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Development of a Rot-Oscillatory Particle Size Analysis Device

[*a]Ngabea, S. A, [b]Jijingi, H. E and [c]Kwino, D. I
[a]Department of Food Science and Technology
[b]Department of Soil Science and Land Resources Management
[c]Department of Agriculture and Bio-Environmental Engineering Technology
[a,b]Federal University Wukari, P.M.B 1020, WukariTaraba State – Nigeria Postal Code; 67001
[c]College of Agriculture Jalingo-Taraba State-Nigeria Postal Code; 660213
Corresponding Author: Ngabea, S. A

ABSTRACT: *It is frequently necessary to categorize for different purposes the size of solid materials in many food processes. Until relatively recently, the food industry primarily focused on traditional sieving, as the most common technique for particle sizing. The manual sieving is slow and labor intensive. In this study, a Rot-oscillatory particle size analysis device was design, fabricated and its performance evaluation undertaken in order to supplement the drudgery involved in the traditional sieving. The device consists of a frame which housed the other components. A two stroke crankshaft with a connecting rod attached and mounted on a frame. The device is made up of set of sieves with wire cloth aperture sizes ranging from 500µm to 0.2mm. It is powered by 1HP electric motor. Performance evaluation showed that the device categorized 2kg of flour into 5 different particle sizes. The throughput capacity and the efficiency of the device are 60kg/hr and 86.5% respectively. Thus, from the results of the investigation, the objectives of the study were achieved. The use of the Rot-oscillatory particle size analyzer by food processors will help in analyzing food flour.*

KEY WORDS:*Food Processors, Rot-oscillatory, Flour, Particle Size*

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I. INTRODUCTION

Many food products and their ingredients exist in particulate form ranging from powders to emulsions, suspensions and pellets. The shape and size distribution of particles can have an important impact on many aspects of food including: taste, texture, appearance, stability, process ability and functionality of the final product. The shape of particles not only affects the mouth-feel and taste of food but also affects how certain products behave during processing**[1]**.

Particle size is an important quality parameter of food flour that greatly affects the processing techniques and end product quality, especially in the case of flour [2]. Different techniques are used for powder particle size determination, including sieve analysis, sedimentation, microscopy, coulter counter, laser diffraction, and near-infrared reflectance spectroscopy [3].

The most easily understood method of determination is sieve analysis, where powder is separated on sieves of different sizes. The particle size distribution is usually determined over a list of size ranges that covers nearly all the sizes present in the sample. Some methods of determination allow much narrower size ranges to be defined than can be obtained by use of sieves, and are applicable to particle sizes outside the range available in sieves.

Sieve analysis continues to be used for many measurements because of its simplicity, cheapness, and ease of interpretation. Methods may be simple shaking of the sample in sieves until the amount retained becomes more or less constant.

Technology related to sieve analysis has come a long way since the reed sieves of ancient Egypt, few new developments have come along since the 1940's. Professor Kurt Leschonski wrote "Sieve analysis is one of the few methods of particle size analysis which has escaped modernization." While the modernization has not come in the actual hardware of sieving, refinements in the application and utilization of existing equipment has proceeded [4].

Harold Heywood wrote "I often refer to sieving as the 'Cinderella' of particle size analysis methods; it does most of the hard work and gets little consideration." Sieve analysis technique is widely used in manufacturing of the components using metal powder. Similarly it is very common in testing ingredients of concrete such as sand and cement [5].

[6] described the analysis of sand measurement by sieving and settling-tube techniques and they concluded that, these procedures avoids the artificiality of pretending that the grains are perfect spheres, that is expressing the grain sizes as “sieve diameters” and “sedimentation diameters”. The same can be applicable in case of flour particle analysis.

The manual method of particle size analysis is still practiced today, but it is slow and labor intensive. The development of a Rot-oscillatory particle size analysis device with a different concept will provide a relief of human labor and speed up the analysis.

II. MATERIALS AND METHODS

The selection of materials and methods of construction of the Rot-oscillatory particle size analysis device are based on the design and the drawing of the machine components carried out.

2.1 Description of the Machine

The device operates in a principle of converting rotational motion to oscillatory motion as the name implies “Rot-oscillatory”. In this case, a two stroke crankshaft with a connecting rod mounted on a frame. The crankshaft revolves at a reasonable speed as the connecting rod is linked with the sieve assembly thereby transforming the rotational motion of the crankshaft to reciprocating motion of the sieve assembly in effecting sieving. Moreover, the device can sieve dry materials more effective than wet material. The particle size analyzer is made up of set of sieves with wire cloth aperture sizes ranging from 500µm to 0.2mm.

The device is powered by the use of 1hp electric motor with a speed of 250 rpm.

The entire construction is brought about by locally sourced material thereby making the cost not prohibitive.

The device elements are easily accessible and detachable to facilitate assembling and maintenance process. Although the device is sufficiently rugged to function properly for a reasonable long period, it is cheap enough to be economically feasible. The pictorial view of the device with components labeled is presented in Fig.1 below

2.2 Construction Materials

The materials used for the construction of Rot- oscillatory particle size analysis device is presented in table 1 below.

Table 1: Materials used for the construction of rot-oscillatory particle size analysis device

S/No.	Items	Quantity
1.	2.5mm angle bar	2
2.	1.5mm flat bar	1
3.	Sieves of different apertures	5
4.	Bearings	6
5.	Bolts and nuts	12
6.	Crankshaft	1
7.	Connecting rod	1
8.	Bearing cap	2
9.	1 horse power electric motor	1
10.	Pulley	2
11.	Belt	1
12.	Electric cable and socket	1
13.	Paint	1 tin

The materials for the construction of the Rot-oscillatory particle size analysis device were selected on the basis of low cost, availability, resistance to corrosion, ease of operation and machining, suitability and convenience.

2.3 Method of Construction

This is the process by which various components of the device are fabricated in stages before being assembled into a complete functional unit.

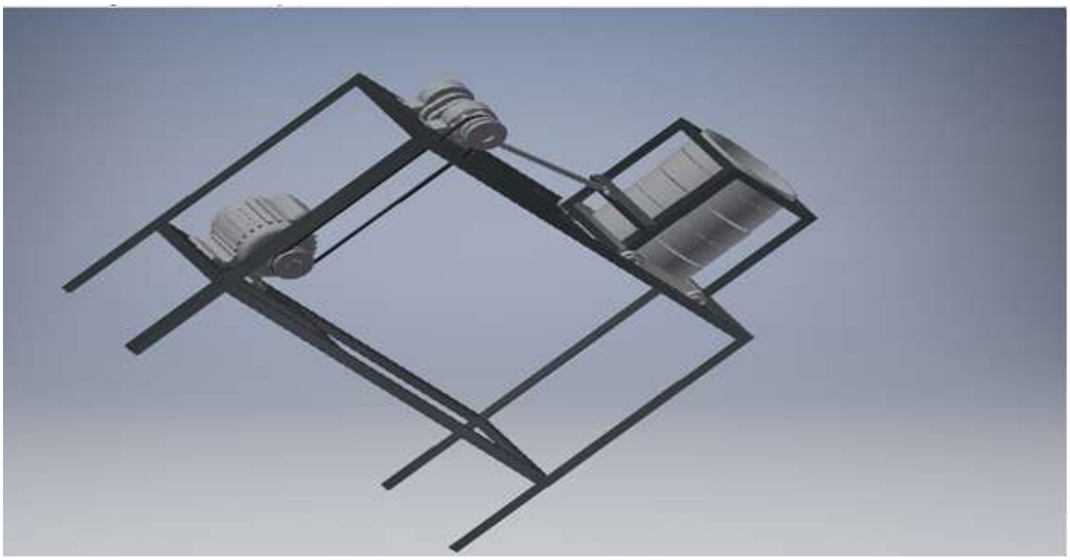

Fig.1: 3-D Sketch of the Rot-oscillatory particle size analysis device

2.5 Design Analysis of the Device

Design is the transformation of concepts and ideas into useful machinery [7]. The design of rot-oscillatory particle size analysis is presented below.

2.5.1 Design consideration of shaft:

A shaft is the rotating machine element which transmits power from one place to another [8]. The shaft of the rot-oscillatory article size analysis device which revolves at a reasonable speed as the connecting rod is linked with the sieve assembly thereby transforming the rotational motion of the crankshaft to reciprocating motion of the sieve assembly in effecting sieving is subjected to twisting moment in operation.

For a shaft subjected to a twisting moment only, the diameter of the shaft was obtained by using the torsion equation given in equation 1 below:

$$T = \frac{\pi}{16} X \gamma X d^3 (1)$$

Where;

T = Twisting moment (Nm)

γ = Torsional sheer stress (N/m^2) given as 42mpa [8].

d = Diameter of the shaft (m)

[8]developed equation for the determination of twisting moment (T) for a belt drive as shown in equation (2) below:

$$T = (T_1 - T_2)R \qquad (2)$$

Where;

T_1 = Tight side tension of the belt (N)

T_2 = Slack side tension of the belt (N)

R = Radius of the pulley (m)

2.5.2 Determination of shaft speed:

To calculate the shaft speed, the following parameters were used:

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \ (3)$$

Where;

D_1 = Diameter of the driving pulley (mm)

D_2 = Diameter of the driven pulley (mm)

N_1 = Speed of the driver (rpm)

N_2 = Speed of the follower (rpm)

This shaft speed is only obtained when there is no slip condition of the belt over the pulley. When slip and creep condition is present, the speed value is reduced by 4% [9].

2.5.3 Determination of length of the belt, L:

[8]developed equation for calculating the length of belt as shown below:

$$L = \frac{\pi}{2}(D_1 + D_2) + 2x + \frac{D_1 + D_2}{4x} \quad (4)$$

Where;

L = Belt length (mm)
x = Centre distance between larger pulley and the smaller pulley (mm)
D_1 = Smaller sheave diameter (mm)
D_2 = larger sheave diameter (mm)

2.5.4 Design of pulley or sheave:

The rotor's pulley diameter was selected using the equation speed ratio shown in equation (5) below:

$$D_r = \frac{D_m N_m}{N_r} \quad (5)$$

N_m = Rotational speed of the powered engine = 850rpm
D_m = Measured diameter of the engine pulley = 60cm
N_r = Rotational speed of the smaller pulley (rpm)

The speed of the smaller pulley (follower) must be high enough to generate air of velocity greater than the critical velocity of the flour to be conveyed and discharged at the cyclone.

2.6 Selection of belt type:

Belts are of different types based on the power ranges and dimensions as shown in table below.

2.6.1 Determination of the belt contact angle

The belt contact angle is given by the equation

$$\mathrm{Sin}^{-1}\,\beta = \left(\frac{R-r}{C}\right) \quad (6)$$

Where

R = Radius of the larger pulley (mm)
r = Radius of the smaller pulley (mm)
C = Centre distance between the larger pulley
β = Belt contact angle (°)

The angle of wrap for the pulleys are given by:

$$\alpha_1 = 180 - \mathrm{Sin}^{-1}\left(\frac{R-r}{C}\right) \quad (7)$$

$$\alpha_2 = 180 + \mathrm{Sin}^{-1}\left(\frac{R-r}{C}\right) \quad (8)$$

Where

α_1 =angle of wrap for the smaller pulley, (^{0})
α_2 =angle of wrap for the larger pulley (^{0})

Comparing the capacities $e^{\mu^a/\sin\frac{1}{2}\theta}$ of the pulley using $\mu = 0.25$; $\theta = 40^0$

For the smaller pulley e^0 25x3.04/sin20^0 = 9.22

For the larger pulley e^0 0.25 x 3.04sin20^0 = 10.68 [9]

Since that of the larger pulley is higher, the larger pulley governs the design.

2.6.2 Determination of the Torque and power transmitted to the shaft

Power transmitted to the shaft is given by

$$p = (T_1 + T_2)\,V \quad (9)$$

Where

T_1 = Tight side tension of the belt (N)
T_2 = Slack side tension of the belt (N)
V = shaft speed (m/s) [10].

2.7 Selection of Bearing

Ball rolling contact bearing of standard designation 307 was selected for the Rot-oscillatory particle size analysis device. This selection was based on the type of load the bearing will support when at rest and during operation and also based on the diameter of the shaft.

The designation 307 signifies medium series bearing with bore (inside diameter) of 25mm [8].

2.8 Theoretical throughput capacity

The throughput capacity is the quantity of material moved, produced or separated per unit time. It can be volumetric or gravimetric. The volumetric throughput capacity was obtained by

$$Q = VA\theta \tag{10}$$

Where

V = velocity of flour passing through each sieve (m/s)
A = Area available for flow of material (m^2)
θ = Coefficient of filling

2.9 Determination of the device efficiency

$$\text{The device efficiency (\%)} = \frac{Q_{fm}}{Q_t} x100 \tag{11}$$

Where

Q_{fm} = Quantity of flour fed into the device (10.5g)
Q_t = Quantity of material (flour) after sieving (12g)

2.10 Power requirement

The power requirement for the rot-oscillatory particle size analysis device was obtained by equation (12)

$$\rho = Q_g Hf \tag{12}$$

Where

H = Height of lift
f = power factor [11].

2.11Determination of the percentage of flour passing through each sieve

The per cent of aggregate passing through each sieve was obtained by equation (13)

$$\% \text{ Retained} = \frac{W_{sieve}}{W_{total}} x\ 100\% \tag{13}$$

Where

W_{sieve} = Weight of aggregate in the sieve (kg)
W_{total}= Total weight of the aggregate (kg)
% Cumulative passing = 100% - % Cumulative Retained [12].

2.12Performance Evaluation

Performance evaluation is a vital step in the process of machine development[13]. After the design and construction, testing is necessary in order to determine the machine performance, exposed defect and area of possible improvement, and appreciate the level of success in the research. Thus, it is important to test and run a machine to determine its work ability and efficiency.

The performance evaluation of the rot-oscillatory particle size analysis device was done at the experimental site of Agricultural and Bio-resources Engineering, University of Nigeria, Nsukka. This evaluation spans through the physical observations and rate of sieving of the flour. The device was evaluated 10 times in December, 2017.

2.12 Procedures used for the testing

Sample of corn and cassava flour was obtained from the market for the performance evaluation. 2kg of dry cassava flour was fed into the device through the set of sieves while machine was off. After feeding the flour, the device was on for 2 minutes to sieve the flour into 5 different particle sizes simultaneously.

III. RESULTS AND DISCUSSIONS

The results obtained from the investigations carried out was used for the computation of the device's parameters as shown in table 2 and 3

3.1 Results of the calculated parameters

The results obtained from design calculations are presented in table 2 below.

Table 2: The physical and technical specifications of the device

S/No	Specifications	Values obtained	Units
1.	Shaft speed	250	rpm
2.	Length of belt	23	cm
3.	Rotor's pulley diameter	06	cm
4.	Driving pulley diameter	03	cm
5.	Shaft twisting moment	19.79	Nm
6.	Driven pulley diameter	12	cm

7.	Belt cross-sectional Area	2.87	mm^2
8.	Size of Bearings	3.0	cm
9.	Belt maximum tension	56.0	N
10.	Belt contact Angle	56.0	Degree
11.	Percentage of flour passing through sieves	69.5	%
12.	Through-put capacity	60	Kg/hr
13.	Device efficiency	86.5	%

3.2 Performance Evaluation

The performance evaluation of the rot-oscillatory particle size analysis device was based on the criteria of throughput capacity (kg/hr) and the device efficiency (%)as earlier reviewed in equations 10 and 11.
The values obtained are recorded in table 3 below.

Table 3: Summary of Performance of the Device

S/No.	Parameters	Values Obtained	Units	Time taken
1.	Quantity of cassava flour handled by the device	2	kg	1min. 48 sec.
2.	Quantity of corn flour handled by the device	2	Kg	2 minutes
3.	Through-put capacity	60	Kg	1 hour
4.	Device efficiency	86.5	%	-

The performance evaluation conducted for the determination of the device efficiency is presented in plate1below.

Plate 1: Photo showing the evaluation of the machine performance

Table 4: PerformanceEvaluation of the Device

Quantity (kg)	1	1	1	1	1	1	1	1	1
Series 1									
Time taken for Cassava flour (sec)	43	45	50	50	51	50	52	53	54
Series 2									
Time taken for Corn flour (sec)	58	58	59	60	61	61	62	63	63

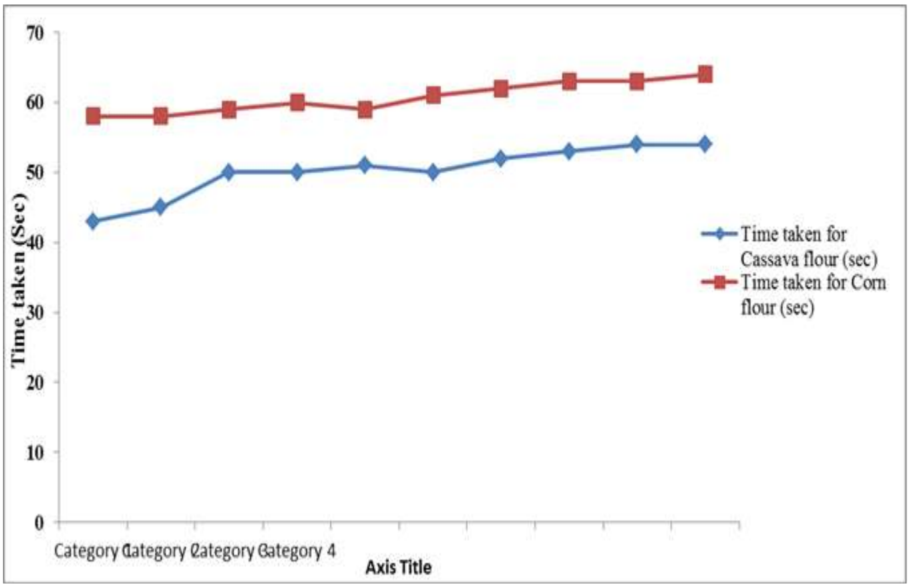

Fig 2.A graph showing the quantity of Cassava and Corn flour handled by the device

Fig. 2 above showed a graph of quantity Cassava and Corn flour handled by the device. The variations in the bars are as a result of the values obtained during the performance evaluation. It can be seen that, the rate of sieving is faster in cassava flour because of its aerodynamic property. The time taken to categorized cassava flour is less compare to that of the corn flour. This is due to the fact that cassava flour is lighter and easily passes through the sieve faster than corn flour.

3.3 Discussions

Table 2 showed that, the rot-oscillatory particle size analysis device based on its design, operated at a speed of 250rpm and was able to categorized 2kg of food flour into 5 different particle sizes in a minutes which is better than [14] device that is only capable of handling particle size range of 40 µm and 125 mm. The measurement range of [14]is limited by properties of the sample such as a tendency to agglomerate, density or electrostatic charging.

During the performance evaluation it was discovered that, the rot-oscillatory particle size analysis device need to be off before loading the flour. The machine was found to be dust free and the parts do not wear when running freely.

From these results obtained, the machine is effective. It has a throughput capacity of 60kg/hr and machine efficiency of 87.5%. The efficiency proves that the machine has served its purpose.

IV. CONCLUSIONS AND RECOMMENDATIONS

The results obtained from the design and performance evaluation showed that, the rot-oscillatory particle size analysis device was designed, fabricated, tested and found to have a throughput capacity 60kg/hr and efficiency of 87.5% also a speed of 250rpm. From the results the following conclusions were made:

1. The machine efficiency was influenced by the strength of the electric motor.
2. There was no damage by the shaft to the sieving component at a speed of 250rpm.
3. The device was able to categorized 5 particle sizes of flour after 1minutes of operation.

Thus, with the extensive job done on the basis of the design, fabrication and performance evaluation of the device as stated above. The aims and objectives of undertaken this project have been achieved. The use of the rot-oscillatory particle size analysis will help reduce the drudgery involve in analyzing flour particle sizes during processing of biomaterials to the minimum level.

The following recommendations are considered pertinent for the maintenance of the rot-oscillatory particle size analysis device:

i. For mass production of the device, stainless steel materials should be used in construction.
ii. An electric motor of rated speed up to 250rpm, 2.0 HP may be used as a power source.
iii. Field trial of the machine performance may be undertaken and the experience gained should be used to optimize the design of the device if necessary.
iv. Given the level of performance achieved. It is recommended that, this rot-oscillatory particle size analysis device should be manufactured and popularized for adoption to avoid drudgery involve in particle size analysis.

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