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Possibility of municipal waste management with Refuse-Derived Fuel (RDF) mixed paper and garden in Depok City

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ABSTRACT

Paper and garden waste are among the various types of rubbish commonly encountered in urban areas in Indonesia, including the city of Depok. Notably, not all paper waste can be recycled by garbage collectors into new products. In addition, garden waste is also garbage, one of the wastes produced daily from gardening activities. This study analyzed the potential for reducing paper and garden waste using as Refuse-Derived Fuel or RDF in Depok City. This study analyzes the quality of RDF based on the parameters of water content, ash content, density, and calorific value resulting from the material substitution. The results were analyzed using the multicollinearity and Kepner-Tregoe Decision Analysis (KTDA). The results of the multicollinearity test showed that the ash and water content could reduce the calorific value of RDF mixed with paper and garden waste. The addition of garden waste composition can increase the calorific value. Based on the results of decision analysis using KTDA, it shows that the variation of the mixture of 75% paper waste and 25% wood waste has the most prominent points compared to other variations. Material Flow Analysis (MFA) utilization of this waste can reduce the generation of paper and garden waste by 3.5% and 12.3%, respectively.

ABSTRAK

Sampah kertas dan kebun adalah beberapa jenis sampah yang biasa ditemukan di perkotaan di Indonesia, termasuk kota Depok. Perlu dicatat, tidak semua sampah kertas dapat didaur ulang oleh pemulung menjadi produk baru. Selain itu, sampah kebun juga merupakan salah satu sampah yang dihasilkan sehari-hari dari kegiatan berkebun. Kajian ini menganalisis potensi pengurangan sampah kertas dan kebun dengan menggunakan Refuse-Derived Fuel atau RDF di Kota Depok. Penelitian ini menganalisis kualitas RDF berdasarkan parameter kadar air, kadar abu, berat jenis, dan nilai kalor hasil substitusi bahan. Hasil penelitian dianalisis menggunakan multikolinearitas dan Analisis Keputusan Kepner-Tregoe (KTDA). Hasil uji multikolinearitas menunjukkan bahwa kadar abu dan air dapat menurunkan nilai kalor RDF yang bercampur dengan kertas dan sampah kebun. Penambahan komposisi sampah kebun dapat meningkatkan nilai kalor. Berdasarkan hasil analisis keputusan menggunakan KTDA menunjukkan bahwa variasi campuran 75% limbah kertas dan 25% limbah kayu memiliki poin paling menonjol dibandingkan variasi lainnya. Pemanfaatan Material Flow Analysis (MFA) limbah ini dapat mengurangi timbulan limbah kertas dan kebun masing-masing sebesar 3,5% dan 12,3%.

Keywords: *garden waste, KTDA, paper waste, RDF, waste to energy*

INTRODUCTION

Each individual generates waste, so an increase in waste is proportional to the exponential growth of the population (M. Sari et al., 2022). However, if viewed from the other side, the increase in waste can be a business opportunity. Numerous paper waste includes HVS paper (computer paper and writing paper), kraft paper, cardboard, plastic-coated paper, and more. Different activities produce different types of paper waste (Abdel-Shafy & Mansour, 2018; Geueke et al., 2018; Suryawan, Fauziah, et al., 2022). Small industries usually accept paper waste as paper art materials such as artistic boxes, greeting cards, souvenirs, and others (Twede et al., 2015). Meanwhile, large industries recycle paper waste into pulp (paper raw material). Unfortunately, paper waste as one of the raw materials for the recycling industry has not been managed optimally so only 70% can be reused or recycled (Wahyono, 2001). In fact, the amount of paper waste generated in Indonesia reach about 12.77% of the total amount of waste (Kementerian Lingkungan Hidup dan Kehutanan, 2021).

Degradable garden waste can be used as compost. Although not all of the waste can be processed into compost, waste such as wood can be used as an alternative fuel, such as refuse-reived fuel (RDF). RDF results from a waste separation process between flammable and non-combustible waste fractions such as metal and glass (Cheremisinoff, 2003; Suryawan, Septiariva, et al., 2022). Sorting RDF should be separated from thermal treatment because the process produces fuel and produces organic fractions that can form raw materials for biological processing. RDF consists primarily of paper, wood, and plastic, with higher energy content than unsorted municipal waste (Brás et al., 2020). Using RDF as a fuel provides advantages such as high calorific value, homogeneity of physical-chemical composition, ease of storage, handling, and transportation. Fewer pollutant emissions are produced, and reduced air is required for the combustion RDF process (Bosmans et al., 2013; Suryawan et al., 2021).

RDF is commonly used in countries with advanced waste management in cement and power generation industries. In a cement kiln, combustion occurs at a very high flame temperature of about 1450 °C and a relatively long residence time (Nathan et al., 2006). Therefore, based on technical and environmental considerations, there is an upper limit for the total consumption of materials. The energy generated is calculated based on the lower heating value (Lower Heating Value/LLV) assumed for energy efficiency. Internal energy use is 18% and 15% of the electrical energy generated. Europe, America, and Japan have applied RDF technology (Chen et al., 2011; Fu et al., 2005; Kupka et al., 2008; M. M. Sari et al., 2023). Waste processed into RDF can be assessed based on calorific value, moisture content, volatile content, ash content, chlorine content, and several other parameters.

Several other parameters strongly influence the calorific value of the RDF manufacturing process. Therefore, it is necessary to test the correlation between the variables in mixing paper and garden waste to achieve the optimum heating value. The current application of RDF has also been carried out to reduce municipal waste generation, including the Depok. Depok City also has paper and garden waste characteristics that must be reduced (Zahra et al., 2022). This research analyzes the potential utilization of paper and garden waste substitution as RDF.

METHODS

This study uses a variation of 25% for each addition to the composition of paper and garden waste to manufacture RDF pellets. RDF's quality was measured by calculating the moisture and ash content using the gravimetric principle. Meanwhile, density was measured using an automatic density analyzer connected to an ultrapyc-quantachrome power cable, and the hydrogen gas regulator was opened to a pressure of 18 psi. Finally, the calorific value is measured using the bomb calorimeter principle.

Before carrying out the decision analysis test, statistical analysis was carried out on the composition of paper, garden, moisture content, ash content, and density on the calorific value. A multicollinearity test is a situation that shows a strong correlation or relationship between two or more independent variables in a multiple regression model. The multicollinearity test in this study used a linear equation with the SPSS program.

Kepner-Tregoe Decision Analysis (KTDA) is a method to provide the best solution from several alternatives (Moseley et al., 2008). This study used the KTDA method to determine the best quality of RDF pellets among the five compositions worthy of being used as raw material for RDF pellets at TPSS Merdeka 3. The test results of the five RDF pellets had values that were not much difference between each variation, so the analysis was needed. There are two categories of assessment, namely must and wants. The must category is carried out at the initial stage of the evaluation, namely scoring in the form of Go and No Go. The Go assessment meets the criteria to be achieved, while the No Go assessment does not meet the criteria to be completed. The wants category is assessed after evaluating the must criteria by giving weight and rating.

This study analyzes the various compositions of paper waste and garden potential raw materials for RDF pellets. Therefore, RDF pellets from various compositions of paper waste and garden must be compared with applicable standards to determine their quality and suitability as fuel. These standards are density standards and RDF quality standards from several countries. The density standard used in this study conforms to the pellet quality standards from Austria, Sweden, America, and France (Bantacut et al., 2013). The quality standards of RDF used in this study follow Italian, Finnish, English, and Indocement standards. The use of density standards and quality standards of RDF pellets is to determine the efficiency of combustion performance of pellets. The standard values that apply to each parameter can be seen in Table 1 and Table 2.

The pellet density and RDF quality standards are compared with the laboratory results to determine their conformity with predetermined standards. The five RDF pellets analyzed the must criteria (mandatory to be met). Furthermore, an assessment of the wants category was carried out to evaluate RDF pellets adjusted to the selected standard, namely in terms of moisture content, ash content, and calorific value prevailing in the Indonesian cement industry, one of which has been implemented by Indocement. In Table 3, an assessment

Table 1. RDF Quality parameter standards

Parameter	Standard			
	Italy*	Finland*	UK*	Indocement**
Calorific Value	15	13-16	18,7	12.56
Water content	Max 25	25-35	7-8	Max 20
Ash Level	20	5-10	12	10

(Source: *Gendebien, 2003; **Qonitan et al., 2021)

Table 2. Standard of pellet density parameter

Parameters	Standard			
	Austria	Sweden	USA	England
Density	1120	600	640	1150

(Source: Bantacut et al., 2013)

of the wants category is carried out by giving a weighting value consisting of weight and rating values. In Table 3, the weight assessment is the level of importance of the criteria, where the higher the weight value, the more important the criteria. The following is a description of the assessment on weight:

- 1-2 (Not important): These parameters do not affect the quality of the RDF, so they do not affect the efficiency of combustion performance.
- 3-4 (Less important): These parameters have little effect on RDF quality but do not affect combustion efficiency or performance.
- 5-6 (Enough): These parameters influence the quality of the RDF and possibly affect combustion efficiency or performance.
- 7-8 (Important): These parameters significantly influence the quality of the RDF and can affect combustion efficiency and performance.
- 9-10 (Very important): These parameters very significantly influence the quality of the RDF and can affect combustion efficiency and performance.

Table 3. Value of weight and rating on wants assessment

Rating	1-2	3-4	5-6	7-8	9-10
Weight (How important)	Tends to be unimportant	Not too important	Enough	Important	Very important
Rating (Fullfilment rate)	Very less	Not enough	Enough	Good	Very good

RESULTS AND DISCUSSION

Waste that can be used as raw material for RDF is combustible waste, including paper and garden waste. The main parameters of the characteristics of waste as raw material for RDF include water content, ash, density, and calorific value (Białowiec et al., 2017; Sarwono et al., 2021; Suryawan, Fauziah et al., 2022; Ulhasanah et al., 2022). Moisture content and calorific value are needed to evaluate alternative processes and recovery systems that can be carried out on solid waste (Kathirvale et al., 2004). Therefore, parameter analysis on paper and garden waste carried out is water content and calorific value to determine its potential as raw material for RDF pellets. Table 4 shows the test results of the RDF's quality characteristics from the variations used.

Table 4. Results of RDF quality laboratory tests

ID	Paper (by w/w)	Garden (by w/w)	Result			
			Water content (%)	Ash content (%)	Density (kg/m^3)	Caloric value (MJ/kg)
K-100%	100%	0%	10.1	9.9	2247	13.1
K-75%	75%	25%	5.8	7.7	2009	16.3
K-50%	50%	50%	9.4	7.1	2637	17.1
K-25%	25%	75%	8.5	6.9	2048	18.3
K-0%	0%	100%	15.3	4.5	1971	19.0

Pearson correlation measures the strength and direction of a linear relationship between two variables. It can be seen that the relationship between the variable paper composition and ash content has a very strong negative relationship with caloric value. At the same time, the provision of garden waste has a very strong positive correlation value in increasing the calorific value of RDF Table 5).

Table 5. Pearson correlation of RDF quality parameter measurement results

Variable	Caloric value (MJ/kg)	Paper (by w/w)	Garden (by w/w)	Water content (%) (by w/w)	Ash content (%) (by w/w)	Density (kg/m^3)
Caloric value (MJ/kg)	1	-0.951	0.951	0.342	-0.936	-0.282
Paper (by w/w)	**-0.951**	1	-1	-0.594	0.948	0.295
Garden (by w/w)	**0.951**	-1	1	0.594	-0.948	-0.295
Water content (%) (by w/w)	0.342	-0.594	0.594	1	-0.586	-0.114
Ash content (%) (by w/w)	**-0.936**	0.948	-0.948	-0.586	1	0.304
Density (kg/m^3)	-0.282	0.295	-0.295	-0.114	0.304	1

Very strong multicollinearity was found in this study (R^2 0.999) (Table 6). There was a strong correlation between the independent variables (X) included in the determination of the calorific value in this study. However, water content and ash content have negative coefficients, which will reduce the heat content in RDF manufacture. Meanwhile, the addition of garden waste will increase the calorific value.

Table 6. Multilinear equations in determining the calorific value of a mixture of garden and paper waste

Model	Unstandardized coefficients
(Constant)	19.977
Garden (by w/w)	0.045
Water content (by w/w)	-0.242
Ash content (%) (by w/w)	-0.516
Density (kg/m^3)	0
R^2	0.999

*Excluded variable composition of paper (%)

The main criteria that must be met in most analyses are that the five variations of pellets must meet the RDF standard provisions. Based on Table 4, pellets K-75%, K-50%, K-25%, and K-0% have completed the applicable RDF standard provisions to be considered for use as fuel. On the other hand, the K-100% pellet did not meet the RDF standard, so no further evaluation was carried out on the wants analysis in KTDA. Furthermore, the four variations of RDF pellets were assessed in the wants category to evaluate RDF pellets adjusted to the selected standard: moisture content, ash content, and calorific value parameters. RDF in this study is applicable in the Indonesian cement industry, one of which has been implemented by Indocement. Therefore, the four variations of RDF pellets in this study have parameters that best match the RDF criteria used by the cement industry. Because the cement industry in Indonesia has adapted to the characteristics of waste and waste collection systems in Indonesia, the selection of cement industry standards is also due to a work plan. Therefore, the quality of the five RDF pellets in this study can be used as a pilot for RDF pellets by the cement industry. Based on the assessment criteria in the must and wants categories, the calculation results are obtained in Table 7.

The calculation results show that K-75% has the most significant total value of 171 because it has a lower water content than others (Table 7). The low water content value will facilitate handling operations so that the quality of combustion performance becomes more effective and efficient and benefits the company. Based on the recapitulation results of alternative evaluations of various variations of RDF pellets using the KTDA method, the selected variation was obtained from pellets K-75% with a mixture of 75% paper and 25% paper garden.

Table 7. Calculation of decision analysis with the KTDA method on the best variation

Weighting		RDF								
No	Must	K-100%	K-75%		K-50%		K-25%		K-0%	
1	Meet standard quality	NO, GO	GO		GO		GO		GO	
Wants	Weight		Rating	Score	Rating	Score	Rating	Score	Rating	Score
1	9	Calculations were not carried out because K-100% did not meet the standard quality criteria	9	81	6	54	6	54	2	18
2	7		6	42	6	42	6	42	8	56
3	8		6	48	6	48	6	48	7	56
Total			171		144		144		130	

The waste processing capacity that can be carried out by TPSS Merdeka 3 every day is 3 tons, so if 75% paper and 25% garden are selected, TPSS Merdeka 3 can process 75% paper waste from the total capacity of 2.25 tons/da and garden of 0.75 tons/day. Then the total waste generated in Depok City is 1070 tons/day. The composition of paper waste is 6%, which is the third-largest component after food waste and plastic. The following are the results of calculating the potential for reducing paper waste and gardens in Depok City using selected RDF pellet variations, namely 75% paper and 25%. Details of the calculations can be seen in Table 8. So based on the results of the above calculations, the potential for paper waste reduction is 3.5%, and garden waste is 12.3%.

Material Flow Analysis (MFA) of the waste utilization can be seen in Figure 1. Applying this RDF can reduce 3.5% of paper waste and 12.3% of garden waste in Depok City.

Table 8. Calculation of waste reduction potential for RDF mixed garden and paper waste

Parameters	Value
Capacity of MRF	3 tons/day
The amount of paper waste and litter that can be processed at the MRF	• Paper waste: 75% (Kementerian Lingkungan Hidup dan Kehutanan, 2021) x 3 Tons = 2.25 tons/day • Garden waste: 25% (Kementerian Lingkungan Hidup dan Kehutanan, 2021) x 3 Ton = 0.75 ton/day
Total waste generation in Depok City	1,070 ton/day (Kementerian Lingkungan Hidup dan Kehutanan, 2021)
Amount of paper waste in Depok City	6% x 1070 ton/day = 64.2 ton/day
Paper waste reduction potential in Depok City	$\frac{2{,}25\ ton/day}{64{,}2\ ton/day}\ x\ 100\% = 3.5\%$
Amount of garden waste in Depok City	0.57% x 1070 ton/day = 6.09 ton/day
Garden waste reduction potential in Depok City	$\frac{0{,}75\ ton/day}{6{,}09\ ton/day}\ x\ 100\% = 12{,}3\%$

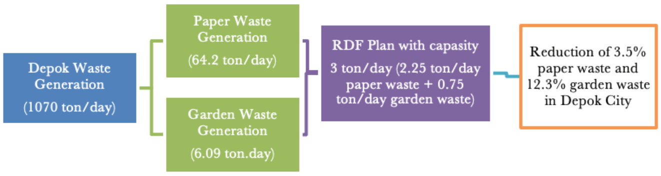

Figure 1. Material flow of paper and garden waste utilization to RDF in Depok City

CONCLUSION

Based on the variation of mixing, 75% paper waste and 25% wood waste have the most prominent points in mixing waste. Based on Material Flow Analysis (MFA), the utilization of this waste can reduce the generation of paper waste and garden waste by 3.5% and 12.3%, respectively.

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