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Research Article

Comparative Assessment of Compression Strength of Solid Biobriquette using Different Binding Materials

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Charcoal and firewood are the most common cooking fuels, despite the fact that they represent a variety of social and economic environmental difficulties in many affluent countries. Apart from the environmental implications of deforestation and resource loss, indoor air pollution caused by cooking with solid fuels causes 2 million fatalities each year. Biobriquettes are then utilized as a substitute for oils. Briquettes are also employed as carbon sources for cooking in various industries such as power plants, brick factories, and bakeries. Five specific binding materials were tested in this study for manual densification of cabbage waste, including beef tallow oil, starch, cassava binder, sodium silicate, and vinyl ester resin. The briquettes are made from a combination of 80% densified biological waste and 20% binder material. The sample density ranges from 545.564 to 591.278 kg/m^3. The samples with the highest calorific value were beef tallow oil and vinyl ester resin, which had 5,357.26 and 5,800.79 kcal/kg respectively. The content of the samples were ashes, fixed carbon content, volatile material, and total humidity is 6.47% ± 1.13%, 18.43% ± 6%, 70.68% ± 6%, and 4.42% ± 4%, respectively. The sample with the most calorific value and densification is the one with the inorganic binder mixture.

1. Introduction

The lack of clean and affordable fuel for domestic cooking and other industrial activities is one of the greatest challenges facing most parts of the world today, particularly in developing countries. The majority of people in these countries cannot afford the use of kerosene, liquefied or natural gas, or electricity for food. This has contributed to the indiscriminate slaughter of trees and depletion of forest resources for the use of fuel wood or charcoal [1]. In Nigeria, for example, millions of families are mainly dependent on firewood or coal for their food and other energy needs in rural and urban areas. This contributed to national deforestation and other environmental destruction issues, such as global warming and the depletion of critical biodiversity [2]. Cylindrical solids are synthetic briquettes that can be used as coal rather than as other fossil fuels. This research explores the use of cabbage waste briquettes and various binders. Cabbage waste is readily available in an abundance of solid waste in India [3]. Huge quantities of chicken are popular in cities around the vegetable market, while some can be harvested at home and in other areas where vegetables, such as bans, fast food centers, etc., are widely used. The country generates ~100,000 metric tons of waste per year, which can be used for energy goods [4]. Biomass has many excellent advantages as a binder source, such as large sources, low prices, and high heating efficiency. The briquette has a lower ignition temperature, a lower slagging index, and lower ash content by using this kind of briquette binder. Biomass as a binder has recently been brought home and abroad to the public's attention [5, 6]. Preparation of an aggregate binder consisting of one or more biomass types, including agricultural waste, aquatic plants, forestry biomass, and aquatic plants. This approach incorporates not only renewable and nonrenewable (coal) energies but also provides new ways to harness and use biomass energy. In the meantime, environmental concerns have been addressed and coal combustion efficiency has been improved [7]. The form, binding, and density of the briquette are important to the efficiency of the briquette in their work. The size and height of the cylinder briquette is 42 mm. The emission rate of briquettes must be small so that the pollution rate reduces [8]. The findings have shown that briquette has increased with the addition of bentonite clay and kaolin clay to sodium humate due to high-temperature strength and thermal stability. Bentonite additives had a more remarkable effect on the high-temperature strength and thermal stability of the briquette than sodium humate [9]. A binder with 85%–10% cements, 5%–10% hydrated lime, and 5%–10% polyvinyl alcohol has been reported to be prepared. The briquette developed with this binder has many benefits, such as high cold and hot strength, high resistance to water, and simple and low-cost production [10]. The possibility of rice straw treated with sodium hydroxide used as a briquette binding agent was explored, and sodium hydroxide concentration was identified as the key factor affecting binder efficiency. At a sodium hydroxide concentration of 2.1%, briquette crush intensity and drop check force limit were 244 N/cm^2 and 82.2%, respectively [11]. The binding capacity of the solid element was reduced when the sodium hydroxide concentration increased to a certain degree and the strength of the briquette decreased [12]. Investigating biomass-briquettes chemical structures made of maize stalks or maize stalks using infrared spectrum, it was found that many unreacted biomass fibers in biomass binders were used to establish briquette network structure, both of which are capable of producing cohesive effects for coal particulates. After the briquette interacted with water, cohesiveness did not vanish within 24 hr [13, 14]. Coal tar pitch is one of the most widely used binders. However, in view of the volatile issues in the binder, the briquettes formed by pitch or petroleum bitumen emit smoke during combustion: the volatile matter in the pitch of coal is high. This form of binder has been slowly washed away with improved environmental protection requirements. Briquette output has been found to meet the quality requirements for gasification of coal using lignosulfonate compound, MJ1MJ2, as a binding agent [15, 16]. The effect of carboxyl methyl starch on briquettes has been studied and found that starch in the binding property is substantially better than that of the original starch and that the consistency of products is better through acid treatment than through alkalis [17]. The study of briquettes with phenolic resins synthesized from the low-temperature carbonization process using the entire coal tar fraction of the material. A great deal of work-focused resources has been available in recent years to efficiently replace fossil fuels with flexible renewable fuels. In order to increase the heat, strength, and emissions of the fuel, different binders are mixed with dried organic waste and made into briquettes [18]. Low pressure, therefore, low agglomeration of biomass particles, is a key issue in the manual densification process. In general, the pressure of the mold is graded approximately as low, moderate, and heavy. High-pressure processes are typically capable of releasing enough lignin to lighten the agglomerate. Intermediate-pressure machines may or may not require external relations depending on the material, while low-pressure materials are generally required. Low pressure application has rarely been tested for suitable binder material [19]. Many studies related to the chemistry associated with biomass particle bonding have been published. Knowledge of the unique structure of the bond formation is necessary for understanding the binding of cod waste particles. Lignin, crude protein, neutral detergent fiber, fat, carotenoids, etc., are the principal components of cabbage waste. The presented work is concentrated on the stepwise formation of organic briquettes when blended with different binding specimens. Biowaste is involved here owing to its excellent quality. It is segregated into tiny particles after drying. Further, the material is subjected to blending with the aid of certain fasteners such a blend is manually pressed in briquette apparatus. Certain specific parameters including heat volume determination, proximate analysis, and final blend analysis were further evaluated. Comparing the resulting values, the best and most efficient briquette is chosen.

Figure 1: Cassava binder.

2. Materials and Methods

2.1. Base Materials. Cabbage was selected as the basic ingredient obtained from local markets or places of widespread use. The raw material is extracted to a depletion of about 10% of the moisture content. The dry substance is then divided into fine powder like a rotor.

2.2. Beef Tallow Oil. This material is widely available all over the world. The moisture content is comparatively low in the form of oil. Possibly all oils have a higher temperature, which is sure to burn, and a higher heat value when the refined raw material is combined.

2.3. Cassava Binder. This is an organic binding agent. It is accessible from the nearest store on the market. The root of cassava is first peeled, pasted, dried, and powdered. The cassava binder is made of gluten, which increases the binding strength of the organic briquette. This binder will also increase the density of the briquette (Figure 1).

2.4. Starch Binder. This has been developed for the development of biobriquettes. It is an organic binder. The briquette forms an elastic bond and therefore gives it greater strength and density (Figure 2).

2.5. Vinyl Ester Resin. Vinyl ester resin is a modified polyester resin that is designed to produce stronger mechanical resin

Figure 2: Starch.

Figure 3: Vinyl ester resin.

with high chemical resistance. The modification has been made. The resin thus helps increase the resistance, compression, and heat value of the briquette (Figure 3).

2.6. Sodium Silicate. It is one of the inorganic binders used in the production of organic briquettes. The silicate content of the binder improves the relationship between the molecules, which increases the strength of the biobriquettes and the sodium content of the briquettes while the calorific value of the biobriquette increases.

2.7. Briquetting Machine. The manually applied pressure was chosen to minimize energy consumption due to the compression cycle. Naturally, the chops are dried and broken into a powder form in a rotor blade. A manual press machine was used to compress biobricks. The machines are plain, made up of a frame, a screw press, and a mushroom. You can supply a briquette with a weight of 1,000 kg. The size of the briquette was measured on the basis of geometry, which was supposed to be almost 1. The size of the briquettes is 30 mm high and 42 mm long, which helps to pick up the cylindrical shape of the briquette during the combustion cycle. The mold was designed to manufacture biobricks of 30 mm heights and 42 mm diameters (Figure 4). The mold was 42 mm in diameter and 50 mm height.

Figure 4: Manual briquetting machine.

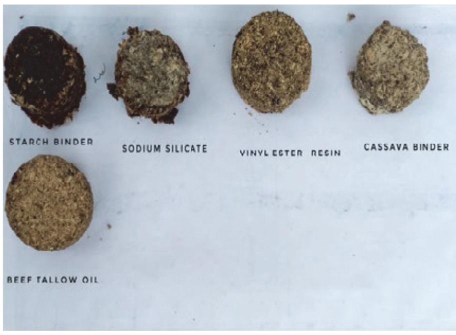

Figure 5: Briquettes.

2.8. Mixing of Materials. The 80% fine crushed raw material is evenly combined with a 20% binder. These binders were mixed by hand with the raw materials, such as cassava binder, starch, and sodium silicate, which required a good mix of water. Each binder is packed with samples. The mixed material was filled to the edge of the mold in the hand press and pushed to the fullest degree by turning the handle. The materials were added until the correct dimensions have been reached. To minimise the humidity of the briquette, the samples are dried for 2 days at room temperature. Finally, the briquettes were measured.

2.9. Preparation of Biocoal Briquette. The briquettes were manufactured using a local briquette machine, which operates with a 10-ton hydraulic jacket, which presses the three square molds compartment containing the mixture of the feed sample (Figure 5). The compacting pressure of the briquette was not registered, but should definitely be less than 10 tonnes. Samples of pulverized materials were thoroughly blended into half-pass stable biomass, polyethylene, charred wood, cassava, calestone, laterite, and water materials and then packed into the molds, and locked and pressed into production with a hydraulic jacket. The briquettes were sun-dried for 3 days or dried in an oven at 110°C for 2 days. The dried briquettes of biocoal have also been weighed and kept dry to be used in the test.

2.10. Determination of Ignition Time, Water Boiling Test, and Other Fuel Properties. Some of the measurements of the briquettes were illuminated by light in the dark house of the briquette. It took the combustion time for the flame to ignite the briquette. This can easily be found at the night. The water boiling test was carried out to determine the time taken to boil 1 kg of water under the same conditions for the given weight (0.7 kg) of the briquette sample first. The boiling of 400 mL of water in a small rustic kettle of 0% of 7 kg of briquette, which recorded the time, measures the specific fuel consumption, the burning rate, and the intensity of the briquette samples. The quenched briquette was allowed to dry and weighed. Specific fuel consumption (SFC), performance, and burning rate of the briquette samples were determined using Equations (1)–(3). Burning processes were also found in briquette samples.

$$\text{Power output} = M_f \times E_f / t, \tag{1}$$

$$\text{Specific fuel consumption} = M_f / M_w, \tag{2}$$

$$\text{Burning rate} = M_f / t, \tag{3}$$

where M_w is the mass of water (kg) boiled by the briquette sample, M_f is the mass of briquette sample (kg) consumed to boil M_w of water, E_f is the calorific value of the burnt briquette sample (kcal/kg), and t is the time taken to boil M_w of water by M_f of the briquette sample.

2.11. Physicochemical and Mechanicaltests

2.11.1. Moisture Content. The moisture content of biomass percent W was calculated in compliance with the French standard NF V 03-921 by Equation (4):

$$\%W = \frac{m_2 - m_3}{m_3 - m_1} \times 100, \tag{4}$$

where m_1 is the mass in the hollow bottle, m_2 is the predrying mass of the sample bottle, and m_3 is the test mass upon drying at 105 ± 2°C.

2.11.2. The Calorific Value. The calorific value was calculated using a method developed using the French NF MO3-005, EN 14918, and ISO 1928. The lowest calorific value (LCV) is obtained through simple calculation of HCVs, precise decomposition, and gasoline moisture quality. This approach allows the actual calorific value (HCV) to be calculated using a bomb calorimeter (Equation (5)).

$$\mathrm{HCV}_{\mathrm{gross}} = \frac{K_1 \times E_{\mathrm{Cal}} \times (T_m - T_i) - K_1 \times E_{\mathrm{Pt}} \times \left(L_i - L_f\right)}{m_{\mathrm{sample}}}, \tag{5}$$

where K_1 is the conversion ratio of calories to joules (3.2453 J/Cal), E_{Cal} is the calorimeter, gun, components, and the water reached in the device is calorimetric equal, (E_{Cal} 1,356 Cal/°C), E_{Pt} is the Platinum's calorific worth: 2.1 Cal/cm, T_m is the higher temperature (°C), T_i is the lower temperature (°C), L_i is the length of initial platinum wire (cm), L_f is the remaining platinum wire length (cm), m_{sample} is the mass of the test portion of the sample to be analyzed, K_2 is the proportionality factor: hydrogen mass present/water mass formed, E_{cond} is the heat of condensation of water (1987 J/kg), H_{ech} is the hydrogen content of the sample (%), and W = Moisture content of the sample (%).

2.11.3. Ash Content. Ash content is the amount of minerals in a fuel, the mass of the obtained ash. It was measured using a process built on the basis of the French norm NF VO3-922 (Equation (6)).

$$\text{Ash content } (\%\,\mathrm{MM}) = \frac{m_3 - m_1}{m_2 - m_1} \times 100. \tag{6}$$

2.11.4. Volatile Matter Content. The ratio of the reactive element is the proportion of substances lost in the gaseous environment as a raw biological force. A system developed in accordance with the French norm NF MO3-004 (Equation (7)) was used to quantify unpredictable material.

$$\text{Volatile matter content } (\%\,\mathrm{MV}) = \frac{m_2 - m_3}{m_2 - m_1} \times 100, \tag{7}$$

where m_1 is the mass in the hollow bottle, m_2 is the predrying mass of the sample bottle before incineration, and m_3 is the test mass upon drying after incineration at 700°C.

2.11.5. Fixed Carbon Rate (FC). Residual volume of carbon after elimination of toxic fuels, ash, and moisture. The accumulated strength, that is, the sum of solid and strength in the volatilized portion (Equation (8)), differs.

$$\text{Fixed carbon rate } (\%\,\mathrm{FC}) = 100 - (\%\,\mathrm{MV} - \%\,\mathrm{MM}), \tag{8}$$

where MV is the amount of volatile matter and MM is the moisture content.

2.11.6. Compressive Strength. The compressive strength is a criterion to test the durability of the briquettes. The longevity of the briquettes is calculated by the compressive intensity. Compressive strength is the ability of the component to cope with the stresses during shipment and handling. This is, in a sense, a test of the significance of various variables. The examination is conducted under axial pressure conditions and the compressive force is measured using a mechanical or hydraulic device. The briquette is in a horizontal location between two metal plates. The flats are constantly lined before the briquette splits with constant rpm. By applying the strength ratio and the area of the transverse part to crash, the compressive strength is calculated as follows (Equation (9)):

$$\text{Compressive strength} = \frac{\mathrm{LF}}{\mathrm{MM}}. \tag{9}$$

2.12. Density of Briquettes. The distribution of the biobriquette samples is shown in Table 1. The diagrams demonstrate the low density of the vinyl ester resin. However, the average density of the sample is more than 500 kg/m^3. The diameter is dependent on the total volume of the material in the briquette. The power of the briquette is measured as well, that is the weight, which is the strength of the briquette.

3. Results and Discussion

3.1. Calorific Value of the Briquettes. The gross caloric value of the samples is shown in Figure 6. The results of the calorific value show that the calorific value of the vinyl ester

Table 1: Density of briquette.

Briquette samples	Mass (*M*) (g)	Volume (*V*) (mm^3)	Density (*P*) (kg/m^3)
Beef tallow oil	95.6	166,253	575.038
Cassava binder	95.3	166,253	573.233
Starch	90.7	166,253	545.564
Sodium silicate	93.8	166,253	591.278
Vinyl ester resin	96.4	166,253	579.85

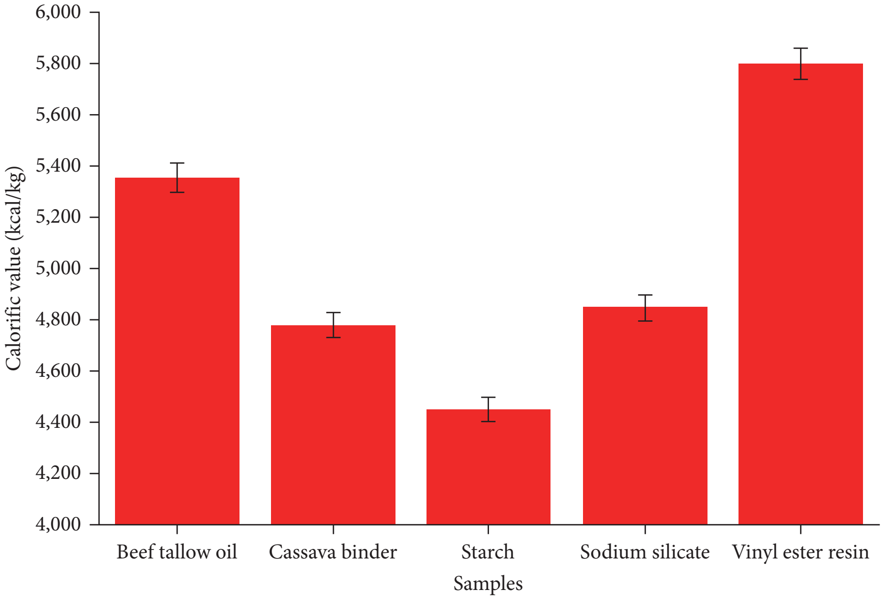

Figure 6: Calorific value of briquettes.

biobriquette sample has the highest inorganic calorific value of 5,800.79. On the organic side, beef tallow oil has a high calorific value of 5,357.26. All other samples were unable to perform calorific value tests. The calorific value refers to the heat produced when 1 g of the sample is completely burned in 1 s. In the biobriquette, this property plays a key role. It also determines the effectiveness of the briquette and plays an important role in determining the effectiveness of the briquette. If the calorific value of the briquette is low, then the briquette is unqualified to use. The efficient briquette must possess high calorific value.

3.2. Proximate Analysis. The proximate analysis values for the samples are shown in Figure 7. It shows the lowest ash content and total moisture content for beef oil samples and the lowest fixed carbon content for vinyl ester resin samples. When the next analysis was performed, all other samples were relatively higher. The ideal briquette must be high in carbon, higher in volatiles, less intact in humidity, and low in ash content. The second is a briquette made of resin vinyl ester, the values of which are 19.2% and 68.77%. The highest fixed carbon content is 18.6% and the total volatile material is 65.51%. These values indicate that the combustion of briquettes is higher, as well as a higher carbon and volatile material value in the combustion process. The amount of ash in beef oil and the total amount of moisture in vinyl ester are 7.51 and 4.52, which are 6.47% and 6.42%, respectively. These values indicate that the briquette produces low residue levels when the briquette is completely burned and that the total moisture content refers to the water content of the briquette.

3.3. Ultimate Analysis. Depending on the American company, the final analysis of the sample is performed. The sample material's composition is provided. For vinyl ester, the calorific value of hydrogen is enhanced to a high calorific value. The nitrogen content of vegetables is derived from protein material. Vinyl has the lowest percentage of nitrogen, which reduces its calorific value. The calorific value of the sulfur content increases, but releases toxic fumes. As the percentage of oxygen increases, humidity and caking capacity decrease. The proportion of carbon, nitrogen, sulfur, and oxygen contents for beef tallow oil is 62.5%, 4.98%, 4.835%, 0.024%, and 27.55%, respectively. The calorific value of the briquette is high due to higher carbon, hydrogen, and oxygen content; the burning period is increased, and pollution or toxic fume emission is reduced due to lower nitrogen and sulfur levels. The values of the briquette made of vinyl ester are 60.66%, 9.48%, 1.12%, 0.02%, and 30.72% which indicates that the carbon, hydrogen, and oxygen percentages are higher so the heat produced on combustion is high and the

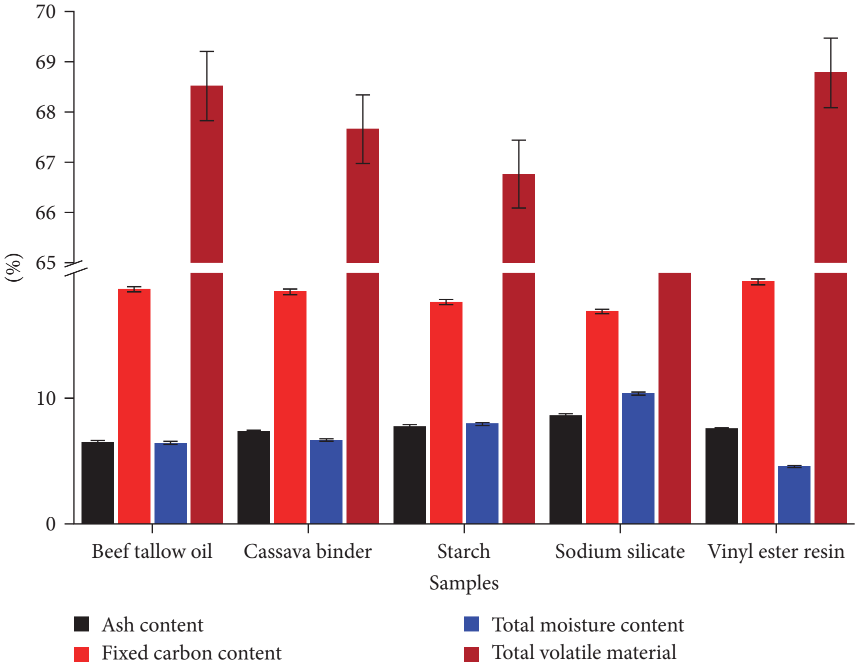

FIGURE 7: Proximate analysis of briquettes.

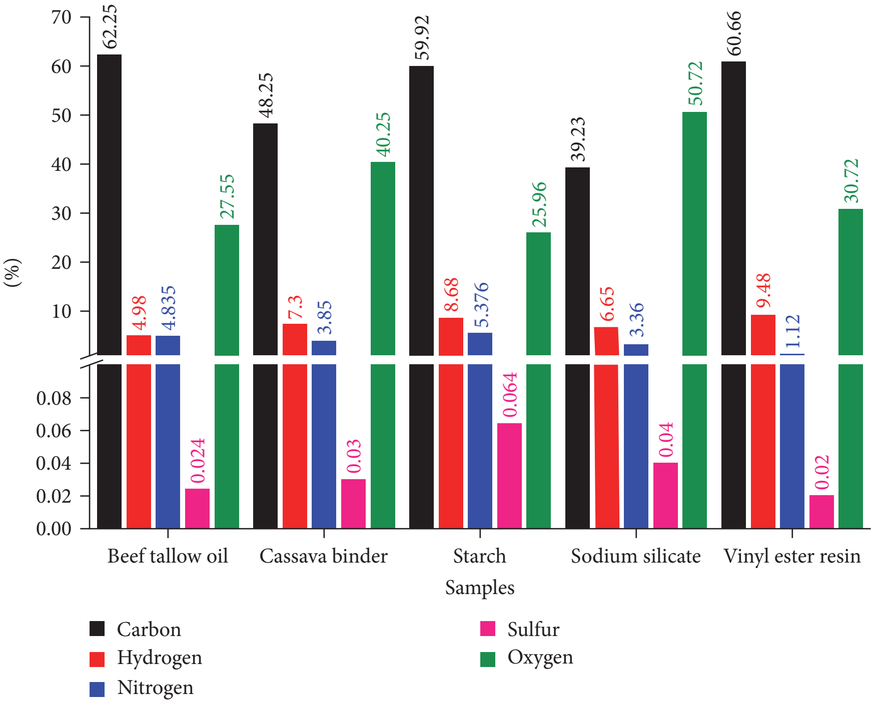

FIGURE 8: Ultimate analysis of briquettes.

time taken for the sample to completely burn in increased, the lower calorific value of nitrogen and sulfur indicates that the briquette when combusted produces comparatively lower poisonous fumes which infer low pollution. The values of the other samples are comparatively lower than these two samples (Figure 8).

4. Conclusion

In conclusion, we use the manual densification technology for cabbage waste. The binding agents must be added externally to obtain the correct binding. The beef oil and vinyl ester resin, with a higher density of 575.038 and 579.85 kg/m^3, are suitable for the production of organic briquettes with a calorific value of 5,357.26 and 5,800.79 kcal/kg. Starch, cassava, and sodium silicate binders were also suitable for the making of biobriquettes, but it experiences a lower calorific value than vinyl binders. Hence the biobriquettes made of beef tallow oil and vinyl ester resin are suitable bio briquettes with high calorific value and required composition of $6.47\% \pm 1.13\%$, $18.43\% \pm 6\%$, $70.68\% \pm 6\%$, and $4.42\% \pm 4\%$ of ash content, fixed carbon, volatile matter, and total moisture content, respectively.

Data Availability

The authors confirm that the data supporting the study's findings are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

P. Bency: conceptualization and methodology; M. Anish: data curation, writing, and original draft preparation; V. Jayaprakash: visualization and investigation; J. Jayaprabakar: supervision; E. Yanmaz: result validation; N. Joy: writing; P. J. Ramulu: reviewing and editing.

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