Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: N.Y. Abd Halim and N.I.S. Muhammad 2025 *J. Phys.: Conf. Ser.* **3003** 012019

Journal of Physics: Conference Series **3003** (2025) 012019 doi:10.1088/1742-6596/3003/1/012019

Correlation of Moisture Content and Heating Value of Refuse-Derived Fuel

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Abstract. Refused Derived Fuel (RDF) from mixed agricultural residues (Ag-Residue) is a potential solution to reduce coal dependency due to its similar energy content. This study aims to determine the correlation between moisture content and heating value (HHV) of five RDF formulations containing PKS, CS, CH, and EFB, with varying moisture content (MC) levels of 5%, 8%, and 10%. The results demonstrated that all samples showed an increase in HHV as the moisture content decreased, as more water content absorbs energy during burning, leading to a decrease in net output. These findings highlight the critical importance of reducing moisture content in RDF to enhance energy output, demonstrating the effectiveness of drying techniques or moisture control methods.

1. Introduction

Energy demand has been rising over the years due to various factors such as population growth, and economic development. One of the crucial forms of energy is electricity. As of today, this energy is mainly generated from coal, and natural gas, as well as renewable sources such as wind, solar and biomass. In Malaysia, most of the electricity comes from fossil fuels such as coal and natural gas [1], [2]. It has been reported that between 2020 and 2022, coal usage for electricity production in this country increased from 6% to 42% [3]. It has been noted that Malaysia heavily relies upon imported coal, which Indonesia is found to be the largest supplier of coal, followed by Australia given bu 63% and 24% respectively [4], [5] According to Tenaga Nasional Berhad (TNB), rising coal prices can lead to higher surcharge rates for customers through the Imbalance Cost Pass-Through mechanism. Recent increases in global coal prices have significantly raised electricity generation costs by 45% in Peninsular Malaysia [6]. Hence, the alternatives to substitute coal have gotten more attention recently.

In Malaysia, approximately 1.2 million tonnes of Agricultural Residue (Ag-Residue) are dumped in landfills annually. This residue is high in energy content and can be utilized in producing solid biofuel which is known as Refuse Derived Fuel (RDF). According to Kaniapan et al., (2021), palm kernel shells (PKS) show the highest Heating Value (HHV) at 20.73 MJ/kg, followed by coconut shells (CS) at 20.53 MJ/kg, and empty fruit bunches (EFB) at 16.98 MJ/kg [7]. Previous studies have shown that RDF from biomass is a potential solution to reduce coal dependency due to its similar energy content [8]. Although previous studies indicate that individual waste types have HHV values closest to coal, fewer studies explore the potential of mixed agricultural residues in producing RDF and its impact on moisture content. Thus, this study aims to determine the correlation between moisture content and HHV value of RDF from mixed Ag-Residue.

2. Methodology

2.1 RDF production

The agricultural residues used in this study include Coconut Shell (CS), Coconut Husk (CH), Palm Kernel Shell (PKS), and Empty Fruit Bunch (EFB). These residues were collected from local palm coconut shops and plants near Gambang, Pahang, Malaysia. The waste was then dried in a hot-air oven at 105°C for 24 hours before being ground using an IKA Multidrive Milling (MI 250 Multidrive Basic). A tap sieve shaker with 4.0 mm mesh sieves was used to obtain powder particles for easier mixing. The procedure followed the ANSI/ASAE S319.4 Standard for particle size distribution. Figure 1 illustrates the RDF production procedure.

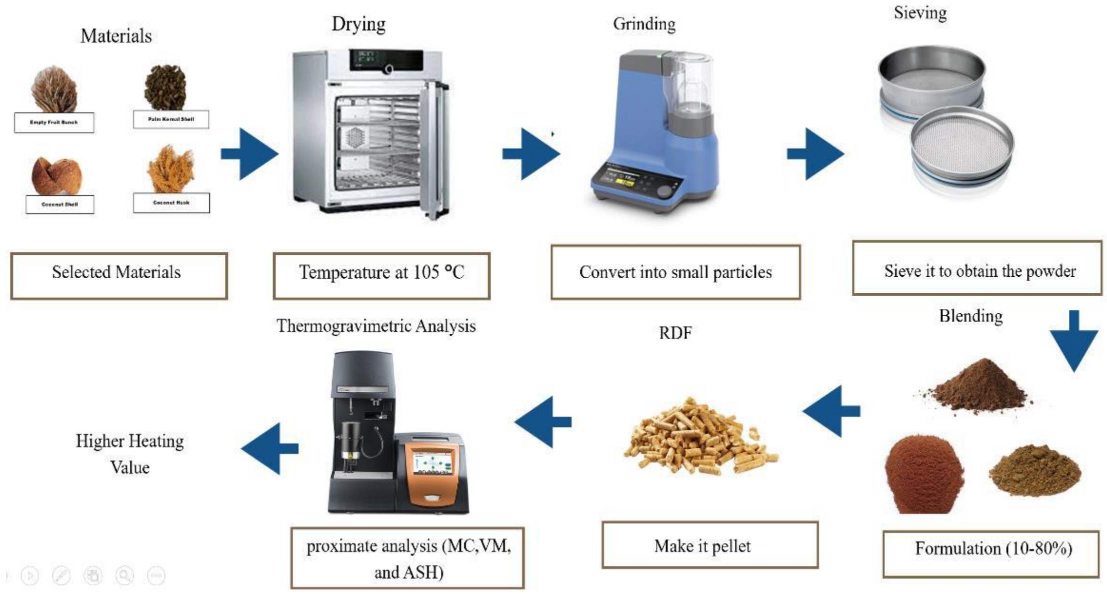

Figure 1. RDF production flow diagram.

There are five RDF formulations used in this study with composition involved in blending PKS, CH, CS and EFB in specific ratios ranging from 10% to 80%, with moisture contents of 5%, 7%, and 10%. The formulation as shown in Table 1.

Table 1. Composition of Ag-Residue

RDF Samples	PKS	CH	CS	EFB
RDF1	-	√	√	√
RDF2	√	√	√	√
RDF3	√	-	√	√
RDF4	√	√	-	√
RDF5	√	√	√	-

[a] the composition range from 10% -80%.

2.2 Proximate analysis

This analysis used TGA (Hitachi / STA7000 Model) to thermally treat RDF from ambient temperature to 900°C in an air environment with a flow rate of 20 mL/min. The impact of heating rates on the sample was investigated at 20°C/min with sample weights between 8-10 mg. TGA-based proximate analysis of RDF followed ASTM Standard D5142, determining moisture content (MC), ash, fixed carbon (FC), and volatile matter (VM) as percentages of the total weight [25]. MC was analyzed from 25–107°C, holding samples at this temperature for 120 minutes without air exposure. VM was measured from 107 to 950°C, heating rapidly to 950°C at 30°C/min, then holding for 7 minutes. Ash content was determined by heating samples to 815°C at 3.6°C/min and holding for 150 minutes. FC was calculated by subtracting the MC, VM, and ash percentages from 100% [9]. The HHV value will be calculated using the equation as stated below [10]

$$HHV = 0.3543FC + 0.1708VM \qquad \text{Eq.1}$$

2.3 Statistical analysis

Pearson correlation coefficients were calculated to assess the linear relationship between moisture content and HHV value. Pearson's r was based on the assumption that the data were normally distributed. Correlations were computed using JMP Pro 17.0 (SAS Corporation, USA).

3. Results and Discussion

3.1 HHV value

Five RDF formulation samples containing PKS, CS, CH and EFB were used to compare HHV. The Ag-Residue was randomly mixed with ratios ranging from 10% to 80% each. The HHV value is calculated based on proximate analysis and equation 1 for MC 5%, 8% and 10%, respectively. The value is tabulated in Table 2.

Table 2. HHV value

RDF Samples	HHV (MJ/kg)		
	MC 5%	MC 8%	MC 10%
RDF1	21.56	21.30	21.12
RDF2	21.64	20.87	20.35
RDF3	21.36	20.83	20.47
RDF4	21.65	20.54	19.79
RDF5	22.75	21.93	21.38

[a] the composition range from 10% -80%.

The data clearly shows that all samples experience a reduction in HHV as the moisture content increases, which aligns with the expectation that higher moisture content reduces the net energy output during combustion. All RDF samples show a decline in HHV as the moisture content increases. This trend is consistent with the understanding that higher moisture content in RDF results in more water that absorbs energy during combustion, leading to a lower net energy output. RDF5 consistently exhibits the highest HHV values across all moisture content levels, indicating its superior energy potential. Specifically, RDF5 maintains an HHV of 22.75 MJ/kg at 5% MC, which decreases to 21.38 MJ/kg at 10% MC. Lower moisture content leads to higher HHV, underscoring the need for effective moisture management in RDF production and utilization. As previous studies indicate, moisture content absorbs some of the energy produced during combustion [11].

3.2 Correlation

Table 3 presents the correlation between moisture content (MC) and higher heating value (HHV) of the RDF samples. The correlation coefficient between HHV and MC is -0.6963, indicating a strong negative correlation. This suggests that as the moisture content decreases, the HHV of the RDF samples increases. This negative relationship is expected, as higher moisture content in RDF means more water is present, which absorbs energy during the combustion process and reduces the net energy output.

The correlation coefficient of -0.6963 is relatively close to -1, further emphasizing that moisture content significantly impacts the HHV. This finding is consistent with the observations from Table 2, where all samples demonstrated a decrease in HHV with increasing moisture content. For example, RDF6, which had the highest HHV values, showed a reduction in HHV from 22.75 MJ/kg at 5% MC to 21.38 MJ/kg at 10% MC. This trend underscores the importance of controlling and minimizing moisture content in RDF to enhance its energy potential.

Table 3. Correlation between moisture content and HHV value

Value	Correlations	Correlations
HHV (MJ/kg)	1.0000	-0.6963
MC (%)	-0.6963	1.0000

4. Conclusion

The study investigates the higher heating value (HHV) of five RDF formulations containing PKS, CS, CH, and EFB, with varying moisture content (MC) levels of 5%, 8%, and 10%. The results demonstrated that all samples exhibited a reduction in HHV as moisture content increased. This is due to the higher water content absorbing energy during combustion, thereby decreasing the net energy output. These findings highlight the critical importance of reducing moisture content in RDF to enhance energy output, demonstrating the effectiveness of drying techniques or moisture control methods. However, lowering the moisture content requires more energy consumption for the drying process. Thus, it is recommended to explore the economic and environmental impact of RDF production highlighting its practical viability.

Acknowledgment

The authors would like to thank the Ministry of Higher Education for providing financial support under Fundamental Research Grant Scheme (FRGS) No. FRGS/1/2022/TK08/UMP/02/59 (University reference RDU220126).

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