EXTRUDATE CHARACTERISTICS PRODUCED FROM HIGH DENSITY SCREW-TYPE EXTRUDER MACHINE

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ABSTRACT Extrudate characteristics of briquettes produced and effects of extrusion factors using an existing screw extruder have been investigated. The feedstock material used in the test is sawdust collected from sawmills around Ibadan metropolis. Particle distribution analysis of materials collected showed that the size varies between 6-8 mm with 10-20% powdery component (< 4 mesh) which is known to give better products. Samples of briquettes produced were used for physical characterization. Physical characteristic studies on samples indicate briquette length (>300mm), dimensionally stable with no significant change in dimension during and after production. Performance tests carried out on machine revealed three (3) critical factors that significantly affect extrusion process; 1) Pre-densification within the extruder barrel results in high pressure requirement to push material through the die ring 2) Due to high pressure requirements as a result of early densification, there is a loss of power along power transmission line 3) Short material dwell time within the die results in weak products. Notable conditions of briquette during extrusion include; 1) extrudate surface cracks, 2) shooting (sudden explosion within the extruder barrel) leading to forceful ejection of materials from the machine and 3) extrudate bowing (warping) attributable to 1) non uniform extrudate thickness, 2) surface quality of the inner race of die ring, 3) loose inter-particle networking and binding properties of material– a condition not favourable to briquette formation, 4) localized heating within the extruder as a result of moisture differentials.

1. INTRODUCTION

Sawdust is a major waste generated in large volumes in the timber industry which constitutes a nuisance to both public health and the environment when not properly managed [1]. It has been affirmed that the volume of sawdust generated in Nigeria is quite high due to the increasing number of sawmills [2]. This is due mainly to the increasing number of operating sawmills. The presence of these wastes in large quantity poses disposal problems for the industry. In the past, these residues were left in the field to be wastefully burnt away. However, in recent times, burning of wood residues in the open has been discouraged because of environmental problems associated with this practice, rather there is a potential for utilizing forestry and wood wastes especially sawdust for energy. These sawdust wastes can be converted to useful form through densification process [3, 4].

Furthermore, saw dusts from these mills are heterogeneous in nature comprising of mixtures of the bark, wood and chemical resins. Also these wastes are products of different species of woods with different strength properties and chemical compositions. Studies on the characterization of these materials have not been extensively carried out in Nigeria. In a study conducted in 100 sawmills in Ijebu area of Ogun State, South west Nigeria, the result showed a potential availability of wood wastes in excess of 212,220 m² (about 66,000 tons) generated per annum. In addition, CO₂ gas

emission that could be saved through the efficient use of the feed stock is in excess of 73,000 tons per year [5].

The presence of these wastes in large quantity poses disposal problems for the industries. Taking advantage of the energy potentials wasted in burning of these massive wastes in open dump sites, their efficient use to meet part of energy demand for heating and gas emissions reduction through conversion processes has become imperative. These wastes can be briquetted through high temperature and pressure applications and utilized as high-grade solid briquette fuels by improving the calorific value and ensuring a clean smoke free flame suitable for small scale industrial and domestic applications.

This work therefore aims at studying the extrudate properties of briquettes produced from sawdust and evaluation of critical factors influencing extrusion using an existing motorized screw-briquetting machine fabricated in the Department of Agricultural and Environmental Engineering, University of Ibadan. In order to achieve this research objective, preliminary investigations were carried out on the experimental machine and the outcome used as bases for engineering design to optimize the extrusion process and performance efficiencies.

2. MATERIALS AND METHOD

Experimental machine setup

The experimental machine used in this test was an electrically powered screw type extruder. The machine is in three segments;

- The power unit comprising of an induction motor and a three-grooved belt-pulley power transmission system. The motor is mounted on an adjustable base joined to the main frame.
- The speed reducer gear assembly which serves dual functions of speed reducer and steady power transmission to the extruder.

Figure 1: Experimental machine

- The extrusion assembly comprising of the extrusion barrel, the screw shaft, the die and heater. The barrel is mounted on the main frame with bolts while the screw shaft is supported (cantilever support) by a large double roller thrust bearing fitly fixed into the extruder barrel. The screw shaft is connected to the reducer gear output shaft through a detachable universal joint. The die comprises of a ring bracket attaching it to the barrel, the bored conical extrusion chamber that necked into a cylindrical bore which produces the final briquette.

Preliminary investigations were carried out on the machine to ascertain the extent of extrusion, the level of compaction and the stability of the briquettes produced as well as the machine performance. The results of preliminary tests carried out formed the basis for machine optimization. Two

variables were identified as critical in the assessment of extrusion performance functions of the machine; these variables are the machine factor and the material factor.

Machine factor: Machine performance factor of importance include the shaft taper angle and screw turn; these parameters determine the clearance angle as well as the retention time of material within the compression zone.

Material factor: Material factors contributing to the quality of briquette formation and extrusion performance include; feed stock sizes and moisture content.

Feedstock material characteristics

Sawdust from sawn wood of different species (Figure 2) were collected from sawmill industries around Ibadan metropolis, sun dried to two moisture contents of 10% and 12%. These materials were sorted for foreign materials and other particulate matters and stored at room temperature conditions in readiness for briquetting. The materials were subjected to particle size analysis following ASAE Standard S319.4 test procedure [6] to determine its physical characteristics.

Figure 2: Sample feedstocks used for briquette production showing variations in particle sizes; a) 2-5mm, 3-6mm and 8-10mm

Briquetting procedure

The experimental machine at start-up was allowed to run at idle speed for five minutes to check for irregularities. Before the commencement of production, the heating elements was energize and subsequent die heating. The estimated start-up time for die heating was 15 minutes to allow enough time for the heaters to raise the temperature of the die to briquetting temperature of about 300°C. The extruder induction motor is then powered and feedstocks loading commenced. The die heater element was set at a temperature of 270 °C and allowed to heat the die gradually to briquetting operating temperature of 300 °C over a period of 10-15minutes. The machine was then loaded with feedstock material intermittently with sawdust. The extrusion time and densified material at two moisture contents were observed. From the point of loading to the time densified briquettes appeared from the die-end was regarded as the start-up time and progressively, the length of extrusion at intervals were measured until the machine stopped or the briquette break off.

Briquette performance test characteristics

Briquettes were tested for dimensional stability, density measurement, and dry matter content, and toughness tests. Dimensional stability of the products was tested immediately after the briquettes were produced and an hour after the product has fully been cooled (Figure 3). Samples of carefully cut briquettes were dressed and measured on electronic weighing balance while the representative weights of samples were recorded.

Figure 3: Measuring sample briquettes for dimensional stability

Briquette dry matter and ash content: Known sample weight of briquettes was grounded (dry matter) into a weighed crucible (Figure 4). The crucible plus sample taken was then burnt in furnace at high temperatures for about 3 hours. About this time it had charred and turned to white ash.

Figure 4: Samples being burnt in furnace

At the end of the process, the crucible plus sample was removed from the oven and transferred to desiccators, cooled for ten minutes and weighed. The dry matter, ash and the moisture contents were calculated from the relations below:

$$\% \text{ Dry matter (DM)} = \frac{W_2 - W_0}{W_1 - W_0} \times 100 \quad (1)$$

Where,

W_0 = weight of empty crucible

W_1 = weight of crucible plus sample

W_2 = weight of sample

The % ash content determined using the formula stated below [7]

$$\text{Ash content} = \frac{\text{Weight of ash}}{\text{Original weight of sample}} \times 100 \quad (2)$$

The % moisture content is determined using the formula stated below

$$\% \text{ Moisture content (DM)} = \frac{W_1 - W_2}{W_1 - W_0} \times 100 \quad (3)$$

Or

$$\% \text{ Moisture content (DM)} = 100 - \% \text{DM} \quad (4)$$

Toughness test: The toughness of the briquettes defined through resistance to gravity drop was evaluated through the percentage of decrease in mass after dropping the briquettes at least three times from a height of 2.0m on to a cemented concrete platform. After each drop, the test piece was put through a sieve with openings smaller than the minimum dimension of the briquette.

Briquette resistance to gravity is evaluated in the equation 5 below:

$$K = \frac{B_z}{B} \times 100 \quad (5)$$

Where:

B = Briquette mass before dropping,

B_z = Mass remaining in filled sieve

The gravitational resistance to drop should attain a value higher than 90% [8].

3. Results and Discussions

Material particle distribution

Preliminary studies on sawdust samples collected showed that geometric mean particle size of feedstock particle varies between 6-8 mm with 10-20% [9] powdery component (< 4 mesh) which is known to give better products and improved packing dynamics and also contribute to high static strength [10]. It is also desirable to have a randomly distributed particle sizes so that an adequate amount of sufficiently small particles is present for embedding into the larger particles.

Extrusion tests on existing machine

Results of the preliminary tests on the material extruded showed that the materials transported from the feed section, through the metering section got stocked in the extrusion section around the screws at the tapered end of the shaft. Samples recovered are well formed, carbonized and stable but defaced with varying degrees of fractures.

Figure 5: Various degree of fractures in samples

Results of trial tests on briquette production after modifications yielded well formed, briquettes with stable dimensions. The time-based extrusion process at different moisture contents (10% and 12% MC) during briquette production is shown in Figures 6 and 7 below. The time-based extrusion process at 10% moisture content is shown in Figure 6. After 7 minutes of start-up time, the briquette extrusion from the die commenced at exactly 8 minutes 10 seconds, (process1), and progressively; (2) 12.08.20, (3) 12.10.58 and 12.13.58 respectively.

Figure 6: Briquette extrusion 7min after start-up time at 10% moisture content; a) 1 minutes 10 seconds b) 10 seconds, (c) 30seconds and d) 2 minutes

Process 2: In Figure 5, briquettes produced from feedstock material at 12% moisture content were weak, and unbounded. The materials at the extremities of the die wall and the shaft tend to bind, but become loose as the thickness increases from zero at the wall to the core. Visibly excessive smoke accompanied the operation (Figure 7(d)).

Figure 7: Briquette extrusion at 12% moisture content 10 minutes startup time; a) 26 seconds, b) 18 seconds c) 12 seconds and d) 23 seconds

High die idle temperature conditions often led to rapid plasticizing and material burning at the surface while the inner layers of the materials around the screw shaft failed to bind consequent on loosely formed briquettes which flattens out immediately it is pushed out of the die.

Process 3: At same moisture content and constant but intermittent feedstock loading rate into the machine, the result shown in 5 minutes after start-up time of machine operation was produced. Moments after the end of operation shown in Figure 8, the process commenced at different operational mode and progressively.

Figure 8: Briquette extrusion at 12% moisture content, 5 minutes startup time; a) 13 seconds, b) 36 seconds c) 15 seconds and d, e, f) 1 second respectively

Extrudate lengths: The result of the time-based extrusion process at two moisture contents (10% and 12% MC) and the extruded length of briquettes formed at 5 seconds intervals during briquette production are shown in Figure 9 below.

Figure 9: Time-based extrusion process at two moisture contents (10% and 12% MC)

There is a structural deflection (Figure 10) noticeable in the 10% MC briquette at the 58th seconds of operation while fracture and failure occurred about same period in the 12% MC briquette.

However, a momentary stoppage of the process for about 90 seconds yielded a stronger, more dimensionally stable and darker briquette.

Figure 10: Briquette extrusion; after 10 seconds and subsequently, 2 minutes

Longer briquettes extruded tend to deflect consequent on appearance of visible cracks around the inflection point (Figure 10). Figure 11 below shows some samples of the briquette produced during the densification test process.

Figure 11: Briquette samples produced

Critical extrusion factors: Three (3) critical factors that significantly affect extrusion process were identified with this condition; 1) Pre-densification within the extruder barrel results in high pressure requirement to push material through the die ring 2) Due to high pressure requirements as a result of early densification, there is a loss of power along power transmission line 3) Short material dwell time within the die results in weak products. Notable conditions of briquette during extrusion include; 1) extrudate surface cracks, 2) shooting (sudden explosion within the extruder barrel) leading to forceful ejection of materials from the machine and 3) extrudate bowing (warping) attributable to 1) non uniform extrudate thickness, 2) surface quality of the inner race of die ring, 3) loose inter-particle networking and binding properties of material– a condition not favourable to briquette formation, 4) localized heating within the extruder as a result of moisture differentials.

Physical characteristics of briquette: The quality of briquette samples produced assessed on the basis of the physical parameters mentioned above revealed that the outer and inner surfaces were smooth (but with visible surface cracks) and cross section cut revealed compact and homogenous particle arrangement. The representative weight, internal and external extrusion diameter, length colour and physical attributes of samples measured after extrusion are as shown in Table 1 below.

Table 1: Weight of briquette samples

Product samples	Weight (g)	Dimensions			Colouration	Physical defects
		Outer dia (mm)	Inner dia (mm)	Length (mm)		
1	206	50.2	20.4	200.2	Char (black)	Cracks visible
2	155	50.3	20.2	160.0	Light brown	None before bowing
3	227	50.3	20.4	141.3	Deep brown	Superficial cracks
4	101	50.2	20.3	121.1	Deep brown	Superficial

Average dimensional changes along the diametric and length axes are 0.23mm and 0.35mm respectively (Table 3). This could be as a result of higher axial compression in the direction of forward movement resulting from screw conveyor.

Table 2: Dimensional stability of briquette samples

Product sample	Diameter moments (mm)	Dimensions		Length moments (mm)	Dimensions	
		Diameter 1hr later (mm)	Elongation (mm)		Length 1 hr later (mm)	Elongation (mm)
1	50.1	50.3	0.2	160.0	160.0	0
2	50.0	50.2	0.2	200	200.2	0.2
3	50.0	50.3	0.3	140.5	141.3	0.8
4	50.2	50.2	0.2	120.7	121.1	0.4
Average	50.075	50.25	0.23	155.3	155.65	0.35
% diametric elongation			0.77	% lengthwise elongation		0.45

The percentage elongations (expressed by the expression below) along both axes are significantly low (0.77% and 0.45%); but evidently higher along the diametrical axis. This condition could be explained by inter-particle interactions during densification. There is higher compression pressure along the length axis than the diametrical axis hence percentage elongation is lower. Table 3 shows the result of the dry matter and ash content of each sample

Table 3: Dry matter and ash contents of solid briquettes

Product samples	Wt of sample (g)	Weighed empty can	wt of can after combustion	Wt of dry matter (g)	% Ash content
1	10	18	18.6	0.6	6.0
2	15	18	19.33	1.33	8.87
3	20	18	19.1	1.1	5.5
4	30	17	19.3	2.3	7.67
5	40	17	20.3	3.3	8.25

The physico-chemical characteristics of the briquette samples shown in Table 3 showed that briquettes produced have averagely low ash content (7.3%). The briquettes produced smoke for a short while before ignition time. This is an indication that the briquette will be user and environmentally friendly due to the low sulphur (0.302%) and nitrogen (0.28%) contents observed for sawdust briquettes [7].

Briquette toughness: After repeatedly dropping each sample of the briquettes from a 2-m height to the laboratory concrete floor, the percentage of weight loss ratio between the loss in weight and the total weight was determined as shown in Table 4. From the tests conducted, after the repeated number of drops, observations revealed that all the briquettes studied did not shatter into pieces. From literatures, the gravitational resistance to drop should attained a maximum value of 93.09% and a minimum value of 89.55% which is in agreement with [10] that gravitational resistance to drop should attain a value higher than 90%.

Table 4: Briquette resistance to gravity and impact at 2-m drop height

Samples	Sample weights (g)	Final wt. after 5 drops (g)	Weight loss (g)	% wt. loss	Toughness (100%)
Light brown (1)	155	144.29	10.71	8.62	93.09
Char (black) (2)	206	188.03	17.97	8.72	91.28
Deep brown (3)	227	205.60	21.4	9.42	90.57
Deep brown (4)	101	90.45	10.55	10.45	89.56

4. CONCLUSIONS

Research outcome showed that material properties and machine design are two critical factors affecting extruder performance. The lesser the shaft profile clearance from the uniform length along the compression and transport sections, the better the performance. Increase in die heater temperature and a continually tapered shaft profile into the die ring, as well as increment of flight pitch/span (length of shaft rod) also improves the machine performance.

There are no significant dimensional changes noticeable in briquettes produced examined moments after extrusion. Also, the briquettes meets impact resistance standard set in literature [11,12], as such can favourably be transported. The study has also revealed that sawdust generated in large quantities and usually burned in open dumpsites to cause environmental hazards can be converted into high-quality and durable solid fuel briquettes suitable for both domestic and industrial energy production for heat generation.

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