

Analysis Characteristics Refuse Derived Fuel (RDF) briquettes from Mixture Rice Straw and Cardboard Waste with Variation Ratio Material as Energy Alternative

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ABSTRAK

Penelitian ini bertujuan untuk menganalisis karakteristik briket Bahan Bakar Turunan Sampah (RDF) yang dihasilkan dari campuran jerami padi dan kardus bekas dengan variasi rasio bahan sebagai sumber energi alternatif. Metode yang digunakan adalah pendekatan kuantitatif dengan metode eksperimental melalui proses pembuatan briket dan pengujian laboratorium. Variasi komposisi bahan yang digunakan adalah 80:20 dan 70:30 (jerami:kardus). Parameter yang dianalisis meliputi panas yang dihasilkan, kadar air, kadar abu, zat mudah menguap, dan karbon tetap melalui uji proksimat dan ultimat. Hasil penelitian menunjukkan bahwa komposisi 70:30 menghasilkan panas yang dihasilkan tertinggi yaitu 2.029,34 kkal/kg dibandingkan dengan komposisi 80:20 yaitu 1.742,03 kkal/kg. Selain itu, komposisi 70:30 memiliki kadar air dan kadar abu yang lebih rendah serta kadar zat mudah menguap dan kadar karbon tetap yang lebih tinggi. Berdasarkan studi kelayakan standar Waste to Energy (WtE), variasi kedua memenuhi kriteria parameter nilai panas, kadar air, dan karbon tetap, tetapi belum memenuhi persyaratan abu dan zat mudah menguap. Secara keseluruhan, komposisi 70:30 menunjukkan kinerja yang lebih optimal sebagai bahan bakar alternatif berbasis limbah. Penelitian ini memberikan kontribusi dalam pemanfaatan biomassa limbah dan limbah padat sebagai sumber energi berkelanjutan.

Kata Kunci: RDF Briquettes; Rice Straw; Waste Cardboard; Energy Alternative: Waste to Energy

ABSTRACT

This study aims to analyze the characteristics of Refuse Derived Fuel (RDF) briquettes produced from a mixture of rice straw waste and cardboard waste with varying composition ratios as an alternative energy source. The research employed a quantitative approach using an experimental method through briquette production and laboratory testing. The composition variations used were 80:20 and 70:30 (straw: cardboard). The parameters analyzed included calorific value, moisture content, ash content, volatile matter, and fixed carbon through proximate and ultimate analysis. The results showed that the 70:30 composition produced the highest calorific value of 2,029.34 kcal/kg compared to 1,742.03 kcal/kg for the 80:20 composition. In addition, the 70:30 composition has lower moisture and ash content, as well as higher volatile matter and fixed carbon. Based on Waste to Energy (WtE) feasibility standards, both variations met the criteria for calorific value, moisture content, and fixed carbon, but did not meet the standards for ash content and volatile matter. Overall, the 70:30 composition demonstrated more optimal performance as a waste-based alternative fuel. This study contributes to the utilization of biomass and solid waste as sustainable energy sources.

Keywords: RDF Briquettes; Rice Straw; Cardboard Waste; Alternative Energy; Waste to Energy

INTRODUCTION

Karawang Regency is known as one of the national rice production centers, contributing significantly to rice production in Indonesia. This region has an area of approximately 1,753.27 km², with rice fields covering around 95,287 hectares. Favorable geographic conditions, supported by well-developed technical irrigation systems, make

Karawang a region with high rice productivity. The high level of paddy production not only produces the main product in the form of grain or rice but also generates large amounts of agricultural waste, particularly rice straw. Rice straw is a by-product of harvesting activities, with quantities that can exceed the amount of rice produced [1]; [2]; [3].

Based on production data, Karawang Regency is capable of producing approximately 1,041,531 tons of paddy annually. For every one

ton of harvested rice, an average of 1.5 tons of straw is generated. Thus, the potential rice straw waste produced in this region is estimated to reach approximately 1,697,965.5 tons per year. This figure indicates that rice straw is one of the most abundant types of biomass waste and has significant potential to be utilized as a valuable energy source. However, its utilization in Karawang Regency remains suboptimal [4]; [5]; [6].

In the field, some big straw rice produced after harvest often left alone piled up on the ground agriculture or even burned in a way open by farmers. Practice burning straw This generally done as method fast for clean land before planting time next. Although considered practical, burning open straw paddy can cause various impact negative to environment [7]; [8]; [9]. Burning the produce greenhouse gas emissions glass like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which contribute to change global climate. In addition, burning straw can also cause pollution air consequence release particle fine (particulate matter) which is dangerous for health man [10]; [11]. Impact other is declined quality land agriculture.

Burning straw cause disappearance material organic as it should be can return to in land as source nutrition natural. Reduced material organic land can lower activity microorganisms land that plays a role important in guard fertility soil and nutrient cycles. In term length, condition This can cause degradation land agriculture and reduce productivity plant [12]; [13].

Besides produce waste from sector agriculture, Regency Karawang is also known as one of the area industry the largest in Indonesia. The existence of various area industry, warehousing, and activity distribution goods cause increasing amount waste non- organic solid produced every day. One of the type sufficient waste Lots produced is waste cardboard that comes from from packaging products, activities logistics, as well as distribution goods [14]; [15]. Although part cardboard box Still can recycle repeat, no A little cardboard that has experienced damage or polluted so that No can utilized return in system recycling repeat conventional. Waste cardboard that is not managed with good potential add burden environment and increase the volume of waste solid that must be handled [16]; [17].

See size potential waste straw from sector agriculture as well as waste cardboard box from sector industry and distribution, is required something effort management more waste effective and sustainable. One of the approaches that can done is with utilise waste the as source energy alternative. Waste biomass like straw paddy own content sufficient cellulose,

hemicellulose, and lignin tall so that potential utilized as material burn [18]; [19]; [20]. Temporary that, waste cardboard made of base fiber paper also has content carbon sufficient tall so that can increase mark energy if utilized as material burn congested [21]; [22].

One of technology that can used for utilise waste the is through processing become Refuse Derived Fuel (RDF). RDF is material burn the resulting solid from the processing process various type waste congested through stages sorting, drying, chopping, and compaction. Materials RDF fuel has potential for used as source energy alternative in Waste to Energy (WtE) system, namely a system that utilizes waste as source energy. RDF generally used as material burn alternatives in industry like cement factory, power plant energy, as well as facility processing energy other [23] Research and Development [25] Agency.

The utilization of rice straw and cardboard as raw materials for RDF offers multiple benefits, including reducing the volume of unmanaged waste, minimizing open burning practices in agricultural areas, and generating a more environmentally friendly alternative energy source. Moreover, converting waste into RDF contributes to the development of a circular economy, where materials that were previously considered of low value can be reprocessed into products with economic and energy benefits [26]; [27].

In scale research, manufacturing RDF briquettes from waste straw and cardboard can done through the production process in the laboratory. Stages production the includes the drying process material standard for lower water content, enumeration or downsizing size ingredients, mixing material with variation ratio certain, as well as the printing process become briquettes. Variations composition mixture between straw and cardboard required for know combination materials that can produce quality optimal RDF [28] briquettes; [29]; [30]. Resulting RDF briquettes Then need tested through testing laboratory for know characteristics technically as material burn. Some important parameters that are usually tested covering water content (moisture content), content ash content, value calorific value, content carbon fixed carbon, and volatile matter. These parameters is indicator important in determine quality material burn dense, because influential to efficiency combustion, stability the energy produced, as well as impact the environment that arises during the combustion process [31]; [32]; [33].

The results of these characteristic tests serve to evaluate the potential of agricultural straw and cardboard waste as standardized RDF

feedstocks, particularly within the context of developing waste-based alternative fuels. Furthermore, this research provides critical insights into the optimal mixing ratios and technical suitability required for further development in Waste-to-Energy (WtE) systems. Consequently, the utilization of straw and cardboard for RDF briquettes is expected to contribute to more sustainable waste management while simultaneously supporting the development of environmentally friendly alternative energy sources. [34]; [35]; [36].

RESEARCH METHODS

This study employs a quantitative approach using an experimental method to analyze the potential utilization of rice straw and waste cardboard as raw materials for Refuse Derived Fuel (RDF). The research was conducted in Karawang Regency. Rice straw samples were collected from paddy field areas in Kutamekar Village and Pinayungan Village, covering approximately 11.2 hectares, while waste cardboard was obtained from a retail industry (PT. X) located in the Surya Cipta Industrial Area, Karawang. The RDF briquette production process was carried out at the Mechanical Engineering Laboratory of Pancasila University, while the characterization of fuel properties was conducted at the laboratory of the National Research and Innovation Agency. The experimental approach in biomass fuel studies is widely used to evaluate the performance and characteristics of alternative fuels in a measurable and systematic manner [39]; [40].

Data used in study This consists of from primary data and secondary data. Primary data is obtained through observation field to embossed waste straw and cardboard, documentation of the production process RDF briquettes, as well as testing laboratory to characteristics material the resulting fuel. Secondary data obtained from literature scientific, report government, as well as document standard development of Waste to Energy (WtE) which is used as reference in analysis eligibility material burn. Use combination of primary and secondary data in study energy biomass assessed important for increase validity results analysis as well as strengthen data interpretation [19]; [23].

Making process RDF briquettes are made through a number of stages, namely preparation material raw, mixing materials, printing, and drying. Waste straw moreover formerly dried in a way experience Then carbonized for produce charcoal straw. Waste cardboard box sorted from contaminants, cut, then destroyed through the blending process until become powder cardboard. Charcoal straw and powder cardboard box furthermore mixed with

adhesive in the form of flour tapioca amounting to 5% of the total mass ingredients. Mixture material arranged in two variation composition, namely 80:20 and 70:30 (straw: cardboard), with a total mass of each variant as much as 1 kg. Mixture the Then printed use hydraulic press machine with pressure around 1 ton until form RDF briquette, then dried in the sun until dry before done testing laboratory. Stages This in line with the densification process biomass that aims increase density, convenience handling and efficiency burning material burn congested [29]; [30]; [32].

The characterization of RDF fuel was carried out through laboratory analysis, including proximate and ultimate analyses. The parameters evaluated include calorific value, moisture content, ash content, volatile matter, and fixed carbon. These parameters are key indicators in determining the quality of biomass fuel, as they are directly related to combustion performance and energy efficiency [11].

Test results laboratory Then analyzed in a way descriptive quantitative with compare results testing to eligibility parameter standards technical development of Waste to Energy (WtE), namely mark minimum heat 1,200 kcal/kg, maximum water content 45%, water content ash maximum 35%, more volatile matter than 40%, and fixed carbon less from 15%. Comparison the used for determine composition mixture the most optimal materials and potential utilization waste straw and cardboard as material burn alternative RDF [24];[17]; [9].

RESULTS AND DISCUSSION

A. Testing Quality RDF Fuel

After the material RDF fuel produced in accordance with the measurements on both variants, steps furthermore is do delivery sample for done testing content material burn RDF to BRIN [25] laboratory. Testing This aim for know characteristics material burn in a way comprehensive, so that can evaluate its eligibility as source energy alternative based waste analysis quality material RDF fuel in general covers testing characteristic physical and chemical through approach standardized laboratory for ensure suitability with technical parameters material burn congested [9]; [23].

The tests conducted included proximate and ultimate analyses to determine key parameters such as moisture content, ash content, volatile matter, fixed carbon, and calorific value. These parameters play an important role in determining combustion efficiency, energy stability, and the emissions generated during the fuel utilization process [11]; [20]. Besides that, testing RDF quality also aims for ensure that material fuel

produced fulfil standard eligibility in Waste to Energy (WtE) system as well can used in a way safe and efficient in application industry [24]; [17].

Testing of RDF combustion materials at BRIN (National Research and Innovation Agency) was carried out through two stages of analysis, namely proximate and ultimate analyses. These methods are standard approaches used to evaluate the quality of biomass fuels and to comprehensively determine their physical and chemical characteristics [11]; [20]. The following section presents the laboratory test results from both analyses.

1. Proximate Analysis

Based on the laboratory test results, there is a significant difference in calorific value between the 70:30 and 80:30 variants. The calorific value of each variant is presented in detail in the following chart. This difference is influenced by the composition of the raw materials used, where the fixed carbon and volatile matter contents play an important role in determining the amount of energy produced during the combustion process. In addition, variations in the composition of rice straw and waste cardboard also affect the energy density of the fuel. Waste cardboard, which has a higher carbon content, tends to increase the calorific value, whereas rice straw, which has a relatively higher ash content, can reduce combustion efficiency [22]; [41]. Therefore, the difference in material mixing ratios in the production of RDF briquettes becomes an important factor in determining the final quality of the fuel burn [29]; [30].

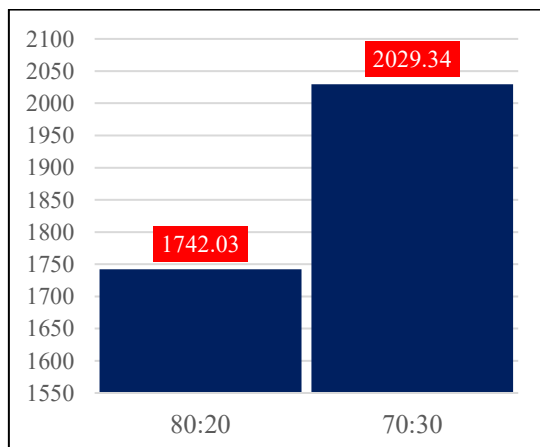


Figure 1. Comparison of Calorific Value of RDF Fuel Laboratory Tests
Source: National Research and Innovation Agency Laboratory Test

Based on the results of the laboratory tests shown in the table, are known that RDF sample Varian 80:20 has mark heat of 1742.03 kcal/kg, while the

70:30 variant has mark more heat high, namely 2029.34 kcal/kg. The difference mark heat between second variants This show that the 70:30 Variant has potential more energy big compared to the 80:30 variant, so that more optimal if used as material burn alternative in RDF form Calorific value is one of the main parameters in determine quality material burn Because show amount energy that can released during the combustion process. The 80:20 variant consists of of 80% straw and 20% cardboard, while the 70:30 variant has composition of 70% straw and 30% cardboard. The difference This indicates that content cardboard box in RDF mix contributes to improvement mark heat. Waste cardboard based fiber cellulose own content more carbon tall compared to straw rice, so that capable increase mark energy material resulting burn [22];[15]. Besides that, the increase proportion material with mark heat tall in mixture biomass will in a way direct increase density energy material burn results densification [29]; [39].

Therefore, a higher proportion of cardboard in the mixture results in greater energy production from the RDF. This finding is consistent with previous studies showing that combining biomass materials with different chemical characteristics can improve fuel quality, particularly in terms of calorific value and combustion efficiency [42]; [34]; [37].

2. Ultimate Analysis

Based on laboratory test results against the *ultimate analysis* parameters, obtained difference significant composition between RDF variant with ratio straw to 80:20 and 70:30 cardboard. Analysis ultimate is method important in determine composition element chemistry material burn like carbon, hydrogen, oxygen, and other elements other influential to characteristics burning [20]; [40].

the moisture content parameter, Variant 80:20 shows mark by 7.62%, slightly more tall compared to the 70:30 variant which has water content 7.19%. More water content low on Variant 70:30 indicates potential more burning efficient Because higher water content A little in material burn. This is caused by Because high water content in material burn biomass can lower mark heat effective, slows down the combustion process, and increase energy required for the water evaporation process during burning [11]; [19].

Besides that, low water content also contributes to improvement efficiency thermal and flame stability during the combustion process, so that material burn easier turned on and produced more optimal energy. Thus, the difference water content between second RDF variants shows that improvement proportion cardboard box in mixture No only increase mark heat, but also contributes in lower water content of the material burn so that produce performance more burning Good [15]; [22].

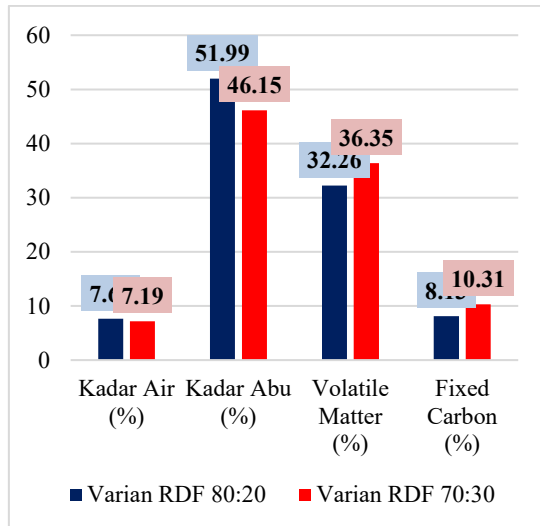


Figure 3. Comparison of Ultimate Analysis Laboratory Test Results
80:20 and 70:30 RDF Fuel variants
Source: National Research and Innovation Agency Laboratory Test

Furthermore, regarding ash content, the 80:20 variant recorded a value of 51.99%, which is higher than the 70:30 variant at 46.15%. A high ash content indicates a greater combustion residue, which potentially lowers energy efficiency by inhibiting the combustion process and reducing the effective heating value of the fuel. Consequently, the 70:30 variant is superior in this regard as it generates less residue. The elevated ash levels in biomass are generally influenced by the mineral content of the raw materials; in this case, rice straw inherently possesses a higher mineral content compared to fiber-based materials like cardboard.

Regarding the volatile matter parameter, the 70:30 variant recorded a higher value of 36.35%, whereas the 80:20 variant reached 32.26%. A higher volatile matter content reflects the material's ability to volatilize and ignite more rapidly, thereby increasing the fuel reactivity during the combustion process [20]; [40]. Alongside increased reactivity, high volatile matter also contributes to ignition stability and promotes a faster combustion initiation.

Lastly, the fixed carbon in the 70:30 variant is 10.31% bigger compared to the 80:20 variant which only has 8.13% content high fixed carbon show potential mark more heat big, in line with results testing mark heat previously. Fixed carbon serves as the primary energy source during the char-burning phase after the volatile matter has been consumed; thus, it is critical in determining combustion duration and stability.

In a way overall, RDF variant with composition 70% straw and 30% cardboard (70:30) shows characteristics more thermal Good compared to the 80:20 Variant. This is indicated by water content

and grade more ash low, and content *volatile matter* and *fixed carbon* which is higher tall factors that are collective support efficiency and effectiveness of the RDF as material burn alternative. Low water content contributes to improvement efficiency burning Because reduce wasted energy for the evaporation process, while level more ash low enable the combustion process ongoing more optimal without produce residue excessive.

On the other hand, a high volatile matter content accelerates the ignition process and enhances fuel reactivity during the initial combustion stage, whereas fixed carbon plays a critical role in maintaining flame stability and providing a longer combustion duration.

Combination characteristics the making the 70:30 Variant not only superior from side mark heat, but also from aspect performance burning in a way as a whole, so that more worthy For developed as material burn alternative based waste in system *Waste to Energy* (WtE). Findings This in line with various research that states that combination composition the right biomass can increase quality material burn congested Good from aspect mark heat and performance burning.

Besides that, the optimization process composition material in manufacturing briquettes biomass proven capable increase density energy as well as repair stability characteristic physical and chemical material burn. Increase density energy. This implication straight to the value more heat height per unit mass, so that briquettes become more efficient in the process of storage, distribution, and its utilization.

On the other hand, stability characteristic physique like strength pressure, water content, and durability to damage mechanics also experience increase, so that briquettes No easy destroyed during the handling and transportation process. In general chemistry, optimal composition helps produce more burning consistent, with higher emissions controlled and more residue A little.

With Thus, optimization composition material No only increase performance energy, but also makes briquettes biomass more reliable and applicable for used in scale industry, good as substitution and alternative material burn conventional [29]; [39]; [30].

B. Compare Contents RDF Fuel with Technical Feasibility Parameters for Development WtE

1. Proximate Analysis

Based on the graph in Table 4.3, a comparison of the heating values between two Refuse Derived Fuel (RDF) variants is shown, specifically compositions of straw and cardboard at ratios of 80:20 and 70:30. The

calorific values were obtained through laboratory testing using proximate analysis, which aims to identify the combustion characteristics of the base materials, such as moisture, ash, volatile matter, and fixed carbon content.

The test results show that RDF with an 80:20 composition produces a calorific value of 1,742.03 kcal/kg. Meanwhile, at a composition of 70:30, the calorific value increases significantly to 2,029.34 kcal/kg. This increase indicates that a higher proportion of cardboard in the mixture contributes positively to the energy quality of the RDF.

Scientifically, cardboard has higher fixed carbon and lower ash content compared to straw, which enhances the calorific value and improves combustion efficiency. Therefore, a greater proportion of cardboard in the mixture results in a higher calorific value. The findings of this study indicate that optimizing raw material composition is a key factor in enhancing RDF performance as an alternative energy source. An appropriate formulation directly influences critical parameters, such as calorific value, combustion stability, and overall energy efficiency. In this context, the 70:30 composition is considered more optimal than the 80:20 ratio, particularly in terms of increasing calorific value and supporting stable combustion characteristics. The higher proportion of cardboard also enhances energy density, making the RDF more effective for energy generation applications.

However, despite these technical advantages, the selection of the optimal composition should not rely solely on calorific value. Practical and operational aspects, including raw material availability, production costs, and emission characteristics during combustion, must also be considered. A balanced evaluation of these factors is essential to ensure that the selected RDF formulation is not only efficient but also economically feasible and environmentally sustainable for large-scale implementation.

Table 1. Comparison of Proximate Analysis Lab Test Results with Technical Feasibility for Waste to Energy (WtE) Development

Parameter	Satuan	WtE	Varian RDF	Uji Laboratorium	
				Hasil Pengujian	Status
Nilai Kalor	kcal/kg (Kilokalori/ kilogram)	≥ 1200	80:20	1742	Memenuhi Standar
			70:30	2029	Memenuhi Standar

Source: Data processing by researchers

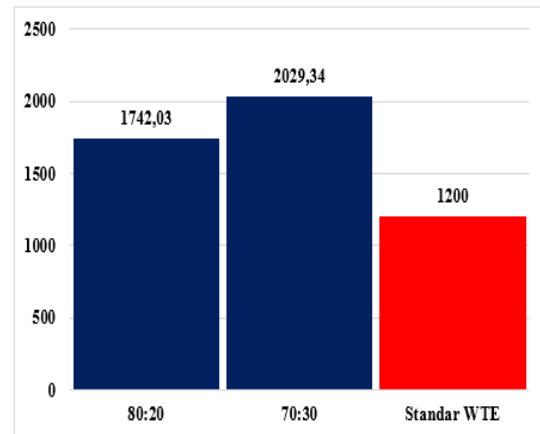


Figure 4. Comparison of the Calorific Value Content of RDF Variants 80:20 and 70:30 with Technical Feasibility for WtE Development
Source: Data Processing by Researchers

A comparison of the calorific values of each variation with the Technical Feasibility Parameter standard for Waste-to-Energy (WtE) development (1,200 kcal/kg) is presented in Figure 4.20. This minimum calorific value standard is an important indicator for determining the feasibility of waste-based fuel materials for use in WtE systems, as it is directly related to energy conversion efficiency [23]; [24]. Based on the results, both composition variations meet and exceed the required minimum calorific value standard.

However, based on calorific value as a technical feasibility indicator, the 70:30 composition shows a higher value and thus greater potential. A higher calorific value reflects a greater ability of the fuel to generate energy during combustion, making it more efficient for application in waste-to-energy conversion systems.. [19]; [13].

Furthermore, these results indicate that increasing the proportion of materials with high carbon content, such as waste cardboard, can enhance the overall energy performance of RDF fuel. This finding is consistent with previous studies, which show that raw material composition significantly influences the energy quality of solid fuels, particularly in terms of calorific value and combustion efficiency [29]; [39]; [42].

2. Ultimate Analysis

Based on Table 4.4, presented comparison RDF laboratory test results with composition straw and cardboard 80:20 and 70:30 based on the ultimate analysis parameters, which include water content, content ash, volatile matter, and fixed carbon, against the Technical Feasibility Parameters for Waste to Energy (WtE) Development. These parameters is indicator important in evaluate quality material burn congested Because related direct with efficiency

combustion, stability energy, as well as emissions produced during the conversion process energy [11]; [20].

Comparison This done for know how far both variation RDF composition meets standard eligibility technical that has been set in development system WtE. Evaluation towards the ultimate analysis parameters is very important Because can give description comprehensive about characteristics chemistry and performance burning material burn based waste [23]; [24]. With Thus, the results comparison This can used as base in determine composition the most optimal materials and worthy for developed as material burn efficient and friendly alternative environment [19];[17]

Table 2. Comparison of Ultimate Analysis Lab Test Results with Technical Feasibility for WtE Development

Parameter	Standar WtE	Varian Uji Lab		Status
		80:20	70:30	
Kadar Air (%)	< 45	7.62	7.19	Memenuhi Standar
Kadar Abu (%)	< 35	51.99	46.15	Belum Memenuhi Standar
Volatile Matter (%)	> 40	32.26	36.35	Belum Memenuhi Standar
Fixed Carbon (%)	< 15	8.13	10.31	Memenuhi Standar

Source: Data Processing by Researchers

Test results show that the water content of RDF in the 80:20 composition is 7.62% and in the 70:30 composition is 7.19%. Both mark the is at far below limit maximum standard WtE by 45%, so that based on water content parameters, second RDF variations are stated fulfil standard eligibility technical. Low water content in the material burn biomass is very influential to efficiency burning Because can minimize lost energy due to the water evaporation process during burning [19]; [11] the level parameter ash, RDF with 80:20 composition has mark by 51.99%, while composition of 70:30 is 46.15%. When compared with standard WtE (<35%), the resulting differences were 16.99 % and 11.15% respectively.

This show that composition 70:30 has wider gap small to standard, so that in a way technical more approach required criteria. The height level ash in material burn biomass generally related with high mineral content and can lower efficiency burning as well as increase residue results burning [13]; [41].

Next, the results of the volatile matter test show that 80:20 composition has mark of 32.26% and the 70:30 composition of 36.35%. Both mark the Still be under the minimum WtE standards required, namely more from 40%. Difference to standard WtE were 7.74% and 3.65% respectively. These values show that second composition is at

relatively near with limit standard, especially in the 70:30 composition which has smallest gap. Content high volatile matter play a role in speed up the ignition process as well as increase reactivity material burn at stage beginning burning [20]; [40].

The analysis results indicate that the fixed carbon content in the 80:20 composition is 8.13%, whereas it increases to 10.31% in the 70:30 composition. Despite the observed increase with a higher proportion of cardboard, both values remain well below the maximum threshold of 15% established for Waste-to-Energy (WtE) applications. Accordingly, based on the fixed carbon parameter, both RDF variants satisfy the technical feasibility criteria for use as alternative fuel materials.

The variation in fixed carbon content further suggests that the incorporation of cardboard enhances the residual carbon fraction, which constitutes a critical component in the combustion process. Fixed carbon predominantly governs the char combustion phase, acting as a sustained energy source following the depletion of volatile matter, thereby contributing to flame stability and combustion continuity. An optimal fixed carbon fraction is therefore instrumental in ensuring stable and sustained energy release during combustion.

Moreover, fixed carbon levels that do not exceed optimal thresholds are advantageous, as they mitigate the risk of excessive solid residue formation post-combustion. Maintaining an appropriate balance of fixed carbon is thus essential for optimizing thermal efficiency while preserving combustion quality in waste-derived fuels. Consequently, the 70:30 composition not only demonstrates superior performance in terms of calorific value but also exhibits more favorable fixed carbon characteristics, supporting combustion stability without exceeding the prescribed standard limits.

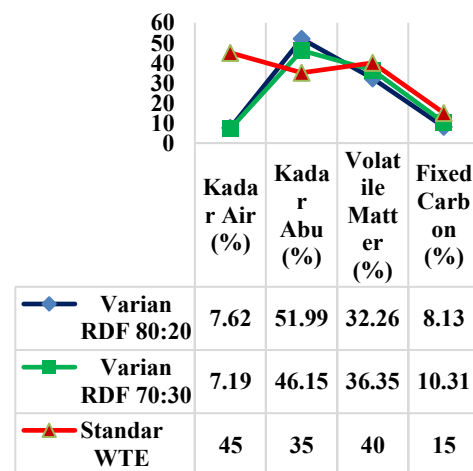


Figure 5. Ultimate Analysis Lab Test Results with Technical Feasibility for WtE Development
Source: Data Processing by Researchers

In a way overall, based on the ultimate analysis results, RDF compositions of 80:20 and 70:30 comply with the technical feasibility standards for WtE regarding moisture content and fixed carbon. Nevertheless, they have not yet met the required standards for ash content and volatile matter. These parameters serve as primary indicators in determining solid fuel quality and suitability for Waste-to-Energy (WtE) systems, as they are directly linked to combustion efficiency and emission profiles [23].

The quality assessment results of Refuse Derived Fuel (RDF) produced from a mixture of rice straw and waste cardboard indicate distinct variations in fuel characteristics across the two composition ratios, namely 80:20 and 70:30. These differences can be systematically evaluated through proximate and ultimate analyses, encompassing key parameters such as calorific value, moisture content, ash content, volatile matter, and fixed carbon. Collectively, these parameters serve as critical indicators for assessing the quality of solid fuels, as well as their technical feasibility for application in Waste-to-Energy (WtE) systems [20]; [24].

Based on results proximate analysis, value heat produced by RDF with composition straw and cardboard of 70:30 reaches 2,029.34 kcal/kg, while in the 80:20 composition the value heat produced of 1,742.03 kcal/kg. This result show that improvement proportion cardboard box in RDF mix contributes to improvement mark heat material the resulting fuel. By theoretical, value heat is the main parameter that determines ability something material burn in produce energy hot during the combustion process [19]; [13]. The calorific value is influenced by the fixed carbon and volatile matter content of the fuel, where higher carbon content and a greater amount of easily combustible organic compounds result in higher heat energy production.

Waste cardboard is fundamentally a cellulose-based material derived from wood fibers, and therefore exhibits a relatively high carbon content. The presence of cellulose and lignin in paper-based materials contributes to enhanced energy potential, as their chemical structures are readily decomposed during the combustion process [22]; [15]. Therefore that, the increase proportion cardboard box in RDF mixture can increase content carbon and repair characteristics burning material burn said. This is in line with theory that waste based paper own mark more heat tall compared to biomass agriculture certain ones that have content ash relatively big [41] [46].

Beyond the calorific value, moisture content represents another critical parameter analyzed in this study. Based on laboratory test results, the moisture content for the 80:20 composition is 7.62%, while for the 70:30 composition, it is 7.19%. Both values are significantly below the maximum WtE standard limit of 45%. Low moisture content is a vital indicator of

solid fuel quality; high water content in fuel can absorb thermal energy during the combustion process for evaporation, thereby reducing overall energy efficiency. [19]; [11].

The research results demonstrate that the carbonization and drying processes applied to the straw, along with the drying process for the cardboard, have successfully reduced the moisture content significantly below the standard requirements. This condition substantially supports the RDF combustion process, as a greater portion of the generated energy can be utilized as thermal energy rather than being consumed for moisture evaporation. Consequently, drying and carbonization are critical stages in enhancing the fuel quality of biomass-based materials [47] [48].

The next parameters analyzed is level ash (ash content). Based on results testing, levels the ash content in the 80:20 RDF composition is 51.99%, while in the 70:30 composition it is 46.15%. This value Still be on top standard eligibility technical WtE which requires level ash not enough from 35%. Ash content is residue remaining inorganic after the burning process and not own mark energy, so that can lower efficiency burning [13];[11]

The height level ash in the generated RDF in study This can caused by characteristics waste straw that has sufficient mineral content high, especially silica. Plants paddy known absorb silica from land during growth, so that residue burning straw produce ash in amount big [49]; [50]). This is consistent with the general characteristics of agricultural biomass, which typically has a higher ash content compared to woody biomass or paper waste. [43]. In addition to ash content, volatile matter parameters were also analyzed in this study. Based on laboratory test results, the volatile matter value for the 80:20 composition is 32.26%, while for the 70:30 composition, it is 36.35%. Both values remain below the WtE standard, which requires a minimum of 40%. From a theoretical perspective, volatile matter plays a critical role in the initial combustion stage, as it determines the ignition ease and the overall reactivity of the fuel [20];[45]

The relatively low volatile matter content observed in this study is likely attributable to the carbonization of rice straw, during which a substantial fraction of volatile compounds is decomposed and released in the initial stages, resulting in a reduced residual volatile content. However, the increase in volatile matter at the 70:30 composition indicates that the addition of cardboard enhances the volatile fraction in the RDF [33]. The last parameter analyzed is *fixed carbon*. Based on results testing laboratory, value *Fixed carbon* in the 80:20 composition is 8.13%, while in the 70:30 composition it is 10.31%. Both mark the be under limit maximum standard WtE by 15%, so that fulfil criteria eligibility technical. *Fixed carbon* is component main role in produce energy hot during

phase burning continued and determined stability burning [32];[22]

The results indicate that the 70:30 composition exhibits a higher fixed carbon content compared to the 80:20 composition. This observation is consistent with the calorific value, which is also higher in the 70:30 variant. From a theoretical perspective, an increase in fixed carbon content enhances combustion duration and stability, thereby enabling more sustained and efficient energy release. [29]

When evaluated comprehensively against the technical feasibility standards for Waste-to-Energy (WtE) applications, both RDF variations satisfy the required criteria for calorific value, moisture content, and fixed carbon, but do not yet meet the specified thresholds for ash content and volatile matter. Nevertheless, the 70:30 composition demonstrates superior overall performance, as it exhibits a higher calorific value, lower ash content, and relatively higher levels of volatile matter and fixed carbon. [34]; [37]. These findings demonstrate that increasing the proportion of cardboard in the RDF mixture significantly enhances the overall fuel quality. Cardboard waste serves as a high-carbon source, while straw functions as the primary biomass feedstock. The synergistic combination of these two materials exhibits substantial potential as an alternative fuel for Waste-to-Energy (WtE) systems [36]; [38].

Consequently, the utilization of agricultural straw and cardboard waste as RDF feedstocks not only mitigates waste accumulation but also contributes to the provision of sustainable energy. The development of RDF derived from biomass and paper-based waste demonstrates significant potential in supporting the transition toward renewable energy and the implementation of a circular economy [27]; [26]; [17].

CONCLUSION

Based on the testing results of Refuse Derived Fuel (RDF) produced from a mixture of agricultural straw and cardboard waste, the material composition significantly influences the quality of the resulting fuel. Proximate analysis reveals that the 70:30 variant achieves a higher calorific value of 2,029.34 kcal/kg, compared to 1,742.03 kcal/kg for the 80:20 variant. Notably, both compositions fulfill and exceed the minimum Waste-to-Energy (WtE) standard of $\geq 1,200$ kcal/kg.

Regarding the ultimate analysis, both variants meet the required standards for moisture content and fixed carbon parameters; however, they have not yet met the standards for ash content and volatile matter. Overall, the 70:30 composition demonstrates superior fuel quality due to its higher heating value and lower ash content.

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