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A Simplified Model to Calculate the Power Absorbed for the Movement of Organic Waste in a Rotary Composter: Industrial Case Study

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ABSTRACT

Rotary composters are widely used for the treatment of organic waste. The energy consumption for moving the organic waste is an important parameter to be considered in the design of the composting machine and the dimensioning of a suitable motor. A simplified model is derived by regression approximation from mechanical equations, with which the power for the movement of organic matter can be described as an explicit function of the composter size, operating parameters and properties of the organic waste. The efficiency of this model is tested with measured data on two industrial rotary composters with satisfactory results and accuracy.

Key words: Industrial rotary composter, Motor, Energy consumption, Movement of organic waste.

1. INTRODUCTION

Rotary composters are bioreactors that treat organic waste by aerobic fermentation [1].the application of these new techniques to rotary composting, which has huge advantages over static composting, remains a design challenge requiring several experiments on prototyping [2], It has been developed to different degrees ranging from continuous training to collaborative R&D and technology transfer (TT) to the industrial sector [3].

They are widely used in industries for the treatment of organic matter. A rotary composter consists mainly of a rotating cylinder usually driven by a motor figure 1 for more details see [4]-[5]. The organic material to be treated is fed continuously or discontinuously through a door located on the longitudinal side of the cylinder, which follows a 20-day treatment cycle to reduce the size of the organic material and produce compost, by rotating the cylinder and controlling all the composting parameters [6]-[7].Depending on the composting process and the quantity to be treated, the size of a rotary composter can reach up to (diameter 3.9 m, length 39 m) with a treatment of up to 100 t/d of organic waste [8]. FFor such a huge industrial rotary composter, the choice of drive system for the rotary unit is very important.

Under- or over-dimensioning of the drive power can lead to engine damage or increased costs for the engine/transmission system. Several factors must be taken into account when selecting the motor capacity, such as the power absorbed by the movement of organic matter and the power required overcoming bearing friction, etc. A number of factors need to be considered when selecting the engine capacity, including the power absorbed by the movement of the material, so its prediction is very important for the designer of the rotary composter.

The present work aims to develop a simplified model for calculating the power absorbed by the movement of organic matter, which must be expressed as an explicit function. This requires knowledge of the dimensions of the rotary composter, the operating parameters of the composter and the property of the material to be treated. In the following sections, the equations available in the literature will be briefly described, from which a simplified model is then derived and tested by measurements on two industrial applications of rotary composting [4]-[5].

2. MODEL STUDY

2.1 Mechanical model

Rotary composters generally operate at low rotational speeds, where the movement of the material is limited to "sliding" or "rolling".All abbreviations described in Table 1.

The material is lifted by the composter wall like a rigid body until it reaches its critical angle of repose θ and begins to tumble Figure 2.This point generally defines the highest power input (noted P) to overcome the gravitational potential energy of the lying material.

$$P = mgv \qquad (1)$$

Where g is the gravitational acceleration ($g = 9.81\ \mathrm{m/s^2}$); m is the mass of material inside the composter, calculated as the product of the density of the material ρ, the length of the composter L and the area S occupied by the material lying in the cross section of the composter.

$$m = \rho L S \quad (2)$$

The velocity v in "1," is the vertical component of the velocity $v0$ for lifting the material.

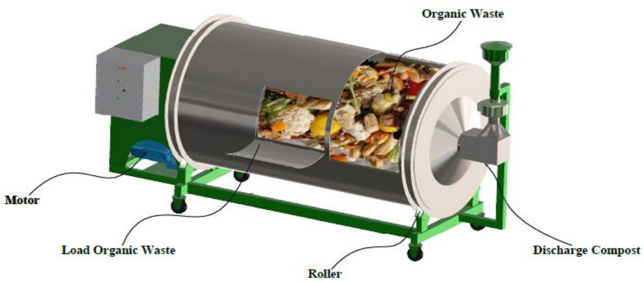

Figure 1: Movement of materials in the industrial rotary composter

$$v = v0\ sin\theta = \pi s\ n sin\theta / 30 \quad (3)$$

Where n is the rotational speed of the composter, s is the distance between the axis of rotation and the center of mass of the lying material, which can be calculated on the basis of a geometrical relation.

$$s = D^3 sin^3\varepsilon / 12S \quad (4)$$

Where D is the internal diameter of the furnace; ε is the filling angle defined as the circumferential angle covering one half of the lying material Figure 2. The filling angle is geometrically correlated with the degree of filling f (the ratio of the surface area of the lying material to the cross section of the composter) by

$$f = (\varepsilon - sin\varepsilon cos\varepsilon) / \pi \quad (5)$$

Substitution of "2," - "4," in "1,") gives

$$P = 0.086\ 10^{-3} n \rho L D^3 sin^3\varepsilon sin\theta \quad (6)$$

Table 1: Attributes of Abbreviation

Abbreviation	Full name
D	Inside diameter of the rotary composter, (m)
f	Degree of filling, (-)
S	Area of the coated material, (m^2)
g	Gravitational acceleration, g = 9.81 (m/s^2)
L	Composter length, (m)
n	Composter rotation speed, (rpm)
P	Power consumption (Kw)
m	Mass of material in the composter, (Kg)
s	Distance between the axis of rotation and the center of mass of the coated material, (m)
ε	Filling angle of the coated material (°)
θ	Angle of repose of the lying material, (°)
ρ	Density of organic waste, (Kg/m^3)
$v0$	Velocity of matter, (m/s)
v	Vertical component of velocity v0, (m/s)

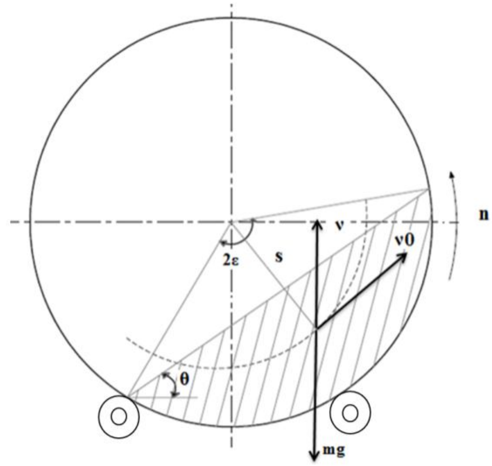

Figure 2: Material movement in the cross section of the composter

In the above equation, [D, L, n, ρ] are usually given as known parameters, on the other hand, it is enough to determine the two unknown parameters the angle of repose θ and the filling angle ε which is in "6,".

2.2 angle of repose

The static angle of repose of organic waste was measured using the casting method [9]. The angle of repose was determined using a bottomless metal cylinder 250 mm high and 150 mm in diameter. The cylinder was placed on the surface of the iron and filled with bulk organic waste. The cylinder was lifted very slowly. A digital camera was positioned exactly in front of the cylinder to take digital images, which were then analyzed for the static angle of rest using computer software. The static angle of rest was calculated using the following equation by [10]:

$$\theta = \arctan(\frac{2h}{d}) \quad (7)$$

Where: θ is angle of repose; h is height of the cone; d is base of the cone. Measurement of the angle of repose was repeated ten times. The angle of repose can range from 5° to 90°, the relationship can be well approximated regression model with a high R-squared value of 0.9993 see figure 3.

$$\text{Sin}\,\theta \approx -0.0001\theta^2 + 0.0213\theta - 0.0327 \quad (8)$$

According to an experimental study described in the section above, we took fresh vegetable waste in sizes ranging from 20 mm to 60 mm with a moisture content of 50% and found an average angle of repose of 40°.

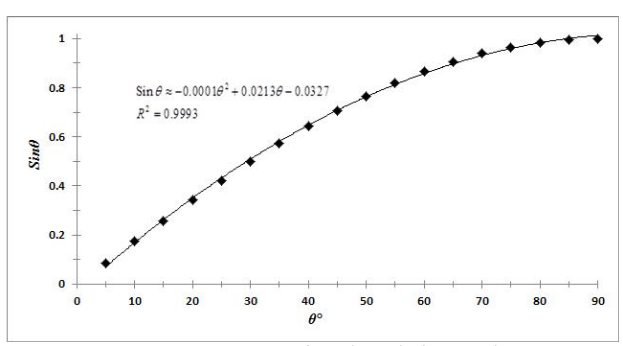

Figure 3: Regression of sinθ on θ (for 5°<θ<90°)

2.3filling angle ε

The determination of the filling angle ε in "6," can be calculated since the total amount of organic matter inside the composter is known as a constant. However, rotary composters generally operate as batch composters, because the outlet of the composter has a smaller orifice that lets out only small grains of compost.

For rotary composters, the degree of filling is generally ($0<f<0.5$) to facilitate the degradation of organic waste. In figure4, the degree of filling f is related to the level of the sinus^{3}ε according to their geometric relationship described in equation (5). For the range of interest ($0<f<0.5$), the relationship can be well approximated regression model with a high R-squared value of 0.9995.

$$sin^3\varepsilon \approx f(-4.33f+4.15) \quad (9)$$

As is shown in Figure 4 by the solid line

2.4proposed model

From the "2," we can obtain the area of organic waste in the cross section of the rotary composter. By dividing S by the area of the cross section of the rotary composter $\pi D^2 / 4$, the degree of filling can be calculated as follows:

$$f = 1.27m / \rho L D^2 \quad (10)$$

Substitution of "8," and "9," and "10," into "6,"

$$P = \begin{bmatrix} 10^{-4} nm(4.15\rho D^2 L - 5.50m)(-0.0001\theta^2 \\ +0.0213\theta - 0.0327)/\rho DL \end{bmatrix} \quad (11)$$

Equation (11) describes the power absorbed for the movement of the organic waste as an explicit function of the size of the rotary composter (L, D), the mass to be fed into the composter (m), the speed of rotation and the properties of the organic waste (θ, ρ), and is therefore very useful for the design of the machine as well as the dimensioning of the motor/drive system. It should be pointed out that, as the material property (repose angle, bulk density) may change due to the properties of the organic waste, in such a case it is suggested that their average value be used for the calculation of energy consumption.

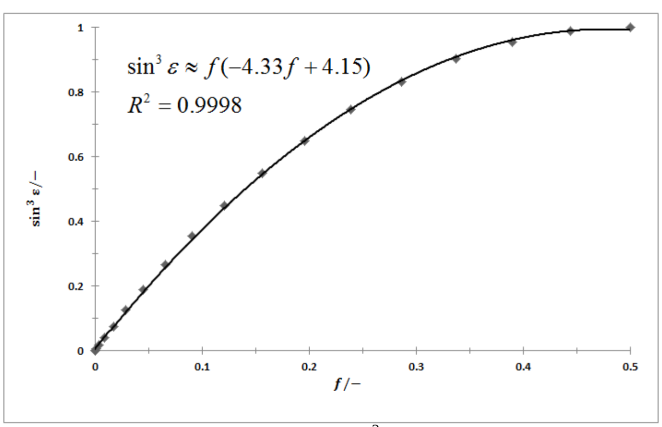

Figure 4: Regression of sin^{3}ε on$f$(for $0<f<0.5$).

3. RESULTS AND DISCUSION

In figure 5, the calculated result of the application of the model proposed in "11" on two industrial applications of rotary composting ([4], figure 6) and ([5], figure 7), the power of movement of the organic matter in the two composters is 0.274 kw for an industrial application [4] and 0.135 kw for the industrial case [5] for a rotation speed of 4 rpm.

In order to validate the proposed model on industrial rotary composting [4] - [5] we have introduced in the two rotary composters of the same type of organic waste, the dimensions of the two industrial rotary composters (composters [4]: diameter 1 m, length 2 m), composters [5] (diameter 0.9 m, length 1.5 m), the density of the waste is (600 kg / m3) and the angle of repose 40 °, both composters operate at the same rotational speed 4 rpm.

We have installed a digital wattmeter downstream of the electric motor to measure the power absorbed by the motor.

For the rotary composter [4] we measured a power value of 0.295 Kw, for the rotary composter [5] we measured a power value of 0.147 Kw.

It can be noticed that the power consumed by the motor for the rotary composter is 8% of the material displacement power for the composter [4] and 9% for the composter [5]. This is obvious because of the losses in the transmission system, losses due to the friction of the drum with the composter rollers [4] and the friction of the drum with the composter bearing [5].

With this model, it is possible to design large rotary composters to process a large quantity of organic waste.

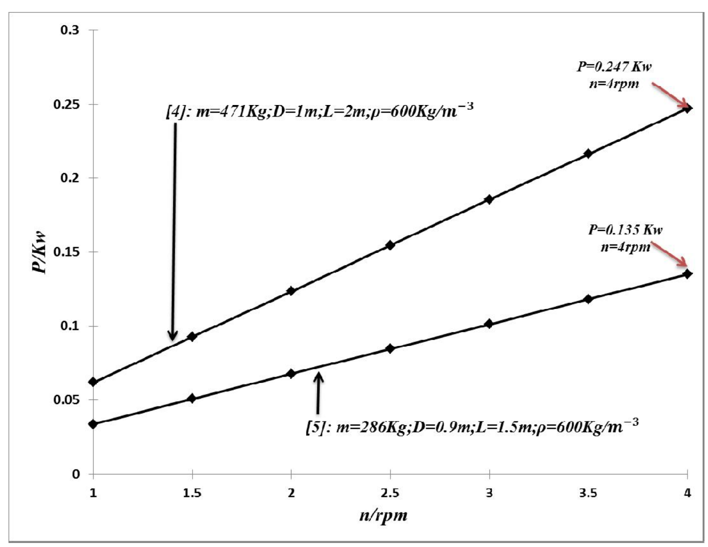

Figure 5: The power draw N in dependence on the rotation speed n.

Figure 6: Industrial Rotary composter [2]

Figure 7: Industrial Rotary composter [3]

4. CONCLUSION

A simplified model is derived to calculate the energy consumption for the movement of organic waste in industrial rotary composters with a filling ratio of (0 <f<0.5) and the angle of repose θcalculated as a function of the mixing percentage and moisture content, With this proposed model it is now possible to determine the power consumed as an explicit function of its dimension (length, diameter), operating parameters (speed of rotation) and the properties of the waste organic to be composted (angle of repose, bulk density), which is advantageous in the design of the industrial composter and the dimensioning of the motor/transmission system . The efficiency of the proposed model is verified by measurements on two industrial rotary composting applications.

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