

Valorization of Textile Waste into Bio-Briquettes: Comparative Calorific Analysis with Activated Carbon

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Abstract

One of the major challenges encountered in recent years is the significant increase in the need for sustainable and renewable energy sources because non-renewable resources such as coal, oil, fossil fuels, and natural gases have been exploited and are on the verge of depletion. By 2030, the world's population will reach over 8 billion people. The demand for fuel is rapidly increasing as fuel is indispensable and is needed in significant powering sectors like industries, transportation, and households. Most people cannot afford fossil fuels, notably kerosene and natural gas, leading to the exploitation of forest resources for wood to be used as charcoal. Each country's community needs an alternative energy source to reduce fossil fuel usage. Solid biofuels such as bio briquettes are a feasible alternative as they are eco-friendly and can be developed from sustainable organic wastes. The work focus on bio briquetting conversion of coir, textile waste which were collected from local tailoring shops in Chennai, Tamil Nadu includes cotton fabrics and cotton cloths, rice husks and corn starch as a binder to formulate a bio briquette which contains 40% of textile waste and 60% of organic waste. Calorific value is determined for the bio briquettes using bomb calorimeter. The energy values were within the range of 1585.53 Cal/g which was compared to activated charcoal 3000 Cal/g to 4000 Cal/g. This study shows that the produced bio briquettes can be used for fuel bio briquette production which is a source of sustainable energy generation. The energy value of the bio briquettes could be increased further by using different binders. It is environmentally

friendly, cost effective and affordable compared to fossil fuels.

Keywords: Textile Bio briquettes, Sustainable energy, Textile waste, Calorific value, Renewable fuel

Introduction

One of the major challenges encountered in recent years is the significant increase in the need for sustainable and renewable energy sources because non-renewable resources such as coal, oil, fossil fuels, and natural gases have been exploited and are on the verge of depletion (1). By 2030, the world's population will exceed 8 billion. Over time, the primary energy demand is expected to double by 2050 from 2023 ("U.S. Energy Information Administration - EIA - Independent Statistics and Analysis" (2025)). The demand for fuel is rapidly increasing in significant sectors such as industry, transportation, and households(2). Tamil Nadu alone has over 8326.86 MW of installed renewable energy capacity, or approximately 25.44% of the approximately 32,730 MW installed capacity throughout India ("ENVIS Centre: Tamil Nadu Status of Environment & Related Issues," n.d.). Each country needs an alternative energy source to reduce fossil fuel usage that is ecologically friendly and sustainable for long-term use. One such alternative energy source of Solid biofuels such as bio briquettes as they are a feasible alternative. Bio-briquettes are compressed blocks of organic materials that are widely used as fuel in domestic and commercial industries. They are eco-friendly, cost effective, carbon-free and can be developed from sustainable organic wastes.

Briquettes are fuels that undergo energy conversion by direct combustion and are utilised for heating and cooking, both domestically and industrially, most effectively in fixed bed chambers due to their physical composition. Bio briquettes are not only helps in sustainable energy production but also promising approach for waste management. Biomass and organic waste that includes agricultural residues like coconut shell Groundnut Shell Biomass and organic waste that includes agricultural residues like coconut shell (3) Groundnut shell (4), Sugarcane bagasse, Paddy straw (5), Cotton stalk (6), Cow dung (7), Paper waste(8). Numerous studies have been focused on these materials for developing different types of briquettes. However, a lot of attention has been focused on biomass and organic waste and the exploitation of forests in Indonesia comparable to over eight million FIFA football fields facing deforestation for wood chip and pellet production for energy (9) but other waste steams with lot of potentials especially those from urban cities and industry have been completely ignored. Textile waste is one of the untapped waste streams which is growing rapidly because of the global fast fashion and textile industry. The textile industry has developed into a crucial sector, significantly contributing to global economic expansion. In 2020, the sector was valued at \$842.6 billion, with projections suggesting an increase to \$1350.2 billion by 2027. Nonetheless, with its economic advantages, the textile industry significantly contributes to waste production. By 2030, worldwide textile waste is anticipated to attain 148 million tonnes annually. Despite significant quantities, just 1% of textile waste is recycled, with 75% finally disposed of in landfills and incinerators which accounts to 92 million tons annually , where decomposition may span from five months to over 200 years, potentially releasing harmful compounds (10) (11). So, there is an essential need for choosing an eco-efficient waste usage strategies that does not natural ecosystem and minimize stress. Textile waste, especially

from natural fibres like cotton, has a lot of cellulose and flammable material in it, which makes it a good raw material for making bio-briquettes. It has a lot of volatile matter and fixed carbon, which makes it good for energy use. But even though this is a good idea, bioenergy research hasn't used much textile waste yet. Using textile waste to make briquettes could not only ease the burden on landfills, but it could also turn a waste stream that is otherwise very harmful to the environment into something useful. Textile Bio-briquettes (TBB) are one of the subcategories of bio-briquettes which could be produced by pre and post textile waste like denim, cotton fabrics, wools and could be further blended with organic plant waste such as rice husk, sugarcane bagasse, coconut coir. In this study, the effort has been made to address two global challenges increasing energy demand and mounting textile waste through production of bio briquette from textile residues as a primary feed stock with an aim of developing sustainable, cost-effective, carbon-neutral alternative solid fuel. The prepared bio briquettes were evaluated for the key fuel characteristics like Calorific value, Ash content, Moisture content. Special focus was placed on comparing the calorific value of the textile bio briquettes with commercial activated charcoal to highlight that non-carbonized textile bio briquette calorific value.

Materials and Methods

Raw Material Collection

Biomass, coating and binding materials where procured from local sources to prepare TBB. Textile waste was obtained from local tailoring shop and it mainly consists of cotton fabrics scraps. Paper waste was acquired from household discards consisting of both printed and plain shredded paper. Agricultural residues like coconut coir, rice husk, Straw where sourced from local farm in the surrounding area. Sugarcane bagasse a fibrous by product of juice extraction was collected from the fresh juice shop located inside SIMATS ENGINEERING campus,

Thandalam, Chennai. To assist in briquetting processes corn starch was used as a binder and Tapioca pearl served as a coating material.

Chemicals and Instruments

Corn starch 99%, Tapioca flour (in pearl form), Distilled water, Bomb Calorimeter (Model CC01/M2), Muffle furnace, Briquette Mould, Weighing balance.

Briquette Preparation

Pre-treatment of Raw Materials

All the raw materials collected were subjected to sun drying for 3-4 days to remove excess moisture content. After drying textile waste, paper waste and agriculture waste were shredded into fine particles of 0.5-1cm to obtain uniform mixing and compression. Sugarcane bagasse was washed and sun dried to loosen it up. Coconut coir was crushed to loosen and breakdown fibre clumps. Rice and Straw were used as received form after drying. Once all the materials were size reduced it was stored in air tight container to prevent excess moisture absorption before briquette formation.

Binder Preparation

Corn starch was used binder due to its high adhesive properties and biodegradable nature. Binder was prepared by taking corn starch to distilled water ratio of 1:5 (w/v) and binder solution was heated under continuous stirring at 60-70°C to obtain uniform gel like solution without clumps. The mixture was heated gently until it reaches as thick paste consistency ensuring complete gelatinization of starch. The binder solution was then allowed to cool before adding it to the pre-treated raw materials for briquetting.

Mixing Procedure

The dried biomass was blended in the following proportion with binder paste in specified ratio which is presented in (Table 1). Textile waste, paper waste, Straw were added in equal quantities to act as base and higher amount of coconut coir, rice husk

and sugarcane bagasse to improve the combustion properties of briquettes (Figs. 2-5). Small amount of Corn starch was aided in binding to enhance the structural stability. The composition was mixed manually to ensure uniform consistency for briquetting.

Briquette Moulding

The prepared biomass mixture was moulded using a plastic mould with dimension of 5×5 cm and height of 2 cm. Manual method

S. No	Biomass used	Composition (%)
1	Textile waste	10%
2	Paper waste	10%
3	Straw	10%
4	Coconut coir	20%
5	Rice husk	25%
6	Sugarcane Bagasse	20%
7	Corn starch (Binder)	5%



Fig 2: Sugarcane Bagasse



Fig 3: Coconut coir

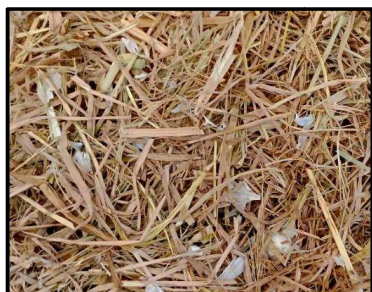


Fig 4: Straw



Fig 6: Structured bio briquette samples



Fig 5: Textile waste



Fig 7: Bio briquettes are coated using tapioca pearls for structural integrity and combustion control

was adapted to press the mixture firmly into the plastic mould to achieve uniform shape. The mould was left undisturbed to dry for 10 mins. The moulded briquette was carefully removed and air dried for 2-3 hours for removing excess moisture content in the binder and to achieve firm structure stability. Final step in moulding involves coating tapioca flour that is obtained from tapioca pearls for the smoothness of bio briquette (Figs. 6 & 7).

Characterisation of Bio briquette

The energetic potential of the TBB are explored. As energy demands surge alongside environmental concerns, identifying low-cost, high efficiency renewable alternative becomes critical. In this research we have analysed the calorific value, moisture content, ash content to understand its energy property.

Moisture content

Moisture content was one of the crucial parameters to be followed for the fuel characterization it refers to the amount of

water present in a sample. the high moisture content efficiency affects various factor such as combustion efficiency and energy output. In this study moisture content was determined by the oven drying method, as per standard procedure. 1 gram of sample was taken and placed in a pre-weighed crucible at 103°C for 1.5 hours. The crucible was taken out and placed in a desiccator, let to cool to ambient temperature, and subsequently reweighed. The process continued until the weight stabilized post-cooling, which was then documented as the final weight; the moisture content of the sample was calculated using the equation.

$$\text{Moisture content (\%)} = \frac{\text{Initial weight} - \text{Dry weight}}{\text{Initial weight}} \times 100 \quad (1)$$

Ash

The amount of inorganic, non-combustible material in the sample can be determined by its ash content. In this study

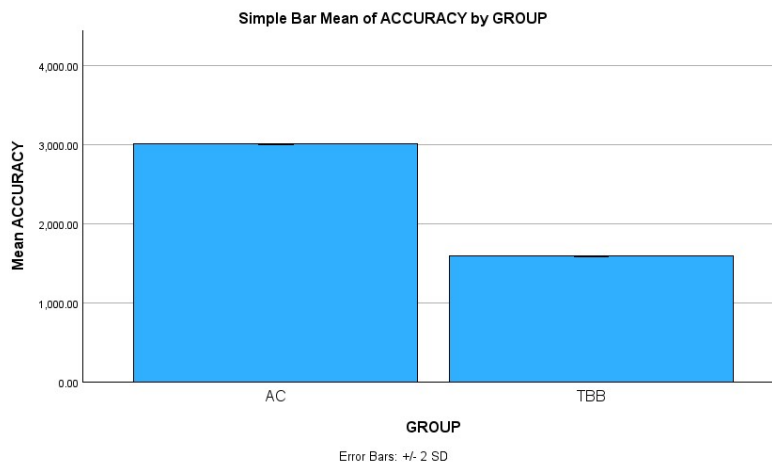


Fig. 8: SPSS graph for Textile Bio-briquettes and Activated charcoal

ash content efficiency determined by incineration the oven-dried material in a muffle furnace at 55-600°C for 4 hours. The residues left over after the combustions represents the total mineral matter. The ash content was calculated for thr dry sample.

$$\text{Ash content (\%)} = \frac{\text{Weight of ash}}{\text{Initial dry weight of sample}} \times 100 \quad (2)$$

Calorific Value

The Calorific value of the sample was determined using bomb calorimeter (Model CC01/M2) to determine a fuel's calorific value also known as its heating value. The experiment was carried out as follows. Initially the sample was collected and oven dried at 105°C for 24 hours to eliminate moisture. 1 gram of the sample was taken and weighed then placed into the crucible of the bomb calorimeter. To ensure full combustion an ignition wire was connected, and the bomb was filled with oxygen at a pressure of 25 to 30atm pressure. The bomb was then placed in calorimeter, which was filled with known amount of water. The initial temperature (T_1) of the water was noted. Combustion was initiated and the final temperature (T_2) of the water was measured once after the burning of

the sample was completed. To calculate the gross calorific value the temperature rise ($\Delta T = T_2 - T_1$) was noted.

$$\text{Calorific value (MJ/kg)} = \frac{(W_g + w_g) \times \Delta T}{w_f} \quad (3)$$

Where, W_g - Weight of the water in calorimeter (kg), w_g - Weight equivalent of apparatus,

ΔT - Temperature rise of water (°C),
 w_f - Weight of fuel sample taken (kg)

Data analysis

Statistical analysis was performed using Statistical Package for the Social Science (SPSS) version 30 for Windows (IBM Corp., Armonk, NY, USA). Independent t-test sample was conducted.

Results and Discussion

Characterization of TBB

Proximate analysis was performed to determine the fuel quality, combustion rate and also to understand the parameters that influence the energy efficiency, ignition characteristics. It also help to optimize the raw material selection, performance and improvement of bio briquettes (12).

Moisture content

The moisture content of the textile bio briquette was found to be 11.11% calculated following IS 1350 (Part 1):1984 standard (13). The obtained value falls within the range of less than 15% which is a fixed standard for bio briquette produced from biomass indicating that the reliable quality briquette. Similar result was reported in (12) where the bio briquette has the moisture content within the range of max 10%. The less moisture helps in spontaneous ignition and low occurrence of slagging tendency indicating cleaner combustion.

Ash content

The ash content in the bio briquette indicates the amount of obstruction in combustion medium. Average percentage of ash content for the TBB was 15.25% listed in Table 2. The ash content of the briquette is dependent upon the kind of biomass and the combustion method employed for the briquette (14). Low ash percentage provides a greater heating value for briquettes, but high ash content generates dust emissions that contribute to air pollution. Elevated ash concentration diminishes calorific value, adversely impacting combustion volume and efficiency (15). The less ash content in the TBB results in better calorific value.

Calorific value

The calorific value of the TBB was 1585.53 Cal/g which is equivalent to 15.855 MJ/Kg when compared with activated charcoal typically exhibits higher gross calorific value which is between the range 4000-5000 (16). Although the TBB calorific value is lower than that of activated charcoal it still has around 48-55% of the commercial activated charcoal. The capability of briquette is notable considering that the briquette is non-carbonized and composed of textile, agricultural and paper waste. Which was used without intensive thermal or chemical treatment. The relatively high calorific value indicates the potential of TBB as low emission fuel alternative, cost effective and sustainable since commercial activated charcoal are

expensive. This study emphasizes that even untreated or minimally processed textile waste derived bio briquette can act as a high combustion biofuel making them a good alternative option.

SPSS analysis

Statistical analysis was conducted using SPSS to determine and compare the calorific values of TBB and activated charcoal. The gross calorific value of TBB is 1585.3 Cal/g, which indicates moderate energy potential. In contrast, the calorific value of the activated charcoal ranged between 3000 and 5000 Cal/g resulting as high-performance fuel. Through the independent samples t-test revealed a statistically significant difference ($p < 0.05$) between the two fuel types.

Conclusion

The comparison of TBB and activated charcoal showed a similar variation, with TBB averaging 1585.53 Cal/g and AC ranging from 3000-4000 Cal/g. This showed a significant of ($p < 0.05$), according to SPSS analysis which emphasizes activated charcoal higher energy efficiency. TBB are valuable beyond its calorific value. Textile waste is a type of industrial waste which presents high amount in the environment causing pollution from incineration and landfill. Turning this waste into a valuable resource and generating energy is an art. TBB combustion capacity could be limited due to its fiber type, moisture content and additives, but its environmental benefits make it more viable for low-cost, localized thermal application. Improving TBB combustion profile is a fascinating opportunity for future studies. Yield of energy and its reliability can be further optimized by the strategies like blending with other biomass sources, densification and carbonization. TBB also supports the economy, reducing the impact on the environment and provides energy alternatives to areas where access for conventional sources is limited. Bio briquette made up of textile can facilitate in sustainable goals regardless of high-performance fuels

like activated charcoal. TBB play a dual role like converting waste in to an energy and also assist in reuse of waste materials. This makes the TBB a compelling candidate for green infrastructure and climate resilience planning. The production, distribution of bio briquettes will also create a job opportunity by introducing recycling of waste to energy to the surrounding communities. Furthermore, Usage of TBB could increase in an agriculture sector, as bio briquettes with high level of organic and mineral content may be examined for their post- combustion-based residues like biochar or partially processed fertilizer. Moreover, Processing the textile waste in to a energy like bio briquettes shows a broader environmental shift towards the circularity of using Agriculture waste. By this we not only reduce industrial pollutants it provides a distributed energy models that support marginalized communities. The study results in energy research, sustainable agriculture, environmental governance and gross development.

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