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Development of a Multi Feed Pelletizer for the Production of Organic Fertilizer

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Abstract: Organic fertilizer is the end product obtained by converting organic wastes such as crop residue, urban waste, poultry dropping and animal dung etc. into a useable fertilizer by composting. In this study, a screw type multi feed pelletizing machine was designed and fabricated. The machine essentially consists of a single phase 3 kW electric motor, 50 mm shaft, screw auger, pelletizer barrel, ball bearing, pulley, 8 mm thick V-belt. The dimension of the machine frame is 800 × 500 × 600 mm. The shaft transmits motion by means of a 3 kW electric motor. The output pellet was formed by compacting the compost through a die opening by a mechanical process. The performance of the machine was based on pelleting efficiency, percentage recovery and throughput capacity of the machine, which was determined at three different mesh sizes; 6 mm, 4 mm and 2 mm. The total mass of pellets was observed to increase as mesh size increases, hence pelleting efficiency increases as mesh sizes increases.

Keywords: Composting, Organic Waste, Multi Feed, Organic Fertilizer, Pellet

1. Introduction

Organic fertilizers are necessary for proper growth and development of plants. Organic-based fertilizers partly solves waste disposal problems through conversion of biodegradable wastes into organic compost ensuring the availability of organic fertilizer for soil conditioning (Moore *et al.,* 1991; Mansell *et al.,* 1981). It help check soil erosion by improving the soil structure and increasing the moisture holding capacity of the soil (Hochmuth *et al.,* 1997) and can convert carbon losses into the gain particularly due to the use of green manure thereby increasing soil fertility. It can also be used as supplements to chemical fertilizers, thereby reducing the import of the chemicals (Mansell *et al.,* 1981). Organic fertilizer is the end product obtained by converting organic wastes such as crop residue, urban waste, poultry dropping and animal dung etc. into a useable fertilizer by composting. Fresh composted manure generally has high nitrogen content than composted manure. However, the use of composted manure will contribute more to the organic matter content of the soil. Fresh manure is high in soluble forms of nitrogen which can lead to sand build up and leaching. If over applied it can introduce pathogens and viable weed seed into the soil. Organic material such as livestock and poultry manure, food waste and yard waste can be composted to provide an improved product for soil application or upgraded use such as horticultural planting mixtures and hydroponics applications. The objective of composting is to provide a proper nutrient balance and environment for the reproduction of aerobic thermophilic bacteria. Factors such as temperature, moisture content, structure, and proper aeration are critical to efficient composting. Operating temperatures of 55 to 65^{o}C are desirable during the aerobic composting process. These temperatures kill fly larvae, pathogens, and weed seeds. Composting is a biological process in which organic wastes are broken down by microorganism and converted into a product to be used as a soil conditioner known as organic fertilizer. This process depends upon the activity of microorganism. These microorganisms require a carbon to nitrogen ration (C:N) between 25 -30 moisture content of 40-60%, pH between 5 and 12 and particle size greater than 30% free air space (Wilson,1989) when manure is composted, its volume decreases and nutrient density increases (Holden, 1990). Nowadays, organic-based agricultural production is the rapidly emerging technology which partly solves waste disposal problems through conversion of biodegradable wastes into organic compost while ensuring the availability of organic fertilizer (Moore *et al.,* 1991). The development of an organic fertilizer pelletizer will make it possible to produce organic fertilizer in different sizes. It will also generate a design database for small, medium and large scale fertilizer plant thereby enhancing production of organic fertilizer for restoring lost fertility to the soil. This will boost crop production. The production process of organic fertilizers include: collection of organic wastes from various localities (agricultural fields, gardens, animal farms; etc.); composting of these materials to obtain the desired carbon to nitrogen ratio; size reduction in a ball mill, blending, impregnation of desired microbial culture, pelletization, drying, and bagging.

The process flow for production of organic fertilizer from organic wastes is described in Figure 1.

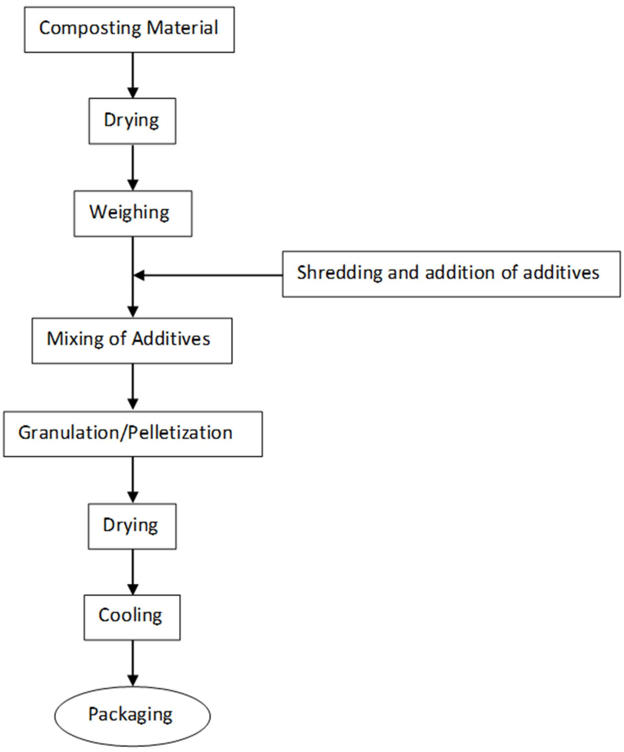

Figure 1. *Process Flow for the Production of Organic Fertilizer.*

2. Method

The work comprises of design, fabrication and performance evaluation of the pelletizer.

2.1. Design and Fabrication of the Pelletizer

Pellets are produced by the process of extrusion. According to Hammed (2013), pelletizing of powdery fertilizer has potential to kill pathogens and enteric parasites. It can also reduce the impact of biological aerosols (bio aerosols) and endotoxins on the manufactures and the end users. According to Reza-Bagheri *et al.* (2011) pellet is safer due to removal of these pathogens and is easier to handle, store, transport and apply than powder organic fertilizer (Hammed, 2013; Erickson and Prior, 1990; Hernandez *et al.,* 2006). Aremu *et al. (*2014) reported that pelletizing can be achieved using extrusion machines which include the rotary pelletizer, the screw type and the hydraulic press however, the most widely used method is the screw type in which the raw materials oil are pressed in a perforated chamber. The developed pelletizing machine consists of the hopper through which the compost is fed into the machine and a worm screw (shaft) which propel a dense mass of compost through a small die opening. The shaft transmits motion by means of a 3 kW electric motor. The output pellet is formed by compacting the compost through a die opening by a mechanical process. The design involves the determination of the pelletizer geometry and capacity as well as the choice of construction material. The following are design considerations: system capacity, hopper capacity, power requirement, forces acting on the shaft and shaft diameter.

2.1.1. System Capacity

The first design consideration is the pelletizer capacity which is determined by the mass balance of input and output throughputs. The sum of the volume of all throughput entering the pelletizer gives the total volume of the pelletizer for one batch. In order to meet a daily production of 250 kg of organic fertilizer, production is calculated as 10 kg per hour. To meet the targeted production capacity, the volume of the pelletizer is calculated as 0.24 m^3. The mass of the compost per batch is given by equation 1.

$$density(\rho) = \frac{mass}{volume} \quad (1)$$

The density of the compost is 350 kg/m^3, volume of pelletizer (0.24 m^3)

Hence, mass of compost is calculated as 84 kg.

2.1.2. Hopper Design

The pelletizing machine comprises of some basic component such as the hopper which feed manure into the machine, to the pelleting chamber which consists of the worm, auger or screw (shaft) which propel the manure. The hopper is in form of rectangular based pyramid frustum, which is made of mild steel.

The selected dimensions are:

i. Upper face of the hopper: 260 mm x 240 mm
ii. Lower face of the hopper: 70 mm x 50 mm
iii. Height: 150 mm.

The development of the hopper is such that the dimensions are marked out and cut out from a mild steel sheet, then welded together. Pellets are produced through the process called extrusion. The shaft transmits motion by means of a 2 kW electric motor. The output pellet is formed by compacting and forcing it through a die opening (with suitable diameter die hole) by a mechanical process.

The inner diameter d_1 = 10 mm and the outer diameter d_2 = 15 mm. With a thickness 2 mm, the ratio of thickness t to inner diameter ratio is $t/d_1 = 0.20$. A cylinder with $t/d_1 < 0.05$ is generally regarded as a thin walled cylinder (Ryder, 1997). Thus, this pelleting cylinder is a thick walled cylinder.

The internal pressure which is equal to the extrusion pressure is given by equation 2.

$$P = \frac{F}{A} \tag{2}$$

where; P is the design extrusion force (10 kN), A is the bore area 0.0201 m^2, hence the internal pressure is calculated as 476 kN/m^2 from equation 4. According to Khurmi (2010), the maximum tensile strength of mild steel plate is given as 250 N/mm^2. Using a safety factor of 1.5, the circumferential stress is calculated as 166.66 N/mm^2.

2.1.3. Worm Screw

The worm screw specified has a pitch diameter, Dp = 20 mm, and thread pitch p_t = 10 mm. According to Doboronoslky *et al. (*1977), the design for thread wear is given by equation 3.

$$d_p = \sqrt{\frac{2P}{\pi \emptyset Perm}} \tag{3}$$

where; P is the force acting along the screw (10 N/m^2), Perm. is the permissible mean nut pressure.

$\emptyset = H/d_p$ = 1.2 to 2.5 for unsplit nuts and H is the nut thickness Taking Ø= 2.0 and Perm = 0.80 kN/cm^2 (for steel screw, cast iron nut). From equation 3, the pitch diameter for the threaded wear is calculated as = 2.0 mm. This is less than the specified pitch diameter of 20 mm.

2.1.4. Motor (Power Requirement)

$$Work = force \times distance \tag{4}$$

$$Power = \frac{work}{time} \tag{5}$$

$$Power = force \times \frac{distance}{time} \tag{6}$$

$$Power = force \times velocity \tag{7}$$

$$Power = force \times screw\ circumference \times rpm \tag{8}$$

$$Power = \frac{P \times \pi DN}{60} \tag{9}$$

P is the design force (10 kN), D is the inner diameter (0.016 m) and N is the number of revolution per minute (100 rpm). The theoretical power requirement is calculated as 0.85 W from equation 9. Using a safety factor of 2.5, a 2 kW electric motor is selected. The developed mechanical pelletizer powered by an electric motor (Figure 2) was used for the pelletizing process. Pellet sizes was in the range of (2 – 6 mm) according to the 3 different mesh sizes (2, 4 and 6 mm) in order to prevent nutrient loss from the soil.

2.1.5. Pelleting Efficiency

The pelletizing efficiency is given by equation 10

$$\square = \frac{w_o}{w_i} \times 100\% \tag{10}$$

where; w_o is the total mass of pellets produced (g) and w_i is the total mass of input manure (g).

Figure 2. *The Developed Pelletizer.*

3. Results

The mesh sizes, mass of pellets produced as well as efficiency of conversion of input manure to pellets at different rotational speed of 150, 200 and 250 rpm is presented in Tables 1, 2 and 3 respectively.

Table 1. *Pelletizing Efficiency of Manure at 150 rpm.*

S/N	Mesh size (mm)	Mass of Pellets (g)	Mass of Input Manure (g)	Efficiency (%)
1	2	10.05	15	67
2	4	10.99	15	73.2
3	6	11.00	15	73.33

The pelletizing efficiency is the percentage ratio of recovered pellets to the total weight of manure fed in. From Table 1, it was observed that pelletizing efficiency increases as mesh size increases at a speed of 150 rpm. Some of the manure got stuck as a result of decreasing mesh size, hence the total mass of output pellets increases as mesh size increases (Figure 3). The only demerit is that the rate of decomposition of manure when applied on soil increases as mass of pellets decreases. The pelletizing efficiency at 150 rpm for mesh sizes 2 mm, 4 mm and 6 mm is shown in Figure 3.

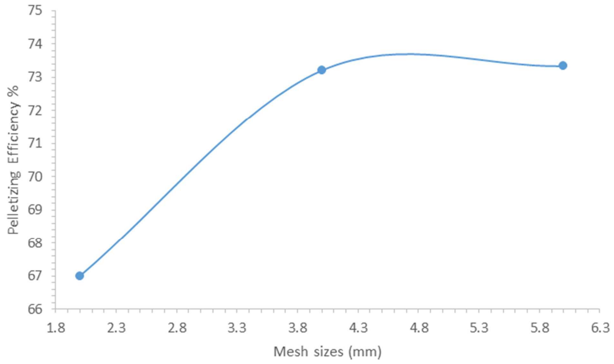

Figure 3. *Pelletizing Efficiency at 150 rpm for different Mesh Sizes.*

Table 2. *Pelletizing Efficiency of Manure at 200 rpm.*

S/N	Mesh size (mm)	Mass of Pellets (g)	Mass of Input Manure (g)	Efficiency (%)
1	2	10.65	15	71
2	4	11.1	15	74
3	6	11.4	15	76

From Table 2, it was observed that pelletizing efficiency increases as the mesh size increases. Some of the manure got stuck as a result of decreasing mesh size, hence the total mass of output pellets increases as mesh size increases (Figure 4). The pelletizing efficiency also tends to increase as the rotational speed of the motor increases from 150 to 200 rpm. The pelletizing efficiency at 200 rpm for mesh sizes 2 mm, 4 mm and 6 mm is shown in Figure 4.

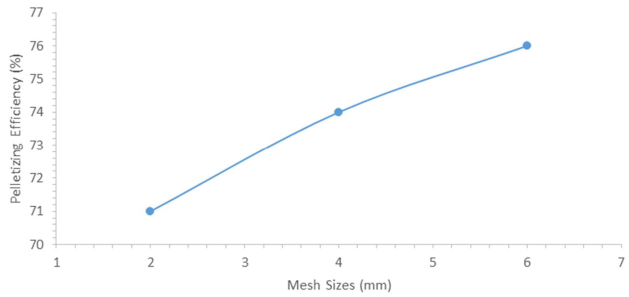

Figure 4. *Pelletizing Efficiency at 200 rpm for different Mesh Sizes.*

Table 3. *Pelletizing Efficiency of Manure at 250 rpm.*

S/N	Mesh size (mm)	Mass of Pellets (g)	Mass of Input Manure (g)	Efficiency (%)
1	2	10.40	15	69.3
2	4	11.01	15	73.4
3	6	11.25	15	75

From Table 3, it was observed that pelletizing efficiency also increases as the mesh size increases, hence the total mass of output pellets increases as mesh size increases (Figure 5).

The pelletizing efficiency at 200 rpm for mesh sizes 2 mm, 4 mm and 6 mm is shown in Figure 5.

The pelletizing efficiency at 250 rpm was found to be greater than that of 150 rpm but lower than the pelletizing efficiency at 200 rpm. The motion supplied by the motor at the speed of 150 rpm may not be sufficient for the optimum pellet formation of the manure. Increase in the speed of the motor up to 200 rpm was observed to be sufficient resulting in high pelletizing efficiency compared to other efficiencies at the speeds 150 and 250 rpm (Figure 6). Gradual decrease in the pelletizing efficiency was observed with further increase in the speed of the electric motor beyond 200 rpm to 250 rpm. Excessive speed of the electric motor beyond the optimum (200 rpm) was observed to decrease the pelletizing efficiency due to agitation of the pelletizer.

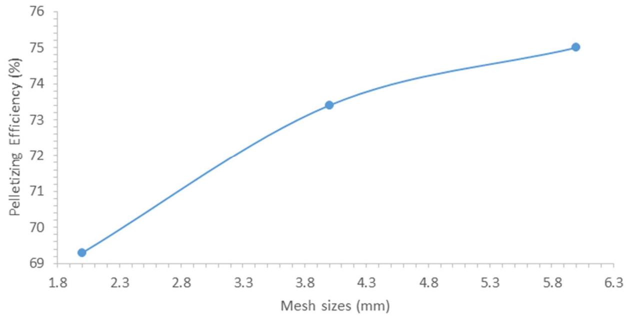

Figure 5. *Pelletizing Efficiency at 250 rpm for different Mesh Sizes.*

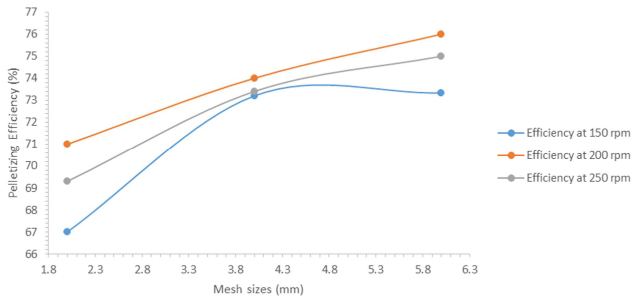

Figure 6. *Pelletizing Efficiency at 150, 200 and 250 rpm for different Mesh Sizes.*

The optimum rotational speed of the electric motor was found to be 200 rpm. The pelletized manure at 200 rpm using 6 mm, 4 mm and 2 mm mesh sizes is presented in Figures 7, 8 and 9 respectively.

Figure 7. *Pelletized Manure using 6 mm mesh.*

Figure 8. *Pelletized Manure using 4 mm mesh.*

Figure 9. *Pelletized Manure using 2 mm mesh.*

4. Conclusion

The pelletizing machine for the production of organic fertilizer plant was successfully designed and fabricated. It consists of an integrated system of a single phase 3 kW electric motor, 50 mm shaft, screw auger, pelletizer barrel, ball bearing, pulley, 8 mm thick V-belt. Pellet sizes of organic fertilizer produced was in the range of (2 – 6 mm) according to the 3 different mesh sizes (2, 4 and 6 mm). The total mass of pellets increases as mesh size increases, hence pelleting efficiency also increases with increase in mesh sizes. The optimum rotational speed of the electric motor was found to be 200 rpm. The pelletizing efficiency increases with increase in rotational speed up to 200 rpm and deceases beyond this speed due to excessive agitation.

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