Design Modification and Comparative Evaluation of Integrated Grain Slurry Milling and Sieving Machine

O. M. Egwuagu, B. N. Nwankwojike

Abstract— An integrated machine for processing grain food slurry was modified by replacing its screw conveyor-sieving system with a cake breaker conyeyor-sieve. Comparative performance analysis revealed that this improved the throughput of this machine by 21.86%, 30.31% and 21.25% when maize, millet and soyabean were processed respectively while 38.96%, 42.07% and 33.42% constitute the corresponding increase in its extraction rate. Its specific energy consumption was also reduced by 27.86%, 32.53% and 27.49% with respect to the grains while its average water comsumption rate reduced by 6.9%. Thus, adoption of cake breaker conveyor-sieving system in the development of grain food slurrt processing is recommended.

Index Terms— Cake Breaker Conveyor, Grain Food Slurry, Integrated Machine, Milling, Screw Conveyor, Sieving

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1 Introduction

The high nutritive and demand indices of grain slurry diets in Nigeria prompts continuous search for effective mechanical system for processing it in order to reduce drudgery and waste. Processing of grains to slurry foods involves soaking, milling, sieving and draining. However, sieving constitutes the most tedious process and the only unit operation that has not been successfully mechanized [1]. Although, there are different models of grain slurry sieving machines developed by [1], [2], [3], [4] and [5], grain slurry processing in Nigeria is still characterized by small scale and poor products quality due to prevailing traditional sieving method in this sector [6]. This revealed that the machines developed by these innovators for this sieving process are yet to meet the end users' desires due to some technical shortfalls and this hinders their general acceptance/adoption.

The ogi slurry sieving machine developed by [5], has low sieving rate due the interference of its filtrate flow stream with the suction at the outlet while multi-purpose sieving machine of [4] consumes a lot of water because low concentration of solid particles in the paste improves its performance. In addition, the efficiency of the sieving machine developed by [3] based on vibratory sieving mechanism did not differ from others significantly.

Although, an integrated machine based on compression sieving process using screw press developed by [1] addressed the quest by [2] for integrating the milling and sieving process in this sector to improve hygiene, its poor extraction efficiencies (< 75%) and incessant tearing of its sieve are not desirable. This caused by continuous grinding of the chaff inside the sieve barrel thereby introducing more chaff into the filtrate and blinding of the chiffon material. However, close observation revealed that the traditional food slurry sieving process involves cake breaking-stirring process and the screw press based sieving mechanism of this machine cannot effect this. Since, the aim of developing mechanical system is to reproduce native process while reducing drudgery, there is need for a grain food slurry cake breaking-stirring sieving system in order to meet the end users desire in this sector. Furthermore, the design should provide for the collection of milled grain paste if desired without sieving. Thus, the objective of this study is design modification and comparative evaluation of an integrated slurry food processing machine to ensure its optimal operation and general adoption by the end users.

2 Meterials and Methods

2.1 Machine Description/Manufacturing Procedure

The modified integrated slurry milling and sieving machine shown in Fig. 1 comprises of the frame, 1.5hp diesel engine, milling and sieving units. The diesel engine drives the milling and sieving units. The frame comprises of cuboid welded sections which mounts other units of the machine while the mill consists of a hopper, auger conveyor, grinder and the ground paste discharging chute. The hopper which feeds the soaked grains to the mill is an inverted pyramidal funnel made from a 3mm stainless steel plate with surface and base areas of 0.072m² and 0.004m² respectively. The conveyor con-

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sists of a 20mm stainless steel shaft upon which a 10mm diameter rod was scroll-welded to a length of 0.12m with a pitch of 0.03m for transporting the soaked grains from the hopper to the grinder mounted at its end.

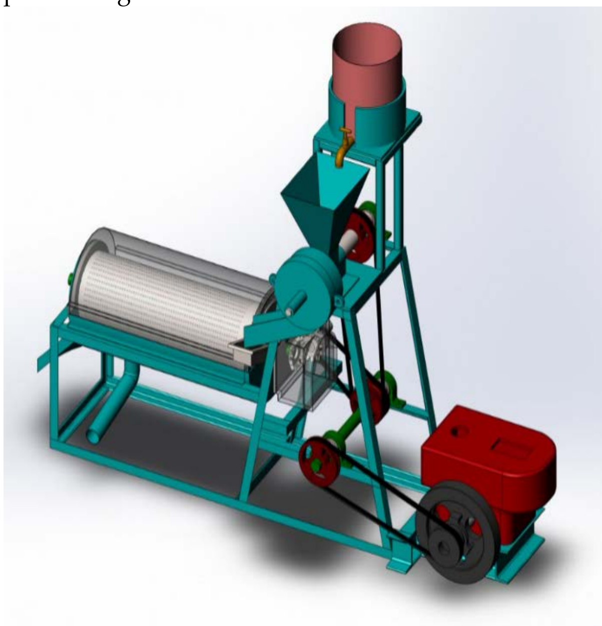

Fig. 1: Modified food slurry milling and sieving machine

The grinder is a pair of 6mm thick, 200mm diameter stainless steel grinding discs housed in a barrel made from a 5mm thick stainless steel plate. Grinding of the soaked grains is effected by the rotatory motion of the unfixed disc as the grains pass through it and the fixed one. An adjustable locknut at the end of the mill shaft regulates the gap between the discs for the achievement of different textures of the ground grain paste as desired. The milled grain paste discharges into the $0.023m^2$ aperture with a regulating plate which opens for the passage of the paste to the sieve and closes when un-sieved grain paste is desired.

Extraction of the slurry food (starch) content of the milled paste is effected in the cake breaker conveyor-sieving unit comprising two different sets of four stainless steel paddles mounted on a 35mm stainless steel shaft housed in a barrel. The first set of the paddles (400mm x 80mm x 5mm) consisting of score pads attached to the edges of slotted flat steel bars welded along the axis of the sieve shaft at the entry of milled paste into the sieving chamber. The un-slotted flat bars of the second paddle set (300mm x 80mm x 5mm) were inclined to the drive axis. The sieve barrel was made by weaving a chiffon cloth inside an 815mm long perforated stainless steel pipe with diameter of 300mm. The perforations are 5mm diameter each with equal spacing of 50mm. The slurry filtrate oozes out of its paste and discharges through the barrel perforations as the paddles agitate, press and transports the milled paste from the right end of the barrel to the left side where the residual chaff discharges through its cover made of 5mm thick steel plate. .

2.2 Design Analysis of the Modified Machine

The power transmission system of the modified grain food slurry processing machine shown in Fig. 2 revealed that its prime mover drives the mill via a primary shaft which also drives the sieving unit via variable speed reducer using belt transmission systems.

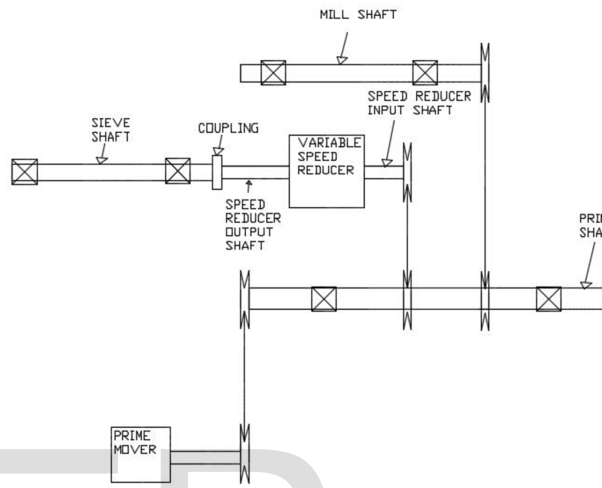

Fig. 2: Power transmission system of the modified machine

Due to availability and cost-performance economy, cast iron pulleys with groove angle (2β) of 38^0 and v-belts of type "A" were selected for designing these drives since power transmitted by each of them is less than 3.75kW [6]. The prime mover drives the primary shaft via driving and driven pulleys with diameters of 75mm and 105mm respectively. The primary shaft drives the mill and speed reducer of the sieve via 70mm and 50mm pulleys respectively and respective driven pulleys of 50mm and 70mm. Variable speed reducer of maximum speed reduction ratio of 46:1 was selected for the sieve to facilitate flexible and optimal operation. The center distances (*C*) between the adjacent pulleys were determined as 450mm, 630mm and 180mm for prime mover/primary shaft, primary shaft/mill and primary shaft/sieve drives respectively while 1183.1mm, 1448.56mm and 548.96mm were computed as the corresponding length (*L*) of drives belts using "(1)"and "(2)" [7]. Consequently, A1219-IS: 2494, A1473-IS: 2494 and A601-IS: 2494 belts were selected for the drives respectively [8]. Thereafter, the actual center distance between the drives' adjacent pulleys used for developing this machine were determined (via "(2)"/inside length of these standard belts) as 173.29, 204.13, 213.58 and 169.61mm respectively.

$$C = \frac{1.5D_2}{(VR)^{1/2}} \quad (1)$$

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$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \qquad (2)$$

Where;

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

D_1 *and* D_2 constitute the driving and driven pulley diameters while N_1 *and* N_2 are their respective speeds in rpm.

The drive shaft diameters, d were determined using the maximum shear stress relation given by [7] as follows;

$$d = \left[\frac{16\left(\sqrt{(K_b M_b)^2 + (K_t M_t)^2}\right)}{\pi\tau}\right]^{\frac{1}{3}} \qquad (4)$$

Where the allowable shear stress (τ) for steel shaft with provision for key ways, combined shock and fatigue factors for bending (K_b) and twisting (K_t) for gradual loading were given by [6] as 42N/mm², 1.5 and 1.0 respectively. The maximum twisting moment on the on each of the drive shafts (M_t) was determined using "(5)" given by [7] as;

$$M_t = (T_i - T_j)\frac{D_2}{2} \qquad (5)$$

The tensions on the tight side (T_i) of prime mover/primary shaft, primary shaft/mill and primary shaft/sieve drives belts were determined as 166.65N, 168.57N and 169.32N respectively along with 9.72N, 9.05N and 10.35N as the corresponding slack side tensions (T_j) using the following relations [6].

$$T_i = T_{max} - T_c \qquad (6)$$

$$T_{max} = \sigma a \qquad (7)$$

$$T_C = mv^2 \qquad (8)$$

$$2.3\log\frac{T_i}{T_j} = \mu\theta cosec\beta \qquad (9)$$

Where the mass per unit length (m), maximum safe stress (σ) and cross sectional area (a) of the selected belts and its coefficient of friction with the selected pulleys (μ) were obtained from [7] and [8] as 0.108 kg/m, 2.1 N/mm², 81mm² and 0.3 respectively. The speeds for the prime mover/primary shaft, primary shaft/mill and primary shaft/sieve drives belts were determined as 5.65m/s, 3.77m/s and 2.69m/s respectively with 3.08, 3.17 and 3.03 radians as the corresponding angles of lap (θ) of the drives small pulleys using "(10)" and "(11)" [6].

$$v = \pi\frac{N_1 D_1}{60} \qquad (10)$$

$$\theta = 180 - 2\left[\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right)\right] \qquad (11)$$

Thus, the maximum twisting moments, on the primary, mill, and sieve shafts were determined as 8238.83N-mm, 3988N-mm and 5563.95N-mm respectively. Force analysis of these shaft with Beamboy software (Fig. 3 to 5) revealed the maximum bending moments (M_b) on them as 23600N-mm, 28100N-mm, and 131000N-mm respectively. Consequently, the diameters of the primary, mill, and sieve shafts of this machine were computed from Equation (3) as 23.22mm, 19.17mm and 30.21mm respectively. Hence, cylindrical mild steel solid shafts with diameters of 20, 14, 16 and 10mm were respectively selected for these drives in line with [9].

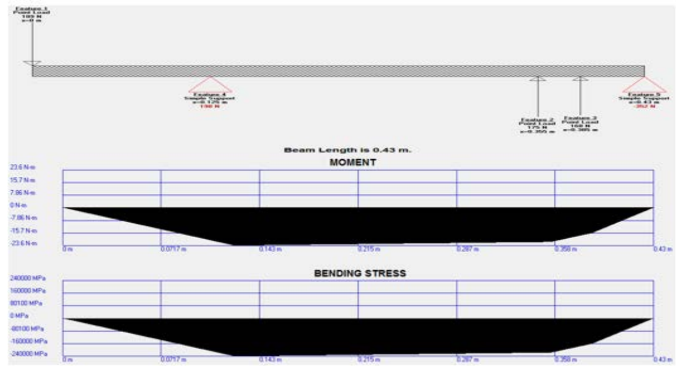

Fig. 3: Force analysis of primary shaft

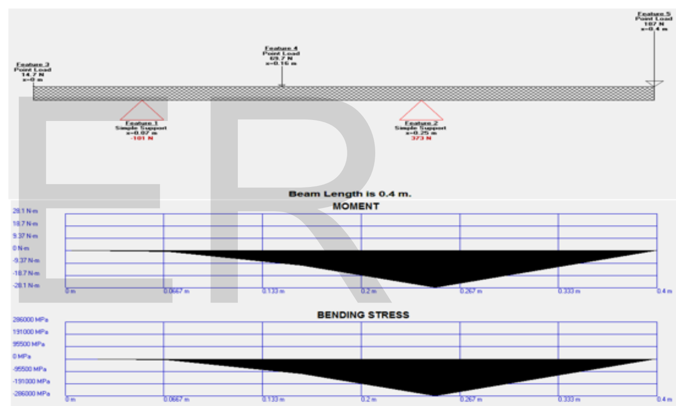

Fig. 4: Force analysis of mill shaft

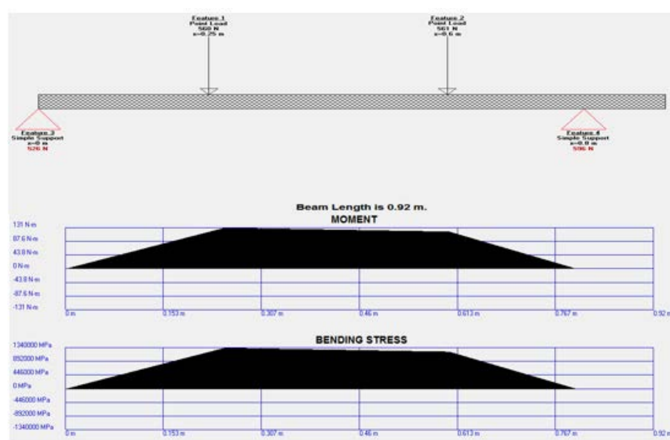

Fig. 5: Force analysis of sieve shaft

The loads on the sieve (w_s) and mill (W_m) shafts due to the grains been processed were determined from the following derivations as 340.68N and 47.31N respectively.

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$$w_s = g\left(0.675\rho_g + 0.075\rho_w\right)\left\{\pi r_c^2 l_c - \left[\pi r_s^2 l_s + n\left(l_f B_f h_f + l_i B_i h_i\right) + n_2\left(l_{f2} B_{f2} h_{f2} + l_{i2} B_{i2} h_{i2}\right)\right]\right\} \quad (12)$$

$$W_m = g\left(0.675\rho_g + 0.075\rho_w\right)\left\{\left(\frac{1}{3} H_h\left(L_h B_h + L_b B_b + \sqrt{L_h B_h L_b B_b}\right)\right) + \left(L_b B_b H_b\right)\right\} \quad (13)$$

Where, grain density $(\rho_g) = 800.923kg$/m³, water density $(\rho_w) = 1000kg$/m³, surface length of the hopper (L_h) = 0.3m, base length of the hopper(L_b) = 0.06m, surface width of the hopper (B_h) = 0.24m, base width of the hopper (B_b) = 0.059m, hopper frustum height (H_h) = 0.251m, hopper base funnel height (H_b) = 0.05m, barrel length (lc) = 0.815m, barrel radius (r_c) = 0.15m, sieve shaft length (l_s) = 0.7m, unslotted paddle bar length (l_f) = 0.03m, unslotted paddle score pad length (l_i) = 0.3m, unslotted paddle bar width (B_f) = 0.003m, unslotted paddle bar score pad width (B_i) = 0.005m, unslotted paddle bar height (h_f) = 0.08m, unslotted paddle bar score pad height (h_i) = 0.08m, number of unslotted paddles, (n)= 2, slotted paddle bar length (l_{f2}) = 0.4m, slotted paddle score pad length (l_{i2}) = 0.4m, slotted paddle bar width (B_{f_2}) = 0.003m, slotted paddle bar score pad width (B_{i_2}) = 0.005m, slotted paddle bar height (h_{f_2}) = 0.04m, slotted paddle bar score pad height (h_{i_2}) = 0.08m and number of slotted paddles (n_2) = 2.

The minimum power rating required of this machine's prime mover which constitutes the sum of driving power of its milling (661.53W) and sieving (470.39W) units was computed as 1.13kW (1.49hp) using "(14)". Hence, 1.5hp I.C. engine was selected as its prime mover.

$$P_m = \sum\left(T_i - T_j\right)vS \qquad (14)$$

Where the correction factor(S) accounting for power losses to the frictional drives is 1.1.

2.3 Comparative Performance Analysis Procedure

The throughput(TP), extraction efficiency (η) and specific energy consumption (S_E) of this modified food slurry processing machine was evaluated after its fabrication using three different grains (maize, millet and soybean) sourced from Umuahia market. This involves soaking/washing of measured quantity of each grain in water for three days before processing of it with the modified machine. Thereafter, the processing time (t), mass of grain processed (M_g), water used (M_w), extracted slurry food (M_f) and chaff (M_c) obtained as per each test were recorded and used to compute the average performance parameters (indicators) of the machine as follows;

$$TP = \frac{M_g}{t} \qquad (15)$$

$$\eta = \frac{100M_f}{M_i} \qquad (16)$$

$$S_E = \frac{3600 \times P_m}{TP} \qquad (17)$$

Where M_i is the expected slurry food content of the grain processed. The modified machine performance was further analyzed by comparing its percentage improvement (*PI*) over the existing model [1] before it as per each performance indicator as follows;

$$PI = \frac{X_m - X_e}{X_e} \times 100 \qquad (18)$$

X_m and X_e constitute performance indicator of modified and existing machines respectively.

3 Results and Discussion

Table 1 revealed 68.50kg/hr, 69.87kg/hr and 57.91kg/hr as the throughput of the modified food slurry milling and sieving machine when maize, millet and soybean were processed respectively while 91.73%, 91.28% and 93.61% constitute its respective extraction efficiencies. Its corresponding specific energy consumptions are 110.89KJ/kg, 108.72kJ/kg and 131.17kJ/kg. Comparative analysis of this machine with latest model developed by [1] (Table 2) showed that its time of processing maize and millet was reduced by about 17%, while that of soybeans reduced by more than 27%. In addition, its throughput improved by 21.86%, 30.31% and 21.25% with maize, millet and soybean respectively while its extraction efficiency increased by 38.96%, 42.07% and 33.42% respectively. Its specific energy consumption also reduced by 27.86%, 32.53% and 27.49% respectively while average water consumption rate associated with it reduced by 6.9%.

TABLE 1
PERFORMACE EVALUATION OF MODIFIED SLURRY FOOD MILLING AND SIEVING MACHINE

Experimental run	M_g (kg)	M_i (kg)	M_f (kg)	M_e (kg)	M_c (kg)	t (hr)	TP (kg/hr)	η_ε (%)	η_D (%)	S_E (kJ/kg)
					Maize					
1	3.14	1.9154	1.76	1.2246	1.18	0.04	78.50	91.89	96.58	
2	3.13	1.9093	1.75	1.2207	1.18	0.05	62.60	91.66	96.50	
3	3.22	1.9642	1.80	1.2558	1.21	0.05	64.40	91.64	96.47	
Average						**0.14**	**68.50**	**91.73**	**96.52**	**110.89**
					Millet					
1	2.62	1.5982	1.44	1.0218	0.98	0.04	65.50	90.10	96.19	
2	2.58	1.5738	1.42	1.0062	0.96	0.04	64.50	90.23	96.24	
3	3.98	2.4278	2.27	1.5522	1.51	0.06	79.60	93.50	96.97	
Average						**0.14**	**69.87**	**91.28**	**96.47**	**108.72**
					Soybean					
1	3.75	2.2875	2.13	1.4625	1.42	0.06	62.50	93.11	96.87	
2	4.35	2.6535	2.50	1.6965	1.65	0.08	54.38	94.22	97.19	
3	3.98	2.4278	2.27	1.5522	1.51	0.07	56.86	93.50	96.97	
Average						**0.21**	**57.91**	**93.61**	**97.01**	**131.17**

TABLE 2
COMPARATIVE ANALYSIS OF MODIFIED SLURRY FOOD MILLING AND SIEVING MACHINE

Performance Indicators	Existing Machine		Modified Machine		Improvement (%)
Quantity processed (kg)	Maize	9.49	Maize	9.49	-
	Millet	9.18	Millet	9.18	-
	Soybean	12.08	Soybean	12.08	-
Throughput (Kg/hr)	Maize	56.21	Maize	68.50	21.86
	Millet	53.62	Millet	69.87	30.31
	Soybean	47.76	Soybean	57.91	21.25
Processing time (hr)	Maize	0.17	Maize	0.14	-17.65
	Millet	0.17	Millet	0.14	-17.65
	Soybean	0.29	Soybean	0.21	-27.59
Extraction efficiency %	Maize	66.01	Maize	91.73	38.96
	Millet	64.25	Millet	91.28	42.07
	Soybean	70.16	Soybean	93.61	33.42
Water consumption (kg/batch)	2.90		2.70		-6.90
Specific energy consumption (kJ/kg)	Maize	153.71	Maize	110.89	-27.86
	Millet	161.13	Millet	108.72	-32.53
	Soybean	180.90	Soybean	131.17	-27.49

4 Conclusion

Adoption of cake breaking-sieving system in the development of grain food slurry processing machine is recommended since it improved performance.

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References

[1] B. N. Nwankwojike, O. S. Onwuka, and N. G. Orji, “Design and Development of Integrated Slurry Food Processing Machine,” *Innovative Systems Design and Engineering*, vol. 6, no. 12, pp. 25-32, Dec. 2015. https://iiste.org/Journals/index.php/ISDE

[2] O. E. Simolowo, “Developing Archetypal Machines for a Sequence of Food-Slurry Processing Operations: An Overview,” *African Research Review,* vol. 5, no. 5, pp. 122-136, 2011. https://www.ajol.info/index.php/afrrev

[3] O. E. Simolowo and O. O. Adeniji, “Prototype Design and Performance Analysis of a Sieving Machine for Improved Food–Slurry Processing in Nigeria,” *Indian Journal of Science and Technology,* vol. 4, pp. 1639-1642, 2011. http://www.indjst.org/

[4] F. T. Fayose, “The Development of a Multi-Purpose Wet Food Sieving Machine,” *The CIGR E-journal,* vol. X, manuscript FB 08006, 2008. http://www.cigrjournal.org/index.php/Ejounral

[5] O. E. Simolowo and C. C. Ndukwe, “The Design of “Ogi” Sieving Machine,” *Nigerian Journal of Engineering Research and Development,* vol. 1, pp. 38-44, 2002. https://searchworks.stanford.edu/view/10376593

[6] R. S. Khurmi and J. K. Gupta, *A Textbook of Machine Design.* Seventh Multi-Colour Edition, Eurasia Publishing House Ltd, 2011. http://prod1.ticketshop.lv/machine-design-by-r-s-khurmi.pdf.

[7] P. C. Sharma and D. K. Aggarwal, *Machine Design.* S.K. Kataria and Sons, 2006. https://www.abebooks.com.

[8] IS 2494-1974; *Indian Standard:* V-Belts-Endless V-Belts for Industrial Purpose. Part I General Purpose-Specification (Second Revision). Bureau of Indian Standards New Delhi. http://bis.gov.in/

[9] ISO/R775: 1969; *Indian Standard:* Power Transmission - Shafts -Dimensions for Cylindrical and L/10 Conical Shaft Ends (Second Revision). Bureau of Indian Standards New Delhi http://bis.gov.in/