Improvement on Design Analysis and Construction of 'Garri' Sieving Machine with Performance Evaluation

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ABSTRACT : *This work is mainly concerned withimproving the design analysis and construction of garri sieving machine for better performance. The performance of the sieving machineis also evaluated for quality assurance. The sieving action is achieved by reciprocation of the sieve using the principle of slider-crank mechanism, which was used to set the sieve housing into motion. The machine is powered by 1-horse power (0.745 kW) electric motor with angular speed of 900 rpm. In order to compare its efficiency with the manual sieving method, sieve of average mesh size 2 mm by 4 mm were used each for sieving machine and the manual sieve. The result of the performance test carried out shows that the average sieving efficiency and the sieving rate of the machine are better than that of the manual sieving method. Therefore, this work presents a meaningful contribution to the processing of garri, which is a staple food in West Africa. The material used for the sieve and its housing were stainless steel to prevent contamination of garri. This makes it edible and free of germs during sieving action.In addition, the machine eliminates the use of hand to sieve garri unlike the manual method where there can be contamination.*

Keywords: Analysis,design, Garri and Improvement.

I. Introduction

Cassava (Manihot esculenta) is a crop, which has high content in starch and is usually processed to edible form of foodstuff before consumption. It is mainly grown in Brazil, Nigeria and some Asian countries like China. Cassava production is high in Africa with 62% of total production in the world [1]. As evidence, cassava is one of the widely grown consumable food crops in the southern and eastern part of Nigeria. This is because it can be transformed from its raw form (tuber) to several finished products, which can serve as food for human consumption such as 'garri', 'fufu', and cassava flour etc. Ethanol, which serves as biofuel, can also be produced from cassava.

Garri is made from peeled, fermented, dewatered, pulverized, sieved and dried cassava tuber. It has a sour taste and white in colour. When dried by roasting it becomes granules and these granules need to be reduced in size to make it more edible. This edible form of garri is used to produce another food prepared with the use of hot water. This food is known as 'Eba' that is consumed withdifferent kind of soups in Nigeria. Garri is also a staple food because it is largely consumed by people in Nigeria and can be stored for a very long time without affecting its edibility.

The design of the sieving machine helps in producing "garri" from unroasted and roasted cassava that has been processed in large quantities. In order to process and produce garri for human consumption, a modified form of garri sieving machine was designed and constructed using some suitable materials in order to remove the possibility of contaminating the garri which is common in the manual sieving method.

Odigboh, [2], developed prototype of a machine, which can pulverize and sift garri mash. This machine is capable of handling 125 kg of garri mash per hour by producing more uniform garri mash than the one produced by manual method. This machine is only suitable for use in small and medium scale cassava processing industries and not for domestic use.

However, a sieving machine whose principle of operation is also slider – crank mechanism was designed and constructed by Ogunleye, [3]. The sieving efficiency of the machine was 78% while the sieving rate was 1 kg/ min. The peripheral speed of the v–belt of the machine was 1.178 m/s, which was too low for the v –belt drive. V–belts can only be used for peripheral speed between 5 m/s and 50 m/s.

Fayose [4] developed a multipurpose wet sieving machine which extracts starch utilizing mechanism of shaking. The machine was developed to solve the problem associated with sieving of starch and other agricultural products in Nigeria. This machine is easy to operate and its maintenance is simple. The highest performance coefficient obtained was 98%. Therefore, it is recommended for use in small and medium scale industries.

A simple and relatively cheaper cassava-peeling machine was designed and fabricated by Abdukadir [5]. The problems of peeling and contamination of cassava by hand has been solved with the existence of this machine which is based on principle of turning using lathe machine. It was recommended further that research should be made on how to increase the efficiency of the machine, which was 65.5%.

Another sifting machine was developed by Adetunji et.al. [6]. This machine runs on a single phase 1hP electric motor at a speed of 1400 revolution per minute (rpm). The result obtained from the performance evaluation shows that it has a sieving efficiency of 92.5%. This shows an improvement in the performance of the machine when compared to previous machines developed.

A sieving machine driven by pedal was designed by Olawale et.al. [7]. The machine is used for sieving dewatered grated cassava. The mechanism of the machine is similar to that of the bicycle in which rotational motion is transmitted to the sieving machine from the pedal so that useful mechanical work can be done. However, human effort is required to drive the machine manually through the pedal.

This present work aims at improving the design analysis and construction of garri sieving machine, which utilizes the principle of slider-crank mechanism. The rotational motion of the crank is converted to the reciprocating motion of the sieve housing through the connecting rod, hence the sieving action.

II. Brief Description of the Machine

The garri sieving machine was designed and constructed to sieve garri hygienically because of the hands-free operation involved and utilization of suitable material which will not make the garri susceptible to contamination. The machine utilizes the principle of slider-crank mechanism in its operation. There is a disc(crank) mounted on driven shaft which is driven by 1-horsepower (0.745 kW) electric motor with angular speed of 900 rpm. Whenever the it rotates, the rotational motion is converted to the reciprocating motion of the sieve case with the presence of the connecting rod attached to the disc. Therefore, the reciprocating action of the sieve housing leads to the sieving action of the garri particles.

Suitable materials were selected for the machine parts (as shown in Fig. 3) to ensure optimal performance of the sieving machine and avoid contamination of garri.

III. Design Considerations

a) Material selection for the sieve. Suitable materials were selected for the machine parts having considered corrosion resistance, cost, weight etc.
b) Mechanism: slider-crank mechanism was utilized in moving the sieve housing.
c) Convenient features (Ergonomics). All the parts were located at convenient positions for ease of operation and control.
d) Type of load and stresses caused by the load. Bending stress on the driven shaft, shear stress on the driven shaft, radial load on the driven shaft etc.
e) Use of standard parts. The parts and parameters were chosen according to Indian Standard (IS: 2494 – 1974).
f) Maintenance. Cleaning and lubrication of machine parts are easy. In addition, it is easy to replace any damaged part by the service personnel because of the simplicity of the machine.
g) Cost of production. Cost effectiveness is also considered, this can be demonstrated in a situation where the machine is produced en-masse for sale.
h) Hygiene. The sieved garri will be hygienic because of the hands-free sieving process and suitable material used unlike the manual method of sieving garri.

IV. Machine Design Analysis

a) For the evaluation of pulley diameters, the speed ratio of the driving and driven shaft is given by:

$$Speed\ ratio = \frac{Speed\ of\ driving\ shaft}{Speed\ of\ driven\ shaft} = \frac{Diameter\ \ of\ driven\ \ pulley}{Diameter\ \ of\ driving\ \ pulley} \qquad (1)$$

The speed reduction ratio 1.62:1 was chosen in order to reduce the speed of the driving pulley which is 900 rpm to the desired speed. The service factor which is determined by the service condition is 1 from the table of standard showing v-belt service factor [8].

$$Design\ power = Power\ transmitted\ \times Service\ factor (2)$$

i. **The diameter of the driven pulley, D_1** is 170 mm. Therefore, from equation (1), the diameter of the driving pulley, D_2 will be 105 mm considering the speed reduction ratio. The centre distance, ***c*** which should not be less than the diameter of the larger pulley is chosen to be 200 mm.

ii. **The peripheral speed, *v*** of the belt can be determined from the equation below:

$$v = \frac{\pi D_1 N_1}{60} \quad (3)$$

$$= \frac{\pi \times 0.105 \times 900}{60}$$

$$= 5.0 m/s$$

The above value of peripheral speed is good and economical for a v-belt drive because centrifugal tension prevents the use of v-belt below the speed of 5 m/s[9].

iii. **The angle of contact on the larger and smaller pulleys** are determined below respectively from the relations:

$$\theta_1 = (180^o + 2\sin^{-1}\frac{R_1 - R_2}{c})\frac{\pi}{180^o} \quad (4)$$

$$= 3.46 rad$$

$$\theta_2 = (180^o + 2\sin^{-1}\frac{R_1 - R_2}{c})\frac{\pi}{180^o}$$

$$= 2.82 rad$$

iv. **Length of belt can determined from the relations below**:

$$L = \frac{\pi}{2}(D_1 + D_2) + 2c + \frac{(D_1 - D_2)^2}{4c} \quad (5)$$

$$= 873 mm = 0.873 m$$

v. Area of the v-belt:

A = Top width of the belt (b) x Thickness of the belt (t) (6)

From the table of standard (IS: 2494 – 1974)

$$A = 13 \times 10^{-3} \times 8 \times 10^{-3}$$

$$= 104 \times 10^{-6} m^2 = 0.000104 m^2$$

vi. Mass density of belt:

$$m = A \times l \times \rho \quad \textbf{(7)}$$

l = unit length of the belt

ρ = density of rubber belt = $= 1140 kg/m^3$

$m = 0.12 kg/m$

vii. **Centrifugal tension in the belt**:

$T_c = mv^2$

$T_c = btl\rho v^2$ (8)

$= 3N$

viii. Maximum tension in the belt

$T = \sigma \times A$

$= 183.04N$

ix. Tension on the tight side of the belt

$T_1 = T - T_c$

$= 183.04 - 3$

$= 180.04N$

$$2.3\log\frac{T_1}{T_2} = \mu\theta\cos ec\beta \quad \textbf{(9)}$$

Where μ ,is the coefficient of friction between the rubber belt and steel pulley. The products of μ and θ for the larger and smaller pulleys were compared; the smaller pulley has the smallest value. This implies that the smaller pulley governs the design. The groove angle is chosen to be $2\beta = 40^0$, therefore $\beta=20^0$.

$$2.3\log\frac{180.04}{T_2} = 0.3 \times 2.823\cos ec20^o$$

$$\log\frac{180.04}{T_2} = \frac{0.3 \times 2.823\cos ec20^o}{2.3}$$

Taking antilog of both sides;

$T_2 = 15.32N$

x. Power transmitted by belt:

$P = (T_1 - T_2)v$ (10)

$= 180.04 - 15.32)5$

$= 823.6\text{ W}$

$= 1.10\text{ Hp}$

xi. Torque exerted on the larger pulley:

$T_l = (T_1 - T_2)R_1$ **(11)**

$= (180.04 - 15.32)0.085$

$= 14.0Nm$

xii. Torque exerted on smaller pulley:

$T_s = (T_1 - T_2)R_2$ **(12)**

$= (180.04 - 15.32)0.0525$

$= 8.65Nm$

b) Design of driven shaft:

The material selected for the driven shaft is low carbon steel 1018, the yield strength is 370 MPa while the diameter $\boldsymbol{d}$ of the shaft is 25 mm. The weights of the flywheel, $\boldsymbol{w}$ and the driven pulley, $\boldsymbol{w_p}$ mounted on driven shaft are 74 N and 117.7 N respectively. The torque, load and bending moments were determined and the maximum bending moments $\boldsymbol{M}$ is 35.94 Nm as shown in Fig 1.

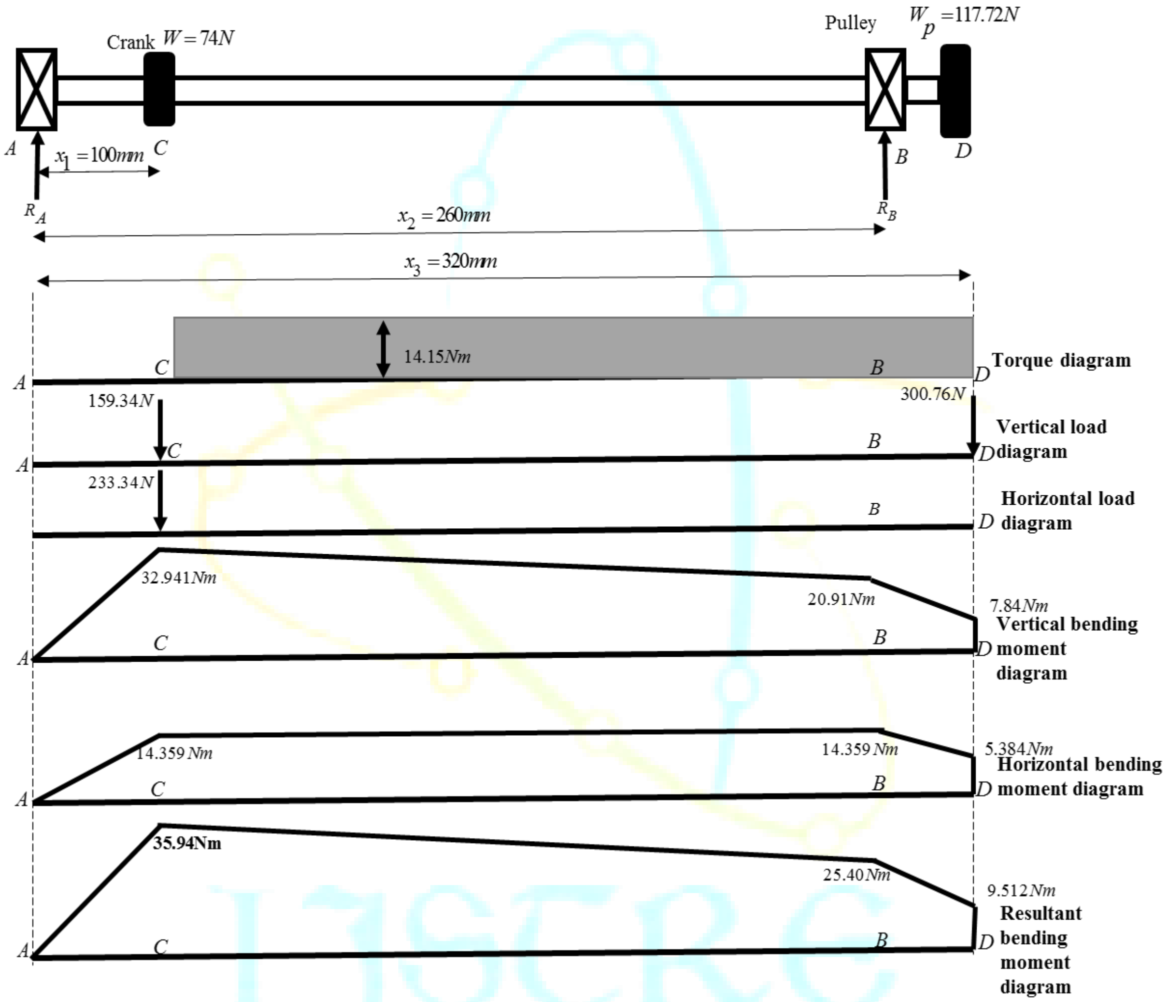

Fig. 1. Torque, load and bending moment diagrams

i. The bending stress developed in the shaft;

$$\sigma_b = \frac{M}{z} \quad \textbf{(13)}$$

$z = \dfrac{\pi d^3}{32}$; where z is the second moment of area

$$\sigma_b = \frac{32M}{\pi d^3}$$

$= 23.42 MPa$

If the axial stress σ_a is negligible on the driven shaft, then the tensile stress σ_t is equal to bending stress σ_b .

ii. **The shear stress, τ developed in the driven shaft of radius r :**

$$T_l = \frac{\tau J}{r} \quad (14)$$

The shear stress developed from (14) is:

$$\tau = \frac{T_l r}{J}$$

$$J = \frac{\pi d^4}{32}$$

Where J is the polar moment of inertia.

$$\tau = \frac{32 T_l r}{\pi d^4} \qquad (15)$$

$= 4.611 MPa$

iii. Maximum shear and bending stresses developed in the shaft

$$\tau_{max} = \frac{16 T_e}{\pi d^3} \quad (16)$$

Where T_e is the equivalent twisting moment, which can be determined from the values of M and T_l ;

$T_e = \sqrt{M^2 + T^2}$

$= 38.63 Nm$

$\tau_{max} = 12.6 Mpa$

Maximum bending stress

$$\sigma_{b\,max} = \frac{32 M_e}{\pi d^3} \qquad (17)$$

Where M_e is the equivalent bending moment;

$$M_e = \frac{1}{2}(M + \sqrt{M^2 + T^2})$$

$$= \frac{1}{2}(M + T_e)$$

$$= 37.3Nm$$

$$\sigma_{b\max} = 24.31MPa$$

c) Movement of sieve case in relation to crank positions

Connecting rod of length ***L*** converts rotating movement of the disc (crank) of radius ***R*** to the reciprocating movement of the sieve housing. It also determines the length of travel ***x*** of the sieve housing from inner dead centre (IDC) to outer dead centre (ODC) in Figure 2.

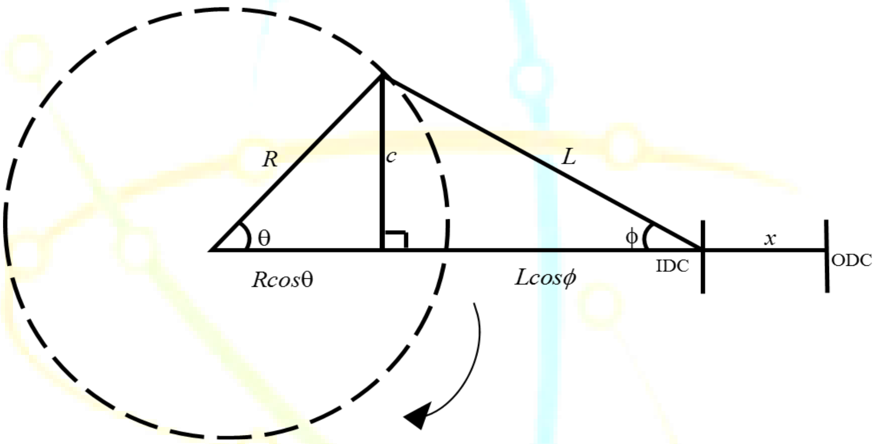

Fig. 2: Schematic diagram of slider – crank mechanis

i. Sieve movement

From trigonometry,

$$\cos^2\phi + \sin^2\phi = 1$$

$$\cos^2\phi = 1 - \sin^2\phi$$

$$\cos\phi = (1 - \sin^2\phi)^{1/2} \quad (18)$$

From **Fig. 2**

$$x = [(R + L) - (R\cos\theta + L\cos\phi)] \quad \textbf{(19)}$$

$$\sin\phi = \frac{c}{L} \quad \textbf{(20)}$$

$$\sin\theta = \frac{c}{R} \qquad \textbf{(21)}$$

$$c = R\sin\theta \qquad \textbf{(22)}$$

Substituting for c in (20)

$$\sin\phi = \frac{R\sin\theta}{L} \qquad (23)$$

$$= \frac{\sin\theta}{L/R}$$; L=120 mm; R=60 mm

Let the ratio of ***L*** to ***R*** be equal to ***m***, the ***m*** is equal to 2. Substituting for $\boldsymbol{\sin\phi}$ in (18);

$$\cos\phi = (1 - \frac{\sin^2\theta}{m^2})^{1/2} \qquad (24)$$

Also substituting for $\boldsymbol{\cos\phi}$ in (19)

$$x = [(R + L) - (R\cos\theta + (1 - \frac{\sin^2\theta}{m^2})^{1/2}] \qquad (25)$$

Angle Ɵ varies from 0^0 to 360^0.

when $\Theta = 0^0$,

$x = [(0.18 - (0.06) + 0.12(1)]$

when $\Theta = 90^0$,

$x = 0.28392m = 283.92mm$

when $\Theta = 180^0$,

$x = 0.36m = 360mm$

when $\Theta = 270^0$,

$x = 0.28393m = 283.93mm$

when $\Theta = 360^0$,
$x = 0$

ii. Inertia force of the reciprocating sieve case

Let the velocity and acceleration of the sieve case at crank angle 60° be v_S and a_S respectively.

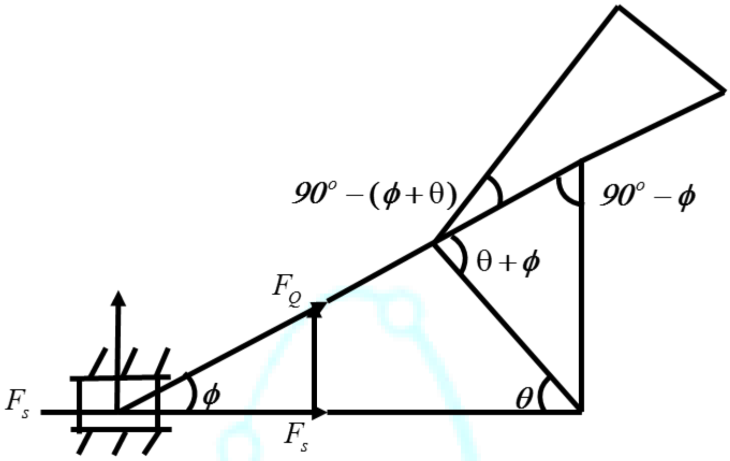

Fig. 2: **Forces acting on the reciprocating parts**

$$v_S = \omega . R(\sin\theta + \frac{\sin 2\theta}{2m}) \quad (26)$$

$$\omega = \frac{2\pi N}{60}; N = 900rpm$$

$$\omega = 58.2 rad / s$$

$$v_S = 3.782 m / s$$

$$v_S = \omega^2 . R(\sin\theta + \frac{\sin 2\theta}{2m}) \qquad (27)$$

$$= 50.843 m/s^2$$

The inertia force F_I of the sieve case;

$$F_I = M_S a_S \quad (28)$$

Where M_S is the mass of the sieve case

$$F_I = 915.2N$$

iii. Net force acting along the line of stroke, F_S negelecting the frictional resistance

$$F_S = (M_G + M_S)g \pm F_I \quad (29)$$

Where M_G **and** M_S are the masses of garri and the reciprocating sieve housing respectively.

$$M_S = \rho_S V$$

Where ρ_S and V are the density of stainless steel (7480 kg/m^3) and volume of the sieve housing respectively.

$M_S = 85kg$; $M_G = 6kg$ (tha maximum load of garri on the sieve)

For accelerated sieve case,

$F_S = (892.71 - (-915.2)$

$= 1807.91\,\text{N}$

Negative sign was used because the sive case is accelerating i.e. it is moving from inner dead centre (IDC) to outer dead centre (ODC) because it opposes the force on the sieve case.

iv. Force F_Q acting along the connecting rod

From (23)

$$\frac{L}{R} = \frac{\sin\theta}{\sin\phi} = 2 \text{ ; if } \theta = 60^{o}$$

$$\phi = 25.6^{o}$$

$$F_Q = \frac{F_S}{\cos 25.6^{o}} = 2004.34N \qquad (30)$$

d) Design of hopper

$$\text{Volume} = length \times breadth \times height = (360 \times 320 \times 300)mm^3$$
$$= 34560000\ mm^3$$

e) Design of frame

Angular bar (mild steel) of dimension 550 mm by 500 mm by 600 mm was used in order to give enough support to the machine during operation.

f) Bearing selection:

Two rolling contact bearings were selected and mounted on the driven shaft in order to bear the load imposed on it. This bearing was chosen because of its ability to withstand momentary shock loads and accuracy in shaft alignment. Also, it is reliable in service, has low cost of maintenance and easy to mount on the shaft.

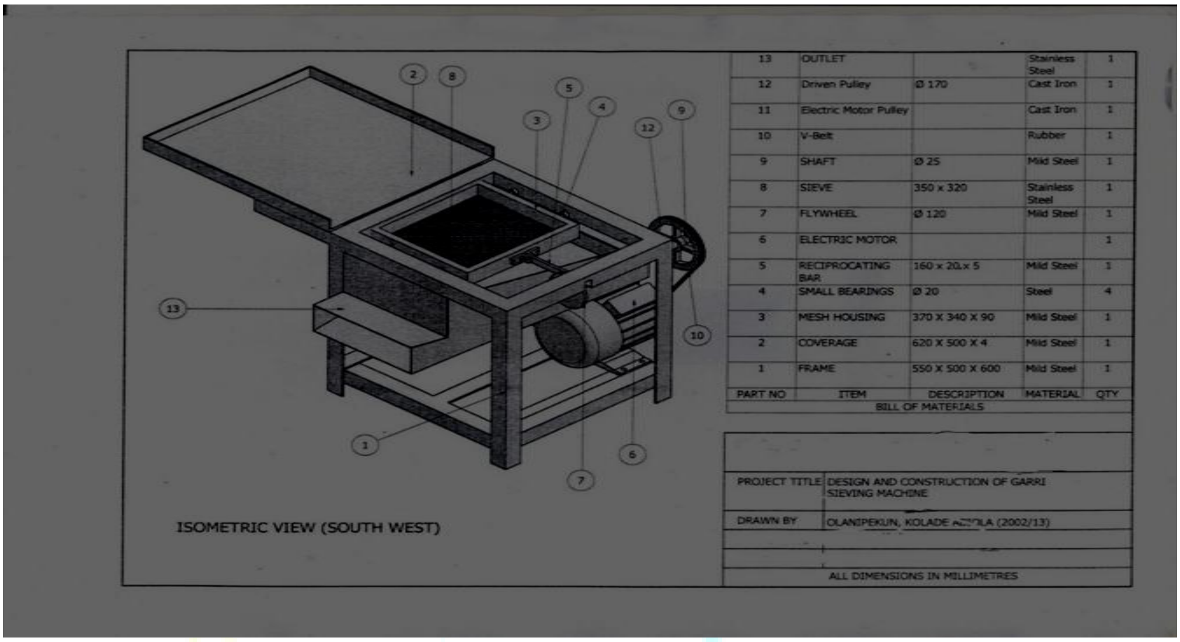

Fig. 3. Isometric view of the sieving Machine

6.0 Performance Test Results on roasted and unroasted garri

6.1 Procedures

a) The mass of an empty container (m_c),was measured and recorded.
b) The container was filled with garri and the mass (m_{cg}), was recorded. Thus the mass of garri m, in the container is the difference between $m_{cg}$and m_c.
c) Garri of mass m was poured into the sieve housing for sieving.
d) The sieving process is allowed for a particular time and the amount of garri (m_s) sieved is measured and recorded.
e) The average sieving rate s_r in kg/minwas determined and recorded.

f) The average sieving efficiency s_e in % was determined and recorded.

The sieving rate and the sieving efficiency were calculated with the formulae below:

Sieving rate, $$S_r = \frac{m_s}{t} \times 60 \quad (31)$$

Sieving efficiency, $$S_e = \frac{m_s}{m} \times 100 \quad (32)$$

Table 1: Values of sieving parameters for manual sieving method (Roasted garri)

Mass of garri, m (kg)	Mass of garri sieved m_s(kg)	Time taken to sieve t(s)	Sieving efficiency (%)	Sieving rate (kg/min)	Sieve movement (rec/min)
0.600	0.337	3.95	56	5.119	122
1.200	0.601	6.01	50	6.000	110
1.800	0.856	7.50	48	6.848	104
2.400	1.104	9.75	46	6.794	92
3.000	1.300	11.42	34	6.830	87
3.600	1.188	14.04	33	5.077	90

Table 2: Values of sieving parameters for sieving machine (Roasted garri)

Mass of garri, m (kg)	Mass of garri sieved m_1(kg)	Time taken to sieve t(s)	Sieving efficiency (%)	Sieving rate (kg/min)	Sieve movement (rec/min)
0.600	0.582	3.40	97	10.27	300
1.200	1.136	5.56	95	12.26	248
1.800	1.683	7.00	94	14.43	213
2.400	2.269	8.99	95	15.14	220
3.000	2.790	10.66	93	15.70	214
3.600	3.362	12.70	93	15.90	208

Table 3: Values of sieving parameters for manual sieving method (Unroasted Garri)

Mass of garri, m (kg)	Mass of garri sieved m_1(kg)	Time taken t(s)	Sieving efficiency(%)	Sieving rate (kg/min)	Sieve movement (rec/min)
0.700	0.337	4.55	53	4.905	119
1.400	0.601	6.12	43	5.892	108
2.100	0.856	8.27	41	6.210	102
2.800	1.104	10.64	39	6.226	102
3.500	1.424	12.59	29	6.786	88
4.200	1.788	14.10	29	7.610	86

Table 4: Values of sieving parameters for sieving machine (Unroasted Garri)

Mass of garri, m (kg)	Mass of garri sieved m_1(kg)	Time taken t(s)	Sieving efficiency (%)	Sieving rate (kg/min)	Sieve movement (rec/min)
0.700	0.585	4.40	84	8.76	270
1.400	1.100	7.14	91	9.24	264
2.100	1.780	10.80	87	9.88	231
2.800	2.490	14.70	89	10.16	233
3.500	2.990	17.18	85	10.44	237
4.200	3.181	20.66	76	10.75	229

Fig. 4. Garri sieving machine showing the detachable hopper

V. Discussion

The results of the performance test are as shown in Tables 1 to 4 when the sieves of mesh size 2 mm by 4mm was used to sieve garri on both the machine and the manual sieving method. This is necessary so that the results from both methods can be compared.

However, the results of the performance test show that the machine is capable of sieving average of 13.948 kg of roasted garri within one minute and 9.802 kg of unroasted garri at the same period of time. Also the average sieving efficiency of the machine for roasted and unroasted garri was found to be 94.35% and 82.83% respectively. The results obtained from the manual sieving method show that average of 6.325 of roasted garri and 5.945 kg of unroasted garri were sieved within one minute. The average sieving efficiency obtained from the manual sieving method was 47.14% when roasted garri was sieved and 40.84% when unroasted garri was sieved. Therefore the sieving rate of the sieving machine were found to be approxiamately221% and 165% of the manual sieving method for roasted and unroasted garri respectively. Also, there is an increase in the efficiency of the machine compared to the existing one. Inclusion of hopper prevents undesired movement of garri particles out of the sieve housing during operation of the machine and also increase the quantity of garri that can be fed into the machine for sieving.

The operation and preventive maintenance of the machine is very easy. It is very useful in the medium scale garri processing industry because of the aforementioned comparative advantages over the manual method. The sieve can easily be removed and cleaned with mild detergent.

VI. Conclusion

Improvement on the design analysis and construction of garri sieving machine has been done. The comparative performance test shows the machine is better thanthe manual method of sieving which is associated with hard labour, contamination of garri and longer time of processing. It is obvious that the machine is capable of working continually which reduces the effort applied by the operator and the idle time thereby increasing the production output of garri.

VII. Recommendations

Based on what has been done so far, the following recommendations were made:

- Further work should be done to increase the sieving efficiency of the machine when unroasted garri is of interest.
- The critical speed of the driven shaft (considering the pulley and the disc mounted on it) be determined at the design stage in order to prevent failure and breakdown of the whole machine.
- The noise emitted from the machine during operation should be reduced by suitable noise reducing materials where possible in the machine parts.

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REFERENCES

[1] Hillocks, R., 2002. 'Cassava in Africa in R. Hillocks, J.Tresh, and A.C. Belloti eds., Cassava Biology, Production and Utilization CABI Publishing.
[2] Odigboh, E.U. and Ahmed S.F., 1984. 'A machine for Pulverizing and Sifting Garri Mash' NIJOTECH Vol. 8 No. 1 Pp 19 – 23.
[3] Ogunleye, O.O., 2003. 'Design and Fabrication of Garri Sieving Machine'. An Unpublished B.Eng. Thesis Submitted to the Department of Mechanical Engineering, University of Ado – Ekiti, Ekiti State, Nigeria.
[4] Fayose, F.T., 2008. 'The Development of a Multipurpose Wet Food Sieving Machine. Agricultural Engineering International: The CIGR Ejournal, ManuscriptFP 08 006. Pp 1- 9.
[5] Abdukadir B.H., 2012 ;Design and Fabrication of Cassava peeling machine'. IOSR Journal of Engineering, ISSN: 2250 – 3021 Vol. 2. Pp 1 – 8.
[6] Adetunji, O.R., Dairo, O.U., Aina, T., and Osunlana, A.S., 2013. 'Development of an Improved Garri Sifting Machine'. The Pacific Journal of Science and Technology Vol. 14, No. 2. Pp 54 – 61.
[7] Olawale J.O., Abdukadir, B.H., Abubakar, M., Alhaji A.A.and Dele, S.J., 2014. 'The Design of a Pedal Driven Pulverizing and Sieving Machine for Dewatered Grated Cassava'. International Journal of Scientific and Research Publications, Vol. 4, Issue 4 ISSN 2250 – 3153. Pp 1 – 5.
[8] Sharma, P.C. and Aggarwal, D.K. 2007."Machine Design S.I. Units, S.K. Kataria & Sons, Delhi, India. Pp 667 – 669.
[9] Gupta, J.K. and Khurmi, R.S., 2005, A Textbook of Machine Design, 14th Edition, S. Chand Co. ltd., New Delhi. Pp 726 – 758.