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Design and Fabrication of an Improved Industrial Impeller Dough Mixer

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ABSTRACT

In bakery industries, dough mixing is a vital operation which improves development of glutten that gives bread a perfect structural composition and high homogenization. Mixing is one of the major operations that determine the mechanical properties of dough, which have a direct consequence on the quality of the end product. Although, there are associated problems and difficulties in the manual method of dough mixing, an improved impeller gearing system dough mixer was designed and developed. Each unit parts of the mixer were designed following standard engineering principles for part-sizing, using locally available materials. Whilst the basin embedded with impeller was made to rotate in clockwise direction. The mixer was tested to ascertain its performance and it has efficiency of 86.67% with mixing rate of 130kg/hr per batch. In this experimental research work, it is inferred that the motorized dough mixing machine will be useful for commercial and for both small and medium scale bakeries that needed to produce bread and other related flour food products.

Keywords—*Design, development, cross-ribbon, dough, mixing, homogenization, embedded, efficiency, rotation*

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I. INTRODUCTION

Generally, in bakery industries, mixing is one of the main operations that determine the mechanical properties of dough to be processed, which have a direct consequence on how good the end product is (Rosell, and Collar, 2009). The properties of the mixed dough are influenced by the ingredients – flour specifications and recipe. Basically, mixing includes two successive stages: firstly, an initial mixing at low speed, for 2 to 4 min, to hydrate ingredients, called “ingredient blending”, and, secondly, the texturing stage at higher speed for 8 to 20 min, called “kneading”, that promotes a more homogeneous blend, through an intensive work input, weaves the gluten network and entraps air (Bloksma, 1990). Despite a great deal of studies about dough mixing, the accurate understanding of the dough formation is still incomplete (Stauffer, 2007). This mixing is an important step in making all kinds of bread and flour processed foods because the characteristics of the mixed dough are critical to successful baking (E.R Pyler 1988) mixing time for each batch of bread dough from the gluten development and the hydraulic absorption level. The mixing operation is summarily to improve the structural development and ingredients homogenization (Hwang, and Gunasekaran, 2001). A perfect dough development is influenced by mixing intensity (mixing speed) and torque imparted (Pastukhov, and Dogan, 2014). To achieve optimal mixing of the dough, the flour is placed in a vessel of some type which allows the material to be moved and stirred in a desired pattern at the desired speed and torque. This is not as simple as there is no one mixer design that universally satisfies all mixing requirements (Vincent, 1966; Okafor, 2015). Despite so many dough mixers available for small and medium scale productions, manual mixing of dough for economic reasons is still common among developing countries (Vincent, 1966; Okafor, 2015). The manual mixing is very slow and laborious with little or no guarantee of homogeneity of the end product (Oni, et al., 2009). Conventional dough mixers such as blade; hook, ribbon and pin-type are mostly used in the industry (Hwang, and Gunasekaran, 2001). In a mixing system with ribbon impellers, mixing proceeds first in the region near the blades and the vessel wall where the material is subjected to high shear strains. Material homogenization is guaranteed by the axial vortex flow induced by the rotation of the ribbon impeller. It has been shown that this kind of impeller is very effective in mixing high viscous fluids (Gray, 1963; Yeng-Yung Tsui, and Yu-Chang Hu, 2011). Therefore, most of these new machines are expensive and sophisticated in operations for small and medium scale bakeries (Godwin, 1961; Okafor, 2015). Conclusively, this research work is devoted to the design, and development of a low cost electric powered cross-ribbon dough mixer that is efficient, easy to operate and maintain for small and medium scale bakeries. Mixing is an important step in making all kinds of bread because the characteristics of the mixed dough are critical to successful baking (E.R Pyler 1988). Large commercial bakeries use highly trained bakers to control the mixing process. These bakeries would like to further automate control of the mixing process to reduce the labor costs of the expert bakers. A baker must determine the optimum ingredient and aroma, and sheen of the dough, all of which relate to the gluten development and the hydraulic absorption level. With some experience, a human subconsciously and accurately senses these critical parameters necessary for good dough mixing must be known (Allais, Edoura-Gaena, Gros,& Trystram, 2007b). Experts (technologists) describe dough properties by qualitative, sensory vocabulary, like “consistent”, “sticky”, and “extensible” dough, implicitly referring to rheology (Elia, 2011). A problem is to represent explicitly this type of knowledge in a computer system (Allais, Edoura-Gaena et al., 2007a), so that mixed dough properties mixed properly. Commercial bakeries use large mixers, powered by " single-phase electrical motor .Currently, there are some mixers that incorporate automatic control system by using the "mix-by-energy" theory proposed by Kilborb and Tipples (E.R Pyler 1988). The main information of dough comes from a special measurement technique named farinography and is acquired from a farinograph equipment. The equipment was the first tool used to measure shear (fluid) and viscosity of a mixture of flour and water. The farinograph is a piece of equipment widely used in the baking industry, and it is employed as an objective measure of flour quality by the acquisition of the dough deformation pattern. Essentially, the equipment measures the resistance that the dough offers to the mixing blades; this resistance will affect the motor torque of the mixing machine. The torque is transmitted to a data acquisition system that records the variation in dough resistance generating a graph called farinographic curve or farinography. In fact, flour rheological characteristics are measured with those instruments to provide information on the whole dough behavior and subsequently, to be used in the decision-making process of food production, considering all this parameters, this bring about the design and construction of an industrial dough mixer to meet all this unique standards in food production.

II. MATERIALS AND METHODS

The materials components selected for dough mixing machine is based on the foods compatibility and availability, sustainability in working condition and cost implications. Some of the properties that influence the choice of selection are : strength, durability, weight, resistance to corrosion, weldability and machinability.

(a) Impeller Shaft Design

The analysis of the shaft design formulas and modeling are shown below, the detail analysis of the shaft diameter prior axial loading is determined by the formula:(Khurmi and Gupta,2003; Hall et al.,1983; Dixon and Poli,1995):

$d^3 = \frac{16}{\pi\sigma_s}\sqrt{(K_b.M_b)^2} + \sqrt{(K_t.M_t)^2}$ ……………………………. (1)

Where, d = diameter of the shaft

K = the stiffness of the shaft

M = Torsion moment of the shaft

M_b = Bending moment of the shaft (N/m)

M_t =Torsion moment of the shaft (N/m)

σ_s = Allowable shear and bending stress for the mild steel used in the construction.

The load on the upper shaft are due to the weight of the roller and the gear and it is calculated to be 4.0kg.

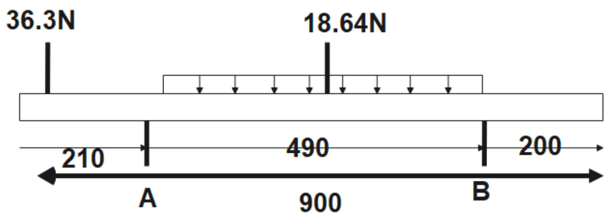
1kgf = 1kg× 9.81m/s^2= 9.81kgm/s^2 = 9.81N (Khurmi and Gupta, 2005)

Weight of the gear = 36.30N

Mass of the impeller shaft was assumed using the density of the galvanized steel = (7850kg/m^3).

Mass of the Impeller shaft= 4.09× 10^{-3}kg/mm.

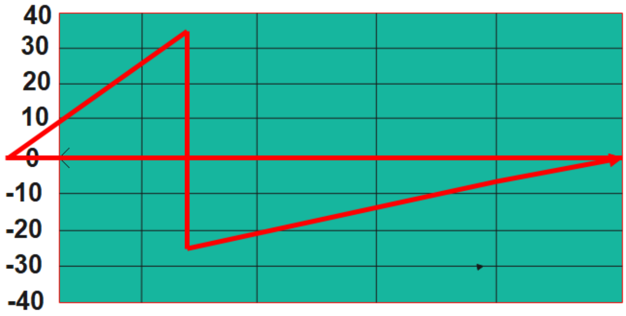
Assuming sum of the clockwise rotation = Sum of the Anticlockwise rotation.



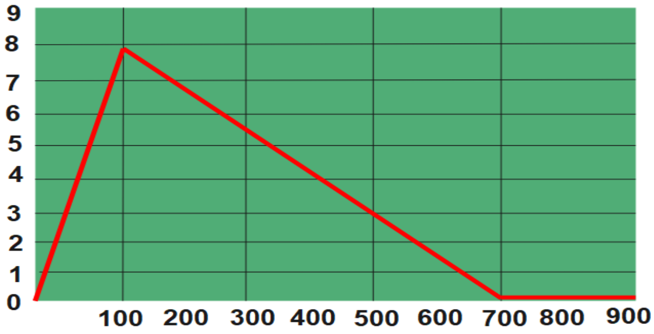
(a)

R_a = 61.18N and R_b= - 6.24N

Maximum bending moment M_b = 7.62Nm



(b)



(c)

Figure 1 Loading, Shear force and Moment diagram for the Impeller Shaft

(b) Volume of Mixing Basin

In designing for a mixer capable of mixing 1000 g (10kg) of blend flour per batch, at 5 inch Hg (16942N/m^2), mixing pressure, 150rpm impeller speed, 1.258g/cm^3= (1258kg/m^3=) dough density is used in dough volume calculation (Campbell, et al., 1993).

Dough volume, $V_d = \frac{m_d}{\rho_d}$ …………………… (2)

Where V_d = dough volume (m^3), m_d = blend flour mass (kg) and ρ_d= dough density (kg/m^3).

Dough Volume = $\frac{10}{1258}$ = 0.00795m^3

Assuming the volume of water + volume of air space +other added ingredients = 30% V_d.

The volume of the mixing basin will then be;

V_d = 0.00795+$(0.30 \times 0.00795) = 0.00795 + 0.002385 = \mathbf{0.00318m^3}$

(c) The diameter of mixing basin

This is determined with the empirical relationship given below:

Volume of mixing basin, $d_d = \sqrt{\frac{4v_b}{\pi h_b}}$ ………………………………… (3)

Where d_d *is the* diameter of mixing basin (m), and h_b height of mixing basin (m)

Let, h_b = 0.048m; $d_d = \sqrt{\frac{4v_b}{\pi h_b}}$ = $\sqrt{\frac{4 \times 0.00318}{0.048}}$ = $\sqrt{0.0843}$ = (0.2903) **= 290.35mm**

(d) Thickness of Mixing Basin

The mixing basin is classified as an open end vessel with only the circumferential or hoop stress induced by the mixing pressure. This circumferential or hoop stress acts in a direction tangential to the circumference of the basin and thickness of mixing basin is determined with the expression by Khurmi and Gupta (2005).

$t = \frac{p \times d}{2\sigma}$ ……………………………………………….. (4)

Where t = thickness of mixing basin (m), p = the mixing pressure (N/), d = internal diameter of mixing basin (m), and = circumferential or hoop stress for steel material.

Let, p = 16942N/m2, d = 0.513m, and σ = 2.5 x 106N/m^2

t = = $\frac{p \times d}{2\sigma}$ = $\frac{16942 \text{ x } 0.513}{2 \text{ x } 2.5 \text{ x} 10^6}$ = 0.00174m (1.74mm), and 2mm thick stainless steel plate is selected.

(e) Power Requirement

The power which the electric motor must develop to drive the mixer is determined with the expression by Khurmi and Gupta (2005).

$P = \frac{2\pi N_m T_m}{60ŋ}$ ………………………………………. (5)

Where P = power developed by the electric motor (watts),

N_m = mixing speed (rpm),

T_m = torque of the driven spindle shaft (Nm),

ŋ = efficiency of the reduction gear

Let, N_m = 150rpm, T_m = 50Nm, ŋ = 0.92

P = $P = \frac{2\pi N_m T_m}{60ŋ} = \frac{2 \times 3.142 \times 150 \times 50}{60 \times 0.92}$ = **0.853kw (1.17hp) .**

Therefore, an electric motor of 1.5hp with speed of 1440rpm is ideal.

(f) Gearbox reducer speed selection

We need to calculate the gear reduction ratio.

Gear reduction ratio $= \frac{Input\ rpm\ (N_2)}{Output\ rpm\ (N_m)} = \frac{Gearbox\ Coupling\ (N_2)}{Mixer\ speed\ (N_m)}$ ……………………….. (6)

Speed of gearbox (according to specifications) = 700rpm (Max.)

Impeller speed at Maximum speed =120rpm

Gear reduction ratio = $\frac{700}{120}$ = 5.8:1 ~ **6:1**

On assumption that the mixer is loaded for 10hrs intermittently mixing operation per day, 1.25 service factors are then selected according to (Fenner, 2012). Thus, using the gearbox consumed power of 0.853kw; the design power is further calculated as;

Design Power = 1.25 x 0.853kw = 1.067kw (1.47hp)

Design Power is approximately = **1.5hp**

This indicates that for a 6/1 gear unit at 120rpm output speed, 1.5hp motor is required to propell the gearbox.

2.1 DOUGH MIXER CONSTRUCTION PROCEDURES

CONSTRUCTION PROCEDURES

The fabrication procedures include the following steps.

(1) SCRIBING: This involves marking out the provided materials to be fabricated into the required specifications.

(**2) CUTTING**: This involving cutting either by sawing or using grinder to chop off materials to the required specifications. There is way there will be fabrication without cutting either by sawing, grinding or use of gas to cut the metal to shapes and the desired pattern.

(3) GRINDING: This involved the use of electric grinder or pneumatic to chop off excess materials, it is highly essential during fabrication in order to ensure adequate smoothness and good surface finished.

(4) DRILLING: Drilling is a cutting process that uses a drill bit to cut a hole of circular cross-section in solid materials. The drill bit is usually a rotary cutting tool, often multi-point. The bit is pressed against the work-piece and rotated at rates from hundreds to thousands of revolutions per minute, any part that needed to be bolted or when there is need to couple two independent shaft together, we can drill, then bolted together.

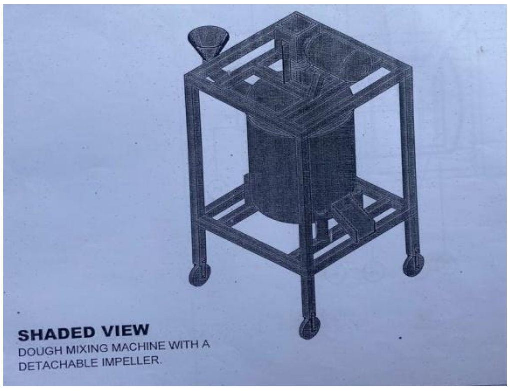
(5). WELDING: This involve mating of two parts under high temperature, it may be by arc or by gas welding. During the fabrication, this two methods was adopted ,gas welding was use to cut out the desired pattern of the dough mixer, and the electric arc welding machine was used to weld all the intricate and assembled parts together.

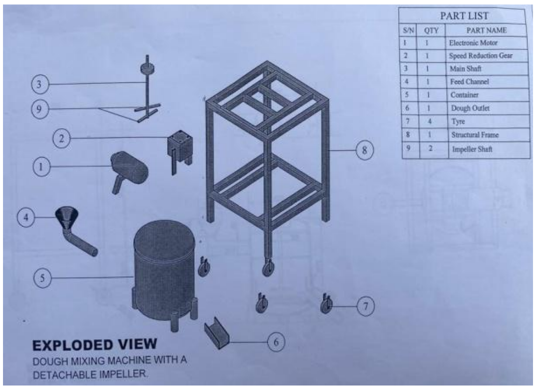
(6) PAINTING: This involves coating to prevent rusting and corrosion, it also adds to the beauty of the component, which makes it attractive to the customer due to its polished and fascinating nature.

(7) TEST-RUN: This involves pre-test of the fabricated components to see if the performance is up to the desired expectation, if it fails, further work will be done on it to ensure it works satisfactorily.

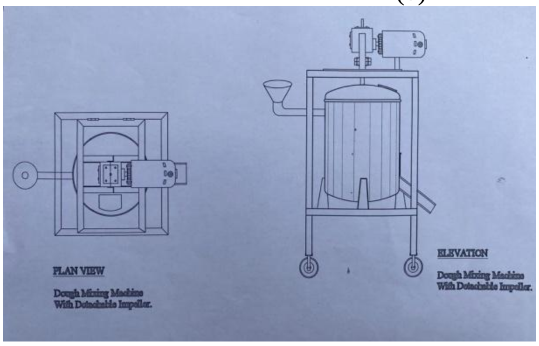
2.2 DOUGH MIXER DESIGN DRAWING

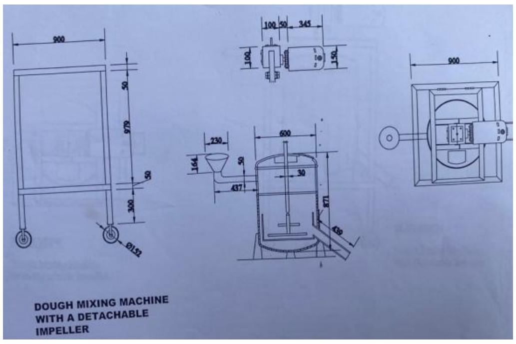
The figure 2 below show the detailed drawing of the dough mixer and figure 3 illustrate the pictorial view of the impeller dough mixer.





(a) (b)





(c) (d)

Figure 2. Shaded Assembly drawing diagram

(a) (b)

Figure 3(a and b) Showing the Industrial Dough Mixer at 80% and 100% completion

2.3. Dough Preparation

This work was not only focused on the mixing capacity, but also on the hygenic nature and the amount of dough in volume it can make within a specified time, this system can be related to the changes in the dough during the mixing process.

2.3.1 Dough Mixer Test-run

To test this, the following recipe was used: For 2 kg of wheat flour (100%), water (25%), soybean oil (5%) and yeast (0.5%) were added to study the system response to the mixing dough process. In the second formulation, to observe any change in the dough behavior, the amount of soybean oil that was reduced to 1%, while the difference in weight was corrected by adding water. Six experimental runs will be carried out for each formulation. It must be noted that dough properties are assessed by a test baker, whose job is to assess the dough properties following the standard NF V03-716 (2002).

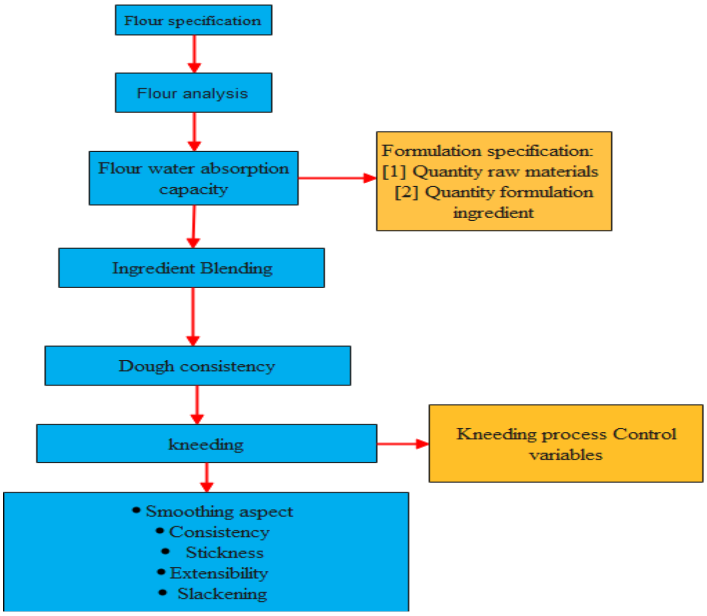


Figure 4 Systematic representation of mixing operation is seen above

III. RESULTS

This was based on the results obtained on completion and final test run of this equipment, and it is based on the load and weight of the flour to be mixed by the fabricated component as shown in Figure (5) and Figure (6) which indicate the performance of the fabricated dough mixer with response to loading (kg) the weight of the flour with the due time taking to mix the flour satisfactorily. Figure (5) shows maximum performance of the dough mixer reaching about 130 kg for 11 minutes, while Figure (6), indicates the fall in the performance while loading the imported dough mixer of the same rating within the same period of time.

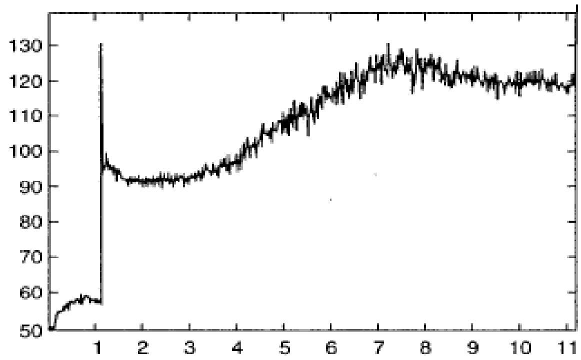


Figure 5 Graph showing test-run of locally fabricated dough mixer under same to mix within a specified time in minute which indicate optimum performance.

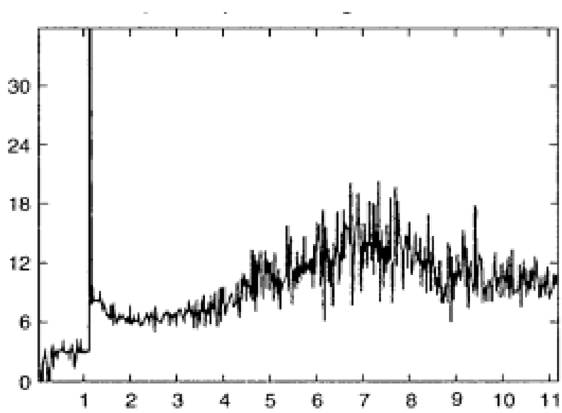


Figure 6 Graph showing test-run of imported dough mixer under same loading to mix within a specified time in minute which indicate low performance

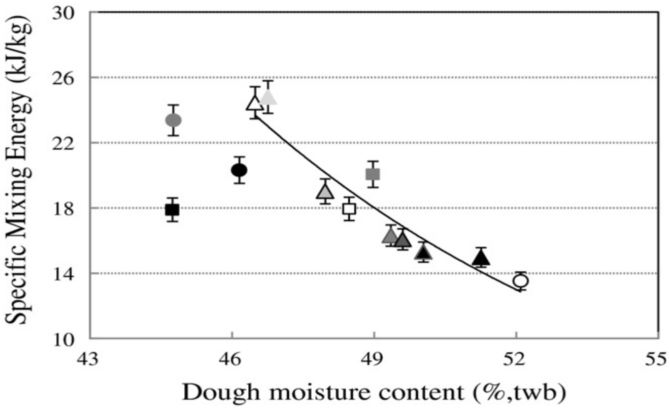


Figure 7 Showing Dough moisture content with Specific mixing energy

3.1 Mixing Efficiency

The dough mixing operation was experimentally scaled to batch process and the impeller shaft dough mixer was designed at 450kg/hr per batch. However, during testing, 130kg of blend flour per batch was used and optimum dough development was achieved in 20 minutes. Thus, in 20 minutes, the mixing rate per batch for 130kg.

This can be mathematically mass x time in (hrs) written as;

Output Mixing capacity = $\frac{\text{mass x time in (hrs)}}{Time\ used\ in\ (minutes\ )} = \frac{130x60}{20}$ = **390kg/hr**

Efficiency = $\frac{output\ \ mixing\ \ capacity\ \ in\ Kg/hr}{Designed\ \ mixing\ \ capacity\ \ Kg/hr}$ x 100

Hence, mixing efficiency = $\frac{390}{450}$ x100 = **86.67%**

IV. CONCLUSION

Knowing that these result can help us to predict mixing performances and dough properties when this dough mixer is employed at the laboratory based on the result obtained. The results of the performance evaluation of this dough mixer presented in this research show the relevance of the underlying qualitative use of locally fabricated dough mixer in different bakery and the research laboratory; this evaluation also provides explanations for observed dough properties. The verification step, gives a matching approximately 90%, better performance when compared with imported ones. Evaluation performed provides meaningful explanations for dough making and its properties, based on the process conditions. However, it has been shown that most of the imported dough mixer spent more than the stipulated time intervals when loaded with the same volume of flour with the locally fabricated one, this ultimately confirm maximum performance of this dough mixer against the imported ones. The deficiency on the imported dough mixer was mostly addressed in this design that is what brings about optimum result during our test-run, although there is still room for future improvement in this design to fully automate the mixing process.

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CONFLICT OF INTEREST

The author has declared that no competing interests exist.

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None.

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