Research Article

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Combustion Analysis of Solid Biomass Derived from Turmeric and Onion, using Nanoclay as a Binding Material, for a Sustainable Environment

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ABSTRACT

The usage of fossil resources has promoted wealth accumulation, exacerbated the negative effects of climate change from GHG emissions, and jeopardized human safety. This research focuses on the utilization of locally generated waste from Turmeric Wastes (TW) and Onion Wastes (TW) for the production of biomass briquettes, employing 10% nanoclay powder as a binder. The biomass waste mixtures were prepared at different ratios, namely 0:100 (C1), 30:70 (C2), 60:40 (C3), 90:10 (C4) and 100:0 (C5), with a constant binder concentration. Densification can be used to turn these residues into elevated, fuel-efficient biomass feedstock. Analysis was carried out for wet content, content of volatile matter and content of fixed carbon. SEM evaluations with EDAX studies were done to identify the major elements available in the produced Turmeric waste - Onion waste briquettes. TGA and DSC investigation implicated the recognition of the burning stage of exothermic and endothermic peaks of the produced briquettes. The briquettes generated exhibit a range of total calorific values, spanning from 11.66 to 15.64 MJ/kg. Notably, these briquettes demonstrate an ignition time within the range of 3.3 to 4.0 seconds and a sustained burning duration lasting between 20 to 28 minutes. Consequently, the utilization of TW-OW in combination with 20% nanoclay binder presents a viable alternative energy source. This is attributable to the briquettes' commendable characteristics, including low moisture and ash content, coupled with a notably high calorific value.

Keywords: Nanoclay binder; Environment sustainability; Densification; Waste to wealth; Energy.

1. INTRODUCTION

The increase in energy demand can be ascribed to the growing population and also a major increase in residential and retail activity around the world (Adeleke *et al.* 2019). Liquid fuels, coal, oil and gas, and other fossil fuels are the major energy sources, accounting for over 80% of worldwide energy requirements (Afra *et al.* 2020). Briquettes made from biomass are powerful enough to compete, with free biomass, allowing easier transport and storage (Balraj *et al.* 2020). It could be transferred over greater distances with reliable energy storage choices while maintaining adequate size and density. In terms of cost, biomass briquettes were inexpensive to purchase, load, and unload (Bhagwanrao and Singaravelu, 2014). Combustion, gasification, and pyrolysis are examples of thermochemical conversion methods that use briquettes (Bhuvaneshwari *et al.* 2019). However, because of its low prices and great reliability, ignition is now the most advanced and commonly utilized technology for such applications (Blessymol *et al.* 2023). After the biomass was molded into compact briquettes, studies indicated that the burning characteristics improved by 20%, and the natural greenhouse effect, NOx, and SO_2 emissions were only one-ninth, one-fifth, and one-tenth of coal (Carraro *et al.* 2019). Solid fuels are used to generate power and heat in both the home and the workplace. Biomass-based alternative source is one of the few demonstrated, cost-effective, and easily accessible solutions for reducing emissions of carbon dioxide (Cavallo and Pampuro, 2017). Biomass briquette manufacturing and usage are deemed environmentally responsible if they meet a set of environmental sustainability parameters, which are divided into four general categories: land usage, water and air quality, earth and wildlife conservation, and carbon stock protection (Debdoubi *et al.* 2005). The goal of this study is to examine biomass briquetting technology as a sustainable bioenergy production method, with a focus on renewable sources, briquetting procedures, technological evaluation, and financial consequences. Several types of biomass materials have been studied; some in combination with non-biomass components used in briquetting. Briquette quality is determined by the raw ingredients used and the briquetting procedure used. Good ignition, durability and stability in handling and storage, and environmental safety when combusted are the desirable properties for briquettes as a fuel (Efomah and Gbabo, 2015). The nature of the raw resources has a big impact on ignition and environmental protection. Morphology, chemical, physical, and purity are the factors to be considered. Environmental awareness is determined by toxic emissions after burning, which are measured by factors such as heat of combustion, ease of ignition, and ash content (Ei and Siha, 2013). Briquettes' longevity and consistency, on the other hand, are determined by the pelleting technique. The characteristics that define strength and longevity are compression test, resistance to abrasion, impact strength, wettability, and density. They are regarded as the most crucial quality attributes for densified biomass (Florentino *et al.* 2019). Based on the measured parameters, pellet quality is a measure of physical, mechanical, toxicological, and thermodynamic conductivity (Gado *et al*. 2013). It also indicates the efficiency of the hardening process and has an impact on its ability to withstand specific impacts from handling, stockpiling, and movement. The escalating global demand for environment-friendly energy solutions has prompted a surge of interest in biomass briquettes. These compacted forms of organic materials offer a sustainable alternative to conventional fossil fuels.

2. MATERIALS AND METHODS

2.1 Processing Raw Materials and Blends

The sourcing of raw materials, namely Turmeric Wastes (TW) and Onion Wastes (OW), was carried out in Jambai village, Erode district, Tamilnadu, India, positioned at latitude 11.342241 and longitude 77.7274709. The choice of this location is attributed to the abundance of agricultural wastes, making it a suitable raw material for briquette production. To diminish moisture content in the raw materials, a thorough sun-drying process was applied to all selected materials. Subsequently, these biomass materials underwent a milling process to achieve a fine powder consistency (Ikelle *et al.* 2020). The resulting mixture was then sieved to obtain fine particles (less than 3 mm).

2.2 Creating the Binder and Establishing the Briquette Composition

Nanoclay binder played a pivotal role as an additive in the formulation of agricultural waste briquettes, with a concentration of 10% of the sample's weight. To create the binder solution, an appropriate amount of binder powder was meticulously weighed and introduced to 150 ml of distilled water, ensuring a lump-free and smooth preparation. The binder solution underwent heating in a water bath set at 70 °C for 5 to 10 minutes, with continuous stirring until a cohesive paste was formed. Following this, TW and OW, each weighing 250 g, were thoroughly blended with the prepared binder solution to achieve a homogeneous, damp mass of consistent size (Jittabut, 2015). For the molding process, a cylindrical briquetting mold with inner dimensions of 76 mm diameter, 4 mm thickness, and 120 mm height was employed. The compaction piston, featuring a diameter of 72 mm, height of 160 mm, and a total weight of 9 kg, facilitated the evacuation of the briquette by displacing the attached steel plate at the base edge, securely fastened. Ensuring uniform size, a hydraulic press, specifically a controlled Universal Testing Machine (TUFC-100 SERVO) with a maximum capacity of 1000 kN, was utilized for briquette production. In adherence to the research protocol, a consistent dwelling time of 90 s was maintained for each press cycle, ensuring the production of uniform TW-OW briquettes.

2.3 Characteristics of Biomass Briquettes

2.3.1 Briquette Dimensions

The diameter of the briquettes was assessed based on the specifications of the molding apparatus utilized during production. Additionally, vernier calipers offered an alternative means of measuring the briquette diameter (Kaliyan and Morey, 2009). The inner diameter of the mold employed in briquette manufacturing was determined to be 76 mm.

2.3.2 Volume Measurement

For precise determination of the radius and height of the briquettes, vernier calipers were employed. The volume of each briquette was subsequently calculated using the formula $\pi r^2 h$ (Kuhe *et al*. 2013).

2.4 Elemental Analysis of TW-OW Briquettes

Using a Scanning Electron Microscope (SEM) equipped with Energy-dispersive X-ray spectroscopy (EDAX), the chemical elemental composition of the biomass briquettes was discerned. The EDAX procedure was implemented to identify both macro and micro-elements. The research employed the SIGMA model with GEMINI column and FESEM by Carl Zeiss (USA), featuring SE2 and BSD detectors with a resolution of 1.5 mm. The EDAX model utilized in the study was the Nano Xflash detector from Bruker (German). Complying with DIN EN ISO 9001:2008 standards, elemental analysis was conducted, allowing for point, area, line, and elemental mapping scans.

2.4 TGA Analysis of TW-OW Briquettes

Thermogravimetric analysis (TG) was employed to determine both mass loss and mass loss rates. The variations in mass loss were meticulously recorded in correlation with temperature, within a nitrogen atmosphere, while the biomass briquette samples underwent decomposition. The TG analysis encompassed all five samples, namely: 0:100 (C1), 30:70 (C2), 60:40 (C3), 90:10 (C4), and 100:0 (C5). The research utilized the NETZSCH-STA-449F3 model, featuring a flow rate and a heating ramp of 20 °C/15.0 (K/min)/460 °C. The percentage of mass loss was extracted from the results obtained from the briquette samples. Additionally, the analysis adhered to ASTM standards, and the decomposition of the samples was discerned through variations in the curve (Velusamy *et al.* 2022).

2.5 DSC Analysis of TW-OW Briquettes

The optimal heating value of the briquettes was determined through the application of differential scanning calorimetric (DSC) analysis. The research utilized the NETZSCH-STA-449F3 model, incorporating a flow rate and a heating ramp of 20 °C/15.0 (K/min)/460 °C. Before analyzing the high heating value, DSC calibration was performed with indium and zinc standards following ASTM guidelines. All DSC tests were conducted in a nitrogen environment using aluminum sample pans, which served as references. The recorded thermogram, illustrating temperature in °C versus heat flow in mW/mg, was then presented. The analysis adhered to ASTM D 3418–15 standards, with a focus on observing variations in exothermic and endothermic phases. Moreover, the DSC analysis facilitated the identification of both high and low heating values, with peak values observed in the exothermic and endothermic phases.

3. RESULTS AND DISCUSSION

3.1 Physical Characteristics

Conforming to ASTM standards, an analysis of the physical characteristics of briquettes derived from TW and OW was done. The examination encompassed various attributes, including texture, height, density, mass in restful phase, comfortable density, soothing ratio, and smashed index. The outcomes of this examination are systematically presented in Table 1.

Table 1. Physical characteristics of the TW-OW briquette

S. No.	Sample ID	Nanoclay Binder, %	Texture	Height	Density kg/m^3	Soothing Ratio	Smashed Index	Mass in relaxed stage (g)
1	C1	10	Rough Brown	40 mm	660	1.05	99.55	230
2	C2			38 mm	700	1.07	99.43	236
3	C3			39 mm	732	1.01	98.89	224
4	C4			41 mm	768	1.12	98.73	213
5	C5			39 mm	800	1.32	99.44	219

Table 2. Proximate analysis of the TW-OW briquette

S. No.	Sample ID	Content of Moisture, %	Content of Volatile matter, %	Content of Fixed carbon, %	Content of Ash, %
1	C1	8.9	72.36	7.68	11.06
2	C2	6.7	75.45	9.76	8.09
3	C3	10.1	66.89	10.67	12.34
4	C4	9.8	66	12.53	11.67
5	C5	11.0	77.9	8.67	13.43

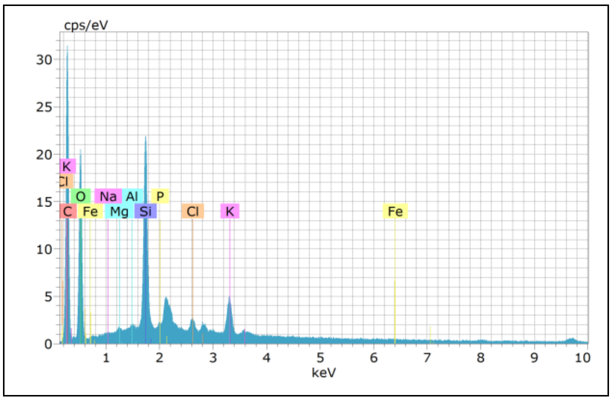

Fig. 1: Elemental analysis of TW-OW briquettes C4 sample

The examination of the conducted tests revealed a consistent diameter of 76 mm for all briquettes. The thickness of the briquettes ranged from 38 to 41 mm, aligning with findings from Velusamy *et al.* 2023. The density of the TW-OW briquettes varied from 660 to 800 kg/m^3. Comparisons suggested that higher briquette density correlated with lower porosity. The soothing ratio for the TW-OW briquettes ranged from 1.01 to 1.32, indicating higher values. The relaxation ratio was nearly uniform across all proportions. The shattered index for all TW-OW briquettes exceeded 95%, aligning with Jittabut *et al.* 2015. Similarly, briquettes with a 10% cassava starch binder also had a shattered index above 96% (Bhuvaneshwari *et al.* 2019)

3.2 Proximate Analysis

The escalating global demand for environment-friendly energy solutions has prompted a surge of interest in biomass briquettes. These compacted forms of organic materials offer a sustainable alternative to conventional fossil fuels. The proximate characteristics of biomass briquettes are presented in Table 2.

The minimum moisture content is 6.7% for sample C2 and the maximum content of moisture is 11.0% for sample C5. The lowest content of volatile matter is 66% and the highest content is 77.9% for the samples C4 and C5. Fixed carbon content varied from 7.68 (C1) to 12.53 (C4). The range of Ash content is very low; it induces a high amount of energy burning from the formed TW-OW briquettes. Nevertheless, the observed ash content percentage was marginally elevated in comparison to recommendations indicating that optimal briquettes should have an ash content within the 3 to 4% range for high-quality production. However, aligning with previous studies, our findings are consistent with the notion that the variability in ash content percentage can be attributed to differences in the types of biomass wastes employed in briquette production and the combustion methodology applied.

3.3 Elemental Analysis of TW-OW Briquettes

The elemental analysis of TW-OW briquettes encompasses the inspection and quantification of the elemental constitution within the briquettes. This procedure predominantly centers on the identification of crucial elements existing in the briquette samples, delivering valuable insights into their chemical structure. The elemental analysis entails the determination of elements like carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), and other potential trace elements based on the specific analytical methodologies employed. This comprehension of the elemental composition enables researchers to evaluate the applicability of TW-OW briquettes for diverse purposes and acquire a more profound understanding of their chemical attributes (Fig. 1).

3.4 SEM Analysis OF TW-OW Briquettes

The SEM analysis of TW-OW briquettes involves the utilization of advanced imaging technology to examine the surface morphology and structure of the briquettes. This analysis allows for a detailed investigation at the microscale, offering insights into the texture, porosity, and overall physical characteristics of the TW-OW briquette surfaces. SEM analysis provides valuable information about the arrangement and distribution of particles, as well as any structural features that may impact the performance and behavior of the briquettes. Researchers can use SEM data to enhance their understanding of the internal composition and surface topography of TW-OW briquettes, aiding in the assessment of their suitability for specific applications (Fig. 2).

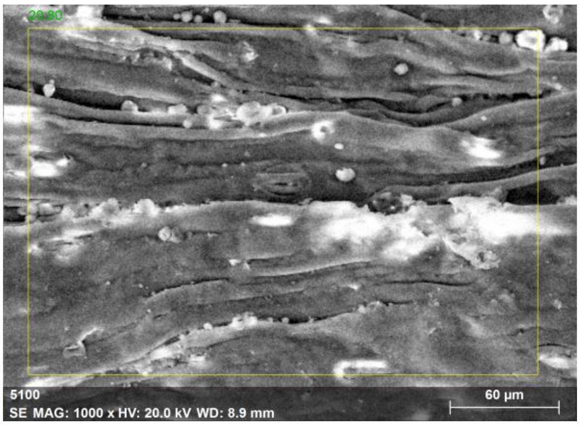

Fig. 2: SEM analysis of TW-OW briquettes for C4 sample

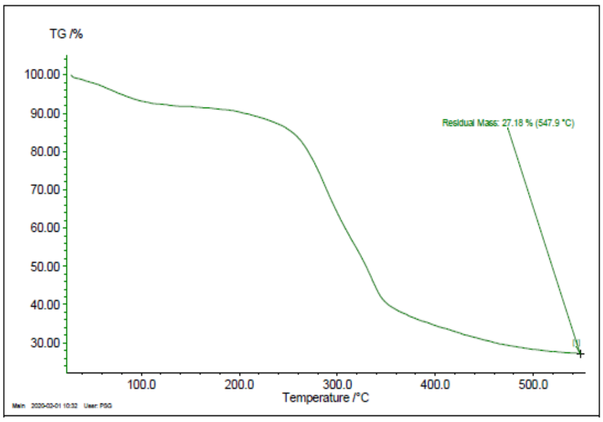

Fig. 3: TGA analysis of TW-OW briquettes for C2 sample

3.5 TGA Analysis of TW-OW Briquettes

TGA of TW-OW briquettes involves subjecting the samples to controlled temperature conditions while measuring the corresponding weight changes. This analysis aids in understanding the thermal behavior of the briquettes by observing how their mass evolves with increasing temperature. During TGA, the briquettes undergo decomposition, and the associated weight loss is recorded.

This information is crucial for determining the thermal stability, combustion characteristics, and the presence of volatile and non-volatile components in the TW-OW briquettes. Researchers use TGA data to assess the suitability of TW-OW briquettes for specific applications, such as combustion or gasification, as well as to gain insights into their thermal performance and behavior under different temperature conditions. The results obtained from TGA analysis contribute to a comprehensive understanding of the thermal properties of TW-OW briquettes, aiding in optimizing their utilization in various contexts (Fig. 3).

3.6 DSC Analysis of TW-OW Briquettes

DSC analysis of TW-OW briquettes is depicted in Fig. 4 (for C2 sample). At 84.3 °C, the evaporation of free water from the briquette sample marked the peak temperature of the endothermic curve. Following this, the second stage entailed the devolatilization of cellulose, hemicellulose, and a fraction of lignin. The peak at 354.6 °C corresponds to an exothermic reaction, releasing energy at a rate of 0.376 J/(g*K). This shift from endothermic to exothermic indicates the liberation of energy from the combustion of organic matter within the briquette sample. The curve consistently displayed an endothermic pattern throughout this process.

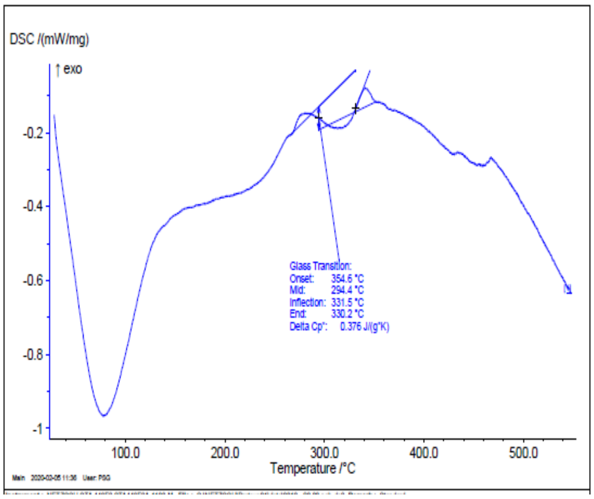

Fig. 4: DSC analysis of TW-OW briquettes for C2 sample

3.7 Compressive Strength Analysis of TW-OW Briquettes

Compressive strength analysis results, obtained through the test apparatus (as per ASTM standards) are presented in Table 3. The maximum load sustainable by the biomass briquettes was measured at 17.86 kN, corresponding to a pressure of 16.49 N/mm^2, elongation of 23 mm, and failure time of 15 s. The briquettes exhibited a range of elongation, from a minimum of 23 mm to a maximum of 27 mm.

Table 3. Compressive strength analysis of TW-OW briquettes

S. No.	Samples	Withstand Load, kN	Elongat-ion, mm	Breaking Time, s
1	C1	17.86	23	15
2	C2	12.34	26	17
3	C3	16.66	25	18
4	C4	15.22	27	19
5	C5	14.66	23	15

The failure process analysis revealed time intervals ranging from 15 to 19 s for samples C1 and C4, respectively. The findings suggest that as compressive load levels increase, the strength of the briquette samples also increases, while pressure levels decrease, as noted by. Higher compressive strength may indicate elastic properties, whereas lower compressive strength may imply improper particle alignment. Compressive strength stands out as a crucial characteristic determining the stability and durability of briquettes, emphasizing its significance in briquette analysis.

4. CONCLUSIONS

The combustion analysis of solid biomass derived from turmeric and onion, employing nanoclay as a binding material for the promotion of a sustainable environment, has yielded valuable insights. The research encompassed various aspects, including proximate analysis, elemental analysis, SEM analysis, TGA, and compressive strength analysis. The proximate analysis revealed important parameters such as fixed carbon, volatile matter, moisture content, and ash content, providing a comprehensive understanding of the briquettes' combustion characteristics. Elemental analysis offered insights into the elemental composition, contributing to the overall understanding of the biomass composition. SEM analysis provided a detailed examination of the surface morphology, revealing structural features and particle distribution. TGA analysis was instrumental in understanding the thermal behavior of the biomass briquettes, shedding light on their decomposition patterns and volatile content. From the DSC analysis, the highest peak recorded was at 354.6 °C, corresponding to an exothermic reaction with the energy release as 0.376 J/(g*k). Compressive strength analysis highlighted the structural integrity and durability of the briquettes under compressive loads. Overall, the utilization of nanoclay as a binding material has shown promise in enhancing the physical and combustion properties of biomass briquettes derived from turmeric and onion waste. The research findings contribute to the broader goal of promoting sustainable practices in biomass utilization. Further exploration and optimization of these techniques hold the potential for advancing eco-friendly solutions in the energy and environmental sectors.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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