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Research article

The Potential of Latex Waste Sludge as an Alternative Fuel Briquettes

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Abstract: This study investigates the conversion of latex waste sludge, a valueless byproduct from rubber manufacturing, into sustainable fuel briquettes. With increasing environmental concerns and energy demands, repurposing industrial waste offers promising alternatives to conventional waste management while reducing dependence on fossil fuels. Using a systematic experimental approach with 3 levels, 2 factors, and 3 replications, we determined optimal formulations for briquette production. The study evaluated various mixing ratios of latex waste sludge with rubber leaves and rubber leaf charcoal. All produced briquettes underwent comprehensive analysis for key parameters, including heating value, moisture content, ash content, volatile matter, and fixed carbon content. Results demonstrated that incorporating rubber plant biomass significantly enhanced the briquettes' fuel properties. The addition of rubber leaves increased heating values and fixed carbon content while decreasing ash content. Furthermore, using rubber leaf charcoal instead of raw leaves substantially improved combustion efficiency and reduced soot and ash production. However, rubber leaf content exceeding 35% compromised briquette structural integrity. The optimal formulation contained 83% latex waste sludge and 17% rubber leaf charcoal by mass. This composition achieved the best balance of thermal performance, structural stability, and reduced emissions. This research contributes to circular economy principles by transforming industrial waste into valuable energy resources. The findings suggest that latex waste sludge, previously considered worthless, can be effectively upcycled into efficient fuel briquettes, providing sustainable solutions for both waste management and alternative energy development.

Keywords: Latex waste sludge; Alternative fuel briquettes; Biomass

1. Introduction

The increasing amount of industrial waste has caused environmental and waste management problems, including the rubber industry, which produces a large amount of waste sludge from the process. Disposal of this waste is often expensive and can potentially have long-term environmental impacts. Therefore, utilizing sludge from rubber factories is an enjoyable alternative for sustainable waste management. One potential method is to use sludge to produce compressed fuel, which can replace fossil fuels and is environmentally friendly. This study focuses on the process of producing compressed fuel from rubber sludge, considering its physical and chemical properties, as well as its combustion efficiency, to lead to commercial application and the development of sustainable alternative energy in the future.

In recent years, the application of industrial waste for energy production has gained widespread attention, especially biomass fuel production from various waste materials such as sludge, food waste, plant waste, or other organic materials. The development of pellet fuel from waste reduces the amount of waste that needs to be disposed of, creates added value, and significantly reduces dependence on fossil fuels. Briquettes are a popular type of fuel because they are solid blocks that are easy to transport and store, have a high density compared to other forms of biomass fuel, and can be used in the combustion process efficiently. Many research studies have shown the potential of industrial waste materials in various sectors that can be used to produce pellet fuel, such as wood chips, rice husks, sugarcane bagasse, and sludge from industrial wastewater treatment processes. In the context of the rubber industry, studies have been conducted on using sludge from the rubber production process, which is a waste from wastewater treatment. It was found that this sludge contains a high amount of organic matter that can be used as an energy source. Related research also indicates that this sludge can produce pellets with suitable combustion properties if adequately processed and improved.

In the past, sludge from rubber industries was managed and reused. One example is a study on the potential of using latex sludge as a reinforcing material in plastic composites. The results of the study show that latex sludge has the potential to be used as a valuable material in plastic composites, which will help reduce waste and improve the properties of the composites [1]. There is also research on the use of sludge from rubber factories as an additive in polypropylene plastic composites, where it has been found to improve the mechanical and thermal properties of the material significantly. It was found that using sludge as an additive can improve the properties of the composites in terms of both mechanical strength and thermal stability, making the materials suitable for use in various industries [2]. There is also research that studies the process of converting sludge from rubber industries into energy, which is another approach to sustainable waste management from the rubber industry. The research discusses the technique of converting sludge into energy through anaerobic digestion. This process was found to efficiently convert sludge into energy, which helps reduce the amount of waste and increase the efficiency of resource use in the industry sustainably [3]. Research focuses on studying the pyrolysis process of the remaining sludge from the rubber industry by using heat in the absence of oxygen to change the sludge into various products such as oil, biochar, and gas. The research found that the decomposition of rubber sludge through the pyrolysis process yielded the main products that could be used as fuel or chemical precursors and biochar, which can be used as soil amendments in the agricultural sector. Products obtained from the process have properties that can be used as renewable energy, especially oil with high heating value.

In contrast, biochar has acidic-basic values and physical properties that are suitable for soil improvement, which helps add value to waste from the rubber industry by using previously discarded sludge to produce renewable energy and agricultural materials, helping to reduce environmental impacts and support sustainable resource use [4]. In addition, research studies the production of biodegradable plant pots from the residue left over from the production process in rubber factories, mixed with waste materials from mushroom cultivation and palm fruit bunches to create environmentally friendly products. These materials help produce biodegradable pots and also have properties that help plants grow well, especially maintaining the soil's pH and electrical conductivity, which are suitable for the growth of various types of plants. The advantage of pots made from this material is that they help reduce waste from industries and mushroom cultivation in communities and reduce environmental problems from using materials that are difficult to decompose, such as plastic. This type of pot can also improve soil quality because the materials used contain nutrients that benefit plant growth [5]. Past research has shown the potential for utilizing rubber industry sludge for various uses, from developing composite materials to generating new energy from waste. In addition, there have been various research studies on pellet fuel from biomass in the past, with topics focusing on the use of agricultural waste and biomass to create pellet fuel, which has the advantage of increasing the value of the material and reducing the impact on the environment. Examples of interesting research include studying the use of corn and palm oil waste biomass to create pellet fuel by evaluating the physical properties and combustion. It was found that the particle size and moisture significantly affect the density, strength, and energy value of the pellet fuel [6,7]. Another research focused on the use of waste from garbage and food waste to create pellet fuel without burning charcoal. It was found that using composite materials helps improve the calorific value and reduce production costs, making it potentially valuable for community areas with limited resources [8]. These studies help increase the understanding of the efficient and sustainable creation of biomass fuel. Other studies have highlighted the benefits of using agricultural waste to produce fuels, demonstrating that charcoal briquettes can be a sustainable alternative to fossil fuels, with good calorific value, low moisture content, and environmentally friendly properties [9]. Several studies have also been conducted on producing charcoal briquettes from biomass, including research on rubber leaves as a raw material. One study investigated converting Tectona grandis (teak) leaves into charcoal briquettes, focusing on high efficiency and significant heat production. The results of this study indicate that dry leaves, such as those from rubber trees, have properties that can also be used to produce charcoal briquettes [10,11].

Therefore, the study of pellet fuel production from rubber factory waste sludge mixed with rubber leaves is an interesting topic in many aspects. Using waste from the production process of rubber factories and rubber leaves, which are abundant biomass in rubber plantation areas, solves the waste problem and reduces the environmental impact. It is the creation of sustainable fuel using mixed biomass with good energy properties, rubber leaves, charcoal, and sludge with high energy content. It also increases energy efficiency, i.e., mixing sludge and rubber leaves increases the heat value and reduces the amount of carbon released when burned, resulting in cleaner and more efficient fuel. It also reduces the dependence on fossil fuels, an essential topic in the current era when many industries are trying to switch to renewable energy. Therefore, this research demonstrates the potential of using waste from the rubber industry and natural resources as fuel briquettes, which are made from rubber leaves, charcoal, and sludge with high energy content in the appropriate ratio to create sustainable energy, reduce waste, and help preserve the environment in the long run.

2. Materials and Methods

This section presents the biomass used, including the origin, preparation, and methods for processing fuel briquettes.

2.1 Materials

2.1.1. Latex waste sludge

The latex waste sludge in this study was obtained from Pattex T.T.R. Co., Ltd., 188 Moo 8, Pabon Subdistrict, Pabon District, Phatthalung Province. The latex waste sludge is a by-product of the company's latex production. It is a waste that has no value, is difficult to destroy, and takes up space for storage. The latex waste sludge used in this study was prepared by removing all moisture by drying it in the sun before being ground into a fine powder with a multi-purpose grinder for easy mixing and further forming. The latex waste sludge in this study has a heating value and various components, as shown in Table 1.

Table 1. Heating value and composition of latex waste sludge.

Parameters	Instrument/methods	Result	
		Latex waste sludge	**Latex waste sludge Charcoal**
Gross heating value (kcal/kg) (As dried basis)	In-house method on BSEN 14918	3,173	1,103
Volatile Matter (%Wt.) (As dried basis)	In-house method on ASTM D7582	42.83	10.95
Fixed Carbon (%Wt.) (As dried basis)	In-house method on ASTM D7582	0.56	5.53
Ash (%Wt.) (As dried basis)	In-house method on ASTM D7582	56.61	83.52
Total Moisture (%Wt.) (As received basis)	Gravimetric method and In-house method on ASTM D7582	36.12	3.70

Test results from Office of Scientific Instrument and Testing, Prince of Songkla University.

The latex waste sludge used in this study was divided into latex waste sludge and latex waste sludge charcoal, as shown in Figure 1(a,b), to compare the properties of charcoal obtained from different raw materials. With the state change, the properties of the latex waste sludge changed significantly, as shown in

Table 1. This study focuses on using latex waste sludge as the main raw material for producing compressed fuel and as a binder for the briquettes, which the latex waste sludge charcoal has lost such properties. The mixing proportion will be explained in the next section.

2.1.2. Rubber leaf

The rubber leaves used in this study were collected from rubber plantations in Phatthalung Province. The rubber leaves were prepared by drying to reduce the moisture content to an acceptable level (below 15%). For efficient pelleting, the rubber leaves were ground using a universal grinder into fine and uniform particles to facilitate uniform compaction. The rubber leaves in this study have heating values and various components, as shown in Table 2.

Table 2. Heating value and composition of rubber leaves.

Parameters	Instrument/methods	Result	
		Rubber leaf	Rubber leaf charcoal
Gross heating value (kcal/kg) (As dried basis)	In-house method on BSEN 14918	4,716	4,550
Volatile Matter (%Wt.) (As dried basis)	In-house method on ASTM D7582	67.70	34.24
Fixed Carbon (%Wt.) (As dried basis)	In-house method on ASTM D7582	17.61	35.58
Ash (%Wt.) (As dried basis)	In-house method on ASTM D7582	14.70	30.18
Total Moisture (%Wt.) (As received basis)	Gravimetric method and In-house method on ASTM D7582	9.64	6.56

Test results from Office of Scientific Instrument and Testing, Prince of Songkla University.

The rubber leaf used in this study was divided into two states: rubber leaf and rubber leaf charcoal, as shown in Figure 1(c,d) to compare charcoal properties obtained from different raw materials. The experimental design was carried out as detailed in the next section to determine the conditions of the ingredients for making fuel briquettes.

2.2 Methods

2.2.1. Experimental design

To determine the number of experiments, a factorial design is used to study the effect of multiple factors simultaneously, with each factor having specific levels to be studied. In an experiment, k represents the number of factors considered, and n represents each level. Therefore, the total number of experiments to be conducted is n^k, which means that all possible combinations of factors and levels must be tested [12]. In this study, two factors correspond to the subsystems defined in numbers 2 and 3, considering three-level variations. For latex waste sludge, the variation ranged from 67% to 100%, with an increase of approximately 17%, while for rubber leaf, the variation ranged from 0% to 33%, with an increase of approximately 17%. The experimental design considers all the possibilities, and 9 experiments will be required, as shown in Equation (1).

$$n_{exp} = n^k = 3^2 = 9 \tag{1}$$

The experimental design in this study is complete, and the axial and center points of the experiment are reproducible. Three replicates were scheduled for this study. Table 3 shows the distribution of the experiment's 3 levels and 2 factors.

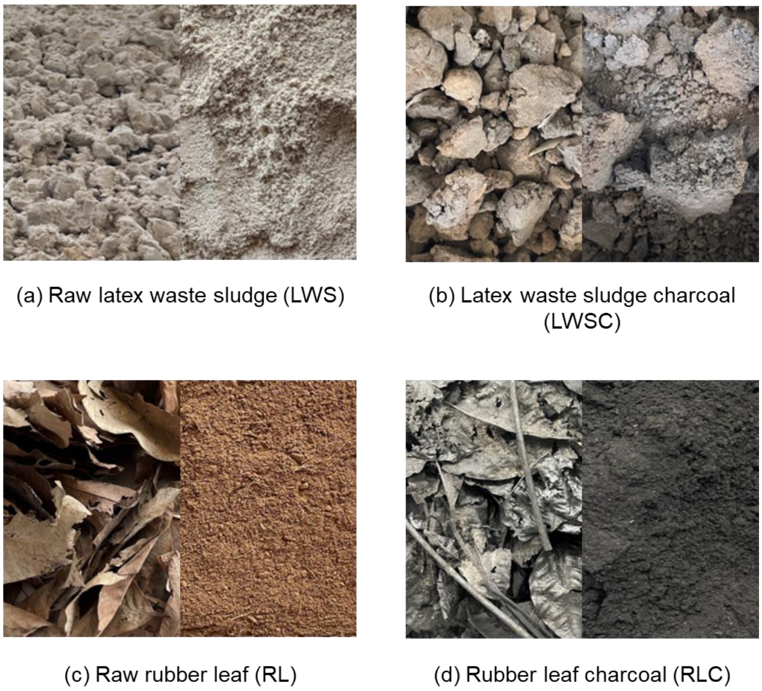

Figure 1. Raw materials for the fuel briquettes production process: (a) Raw latex waste sludge (LWS); (b) Latex waste sludge charcoal (LWSC); (c) Raw rubber leaf (RL); (d) Rubber leaf charcoal (RLC).

Table 3. Experimental conditions in which the variables and levels used in the experiment are defined.

Factor	**Levels**		
	-1	**0**	**+1**
The ratio of raw materials to the total mass of the mixture (%)	LWS100-RL0	LWS83-RL17	LWS67-RL33
State of latex waste sludge	LWSC100-RL0	LWSC83-RL17	LWSC67-RL33
State of rubber leaf	LWS100-RLC0	LWS83-RLC17	LWS67-RLC33

2.2.2. Data collection

In this study, data were collected to evaluate the value of fuel briquette products in terms of fuel properties and economics for data collection for fuel property analysis. Data from experimental results were collected by determining the ratio between latex waste sludge and dry rubber leaves and between latex waste sludge and rubber leaf charcoal to analyze the fuel properties. The following values were considered: heating value, volatile matter, fixed carbon, ash, and total moisture.

2.3 Experimental apparatus

2.3.1. Equipment for the raw material preparation process

In this study's raw material preparation process, there is one 200-liter furnace set and one multi-purpose grinder.

Figure 2. The 200-liter furnace set.

Figure 3. The multi-purpose grinder.

The 200-liter furnace set, as shown in Figure 2, is a smokeless charcoal burning stove with a reinforced base at the bottom of the tank and heat insulation. The working principle of the 200-liter furnace set drum relies on the pyrolysis process or incomplete combustion by controlling the air and using heat to burn the evaporated gas, which reduces smoke and increases the efficiency of complete charcoal burning. This furnace set can burn charcoal without having to watch the stove and without having to turn it off. The resulting charcoal will be smokeless. The crushing set, as shown in Figure 3, is a multi-purpose grinder consisting of a multi-purpose grinding bowl, size 800 g, a grinding bowl made of grade 304 stainless steel, a blade made of grade 304 stainless steel, and an all-aluminum body consisting of a copper coil motor supporting 3,000 W of electrical power. The crushing set uses a motor to rotate the blades to break down materials into smaller sizes as needed.

2.3.2. *Equipment for the fuel briquette process*

This study's fuel briquette pressing process consists of 1 set of fuel briquette pressing mold, 1 digital scale, and 1 set of 6-ton hydraulic presses.

Figure 4. The fuel briquette pressing mold.

The fuel briquette mold set, as shown in Figure 4, consists of a cylindrical mold made of grade 304 stainless steel, consisting of a 7 cm diameter target, 25 cm high, a 7 cm diameter circular press plate connected to a 1 cm press rod, 30 cm long, and a 13 cm wing. The fuel briquette mold set has a press plate made of grade 304 stainless steel, 1.5 mm thick and 30x30 cm in size.

Figure 5. Digital scale.

Digital scales, as shown in Figure 5, can weigh from 1-5,000 g. It uses 2 AAA batteries, and its surface is 304 stainless steel. The body is made of ABS plastic with an LED display showing value. It also has a function to cut off the weight of the container.

Figure 6. 6-ton hydraulic presses.

As shown in Figure 6, the hydraulic press is small, with a high-pressure of up to 6 tons. Made of steel, 420 mm wide, 950 mm high, 110 mm working distance, 340x250 mm working area, weight 30 kg.

3. Results and Discussion

The development of fuel briquette products in this study considered improving the quality of fuel briquette processed from latex waste sludge mixed with rubber leaves, as shown in the conditions and results of the study of fuel briquette properties in Table 4.

Table 4. Conditions and results of the study of the properties of fuel briquettes.

	Conditions (%)				Results				
No.	Latex waste sludge	Latex waste sludge charcoal	Rubber leaf	Rubber leaf charcoal	Gross heating value (kcal/kg)	Volatile Matter (%Wt.)	Fixed Carbon (%Wt.)	Ash (%Wt.)	Total Moisture (%Wt.)
1	100	0	0	0	3,173	42.83	0.56	56.61	36.12
2	83	0	17	0	3,503	47.36	2.36	50.29	30.72
3	83	0	0	17	3,339	41.07	7.67	51.26	31.96
4	67	0	33	0	3,750	51.34	5.03	43.64	26.52
5	67	0	0	33	3,695	40.30	10.92	48.75	25.47
6	0	83	17	0	1,785	20.90	6.43	72.68	3.84
7	0	83	0	17	1,757	15.21	9.44	75.31	3.29
8	0	67	33	0	2,363	29.98	8.36	61.67	4.80
9	0	67	0	33	2,309	18.94	14.25	66.78	3.77

Latex waste sludge can be compressed into fuel briquettes using rubber waste sludge as the main raw material and as a binder to make the raw material stick together simultaneously. This process is different from the production of fuels from other types of biomass that use starch as a binder. All experimental conditions were carried out by forming a fuel briquette and testing the properties of the fuel briquette obtained, as shown by the characteristics of the fuel briquette obtained from different conditions in Figure 7 (a-f).

Figure 7(a). Characteristics of fuel briquette obtained from 100% latex waste sludge condition.

Figure 7(b). Characteristics of fuel briquette obtained from the condition of 83% latex waste sludge mixed with 17% raw rubber leaves.

Figure 7(c). Characteristics of fuel briquette obtained from the condition of 67% latex waste sludge mixed with 33% raw rubber leaves.

Figure 7(d). Characteristics of fuel briquette obtained from the condition of 83% latex waste sludge mixed with 17% rubber leaf charcoal.

Figure 7(e). Characteristics of fuel briquette obtained from the condition of 67% latex waste sludge mixed with 33% rubber leaf charcoal.

Figure 7(f). Characteristics of fuel briquette obtained from the condition of 67% latex waste sludge charcoal mixed with 33% rubber leaf charcoal.

The forming results of the fuel briquette are shown in Figure 7 (a-f), indicating that the state of the raw materials has a significant effect on the forming. Figure 7 (f) shows that the fuel briquette could not remain as a briquette. However, previous research [1,2] has stated that the sludge from the rubber industry has the potential to be used as a reinforcing material in plastic composites and improve the mechanical and thermal properties of the composites since the main component of the latex waste sludge is starch, which is an organic compound with large molecules. Starch can be destroyed when exposed to high heat during the combustion process. Starch will decompose into carbon and various gases. These volatile substances cause the starch to lose its adhesion properties. In addition, the latex waste sludge contains water and organic compounds that allow it to adhere to materials. However, when these water and volatile substances are removed from the starch during the combustion process, as shown by the significantly reduced moisture content in Figure 8, the latex waste sludge will lose its adhesion properties, resulting in an unstable fuel adhesion. This is consistent with previous research that has studied the use of biomass from corn and palm oil wastes to produce pellet fuels [6,7], which found that particle size and moisture content significantly affect the density, strength, and energy value of the pellet fuels.

However, the results of the study of the properties of the fuel briquettes from the conditions of the designed mixture ratios are shown in Table 4. It shows that the properties of the fuel briquettes from latex waste sludge mixed with rubber leaves have significantly higher heating values.

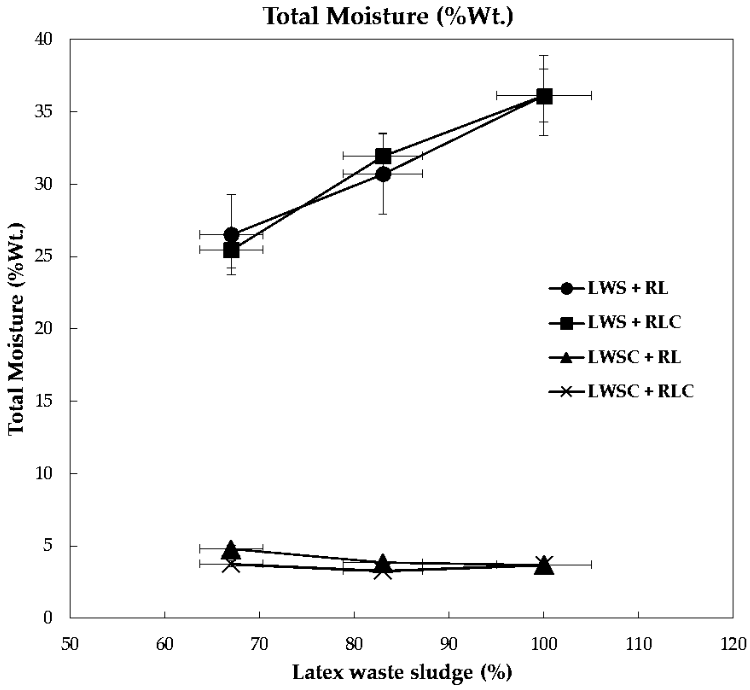

Figure 8. Relationship between total moisture and different experimental conditions.

Latex waste sludge, which consists of organic matter, can be used as an energy source. In the case of using the main raw material as latex waste sludge, it gives a high gross heating value. Figure 9 shows that the fuel briquettes produced from the mixture of latex waste sludge can provide a higher heating value than the latex sludge converted to charcoal. This is due to the combustion process and the change in the material's chemical structure. The combustion process causes the removal of some organic matter and volatile matter, as shown in Figure 10.

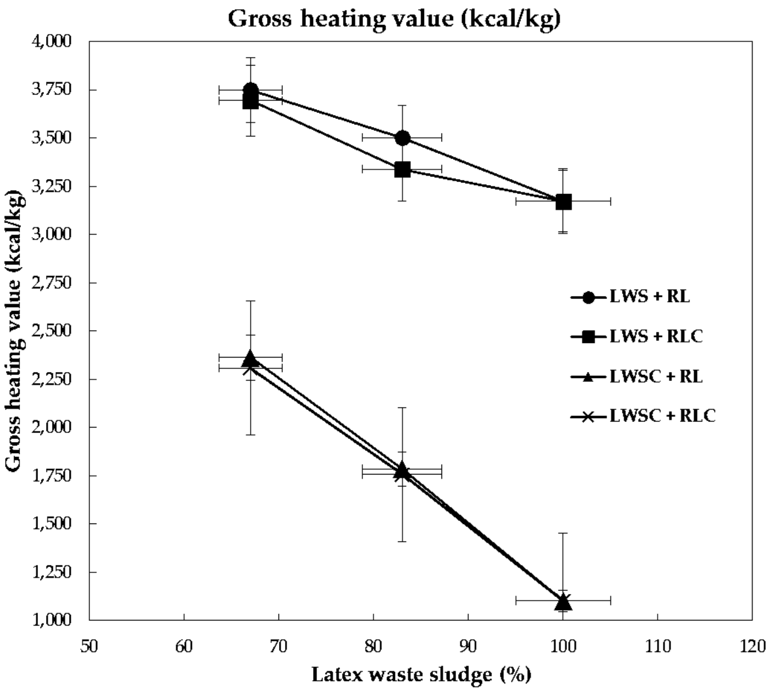

Figure 9. Relationship between gross heating value and different experimental conditions.

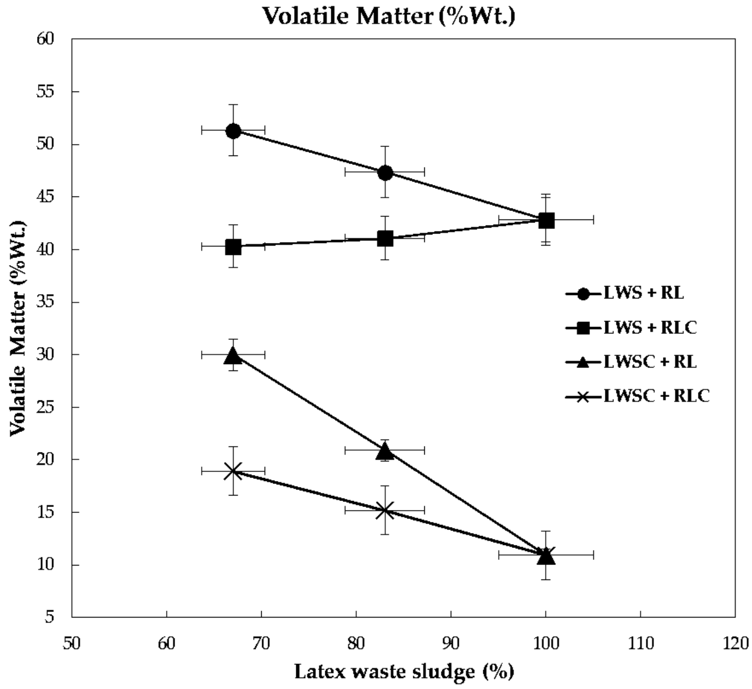

Figure 10. Relationship between volatile matter and different experimental conditions.

Although the results show that using latex waste sludge with rubber leaf charcoal gives a high fixed carbon content, as shown in Figure 11, some high-energy organic matter is burned off during this process. Therefore, it can be concluded that even though the original latex waste sludge contains organic and volatile matter, these can be burned quickly and release high energy. This volatile matter will be removed when converted to charcoal, leaving only carbon that burns slower and gives lower power than the original latex waste sludge. Therefore, the charcoal obtained usually has a lower heating value than the original material.

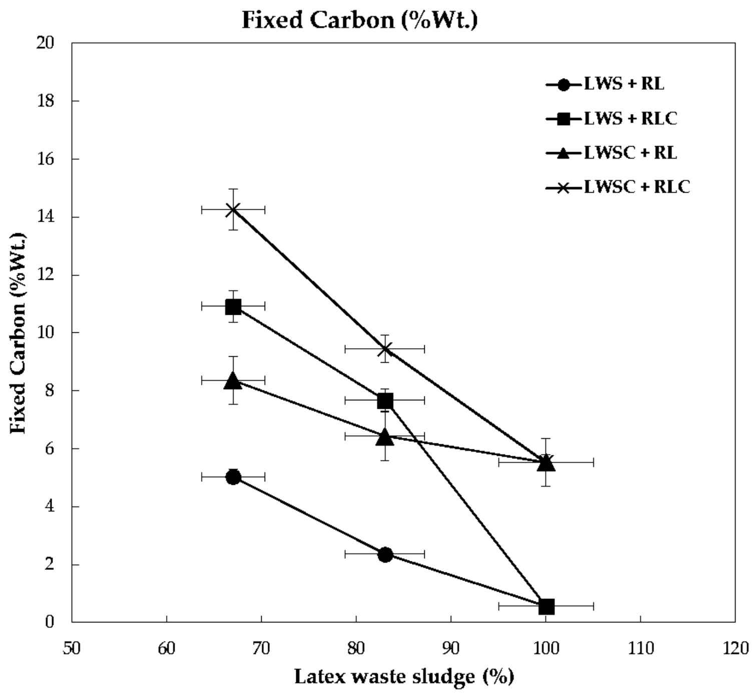

Figure 11. Relationship between fixed Carbon and different experimental conditions.

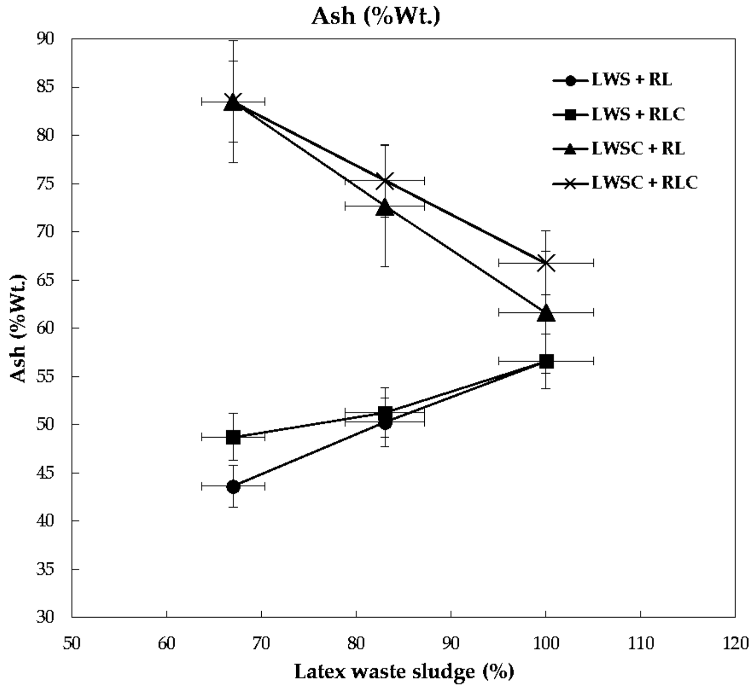

Figure 12. Relationship between ash and different experimental conditions.

This shows that the ash and total moisture contents were significantly reduced when using raw materials converted to charcoal, both latex waste sludge and rubber leaves, as shown in Figures 12 and 8.

Latex waste sludge mixed with rubber leaf charcoal can produce fuel briquettes with appropriate moisture content, volatile matter, residual carbon value, and ash. As reviewed in the research on the process of charcoal briquettes [10, 11], the results showed that dry rubber leaves have properties that can be used to produce charcoal briquettes, as shown in the properties of fuel briquettes obtained under the appropriate conditions in Table 5.

Table 5. The properties of the fuel briquette were obtained from the condition of 67% latex waste sludge mixed with 33% rubber leaf charcoal.

Conditions	Results				
	Gross heating value (kcal/kg)	Volatile Matter (%Wt.)	Fixed Carbon (%Wt.)	Ash (%Wt.)	Total Moisture (%Wt.)
LWS 67% + RLC 33%	3,695	40.30	10.92	48.75	25.47

The gross heating value test of latex waste sludge results show a relatively high heating value, passing the fuel briquette standard (should not be less than 3,000 kcal/kg). The gross heating value obtained is at a level that can be used as fuel for households or small industries. The fuel briquettes from latex waste sludge have good combustion efficiency and low ash content, which is a good characteristic for fuel use in a kiln system that requires cleanliness. In addition, the use of latex waste sludge in the production of fuel briquettes adds value to waste from the rubber production process, reduces waste disposal that pollutes the environment, promotes the efficient use of natural resources, can reduce waste management costs, and generates additional income for entrepreneurs.

4. Conclusions

This study successfully demonstrated the feasibility of using latex waste sludge in combination with rubber leaves to produce high-quality fuel briquettes. The results indicated that the optimum mixture was a ratio of 67% latex waste sludge and 33% rubber leaf charcoal, which yielded a total heating value of 3,695 kcal/kg, exceeding the minimum requirement. This mixture was balanced and characterized by an appropriate level of volatile matter, fixed carbon, and low ash content. It was possible to use latex waste sludge as the main raw material for producing fuel briquettes without adding additional binders. Still, latex waste sludge was used as a binder. The study's results highlight the potential of latex waste sludge as a renewable energy source, which enhances energy production and aids in waste management by converting secondary products from the rubber industry into valuable fuels. The study highlights the advantages of this new approach, including reduced environmental pollution, improved resource utilization efficiency, and the potential for economic benefits to producers. Overall, the production of fuel briquettes from latex waste sludge and rubber leaf charcoal represents a sustainable alternative for energy production, promoting both ecological balance and profitability in the rubber industry. Future research may focus on further optimizing the production process and exploring additional biomass blends to improve the properties and performance of fuel briquettes.

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