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Molding of Sugar Cane Residues (Bagsse)

Horia M. Abd El-Ghany
Agricultural Engineering Research Institute (AEnRI)- ARC, Egypt

ABSTRACT

This research aims at forming sugar cane residues in the form of regular molds so as to facilitation of trade it with better natural properties than that the original ones. They get easy to handle, transport and storage templates that are then used as an alternative to energy. Moreover, reduce environmental pollution. The studied factors were: particle size of less or equal 1 mm, between 1.4 - 2.8 mm, more than 2.8 mm, and chopped from the machine without separation, at four molding pressure of 150, 200, 250 and 300 bar, (30, 40, 50 and 60 MPa), bonded material (molasses 5, 10 and 15 %) and without bonded material. From the main results, the optimum conditions of sugarcane briquettes were; molding pressure of 60 MPa, particle size of < 1 mm, and molasses percent of 15 %. Which gave briquettes bulk-density of 992 kg m^{-3}, compression ratio of 12.4, resiliency of 4 %, the max., caloric value of 14720 kJ kg^{-1},and the min, caloric value of 6500 kJ kg^{-1}, durability of 98.33%, combustion efficiency of 46%.

INTRODUCTION

Sugarcane considered the most promising agricultural sources of biomass energy in the world. It is the appropriate to produce energy locally in the countries. Sugarcane residues used through recycling and reduce the cyclonic winds, drought, pests and diseases, and its geographically widespread cultivation. Sugarcane is considered one of natures most effective storage devices for energy and the most economically significant energy crop because of its high energy to volume ratio. The climatic and physiological factors that limit its cultivation to tropical and sub-tropical regions have resulted in its concentration in developing countries, and this, in turn, gives these countries transition to sustainable use of natural resources (Zafar, 2016).

The cultivated area of sugar cane in Egypt was about 328,116 feddens, yearly producing about 15,903,336 Mg, with an average yield of 48.47 Mg fed^{-1}, (Bulletin of Estimates Agricultural Income, (2015).

Jekayinfa and Omisakin (2005) mentioned that the availability of energy for domestic use in Nigeria continues to pose a formidable challenge, using cooking gas and kerosene is the high cost of and the Environmental problems associated with firewood. Alternative forms of energy need to be sourced. This need to improve on the use of agro - wastes as alternatives. Quantity of agricultural residues and wastes are generated in the country, but it was poorly utilized and rarely managed. So, most of these wastes are left or they are burned in the field resulting in environmental pollution and degradation. Marianela (2003) stated that sugarcane is used in both Cuba and Brazil as fuel in furnaces, fuel for cars, energy production in sugar factories where self-sufficiency is the factory, and there are experiments on a commercial scale to use sugar cane straw as fuel. As well as to produce ethyl alcohol, so as to produce vapor with efficiency rates of about 60 - 65%, while it is possible to achieve efficiency of nearly 95%. With a design to recover heat and reduce the final temperature of combustion gases.

Huang (2016) stated that there are a lot of sugar factories in Southeast Asia. For each ten ton of sugarcane produce three ton of wet bagasse. Some of sugar factories used the cane residue as fuel. Big mass of burned bagasse produces sufficient heat energy to supply all the needs of a typical sugar factory. The rest of the bagasse can be processed to biomass pellets and exported to other countries as fuel. Sugar cane is a renewable resource, which makes it superior to other kind of fuels. Sugarcane bagasse pellets can be a wise choice because of high calorific value of 3400 to 4200 kCal, and low ash. Zafar (2016) said that bagasse was traditionally used as a fuel in the sugar factory to produce steam for the process and electricity. Mullen *et al*. (2005) mentioned that due to high moisture content, irregular shape and sizes, and low bulk density, biomass is very difficult to handle, transport, store, and utilize in its original form. One of the solutions to these problems is densification of biomass materials into pellets, briquettes, or cubes. Densification increases the bulk density of biomass from an initial bulk density (including baled density) of 40–200 kg m-3, to a final bulk density of 600–800 kg m-3.Panwar *et al*. (2011) stated that densification is a process for improving the handling characteristics and enhancing volumetric calorific value of the biomass. Environmentally, pellet biomass fuels provide advantages of less ash, smoke and other compound emissions including carbon particles, (CO, NOx and SOx). Due to the use of biomass pellets produces much fewer greenhouse gases when the biomass was sustainably produce. There has been recently replace fossil fuels with biomass fuels. Nalladurai and Morey (2009) mentioned that the densification process resulted a strong and durable bonding such as pellets, briquettes, and cubes. Durability of pellets, briquettes, and cubes found using the strength testing (compressive resistance, impact resistance and water resistance) and durability (abrasion resistance) of the densified products indicate the maximum force/stress that the densified products can withstand, and the amount of fines resulted during handling, transportation and storage. Nalladurai and Morey (2010) concluded that the durability of briquettes is a measure of the ability of the briquettes to withstand the destructive forces such as compression, impact and shear during handling and transportation. Also, the durability values represent the relative strength of the bonding between particles in the briquettes/pellets. Chin and Siddiqui (2000) concluded that the forming of biomass into briquettes depends on the physical properties of soil and the treated variables during pelletizing proses. Fuel briquettes were produced under different conditions to have different handling characteristics. These characteristics were found to be strongly affected by raw material properties. Briquette density is one of the most important properties which bear on the combustion characteristics, handling characteristics including the ignition behavior of briquettes. Therefore, it is crucial to understand the effects of these factors on briquette density. Among the factors, die pressure seems to be one of the most important ones. The correlations of briquette density as a function of die pressure for the produced briquettes from several kinds of agricultural residues were studied.

The objectives of this research are; Molding of sugar cane residues (bagasse) in briquettes, and study the affect some factors such as particle size of chopped material, molding pressure and bonded material (molasses) on at the briquettes quality.

MATERIALS AND METHODS

The molding of sugarcane residues (bagasse) was carried out in the faculty of Agricultural Engineering, Al-Azhar University, Egypt and the measurements are done at AEnRI.

Bagasse was collected from different cane juice shops. Then it was spread on the floor in the front of workshop in the AEnRI to get the suitable moisture content for grinding. Fresh sugarcane bagasse moisture content is about 48~50%, and dried to 10-12% to solidify the bagasse.

Raw material (bagasse) grinding to powder with granularity of 3 - 5mm, by hammer mill machine (Mohamed *et al*. 2015). Fig 1 shows the sketch of the hammer mill machine.

The stack of sieves which arranged from the largest to the smallest opening was used to separate the different particle size of the chopped sugarcane residues. A sample of 800 g was taken, and categorized. The chopped sugarcane residues, which were used in this work, were separated to three main categories as shown in Table 1, and also the chopped materials without separation (mixture) as shown in Fig 2, were used in this experiment.

Table 1. Particle size distribution

Particle size	≤ 1 mm	≥ 1.4mm ≤ 2.8mm	> 2.8mm
Weight, g	250.32	258.94	290.47
Percentage, %	31.29	32.36	36.35

Hydraulic cylinder was used as molding apparatus to get different pressure forming briquettes from bagasse. The main components of hydraulic cylinder presented in Fig 3. The gauge of hydraulic cylinder ranged from zero to 60 MPa, with accuracy of 2 Mpa Fig (3), the hydraulic cylinder made by SICMI (Parma), Italy (1996). The calibration was carried out according to (EL-Bessoumy, 2005). Fig 4. shows the calibration results of molding pressures. The molding apparatus was calibrated and being adjusted to form the samples. The samples molding process was executed at four different levels of oil cylinder of 150, 200, 250, and 300 bar, according to calibration. (Fodah, 2017). Molding cylinder is a hollow round cylinder which was used to compress samples inside it. It was manufactured from mild steel. Its inner diameter is 70 mm; outer diameter is 75 mm and length of 200 mm. In order to compress the sample inside the molding cylinder, two blind flanges of steel were used. The diameter of blind flanges is 69 mm (1 mm less than Molding cylinder diameter) to avoid the friction between blind flanges and the cylinder inner surface and also to allow air escape upward during compression. The thickness of upper and lower blind flanges is 20 mm. The specimens obtained from the cylinder after pressing operation formed in briquettes with diameter of 70 mm and the thickness was differed according to the type of treatment. Fig 5 shows molding cylinder, two blind flanges and extruder base. Extruder base is a hollow, round cylinder which was used to eject briquettes gently through it. It was manufactured from mild steel. The dimension of its diameter was selected that the molding cylinder set 15 mm inside it and also the dimension of its height was a incinerator was used to burn the sugar cane briquettes. Two cylindrical aluminum tubes are placed on each other. The upper tube is perforated from the bottom with 15 mm, holes, so that the air can pass through it and is completely opened from above. The above opening is surrounded from aluminum paper. The sensor of the fuel gas analyzer is set by the aluminum paper to reach the combustion gas. The lower tube is closed from bottom and is used as a base, but the upper side is open to supply the upper tube with air. Each tube has a diameter of 150 mm, a length of 350 mm, and a wall thickness of 2 mm, (Fig 7).

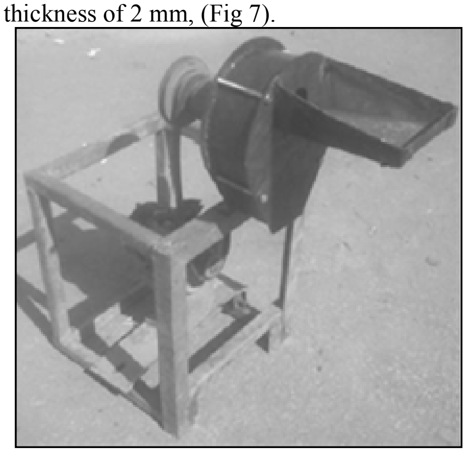
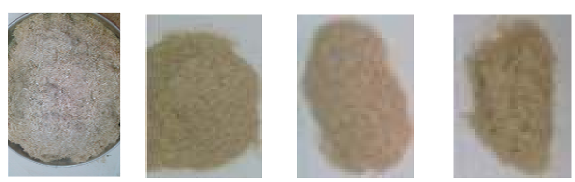


Fig 1. Image of the Hammer mill machine. (Mohamed *et al*., 2015)



Mixture   PZ ≤ 1mm   1.4mm≤ PZ ≤ 2.8mm   PZ > 2.8mm

Fig. 2. Particle size (PZ) distribution

Fig. 3. Hydraulic cylinder

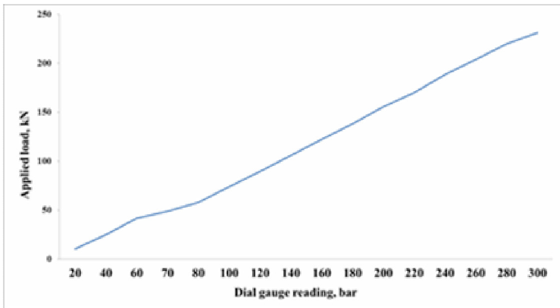


Fig. 4. Calibration of hydraulic cylinder, (EL-Bessoumy, 2005).

For this test, the investigated factors were: particle size of less or equal 1 mm, between 1.4 - 2.8 mm, more than 2.8 mm, and chopped from the machine without separation, at four formation pressure of 150, 200, 250 and 300 bar (30, 40, 50 and 60 MPa); bonded material (molasses 5, 10 and 15 %) compared with without bonded material. A sample of 50 g, of each sample was weighted. The sample was filled inside a molding cylinder and compressed between two blind flanges by hydraulic cylinder which was pressed at a selected molding pressure. After holding time of 5 min., the chopped material take the shape of the briquette, then it was gently ejected by using extruder base and the piston of hydraulic cylinder. The length of the sample was recorded after the pressing operation to calculate the bulk density. (Fig 8) illustrates some samples after pressing.

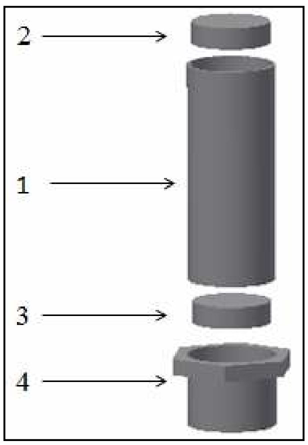


Fig. 5. Molding cylinder (1), two blind flanges (2&3) and extruder base (4).

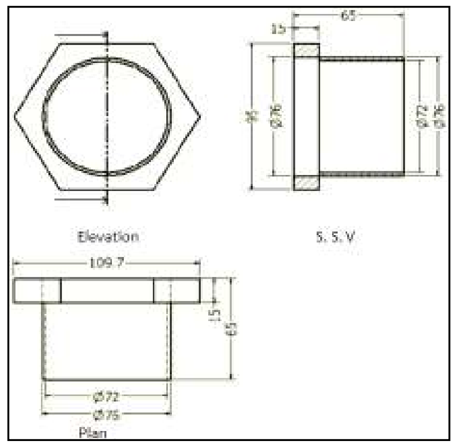


Fig. 6. Elevation, Plan and side view section of Extruder Base, Dims. in mm.

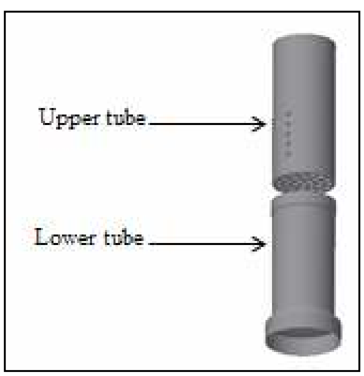


Fig. 7. The upper and lower tubes of the incineration stove

Fig. 8. some format briquettes.

The bulk density was determined by following equations.

$$\rho_b = M/V \quad \ldots\ldots\ldots\ldots\ldots 1$$

$$V = \pi r^2 * t \quad \ldots\ldots\ldots\ldots\ldots 2$$

Where "ρ_b" is the bulk density [kg m^{-3}]; "M" is mass of briquette [kg]; "V" is volume of briquette [m^3]; "r" is radius of briquette [mm]; and "t" is length of briquette [mm]

The compression ratio was calculated using the following equation, (Jha *et al.,* 2008):

$$CR = \rho_b / \rho_{raw} \quad \ldots\ldots\ldots\ldots 3$$

Where "CR" is compression ratio; and "ρ_{raw}" is bulk density of chopped sugarcane [kg m^{-3}].

Resiliency was determined as the ratio between the increases in length to the initial length of the briquette according to following Equation (Jha *et al.* 2008).

$$R = [(T-Ti)/ Ti] \times 100 \quad \ldots\ldots\ldots\ldots\ldots 4$$

Where "R" is resiliency [%]; "T" is thickness of steady briquette [mm], and "Ti" is initial length of briquette (mm).

Durability test for air dried briquettes is done from a height (2 m) for 10 times, according to Singh (1996). The Durability was calculated using the following equation,

$$DU = (M_A/M_B) \times 100 \quad \ldots\ldots\ldots\ldots 5$$

Where "DU" is durability [%]; "M_A" is mass of briquettes after deformation [g]; and "M_B" is mass of briquettes before deformation[g].

Gases emission was carried out for chopped sugarcane residue (raw material), as well as for the briquettes with and without molasses. The samples characteristics that used in this test are shown in Table

2. Ethanol was used as an assistant in the beginning of the burning process. The gases emissions, (CO and CO_2), were recorded each 15 min during incineration process. The combustion efficiency was calculated from the following equation (EL-Sisi, 2012):

$$\eta = [CO_2\% / (CO_2\% + CO\%)] \ldots\ldots 6$$

Table 2. Characteristics of samples that used for combustion

Parameter	sugarcane residue	
	Chopped	Briquette
Length, mm	<1 to >2.8mm	26mm
Diameter, mm	--	70mm
Moisture content, %	9	11
Bulk density, kg m^{-3}	80	500
Mass, g	50	50

RESULTS AND DISCUSSION

Bulk density of briquettes.

Fig 9A, shows the effect of molding pressure (MPa), particle size (mm), and bonded material (%) on bulk density of briquettes. The maximum bulk density of 992 kg m^{-3}, was obtained with molding pressure of 60 MPa, particle-size of ≤ 1 mm, and bonded material (molasses) percent of 15 %. Meanwhile, the minimum bulk density of 625 kg m^{-3} was obtained under molding pressure of 30 Mpa, > 2.8 mm particle-size and without bonded material (molasses). Data illustrates that by increasing molding pressure from 30 to 60 Mpa, the bulk density increased by 13.89 %, at all tested particle-sizes and bonded-materials. Also results illustrate that by increasing particle size from ≤ 1 to > 28 mm, the bulk density decreased by 7.4 %, at all tested molding-pressures and bonded-materials. By increasing bonded-material (molasses) percent from 0 to 15 %, the bulk density increased by 13.35 %, at all tested molding-pressures and particle size. Increasing bulk density by increasing molding pressure and decreasing of particle size is due to decreasing the volume of briquettes. Increasing bulk density by increasing bonded-material percent is due to increasing the mass of briquettes.

Compression ratio of briquettes

The maximum compression-ratio of 12.40 was obtained with molding pressure of 60 MPa, ≤ 1 mm, particle-size and bonded material (molasses) percent of 15 %. Meanwhile, the minimum compression-ratio of 7.81 was obtained with molding pressure of 30 Mpa, mixture particle-size and without bonded material (molasses).

Resiliency of briquettes

Fig 9B, shows the effect of molding pressure, particle size and bonded material percent on resiliency for sugarcane residues (bagasse) briquettes. The maximum resiliency of 20.55 %, was obtained under molding pressure of 30 MPa, > 2.8 mm, particle-size and without bonded material (molasses). Meanwhile, the minimum resiliency of 4% was obtained under molding pressure of 60 Mpa, particle-size ≤ 1 mm, and 15%, bonded material (molasses). Data illustrates that by increasing molding pressure from 30 to 60 Mpa, the resiliency decreased by 29.94%, at all tested particle-sizes and bonded-materials. Results illustrate that by increasing particle size from ≤ 1 to > 2.8 mm, the resiliency increased by 18.17%, at all tested molding pressures and bonded-materials. By increasing bonded-material (molasses) percent from 0 to 15%, the resiliency decreased by 79.94 %, at all tested molding-pressures and particle size. These Results are due to bad storage and to moisture content.

Caloric value of briquettes

Fig 9C, shows the effect of molding pressure, particle size and bonded material percent on caloric value for bagasse briquettes. The max., caloric value of 14720 kJ kg^{-1}, was obtained under molding pressure of 60 MPa, ≤ 1 mm, particle-size and of 15% bonded material (molasses). Meanwhile, the min., caloric value of 6500 kJ kg^{-1}, was obtained with molding pressure of 30 Mpa, particle-size > 2.8 mm, and without bonded material. Data illustrate that by increasing molding pressure from 30 to 60 Mpa, the caloric value increased about 33.54.%, at all tested particle-sizes and bonded-materials. Results illustrate that by increasing particle size from ≤ 1 to > 2.8 mm, the caloric value decreased by 26.04%, at all tested molding-pressures and bonded-materials. By increasing molasses percentage from 0 to 15%, the caloric value increased about 15.63%, at all tested molding-pressures and particle size. Increasing caloric value by increasing molding pressure and bonded-material is due increasing briquettes density, and molasses caloric values. Decreasing caloric value by increasing particle size is due increasing porosity of briquettes.

Durability of briquettes at constant molding pressure

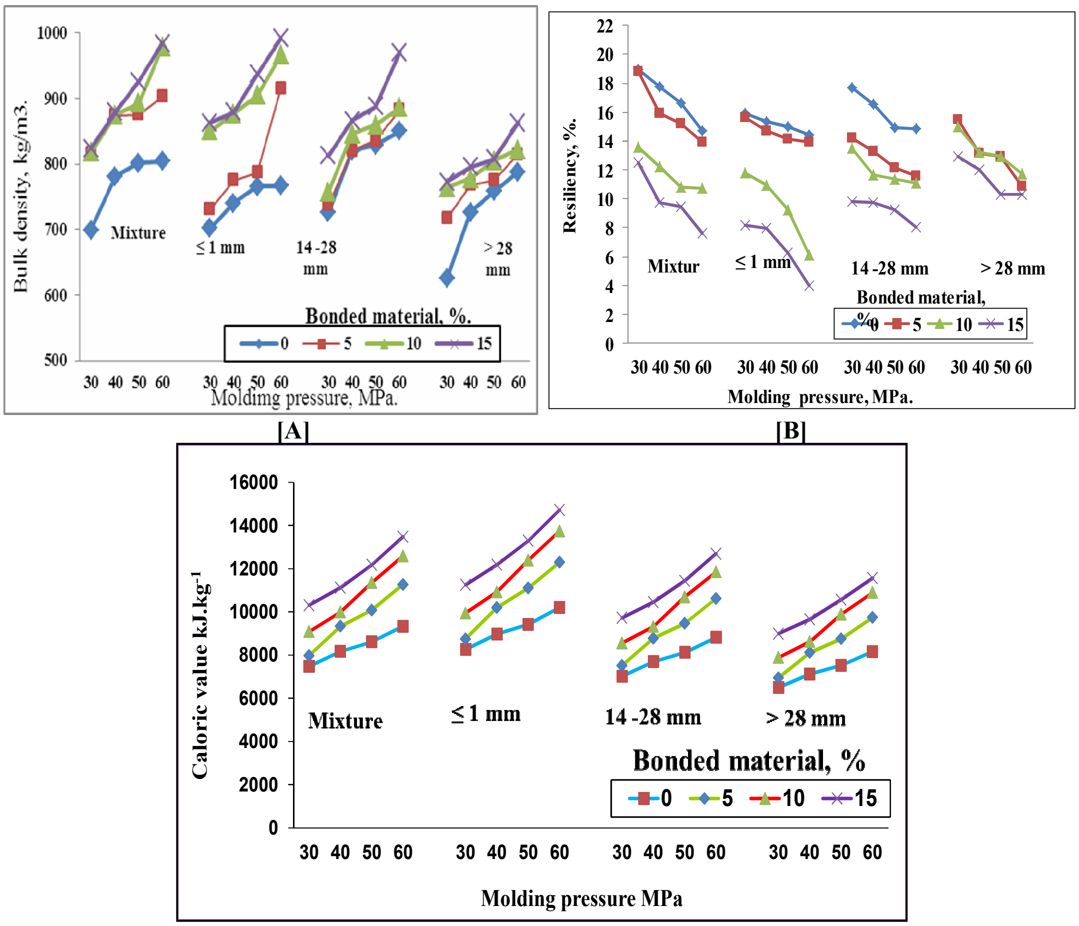
Fig 10 shows the effect of particle size and bonded material on durability for sugarcane residues (bagasse) briquettes at constant molding pressure. The maximum durability of 99.18 % was obtained under molding pressure of 60 MPa, mixture particle-size and bonded material (molasses) percent of 15 %. Meanwhile, the minimum durability (53.78%) was obtained under molding pressure of 60 MPa, particle-size > 2.8 mm and without bonded material (molasses). By increasing particle size from ≤ 1 to > 2.8 mm the durability slightly affected at molding pressure of 60 MPa and with bonded material (molasses). Fig 10 indicated that, at particle size of ≤ 1 mm is the best results which gave 97.95% and 98.33% of durability with and without bonded material respectively at the same molding pressure of 60 Mpa Decreasing durability by increasing particle-size at constant molding pressure and without bonded-material may be due to increasing porosity of briquettes.

Measuring gases emissions

Table 3 shows gas emissions of briquettes combustion at molding pressure 60 MPa, mixture particle-size and with bonded material (molasses 15 %) and without bonded material. Gas emission resulted from combustion of chopped sugarcane residues were CO of 21.76 g m^{-3}, CO_2 of 22.79 g m^{-3}, combustion efficiency of 51 % and burning time of 12 min. Meanwhile, gas emission resulted from combustion of briquette with molasses were CO of 17.26 g m^{-3}, CO_2 of 12.97 g m^{-3}, combustion efficiency of 43 % and burning time of 62.5 min. Also, gas emission resulted from combustion of briquette without molasses were CO of 16.51 g m^{-3}, CO_2 of 14.15 g m^{-3}, combustion efficiency of 46 % and burning time of 59 min. Increasing combustion efficiency of chopped sugar-cane residues comparing with briquette with and without molasses is due to decreasing of moisture content. The data indicates that, the CO values of sugarcane briquettes without and with bonded material (molasses) were lower by 21% and 13%, than the CO values of chopped sugarcane residue respectively. The CO_2 values of sugarcane residue briquettes were lower by 43% and 38% than the CO_2 values of chopped sugarcane residue, respectively.

Table 3. Gas emissions of briquettes combustion at formatting pressure 60 MPa, mixture particle - size for molasses percent of zero and 15 %.

Item	Gases emission		η	Burning
	CO g m^{-3}	CO_2 (g m^{-3})	(%)	time Min
Chopped	21.76	22.79	51	12
Briquette with molasses	17.26	12.97	43	62.5
without molasses	16.51	14.15	46	59



[A] [B]

[C]

Fig. 9. Effect of molding pressure (MPa), particle size (mm), and bonded material (%) on A) bulk density kg m^{-3}., B) resiliency %, C) caloric value kJ kg^{-1} briquettes.

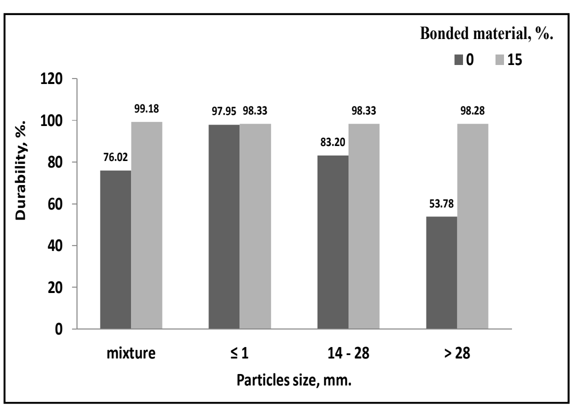


Fig. 10. Effect of particle size and bonded material percent on durability for briquettes at constant molding pressure.

CONCLUSION

For optimum conditions for sugarcane molds, the residue must be grinded to a less size of 3 mm and pressed at 60 MPa with 15% molasses (bonding material).

For easy handling, transportation and storage, the molds should not be exposed to high humidity and stored in a dry place.

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قولبة مخلفات قصب السكر (المصاص)

حوريه محمد عبد الغنى

معهد بحوث الهندسة الزراعية- مركز البحوث الزراعية

يهدف هذا البحث الى تشكيل بقايا قصب السكر (المصاصه) في شكل قوالب منتظمة وسهلة التداول والنقل والتخزين لإستخدامها كمصدر رخيص للطاقة. وأيضا للحد من التلوث البيئي. وكانت العوامل المدروسة: حجم المفروم ≤ 1مم - 1.4 : 2.8 مم - > 2.8 مم، والمفروم بدون فصل، وكبسه بمكبس هيدروليكى بأربعة ضغوط 150، 200، 250 ، 300 بار (30، 40، 50 و 60 ميجا بسكال)، استخدام مادة رابطه (المولاس) , بنسب (0، 5، 10 و 15٪) , لإنتاج قوالب دائرية بحجم 76.93 سم^3(قطر70مم^2 × ارتفاع 20مم).وكانت أهم النتائج المتحصل عليها كالتالى: (1) الكثافة الظاهرية للقوالب: سجلت أعلى كثافة 992 كج/م^3 عند ضغط 60 ميجا بسكال، لحجم المفروم ≥1 مم، ومادة رابطه 15%. بينما وجد أن أقل كثافة ظاهرية كانت 625 كج/م^3 تم الحصول عليها عند ضغط 30ميجا بسكال، وحجم مفروم > 2.8 مع عدم وجود مادة رابطة. (2) نسبة الإنضغاط: وجد أن أعلى نسبة الإنضغاط هى 12.4 وتم الحصول عليها عند ضغط تشكيل 60 ميجا بسكال، حجم جزيئات أصغر من أو يساوى 1 مم، ونسبة مولاس 15 % . بينما وجد أن أقل نسبة الإنضغاط هى 7.81 وتم الحصول عليها عند ضغط تشكيل 30 ميجا بسكال، حجم جزيئات خليط وفى عدم وجود مولاس كمادة رابطة. (3) رجوعية القوالب %: أعلى رجوعية للقوالب سجلت هى 20.55% ، عند ضغط 30 ميجا بسكال، حجم مفروم > 2.8 مم، مع عدم وجود مادة رابطة. بينما وجد أن أقل رجوعية للقوالب هى 4% كانت عند ضغط 60 ميجا بسكال، حجم مفروم ≥1 مم، ونسبة مادة رابطة 15%. (4) متانة القوالب %: وجد أن أعلى متانة القوالب هى 99.18% كانت عند ضغط 60 ميجا بسكال، حجم مفروم بدون فصل (خليط)، ونسبة مادة رابطة 15%. بينما وجد أن أقل متانة القوالب هى 53.78% وتم الحصول عليها عند ضغط 60 ميجا بسكال،حجم المفروم > 2.8 مم، مع عدم وجود مادة رابطة. (5) القيمة الحرارية : الحد الاقصى للقيمة الحرارية للفوالب كانت 14,720كيلو جول/ كيلو جرام عند ضغط 60 ميجا بسكال وحجم مفروم جزيئات ≥1 مم مع مادة رابطه بنسبة 15 %. بينما كان الحد الادنى للقيمة الحرارية كانت 6,500 كيلو جول/ كيلو جرام عند ضغط 30 ميجا بسكال وحجم مفروم >2.8 ، وبدون مادة رابطة. (6) الغازات المنبعثة وكفاءة الاحتراق: اعلى نسبة انبعاث (21.76, 22.79) لغازى CO ، CO_2 على التوالى للمفروم دون ضغط وبدون مادة ربط ، وزمن احتراق 12 دقيقة وكفاءة احتزاق 51% ، بينما كان اطول فترة للاحتراق 62.5 دقيقة/ قالب، وانخفاض نسبة انبعاث غازى CO_2، CO (12.97، 17.26) على التوالى، بكفاءة احتراق 43%، وهى للقوالب عند ضغط 60 ميجا بسكال وحجم مفروم خليط مع مادة رابطه بنسبة 15 %.