Design, Development and Evaluation of a Small Scale Kitchen Waste Composting Machine

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Abstract: -The huge cost incurred in the packing and transportation of domestic waste in Nigeria accounts for not less than 60% of the total budget for waste management. The design of a cost effective composting machine for small-scale production of manure (compost) from kitchen wastes is achieved. Actual efficiency of 64.09% was recorded as compared to the theoretical efficiency of 80%.

Keywords: - *Composting, Kitchen Wastes, Efficiency, Recycling*

I.   INTRODUCTION

As families and communities search for safe and effective ways to manage kitchen wastes, compostingbecomes a more attractive management option, this not onlyrestore value to it but also lead to a reduction in the amount of waste that require disposal. Although informal recycling activities of waste materials is wide spread in developing countries, the treatment and use of biodegradable organic fraction, especially for kitchen waste, is still fairly limited. Increasingly, international and municipal authorities now look at new ways to manage their organic solid waste through the introduction of compost plants (in developing countries) which is an excellent way to avoid wasting useful, natural resources and also avoid creating environmental problems, while at the same time producing a high quality and inexpensive soil amendment (Rynk, 1999). The first industrial station for the transformation of urban organic materials into compost was set up in Austria in the year 1926 (Ellis, 2000).Composting is the biological process of breaking up of organic waste such as kitchen waste, manure, leaves, grass trimmings, worms, and coffee grounds, etc, into an extremely useful humus-like substance by various micro-organisms including bacteria, fungi and actinomycetes in the presence of oxygen (Wilson, 2009). Composting is the biological degradation of organic substrates aerobically or anaerobically under conditions of temperature and moisture suitable for acting micro-organisms to thrive, with a final product stable for storage and application to soil without adverse environment environmental impact.

II.   DESIGN

2.1 Design Considerations

Design factors such as availability of component parts, ease of machinability, affordability, efficiency and ease of operation were considered in the design of the kitchen waste composting machine.

2.2 Design Description

The composting machine consists of a composting drum made from galvanized steel, and is enclosed by an outer cylinder mounted directly on a frame. A feeding hopper enters from outside through the cylindrical enclosure into the composting drum. The cylinders, both inner and outer, are designed together such that there is a vacuum between them. The outer cylinder bears a box together such that there is a vacuum between them. The outer cylinder bears a box on one of its sides. This box houses a heating coil and a fan mounted just behind it. Perforations are created through the outer cylinder on the side which is attached to the box. Heat is produced by an electrically controlled heating coil, regulated by a thermostat, which warms up the air in the box, together with air coming from outside through an opening created at the back of the box. The fan drives the heated air in a desired direction (through the perforations) into the vacuum between the inner and the outer cylinders. This heated air, by means of convention heat transfer, warms up the inner cylinder/composting drum in which the waste materials to be composted are stored in order to achieve a slow drying of the materials to be composted are stored in order to achieve a slow drying of the materials. A 30mm diameter shaft passing through the center of the composting drum horizontally and spans through the length of the composting drum inside, on which a masher having its design like that of a worm conveyor is mounted, is being driven by a 2.5HP geared motor with an average output speed of 60rpm. The masher does the task of mashing the waste materials against the inner walls of the composting cylinder. Simultaneously, the mashing, mixing and the low-heat addition (drying) processes occur over a period toachieve the desired result.

2.3 Design of Machine Elements

2.3.1 Composting Drum

The composting drum is a small sized cylindrical-shaped hollow solid made of galvanized steel pipe of 300mm diameter and a length of 500mm. it is the major container of the waste materials, and it houses the masher with its shaft.

The composting drum's total volume is given by:

$V = \pi r^2 l$

Where,

V= volume of the drum

r= inner radius of the drum

l= total length of the drum

Inner radius $r = \frac{300}{2} = 150$mm

Total length $l = 500$mm

Volume = $\pi \times 150^2 \times 500 = 35, 342, 917.3$mm^3

2.3.2 Masher Assembly Design

B = Axial distance between mashers = 65 mm

T = Tolerance between drum and first mesh = 15mm

W = Distance of flight perpendicular to flight

$$\frac{B}{Cos\phi} + T \dots\dots\dots\dots\dots\dots\dots (2.1)$$

$\emptyset$ = helix angle = 15°

Masher Thickness = $\frac{(length\ of\ inner\ drum\ -w)}{(No\ of\ mashers)}$

Volume of masher $= \frac{1}{3}\pi r^2 T$

for 5 mashing surfaces, volume = V x 5

Mass of masher = density x volume

$$force\ per\ unit\ lenght = \frac{force}{total\ lenght}$$

2.3.3 Shaft Diameter

The diameter of the shaft is given by the equation:

d^3 = 16 /π (Ss $\sqrt{}$Mb x Kb)^2 x (Mt x Kt)^2

Where,

Mb = 22.84 Nm

Mt = maximum torsion moment, 324 Nm (calculated)

Kb = combine shock and fatigue applied to bending, 1.5

Kt = combine shock and fatigue applied to torsion, 1.0

Ss = allowable shear stress for shaft with keyways, 40MPa or 40 x 10^6

Using a factor of safety of 0.9

Thus, a shaft of 30mm is selected.

2.3.4 Shaft Key Design

The shaft key is maximum allowable shear stress.

Width of key, w = d / 4

Thickness of key, t = $\frac{2w}{3}$

Where,

d = inner diameter of the shaft to be selected, 30mm

(Khurmi and Gupta, 2005)

2.3.5 Maximum Volume of Food Waste

Maximum volume of food waste that can be composted at a time is given by

$V_A = V_D - V_M$

Where,

V_A= Actual volume of inner cylindrical drum

V_D = Volume of inner cylindrical drum = 0.035m^3

V_M = Volume of mashers

2.3.6 Design for the Gear

The minimum number of teeth on the pinion, Tp, in order to avoid interference is given by:

$$Tp = \frac{2AW}{G}\left(\sqrt{1} + G\left(\frac{1}{G} + 2\right)sin^2\phi - 1\right)$$

(Khurmi and Gupta, 2005)
Where,
Tp = minimum number of teeth on the pinion
A_w = fraction by which standard addendum
G = gear ratio or velocity ratio
$G = \frac{Tg}{Tp} = \frac{Dg}{Dp}$ ... ... (2.2)
Ø = pressure angle
The tangential load can be used to obtain the power transmitted using the pitch velocity.
$W_T = (\frac{P}{V})$ x Cs ... ... (2.3)
Where,
P = Power transmitted in watts
Cs = Service factor, which is 1.25 for a steady load within 18 – 24 hours per day. Hence,
$P = \frac{WTxV}{Cs}$
$= \frac{4231.4 \; x \; 0.509}{1.25}$
Multiplyingp by 1.34 gives the horsepower
= 1723 x 1.34
= 2308.86
P = 2.3 hp
Thus, an electric motor of 2.5 hp is selected for the composting machine.

2.3.7 Calculation of Gear Torque
The gear torque is given by
$W_T = T / (D_p / 2)$
Where,
T = torque acting on pinion
D_p = pitch diameter, 162 mm (calculated)
WT = 4231.4 = T / $(\frac{162}{2})$
4231.4 = $\frac{T}{81}$, T = 342 Nm

2.3.8 Heat Generated and Power Consumed By the Heater
An electric heating coil made of Ni-chrome (Nickel and Chromium) is used to heat the inner cylindrical drum where composting takes place, which will require a temperature of 70°C. This temperature is being monitored and regulated by a thermostat. The amount of heat generated Q, is determined using,
Q = MC (ø2– ø1)
Where,
M = Mass of heating coil
C = Specific heat capacity of air = 1.0035J/KgK = 1003.5J/gK
ø2 = Final Temperature of heating coil = 70°C (343K)
ø1 = Initial temperature of heating coil = 25°C (Room Temp.)
Mass = Density x Volume of heating coil
Where,
Density of Nickel heating coil = 1.225kg / m3
Diameter of heating coil = 0.2 m
Volume of heating coil = Area x Thickness Area $(A) = \pi r^2$ = 3.142 x 0.1^2
= 0.03142m^2
Thickness of the plate = 0.005m
Volume of heating coil = 0.03142 x 0.005 = 0.000157m^3
Mass = 1.225kg/m^3 x 0.0001571m^3
= 0.00019245kg
= 0.1925g
Heat Generated Q, from equation 3.32
= 0.1925g x 1003.5J/gK x (343 – 298k)
= 8688.3J = 8.69KJ
Power consumed P is the heat generated per hour, which is given by:
$P = \frac{Q}{T}$
Where T = Time (in seconds) = 3600sec (For 1 Hour)

$P = \frac{8688.3}{3600}$

$= 2.4KW$

An electric heater with rating 2.0KW is selected for this work.

2.3.9 Fan Speed Calculation
The speed of fan V is determined using:

$V = \frac{\pi DN}{60}$

Where,

D = diameter of fan = 0.1 m

N = speed of motor in the fan = 180rpm

V = (3.142 x 0.1 x 180) / 60

V = 0.9426 m/S

2.3.10 Machine Frame
The machine frame consists of the following parts: the outer cylinder (composting drum and chamber), the hopper and the heater box

2.3.11 Outer Cylinder
The outer layer, which serves as the housing chamber for the composting drum, is also a cylindrical – shaped hollow solid made of mild steel pipe of ø 400mm and a length of 600mm. it is directly attached to the frame which supports the machine.

It also a thickness of 2mm. the delivery chute for collecting the end product passes through an opening at its lower end. Its total volume is given by the equation below:

$V = \pi R^2 L$

Inner radius = 400 / 2 = 200mm

Total length L = 600mm

$V = 3.142 \times 200 \times 200 = 75, 398, 223.6mm^3$

2.3.12 Design for Hopper
Slant Height

L1 = Top length of hopper = 240mm

B1 = Top breadth of hopper =240mm

L2 = Bottom Length of hopper = 120mm

B2 = Bottom breadth of hopper = 120mm

H = Height = 200mm

S = Slant height

Ø = Angle of inclination of hopper

$V_b = L x B x h$

V_b= 240mm x 240mm x 200mm

V_b = 0.24m x 0.24m x 0.2m

$= 0.0152m^3$

$V_{sm} = l \times b \times h$

$= 0.12m \times 0.12m \times 0.2m$

$= 0.0288m^3$

$V_H = (0.0152m3 – 0.0288m3)$

$= 0.0123m3$

2.3.13 Volume of Hopper
The volume of hopper is calculated using:

Volume of hopper, $V_h = V_b – V_{sm}$

Where V_b= volume of inlet

V_{sm}= volume of outlet

2.3.14 Heating Chamber Design
Volume of heater and fan chamber = L x B x h

= 215mm x 180mm x 130mm

= 0.215m x 0.18m x 0.13m

$= 0.005031m^3$

III.   RESULTS AND DISCUSSION
26.9865% demoisturization was achieved within a period of 3hours with varying masses. Normal composting for this same amount of waste using traditional means without a controlled environment, as discussed earlier, will take about 3-4 weeks (about 504-672 hours) to complete the process of composting.

The total output of the wet and dry food waste was obtained and the average value calculated to be 6.67kg and 4.87kg respectively.

Efficiency of the initial composting machine (**Previous**) =

$\frac{2.45}{4.75}$* 100%

Efficiency (**Previous**) = 51.58%

(Ojumu and Opafunso, 2012)

Hence the efficiency of the machine (**new**) =
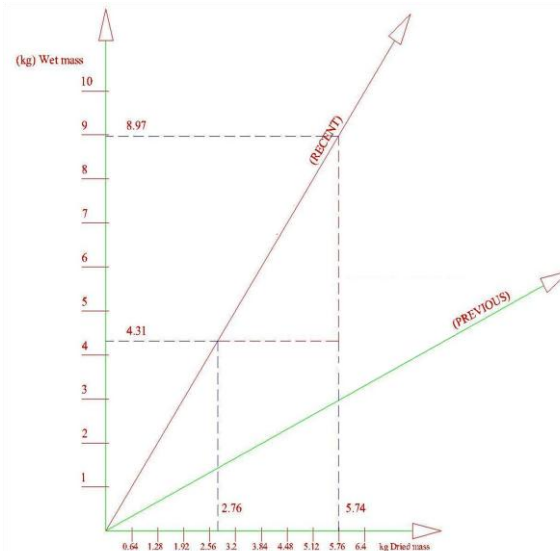
$\frac{4.87}{6.67}$ * 100%

Efficiency (**New**) = **73%**

Fig 1: A Comparative Efficiency Graph of the Previous and New Tests

IV.   CONCLUSION AND RECOMMENDATIONS

Based on the design, and fabrication of an effective composting machine for small-scale agricultural processes is achievable using local content materials and indigenous technology. The efficiency of the machine is at a value above average, further research can be carried out to improve the existing design. Furthermore, the design aim and objectives were achieved. The machine can thus be said to have appropriate technology for efficiency in output, and if further research is carried out on the study, the quantity of output and time of operation can be improved upon. With the machine, composting time and cost of purchasing manure will be saved on a long term basis, while agricultural practices and machine fabrications using indigenous technology will be encouraged.

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