

Development and Performance Evaluation of a Dough Mixing Machine

Adeleke, A.E., Oni, O.K., Ogundana, T.O., Satimehin, A. A. and Oyelami, S.

Abstract: In view of the numerous problems encountered with the manual method of mixing, an electric motor gear driven dough mixing machine was designed and fabricated from available local materials using standard engineering principles. A step turned shaft of diameters 16 mm and 32.5 mm was attached to speed reducer gearbox which engaged 1hp, single-phase electric motor to transmit torque required to effectively turn and mix the dough in the bowl. The performance evaluation was carried out, the average mixing time for dough of 3.964 kg was 7.67minutes and average mixing efficiency was 94.6% with a mixing capacity of 31 kg/hour operating at 280 rpm of the agitator shaft blade/ arm. The dough produced using the mixing machine was baked into bread and sensory evaluation was conducted and compared favourably with bread baked through hand mixing of dough at 0.05 level of significance. The results further showed that sample B was most accepted followed by sample A (control). Sample C received the least mean score. However, no significant mean difference among the bread attributes at the 0.05 level except for bread texture where samples A and D differ significantly. The cost of fabrication was ₦67,550.00(147dollars) and result of operating cost analysis on per day basis indicated that the owner of the machine can pay back the capital investment in a period of 359 days (1 year) of continuous production.

Keywords: Design, Performance Evaluation, Mixing Machine, Mixing Time, Dough

I. Introduction

Mixing is a very germane unit operation in the processing of dough. It is the random distribution throughout a system of two or more initially separated ingredients. Mixing is the intermingling of two or more substances in such a way that a desired degree of mingling is obtained [1]. Mixing of wheat flour helps to distribute the ingredients homogeneously throughout the mixture and in the entrainment of air. It develops the dough when mechanical energy is applied to stretch the long molecules, in particular, glutenin

from an unperturbed state to a more extended configuration that allows the molecules to align and form non-covalent bonds, thus imparting elasticity to the dough that gives its machinability and gas retention properties [2]. Dough is a mixture of flour and water with other ingredients, such as leavening agents, sugar, salt, egg and various flavouring materials used to make baked products. It is a thick and elastic and can be shaped, kneaded and rolled [1-5]. The effectiveness of a dough mixer can therefore be evaluated by looking at the ability of the mixer to distribute ingredients and stretch the dough molecules, as well as disperse air bubbles and cohesive clumps. Commercial production of bread and baked foods is on the increase, but the process cycle has remained largely manual especially the mixing unit operation. This manual mixing of dough is very slow and laborious, with little or no guarantee of homogeneity of the end-product hence the need for an affordable flour mixing machine is on the increase. Therefore,

Adeleke, A.E. and Ogundana, T.O. (Department of Mechanical Engineering, Federal University Oye-Ekiti, Nigeria)

Oni, O.K. (Department of Food Science and Technology, Federal University Oye-Ekiti, Nigeria)

Satimehin, A.A. (Department of Agriculture and Bioresources Engineering, Federal University Oye-Ekiti, Nigeria)

Oyelami, S. (Department of Mechanical Engineering, Osun State University, Osogbo, Nigeria)

Corresponding author: ademola.adeleke@fuoye.edu.ng

Telephone Number: +234-805-481-3210

this project is devoted to the local fabrication of cheap electric-powered mixing system as an integral part of the bread processing plant.

II. Materials and Methods

A Materials, Design and Selection of Components

The materials used are: 5 mm x 3 mm H-Chanel (Mild steel), Mild steel sheet (2.5 mm gauge), Iron rods (Stainless), Welding electrodes (Gauge 12), Full Length of ½ inch pipe (12.7 mm), Thrust bearing, Lathe machine, Arc welding machine, Hacksaw, Electric firing stone, V. calliper, Top Loading balance (LP 4001 A), Spray machine, Oven (Kinelco), Pan (Aluminum), Bench vice and Stopwatch (Nokia GSM).

B Machine Components

The dough mixing machine is made of the following components, the Machine frame (four-column bars of 5 x 3 H- channel mild steel), Mixing bowl (stainless steel basin having a support constructed with a 12.7 mm gauge pipe), Bearing (No 6204 corresponds to the shaft diameter 32.5 mm), Shaft (solid stainless steel, 32.5 mm and step-turned at the other end to 16 mm diameter in order to connect to the gearbox spindle shaft using a 13 bolt), Agitator blade (stainless steel rod of length 450 mm and of 10 mm diameter), Electric motor (Motor = 1hp (0.75 kW), Phase = Single, Current = 5.57 A, Voltage = 220 V, = Speed = 1400 rpm, Frequency = 50 Hz, Number = 95036), speed reduction gearbox (gear ratio 5 to 1).

C Design Analysis

The major design considerations were based on the following

i. Power Requirements of the Electric Motor

The following equations were used:

The consumed electric power of the motor is defined by the formula; (simplemotor.com/ accessed June 2016).

$$P_{in} = IV \quad (1)$$

where, P_{in} = input power (W), I = current (A), V = applied voltage (V)

The output mechanical power of the electric motor was given by [4].

$$P = T\omega = \frac{T2\pi N}{60} \quad (2)$$

The efficiency of the electric motor (η) is calculated as mechanical output power divided by the electrical input power

$$(\eta) = \frac{\text{output power}}{\text{input power}} \times 100 \quad (3)$$

Speed of electric motor $N_1 = 1400$ rev/min

$$\begin{aligned} \text{Gear reduction ratio} &= N_1/N_2 \\ &= 4.67 \text{ (5 to 1 used)} \end{aligned} \quad (4)$$

where, N_2 = rpm of gear box spindle shaft

The electric motor torque (T) is given by simplemotor.com (accessed 2016)

$$T = \frac{IXVXE60}{2\pi N} \quad (5)$$

The horse power of the electric motor is obtained from the formula,

$$H_p = \frac{T_{rpm}}{5252} \quad (6)$$

where, 5252 = constant (33,000 divided by 2π)

The angular speed of the electric motor is calculated from the formula,

$$\omega = \frac{2\pi N}{60} \quad (7)$$

Rotational speed of the agitator shaft

$$N_2 = \frac{1400}{5} = 280 \text{ rpm}$$

Angular speed of agitator shaft (ω_2)

$$\omega_s = 2\pi N_2 / 60$$

Torque on the agitator shaft (Ts)

$$T_s = \frac{P}{\omega_s} \quad (8)$$

ii. Mixing Bowl Capacity: Density, Mass and Volume Relationship

Using density, mass and volume relationship, an estimate was made for the capacity of the mixer by volume and weight.

Diameter of bowl (D_b) = 479 mm, Height of bowl (H_b) = 169 mm

Volume of bowl (V_b)

$$V_b = \pi D_b^2 H_b / 4 \quad (9)$$

The total volume is 0.030454m^3 from the above equation as expressed by

Thus,

$$D_b = \sqrt{4\text{vol} / \pi H_b} \quad (10)$$

The diameter and height of basin can be obtained from equation (2).

Mass of dough (M_{d0}) = 3.964 kg, Volume of dough (V_{d0}) = $3.80675 \times 10^{-3} \text{m}^3$

Density of dough (ρ_{d0}) = mass/volume (11)

Force on agitator shaft (Fs) = mass x g (12)

The mixer capacity (MC) was determined using a relationship by [3],

$$MC = \frac{\text{mass of dough (kg)}}{\text{time (min)}} \quad (13)$$

Diameter of agitator shaft (d_s) = 32.5 mm

Radius of mixing blade or arm (r_b) = $d/2 = 5\text{mm}$

Angle of inclination of mixing shaft to the bowl

$$(\theta_s) = \text{opp/hyp} = \sin\theta \quad (14)$$

Efficiency of mixing

$$E_m = \frac{T_i - S_i}{T_i} \times 100 \quad (15)$$

where, T_i = total mass of ingredients fed into the mixing bowl, S_i = splashed mass of ingredients during the mixing process, $3964 - 215 / 3964$ (mean from 3 batches of mixing) x 100

iii. Bearings

The outer diameter of the collar bearing is usually taken as 1.4 to 1.8 times the inner diameter of the collar i.e. diameter of shaft [4].

iv. Shaft Design

For any solid shaft without axial loading the diameter of the shaft from ASME CODE is given by the following equation [5],

$$d_s = \sqrt[3]{\left[\frac{16}{\pi \sigma_s} (K_b M_b)^2 + (K_t M_t)^2 \right]} \quad (16)$$

where, k_b = combined shock and fatigue factor for bending moment, k_t = combined shock and fatigue factor for Torsion (T), M_b = bending moment Nm, M_t = torsion moment σ_s = allowable shear stress for bending and torsion moment for mild steel (56MN/m^2) [3].

The shaft under consideration is 32.5 mm. The angle of inclination of the agitator shaft 32° was obtained using Pythagora's theorem.

D Fabrication and Assembly of the Dough Mixing Machine

The machine was fabricated from 5 x 3 H-channel mild steel. Four-column bars of the H-channel mild steel were cut using electric firing stone and welded together by arc welding. This forms the frame (Plate 1) to which a cover plate of 2.5 mm gauge mild steel is attached. The overall dimension of the machine frame is 921 mm x 920 mm x 310 mm, forming a trapezoidal shape with a support stand of height 700 mm from the top of the frame.

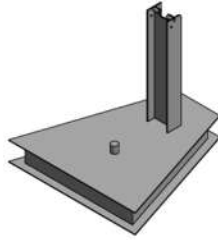


Plate 1: Flour mixer stand pictorial

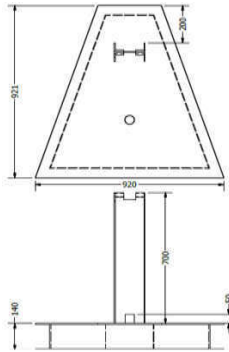


Figure 1: Orthographic projection



Plate 2: Pictorial view of mixing bowl

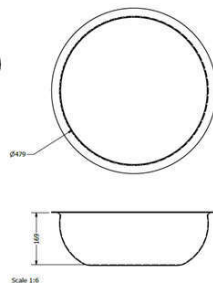


Figure 2: Orthographic projection of mixing bowl

Mounted on the cover plate is a flat collar bearing to take the axial thrust of the rotating shaft in case there are any axial loads. Attached to the collar bearing is a cage

constructed with 12.7mm (1/2 inch) gauge pipe to support the mixing bowl (Plate 2) as it rotates. The support stand for the electric motor, speed reducer gear-box and shaft assembly was also constructed using H-channel mild steel.

Agitator shaft design (Figure 3) with mixing arm or blade: This was constructed using stainless steel rod of length 450 mm and 10 mm diameter. The steel rod was bent in a circular-shape with an internal diameter of 125 mm and outside diameter of 145 mm and a small arc of about 40 mm cut away from it to produce dough kneading arm. This was cross-welded to a shaft of 380 mm length. The shaft was step-turned to 16 mm to be bolted to a speed reducer gear-box shaft by a 13 bolt. The length of the step-turned section is 130 mm while the remaining length to which the mixing blade is attached is 250 mm.

Two coupling pins (Figure 4 and plate 3) were constructed using mild steel rods for mounting of the electric motor and speed reducer gearbox assembly. An electric motor with 1400 rpm was connected to speed reducer gear-box with a gear ratio of 5 to 1. The supporting stand for the mounting of the electric motor, speed reducer gearbox and shaft assembly which forms part of the machine frame was also constructed with H-channel mild steel so that it can withstand the various weights of ingredients to be mixed. The mixer assembly is as shown in plate 4.

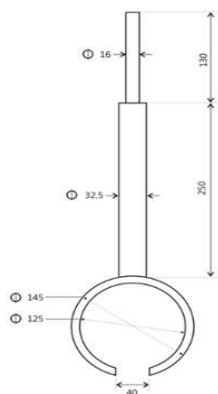


Figure 3: Agitator shaft design with mixing arm

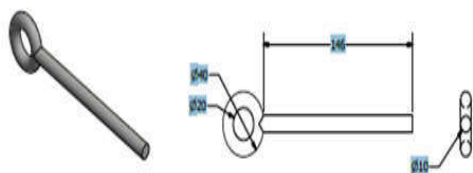


Figure 4: Couple pin design.

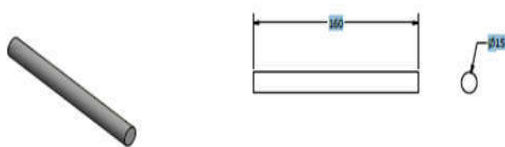


Plate 3: Couple pins. Figure 5: Coupling pins design

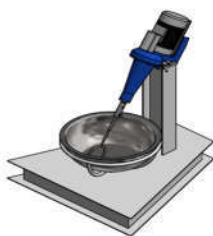


Plate 4: Pictorial view of the mixer assembly.

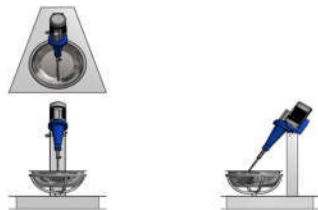


Plate 5: Mixer assembly shown in orthographic

E Operation of the fabricated dough mixing machine

When the power is switched ‘ON’ the electric motor shaft transmits power by means of speed reducer gearbox spindle shaft. The spindle transfers the motion to the agitator’s arm. The agitator shaft which is inclined at an angle of 32° to the mixing bowl rotates in a clockwise direction while the mixing bowl rotates in anti-clockwise thus, producing a uniform mixture.

Discharge of the contents of the bowl is achieved by raising the electric motor and gearbox spindle assembly off the mixing bowl. The basin or bowl which is not permanently fixed to the frame of the machine can then be removed from the support cage, cleaned and is ready for another batch of mixing. The maintenance of the mixer is mainly on the bearings which require some form of lubrication. Clean the mixing bowl after every mixing operation and keep in a dry cool place when not in use.

F Test Samples Preparation and Ingredients Formulation

Dough samples were prepared using the Golden Penny Confectionary Wheat flour (manufactured by Flour Mills of Nigeria), yeast, salt, and other bakery ingredients were purchased from King’s market, Ikole Ekiti, Nigeria. Recipes were formulated as described by Ihekoronye and Ngoddy [6] with slight modifications. The unit operations for the bread samples preparation include: Ingredient weighing, Mixing, Kneading, Molding and Panning, Proofing (55 min), Baking ($120^{\circ}\text{C} - 200^{\circ}\text{C}$ for 1hour), Bread, Cooling, and Packaging.

G Performance Evaluation of the Fabricated Mixer

Free rotation and full load evaluation tests were conducted as described by Matthew et.al. [7] and Uhuunmwangho et.al [8]. Mixing time was determined by the use of a stopwatch (GSM type) while operating capacity (OC) was determined using the relationship by [9]. Friction factor of the mixer was determined using the relationship given by

$$3t_{\text{dough}}^{\circ} - (t_{\text{room}}^{\circ} + t_{\text{flour}}^{\circ} + t_{\text{water}}^{\circ}) = \text{friction factor} \quad (17)$$

Efficiency of mixing dough machine was calculated using the relationship in equation 18.

$$\eta = \frac{T_i - S_i}{T_i} \times 100 \quad (18)$$

where T_i = total weight of ingredient put into the mixer bowl; S_i = splashed weight of ingredient during mixing.

H Analysis

Texture and feel of the flour quality were determined using a relationship according to www.univexcorp.com, accessed Jan., 2016. Protein, moisture, ash content and water absorption ratio were determined using methods described by New Zealand Flour manufacturing Association (NZFMA) (accessed March, 2016) while water absorption capacity was determined as described by [10] with slight modifications. Bulk density and True density of the flour were determined as described by [3].

Sensory evaluation was carried out using a panel of ten (10) students drawn from the Department of Food Science and Technology, Federal University Oye-Ekiti. Bread attributes such as colour, crust, crumb, texture, taste and general acceptability were evaluated using a 7–point hedonic scale [6]. Data obtained were

subjected to statistical analysis of variance (ANOVA) using SPSS (version 21) and the samples' means separated using Duncan's multiple range comparison test. The least significance difference (LSD) was also used to evaluate the significance of the difference between pairs of treatments at 5% level of significance using relationship by [13].

III. Results and Discussion

The results of the calculated parameters of the fabricated dough mixer are presented in Table 1. The power requirements, torque and speed of the electric motor of the fabricated dough mixer were 1225.4 W (1.23 kW), 3.75 Nm and 1400 rpm respectively. The rotational and angular speeds of the mixing shaft were found to be 280 rpm and 29.3 rad/s with a torque of 41.8 Nm. However, the speed, torque, power and efficiency of the electric motors were not constant. This could be attributed to the fact that motor torque changes with the speed. At no load, you have maximum speed and zero torque. Load adds mechanical resistance. The motor starts to consume more current to overcome this resistance and the speed increases.

Moreover, the results proved that, though the electric motor torque is very small (3.75 Nm), the power produced is not constant because it changes with the speed to meet the energy demand. This may be attributed to the fact that the prototype mixer had a high mixing efficiency of 94.6%. The agitator shaft speed of 280 rpm was also very high (31 kg/hr), thus contributed to the high efficiency of the fabricated dough mixing machine. The angle of inclination of the shaft was calculated to be 32° and the force acting on the shaft in operation was found to be 38.9 N. This force depends on the mass of dough since it is the gravitational force acting on the shaft. Since the speed of rotation is one of the functions of mixing time, the prototype machine with

mixing speed of 280 rpm has the capacity to mix a batch quantity of 3.864 kg in an average time of 7.67 minutes (Table 3).

The results of the quality of flour used shown in Table 2 indicated that the texture and feel of the flour were slightly coarse. This agreed with NZFMA [12] knowledgebase flour

Table 1: Results of calculated design parameters

Parameter	Value	Unit
Diameter of bowl	0.479	M
Height of bowl	0.169	M
Volume of basin or bowl	0.030	M ³
Power requirement (power output)	550	W
Power input	1225.4	W
Efficiency of the electric motor	45	%
Electric motor Torque	3.75	Nm
Electric motor horsepower	1	Hp
Angular speed of electric motor	147	rad/sec
Speed of electric motor	1400	Rpm
Force on shaft	38.9	N
Torque on shaft	41.8	Nm
Angular speed of shaft	29.3	rad/sec
Rotational speed of shaft	280	Rpm
Diameter of agitator shaft	0.325	M
Radius of agitator blade	0.005	M
Gear reduction ratio	5 to 1	-
Angle of inclination of agitator shaft	32°	Ø
Capacity	31	Kg/hr
Average mixing efficiency of the machine	94.6	%

Table 2: Flour quality parameters

Parameter	Flour quality
Texture and feel	<i>Slightly coarse</i>
Moisture (%)	14 – 15*
Water absorption ratio (%)	63.0
Water absorption capacity % range	20.5 – 63.0**
Bulk density (g/cm ³)	0.56
True density (g/cm³)	0.64

Source: [12]

quality parameters (accessed 2016) assertion that bread flours are usually slightly coarse. Flour quality is an important index in dough development during dough mixing process. The texture and size of flour granulation plays important role in kneading and also determines the speed at which the dough rises. This could be the reason why the rate of mixing 3.964 kg batch of ingredients was high with the fabricated machine, the quality of flour used influencing dough rise.

The results of absorption ratio/capacity of the flour was 63% which is slightly above 62.5% absorption characteristics of flour described by [13]. Water absorption capacity determination showed that water absorption increases with time from 5 minutes (20.5%) to 30 minutes (63%). This is the amount of water taken up by the flour to achieve the desired consistency or optimal end result. Dough with high water absorption stretches easily and has a good pan flow. The moisture content of flour was assumed to be in the range of 13 - 14% which falls within the range given by Newzeland Flour Manufacturing Association which is from 14 -15 % (Table 2) and is important mainly for the issue of storage. When the moisture level of flour excels 16%, the shelf –life of the flour is reduced.

The results of bulk and true densities of the flour were 0.56 g/cm³ and 0.64 g/cm³ respectively. The bulk density of the flour facilitated dough kneading with the fabricated dough mixing machine. This can be seen in the shortest average time of 7.67 minutes of dough development when 3.964 kg of ingredient was mixed (Table 3). Bulk density affects both the particle size and density of flour or flour blends. It is also germane in determining raw material handling and packaging requirements in the food industry

A Performance Evaluation

The results of the performance test showed that the fabricated dough mixing machine has a mixing capacity of 31 kg/hr and average mixing efficiency of 94.6%. The results of mixing time, analysis of bread produced and sensory evaluations are presented in Tables 4, 5 and 6 respectively.

B Operational Cost Analysis of the Fabricated Machine

Based on basic operational costing data, the following results were obtained

Direct cost and Indirect cost per day were ₦162.00 and ₦99.62 respectively

Total production cost = sum of direct cost and indirect cost

$$= \text{₦}162.00 + \text{₦}99.62 = \text{₦}261.62$$

Daily Revenue or income per day:

The total dough material (ingredients) handled per day is 31 kg and based on 98% of dough produced per day gives

$$= 31 \times 98 / 100 = 30.39\text{kg}$$

At ₦14.80 per kg

$$= 14.80 \times 30.39 = \text{₦}449.77$$

Therefore,

Income = total revenue – total cost of production

$$= \text{₦}449.77 - \text{₦}261.62 = \text{₦}188.15$$

The above estimate shows that the owner of the mixer can pay back his/her capital investment acquiring the machine in about 359 days of continuous production (about a year).

C Performance Evaluation

The results of performance tests showed that at 'No' load test the fabricated dough mixing machine operated freely without noise and there were no visual malfunctions. At the 'Full' load test the fabricated machine accomplished mixing of 3.964 kg ingredients in an average time of 7.67 minutes (31 kg/hour) compared to 15 minutes hand mixing (control A) of the same quantity (Table 4). This could be attributed to the speed of the mixing shaft which is 280 rpm.

The performance results further showed that the dough mixing machine has an average mixing efficiency of 94.6% which can be attributed to the mixing speed of the machine. However, with this high efficiency, there were some elements of the splashed quantity of dough during the mixing process.

Table 3: Results of Mixing Time

Sample	Weight of ingredients (kg)	Time (min)
A	Control	15
B	3.964	10
C	3.964	7
D	3.964	6
	Mean	7.67

Table 4: Weights of Dough and Bread Loaf after Baking

Sample	Weight of dough (g)	Weight of bread loaf (g)	Weight loss (g)	% wt. loss
A ₁	624	559.0	65.0	10.4
A ₂	624	562.1	61.9	9.9
A ₃	624	573.4	50.6	8.1
B ₁	624	562.6	61.4	9.8
B ₂	624	581.8	42.2	6.8
B ₃	624	590.6	33.4	5.4
C ₁	624	574.1	49.9	7.9
C ₂	624	579.2	44.8	7.2
C ₃	624	582.5	41.5	6.7
D ₁	624	575.0	49.0	7.9
D ₂	624	598.0	26.0	4.2
D ₃	624	573.8	50.2	8.0

Table 5: Mean of Sensory Scores of Bread Samples

Bread Sample	Bread Attributes					Gen. accept
	Colour	Crust	Crumb	Texture	Taste	
A	5.0 ± 0.94 ^a	5.3 ± 1.34 ^a	5.3 ± 0.82 ^a	5.3 ± 0.82 ^a	4.7 ± 1.06 ^a	5.40 ± 1.08 ^a
B	5.1 ± 1.37 ^a	4.7 ± 1.42 ^b	5.0 ± 1.05 ^a	5.0 ± 1.16 ^b	4.9 ± 1.29 ^a	5.6 ± 1.08 ^a
C	5.2 ± 1.55 ^a	4.9 ± 1.10 ^c	4.6 ± 1.65 ^{ab}	4.7 ± 1.16 ^b	4.5 ± 1.43 ^a	4.8 ± 1.55 ^a
D	5.1 ± 1.60 ^a	4.5 ± 1.58 ^c	4.8 ± 1.14 ^{abc}	4.2 ± 1.48 ^b	4.1 ± 1.37 ^a	4.9 ± 1.52 ^a
SE	0.21	0.21	0.19	0.19	0.20	0.21
LSD	0.43	1.81	1.22	1.76	1.81	2.05

Value represents mean ± SD. (n = 3). Values bearing the same superscripts within the same column are not significantly different at (P<0.05) probability.

Key: A = control, B = machine mixed dough, C = machine mixed dough, D = machine mixed dough, SE = Standard Error, LSD = Least Significant Difference.

The efficiency of the machine for the three batches of mixing ranged from 93.5 – 95.9%. Apart from speed, other factors such as friction factor, angle of inclination of the mixing arm to the mixing bowl and water absorption capacity directly affects the performance of a mixer. The friction factor developed by the fabricated mixing machine

and the angle of inclination of the mixing shaft to the mixing bowl were found to be 10°C and 32°C respectively. The determination of the friction factor is to be able to calculate the temperature of water needed in order to get a predetermined dough temperature.

In conventional spiral Mixer, the mixing time for the dough of about 165 kg is approximately 12 minutes depending on the quality of the flour and mixing method (www.classofoods.com/page_2S-I.html, accessed June, 2016). This also explains why the fabricated dough mixing machine has the capacity to mix 3.964 kg of dough in an average time of 7.67 minutes

The fabricated dough mixing machine compares favourably with the www.jasenterorise dough kneader or mixer model No Jas -DK- 10, capacity 10 kg/batch and one horsepower (1hp = 0.75 kW). The Jas-DK-10 kneader operating at 10 kg/batch by 4 batch per hour has a capacity of 40 kg/hr. while the fabricated dough mixing machine 1hp (0.75 kW) operating at 3.964 kg/batch yielded 31kg/hr of kneaded dough. The machine was designed for mixing capacity of 30.454 kg per batch but only about 1/8th (3.964 kg) of the capacity was utilized in the performance evaluation test.

D Analysis of Bread Samples

The results indicated that there were variations in the weight loss of the bread loaves ranging from 26.0 - 65.0 g. The weight loss of bread could be attributed to moisture lost in the dough during baking. The least weight loss of the bread loaf after baking was 26.0 gram representing 4.2% moisture lost. The highest weight loss of bread loaf was 65.0 grams representing 10.4% (Table 5). In bread baking, moisture loss in bread loaves can be attributed to crust formation. Crust formation restricts the expansion of the dough. It affects the amount of moisture evaporating from wet

dough during the baking process as a thick crust is produced with a higher moisture loss in bread.

Sensory evaluation of the bread attributes is presented in Table 6. The mean scores for the colour were 5.0 ± 1.60 , 5.1 ± 1.37 , 5.2 ± 0.94 and 5.1 ± 1.55 for samples A, B, C and D respectively. There was no significant difference in the colour of all the bread samples at ($p < 0.05$) level of probability. Sample C was however, rated highest in terms of colour with a mean value of 5.2 ± 0.94 but is not significantly different from the rest of the samples at 5% level of significance. This is in perfect agreement with [14].

The mean scores for the crust of the bread samples ranged from 5.3 ± 1.34 to 4.5 ± 1.58 . The control sample A was most preferred by the panellists in terms of crust texture hence the highest mean score of 5.3 ± 1.34 . The least preferred was sample D with a mean score of 4.5 ± 1.58 (Table 6). This comparison showed that the prototype mixer achieved dough mixing which can be compared with other dough mixers.

For general acceptability of the bread samples, sample B was rated highest with a mean score of 5.6 ± 1.08 followed by sample A with a mean value of 5.4 ± 1.08 . This however did not show any significant difference at ($p < 0.05$) probability. The general acceptance of sample B followed by sample A showed that the fabricated dough mixing machine has been accepted for quality dough production and could be recommended for use in bread dough preparation.

There were no significant mean differences in all the bread samples presented for quality evaluation. However, there was a significant difference at 5% level between bread samples A (control) and D in terms of the texture of the bread.

E Operational Costs Analysis of the Machine.

Production cost which is given as the sum of direct and indirect costs gave a total production cost of two hundred and sixty-one naira, sixty-two kobo (₦261.62) while daily revenue from the operation of the machine yielded four hundred and forty- nine naira, seventy -seven kobo (₦449.77). This gives net income of one hundred and eighty-eight naira, fifteen kobo (₦188.15) per day. The cost analysis shows that the owner of the fabricated dough mixing machine can pay back his/her capital investment in 359 days (about a year) of continuous production. However, this cost of production is only based on 1/8th of the capacity of the mixer. If the machine was operated at full designed capacity, the time taken to pay back capital investment would have been less than what is obtained at the stated capacity. The total cost of the machine is ₦67,550.00 (Table 7) which is affordable compare to the imported mixers (Table 8)

IV. Conclusion and Recommendations

The design, fabrication and performance evaluation of a dough mixing machine have been achieved. It is gear driven and powered by an electric motor with a maximum power supply of 1225.4 W (1.23 kW). The machine has a mixing capacity of 31kg/hour and average efficiency of 94.6% operating at 280 rpm.

The operational cost analysis of the machine on per day basis shows that the owner of the machine can pay back his/her capital investment in about 359days (about 1year) of continuous operation.

The use of the machine will eliminate the problems associated with manual methods of dough mixing and will save the country of huge foreign exchange used in importing

mixers for bread production and other confectionaries.

To avoid the problem of dough splashing during mixing a deeper bowl or a cover is recommended for the type of bowl used in this study.

For high efficiency, it is recommended that the machine be used to enhance the production of bread.

Manufacturers should take up the challenge to reproduce the fabricated prototype dough mixer in this study for marketing to bakery industries.

References

- [1] Oni O.K., Alakali J.S. and Akpapuman, M.A. "Design, Fabrication and Performance Evaluation of a Powered Soy-Gari", *Journal of Engineering and Applied Sciences*, vol. 4, no. 3, 2009, pp 164 – 169.
- [2] Belton, P.S. "The Molecular Basis of Dough Rheology. In S.P. Cauvain (Ed.), *Bread Making—Improving Quality* (pp. 273–287), Cambridge, England: *CRC Press, Woodhead Publishing Limited*, a-b, Belderok, Robert 'Bob, Mesdag, Hans. 2003.
- [3] Dahiru, D.Y., Sumaila, M. and Hammar Y. "Design, Construction and Performance Evaluation of a Manually Operated Dough Kneading Machine", Mechanical Engineering Department FUT Yola Adamawa State, Nigeria 2007.
- [4] Emmanuel P., Vivian O. and Salvadori "Bread Browning Kinetics during Baking", *Journal of Food Engineering*, vol.80, Issue 4, June 2007, pp 1107-1115.
- [5] Emmanuel, P. "Browning Development in Bakery Products: A Review", *Journal of Food Engineering*, vol. 99, Issue 3, August 2010, pp 239-249). FAOstat. Retrieved 27 Jan. 2015.
- [6] Khurmi, R.S. and Gupta J. K. "Theory of Machines [A Text book For Students of B. E./B Tech. U.P.S.C (Engineering Service) Section 'B' of A.M.E (1)]" *EURASIA*

Publishing House (PVT) Ltd., 14thed, 2005, pp 30.

[7] Khurmi, R.S. and Gupta, J.K. “A TextBook of Machine Design”, *Eurasia Publication House Ltd*, New Delhi, India, 2005.

[8] Ihekoronye, A.I. and Ngoddy, P.O. “Integrated Food Science and Technology”, *Macmillan Publishers*, New York, 1985, pp 296 – 301.

[9] Matthew, N.O., Sadiku and Mohammed, L. “Performance Analysis of Token Passing Local Area Networks”, *Journal of Engineering Research*, vol. 2, no. 1, 1997.

[10] Uhuunmwangho, R., Ofojdu, J.C. and Emiri, U.V. “Performance Evaluation of a Turbine Engine”, *Journal of Engineering Research and Development*, vol. 2, no. 1, 2003, pp 66.

[11] Kachru, R.P., Balasubramanian, D. and Kotwaliwale, N. “Design, Development and Performance Evaluation of Rotary Slicer for Raw Banana Chips”, *Journal of agric. Mechanization in Asia, Africa and Latin America*, vol 29, no 4, 1996, pp 1- 64.

[12] Andersen, R.S., Gras, P.W. and MacRitchie, F. “The Inter-independence of the Mixing of Wheat Flour Dough to Peak Dough Development” *Journal of Cereal Science*, vol. 27, 1998, pp 167–177.

[13] Egbekun, M.K. and Akubor, P.I. “Research Methods for Science Studies”, *Published in Nigeria by: AMBIK Press LTD* ISBN:978-978- 8400- 08-0, 2013.

[14] NZFMA. Knowledge base Flour quality parameters. Okafor, B.E. (015), “Design of Power Driven Dough Mixing Machine”, *International Journal of Engineering and Technology*, vol. 5, no. 2, pp 71 -74, (accessed June 2016).

[5] Alireza, S., pour- Damando, Jafary, A. and Rafiee, S.H. “Kinetics of the Crust Thickness Development of Bread during Baking”, *Journal of food science and technology*, vol. 5, no. 11, 2014, pp 3439-3445. Published online 2012 oct. 24 Doi: 10.1007/s13197 -012 -0877 -2. PMID: PMC471265