advances in Technology

Adv. Technol. 2024, 4(2), 135-145

Full Paper

Production of High-Energy-Density Biomass Material Utilizing Bagasse and Waste Oil Derived from the Service Center Operations

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Received: 19 April 2024; Revised: 22 July 2024; Accepted: 27 July 2024; Published: 20 February 2025

Abstract

Bagasse is produced through the milling process of cane sugar manufacturing. These fibrous residue products are used for energy production. Waste crankcase oil (WCO) is a significant waste of a vehicle service center. This waste is generated through the motor engine oil changing procedure. Already, this waste product is polluting the environment. Densification is a promising technology for producing renewable fuels by compressing and reducing biomass volume, which is crucial for storing, handling, and transporting biomass. This study focuses on the production of high-energy-density briquettes utilizing sugarcane bagasse and WCO, with briquettes produced in various ratios ranging from 1:3 to 1:8 bagasse to WCO. The manual hydraulic press briquette machine is used for the production of briquettes. The physical properties of the briquettes are analyzed using calorific value (CV) and compressive strength. These physical properties are measured using an automatic calorimeter and a universal testing machine. FTIR was used to determine the chemical composition of the briquettes. The average CV of dry bagasse is approximately 21000 kJ/kg. The 1:8 briquettes observed the highest CV at 41141 kJ/kg, while the 1:3 ratio sample displayed the lowest at 26465 kJ/kg. The standard deviation of 7338 for the briquetted CV is significant. The findings show that an increased CV positively correlates with the amount of WCO. Compressive strength values are 6 MPa (1:3) and 6.1 MPa (1:8) ratio. The standard deviation of strength was 0.05. Based on the standard deviation, adding WCO did not significantly enhance the compressive strength of the briquettes. Chemical compositions are obtained by FTIR analysis, which shows that the 1:3 ratio has a phenolic, amide, and C-O component compared to the 1:8 sample. The 1:3 ratio is less harmful to the environment; however, the 1:8 ratio is useful to obtain a higher CV. Considering these findings, industries can develop high-energy-density briquettes to enhance energy efficiency and reduce environmental impact.

Keywords: bagasse, calorific-value, densification, FTIR, waste crankcase oil

Introduction

Future energy crises have been made more likely by the ongoing depletion of fossil fuel reserves and the fluctuating energy cost on the global market. Thereafter, alternative energy sources, particularly biomass wastes, are being sought to replace fossil fuels in various ways [1]. The study's significance lies in addressing the rising need for sustainable and alternative energy sources. The need to investigate renewable energy options is critical, as conventional fuel reserves are depleting and environmental concerns are growing. This research aims to address waste management and energy requirements by focusing on the production of briquettes from bagasse, a byproduct of sugarcane processing, and waste crankcase oil (WCO). The lack of research on using these particular materials together to produce briquettes is the source of the research gap. Although there may be some studies on individual WCO uses or bagasse-based briquettes, there may not be much on their combined use, particularly for high- energy-density briquettes. Bagasse, widely regarded as waste, is easily obtained from sugarcane mills and has a high cellulose content. WCO, on the other hand, is a plentiful but untapped resource. A viable path for generating sustainable energy is combining these elements to make high-energy-density briquettes.

Sugarcane (*Saccharum officinaram*) is a perennial grass categorized within the Poaceae family. Renowned as one of the foremost cash crops globally, sugarcane holds a prominent position, constituting approximately 21.1% of the overall global crop production volume as of 2016. Notably, countries such as Brazil, India, China, and Thailand emerge as the primary contributors to the cultivation of this prolific crop, accounting for an approximate average of 41%, 16%, 6%, and 6%, respectively, of the global production output. Moreover, approximately 31% of a substantial portion is cultivated across more than 100 nations worldwide, solidifying sugarcane's widespread cultivation and economic significance internationally [2]. Bagasse is the fibrous, pulpy substance that remains after crushing sugarcane to extract the juice. All of the fuel used in sugar plant production operations is sugarcane bagasse, which produces heat and power. As an important renewable energy source, bagasse has a minimal impact on the atmosphere [3]. Converting sugarcane bagasse into feedstock materials or extracting particular components, each with a defined use, are two ways to optimize its value. Owing to its nutritional qualities, sugarcane bagasse can be used to extract lignin, hemicellulose, and cellulose or as a source of dietary fiber [4]. However, despite its renewable energy value, not all bagasse produced finds efficient use due to inherent challenges in its management. Handling and transporting bagasse pose logistical complexities owing to its bulky and fibrous composition. These inherent characteristics make efficient handling and transportation a daunting task within factory premises. Furthermore, limited storage facilities exacerbate the issue, causing surplus bagasse to be discarded in the compound surrounding the factory. Bagasse is highly combustible, so its excess disposal has several environmental risks, chief among them being the possibility of fire. When bagasse is improperly stored in the compounds, it immediately risks the safety and ecological integrity of the factory environment. Bagasse disposal has become a significant issue, and vast amounts of bagasse are frequently deposited in open areas around sugar factories, affecting the delicate environment. The industry should use an environment management system to improve the environmental and economic performance of sugar processing units and lessen the pollution risk. The use of bagasse in the briquette-making process has emerged as a viable option in the search for new and sustainable energy sources [5]. Waste crankcase oil (WCO) refers to the used lubricating oil that has been drained or removed from the crankcase of internal combustion engines, having undergone thermal and chemical degradation during its potential use, thereby accumulating contaminants, impurities and degraded additives, rendering it unsuitable for further conventional use without undergoing specialized treatment or refining processes [6]. Waste crankcase oil(WCO) constitutes one of the transport industry's pollution causes. During the process of changing the engine's oil, the WCO is extracted from the engine's crankcase (engine sump). To lubricate engine components, motor oil is utilized in automobile engines. The globe uses a lot of motor oils, and a sizable portion of them leak onto roads or are disposed of incorrectly. Because of the growing amount of lubricating oils produced and improper handling and disposal, WCO constitutes a severe environmental risk [6].

The rise in the number of vehicles on the road has indeed made the recycling of waste engine oil crucial for extracting energy because of the valuable chemicals it contains. WCO is concerned that a significant portion of automotive lubrication oil, around 40%, is disposed of without proper treatment. Recycling this oil not only helps in energy extraction but also prevents environmental pollution and conserves resources. The energy potential and chemical components present in waste engine oil make it a valuable resource that should not be wasted. Implement proper recycling methods can significantly reduce this wastage and benefit both the environment and energy conservation initiatives [7].

Biomass densification is a promising technology for the production of renewable fuels. By lowering its volume and agglomerating it into a compressed state, biomass is converted into fuel through a variety of methods known as biomass densification. The densification is achieved by applying pressure to raw biomass material. When producing homogeneous feedstock resources for bioenergy consumption, pelletizing and briquetting are the two most common approaches to achieve densification. As agglomeration, briquetting helps improve solid biomass's structural integrity while producing finished goods with consistent characteristics [8]. Solid biofuel is produced when the bulk feedstock, or briquette, is densified into bio-briquette form. This process improves the fuel characteristics and efficiency, producing less smoke and more heat during combustion, making furnace feeding more feasible [4]. Benefits of densification include enhanced handling and conveyance efficiencies in the supply system and biorefinery infeed; regulated particle size distribution for improved density and uniformity of feedstock; fractionated structural components for improved compositional quality; and adherence to supply system specifications and predetermined conversion technology [8].

Materials and Methods

This research study’s experimental research method for incorporates both qualitative and quantitative analysis to investigate the development of high-energy density briquettes using various ratios in sugarcane bagasse and WCO. The bagasse was collected from Lanka Sugar's Sevanagala unit in the Monaragala district, Sri Lanka, while the WCO samples were obtained from a vehicle service center. Drying the bagasse material to lower its moisture content is necessary, but it should not be dried excessively. A trace amount of moisture is helpful to bind the biomass particle. Natural exposure to sunshine is used to complete the drying process. Size reduction is crucial for the production of densified biomass material. Breaking up large particles into smaller ones enhances the total surface area, improving the bonding qualities between the particles and increasing biomass bulk density. The bagasse was crushed using a grinder to make it smaller for briquette production. The blended biomass mixture was produced by mixing WCO and sugarcane bagasse in weight ratios of 1:3, 1:4, 1:5, 1:6, 1:7, and 1:8 (w/w%). The briquettes were made based on considering the optimum stable condition by visual inspection and to utilize the maximum amount of waste oil. The rations higher than 1:8 do not provide stable briquette. Moreover, the different rations were used to identify the CV variation with WCO insertion to the briquettes. The briquettes were prepared by uniformly mixing the sugarcane bagasse and WCO.

The process begins by feeding the weighted mixture into the laboratory briquetting machine. Next, the energy densification process was carried out with the help of a manual uniaxial hydraulic press and a cylindrical mold. The mixture is then manually placed into the die of the hydraulic press machine, which is compressed into the desired shape by applying pressure manually. A hydraulic piston machine, which presses the material with 500 N of force, is used to create densified biomass. Finally, after the densification process, the densified products are stored at room temperature. The CV and FTIR analysis were performed to describe the data collection section.

The most important combustion characteristic for determining whether a briquette is suitable as fuel is its calorific value (CV). The CV quantifies the total amount of heat energy produced during the complete combustion of a specific amount of material. CV measures the energy content contained within a substance, typically expressed in terms of energy per unit mass or volume [5]. There generally are two calorific values a gross calorific value (GCV) and a net calorific value (NCV). A bomb calorimeter can measure the GCV, which is the total energy released during burning. The NCV is the GCV without the latent heat of the water produced during combustion [9]. The strength of the densified product is measured in two ways: compressive strength and tensile strength. Crushing is a standard method for evaluating the quality of a densified cylindrical product. The crushing might be used parallel or perpendicular to the cylindrical axis. The sample's compressive strength is typically stronger in the direction of the cylindrical axis. A sample's tensile strength is perpendicular to its cylindrical axis [10]. The greatest compressive force a briquette can sustain while being handled, stored, and transported is simulated by its compressive strength. The greatest axial force a densified biomaterial might sustain before breaking or rupturing, or a gauge of its internal bonding strength is known as its compressive strength [11].

The Fourier Transform Infrared (FTIR) technique is advocated as the preferred method for the implementation of infrared (IR) spectroscopy. Within the context of IR, a sample is subjected to the transmission of infrared radiation. During this process, the sample selectively absorbs a fraction of the incident infrared light, allowing the remaining portion to pass through (transmit). The resultant spectrum yields a molecular fingerprint of the material, providing a graphical representation of the molecular absorption and transmission characteristics [12]. The FTIR was used to determine the primary constituents present in raw bagasse, WCO, rations of 1:3, 1:8, and bagasse mixed with WCO.

Data Collection

The compressive strength, calorific value, and FTIR analysis of briquette samples were measured.

CV Measurement

An automatic calorimeter model 5E-C5508 was used to determine the CV of the densified biomass sample and raw bagasse, following the ASTM standard D5865. 0.5 g of raw bagasse and 1 g of bagasse to WCO ratios (1:3,1:7, and 1:8) were used to measure CV value. The densified sample was placed in the bomb, and an ignition source ignited it. The sample was allowed to continue burning until total combustion was reached. The calorimeter chamber absorbed the heat energy released as the sample burned, and the resulting temperature change was measured precisely. The energy content of the briquettes was expressed in kilojoules per kilogram (kJ/kg) by the results of the calorific value measurement.

Compressive Strength Measurement

Compressive strength of two briquette ratios, namely 1:3 and 1:8 (bagasse to WCO), were measured. The compressive strength of the briquette sample was measured using a universal testing machine. The briquettes were positioned horizontally between two jaws and subjected to a forceful load at a specified loading rate until they broke. Then, load, stress, and displacement were measured. A universal testing machine was used to apply vertical directions load to the briquettes, and the resultant load was measured in kilonewtons (kN). Megapascals (MPa) are the unit of measurement for stress, which is the internal resistance to the imposed load. Furthermore, the displacement was expressed in millimeters (mm), representing the distance the briquette deformed due to the applied stress. These measurements were graphically represented in this study to examine the compressive strength of the briquette samples.

FTIR Spectroscopy Analysis

FTIR spectroscopy was used to characterize the biomass samples, WCO, and briquette samples with respect to their absorption spectrum. The experiments were conducted using FTIR in the infrared range of 600-4000cm$^{-1,}$ and 32 scans were performed. The attenuated total reflectance (ATR) method was used for the test, and the instrument's resolution was 2 cm^{-1}. Opus software was used to collect and analyze the spectral data from the setup.

Results and Discussion

The research findings were obtained across various parameters from the study on producing high-energy-density biomass material from bagasse and WCO from the sugar industry and service center operations.

CV Results

Figure 1 illustrates the CV of raw bagasse and bagasse mixed with WCO briquette in different ratios (1:3, 1:7, and 1:8). The study analyzed the CV of pure bagasse used for the production of briquettes. The CV defines the total heat energy that occurs in a biomass sample. The CV of the raw bagasse sample was 21035 kJ/kg. In literature, the WCO calorific value is 41,000-42,600 kJ/kg. In this study, the lowest value of the bagasse and WCO ratio combination was 1:3, whose CV was 26465 kJ/kg. The CV of the briquette produced in the ratio of 1:7 is 38501 kJ/kg. The maximum CV was recorded in the ratio of 1:8 briquette sample. This value was 41141kJ/kg. The 1:3 bagasse to WCO briquettes sample includes the WCO percentage of 75%, the 1:8 briquettes sample WCO percentage has 89%, including the WCO percentage is 75%, and the 1:8 briquettes sample WCO percentage has 89% when the amount of WCO increases from 25.81% to 95.58% the calorific value. The result shows that when the amount of WCO increases, the CV of the briquette increases significantly.

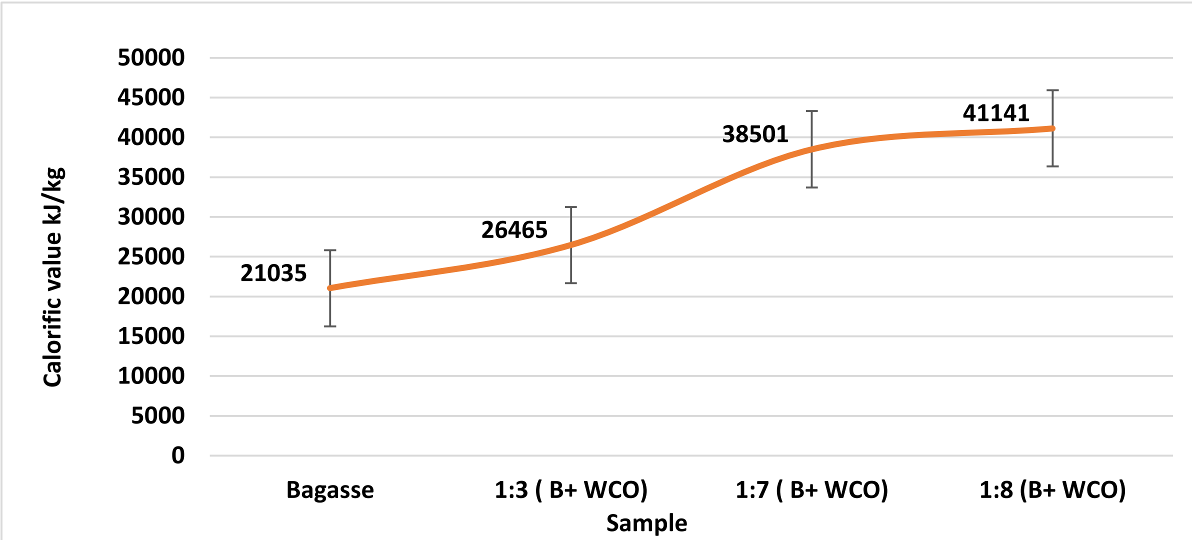

Figure 1. CV measurement

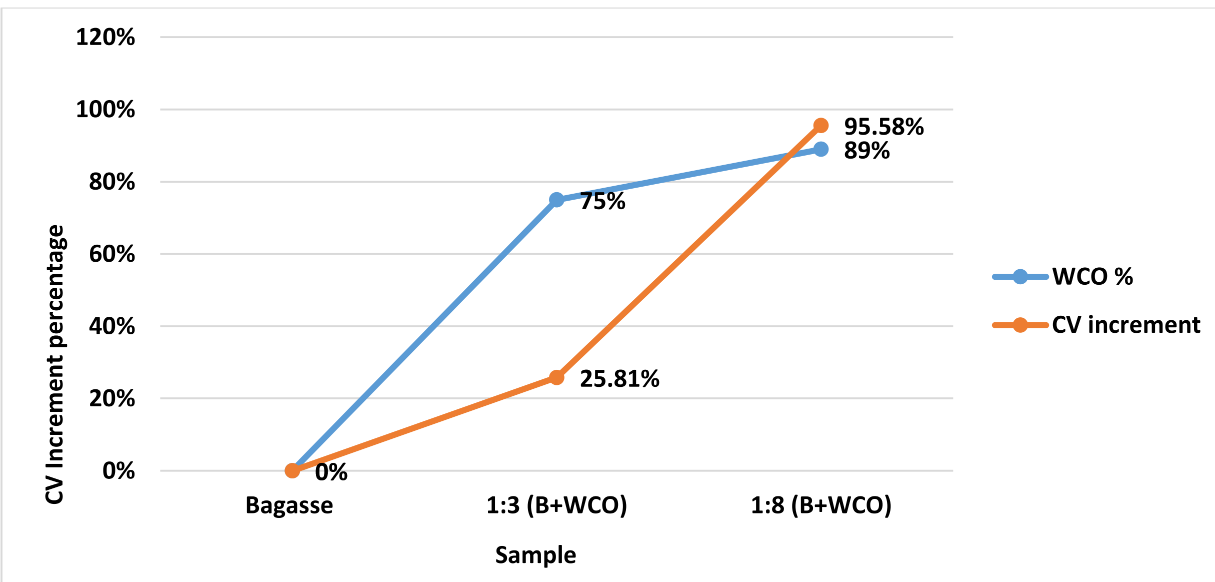

Figure 2. CV value increment with WCO change

Compressive Strength of the Briquette Increment

Determination of compressive strength is important within. In contrast, bio-briquette fuel handling, storage, and transportation, and a high level of compressive strength is required. These ratios, one of which represents a comparatively lower percentage of WCO (1:3) and the other higher quantities (1:8), were chosen to methodically examine the impact of varying composition on the strength characteristics of briquettes produced from WCO and sugarcane bagasse. The compressive strength of bagasse mixed with waste oil 1:3 and 1:8 ratios were measured to compare the compressive strength variation with higher and lower WCO content and the strength value with commercially available briquettes. Table 1 shows compressive strength measurement for two ratios of briquette sample with bagasse mix with WCO.

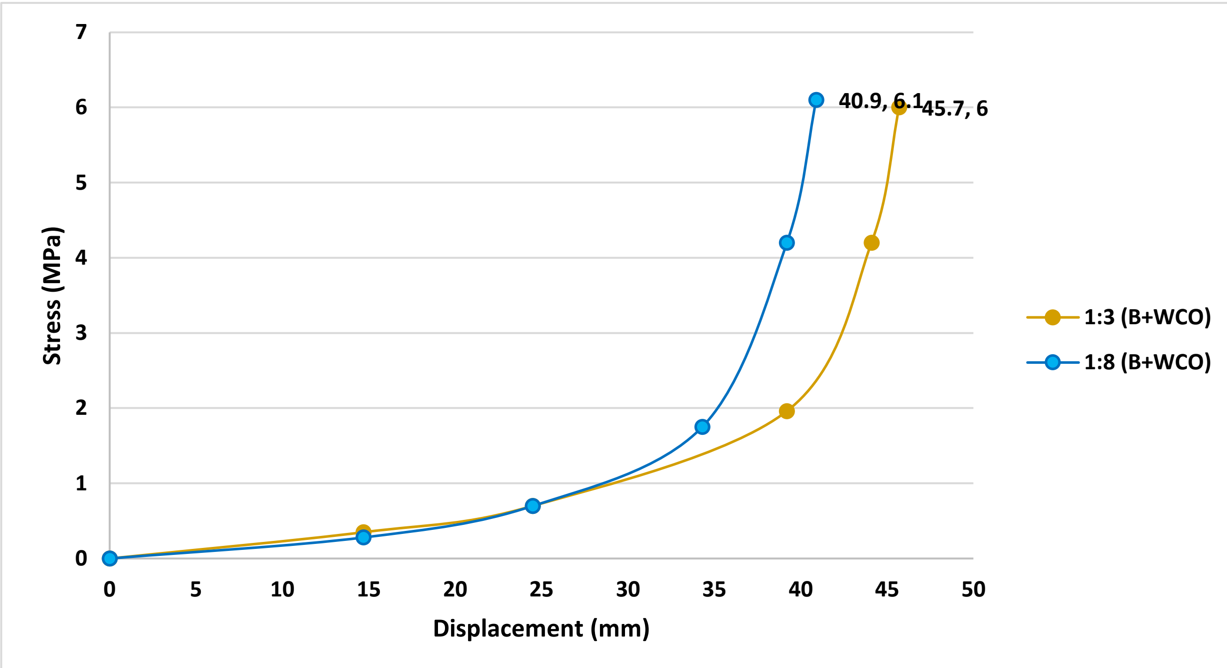

Figure 3. Stress (MPa) vs 1:3 and 1:8 (Bagasse +WCO) samples

Table 1. Compressive strength measurements of briquette samples

Sample	Strength (MPa)	Load (kN)	Displacement(mm)
1:3 (Bagasse+ WCO)	6.0	20.1	45.7
1:8 (Bagasse+ WCO)	6.1	20.7	40.9

Figure 3 shows the stress vs displacement of 1:3 and 1:8 (Bagasse +WCO) samples. The stress of the 1:3 briquette was 6.0 MPa and 1:8 bagasse to WCO sample was 6.1 MPa. Figure 4 shows load (kN) vs displacement of 1:3 and 1:8 (Bagasse +WCO) samples. The load and displacement of the 1:3 bagasse to the WCO briquette sample were 20.1kN and 45.7 mm. The load and displacement of the briquette were 20.7kN and 40.9 mm, respectively, in the 1:8 bagasse to the WCO briquette sample. Based on the literature briquettes produced of shell and fiber were shown to have improved combustion characteristics when starch was added to the binder along with water, resulting in a compressive strength of 2.56 MPa [13]. Sawdust briquettes had compressive strengths ranging from 2.06 to 5.15 MPa [14].

FTIR Analysis

FTIR spectroscopy is used to examine the chemical composition of the production briquette. An FTIR spectroscopy graph's axes show how much-infrared light a sample absorbs at various wavelengths. The wavenumber, the reciprocal of the infrared radiation's wavelength, is commonly shown on the x-axis. Transmittance (%T), or the infrared radiation intensity, is represented on the y-axis. Figure 5 shows the FTIR analysis of raw bagasse, waste oil, and a 1:3, 1:8 bagasse to waste oil mixed briquette sample to compare the structural variation with higher and lower WCO content with bagasse mix. FTIR determined the composition changes of the sugarcane and WCO mixed briquettes.

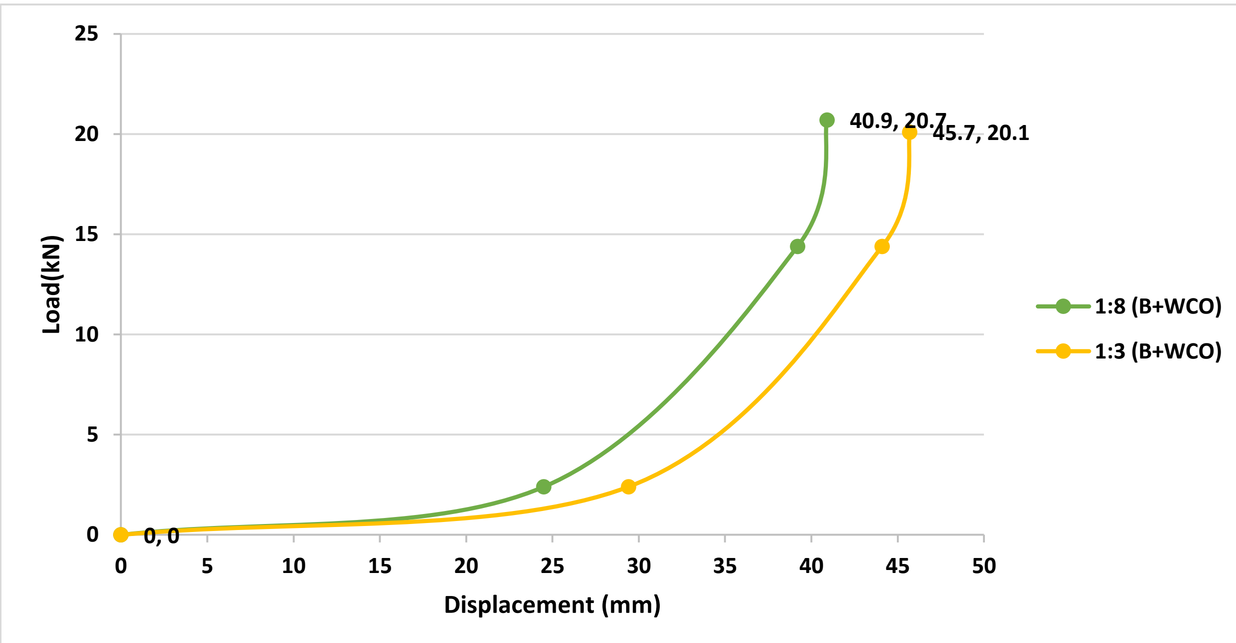

Figure 4. Load (kN) vs 1:3 and 1:8 (Bagasse +WCO) samples

The peak observed around 3200-3400 cm^{-1} indicates the presence of phenolic compound (O-H stretching bonds) of hemicellulose and cellulose [15]. While the broad peak observed around the range of 900-1200 $cm^{-1,}$ the spectrum indicates the C=C bending of sugarcane bagasse and WCO mixed briquettes. The peak at 1035 cm^{-1} indicates the C-O, C=C, and C-O-C stretching vibrations in carbohydrates [16]. This region indicating indicates the presence of glycosidic linkages. The peak observed between 1600-1700 cm^{-1} indicates the aromatic ring found in the bagasse [17]. These bands disappear in the WCO spectrum. These bands appear in 1:3 and 1:8 (Bagasse: WCO) briquette samples. The peak around 1244 cm^{-1} indicates the C-O starching vibrations in bagasse [17]. This peak appears in 1:3, 1:8 (Bagasse: WCO) briquette samples. The wavenumber of 1244 cm^{-1} is absent in the WCO spectrum. The peak between 1680 and 1630 cm^{-1} indicates the presence of an amide compound [18]. The peak observed around 2800-3000 cm^{-1} indicates the C-H stretching region in the sample. This region's presence of the aliphatic hydrocarbon functional group is included in the WCO. The peak observed between 2850 and 2950 cm^{-1} specifically indicates the presence of alkane compounds [15]. The peak observed at 1465 cm^{-1} indicates the presence of alkanes. The peak observed at 725 cm^{-1} corresponds to the C-H bond of alkanes. These bands are absent in the raw bagasse spectrum; however, this band is present in the 1:3, 1:8 (Bagasse: WCO) briquette samples spectrum. Moreover, the peak observed at 1374 cm^{-1} indicates the C-H bond, CH_3 compound of WCO [17].

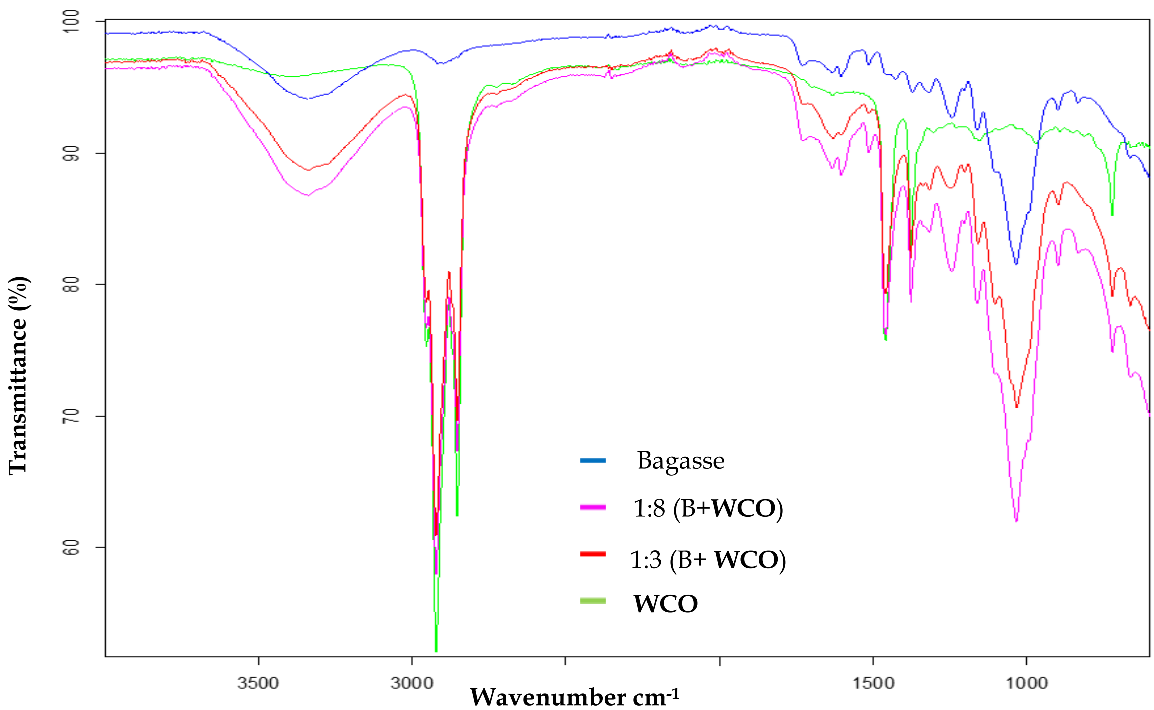

Figure 5. FTIR analysis of raw bagasse, waste crankcase oil 1:3 and 1:8 (Bagasse: waste oil) briquettes sample

Conclusion

High-energy-density briquettes were produced using a combination of bagasse and WCO in various ratios ranging from 1:3 to 1:8. The 1:8 bagasse to WCO sample observed a maximum CV of 41141 kJ/kg. In contrast, the minimum CV of 26465 kJ/kg was observed in the 1:3 bagasse to WCO sample. The significant contribution of WCO to raising the energy content of the briquettes is demonstrated by the apparent correlation between the higher energy content of this oil and an increase in CV. The 1:3 and 1:8 briquette samples have compressive strengths of 6 MPa and 6.1 MPa, respectively. In contrast to the 1:8 briquette sample, the 1:3 briquette sample showed less displacement. The 1:8 bagasse to WCO briquette sample has a slightly better compressive strength value. The FTIR analysis reveals the unique chemical composition of raw bagasse, waste oil, and co-briquette samples in various ratios. Identifying specific compounds in the briquette samples, particularly in the 1:3 and 1:8 ratios, 1:3 bagasse to WCO ratio indicates the phenolic, C-O, C=O, C-O-C and amide component. WCO spectrum indicates the aliphatic hydrocarbons, CH_3 and alkane compounds. According to the results, when considering CV, strength and displacement, the 1:8 briquette ratio provides a high energy content and best quality for the briquette production. However, regarding environmental impact, the 1:3 ratio proves to be more favorable compared to the 1:8 bagasse to WCO briquettes sample.

A promising approach to energy generation and efficient waste management is the use of bagasse-to-WCO briquettes. This innovative briquette generates energy and provides a sustainable way to dispose of WCO. Due to its substantially higher CV and strength, the briquette is a valuable and effective resource for energy generation.

Acknowledgment

The authors would like to express deepest gratitude to the following individuals and organizations who have played a crucial role in the completion of this thesis: I am indebted to my supervisor, Mr. E.R.J.M.D.D.P. Wijesekara, for their unwavering guidance, support, and expertise. Their insightful feedback and constructive criticism have significantly shaped the direction of this research. I am grateful for the mentorship that went beyond academic boundaries. My heartfelt thanks go to my family for their constant encouragement and understanding. Their love and support provided the emotional foundation that sustained me through the challenges of this academic endeavor—Industrial Training Institution for facilitating the FTIR experiment in my research projects. I would especially like to express my sincere gratitude to lecturer Mr. Amalka Indupama from the Faculty of Technology for providing access to the hydraulic briquette machine. I extend my sincere appreciation to the academic and non-academic staff of the Faculty of Technology during the course of this research. Their contribution and support significantly enhanced the quality of this work. This research was made possible through the financial support of a research grant. Their commitment to advancing research in the bioenergy field is commendable, and I am grateful for the resources provided.

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