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Development of briquettes from cotton stalks with the high-pressure briquetting machine

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Abstract
Agricultural residues are principal energy sources for domestic and industrial activities. This study aims at converting cotton stalks which is a commercial crop of the farmers in Andhra Pradesh, into briquettes so that energy crisis faced in rural area can be addressed. In this research, cotton stalks were produced from high pressure briquetting machine (118 MPa). The different physical, strength and thermal characteristics namely moisture content, compressed density, relaxed density, relaxation ratio, water absorption, shatter resistance, ash content and calorific value was evaluated by standard ASTM procedures. The obtained value of bulk density of milled cotton stalks before briquetting was 187.66 kg m^{-3}. The results showed that the moisture content and ash content of briquette was 4.44% and 3.89% respectively. The compressed density and relaxed density of cotton stalk briquettes was 900.63 and 886.61 kg m^{-3}. The shatter resistance, water absorption of maize cob briquettes was 93.66 and 32.96% respectively. It was noted that the change in dimensional stability of briquette in longitudinal direction after 3 days, 5 days, 7 days and 20 days were -2.76 %, -4.07%, -3.29% and -0.87 % respectively. It was also noted that the change in dimensional stability of briquette in diametric direction after 3 days, 5 days, 7 days and 20 days were 0%, 5%, 0% and 2.38 % respectively. The calorific value of briquettes is 3197.47 kcal kg^{-1}. These results showed that cotton stalk briquettes have good potential in fuel quality in terms of strength and heating value.

Keywords: Cotton stalks, briquette, compressed density, shatter index, calorific value

Introduction

Crop production generates considerable amount of residues that can be used as energy source. This could be distinguished into the field residues and process residues. Field residues are residues that are generated during crop processing e.g. milling. Crop residues includes stems, branches, leaves, chaffs, stalks etc., are used as energy sources as fodder, raw manufacturing materials and in some cases, they are just burnt as wastes. Due to the high energy content, crop residues can present an attractive alternative energy source to fossil fuels. These residues constitute a major part of biomass and are important potential sources of energy, both for domestic as well as industrial purposes.

In Andhra Pradesh, cotton is one of the most important commercial crops. Cotton, the ‘White gold’, is an important commercial crop playing a key role in economic, political and social affairs of the world (Bhatt, 1992; Kairon *et al*., 2004; Singh, 1997) [8, 11]. India is the second largest cotton producing country in the world with the largest area under cotton, accounting for about one fourth of world’s area of cultivated cotton. BT cotton in India is grown in an area of 126.22 lakh hectares with an annual production of 400 lakh bales and a productivity of 537 kg lint ha^{-1}. Andhra Pradesh occupies an area of about 7.36 lakh hectares with an annual production of 21.10 lakh bales and productivity of 624 kg lint ha^{-1} (AICCIP, 2015) [7].

Cotton stalks (stem and branches) and cotton liners (short fibres remaining on the seed after the staple fibres are removed by ginning) are important by-products of cotton. Cotton stalk residue generated annually in India was about 30.79 million tons (Lali, 2010) [14]. Cotton stalks are generally composed of 33% glucan, 17% xylan and 28% klason lignin (Akpinar *et al*., 2011) [5]. Because of its lignocellulosic nature, cotton stalks have the potential to be used as a raw material for briquetting.

Briquetting can be defined as the process of converting low bulk density biomass into high density and energy concentrated fuel briquettes. Process of translating biomass into solid fuel involves drying, cutting, grinding, and pressing with or without the aid of a binder. Densification of biomass materials could reduce the costs of transportation, handling, and storage.

Densified products, because of uniformity in shape and size can be easily handled using the standard handling and storage equipment. Briquetting increases strength, density, handling and transport qualities and the amount of heat emitted per unit volume of the biomass. Briquetted fuel can be used by the industrial, commercial and household sectors. It is ideally suited for boilers, forges and foundries, brick kilns and ceramic units, residential heating, gasification and agriculture.
In Andhra Pradesh, large quantities of cotton stalks were produced annually. These residues are being left to rot away or burning directly in the field which causes environmental pollution. The residues are bulky and have low energy density which make them difficult to handle, store, transport and utilize in their raw form. Hence, there is the need to subject them to conversion process in order to mitigate these problems. Lot of research has been done on briquetting technology in other countries and stoves for domestic use and industrial use. In our country, still briquettes were not utilized and not yet commercialized due to various reasons. So, it is necessary to utilize these residues to convert into useful source as fuel which replaces fossil fuel need in future.
The main objective of the present study was to develop the briquettes from high pressure briquetting machine (118 MPa) and also to assess its different briquette characteristics.

Materials and methods

Raw material Collection and Preparation

Cotton stalks were collected from the fields of Agricultural farm, Bapatla. Generally, Cotton stalks were bulky and irregular in size and were difficult to handle. The size of the cotton stalks was reduced by passing it through chaff cutter, where small size (6 cm) of stalks was produced. Prior to briquetting the moisture content of the sample was determined using ASTM procedure.

Chaffed cotton stalks

Cotton stalk briquettes

High Pressure Briquetting Machine Details

Briquettes of cotton stalks were produced by using high pressure briquetting machine, in which the piston exerts a high pressure of 118 MPa.

High pressure briquetting machine

Salient features of briquetting machine

Description	Specifications
Capacity	250 kg h^{-1}
Input volume	2.2 $m^3 h^{-1}$
Nominal diameter of briquettes	40 mm
Speed of press	300 rpm
Piston press pressure	1200 kg cm^{-2}
Power requirement	
Briquette press	15.0 hp
Hammer mill	7.5hp
Inclined screw conveyor	0.5 hp
Vertical screw conveyor	1.0 hp
Dust suppression	1.0 hp

Analysis of Briquettes
Physical properties of the briquettes are very important to know the quality of briquettes. Physical properties like compressed density, relaxed density, relaxation ratio, moisture content, diametral expansion, longitudinal expansion, shatter resistance, water absorption and compressive strength were determined by standard procedures.

Determination of Compressed Density
Briquettes were randomly selected from production batch for evaluation of physical properties. The compressed density also called maximum density (density immediately after compression) of the briquette was determined immediately after ejection from the moulds. The densities of the briquettes were then determined as the ratio of mass to volume (ASTM D 2395 – $14^{\varepsilon 1}$ (2015)) [4].

$$\text{Compressed density, kg m}^{-3} = \frac{\text{Weight of the sample,Kg}}{\text{volume of the sample,m}^3}$$

Determination of Relaxed Density
It is the density of the briquette determined in dry condition after about 19 days (Oyelaran *et al.* 2014).The relaxed density was calculated as the ratio of the briquette weight to the new volume.

$$\text{Relaxed density, kg m}^{-3} = \frac{\text{Weight of the sample,kg}}{\text{New volume of the sample, m}^3}$$

Determination of Moisture Content
The moisture content of maize cob briquette samples was determined in accordance to moisture measurement method of ASTM E871−82 (Reapproved 2013) [1] by using hot air oven method. Five briquettes produced from maize cobs were weighed and oven-dried (103 ±1° C) to constant masses. The loss in mass, expressed as a percentage of final oven-dry mass, was taken as the moisture content of the briquettes.
The percent moisture in the analysis sample was calculated as follows;

$$\text{Moisture in analysis sample, \%} = \frac{(Wc - Wf)}{(Wc - Wi)} \times 100$$

wahere,

W_c = Weight of container, g
W_i = Initial weight of sample, g
W_f = Final weight of sample, g

Determination of Shatter Resistance
A test sample of briquettes of known weight was placed in a plastic polythene bag. The bag was dropped from a height of 2 m on to concrete floor three times. After the dropping, the briquettes and fractions were placed on top of a 0.35 cm mesh screen and sieved (ASTM D440-86 (1998)) [2].
The durability rating for each type of briquette was expressed as the ratio of weight of material retained on the screen to weight of briquettes before the dropping.
The handling durability of the briquettes was computed as follows;

$$\text{Shatter index} = \frac{B_z}{B} \text{x } 100$$

Where,

B_z- Weight of briquette retained on the screen after dropping (g).
B- Weight of briquettes before dropping (g).

Determination of Water Absorption
A measure of the percentage of water absorbed by a briquette when immersed in water was determined. Each briquette was immersed in water at room temperature for 30s (Koushik *et al.* 2009) [13] and the percent gain was then calculated and recorded as follows;

$$\text{Water absorption (\%)} = \frac{\text{A} - \text{B}}{\text{A}} \text{x } 100$$

Where,

A= Weight of briquette (g)
B = Weight of saturated surface sample (g)

Determination of Diametric and Longitudinal Expansion
Generally, Briquette stability is measured in terms of its dimensional changes when exposed to the atmosphere (Sotannde *et al.* 2010) [16]. The stability of briquettes produced from the maize cobs and cotton stalks with two binder ratios examined in this study was determined in terms of dimensional expansion as shown in Plate 3.13 and Plate 3.14. Immediately after production of briquette from the mould, the briquette length and diameter were measured using Vernier callipers. Additionally, the dimensions of each briquette formed were measured after 3, 5, 7 and 20 days to determine the diametric and longitudinal expansion.
The percentage dimensional stability was obtained from equation below as expressed by (Oladeji and Enweremadu, 2012) [15]

$$\text{\% Expansion} = \frac{I_f - I_i}{I_i} \times 100$$

Where,
I_i = Initial height of briquettes, cm
I_f = Final height of briquettes, cm

Determination of Calorific Value
The gross calorific value of solid form of briquettes was determined by the bomb calorimeter method.

$$\text{Water equivalent} = \frac{(\text{Heat of combustion of std.solution} \times \text{sample weight}) + 45}{\text{rise in temperature}}$$

$$\text{Gross calorific value (kcal kg}^{-1}) = \frac{(\text{water equivalent} \times \text{rise in temperature}) - 45}{\text{Sample weight}}$$

Results and Discussion
Density of briquette
Initial density of milled cotton stalks and cotton stalk briquette were 187.66 kg m^{-3} and 900.63 kg m^{-3}, respectively.

From these results, it was inferred that compared to raw material density, Briquette density was nearly increased five times due to densification process. The Relaxed density of the cotton stalk briquette was 886.61 kg m^{-3}. Relaxed density value was less than compressed density. Less value of relaxed density indicates more volume displacement due to briquette expansion. The briquette density immediately produced from the briquetting machine was maximum and after some days its density was decreased due to the environmental conditions. The compressed density of briquettes obtained from all the treatments could be considered adequate since they fall within the recommended values of compressed density i.e. > 600 kg m^{-3} (Kaliyan *et al.*, 2009) [12].

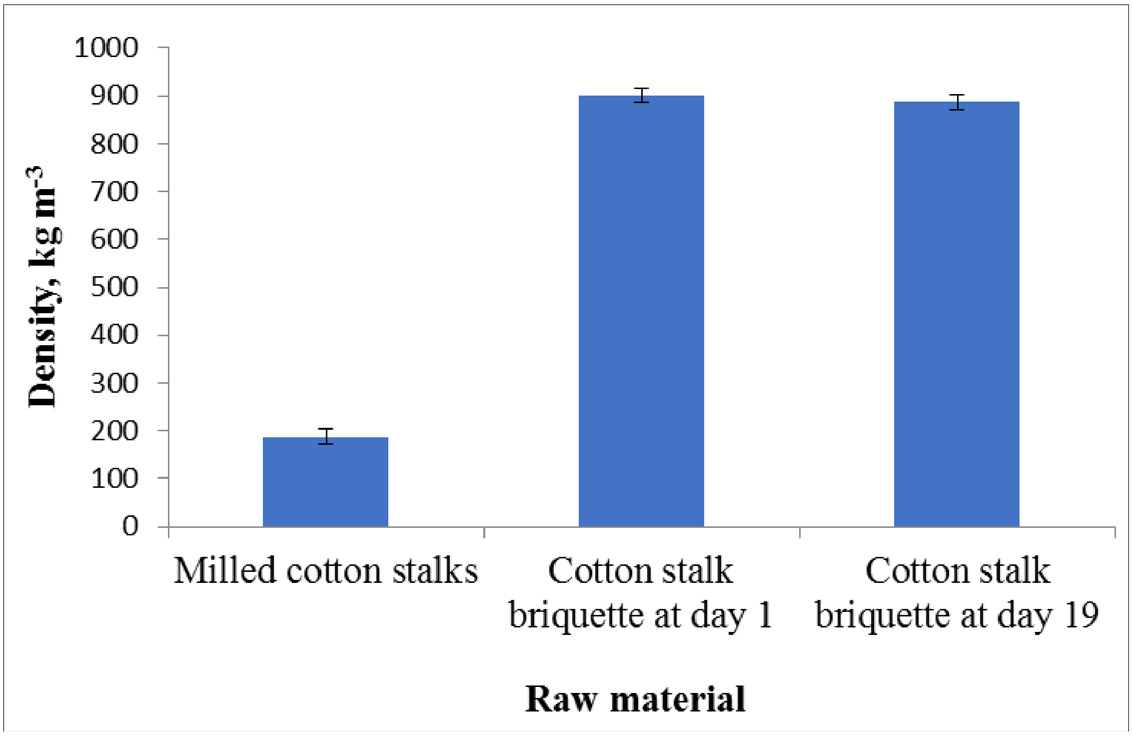

Fig 1: Effect of density on milled cotton stalks and its briquette

Dimensional stability of cotton stalk briquette.
The stability of the briquettes, which is expressed in terms of percentage longitudinal and diametral expansions when exposed to atmosphere.

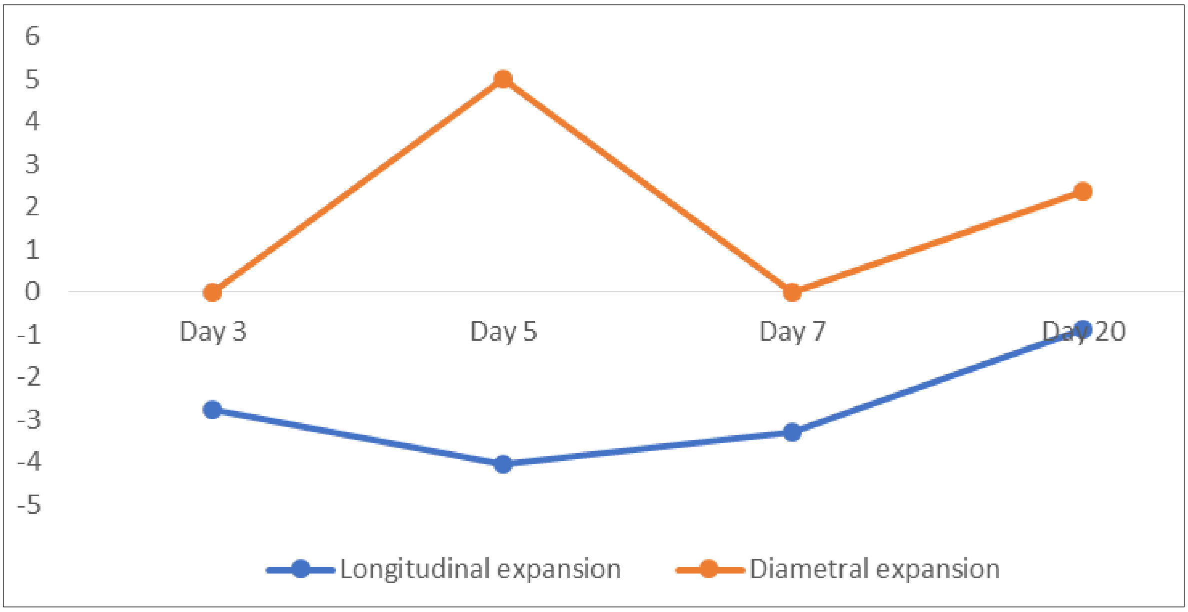

Fig 2: Effect of dimensional stability on maize cob briquette

It was observed that there was a change in dimensional stability of briquette in longitudinal direction after 3 days, 5 days, 7 days and 20 days. The fixed diameter of briquette was 4 cm at the time of production of briquette from mould. It was observed that there was a change in dimensional stability of briquette in diametral direction after 3 days, 5 days, 7 days and 20 days (Fig. 2). In longitudinal direction, the percentage stability values were negative due to the shrinkage whereas in diametral direction, the percentage stability values were positive due to the expansion nature of briquette after exposing to atmosphere.

Table 1: Characteristics of cotton stalk briquettes

Parameters	Units	Value
Before briquetting		
Moisture content	% (w.b.)	13
Bulk density	Kg m^{-3}	187.66
After briquetting		
Compressed density	Kg m^{-3}	900.63
Relaxed density	Kg m^{-3}	886.61
Relaxation ratio	-	
Shatter resistance	%	93.66
Water absorption	%	32.96
Moisture content	% (w.b.)	4.44
Ash content	%	3.89
Calorific value	Kcal kg^{-1}	3197.47

From these results, the moisture content of the briquette was low, 4.44% (w.b.) which was less than 10% showing that this briquette is good for combustibility (Ilochi *et al*., 2016) [10]. The ash content was also low, 3.89%, and calorific value high (3197.47 Kcal/kg), therefore it will not cause an increase in the combustion remnant in the form of ash (Sotannde *et al*., 2010) [16]. It was also observed that the calorific value is high due to less moisture content and high lignin content.

The Shatter resistance and water absorption of cotton stalk briquettes was observed as 93.66% and 32.96%, respectively. Shatter resistance measures briquettes resistance to mechanical action, which affects its handling and transportation. Briquettes are recommended in terms of shatter resistance (90%) and ability to offer considerable resistance to mechanical aberrations during handling and transportation (Borowski, 2007) [9]. These briquettes shatter resistance was maximum, due to the high porosity nature of raw material combination leaded to better compaction and greater hardness. (Antwi and Acheampong, 2016) [6]. Thus, the water absorption was 32.96% due to the inherent binder (lignin) content.

Conclusion

Cotton stalk briquettes are a suitable biomass for densification process to produce briquettes. The briquettes showed adequate characteristics namely low moisture content (below 7.5%), High shatter resistance (93.66%), Good compressed density (900.63 kg m^{-3}) and high calorific value (3197.47 kcal kg^{-1}). Expansion and shrinkage of briquettes was observed in diametric direction and longitudinal direction. These results showed that cotton stalk briquettes have good potential in fuel quality in terms of strength and heating value.

Further studies were required to lower water absorption quality to increase the briquette resistance in humid conditions. Overall, biomass briquettes, either from cotton stalks or other potential raw material, remain an interesting solution to provide an alternative fuel for India.

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