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Thermogravimetric Analysis of Eucalyptus Leaves as An Alternative Fuel for Rural Areas

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Abstrak
The utilization of biomass waste as a substitute for conventional energy sources has gained popularity, and one possible source is the litter generated by eucalyptus plantations. The present study used thermogravimetric analysis (TGA) gain insight into the thermochemical characteristics of eucalyptus leaves. It was identified by heating the sample in a nitrogen environment from ambient temperature to 850°C at a rate of 10 °C/minute. Eucalyptus leaves have a high volatile matter (VM) content and a calorific value (CV) of 17.26 MJ/kg, according to the ultimate and proximate analysis. Additionally, the TGA results showed that eucalyptus leaves had a lower ignition temperature than other biomasses. Eucalyptus leaves began to devolatilize at 119 °C, reaching a peak temperature of 326 oC, and losing 68% of their weight as a result.

INTRODUCTION

Over the past ten years, the world's population has grown significantly, as has the level of living, particularly for fossil fuels, which are the primary energy source. As a result, fossil fuel reserves are depleting, there are major environmental issues, and there are high greenhouse gas (GHG) emission levels. Numerous efforts have been made to develop alternate fuels and renewable energy sources in order to overcome these difficulties. Biomass energy is one of the more promising alternatives among the renewable energy sources and alternative fuels currently being developed. In addition to being abundant globally, biomass also has a low N and S content, which allows it to lessen the NOx and SOx emissions produced by fossil fuels. Biomass fuel is also carbon neutral fuel since the CO_2 released in the atmosphere by fuel burning will re-absorbed by plants for its growth (Priya et al., 2022).

In tropical climates, eucalyptus trees grow quickly and provide biomass with good grade wood. Considering the benefits, it has become one of the most commercially significant trees in the world. Eucalyptus trees produce biomass residues derived from litter fall in addition to wood, which serves as the tree's primary source of biomass. Before reaching the age of a year, eucalyptus trees have been generating the litter fall. Eucalyptus plantations generate annual litter fall of up to 13.4 OD t/ha/year, with leaves accounting for the vast bulk (95% at 2-year-old trees), which continues to accumulate and spread throughout the plant (Maarasyid et al., 2017). In most cases, the leaf litter is left to naturally degrade as a source of nutrients for the plantation's environment. Although the amount of eucalyptus leaf litter continues to grow and increase, the natural decomposition rate is relatively sluggish (Cizungu et al., 2014). Additionally, because of the accumulation of dried leaves in the plantation, the excessive heat weather might trigger forest fires.

A possible source of biomass for use as a solid fuel is undoubtedly from the abundance of leaf litter in the eucalyptus plantations. However, there is little available data and research on using eucalyptus leaves as a source of biomass energy. In order to analyze the thermochemical characteristics of eucalyptus leaves for solid fuel purposes, this study was performed by using thermogravimetric analysis. Additionally, the behavior of thermal decomposition as well as thermal characteristics like ignition temperature, peak temperature, and devolatilization characteristic will be discussed.

MATERIALS AND METHODS

The eucalyptus leaves utilized in the present study were obtained from PT. Arara Abadi Plantation in Riau, Indonesia. The flow diagram of experimental methods was presented in Figure 1. The raw material was air-dried, crushed, and sieved before the analytical testing. For the experimental runs, particles of a size between 250 and 500 µm were selected. Proximate and ultimate analyses were employed to characterize the feedstock's characteristics. Regarding the objective of determining the moisture content, volatile matter, ash content, and fixed carbon content of biomass samples, proximate analysis was performed in accordance with ASTM D3173 standard procedures. Elemental analysis (C, H, O, N, and S content) was performed using CHNS elemental analyzer (Elementar vario macro cube model from Elementar Analysensysteme GmbH). Using a bomb calorimeter (Model C200 from IKA-Werke GmbH & Co. KG), the higher heating value of the eucalyptus leaves was identified.

In addition, a thermogravimetric analyzer (TGA) Model Q500 from TA Instrument was set up to figure out the thermal degradation behavior of the utilized feedstock. The ten-milligram sample was placed into the crucible, and the temperature raised up to 850 ºC at a regulated rate of 20 ºC/min. Flow rates of 80 ml/min of nitrogen were employed during the testing period.

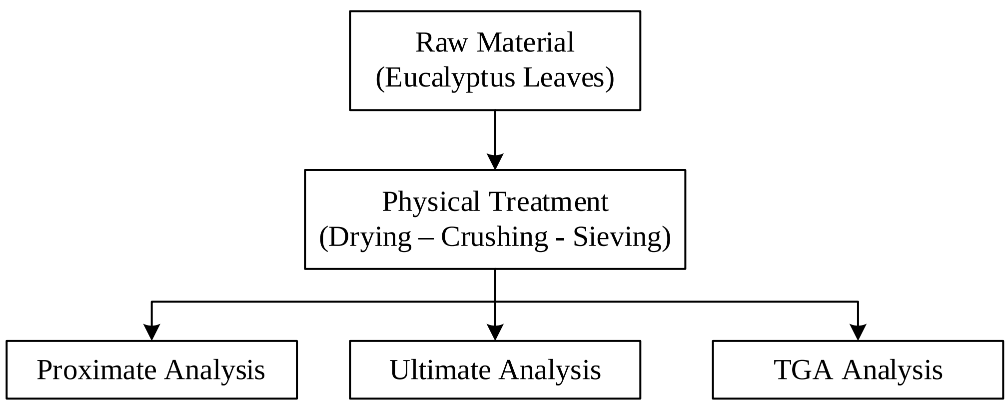

Fig.1. Experimental flow diagram.

RESULTS AND DISCUSSION

The initial and most significant step in examining and deciding whether to utilize eucalyptus leaves as a solid fuel source is to identify and characterize their composition. These compositions are a special fundamental formula that distinguishes and establishes the characteristics, excellence, prospective uses, and environmental issues connected to each fuel. This was accomplished by characterizing solid fuels using widely recognized physical (proximate) and chemical (ultimate) research.

The percentage of volatile matter (VM), fixed carbon (FC), and ash contents was assessed using proximate analysis. Table 1 provides an examination of Eucalyptus leaves and compares them to other biomass and coal, which are typically utilized as solid fuels in rural areas. The calorific value (CV), which is defined as the amount of heat released by the unit mass of fuel, is one of the special characteristics used to identify solid fuels. Table 1 makes it very clear that the CV of biomass is almost half of the coal. The CV of eucalyptus leaves is 17 MJ/kg, approximately similar with the CV of the oil palm fiber, and slightly lower compared to the wood.

Table 1. Proximate analysis of Eucalyptus leaves and other biomass (% wt).

Biomass	CV (MJ/kg)	VM (%)	FC (%)	Ash (%)	References
Eucalyptus leaves	17.26	77.48	15.48	7.04	This study
Rice straw	15.09	71.60	14.5	13.9	(Worasuwannarak et al., 2007)
Oil palm fiber	17.13	72.46	20.51	7.03	(Chen et al., 2014)
Wood	18.60	82	17	1	(McKendry, 2002)
Bitumen coal	34	35	45	9	(McKendry, 2002)

Proximate analysis is very important to study the combustion phenomenon of biomass. Volatile matter (VM) and fixed carbon content (FC) provide a measurement of the ease of the biomass can be ignited and subsequently gasified or oxidized (McKendry, 2002). Table 1 points out that compared to coal, eucalyptus leaves and other biomass have a greater VM content and are easier to burn. Additionally, there is an extensive connection between the VM and FC content and the CV of the biomass itself. Sheng and Azevedo (2005) investigated several empirical correlations of proximate analysis features and found that both of them had a favorable impact on the CV, however ash content may have a negative impact on the CV of biomass. The CV characteristics of Eucalyptus leaves are still lower than those of wood, as demonstrated in Table 1, which is possibly as a consequence of its ash concentration. Since high ash content in biomass might lead to combustion issues, it should be taken into consideration when using it as a solid fuel. Low melting point of the dissolved ash causes problems with fouling and slagging (Cieplik et al., 2010). The eucalyptus leaves have a low value when compared to coal and rice straw for their ash content, which is approximately identical to that of oil palm fiber.

Studying the biomass fuel qualities should also take into consideration the ultimate analysis, which is presented in Table 2. In evaluating the environmental effects of biomass, it is helpful to assess the atomic proportion of N and S. The contents of N and S for eucalyptus leaves and other biomass were obviously lower than the coal. Low values for these characteristics can turn the biomass into a green fuel by reducing corrosion and NOx emissions into the environment. Additionally, it is possible to estimate the heating value of these fuels using the percentage of C, H, and O in the ultimate analysis. Together with hydrogen, carbon increases the CV of biomass and is the main heat source released during fuel combustion. In contrast, despite being conducive to fuel combustion, oxygen may decrease the CV of biomass (Chen et al., 2015). From Table 2, it seen that generally biomass has the lower content of carbon and high content of oxygen.

Table 2. Ultimate analysis of Eucalyptus leaves and other biomass (% wt).

Biomass	C	H	N	O	S	References
Eucalyptus leaves	44.1	6.09	0.18	43.27	0.37	This study
Rice straw	44.2	6.2	0.8	48.8	-	(Worasuwannarak et al., 2007)
Oil Palm Fiber	51.94	4.75	2.43	40.88	-	(Chen et al., 2014)
Wood	51.6	6.3	0	41.50	0.1	(McKendry, 2002)
Bitumen coal	73.1	5.5	1.4	8.7	1.7	(McKendry, 2002)

Thermogravimetric method was used to evaluate the thermal degradation and reactivity of Eucalyptus leaves. Fig. 2 displays the typical time courses of the sample mass (TG curve) and its derivative mass (DTG). Decomposition of Eucalyptus leaves is shown in the figure to take place in 3 stages: drying and evaporation (A), devolatization (B), and char aggregation (C). The profiles of each stage for Eucalyptus leaves decomposition are shown in Table 3.

Two distinct peaks with extreme at 231 ºC and 326 ºC that can be seen in the stage B of DTG curve could be corresponding to hemicellulose and cellulose, respectively. The volatile yield corresponding to identified lumps can be read out from mass loss under the single peak area in Fig. 2. It is interesting that the second and third lumps in the stage B corresponding to cellulose and lignin decomposition represent almost the same fraction of the biomass, while the hemicellulose degradation that figured as first lump was 18.81%. The maximum combustion rate for both of these components was 2.4 and 3.7 mg/min for hemicellulose and cellulose of Eucalyptus leaves, respectively.

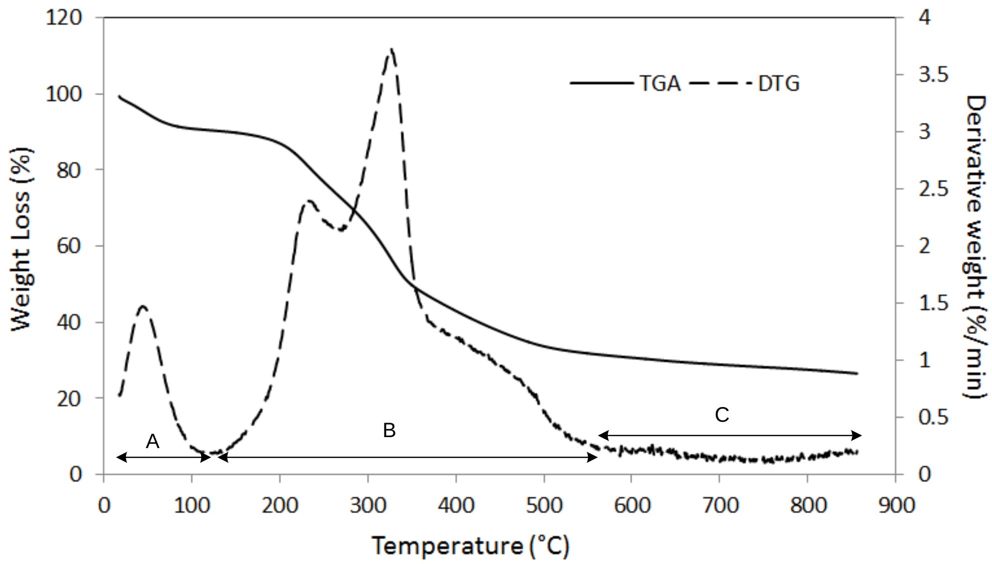

Table 3. TGA/DTG profile of Eucalyptus leaves.

Stage	Process	Onset (ºC)	End (ºC)	Mass Loss (% wt)	Duration (min)
A	Drying and Evaporation	18	119	9.51	12.20
B	Devolatilization	119	555	67.93	43.36
	1^{st} lumps	*119*	*274*	*18.81*	*15.13*
	2^{nd} lumps	*274*	*350*	*24.87*	*9.52*
	3^{rd} lumps	*350*	*555*	*24.25*	*18.71*
C	Char Aggregation	555	855	5.51	29.95

Ignition temperature and peak temperature are the two most significant characteristic temperatures associated with a thermal decomposition profile. TGA/DTG curve profiles could be utilized for determining among them. The temperature at which there is a sudden spike in thermal deterioration is called the ignition temperature. Peak temperature refers to the point on the DTG curve where the rates of weight loss resulting from thermal breakdown are at the highest level. The peak temperature is typically utilized as an indicator of the sample's reactivity and is mostly brought on by the volatile matter content of the biomass sample. High volatile matter content of the biomass sample causes an increase in the peak temperature (Saidur et al., 2011). The eucalyptus leaves' peak temperature and ignition temperature were determined from the TGA/DTG curve in Fig. 2 and were found to be 326 °C and 119 °C, respectively. Table 4 evaluates the peak temperature and ignition characteristics of different biomasses and coal.

Table 4. The Ignition and peak temperature profiles of Eucalyptus leaves and other biomass.

Biomass	Ignition Temperature (°C)	Peak Temperature (°C)	References
Eucalyptus leaves	119	326	This study
Rice straw	230	310	(Worasuwannarak et al., 2007)
Oil Palm Fiber	206	325	(Nyakuma et al., 2014)
Wood	250	330	(Magdziarz & Wilk, 2013)
Coal	300	483	(Magdziarz & Wilk, 2013)

The ignition temperature of biomasses is often lower than that of coal, as can be observed in Table 4. Since Eucalyptus leaves ignited at a lower temperature than other biomasses, they could be burned as a solid fuel for rural areas more easily than other biomasses. The presence of essential oils in the eucalyptus leaves could be believed the main factor causing its flammability. The chemical components of essential oil in eucalyptus leaves are shown in Table 5. The essential coil content in eucalyptus leaves reaches 5% with varies chemical compounds depending on the species and planting location. By knowing the composition and characterization of Eucalyptus leaves, it will helpful to utilized them as the solid fuel for direct combustion, pyrolysis or gasification in the rural areas.

Table 5. Essential oils and its chemical component from several eucalyptus leaves.

Chemical Component	Molecular Formula	Flash Point (°C)	References			
			(Kartiko et al., 2021)	(Achmad et al., 2018)	(Limam et al., 2020)	(Ameur et al., 2021)
Essential oil yield			0.86	0.5 - 3.25	0.1 - 6.16	1.4 - 5.2
α-pinene	$C_{10}H_{16}$	32	33.49	0.5 - 17.53	0.43 - 28.24	3.9 - 38.2
p-cymene	$C_{10}H_{14}$	47	0.78	0 - 18.44	0 - 0.32	0.4 - 35.8
Eucalyptol (1.8-cineole)	$C_{10}H_{18}O$	49	6.7	0.12 - 45.47	16.31 -71.16	20 - 66.3
Patchouli alcohol (viridiflorol)	$C_{15}H_{26}O$	122	13.77	0 - 13.77	0 - 5.46	0.1 - 12.7

CONCLUSION

This study examined the thermochemical characteristics of eucalyptus leaves to be utilized as a solid fuel. According to the findings, eucalyptus leaves have a higher calorific value than rice straw and oil palm fiber due to its high volatile matter content and fixed carbon content, which results in a calorific value of 17.26 MJ/kg. The TGA result revealed that the ignition temperature of eucalyptus leaves was lower, indicating that they burn more readily than other biomasses. The devolatization process for eucalyptus leaves began at 119 °C and reached a peak temperature of 555 °C with a peak at 326 °C. A total of 68% of the mass was lost throughout this process. The results of this study are crucial because they offer insight into the potential use of eucalyptus leaves as a source of solid fuel for energy generators in the rural area.

REFERENCES

Achmad, H. N., Rana, H. E., Fadilla, I., Fajar, A., Manurung, R., & Abduh, M. Y. (2018). Determination of yield and chemical composition of eucalyptus oil from different species and locations in Indonesia. *Biological and Natural Resources Engineering Journal*, *1*(1), 36–49. https://doi.org/10.31436/cnrej.v1i1.22

Ameur, E., Sarra, M., Yosra, D., Mariem, K., Nabil, A., Lynen, F., & Larbi, K. M. (2021). Chemical composition of essential oils of eight Tunisian Eucalyptus species and their antibacterial activity against strains responsible for otitis. *BMC Complementary Medicine and Therapies*, *21*(1), 1–16. https://doi.org/10.1186/s12906-021-03379-y.

Chen, W. H., Kuo, P. C., Liu, S. H., & Wu, W. (2014). Thermal characterization of oil palm fiber and eucalyptus in torrefaction. *Energy*, *71*, 40–48. https://doi.org/10.1016/j.energy.2014.03.117.

Chen, W. H., Peng, J., & Bi, X. T. (2015). A state-of-the-art review of biomass torrefaction, densification and applications. *Renewable and Sustainable Energy Reviews*, *44*, 847–866. https://doi.org/10.1016/j.rser.2014.12.039.

Cieplik, M. K., FrydaL, L. E., van de Kamp, W. L., & Kiel, J. H. A. (2010). Ash formation, slagging and fouling in biomass co-firing in pulverised-fuel boilers. In P. Grammelis (Ed.), *Solid Biofuels for Energy: A Lower Greenhouse Gas Alternative Solid Biofuels for Energy* (pp. 197–217). Springer. https://doi.org/10.1007/978-1-84996-393-0.

Cizungu, L., Staelens, J., Huygens, D., Walangululu, J., Muhindo, D., Van Cleemput, O., & Boeckx, P. (2014). Litterfall and leaf litter decomposition in a central African tropical mountain forest and Eucalyptus plantation. *Forest Ecology and Management*, *326*, 109–116. https://doi.org/10.1016/j.foreco.2014.04.015.

Kartiko, A. B., Putri, A. S., Rosamah, E., & Kuspradini, H. (2021). Evaluation of antibacterial activity and physico-chemical profiles of eucalyptus pellita essential oil from East Kalimantan. *Proceedings of the Joint Symposium on Tropical Studies (JSTS-19)*, *11*, 9–13. https://doi.org/10.2991/absr.k.210408.002.

Limam, H., Ben Jemaa, M., Tammar, S., Ksibi, N., Khammassi, S., Jallouli, S., Del Re, G., & Msaada, K. (2020). Variation in chemical profile of leaves essential oils from thirteen Tunisian Eucalyptus species and evaluation of their antioxidant and antibacterial properties. *Industrial Crops and Products*, *158*(September), 112964. https://doi.org/10.1016/j.indcrop.2020.112964.

Maarasyid, C., Muhamad, I. I., Nik Mahmood, N. A., & Zulfansyah. (2017). Solid fuel feedstock from leaves litter of industrial forestry in Riau, Indonesia. In *Materials Science Forum* (Vol. 883). https://doi.org/10.4028/www.scientific.net/MSF.883.102.

Magdziarz, A., & Wilk, M. (2013). Thermogravimetric study of biomass, sewage sludge and coal combustion. *Energy Conversion and Management*, *75*, 425–430. https://doi.org/10.1016/j.enconman.2013.06.016.

McKendry, P. (2002). Energy production from biomass (part 1): Overview of biomass. *Bioresource Technology*, *83*(1), 37–46. https://doi.org/10.1016/S0960-8524(01)00118-3.

Nyakuma, B. B., Johari, A., Ahmad, A., & Amran, T. (2014). Thermogravimetric analysis of the fuel properties of empty fruit bunch Briquettes. *Jurnal Teknologi (Sciences and Engineering)*, *67*(3), 79–82.

Priya, Deora, P. S., Verma, Y., Muhal, R. A., Goswami, C., & Singh, T. (2022). Biofuels: An alternative to conventional fuel and energy source. *Materials Today: Proceedings*, *48*, 1178–1184. https://doi.org/https://doi.org/10.1016/j.matpr.2021.08.227.

Saidur, R., Abdelaziz, E. a., Demirbas, a., Hossain, M. S., & Mekhilef, S. (2011). A review on biomass as a fuel for boilers. *Renewable and Sustainable Energy Reviews*, *15*(5), 2262–2289. https://doi.org/10.1016/j.rser.2011.02.015.

Sheng, C., & Azevedo, J. L. T. (2005). Estimating the higher heating value of biomass fuels from basic analysis data. *Biomass and Bioenergy*, *28*(5), 499–507. https://doi.org/10.1016/j.biombioe.2004.11.008.

Worasuwannarak, N., Sonobe, T., & Tanthapanichakoon, W. (2007). Pyrolysis behaviors of rice straw, rice husk, and corncob by TG-MS technique. *Journal of Analytical and Applied Pyrolysis*, *78*(2), 265–271. https://doi.org/10.1016/j.jaap.2006.08.002.