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Prediction of recovery energy from ultimate analysis of waste generation in Depok City, Indonesia

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ABSTRACT

Refuse derived fuel (RDF) is an environmentally friendly renewable fuel developed to reduce waste generation. RDF can consist of various kinds of waste such as paper and gardens. One of the critical parameters is the chemical element and calorific value. The purpose of this study was to determine the potential for waste reduction and the relationship of ultimate longevity in RDF to the calorific value. This study's paper and garden waste mixture were P0 (100% paper), P25 (75% paper and 25% garden), P50 (50% paper and 50% garden), P75 (25% paper and 75% garden), and P100 (100% garden). The calorific value of the mixture can reach 3.6-5.2 kWh/kg. Simultaneously the relationship of ultimate elements nitrogen (N), hydrogen (H), oxygen (O), and ash affects the heating value of RDF. Sampling the application in Depok City can reduce waste by 6.67%, with the potential for electrical energy from paper and garden wastes of 358,903.8 kWh and 48,681 kWh, respectively. This shows that this energy waste can supply 0.1% of the total daily electricity demand in Depok City.

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1. INTRODUCTION

Waste management is a crucial thing to do in Indonesia [1]–[4], one of the waste management carried out is waste into energy with refuse derived fuel (RDF). RDF is a fuel produced from waste processing to get good quality fuel. This technology involves pre-treatment such as chopping/reducing size, separating, drying, and pelletizing. The size and uniformity of the pellets make it easier to transport, store and use them. Pellets can be used in gasification installations to produce gas or can also be used as fuel for biomass stoves to replace liquefied petroleum gas (LPG) for household needs [5]. The advantages of RDF are easy to transport, low water and ash content, more homogeneous physical shape and characteristics, higher calorific value, and more environmentally friendly emissions [6]–[8]. Processing waste into RDF consists of chopping, drying, and molding/pelleting so that the mass density and energy potential [9], [10]. Waste that is not mechanically processed tends to have the characteristics of high water content, high ash content, low calorific value, and heterogeneous waste size [11]–[13].

Processing waste into RDF aims to increase the fraction of combustible waste to produce fuel as a substitute or complement to fossil fuels. The main parameters of RDF characteristics include water content, ash content, calorific value, sulfur, and chlorine. The characteristics of each RDF fuel can vary depending on the source of the waste, such as household, construction, and the method of separation, collection, and processing of the waste [14], [15].

The utilization of waste into RDF is expected to reduce the volume of landfill waste, reduce greenhouse gases due to waste, CO_2 emissions due to coal, and support the target of using alternative energy. RDF as an alternative fuel has been applied in the cement industry because of its high energy requirements [16]. The use of RDF in the cement industry has been widely practiced in several European countries, Japan, America, and Korea [8], [17], [18]. In Indonesia itself, the use of RDF is still relatively new. In Indonesia, the use of waste from landfill to RDF has been carried out in Cilacap, Gresik, and Bogor cities in collaboration with the cement industry, as a positive contribution to reducing municipal waste and sustainable development programs [19]–[21].

Paper waste has similar characteristics to garden waste in that it is made of wood fibers, which gives the fuel good density qualities. Paper has a calorific value of 13.88 and can be used as RDF pellets [22]. In this study, a mixture of the two waste compositions was carried out, aiming to increase the calorific value of RDF pellets and optimize the fuel properties of pellets. The purpose of this study was to determine the effect of mixing chemical elements consisting of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) levels on the calorific value. In addition, this research was conducted to determine the potential utilization of garden waste and paper to be used as the central recycling in waste energy recovery.

2. METHOD

The first step in making this pellet is the preparation of the materials needed. The raw materials prepared as raw materials for RDF pellets are garden waste (wood twigs and dry leaves) and paper waste Figure 1. The wooden twigs are pre-cut about 10 cm to make them easier to put into the chopper. Next is the process of mixing paper and garden waste with an interval ratio of 25%, namely 100%:0% (100% paper waste), 75%:25% (75% paper waste and 25% garden waste), 50%:50% (50% paper waste and 50% garden waste), 25%:75% (25% paper waste and 50% garden waste), 0%:100%, (100% garden waste) respectively. It takes the addition of 1,000 mL of water and 10% tapioca flour by 200 grams. After that, mixing is carried out until all the ingredients become homogeneous.

Raw Garden Waste Raw Paper Waste

Figure 1. Raw material garden and paper waste

The ultimate analysis is a component of chemical elements consisting of levels of C, H, O, and N. The ultimate analysis results serve as the presence of organic matter in the chemical composition. The method used to measure the ultimate is ASTM D-591. The test procedure is a sample of 50 to 200 mg homogeneous test in a capsule, and then the solid sample is weighed in a tin capsule. The pressure of the oxygen and helium carrier gases is 40 psi. The analysis starts from an empty capsule following calibration standards. The calibration value and the calibration concentration are entered into the microprocessor to produce a calibration curve. The relationship between ultimate analysis results and environmental impacts caused in the combustion process can be seen from Table 1. Each element namely C, H, N, S and O which comes from emissions from various population activities, produces its own environmental impact.

Table 1. Relationship between ultimate analysis results and environmental impacts caused in the combustion process

Element	Emission	Environmental Impact
Carbon (C)	CO_2	The higher the C, the higher the value of higher heating value (HHV)
Hydrogen (H)	H_2O	The higher the H, the lower the value of HHV
Nitrogen (N)	NO_x	Air contaminants: the higher the N, the higher the formation of NO_x
Sulfur (S)	SO_x	Air contaminants: the higher the S, the higher the formation of SO_x
Oxygen (O)	CO_2, H_2O, NO_x, SO_x	The higher the H+C/O, the higher the HHV, and the higher the formation of SO_x and NO_x

Calorific value analysis is carried out to describe the energy content of a material. Calculation of the calorific value is carried out using a bomb calorimeter device. Bomb calorimeter is a tool used to measure the amount of heat liberated on complete combustion of a compound, food, fuel. A number of samples are placed in an oxygenated tube immersed in a heat-absorbing medium (calorimeter), and the sample will be burned by an electric flame from a metal wire attached to the tube. The method used for the calorific value analysis is the American Standard Test Method for Gross Calorific Value D5865-11a. The calorific value test procedure is a sample in dry conditions (heating to 105 ºC) as much as ±0.5 grams is placed in a cup and automatically inserted into the bomb calorimeter. The calorific value results will come out of the tool. Several samples are placed in an oxygenated tube immersed in a heat-absorbing calorimeter, and the sample will be burned by an electric flame from a metal wire attached to the tube.

3. RESULTS AND DISCUSSION

The ultimate analysis was carried out to determine the chemical composition of elements, including levels of C, H, O, and N. The main components that are most important in combustion are the elements carbon and hydrogen. Carbon and hydrogen are the main combustion elements and correlate with heating values [23], [24]. An exothermic reaction between carbon and hydrogen with oxygen produces CO_2 and H_2O during combustion. Meanwhile, the nitrogen element indicates combustion emissions because it reacts with air to become NO_x [25]. Table 2 shows the ultimate test result data for each variation.

The highest carbon value was found in P0 pellets at 42.25. The addition of garden waste to the pellets can increase the percentage of carbon. The higher garden waste carbon content is 41.93%, while the paper's carbon content is lower, namely 34.96% [26]. Carbon value correlates with heating value. The higher the carbon value, the higher the heating value and the better the pellet quality. So, mixing the two waste compositions is an effective way to optimize the properties of pellet fuel.

Biomass energy with high potential is fuel in pellets from raw materials of twigs, stems, branches, leaves, and others [27], [28]. Pellets are biomass energy from the pressing or densification process using high pressure. Biomass generally consists of cellulose, hemicellulose, and lignin [29], [30]. High temperature and pressure during the molding process will affect the softening of lignin, increasing the ability to bind biomass and increasing its energy density [31], [32]. Table 3 is the result of the calorific value test for the variation of RDF made. Table 3 shows the caloric value in each variation of the pellets used. Each variation has its own calorific value.

Table 2. Ultimate analysis in each variation of the pellets used

Variation	Composition (%)				
	C	H	N	O	Ash
P100	35.3	4.8	0	50.05	9.85
P75	34.1	4.1	0	53.27	8.53
P50	35.56	4.81	0.1	52.43	7.1
P25	42.1	4.91	0.3	47.06	5.63
P0	42.25	5.33	0.4	47.48	4.54

Table 3. Caloric value in each variation of the pellets used

Variation	Caloric Value		
	kcal/kg	MJ/kg	kWh/kg
P100	3131	13.0	3.6
P75	3896	16.2	4.5
P50	4075	17.0	4.7
P25	4378	18.2	5.1
P0	4545	18.9	5.2

The advantage of biomass pellets is that they produce low emissions [29], [33], [34] because biomass is carbon neutral, reduces greenhouse gas emissions, and has low ash and sulfur content. Indonesia has also started to support the development of biomass pellets to be applied in the industry as a substitute for coal (cofiring) and households as an alternative to LPG [35]. Paper is a flammable material, which indicates that paper has high energy value [36]. Paper is a material derived from wood fibers that consist of cellulose and hemicellulose [13]. This wood fiber provides a good density quality in the fuel, and the wood fiber that is burned will provide a calorific value. The presence of paper content will make the pellet structure more substantial and more durable so that paper has the potential as raw material for RDF pellets.

Independent T-Test is a comparative or different test to determine whether there is a significant difference in the mean or mean between each RDF parameter. It can be seen that all parameters have different averages, but in the parameter Nitrogen, the significance is only 0.12. This shows that Nitrogen in RDF is not too different from other variations. Table 4 shows the value of the independent T-Test on each variable.

Table 4. Independent T-test in each variation of the pellets used

Parameters	t	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
				Lower	Upper
C (%)	21.29	0.00	37.86	32.93	42.80
H (%)	24.22	0.00	4.79	4.24	5.34
N (%)	1.97	0.12	0.16	-0.07	0.39
O (%)	39.84	0.00	50.06	46.57	53.55
Ash (%)	7.45	0.00	7.13	4.47	9.79
Caloric (kWh/kg)	16.27	0.00	4.62	3.83	5.41

Waste processed into RDF fuel has essential water content, ash, and calorific value criteria [22], [32], [37]. The grade value can be different for each city or country because it depends on the source of the waste, such as from households, offices, buildings, and the waste collection and processing system. Mixed waste will be different from waste that has been separated from the source of the waste [38]–[41]. Based on Gendebien *et al.* [42], RDF technology has been used for a long time by European countries, namely England, Italy, and Finland. Europe has its RDF quality standards that must be met in the manufacture of RDF fuel. Therefore, the correlation for each ultimate value shows a different correlation Table 5.

Table 5. Person correlation in each variation of the pellets used

Correlation Pearson	Caloric (kWh/kg)	C (%)	H (%)	N (%)	O (%)	Ash (%)
Caloric (kWh/kg)	1	0.736	0.416	0.838	-0.435	-0.953
C (%)	0.736	1	0.768	0.968	-0.93	-0.878
H (%)	0.416	0.768	1	0.79	-0.789	-0.665
N (%)	0.838	0.968	0.79	1	-0.829	-0.958
O (%)	-0.435	-0.93	-0.789	-0.829	1	0.648
Ash (%)	-0.953	-0.878	-0.665	-0.958	0.648	1

The parameters that have the most significant effect on increasing the calorific value are all variables simultaneously except for the composition carbon. The variance inflation factor (VIF) value>10.00 for the parameters nitrogen, oxygen, and ash shows the occurrence of multicollinearity in the regression model Table 6. Garden and paper waste utilization in Depok City can minimize waste generation by 6.67% Table 7. Along with public concern for the environment, the cement industry implements an eco-label program by reducing fossil fuel consumption and zero waste [43], [44]. In addition, the use of RDF can supply electrical energy of 0.1% of the total electricity demand of Depok City.

Table 6. Calculation results of equation models in determining calorific value (kWh/kg) in RDF paper and garden waste

Parameters	B	Sig.	VIF
(Constant)	9.484	***	
C (%)	0	exclude variable	-
H (%)	-0.422	***	3.8
N (%)	-0.984	***	170.2
O (%)	0.007	***	19.8
Ash (%)	-0.427	***	86.5
R^2		1	

Table 7. Ultimate analysis in each variation of the pellets used

Parameters	Value	Unit
Waste generation in Depok	1,627.99	ton/day
Paper waste in Depok	6.1	%
Paper waste in Depok	99.30739	ton/day
Garden waste in Depok	0.57	%
Garden waste in Depok	9.28	ton/day
Total waste reduction	6.67	%
Electricity waste potential from paper waste	358,903.8	kWh
Electricity waste potential from garden waste	48,681.0	kWh
Electricity consumption	6,779,419.4	kWh
Presentation of potential waste utilities as electricity	0.1	%

The utilization of RDF is used as a fuel for coal substitution with biomass or co-firing in the cement industry [14], [45], [46]. The cement industry uses high energy because it requires large amounts of coal as fuel used for the combustion process in the rotary kiln [47]. The tendency to use high coal causes an increase in the cost of fossil fuels, so the cement industry must have a policy of using alternative fuels that can provide benefits for the efficiency of the use of coal and have benefits for the environment to reduce CO_2 emissions [48].

4. CONCLUSION

The results of this study indicate that the ultimate analysis test results for each variation of the mixture of paper and garden waste simultaneously affect the calorific value of RDF pellets. The total potential for waste reduction with a case study of Depok City, Indonesia, can reduce waste by 6.67%. The energy recovery potential is 358,903.8 kWh for paper waste RDF and 48,681 kWh for garden waste RDF. This energy recovery potential can supply 0.1% of the total daily electricity demand in Depok City.

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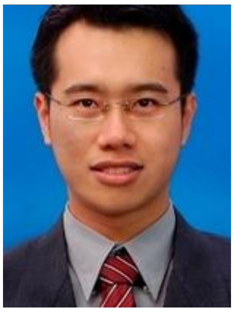

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