Development and evaluation of a fish feed mixer

Adenigba Ademola Adebukola[1*], Olalusi Ayoola Patrick[2]

(1. *Department of Agricultural and Bio-Environmental Engineering, Federal Polytechnic Ilaro, Ogun State, Nigeria. P.M.B 50*;
2. *Department of Agricultural Engineering, Federal University of Technology, Akure, Nigeria, P.M.B 704*)

Abstract: A fish feed mixing machine was designed, developed and the effect of speed and retention time on the performance of the mixer was evaluated. The mixing system was tested using three fish feed ingredients; bone meal, groundnut cake and maize grain which was purchased from the market in Akure, Ondo State, Nigeria. The moisture content of the bought ingredients was determined to be 13.1%, 14.7% and 17.5% moisture content dry basis (db) respectively. The mixer was tested using a feed component of three equal measures of 10 kg of ground corn (maize), milled groundnut cake and bone meal which were initially retained on 2 mm, 850 µm and 150 µm sieve respectively. The experiment was replicated thrice at four retention time (5 min, 10 min, 15 min and 20 min) and five mixer screw speed (100 rpm, 150 rpm, 200 rpm, 250 rpm and 300 rpm).

Regression analysis was carried out on the data collated during the evaluation of the mixer, the analysis was used to develop models which is capable of predicting the electrical energy (kJ) consumed, degree of mixing (%) and average power (kW) consumed during mixing.

An average CV of 4.04% was obtained at 200 rpm in 20 minutes retention time while 356.4 kJ electrical energy was consumed, this shows a significant reduction of non-uniformity in feed components for the samples tested. The degree of mixing attained was 95.96% which portrays an improvement of about 0.2% reduction in non-uniformity of components among samples when the mixing duration was 20 min at 150 rpm. The average power and electrical energy consumed during mixing was observed to be significantly dependent on the retention time while speed does not have a significant effect on the average power and energy consumed during mixing, the degree of mixing increases as the retention time increases. There is a decrease in energy consumed as the speed increases under a constant retention time while the energy consumed increases as the retention time increases with a constant speed.

Keywords: bone meal, groundnut cake, ground corn, mixing machine, degree of mixing, coefficient of variation

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1 Introduction

Production of palatable and nutritious diet for aquatic life involves a range of activities, which include grinding, mixing, pelleting and drying operations. There are different types of machinery needed for the production of various types of feeds and they include grinders, mixers, elevators and conveyors, extruders, cooker, driers, fat sprayers and steam boilers. The mixing operation in particular, is of great importance, since it is the means through which two or more ingredients that form the feed are interspersed in space with one another for the purpose of achieving a homogenous mixture capable of meeting the nutritional requirements of the target livestock, poultry or aquatic life being raised (Balami et al., 2013).

Essentially, feed mixing can be done either manually or mechanically. The manual method of mixing feed entails the use of shovel to intersperse the feed's constituents into one another on open concrete floors. The manual method of mixing feed ingredients is generally characterized by low output, less efficient, labour intensive and may prove unsafe, hence, hazardous to the health of the intended animals, birds or fishes for which the feed is prepared. The mechanical method of mixing is achieved by using mechanical mixers developed over the

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*** Corresponding author: Adenigba, Ademola Adebukola**. Department of Agricultural and Bio-Environmental Engineering, Federal Polytechnic Ilaro, Ogun State, Nigeria. P.M.B 50. Email: ademola.adenigba@federalpolyilaro.edu.ng. Tel: +2348067338770.

years to alleviate the shortcomings and drudgery associated with the manual method.

A satisfactory mixing process produces a uniform feed in a minimum time with a minimum cost of overhead, power and labour. Some variation between samples should be expected, but an ideal mixture would be one with minimal variation in composition (Lindley, 1991). Mixing is a case where more is not necessarily better. There is usually an optimal mix time, which must be determined experimentally. The experiment is tedious because mixing is determined by measuring the standard deviation of some critical component. This requires taking multiple samples, at least ten, from various parts of the mixer at a succession of times. Makange et al. (2016) tested an animal feed mixing machine using a feed component divided into 3.5 kg for maize bran, 1.25 kg for cotton/sunflower cake, 0.15 kg for lime, 0.075 kg for bone meal and 0.018 kg for salt replicated thrice at two mixing durations of 10 and 20 min. the average CV was 5.93% which shows a significant reduction in feed components for the samples tested. Often, mixing times are determined by using an easy-to-analyse component, such as salt, but care must be taken that the results apply to the material of most interest, since it may have different particle size and density than salt does (Clark, 2005). This study is an attempt towards designing and fabricating a machine capable of mixing fish feed constituents. The design incorporates the use of locally available materials for the construction. The machine was designed and fabricated with a view of reducing human effort, time and electrical energy consumed during mixing by exploring the various machine parameters associated with the performance of the mixer.

2 Methodology

2.1 Materials

The key components of the machine such as the mixing chamber, the screw auger and the feed outlet were fabricated with stainless steel while the supporting frames are made of mild steel. The machine also consists of a reduction gear which reduces the driving speed from the electric motor at a ratio of 10:1. A driving sprocket (41 teeth) is attached to the outlet of the reduction gear and is connected through a chain to the driven sprocket (21 teeth).

The materials used for evaluating the machine were sourced locally, these materials are cheap to own and use by the stock raisers. The mixing system was tested using three fish feed ingredients; bone meal, groundnut cake and maize grain which was purchased from the market in Akure, Ondo State, Nigeria. The moisture content of the bought ingredients was determined to be 13.1%, 14.7% and 17.5% moisture content db. respectively.

2.2 Design calculations

(1) Volume of mixing chamber

The mixing chamber consists of a rectangular section and curved sections which consist of two semi-circular troughs as shown in Figure 1.

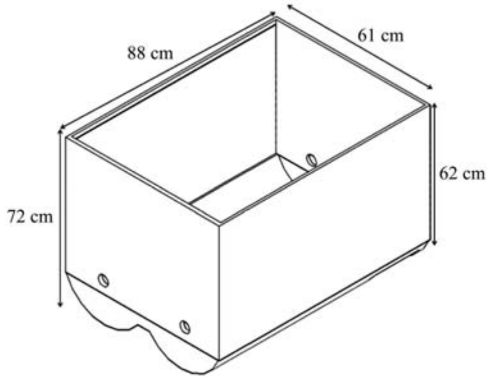


Figure 1 Mixing chamber

The total volume of this chamber is computed using the relationship:

The total volume of this chamber is computed using the relationship:

$$V_T = V_R + V_{SC} \tag{1}$$

where, V_T is the total volume of mixing chamber (m^3); V_R is the volume of the rectangular chamber (m^3); V_{SC} is the volume of the curved sections (two semi-circular trough) (m^3).

(2) Capacity of the conveyor

Two horizontal acting auger conveyors (Figure 2) which operates inside the rectangular chamber and semi-circular trough to effect blending of feed components were designed for the machine. The augers were designed with helices of uniform diameter of 210 mm and a pitch of 183 mm.

The capacity of the auger is computed using Equation 2 given by (Balami et al., 2013) as:

$$Q = 60n\phi p\gamma (D^2 - d^2)\frac{\pi}{4} \tag{2}$$

where, Q is capacity of conveyor, t h^{-1}; γ is bulk density of conveyed material, kg m^{-3}; n is number of screw rotations; p is conveyor pitch, 183 mm; D is pitch diameter of conveyor, 210 mm; d is diameter of shaft, 38 mm; π is constant, 3.142; ϕ is factor introduced for inclined conveyor, 0.33 (Balami et al., 2013).

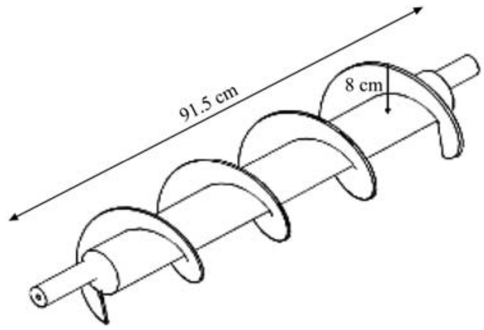


Figure 2 Horizontal acting auger conveyor

(3) Determination of machine power consumption

The power required to operate the mixing machine was computed using Equation (3) as expressed by (Balami et al., 2013):

$$L = 0.7355ClQ \tag{3}$$

where, L is power required by the conveyor, kW; C is coefficient, constant for conveyed material, 0.3; l is length of conveyor, m; Q is capacity of conveyor, t h^{-1}.

(4) The drive

V-belt and pulley arrangements were adopted in this work to transmit power from the electric motor to the shaft of the reduction gear while chain and sprocket were used to transmit power from the reduction gear to the shaft of the mixing unit. The main reasons for adopting the v-belt drive are its flexibility, simplicity, and low maintenance costs. Additionally, the v-belt has the ability to absorb shocks thereby mitigating the effects of vibratory forces. The reduction gear which is of ratio 1:10 was used to reduce the rotational speed from the electric motor in order to achieve the required speed at the mixing unit (Balami et al., 2013).

(5) Pulley diameters

The sprocket on the reduction gear and the mixing unit was made constant throughout the period of evaluation. The sprocket reduces the speed from the reduction gear at a ratio of 2:1 on getting to the mixing unit. The pulley diameter for the mixing auger is calculated using Equation (4) expressed by Ikechukwu et al. (2014) as:

$$N_1D_1 = N_2D_2 \tag{4}$$

where, N_1 is speed of the driving pulley in rpm (speed of the electric motor); D_1 is diameter of the driving pulley (mm); N_2 is speed of the driven pulley in rpm (reduction gear); D_2 is diameter of the driven pulley (mm).

(6) Belt speed

The belt speed for the mixer drive (reduction gear) is calculated using Equation (5) as expressed by Shigley and Mischike (2001).

$$V = \frac{\pi DN}{60} \tag{5}$$

(7) Determination of mixer shaft diameter

The equations for computing equivalent twisting moment (Te) and that of a mixer shaft diameter (d) are given by Khurmi and Gupta (2004) as:

$$T_e = \sqrt{(MK_b)^2 + (TK_t)^2}\,\frac{\pi DN}{60}$$
$$d^3 = \frac{16T_e}{\pi\tau} \tag{6}$$

where, T_e is equivalent twisting moment, Nm; M is maximum bending moment, Nm; T is torsional moment, Nm; K_b is fatigue factor due to bending, 2.0; K_t is fatigue factor due to torsion, 1.5; τ is maximum allowable shear stress, N mm^{-2}; d is diameter of mixer shaft, mm.

2.3 Description of the machine

The mixing system consists of the following components; electric motor, transmission system, reduction gear, gear system, mixing chamber, outlet, support frame, mixer auger, chain and sprocket. Figure 3 shows the exploded view of the machine. The mixing chamber consist of a rectangular section and curved sections which have two semi-circular troughs as shown. The upper part which is the rectangular section is made with a diameter of 880 mm by 610 mm and height of 620 mm. The lower section which has two semi-circular trough has a height of 100 mm and a diameter of 300 mm.

Electric motor: The system was powered by an electric motor of 3.73 kW which has a revolution of 1460 rpm.

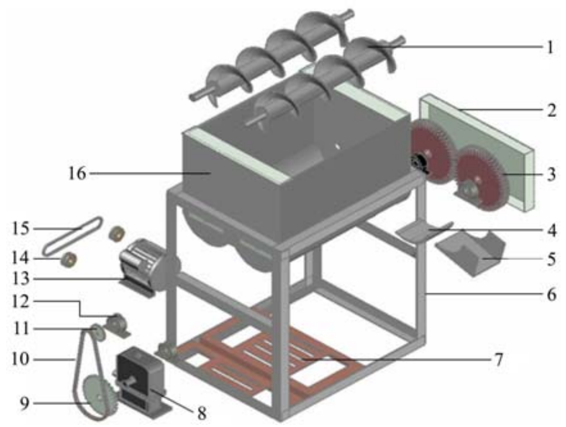
Transmission System: It consists of shafts, pulleys and belts. The electric motor is the prime mover of the machine, as the pulley which is connected to the shaft of the electric motor is being propelled into action by the rotation of the electric motor; power is being transmitted from this pulley via a belt to another pulley which is connected to the shaft of the reduction gear.

Reduction gear: The reduction gear reduces the speed (rpm) derived from the electric motor at a ratio of 1:10.

Sprocket: The driving sprocket has 41 teeth while the driven sprocket has 21 teeth, this implies that there is an increase in speed at a ratio of 2:1 at the driven sprocket.

Gear system: This is made up of mesh gears which drive the shaft within the mixing chamber.

Mixer auger: The auger is made up of a shaft and helical blade. The helical blade is wound round a cylindrical drum which is attached to the shaft; hence the helical blade forms a spiral shape on the shaft. The auger is the component of the mixer which performs the mixing. The mixing chamber is provided with two horizontal auger conveyor which works simultaneously to perform proper mixing of the feed ingredients. The augers were constructed on mild steel rods of 38 mm diameter shafts. Its helices were made with a uniform diameter of 210 mm and pitch of 183 mm.



Item	Description	Qty	Items	Description	Qty
1	SCREW AUGER	2	9	BIGGER SPROCKET	1
2	GEAR COVERING UNIT	1	10	CHAIN DRIVE	1
3	MESH GEAR	2	11	SMALLER SPROCKET	1
4	OUTLET OPENER	1	12	BEARING	4
5	OUTLET	1	13	ELECTRIC MOTOR	1
6	FRAME	1	14	PULLEY	2
7	ENGINE SEAT	1	15	BELT DRIVE	1
8	REDUCTION GEAR	1	16	MIXING CHAMBER	1

Figure 3 Exploded view of the mixer

2.4 Performance test of the mixer

Preliminary testing of the mixer is targeted at evaluating its ability to blend feed components, duration of mixing and rate of discharge both through the discharge and the transfer channels. At the onset of the test, 10 kg of ground corn, 10 kg of groundnut cake and 10 kg of bone meal which was retained on 2 mm, 850 μm, 150 μm sieve respectively was poured into the mixer, and the mixer's performance test was conducted and replicated thrice according to the standard test procedure for farm batch feed mixers developed by ASAE (2006), Ibrahim and Fasasi (2004). Four mixing durations of 5, 10, 15 and 20 min at five mixing speed of 100, 150, 200, 250 and 300 rpm were used in the cause of conducting the tests. At the end of each test run, ten samples of 300 g were drawn from ten specified locations within the mixed components and the coefficient of variation among blended samples and mixing levels, was computed using the expressions below as given by (Ibrahim and Fasasi, 2004):

$$CV = \frac{s}{x} \tag{7}$$

$$\%Dm = (1 - cv) \times 100 \tag{8}$$

$$S = \sqrt{\frac{£(X - x)^2}{(n - 1)}} \tag{9}$$

where, CV is Coefficient of variability; DM is Percent mixing level; S is Standard deviation; X is Weight of corn in the samples; x is Mean value of corn in the samples; n is Number of samples (Balami et al., 2013).

2.5 Statistical analysis

Mixing performances parameters' values (degree of mixing, average power consumed and energy used during mixing) were subjected to statistical analysis to determine the mean, standard deviation, coefficient of variation, linear and nonlinear regressions. One-way ANOVA was used to test for significance among the treatments and post hoc comparison using Tukey test to separate significantly differing treatment means after main effects were found significant at $p<0.05$. The significance tests of the mixing performances parameters' (degree of mixing, average power consumed and energy used during mixing) of the main treatment effects (mixer screw speed and retention time) and their interactions were performed using the Analysis of Variance (ANOVA) within the General Linear Model (GLM) procedure using Minitab 17 statistical software.

3 Results and discussion

3.1 Results

The Tables (1, 2, 3, 4 and 5) bellow give the average weight of corn recovered from each of the 10 samples drawn from the mass of mixed components after a mixing period of 5, 10, 15 and 20 minutes in respect of the three replicated tests carried out at five different speeds (100, 150, 200, 250 and 300 rpm).

Table 1 Mixing machine's performance at 100 rpm

S/N	Time (mins)	Mean weight of corn (g)	Coefficient of variation (%)	Degree of mixing (%)	Average power consumed (kW)	Energy used during mixing (kJ)
1	5	91.8	11.22	88.78	0.1	29.99
2	10	91.6	9.16	90.84	0.2	120.24
3	15	95.6	8.09	91.91	0.2	180
4	20	93.8	6.313	93.63	0.3	356.4

Table 2 Mixing machine's performance at 150 rpm

S/N	Time (mins)	Mean weight of corn (g)	Coefficient of variation (%)	Degree of mixing (%)	Average power consumed (kW)	Energy used during mixing (kJ)
1	5	98.2	9.92	90.08	0.1	29.99
2	10	102.8	8.79	91.21	0.2	120.24
3	15	98.6	5.18	94.82	0.4	360
4	20	101.2	4.24	95.76	0.5	594

Table 3 Mixing machine's performance at 200 rpm

S/N	Time (mins)	Mean weight of corn (g)	Coefficient of variation (%)	Degree of mixing (%)	Average power consumed (kW)	Energy used during mixing (kJ)
1	5	81.2	8.72	91.28	0.1	29.99
2	10	100.7	6.25	93.75	0.2	120.24
3	15	91.4	4.41	95.58	0.2	120.24
4	20	93.3	4.04	95.96	0.3	356.4

Table 4 Mixing machine's performance at 250 rpm

S/N	Time (mins)	Mean weight of corn (g)	Coefficient of variation (%)	Degree of mixing (%)	Average power consumed (kW)	Energy used during mixing (kJ)
1	5	95.4	10.5	89.5	0.1	29.99
2	10	100	8.61	91.39	0.2	120.24
3	15	87.8	5.58	94.43	0.3	270
4	20	89.5	5.48	94.52	0.4	475.2

Table 5 Mixing machine's performance at 300 rpm

S/N	Time (mins)	Mean weight of corn (g)	Coefficient of variation (%)	Degree of mixing (%)	Average power consumed (kW)	Energy used during mixing (kJ)
1	5	95.4	10.5	89.5	0.1	29.99
2	10	91.7	9.16	90.84	0.1	60.12
3	15	100	8.61	91.39	0.2	180
4	20	100.7	6.25	93.75	0.3	356.4

3.2 Discussion

3.2.1 Effect of speed and retention time on degree of mixing

There is increase in the degree of mixing (Figure 4) as the retention time increases from 5,10, 15 to 20 minutes for all the corresponding speed, however the effect of speed on the degree of mixing is unlike that of retention time. There is increase in the degree of mixing from 100, 150 to 200 rpm and a decrease at 250 to 300 rpm. This shows that the mixer was able to achieve effective mixing between 150 to 200 rpm while further increase in speed does not give a better degree of mixing but a close result to that of 200 rpm or a decrease in the degree of mixing. This corroborate the report of (Ugwu, 2015) which states that typical bottom fed mixer of conical shape usually operates at a speed of 400-600 rpm and requires more power for a given capacity than top feed mixer which usually operates effectively at 150-200 rpm. Figure 5 illustrates the interaction plot for degree of mixing (%) fitted means, it was observed that degree of mixing increases with increase in retention time. At 5 min, retention time of the 100 rpm degree of mixing was 88.78%, while at 10 min, retention time the degree of mixing was 90.84%. The 5 minutes increase in retention time gave a corresponding increase of 2.06% in degree of mixing. The result showed a significant increase in degree of mixing at 20 minutes as the degree of mixing attains 93.63%. This is in uniformity with the findings of (Brennan et al., 1998), who reported that in a mixing operation, non-uniformity among components in the mixture decreases with time of mixing until equilibrium mixing is attained. Figure 6 gave also illustrates the effect of speed and retention time on the degree of mixing. At a constant speed of 200 rpm, the degree of mixing gradually increases as the retention time increases from 5, 10, 15 and 20 minutes respectively. However, at 250 rpm the degree of mixing increased with increase in retention time from 5 to 10 and 15 minutes while there was a negligible reduction in the degree of mixing as the retention time increases to 20 minutes.

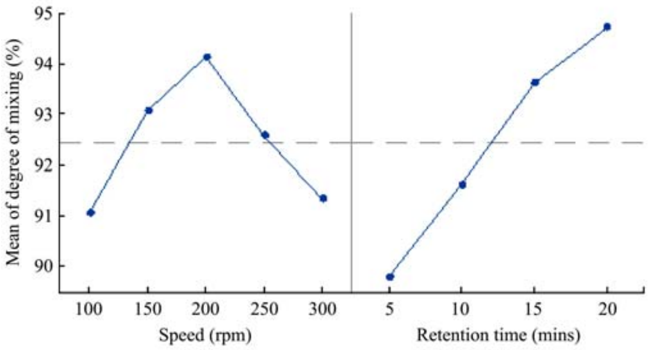


Figure 4 Main effect plot for degree of mixing

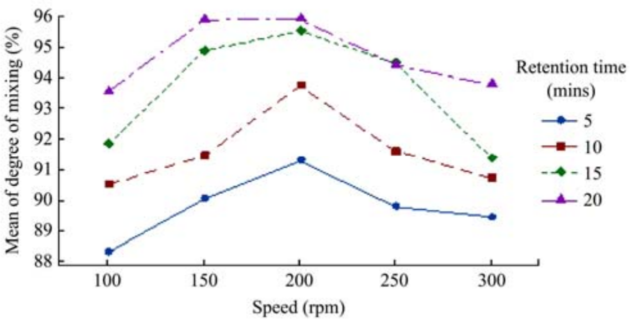


Figure 5 Effect of speed on degree of mixing (%) fitted means

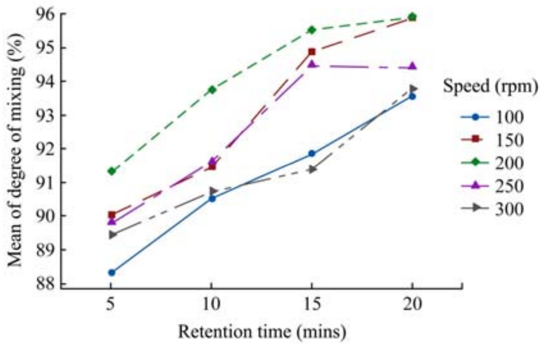


Figure 6 Effect of retention time on degree of mixing (%) fitted means

3.2.2 Average power consumed during mixing

Statistical analysis of variance of the data collated during evaluation of the mixer shows that speed (P-Value: 0.231) does not have a significant effect on the average power consumed during mixing while retention time (P-Value: 0.017) has significant effect. The interaction between speed and retention time (P-Value: 0.388) does not have a significant effect on the average power consumed during mixing. The R^2 (43.19%) depicts that speed and retention time was able to explain only 43% variation in average power consumed which means there are still some other factors which affects average power consumed during mixing.

Figure 7 shows that average power consumed does not have a linear relationship with the speed of operation because there is haphazard trend when speed was compared with power consumed. This implies that speed does not have a significant effect on average power consumed. The effect of retention time on average power consumed shows that there will always be an increase in power consumed for any substantial increase in retention time. Figure 8 shows that there is increase in power consumed at a retention time of 5minutes when the speed was increased from 250-300 rpm while there was a decrease in the average power consumed at 15 and 20 min. retention time when the speed was increased from 250 rpm to 300 rpm.

3.2.3 Energy consumption during mixing

There is increase in the energy used during mixing as the retention time increases while the speed does not have a significant effect. As the speed increases from 100-150 rpm the energy used increased and there was a subsequent drop in the energy used at 150-200 rpm. There was also an increase in the energy used at 250 rpm and followed by a decrease at 300 rpm. Hence it was observed (Figure 9) that a wavy trend occurs in the energy used and the trend exhibits its wavy character at every interval of 50 rpm increase. The interaction plot for energy used during mixing (fitted means) is shown in Figure 10, where it was observed that the mean energy used during mixing at 5 minutes retention time is below 100 kJ and it was observed to exhibit uniform energy consumption under the various speeds considered.

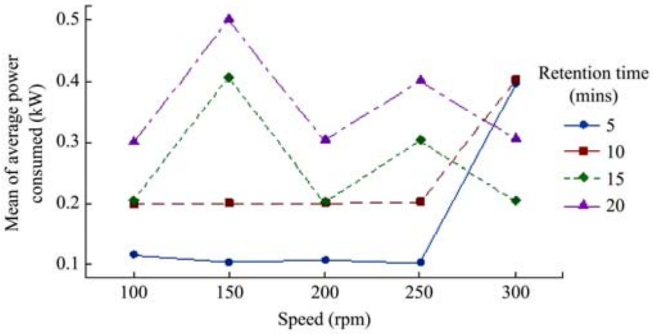


Figure 7 Effect of speed on average power consumed

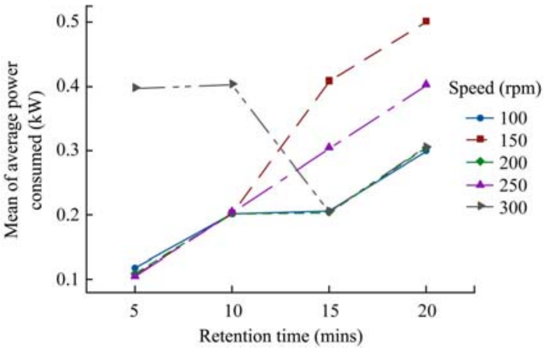


Figure 8 Effect of retention time on average power consumed

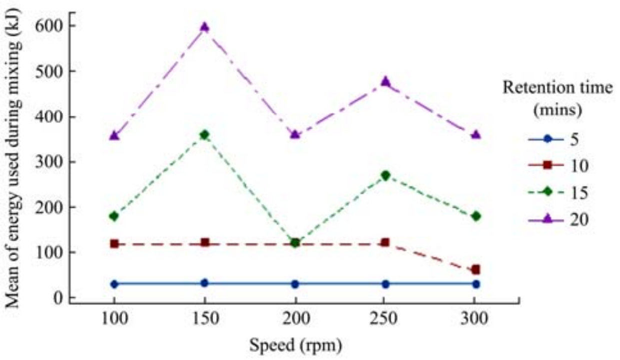


Figure 9 Effect of speed on energy consumed during mixing (fitted means)

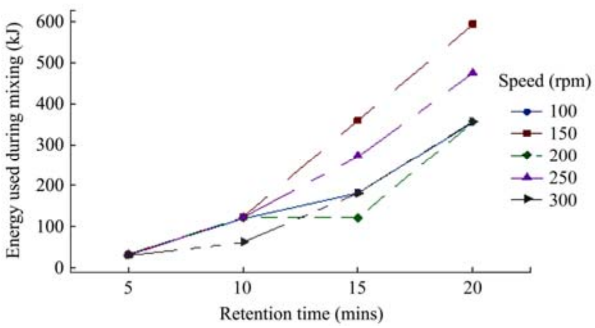


Figure 10 Effect of retention time on energy consumed during mixing (data means)

3.3 Regression analysis

The model that best described data characteristics is the one that gives the highest R^2, the lowest χ^2 and RMSE values. In the tables below R_t and S_p represent the retention time and mixer screw speed respectively. Based on these criteria, the highlighted models are the best fit for the data.

Table 6 Regression analysis of energy used during mixing (kJ)

Model No	Model Equation	R^2
I	$-96.7-0.16S_p+26.09R_t$	0.808
II	$-128.4-0.005S_p+28.63R_t-0.013S_p\times R_t$	0.809
III	$-254.1+1.64S_p+26.09R_t-0.005S_p^2$	0.821
IV	$61.9-0.16S_p-5.63R_t+1.269R_t^2$	0.846
V	$-95.4+1.64S_p-5.63R_t-0.005S_p^2+1.27R_t^2$	0.859
VI	$-127+1.79S_p-3.09R_t-0.005S_p^2+1.27R_t^2-0.01S_p\times R_t$	0.860

Table 7 Regression Analysis: Degree of mixing (%)

Model No	Model Equation	R^2
I	$88.19+0.0002S_p+0.34R_t$	0.681
II	$87.09+0.006S_p+0.42R_t-0.0004S_p\times R_t$	0.687
III	$79.09+0.10S_p+0.34R_t-0.0003S_p^2$	0.910
IV	$87.26+0.0002S_p+0.52R_t-0.007R_t^2$	0.688
V	$78.16+0.10S_p+0.5226R_t-0.0003S_p-0.007R_t^2$	0.917
VI	$77.06+0.11S_p+0.61R_t-0.0002S_p^2-0.007R_t^2-0.0004S_p\times R_t$	0.922

Table 8 Regression analysis of average power (kW) consumed (mixing)

Model No	Model Equation	R^2
I	$0.03+0.0004S_p+0.01R_t$	0.18
II	$-0.21+0.002S_p+0.03R_t-0.00009S_p\times R_t$	0.23
III	$0.13-0.0008S_p+0.01R_t+0.000003S_p^2$	0.18
IV	$0.06+0.0004S_p+0.007R_t+0.0002R_t^2$	0.18
V	$-0.08+0.0005S_p+0.03R_t+0.000003S_p\times S_p+0.0002R_t^2-0.0001S_p\times R_t$	0.23

4 Conclusion and recommendation

4.1 Conclusion

This study was conducted to evaluate the effect of speed and retention time on the performance of the mixer. Based on the experimental findings, it can be concluded that:

i) Maximum mixing performance of 95.96% was attained in 20 minutes of operation at 200 rpm and 356.4 kJ electrical energy was used in attaining this degree of mixing at 4.04% coefficient of variation.

ii) An average CV of 4.04% was obtained at 200 rpm in 20 minutes retention time.

iii) There is a significant reduction of non-uniformity in feed components as retention time increases with a constant mixer screw speed.

iv) The average power and electrical energy consumed during mixing was observed to be significantly dependent on the retention time while speed does not have a significant effect on the average power and energy consumed during mixing,

4.2 Recommendation

Based on the experimental results, the following recommendations are made:

i) The mixer should be operated at mixing auger speed of 200 rpm for a period of 20 to 25 minutes per batch of mixing,

ii) Further research should be carried out to determine the effect of moisture content on the performance of the machine,

iii) The use of a conveyor system may be considered for use as this will ease delivery of materials into the mixer.

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