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Development of Screw-Type Briquetting Machine for Municipal Solid Waste

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ABSTRACT
The Hydra headed problem of deforestation and Municipal Solid Waste (MSW) Management has bedeviled Nigerian States. Deforestation has put Nigeria on the world's map as the highest contributor to the world's deforestation of its primary forest (contributing over 50%), as over 70% of its population depends on firewood and charcoal for cooking and heating. The rising profile of MSW, characterized by inefficient management methods make most Nigerian cities an eye sore, with uncollected waste littering almost every available space, drainages and water channels which poses great danger to human existence. Without alternative energy source available to the growing population, deforestation will continue unabated and in the nearest future Nigeria risk losing all of its forest resource. A Screw-Type briquetting machine was developed that utilizes crushed, combustible MSW to form briquettes to be used for cooking and heating, which is using one problem to fix another. MSW was formulated, crushed and used to form briquette. The briquettes produced burn in similar way to charcoal when compared. This will reduce to the barest minimum, deforestation rate and improve the management of MSW by utilizing as a resource what is termed waste. The developed machine has a throughput capacity of 2605.4Kg/hr and is driven by a 5 Horsepower (5 hp) electric motor.

Keywords: ***Briquetting, Machine, Waste***

1 INTRODUCTION

The continuous inadequacies in quantity, quality and access to energy in Nigeria, despite its potentials in renewable and nonrenewable energy is affecting domestic energy supply, which has resulted in a threat to Nigeria's forest. Widespread deforestation has become the order of the day in pursuit of survival, as the populace greatly relies on firewood and charcoal for cooking and heating (Al-Amin, 2014). Food and Agricultural Organization (FAO) report has it that Nigeria account for 55.7% of the world's deforestation. Also, deforestation rate in the country is put at 3.5% annually, translating to a loss of about 350,000 to 400,000ha of land, with firewood and charcoal production being the major contributing factor. Study shows that Nigeria's forest is put at about 923,767Km^2 or about 10million hectares which is far below FAO's recommended minimum of 25% (Ladipo, 2010). Table 1 shows the percentage distribution of households by type of fuel used for cooking and heating, for all states in Nigeria, which put clearly why the country accounts for the highest deforestation rate worldwide.

Table 1: PERCENTAGE DISTRIBUTION OF HOUSEHOLDS BY TYPE OF FUEL FOR COOKING

State	Electricity	Gas	Kerosene	Wood	Coal
Abia	0.0	0.7	25.8	73.6	0.0
Adamawa	0.5	0.0	6.2	93.4	0.0
Akwa-Ibom	0.0	0.2	18.3	81.0	0.4
Anambra	0.4	0.3	26.8	72.2	0.3
Bauchi	0.0	0.0	2.1	97.6	0.3
Bayelsa	0.9	0.0	41.3	57.6	0.2
Benue	0.0	0.4	3.1	94.5	2.0
Borno	0.0	0.0	1.3	98.4	0.3
Cross River	0.0	0.2	19.6	79.8	0.3
Delta	0.0	1.6	21.3	76.6	0.5
Ebonyi	0.1	0.8	9.2	90.0	0.0
Edo	2.1	0.1	18.6	78.7	0.5
Ekiti	0.0	0.0	24.2	74.3	1.5
Enugu	0.1	2.1	28.3	68.9	0.6
Gombe	2.1	0.0	5.5	92.4	0.0
Imo	0.2	0.7	13.6	85.1	0.4
Jigawa	1.0	0.0	3.9	95.1	0.0
Kaduna	0.3	1.2	9.8	88.5	0.2
Kano	1.3	0.1	3.4	94.9	0.3
Katsina	1.7	0.0	0.5	97.5	0.2
Kebbi	0.5	0.2	0.0	99.2	0.1
Kogi	0.3	0.0	12.0	86.6	1.0
Kwara	1.1	0.0	15.5	62.0	21.4
Lagos	2.8	3.8	89.7	3.1	0.6
Nassarawa	0.0	0.0	9.2	90.8	0.0
Niger	0.7	0.0	5.2	92.9	1.2
Ogun	2.0	0.0	48.8	49.0	0.3
Ondo	0.2	0.2	32.6	66.7	0.3
Osun	0.8	0.2	27.1	56.0	15.9
Oyo	0.1	1.3	44.7	50.2	3.8
Plateau	0.6	0.4	16.8	80.8	1.4

Rivers	0.0	2.8	31.3	65.2	0.7
Sokoto	0.6	0.3	2.5	96.2	0.5
Taraba	0.0	0.0	1.0	98.8	0.2
Yobe	0.0	0.0	0.9	98.7	0.4
Zamfara	0.1	0.1	4.1	95.5	0.3
FCT (Abuja)	0.7	3.4	34.5	57.4	4.0
SECTOR					
Urban	1.5	2.0	54.1	39.0	3.4
Rural	0.3	0.1	7.0	92.0	0.6
National	0.7	0.7	22.9	74.1	1.6

Source: (Audu, 2013)

Solid Waste Management has emerged as one of the greatest challenges facing states and local government environmental protection agencies in Nigeria. In the country, over 25million tones of MSW are generated annually, with generation rate ranging from 0.66Kg/capita/day in urban areas to 0.44Kg/capita/day in rural areas according to Ogwueleka (2009). Solid waste management in Nigeria is characterized by inefficient collection methods, insufficient coverage of the collection systems and improper disposal. Basically, the commonly practiced waste management option in Nigeria involves the collection of mixed waste materials and subsequent dumping at designated dumpsites and burning in an inefficient manner. The direct burning of loose biomass and combustible MSW is associated with very low thermal efficiency and widespread air pollution. The conversion efficiencies are as low as 40% with particulate emissions in the flue gases. In addition, a large percentage of un-burnt carbonaceous ash has to be disposed of (Bhattacharya *et al*., 1992; Centre for Energy & Environment Nepal, 2014). The recent trend towards MSW in many countries is to look at it as a resource and not waste. According to Shrestha and Singh (2011), waste-to-energy conversion would be an economical and eco-friendly way for addressing both the issues of waste management and energy shortage. The heat energy content (caloric value) of some of the constituent of Municipal Solid Waste is as given in Table 2, which shows what is wasted that would have been utilized each time MSW is burnt.

Table 2: CALORIFIC VALUE OF SOME MATERIALS

MATERIAL	Btu per pound	Kilojoules Per Kilogram
Fuel oil	20,900	48,500
PLASTICS		
Polyethylene	48,500	48,500
Polypropylene	48,500	48,500
Polystyrene	48,500	48,500
Polyethylene terephthalate, PET	48,500	48,500
Polyvinyl chloride, PVC	48,500	48,500
Coal	11,500	48,500
Newspaper	7,200	48,500
Wood	6,700	48,500
Average MSW	4,650	48,500
Yard waste	3,000	48,500
Food waste	2,600	48,500

Source: Environment and Plastic Industry Council (EPIC), 2004.

2 MATERIALS AND METHODS

The screw extruder-type briquetting machine consists of the following major components;

- Hopper
- Doubled walled waste pre-heater
- Extrusion barrel
- Die
- Die heating stove
- Connecting pipe
- Chimney
- Briquette collector
- Screw Extruder
- Screw Conveyor

2.1 SPECIFICATIONS IN THE DESIGN PROCESS

In the design, die diameter is 60mm while length is 200mm. The extrusion barrel length is 800mm so that the sum of the extrusion barrel length and the die is 1000mm. Extrusion barrel 100mm diameter, screw extruder diameter 90mm given a clearance of 5mm for both the top and bottom between the screw extruder and the extrusion barrel. Die heating stove is of size 200×200×600mm, double walled and lagged with 30mm thick refractory material (clay) to reduce heat loss to the environment. Pitch length is 0.6-1 of the screw diameter (Crosbie, 2003), in the design of the screw extruder and pre-heater conveyor, pitch length of 0.8 of the screw diameter is used. MSW in Nigeria has density of 280-370Kg/m^3 (Ogwueleka, 2009), in the design, maximum value of the density that is, 370Kg/m^3 was used.

Revolution of the screw extruder was taken to be 370revolution per minute (370rpm) because, from experiment, a pre-heat temperature of 110-120^{0}C for screw running at that number of revolution was found to be the optimum for minimizing briquetting energy consumption (RERIC, (2005)). For the pre-heater, revolution of 270rpm was assumed in order that the pre-heater conveyor can run slower than the screw extruder so as to allow for absorption of heat by the fed material in the pre-heater. In calculating the permissible shearing stress τ_s, Mild Steel 1090 was used and the ultimate tensile strength $\delta_u = 841\text{MPa}$ and yield strength $\delta_y = 248MPa$.

2.2 VOLUME OF CYLINDRICAL BARREL AND TAPERED DIE

The volume of the cylindrical barrel was obtained by applying the equation:

$$V = \pi r^2 l \tag{1}$$

Where;
r is the radius of the barrel
l is the length of the barrel

For the tapered die, it has the shape of a frustum of a circular cone as shown in figure 1, which is cut out of a full cone to form the frustum. Hence, the volume of the die was calculated by using the volume of the frustum of a cone formula stated in equation 2.

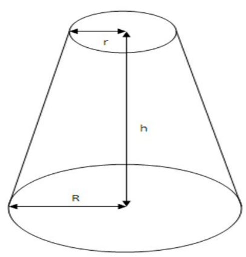

Figure 1: Frustum of a circular cone

$$V = \frac{\pi h[R^2 + r^2 + R \times r]}{3} \tag{2}$$

2.3 DETERMINATION OF THROUGHPUT CAPACITY (VOLUMETRIC CAPACITY) AND POWER REQUIREMENT

Throughput capacity in m^3/hr was obtained from;

$$Q = 47.2(D^2 - d^2) \times P \times n \tag{3}$$

Capacity in t/h r = $\frac{capacity, m^3/hr \times material\ density}{1000}$ (4)

While power required is given by the expression;

Horsepower = $QWLF/4560$ (5)

Based on the obtained Horsepower value, the following conditions hold according to Reedy and Aruna (n.d): If calculated horsepower is less than 1.0, the value is doubled, if calculated horsepower equals 1 to 2, multiply value by 1.5, if calculated horsepower equals 2 to 4, multiply value by 1.25, if calculated horsepower equals 4 to 5, multiply value by 1.1, and if horsepower value is more than 5, correction is not required.

2.4 DETERMINATION OF BELT LENGTH AND ANGLE OF WRAP

According to Harmock et al., (2005), the relation used to determine the length of belt connecting two pulleys is given by;

$$L = \sqrt{(2C_d)^2 - (D_2 - D_1)^2} + \frac{\pi}{2}(D_1 + D_2) + \frac{\pi(D_2 - D_1)}{180}\sin^{-1}\frac{D_2 - D_1}{2C_d} \tag{6}$$

Angle of wrap is determined using the relationship given as;

$$\phi_1 = 180^0 - 2\alpha$$
$$\phi_2 = 180^0 + 2\alpha$$

α is the angle used to describe the loss of arc of contact, which is created because pulleys do not have 1-to-1 ratio and is given as;

$$\sin\alpha = \frac{D_2 - D_1}{2C_d} \tag{7}$$

2.5 SHAFT DESIGN

From the work of Ajayi and Osumune (2013), same power transmitted by shaft equation was applied and which is presented as;

$$P = T_1\left(1 - \frac{T_2}{T_1}\right)V \tag{8}$$

But tension ratio in belts is given by;

$$\frac{T_1}{T_2} = e^{\mu\theta} \tag{9}$$

$$\Rightarrow P = T_1\left(1 - \frac{1}{e^{\mu\theta}}\right)V$$

But with V = ωr and ω = 2πN/60

$$\therefore P = T_1(1 - e^{-\mu\theta}) \times \frac{2\pi N}{60} \times r \tag{10}$$

The diameter of the shaft used was obtained from the relation:

$$d^3 = \frac{16\sqrt{(K_b M_b)^2 + (K_t M_t)^2}}{\tau_s \pi} \tag{11}$$

For the gradually applied load condition, K_b and K_t are taken to be 1.5 and 1.0 respectively.

The pictorial view of the developed screw-type briquetting machine is shown in figure 2

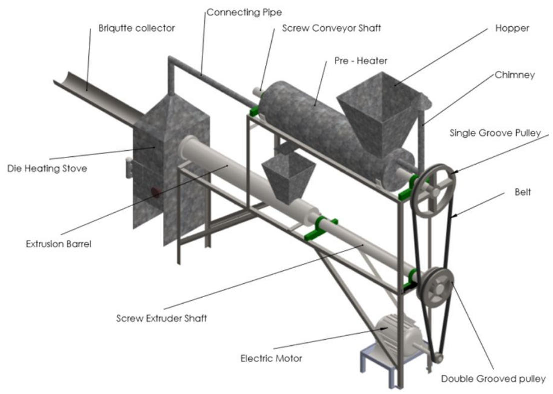

Figure 2: Developed briquetting machine

3 RESULTS AND DISCUSSION

The moisture content of the dried and crushed MSW was determined by weighing samples, drying in an oven for 24 hours and then reweighing to determine the percentage of water to be added to the waste and the result is given in Table 3.

Table 3: MUNICIPAL SOLID WASTE (MSW) MOISTURE CONTENT

Can Number	A_4	A_5	A_9
Weight of Can (g)	19.9	19.8	22.1
Weight of Can + wet sample (g)	25.2	27.1	28.2
Weight of Can + dry sample (g)	25.2	27.0	28.1
Weight of wet sample (g)	5.3	7.3	6.1
Weight of dry sample (g)	5.3	7.2	6.0
Percentage weight of moisture	0	1.4	1.6

From table 3, the average moisture in MSW= $\frac{1.4+1.6}{2} = 1.5\%$

It was necessary to control moisture content so as to allow for smooth production of the briquette and also to produce briquettes that are strong and free of cracks as high percentage moisture will lead to erratic production, blockage and also, shooting of the briquette from the die as a result of trapped moisture, it can also lead to longer drying time of the formed briquette. The die was heated and temperatures noted at given time intervals, the variations in die heating time and temperature are summarized in table 4.

Table 4: DIE HEATING TIME AND TEMPERATURE

Die heating Time (minutes)	Die Temperature (^{0}C)
0	22
15	129
30	274
45	327
60	412

MSW composition at Minna Government approved dumpsite was observed and MSW was formulated to reflect what is found at the dumpsite shown in figure 3.

Figure 3: Formulated MSW

The MSW were shredded using farm cutlass as shown in figure 4, crushed using a jaw crusher and sieved, while the obtained sieved waste is shown in figure 5.

Figure 4: Shredded MSW

Figure 5: Crushed MSW

The prepared MSW was fed into the machine at each of these temperatures to ascertain the optimum heating time and temperature for briquetting. It was observed that at lower temperature, the briquette was not well formed as they easily crumble. Cohesion improved as the heating time and temperature increases, better formed briquettes shown in figure 6, which do not easily crumble were formed from observation at die heating time of 45minutes and temperature of 327^{0}C which continues even at temperatures above this value. The formed briquette after drying was burnt to observe its performance; it was observed that the briquette burns similar to conventional charcoal when compared.

Figure 6: Formed Briquette

4 CONCLUSION

Briquetting provides alternative source of energy other than the conventional firewood and charcoal thereby reducing the menace of deforestation for the purpose of providing energy. A screw-type briquetting machine for municipal solid waste was successfully designed, fabricated and tested, the briquette produced by this machine has a central hole which traps air and improve the combustion performance of the briquette. Producing briquette from combustible municipal solid waste has the ability to generate energy from waste (waste to energy), reduce the amount of waste that goes to the dump site by ensuring that only waste material that cannot be put to further use are finally disposed of at the dump site thereby saving land and also resulting in better environmental sanitation by utilizing waste that would have ended up in the drainages, vacant plot of land and along the road side. These ultimately result in safer and cleaner environment.

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