Energy Densification of Bagasse as Briquettes for Bioenergy Production through Integrated Utilization of Spent Wash

HMIS Muhandiram, ERJMDDP Wijesekara#, AMPC Amarasinghe.

Department of Biosystems Technology, Faculty of Technology, Sabaragamuwa University Sri Lanka
#Corresponding Author: dasith@tech.sab.ac.lk

1 Introduction

Sugarcane *(Saccharum officinarum)* is most cultivated in considerable quantities in tropical countries. In 2022, about 1.92 billion tons of sugarcane were produced worldwide. Brazil is a major global sugarcane producer (*Statista.Com*, n.d.). There are five crucial species of sugarcane, *Saccharum officinarum, Saccharum sinense, Saccharum barberi, Saccharum robustum* and *Saccharum spontanuem.* The first three varieties are commonly cultivated (INDIA et al., 2013). Sri Lankan per capita consumption of sugar is 40kg. Lanka's sugar sector fulfills only 10% of the local requirement, and the rest is imported. Tropical climatic temperature is more suitable for cane cultivation, and good drainage conditions are needed for optimum growth and development (Samaraweera, 2012). In the sugar manufacturing process, sugarcane milling step is used to extract the juice. After the sugar milling, 30% of the pulpy fibrous residue is produced. This residue is known as bagasse (Mahmud & Rahman, 2021). Bagasse is commonly used as fuel in factory boilers to generate steam and electricity. Large quantities of bagasse are generated from the milling processes and stored in open spaces around the sugar factory. Bagasse is challenging to handle and transport, and where storage facilities are lacking. Bagasse storage faces many difficulties, including fire hazards, creating human health and environmental problems. To reduce that problem, a company should implement an environment management system (Myers & Mitchell, n.d.). The moisture content of bagasse is around 50%. To more effectively utilize bagasse as fuel, the moisture of bagasse has to be minimized. Several methods can be applied to reduce the moisture content of bagasse. Direct or indirect dryers, open-air drying methods, and solar drying methods can be used for bagasse drying. The dried bagasse helps to improve combustion (Joel, 2016).

Molasses is one of the by-products generated by the sugar manufacturing industry. Commonly, this molasses is used in ethanol manufacturing. Ethanol has several uses in the pharmaceutical, food, beverage, and biofuel manufacturing industries (Repository, 2012). Distillery industries are the key contributor to the world's economy. However, it is one of the significant sources of environmental pollution. About 40 billion liters of spent wash annually are produced. Raw spent wash is usually discharged into the open land or water bodies (Molasses & Rsw, 2008). Distillery spent wash is a dark-colored wastewater with high biological and chemical oxygen demands, that contains total solids, sulfate, phosphate, and various toxic metals. Distillery waste creates many problems in agricultural activities, including inhibition of seed germination and depletion of vegetation by reducing soil alkalinity and manganese availability (Chowdhary et al., 2018). To manage the environmental problems created by the use of a distillery spent wash, it can be used as a binding agent in bagasse briquette manufacturing. Distillery waste is also a massive problem in the ethanol industry. This research helps to minimize the high volume of spent wash generation. Evaporation of raw distillery spent wash helps to reduce the volume. However, this evaporated vapor should be purified after being discharged into the environment.

This research provides a sustainable solution for waste generation. In addition, using spent wash for briquette manufacturing is a valuable solution for overcoming the environmental and health problems of spent wash. Furthermore, the adverse effect of the use of fossil fuels on the environment and public health causes an increase in the demand for renewable energy. This research for new alternative sources of environmentally friendly energy, such as bagasse and spent wash to produce briquettes, has become a good alternative. The briquette is a type of densification method. Briquetting plays a considerable role in bioenergy in developing and developed countries to achieve sustainable applications in industries, and it reduces fossil fuel dependency. In the densification process, the compaction of biomass with or without a binding agent is performed under relatively high temperatures and pressures to achieve higher energy per volume of the material. It generally increases the bulk density and improves the handling and logistics. It also reduces the labor cost of handling and storing, improves biomass's thermal properties, and is vital for effective direct or co-combustion. To create the briquettes, hydraulic piston presses, mechanical piston and ram presses, roller presses, manual presses, and extruders are commonly used. Compressive resistance is also known as crushing resistance or hardness. Compressive resistance is the maximum crushing load a pellet or briquette can withstand before cracking or braking (Kaliyan & Morey, 2009). These parameters help to identify the best ratios for briquette manufacturing. Briquettes were produced by mixing bagasse with spent wash, which can be used as an energy fuel for the boilers. However, in the combustion process, some hazardous chemical compounds can be emitted with the exhaust gas. This is because with the insertion of spent wash into bagasse, the components in spent wash such as C-H stretch Alkyne groups and C=C Alkene groups can be emitted with exhaust in burning the densified briquette (Wagh & Nemade, 2017). The FTIR Analysis (Fourier Transform Infrared Spectroscopy) is critical to identify the chemical compounds of produced briquettes. Analysis can give an idea about the exhaust gas purification methods, changes, and further developments in the manufacturing process of bagasse with spent wash briquettes (Mohamed et al., 2017).

2 Methodology

2.1 Materials

Sugar factory bagasse and distillery spent wash were collected from a sugar and ethanol manufacturing company. The briquettes were manufactured by briquette molding machine. Automatic Calorimeter (5E-C5508) was used to find Calorific Value. Compressive strength was measured by using Universal Testing Machine 100KN and FTIR analysis was done by using Fourier Transform Infrared Spectroscopy.

2.2 Method

Raw Material Preparation
The moisture content of bagasse was reduced by sun drying. Dried bagasse was mixed with non-evaporated spent wash in 1:1, 1:2, 1:3, 1:4, 1:6, and 1:8 ratios. Then the raw spent wash was taken and evaporated at 370°C for 2 hours using a hotplate. After that, sun-dried bagasse was taken and mixed with evaporated spent wash with 1:1, 1:2, 1:3, and 1:4 ratios. Since one of the purposes of this study is to provide a waste management solution to the large volume spent wash, higher spent wash ratios compared to bagasse were used for the experiment starting from 1:1.

Densification Process
A laboratory scale briquette molding machine was used to prepare the briquettes. Prepared samples with different weight ratios were filled to the briquette mold and the pressure was applied. The resulting briquettes products were placed on a flat surface and kept for 14 days to dry in a closed room.

Calorific Value Test
The Automatic bomb calorimeter was used to measure the calorific value. 1g of bagasse briquette sample was placed in the Automatic Calorimeter (5E-C5508). The machine was run and the results were given within 20 minutes.

Compressive Strength Test
Briquette was placed in the Universal Testing Machine 100KN and the compressive force was applied until failure or rupture. Then compressive strength values were recorded.

FTIR Analysis
FTIR spectroscopy was used to determine the chemical compounds of briquette samples. FTIR was used in carrying out the experiments at the infrared range of 400 – 4000cm^{-1}. The attenuated total reflectance (ATR) method was used for the test, and the resolution of the instrument was 2cm^{-1}. Opus software was used to collect and analyze the spectral data from the setup.

3 Results and Discussion

3.1 Calorific Value

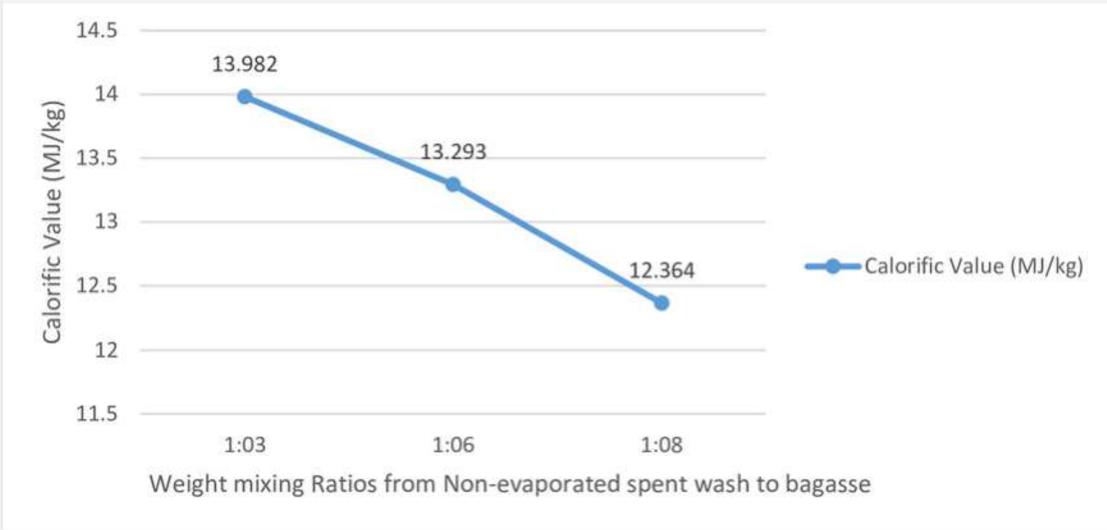

Fig. 1: CV of all ratios non-evaporated spent wash with bagasse from Automatic Calorimeter

According to this research study (Fig. 1), the calorific value (CV) of bagasse mixed with distillery spent wash in different ratios was decreased than the CV value of pure bagasse. CV of pure bagasse was 21.035 MJ/kg. The CV value of the 1:3 ratio of non-evaporated spent wash with bagasse was 13.982MJ/kg. A 1:3 ratio of non-evaporated spent wash with bagasse has a higher CV value than the 1:6 and 1:8 ratios.

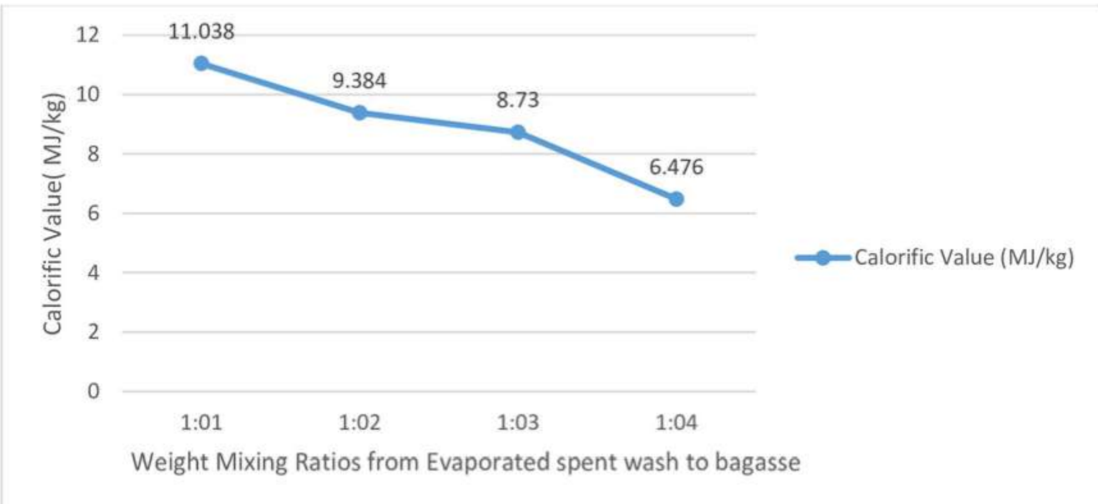

Fig. 2: CV of all ratios evaporated spent wash with bagasse from Automatic Calorimeter

Fig. 2 shows the CV values of evaporated spent wash with bagasse in all ratios of briquette samples. According to the results, a 1:1 ratio of evaporated spent wash with bagasse briquette sample has a higher CV value than the other ratios of evaporated spent wash with bagasse briquette samples. However, pure bagasse has a high CV value (21.035MJ/kg) and also CV value of non-evaporated spent wash with bagasse briquette samples; CV value of 1:3 ratio was 13.982MJ/kg, CV value of 1:6 ratio was 13.293MJ/kg, CV value of 1:8 ratio was 12.364MJ/kg were varied by minimal amount [].

3.2 Compression Strength Measurements

Fig. 3 shows the strength (MPa) of non-evaporated spent wash with bagasse in all ratios of briquette samples. According to this research, 1:1, 1:2, 1:4 ratios of briquettes were in the 5.6MPa- 5.5MPa strength range. The 1:3 ratio of briquette was the highest strength. It was 10.72MPa. The compressive strength of commercially available biomasses can vary from 10 to 20 MPa range, and this 10.72 MPa value is within the commercially acceptable range (U.S.P.R.Arachchige, 2021). When the briquettes are produced from a 1:3 ratio, they can effectively handle storage and transport without breaking. This graph also shows the displacement of non-evaporated spent wash with bagasse in all ratios of briquette samples. According to this research, a 1:3 ratio has a lower displacement of 32.7mm against external force. That shows that the 1:3 ratio has better results with effectively storing, handling and transporting the briquettes. The Displacement of 1:1, 1:2 and 1:4 ratios show a displacement value between 65mm and 75mm, which are higher than the value for 1:3 ratio..

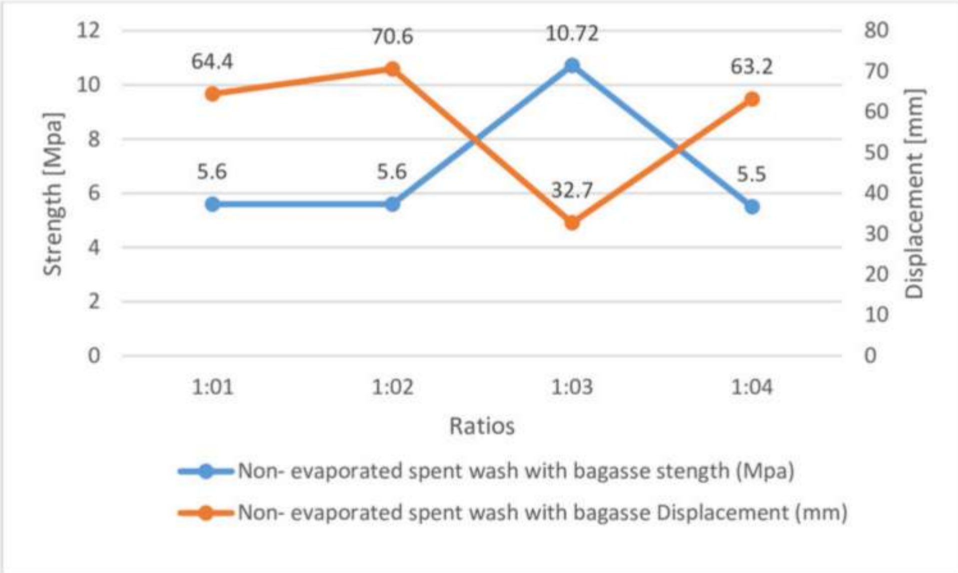

Fig. 3: Strengths and displacement of all ratios of non-evaporated spent wash with bagasse from Universal Testing Machine

Fig. 4 shows the strength (MPa) of evaporated spent wash with bagasse in all ratios of briquette samples. According to this research, 1:1, 1:2, and 1:4 ratios of briquettes were in the strength range of 5.5MPa to 5.6MPa. The 1:3 ratio of briquette was the highest strength. It was 5.9MPa. When the briquettes are produced from a 1:3 ratio, they can effectively handle storage and transport without breaking. This graph also shows the displacement of evaporated spent wash with bagasse in all ratios of briquette samples. According to this research, a 1:3 ratio has a lower displacement. It was 36.7mm. That helps to store, handle and transport the briquettes effectively. Also, the displacement of 1:1, 1:2 and 1:4 ratios showed a displacement value between 60mm and 75mm.

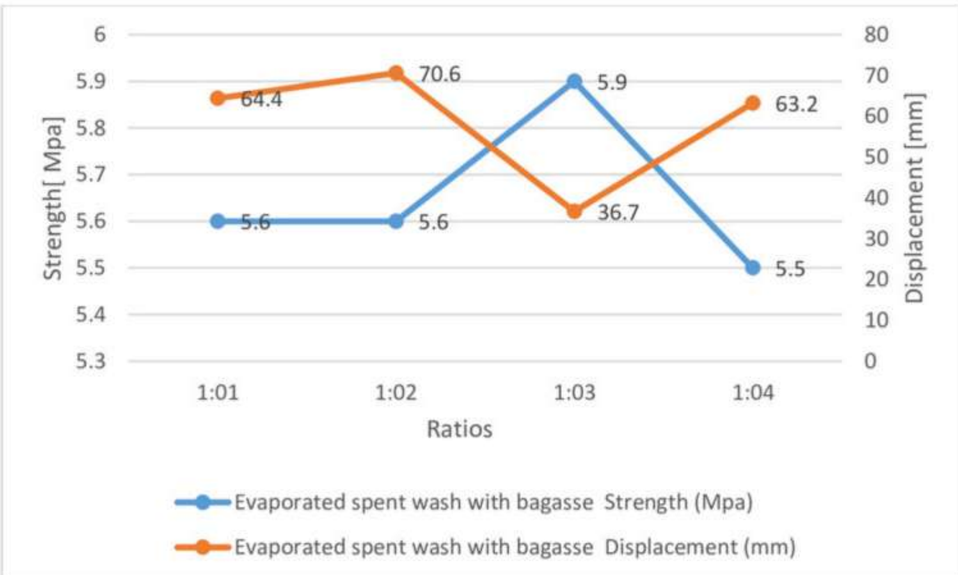

Fig. 4: Strengths and displacement of all ratios of evaporated spent wash with bagasse from Universal Testing Machine

According to the results of non-evaporated and evaporated spent wash with bagasse briquettes, the 1:3 ratio provided the optimum results. The CV was 13.982MJ/kg, strength was 10.72MPa, and displacement was 32.7mm. Higher strength and lower displacement of briquettes improved effective transport, handling and storage. Also, it was a sustainable waste management solution for large amounts of spent wash generation. The ratios below 1:1 was not used in this study since the major purpose of this study is to utilize higher amounts of spent wash to reduce the content while producing an energy dense product. Also, the ratios over 1:8 with higher spent wash volume doesn't provide a stable briquette. Ultimately the 1:3 ratio of bagasse with non-evaporated spent wash briquet provides the best results among the experiment samples with a reasonable calorific value and strength, together with lower displacement. The best CV achieved 1:3 ratio briquet results were compared with commercially available biomass briquet products, and the results were shown in Fig. 5.

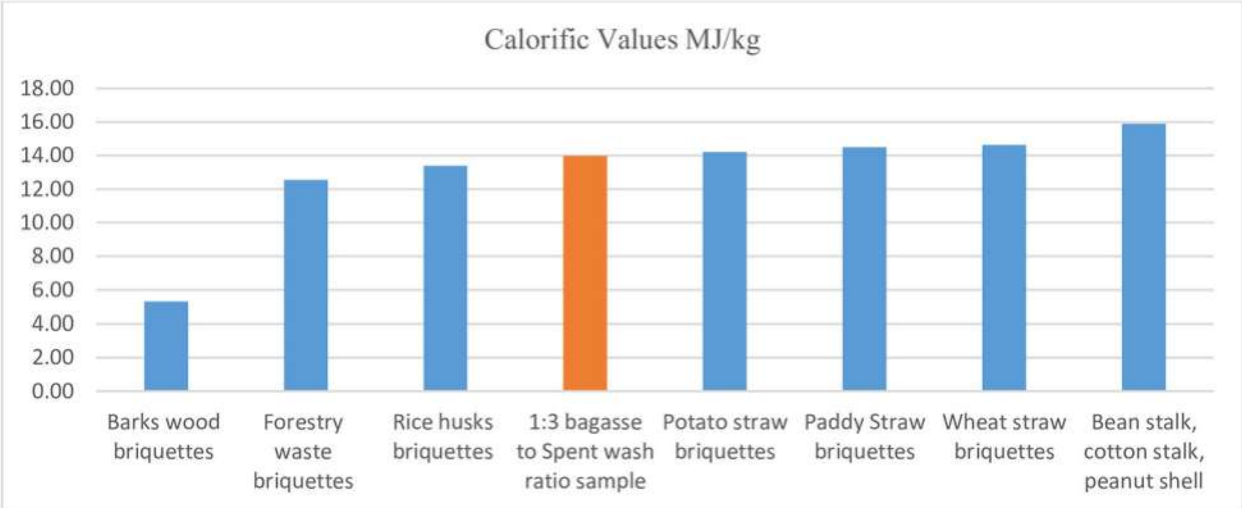

Fig. 5: Strength and displacement of all ratios of evaporated spent wash with bagasse from Universal testing machine {Pellet-making.com, n.d.)

Based on the CV values of commercially available biomass briquet, the 1:3 bagasse to spent wash ratio sample has an acceptable energy level for consumption as a densified biomass material. The rice husk, forestry waste, and bark wood biomass showed lower CV values than the experimented results. The available biomass briquet CV value can be varied between 11 to 16 MJ/Kg range (U.S.P.R.Arachchige, 2021).

3.3 FTIR Analysis

Fig. 6 shows the FTIR analysis of pure bagasse, 1:1 ratio of non-evaporated spent wash with bagasse, and 1:3 ratio of non-evaporated spent wash with bagasse.

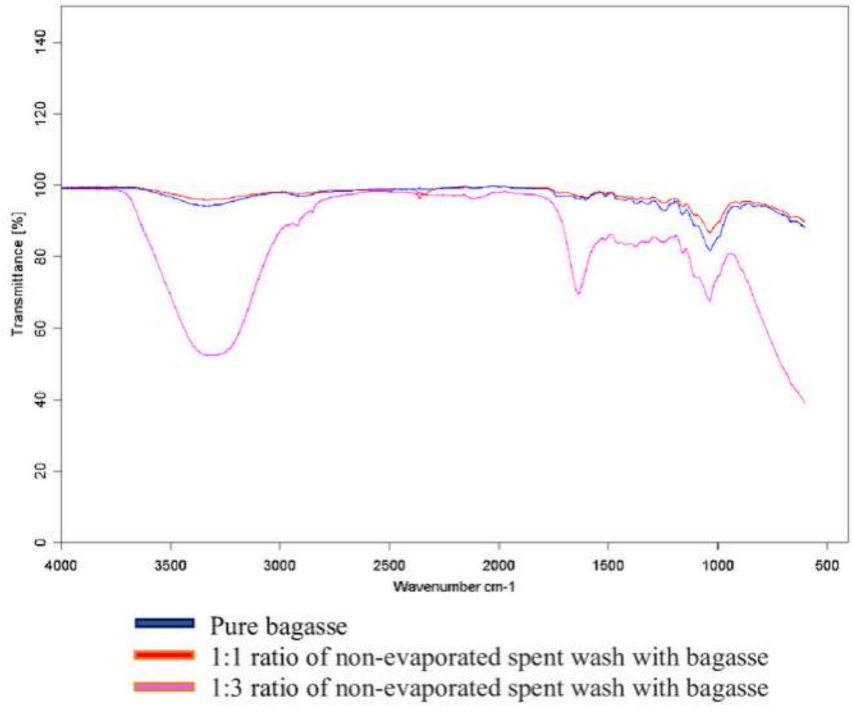

Fig. 6: FTIR analysis of bagasse, 1:1 and 1:3 ratios of non-evaporated spent wash with bagasse by FTIR spectroscopy

Based on the Fig. 6 FTIR comparison analysis of pure bagasse with produced briquets of 1:1 and 1:3 non-evaporated spent wash and bagasse mixed samples, the highest peaks were observed in the 1:3 non-evaporated spent wash mixed with bagasse sample at around 3313 cm^{-1}, 1635 cm^{-1}, and 1043 cm^{-1} FTIR spectrums. The 3313 cm^{-1} FTIR spectrum represents the C-H stretch Alkyne groups present in the spent wash, and 1635 cm^{-1} spectrum signifies the C=C Alkene groups present in the spent wash (Ishwar Chandra, 2019; Naik et al., 2010). Furthermore, the FTIR spectrum peak symbolized at 1043 cm^{-1} denotes the carboxylic (–COOH) bonds that exist in the spent wash. Henceforth, these components can be emitted to the environment more during combustion of 1:3 non-evaporated spent wash and bagasse mixed samples compared to pure bagasse and lower ratios samples (Wagh & Nemade, 2017).

Conclusion

The CV value of non-evaporated spent wash with bagasse in a 1:3 ratio was 13.982MJ/kg. It was higher than the other ratios of non-evaporated spent wash with bagasse briquettes and evaporated spent wash with bagasse briquettes. The strength of the 1:3 ratio of non-evaporated spent wash with bagasse briquette was 10.72MPa. The 1:3 ratio had the lower displacement value. It was 32.7 mm. The highest strength and lower displacement are important to storing, handling, and transporting of bagasse briquettes without breaking or damaging them. During the combustion of a 1:3 ratio of non-evaporated spent wash with bagasse briquette, C-H stretch Alkyne groups, C=C Alkene groups, and carboxylic (–COOH) bonds were emitted. To minimize the volume of spent wash generation, briquettes can be manufactured from the evaporated spent wash with bagasse. According to these results, the ideal ratio is a 1:3 ratio of non-evaporated spent wash with bagasse for briquette manufacturing in which the CV and strength are higher than other ratios, along with lower displacement with external force. This study provides a valuable indication for large scale bagasse briquettes manufacturing. The produced briquet has the possibility of being utilized as a densified energy fuel for combustion application compared to the current available briquet products, and more environmental impact assessment needs to be executed in future considering the FTIR analysis to maintain a smooth combustion process with acceptable air emission limitations.

Keywords: Bagasse, Spent wash, Energy densification, Briquettes, Bio energy production

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