperatures to prepare Japanese cedar charcoal. According to the heating value and power consumption, the better carbonization temperature and cohesive LS were selected to develop "BCB" subject to the utilization of wood–based derivatives. The briquetting conditions were likely to be influenced by particle size, mixing percent weight, and predetermined density. The gas combustion result was analyzed by CEM. The emission contents of CO, SO_2, NO_X, and C_XH_Y generated in various conditions were compared for the development of "BCB". Afterward, the heating value was determined by actual sampling point–selected, and compared with the other charcoals and fossil fuels. The developed BCB are expected to increase the utilization and value–added of wood–based derivatives, and reduce the gaseous emission during combustion of biomass energy.

MATERIALS AND METHODS

Test materials

Japanese cedar (*Cryptomeria japonica* D. Don; JC) wood processing residues was crushed into 4–8 mesh placed in a ventilated area for air–dried. lignosulfonate (LS) was the byproduct of the sulfurous acid pulping process. Its average molecular weight was 8×10^3 g/moL. It is brown yellow, soluble in water and insoluble in organic solvents. Commercially refined coal and available wood charcoals A and B were prepared from tree strip barbecue, produced in Vietnam.

Test method

Moisture content

Refer to CNS 452 (2018) Wood – Determination of moisture content for physical and mechanical tests to measure moisture content (MC).

Preparation of Japanese cedar charcoal

Absolute–dried weight 100 g of JC was put in the closed container of the super–high temperature vacuum carbonization equipment (Chi–How Heating Co., Ltd.). The gas N_2 was admitted, where the gas flow was 200 mL/min, in order that the container was free of oxygen. The carbonization temperatures were 300, 400, 500, and 600°C, the heating rates were 5°C/min and 10°C /min (Hayashi *et al.*, 2002; Inguanzo *et al.*, 2002), the carbonization process was completed, and the Japanese cedar charcoal (JCC) yield (%) was calculated by yield (%) = (absolute–dried weight of JCC / absolute-dried weight of JC)×100 (Lin *et al.*, 2015a; 2015b).

Power consumption

Power consumption (kWh) = electric meter reading of carbonization furnace turned off after carbonization was completed – electric meter reading before carbonization furnace was actuated.

CO_2 emission

The electricity carbon emission coefficient (CO_2 emission CO_2e, kg) = Power consumption (kWh)×0.509 (Taipower, 2005).

Element analysis

The carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) contents of the specimens were determined using the elemental analyzer (Elemental Vario CHNS/O Analyzer, EA, Germany), and oxygen (O) was calculated.

Combustion emission gas analysis

The specimens of biomass charcoal briquettes (BCB) at the preparing conditions of JCC particle size of, mixing percent weight of JCC to LS (JCC/LS, wt%), and predetermined density of charcoal briquette (PD), and BCB were placed in a 45° heating test device by Continuous Emission Monitoring (CEM). The emission contents (ppm) of CO, NO_X, SO_2 and CxHy were zero, and the volume concentration percentages (VOL %) of O_2 and CO_2 were the preset standard values: O_2 was 20.7%, and CO_2 was 0.2%. When the emission temperature was room temperature, liquid propane was used as the fuel, the temperature of the Bunsen burner was 837.5±6.5°C, and the flame temperature was tested by connecting the temperature recorder (MMS–3000–T6V4) to the high temperature probe. To know the emission pollution source, the emission contents from the combusted specimens were determined by flue–gas analyzer (E 8500 plus Flue–gas analyzer, USA), where the gas probe was connected to the 45° heating test device emission port to determine the emission gases from combustion (Lin *et al.*, 2004; 2006; 2007a; 2007b; 2011; 2021).

BCB preparation conditions

(1) Preparation of JCC particle size: Crushed by a pulverizer. Different particle sizes were screened out of screen mesh including 60–80, 100–200, and above 200 mesh. The JCC particle size was selected in accordance with the results of emission contents from CEM.

(2) The mixed percent weight of JCC/LS: After selecting the particle size of JCC, the mixing percent weight of JCC/LS was set at 90/10, 85/15, 80/20, 75/25, 70/30, and 60/40 wt% for thorough mixing. The emission contents were analyzed by CEM, and then the JCC/LS mixed percent weight was selected.

(3) The predetermined density of charcoal briquette (PD): after the charcoal particle size and JCC/LS selected, densities 0.6, 0.8, and 1.0 g/cm³ in the same volume condition calculated the JCC and LS weights. The LS and water mixed into a charcoal briquette. The briquette was dried in the oven at

103±2°C. The emission contents were analyzed by CEM, and then the PD was selected.

Cold–press molding of BCB

The BCB preparation conditions included JCC particle size (60–80, 100–200, and above 200 mesh), JCC/LS (90/10, 85/15, 80/20, 75/25, 70/30, and 60/40 wt%), and PD (0.6, 0.8 and 1.0 g/cm³). The JC processing residues was prepared into charcoal by carbonization which was ground charcoal powder (mesh). The charcoal powder was mixed with LS according to the mixing percent weight and PD. The LS and water were mixed into a briquette mat by 1:2 wt%, and was put into the mold having the following dimensions 10 (L)×10 (W)×1.8 (T) cm. The briquette mat was cold–pressed by oil press for 5 min. The BCB was obtained after decompression and demolding.

Heating value of BCB

Heating value determination of an actual specimen of BCB: The heating value performed with the actual sampling points–selected. The heating values at 10 points in the upper, middle, and lower parts of BCB were measured by an adiabatic calorimeter (1341 Plain Jacket Calorimeter), and then the average and standard deviation were calculated (Lin *et al.*, 2021).

Statistical analysis

The Statistical Product and Service Solutions 12 was used for Duncan's multiple range analysis. The charcoal yield and the heating value differences of JC, JCC, BCB, and fossil fuel were compared ($p<0.05$). The differences of the emission contents in different preparation conditions were determined by variation coefficient analysis. The heating values compared by independent sample T–test.

RESULTS AND DISCUSSION

Charcoal yield, heating value, and power consumption

The air–dried MC of JC and LS was 10.36 and 5.79%, respectively. The air-dried MC of the charcoal carbonized at 300°C was 3.72%. **Table 1** shows the charcoal yield, heating value of JC, LS and the JCC prepared at different carbonization temperatures, and power consumption and CO_2 emission of JCC. The JCC charcoal yields of carbonization at temperatures of 300, 400, 500, and 600°C were 42.09, 37.75, 35.17, and 33.22%, respectively. Lin *et al* (2021) indicate that the charcoal yield decreases as the carbonization temperature and time increases, and the heating value increases with carbonization temperature and time. After carbonization, the heating value of JC increased from 15.54 MJ/kg to 24.51–28.54 MJ/kg of JCC, about 1.58–1.84 times.

The power consumption increased with carbonization temperature and time. The power consumption of carbonization at the temperature of 600ºC was 8.0 kWh, which was 2.35 times of 3.4 kWh at the temperature of 300ºC. The CO_2 emission CO_2e is 0.509 kg CO_2e/kWh (Bureau of Energy, 2019). The CO_2 emission at the carbonization temperature of 600°C was 4.07 kg, which was 2.35 times of 1.73 kg at the carbonization temperature of 300°C. Considering energy saving and carbon reduction, the preparation condition–carbonization temperature of 300°C had a higher charcoal yield, minimum power consumption, and minimum CO_2 emission, this carbonization temperature was selected to develop BCB.

Elemental analysis

Friedl *et al* (2005) indicate that the elementary composition of biomass can used for estimating the heating value. The C, H, S, N, and O percentages of substances can obtain by elemental analysis. The C content in biomass was generally 45.70–50.50%. The C content in LS and JC was 45.51 and 51.89%; the H content was 9.07 and 11.85%; the N, and S contents were 0.16 and 0.20%, and 0.12 and 4.68% respectively, while the O content was 35.96 and 40.59% (**Table 2**). The JC was prepared into JCC at the carbonization temperature of 300°C and the C content increased from 51.89 to 74.48%. As the pyrolysis the H_2O, tar, CO, and CH bond rupture (Tang abd Bacon, 1964), the C content increases relatively (Hu *et al.*, 2000). The C content of JCC increased about 73.50%, and is close to commercial charcoals (Tejado *et al.*, 2007). The H and O contents decreased relatively. The H content decreased by about 62.62% and the N and S contents relatively increased

Table 1. Charcoal yield, heating value, of Japanese cedar, lignosulfonate and charcoals prepared at different carbonization temperatures, and power consumption and CO_2 emission of charcoals

Specimen [1]	Yield (%)	Heating value (MJ/kg)	Power consumption (kWh)	CO_2 emission (kg)
LS	–	15.43 (0.51)	–	–
JC	–	15.54 (0.57)	–	–
JCC–300	42.09 (0.76) [a3]	25.62 (0.85) [a3]	3.4	1.73
JCC–400	37.75 (0.36) [b]	24.51 (0.34) [b]	4.6	2.34
JCC–500	35.17 (0.70) [c]	26.95 (0.21) [c]	5.8	2.95
JCC–600	33.22 (0.41) [d]	28.54 (0.29) [d]	8.0	4.07

[1] LS: lignosulfonate, JC: Japanese cedar, JCC: JC charcoal; JCC–carbonization temperature
[2] Mean (standard deviation) by Duncan's multiple range tests at 5% significant level with lowercase English words for the difference of different carbonization temperature

while the O content decreased by about 42.99%. As LS belonged to a sulfonic group, it had higher S content.

JCC particle size

General combustion is the high–energy molecular collision between fuel and oxygen molecules. Smaller charcoal particles during combustion make a large surface area of contact and increase the combustion rate.

The JC particle size is related to the feasibility of making LS into BCB. After the LS screened through the screen mesh, the particle size was 60–80 mesh. The JC particle size; therefore, was designed as 60–80, 100–200, and above 200 mesh. Figure 1 shows the combustion emission gases of JCC with different particle sizes and LS. The combustion temperature and CO_2 of various specimens increased with time. The O_2 decreased relatively

Table 2. Element analysis of Japanese cedar, lignosulfonate and charcoal prepared at 300°C of carbonization temperature

Specimen [1]	C (%)	H (%)	N (%)	S (%)	O (%)
LS	45.51 (0.07) [1]	9.07 (0.01)	0.16 (0.01)	4.68 (0.18)	40.59 (0.11)
JC	51.89 (0.26)	11.85 (0.04)	0.20 (0.02)	0.12 (0.02)	35.96 (0.30)
JCC–300	74.48 (0.09)	4.43 (0.11)	0.24 (0.01)	0.36 (0.07)	20.50 (0.05)

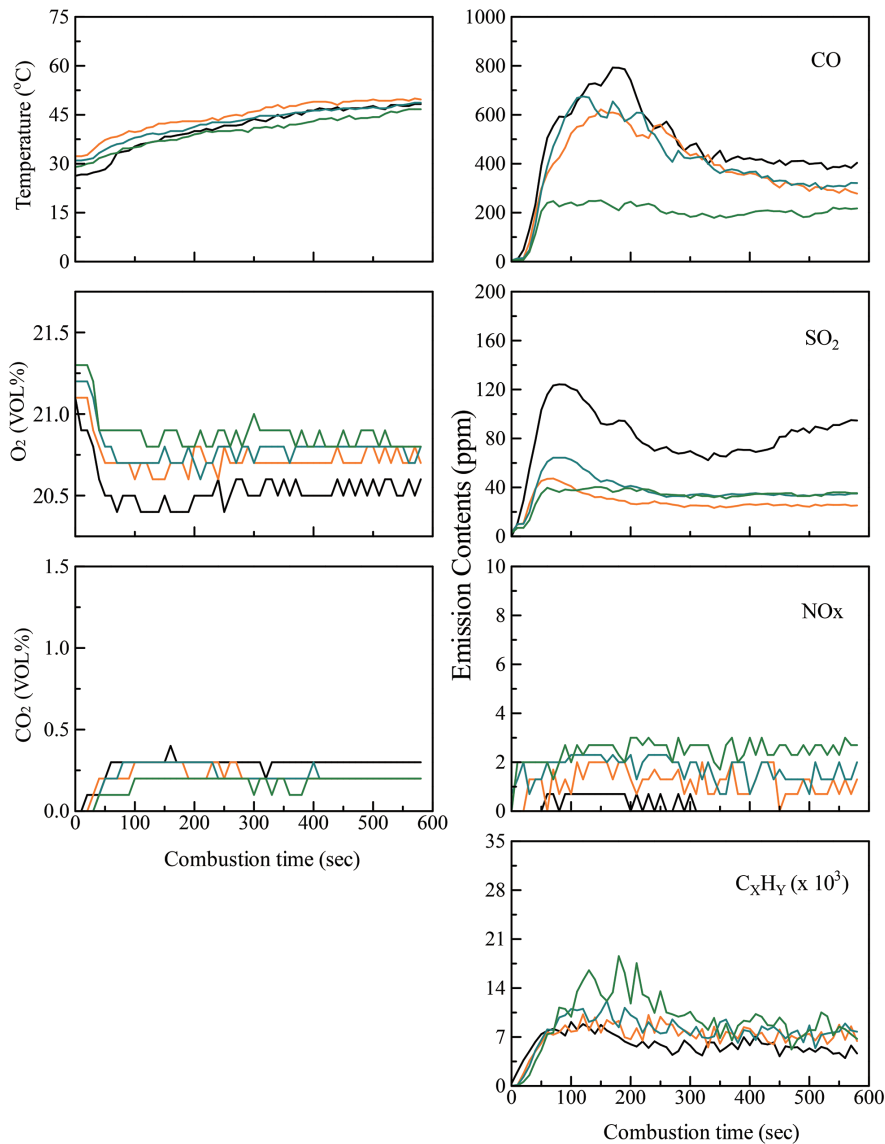[1] See Table 1
[2] Mean (standard deviation)

Fig. 1. Relationships between combustion time and emission gas temperature, O_2, CO_2 concentration, emission contents for briquetting condition with different particle size.
Legends Particle size (mesh): ——— : 60-80; ——— : 100-200; ——— : Over 200, and ——— : LS
Note   LS: See Table 1

as CO_2 increased (Hu *et al.*, 2000; Lin *et al.*, 2004; 2006; 2007a; 2007b).

At about 100 s of combustion, the combustion temperatures of three of particle sizes–60–80, 100–200, and over 200 mesh increased rapidly which were 36.0, 33.3, and 33.7°C. At about 600 s of combustion, the temperatures were 64.7, 59.0, and 58.3°C, respectively, and at 100 s and 600 s of combustion, the LS combustion temperatures were 34.0 and 48.0°C. The emission contents of CO, SO_2, NOx, and C_XH_Y increased with time. In terms of emission content of SO_2, the three particle sizes had similar result tendency. For the peak at about 50 s of combustion, the emission contents of 60–80 mesh was 61 ppm, for 100–200 mesh it was 50 ppm, and above 200 mesh it was 54 ppm. The NOx emissions of them were within the standard of 100 ppm for air pollutant emission (EPA, 2018). **Table 3** shows the cumulated combustion emission contents of CO, C_XH_Y, NO_X, and SO_2. The cumulated combustion emission contents of 100–200 mesh had a lower variation coefficient than those of 60–80 mesh and above 200 mesh.

In terms of emission content of CO, the peak occurred at 200 s of combustion. The 60–80 and above 200 meshes had higher emission, which were 753 and 590 ppm respectively. The 100–200 mesh had lower emission, which was 525 ppm (Fig. 1). The cumulated CO of 60–80 mesh from the beginning of combustion to the end of the test was about 28733 ppm, The cumulated CO of 100–200 mesh and above 200 mesh was 22245 and 29222 ppm, respectively. The 100–200 mesh had lower CO emission (Table 3).

According to the SO_2 and NOx emission results, the 60–80, 100–200, and above 200 meshes had similar emission tendencies. The emission contents of CO and C_XH_Y for 100–200 mesh was lower. The 60–80 mesh had a larger particle size. A higher CO emission (792 ppm) meant there might be incomplete combustion. The above 200 mesh had a smaller particle size but the emission was higher. It leaded to incomplete combustion (**Fig. 1**). The JCC particle size used 100–200 mesh as the BCB preparation condition. Moreover, The CEM result of LS showed that the CO, SO_2, and NOx emissions increased with time. The cumulated combustion emission gas of NOx (256 ppm) for LS was higher than that for JCC, and that for C_XH_Y showed the LS had higher emission than JCC (**Table 3**).

The peak of emission content of C_XH_Y occurred at 200 s of combustion. The emission of 60–80 mesh was 6622 ppm; that of 100–200 mesh was 6841 ppm, and for above 200 mesh it was 9312 ppm (**Fig. 1**). From the beginning to the end of combustion, the cumulated C_XH_Y of 60–80 mesh was 317836 ppm, that of 100–200 mesh was 207367 ppm, and for above 200 mesh, it was 343263 ppm (**Table 3**). The cumulated combustion emission gas of 100–200 mesh was lower than above 200 mesh by 26.5% (**Table 3**). The 100–200 mesh with lower emission contents was as the briquetting conditions.

Mixing percent weight of JCC/LS

The mixing percent weight of JCC/LS related to one of the briquetting conditions. For CEM evaluation, 90/10, 85/15, 80/20, 75/25, 70/30, and 60/40 wt% of JCC/LS were used. The gas emitted during combustion showed the same tendency in the particle size and O_2–CO_2 relationship. The emission contents of CO, SO_2, NOx, and C_XH_Y increased with time. The emission content of NOx had the same tendency as the particle size. The cumulated combustion emission contents of CO were 26765 to 29553 ppm. The cumulated combustion emission contents of SO_2 were 2068 to 4581 ppm. The cumulated combustion emission contents of C_XH_Y were 281824 to 474559. The combustion emission gas result of 80/20 wt% was better and used as the preparation condition for comparing heating values next (Results no showed in Table and Fig).

Predetermined density of BCB

The predetermined densities of BCB were 0.6, 0.8, and 1.0 g/cm³ with the JCC/LS at 80/20 wt%. The briquetting conditions–JCC/LS/PD was 80/20/0.6, 80/20/0.8, and 80/20/1.0. The combustion temperature and the O_2–CO_2 relationship had the same tendency as the above results. In the same mixed percent weight and different density conditions, the 80/20/1.0 had relatively lower emission contents for CO, SO_2, and C_XH_Y (**Fig. 2**). According to the cumulated combustion emission contents, there were insignificant differences between CO and SO_2. According to the C_XH_Y emission result, the 80/20/1.0 (300175 ppm) had a lower cumulated combustion emission contents than 80/20/0.6 and 80/20/0.8 (338182 and 348884 ppm), but the variation coefficient were insignificantly. The 80/20/1.0 had lower cumulated

Table 3. Cumulated combustion emission contents of CO, SO_2, NO_X, and C_XH_Y for briquetting content with different particle size and lignosulfonate

Specimen[1]	CO (ppm)		SO_2 (ppm)		NO_X (ppm)		C_XH_Y (ppm)	
	M (STD)[2]	CV[3]	M (STD)	CV	M (STD)	CV	M (STD)	CV
JCC–60–80	28733 (2243)	0.08	546 (345)	CV	34 (57)	1.68	317836 (86389)	0.27
JCC–100–200	22245 (1578)	0.07	3801 (272)	0.10	126 (38)	0.30	207367 (51921)	0.25
JCC–over 200	29222 (7513)	0.26	3620 (1431)	0.07	89 (34)	0.38	343263 (164987)	0.48
LS	7685	–	256	–	1758	–	573229	–

[1] LS and JCC: See Table 1; JCC–particle size (mesh)
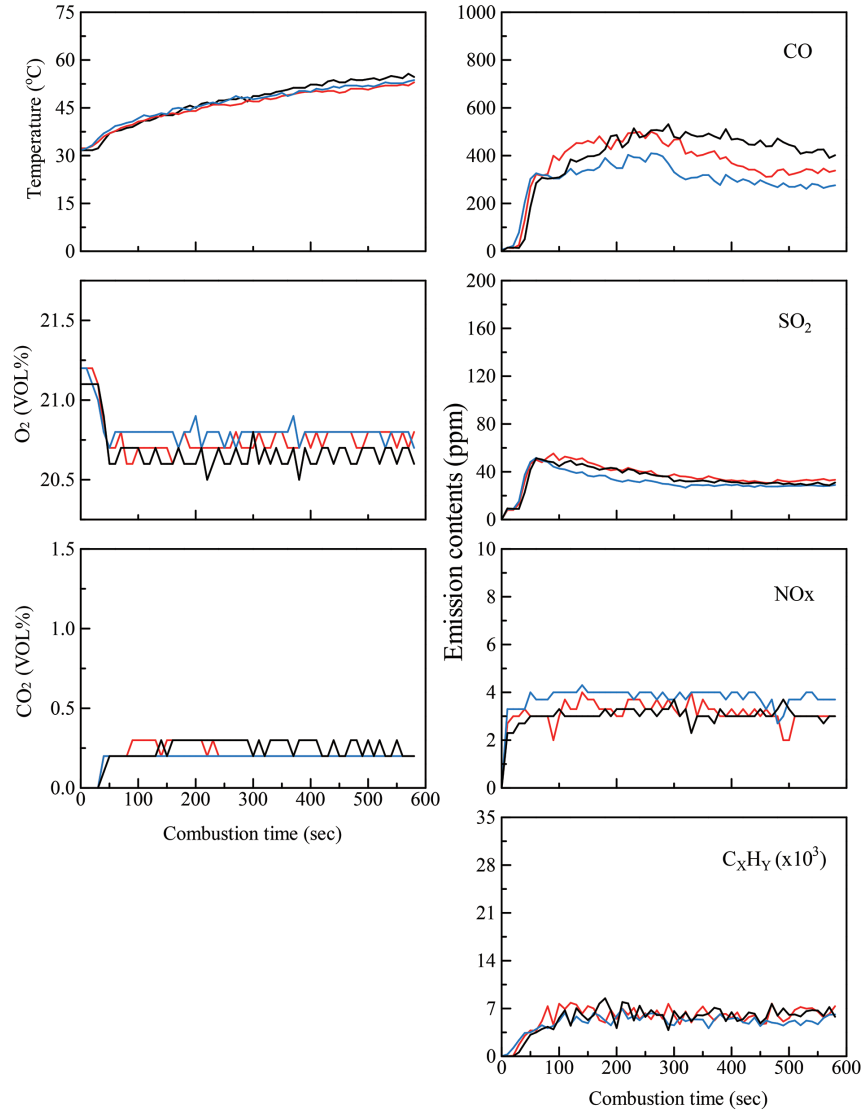[2] See Table 2
[3] CV: Variation coefficient

Fig. 2. Relationships between combustion time and emission gas temperature, O_2, CO_2 concentration, emission contents for biomass charcoal briquettes with the same mixing percent weight at different density

Legends Briquetting condition: ——: 80/20/0.6; ——: 80/20/0.8; ——: 80/20/1.0
Note   JCC/LS/PD: See Table 4

combustion emission contents. It used as the selected preparation condition for developing BCB.

Preparation and heating value of BCB

According to the heating value and the power consumption in the carbonization process (**Table 1**), the JCC of carbonization temperature 300°C was as the BCB of prepared condition. The briquetting conditions with less emission contents were as the selected preparation condition. The JCC particle size (**Fig. 1**), and JCC/LS/ PD (**Fig. 2**) were as the BCB of prepared condition. There were 10 points of briquette for heating value determination to evaluate "BCB". **Table 4** shows the heating values of the specimens, BCB, and other charcoals. The JC was prepared into JCC by carbonization. Its heating value increased from 15.54 MJ/kg to 25.62 MJ/ kg. There were significant differences between them according to independent sample T–test. The heating value of LS was 15.54 MJ/kg. The heating value of BCB

prepared by mixing them at different percentages and densities was 21.02–22.68 MJ/kg, which was higher than that of JC by 45.94%. The difference between the heating values of the BCB 90/10/0.6 (21.02 MJ/kg) and 80/20/0.6 (21.28 MJ/kg) prepared at the same density, and different mixed percent weight was only difference 0.26 MJ/kg, which was insignificantly different. The heating values of the BCBs prepared at different densities–80/20 wt%, densities 0.6, 0.8, and 1.0 g/cm³ were 21.28, 21.32, and 22.68 MJ/kg, respectively. This suggests that a higher predetermined density yields, a higher charcoal content and a higher heating value are. According to Duncan's multiple range analysis, there was insignificant difference among the commercially available charcoal B (22.36 MJ/kg), coal (22.24 MJ/kg), and BCB 80/20/1.0 (22.68 MJ/kg). This indicates that the heating value of JC increases after carbonization, and the heating value of the BCB prepared at the same mixed percent weight increases with PD.

Table 4. Heating value of lignosulfonate, Japanese cedar, Japanese cedar charcoal, biomass charcoal briquettes, and various wood charcoals, fossil fuels

Specimen [1]		Heating value (MJ/kg)
LS		15.43 (0.51)
JC		15.54 (0.57) [a4]
JCC		25.62 (0.85) [b]
Biomass Charcoal Briquettes (BCB): JCC/LS/PD [2]	90/10/0.6	21.02 (0.88) [em]
	80/20/0.6	21.28 (0.16) [eim]
	80/20/0.8	21.32 (0.20) [im]
	80/20/1.0	22.68 (0.63) [jnq]
Wood charcoal	Wood charcoal A	23.77 (0.17) [r]
	Wood charcoal B	22.36 (0.07) [q]
Fossil fuel [3]	Refined coal	22.24 (0.47) [q]
	Imported bituminous coal	23.86
	Sub–bituminous coal	20.51
	Anthracite	29.72

[1] See Table 1

[2] JCC/LS/PD: BCB preparation conditions, Japanese cedar charcoal/lignosulfonate/predetermined density of charcoal briquette

[3] Heating value from Bureau of Energy, Ministry of Economic Affairs (2021)

[4] Mean (standard deviation) by Duncan's multiple range tests at 5% significant level with lower-case English words: ab for Japanese cedar, Japanese cedar charcoal; ef for the same density with different mixing percent weight; ij for the same mixing percent weight with different density; mn for various BCBs; qr for BCB: 80/20/1.0, wood charcoals, and refined coal

reference for developing BCB into biomass energy.

CONCLUSION

The heating value of JCC increased with carbonization temperature. It was 24.51–28.54 MJ/kg and higher than the 15.54 MJ/kg of JC by 57.72–83.66%. The carbonization temperature of 300°C was as for developing energy–saving and environmentally friendly biomass. The CEM analysis performed with various briquetting conditions to evaluate lower cumulated combustion emission contents of CO, SO_2, NOx, and C_xH_Y. In terms of selection of JCC particle size, the 100–200 mesh had the minimum CO, C_xH_Y, relatively lower cumulated SO_2 and NOx, and a smaller variation coefficient. The JCC/LS/PD was 90/10/0.6, 80/20/0.6, 80/20/0.8, and 80/20/1.0 g/cm³. According to the CEM analysis, the 80/20/1.0 had the minimum C_xH_Y and SO_2, and lower cumulated CO and NOx emissions relatively with lower variation coefficient. In terms of the heating value of BCB prepared by cold–press molding, among the following briquetting preparation conditions 90/10/0.6, 80/20/0.6, 80/20/0.8, and 80/20/1.0, the 80/20/1.0 had a higher heating value of 22.68 MJ/kg. It was higher than that of JC by 45.94%. The heating value of the BCB at the same mixed percent weight increased with PD. The heating value of BCB 80/20/1.0 was 22.68 MJ/kg, which was higher than the 22.24 MJ/kg of refined coal, but there was insignificant difference. The JC processing residues carbonized into JCC, and then mixed with LS to develop "BCB". The 80/20/1.0 had a lower combustion emission gas and a higher heating value, and might be a

AUTHOR CONTRIBUTION

Han Chien LIN designed the study and wrote this paper. Chia–Hsuan LIAO, Liang–Yu ZHAO, Yun–Chi CHEN, Pin–Rong CHU, Hong–Ching YOU performed the experiments and evaluated data with the statistical analysis. Noboru FUJIMOTO discussed the experiments and supervised the work. The authors assisted in editing of the manuscript and approved the final version.

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