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Characterization and elemental composition of lignite and rubber wood sawdust pellets

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Abstract

To meet the environmentally-friendly and sustainable global energy-sharing, lignite and rubber wood sawdust could be combined into a cylindrical pellet in order to reduce the amount of lignite used. In this study, the lignite/rubber wood sawdust-blend pellet properties are studied. The properties include the ultimate analysis, the proximate analysis, the calorific value, the elemental composition, and the particle size distribution, the density and the compressive resistance. The results show that combining 50%wt. of rubber wood sawdust and lignite leads to the decreasing of ash content by 50 %, the decreasing of N and S contents to 0.8 and 1.8 % (daf.), respectively. The calorific value is 17 MJ/kg (db.) with 0.71 g/cm^3 of pellet density and 4,162 kN/m^2 of compressive resistance. The combination of lignite and rubber wood sawdust as a pellet is an interesting approach for a long term extension of fossil fuel utilization and the reduction of greenhouse gas and heavy metals.

Keywords: Lignite, Rubber wood sawdust, Lignite/rubber wood sawdust-blend pellets, Heavy metals, Greenhouse gas

1. Introduction

Coal demand including lignite is not only rapidly increasing due to the global energy demand but its price is also increasing by approximately 1% per year, i.e., $1.84/million Btu in 2013 to $2.44/million Btu in 2040 [1]. Due to the high demand, the coal/lignite sources might be run off in the near future. In order to sustainably utilize lignite, the other materials should be combined with lignite as a supplement. Thailand is the world leader of rubber wood plantation, especially in the southern and eastern regions. Each year, the rubber wood trees are cut down and transported to 561 woody manufacturing factories. Around 0.16 million tons per year of rubber wood sawdust is generated. These huge quantities are able to use as fuels in the industries [2]. Unfortunately, the rubber wood sawdust can be counted as biomass and is a renewable and clean-energy fuel organic waste because it is a carbon-neutral material as well. Relative to the biomass, coal/lignite produces not only higher calorific values but also heavy metals and toxic emissions. In comparison to the biomass combustion, coal distributes less particulate matter during the combustion process. By combining coal with the biomass in a pellet form, the calorific value is enhanced while the air pollution is reduced but the particulate matter may be occurred [3]. Many studies on biomass densification alone or biomass blends were conducted [4-6]. However, a few studies on biomass blends/lignite blends. The important factors in these studies include the durability, moisture content, die temperature, pressure, and particle sizes.

In this study, the physicochemical characterization of lignite/rubber wood sawdust-blend pellet is examined based on the ultimate analysis, the proximate analysis, the caloric value, the density, the compressive resistance, and the heavy metals. The results of this study can be used to provide a suitable blending ratio and to improve the quality of the pellets. The optimum blending ratios of lignite to rubber wood sawdust in cylindrical pellets by adding starch as a binder are also discussed.

2. Materials and methods

2.1 Materials

Lignite was adapted from Mae Moh coal power plant, located in Mae Moh, Lampang, Thailand. The rubber wood sawdust was obtained from a rubber wood manufacturing factory, located in Rattapoom, Songkhla, Thailand. Lignite and rubber wood sawdust were ground with the mortar and then maintained with US standard sieves in order to obtain -850+75 um of particle sizes before the pellet preparation process. The chemical characteristic of the lignite and the rubber wood sawdust is shown in Table 1.

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Table 1 Chemical characteristic of raw materials

Samples	Proximate analysis (%db) (n=6)			Ultimate analysis (%daf) (n=3)					Calorific value (MJ/kg, db.) (n=3)	
	MC	ASH	VM*	C	H	O	N	S	HHV	LHV*
Lignite	27.09	40.14	59.86	51.21	5.63	36.52	1.81	4.82	15.41	13.65
Sawdust	10.59	0.94	99.06	48.86	6.64	44.49	ND	ND	17.92	16.18

Note: (ND) non detectable, (*) by different, (db.) dry basis, (daf.) dry ash free basis, (n) number of testing samples

2.2 Pellet preparation

The pellets were prepared in various ratios of lignite to rubber wood sawdust, i.e., 0, 25, 50, 75, and 100% lignite or rubber wood sawdust blends. Starch made from cassava root (Kriangkrai, Thailand), approximately 10 %wt., was used as the glue to bind both materials. To improve the bounding mechanism, the water was added. The cylindrical pellets were formed by a modified cool screw press with a monitor model WMDC-C400 (Wikiki, Thailand).

The resulting cylindrical pellets were 8-10 mm in diameters as shown Figure 1. The pellet length increased with the producible time. The long pellets could easily be broken. Thus, the recommended length of the lignite and rubber wood sawdust blend pellets were 3.15-40 mm for EN 14961-2 standard [7] and ≤38.1 mm for PFI standard [8]. However, EN 14961-2 and PFI standards have set the optimum diameters of 7-9 mm and 5.84-7.25 mm, respectively; the diameter of 10 mm was still optionally obtained in a limited degree [9].

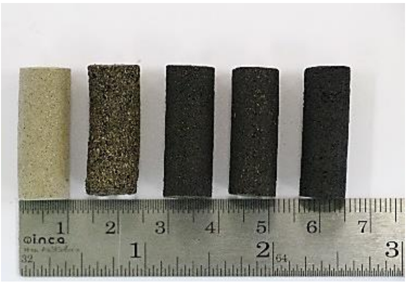

Figure 1 Pellet fuels of lignite and rubber wood sawdust mixture with binders – starch by 10 % wt. (0, 25, 50, 75, and 100% lignite blends)

2.3 Physical analysis

The particle size distribution of lignite and rubber wood sawdust were conducted following ASTM D-293 and the protocol of Das (2002) [10]. The samples were selected by cone and quartering sampling technique. Then, the samples were tested for 10 min in a standard sieve ASTM E-11 with the following sieve N20, N40, N100, N200, and pan. The pellet density was measured by selecting 20-random pellets via weight to volume ratio. Compressive resistance was determined by an unconfined compressive machine model E.L.E S452 (E.L.E Ltd, England).

2.4 Chemical analysis

The ultimate analysis was examined by the CHNS-O analyzer – CE Instruments Flash EA 1112 series (Thermo Quest, Italy). The proximate analysis was examined including moisture content (MC, ASTM D-3173) and ash content (ASH, the protocol of Obernberger and Thek (2004) [9] at 550°C). Furthermore, the calorific value was measured by the oxygen bomb calorimeter – Plain Jacket Calorimeter model Parr 1341 (Parr, USA).

The target heavy metals analyzed in this study include Cu, Al, Cd, Fe, Pb, Cr, Hg and Zn, using the Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) model Optima 4300DV (Perkin Elmer, USA), with an exceptional of Hg. Hg was measured by the Atomic Absorption Spectrometry (AAS) model FIMS 100 (Perkin Elmer, USA).

3. Results and discussion

3.1 Physical characterization

As shown in Figure 2, the particle size of lignite is finer than that of the rubber wood sawdust. 80% of lignite and rubber wood sawdust particle size are 640 and 680 μm while 50% of lignite and sawdust particle sizes are 340 and 470 μm, respectively. The pore space of pellets may be filled by the finer lignite particles to enhance the particle-bound interaction between the large and the fine particle size materials.

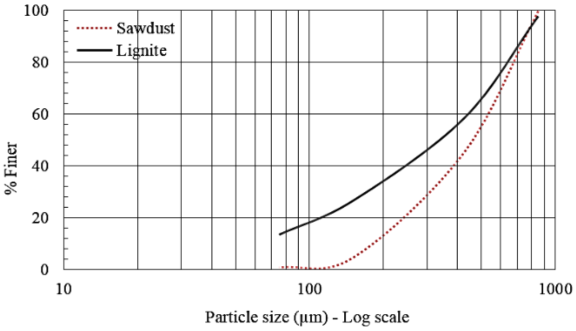

Figure 2 Particle size distribution of lignite and rubber wood sawdust (n=3)

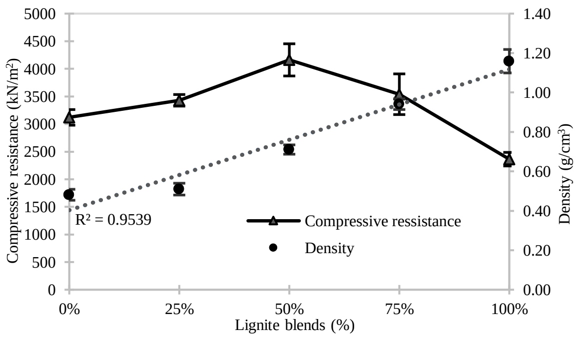

Figure 3 Compressive resistance (n=3) and pellet density (n=20) with various lignite blends

Density of pellets dramatically increases due to the increasing amount of lignite as shown in Figure 3. The resulting density of the 0, 25, 50, 75, and 100 % (R^2=0.9539) of lignite blending ratios are 0.48, 0.51, 0.71, 0.94, and 1.16 g/cm^3, respectively. The particle sizes of the rubber wood sawdust and the lignite can improve the density of the pellets because of the naturally high density of lignite. The densified particle in the pellets influences the density of pellets resulting in a longer burning rate during the combustion process. Varol et al. (2010) [11] reported that the thermal degradation of the biomass firing started sooner than that of the lignite firing. The rapid thermal reactivity of biomass caused by the low auto-ignition temperature in the range of 150-200 ℃. The biomass was moving to the devolatilization stage while the lignite began its char oxidation domination process. The low auto-ignition temperature influenced the high volatile matter and the high burning rate was at the low temperature during the co-firing process.

Even though the density of the 100% lignite blending ratio pellets is very high, its pellet compressive strength is the lowest among all. The 50% of lignite blending ratio pellet provides the highest compressive strength of 4,160 kN/m^2 followed by 75%, 25%, 0% and 100% of lignite blending ratios. The strength of the pellets increases as the amount of the lignite increases until reaching the 50% of lignite blending ratio. After the 50% of lignite blending ratio, adding more amount of lignite results in decreasing of the pellet compressive strength which causes by the lack of the reactive binder and the interaction of particle sizes. The rubber wood sawdust sometimes conducts itself as the binder because of lignin, which is amorphous polymers to improve the plasticity and flow ability. Lignin could converts itself to wax and oil similar to the binder [5, 12]. By adding the biological additive binder – starch – by 10% wt. into the pellets, the conversion of oil and wax increases; the water enhances the migration flow of wax and oil into the body of the pellets which causes a strong durable particle bounding reaction. Significantly, the additive binder by 10 %wt. would not strengthen the particle bound of lignite differ to rubber wood sawdust or lignite/rubber wood sawdust. Similarly, Yaman et al. (2001) [13] reported on the lignite briquette blended with biomass behaved as the binder on 250-MPa supplement pressure. The compressive strength decreased when approximately 10 %wt. of sawdust/paper/pine cone was added to form the lignite briquette and rapidly increased upon adding the same materials at above 10 %wt. Additionally, Zhang et al. (2001) [14] reported on the lignite briquette under 294-MPa supplement pressure that without the treated rice straw as the binder, the compressive strength of the lignite briquettes was 1,220 kN/m^2 ; With 20 %wt. of the treated rice straw using lime and sodium hydroxide, the compressive strength increased to 2,280 kN/m^2 and 2,480 kN/m^2, respectively. In comparison to the lignite briquettes with the treated rice straw, the compressive strength of the 100% lignite blend pellet in this study shows similar value at 2,364 kN/m^2. By increasing the amount of binder, the cost of the pelletizing process increases and the emissions released from the binder have to be investigated.

3.2 Chemical characterization

The chemical properties of the pellets are shown in Table 2. The MC of pellets is controlled due to the minimum and maximum levels (5-8%) of the protocol of Tumurulu et al. (2011) [6] and the American PFI Premium standard [8], respectively. The European woody pellet standard [7], EN 14961-2, also recommends the maximum MC at no higher than 10% (db.). The various pellets obtain the MC at around 5% (db.), with an exception of the 6.99% (db.) of 100% lignite blends. In the limitation range of MC, the bacterial and fungal decomposition in the pellets will be prevented and the easiness of handling and transportation is suitably operated [6]. Paralleling to the other researchers [3, 11, 15], biomass presents higher VM and lower ASH in contrast to that of lignite. The rubber wood sawdust is added into the pellets to reduce the effect of ASH in preventing the heat distribution during the combustion process and to reduce the amount of heavy metals. However, the rubber wood sawdust may cause the increasing of particulate matter due to the promotion of higher VM.

The CHONS contents are clearly examined. The results show that the lignite pellets contain high amount of C, N, and S in contrast with the rubber wood sawdust pellets which contain high amount of H and O. During the lignite-rubber wood sawdust blending-pelletizing process, the CHONS contents of the resulting pellets will be balanced by trading or blending with each other. The N and S contents are decreased from 1.69 to 0.15% (daf.) and 4.31 to 0% (daf.), respectively by the properties of rubber wood sawdust. According to the reduction of N and S amount, the resulting pellets during the combustion process will provide less amount of NO_x and SO_x which can lead to HNO_3 and H_2SO_4. Both HNO_3 and H_2SO_4 are the cause of acid rain. Also, the decreasing of N and S contents could determine the positive results of the decreasing of ASH [15]. The C content might enhance the calorific value of pellets due to the lower ASH and MC contents [9, 15]. Furthermore, the C, H and O contents of the pellets during the combustion process could change into CO_2 and H_2O. The O content might intensify the air supply in the combustion process resulting in a complete combustion process leading to the reduction of CO emission [9].

The calorific value of lignite pellets is lower than that of the rubber wood sawdust pellets. By increasing amount of rubber wood sawdust in the pellets, the heating values increase, i.e., the higher heating value of 15.52-17.61 MJ/kg (db.) and the lower heating value of 14.43-16.06 MJ/kg (db.)

Table 2 Chemical properties of pellets

Samples	Proximate analysis (%db) (n=6)			Ultimate analysis (%daf) (n=3)					Calorific values (MJ/kg, db.) (n=3)	
	MC	ASH	VM*	C	H	O	N	S	HHV	LHV*
LN0:RW100	5.63	0.79	99.21	49.42	6.60	43.83	0.15	ND	17.61	16.06
LN25:RW75	5.57	7.43	92.57	49.44	6.01	43.30	0.46	0.80	17.23	15.88
LN50:RW50	5.38	15.37	84.63	51.13	6.07	40.17	0.82	1.81	17.10	15.78
LN75:RW25	5.16	24.97	75.03	53.19	5.67	36.79	1.22	3.14	16.14	15.00
LN100:RW0	6.99	32.90	67.10	54.33	5.42	34.24	1.69	4.31	15.52	14.43

Note: (LN) lignite, (RW) rubber wood sawdust, (number) blending percentages of materials

Table 3 Heavy metals of lignite and rubber wood sawdust

Elements	Units	Lignite	Sawdust	Bituminous coal, Poland [16]	Pine sawdust, Poland [16]	Sub/bituminous coal, US [17]
Hg	ppb	156.48	ND	29	21	180
Al	ppm	7,415.56	34.16	NA	NA	NA
Cd		ND	ND	0.14	0.8	2.5
Cr		4.99	ND	4.9	1.2	15
Cu		3.83	1.8	5.6	3.7	19
Fe		7,919.64	15.8	2,200	1,500	NA
Pb		3.38	ND	22	3.3	16
Zn		18.64	5.59	22	30	39

Note: (ND) non detectable, (NA) non available

The heavy metals of lignite are high in comparison to that of rubber wood sawdust as shown in Table 3. The rubber wood sawdust does not contain any public-health-concern heavy metals namely Hg, Cd, Cr, and Pb while such amount is also low in the lignite in comparison to the Polish and US coal, with an exception of the Hg amount. The Hg content of lignite in this study is 156.48 ppb, which is 352 times lower than that of the coal in Guizhou, China (55 ppm) [18], but it is 5 times higher than that of the Polish coal while it is of similar amount to that of the coal in the US.

4. Conclusions

The most appropriate pellet blending ratio is 50%wt. of lignite and 50%wt. of rubber wood sawdust (LN50:RW50) which provides the highest strength of 4,162 kN/m^2 with the calorific value of 17 MJ/kg. Its density is on the medium density of the rubber wood sawdust pellets and lignite pellets, 0.71 g/cm^3. Furthermore, the heavy metals and ash contents in the rubber wood sawdust are lower than that of lignite, which makes the rubber wood sawdust a good choice of lignite compromising supplement economically and environmentally. The ash contents decrease by 50% from 32.9 to 15.75%. Also, the N and S contents reduce to 0.8 and 1.8%, respectively. The coal utilization may reduce by approximately 50%, which is a good sustainable coal management and it can extend the lifetime of coal usage. In addition, the heavy metals in the ash contents can be reduced as well as the reduction of the exhaust gas emission during the combustion process.

5. Acknowledgements

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