MANUFACTURING AND PERFORMANCE EVALUATION OF A LOCAL ANIMAL FEED HORIZONTAL MIXER

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ABSTRACT

The present research was carried out to manufacture and evaluate some operating parameters affecting the performance of an animal feed horizontal mixer to improve product quality. The mixer performance was studied as a function of change in material batch size and mixing time. Performance evaluation of the horizontal mixer was carried out in terms of mixing homogeneity, coefficient of variation, specific energy and mixing cost.

The experimental results revealed that coefficient of variation; mixing homogeneity; specific energy and mixing costs were in the optimum region under the following conditions:

- *The mixer shaft is designed at a diameter of 80 mm.*
- *Operate the mixer at a batch size of between 700 to 850 kg.*
- *The mixing time should be of between 15 to 20 minutes.*

INTRODUCTION

Mixing is one of the essential technological processes for production of compound feed additives for animals and it has important influence on the quality of the final product. The objective of the mixing process is to produce feed additives in which nutrients and medication are uniformity distributed and well mixed. This efficiency of the mixer will be expressed by the homogeneity obtained after different or usual mixing times for the used mixer and material composition.

The homogeneity of the mixture after the usual mixing time and after conveying the mixture to the final stations expressed by the coefficient of variation.

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Satisfactory mixing process produces a uniform feed in a minimum time with a minimum cost of overhead, power, and labor. Some variation between samples should be expected, but an ideal mixture would be one with minimal variations in composition. **Dirksen *et al.* (1980)** mentioned that stationary mixing equipment is available commercially. A batch mixer to prepare separate batches of feed is a practical system. On-farm feed systems normally use three types of mixers: vertical, horizontal, or rotating drum. Mixing times on vertical mixers normally run 10 to 15 min. Horizontal and rotating drum mixers can mix in 5 to 10 min. The vertical mixer is composed of an upright tank, usually round, with a vertical auger in the center to mix the feed. Smaller, less costly mixers are usually of the vertical type. Typical vertical mixers are available in models ranging in size from a 1/2-ton model requiring a 3-horsepower motor up to a 4-ton model requiring a 25-horsepower motor. Larger mixers are usually of the horizontal type with a horizontal shaft in the center carrying paddles or ribbons for the mixing. Power requirements range from 3 to 5 horsepower for an l/2-ton mixer up to 20 to 30 horsepower for a 3-ton model. **ASAE (1997a, b)** identified a number of methods of on-farm feed mixing which are available to livestock farmers. Mixer wagons (mobile equipment for producing complete diet feeds or " total mixed rations " are more likely to be used on mixed arable and livestock farms or farms that grow a number of different grass crops, rather than all-grass farms. **Portillo *et al.* (2007)** looked at a wide range of parameters that influence blending in a bladed mixer. They report that mixing improves with decreasing rotation rate even though powder is subjected to greater shear forces at larger rotation rates. They hypothesize that the reduced mixing at higher rotational speeds is due to turboelectric effects. Surface charges developed by greater stirring and shaking, and hence increased turbo charging, lead to the formation of powder deposits within the mixer which degrade output homogeneity. **Avik and Wassgrena (2009)** investigated the influence of fill level and impeller rotation rate in a horizontal bladed continuous mixer. Particle flow within the mixer was found to be strongly dependent on the impeller rotation rate and fill level. The axial flow rates showed significant variation with impeller rotation rate and fill, and also showed considerable variation over the course of a shaft revolution.

Favorable mixing was obtained at smaller impeller rotation rates for larger fills, but at larger impeller rotation rates for smaller fills. **Onyegu *et al.* (2012)** designed and fabricated an automated industrial poultry feed tumble mixer with 0.78 m^2 collector area to be used in experimental mixing tests. The fabricated mixer was used to mix poultry feed ingredients under controlled conditions. The fabricated mixer yielded an acceptable output hereby saving time and energy.

There are many factors that control the performance of the horizontal animal feed mixer. These factors include mixer speed, mixing time and batch size. The mentioned factors affect directly on the feed homogeneity, energy requirements, efficiency, productivity, and the total operational cost. Feed manufacturers can control most of these variables through equipment maintenance and operation.

So, the objectives of the present study are to:

- Manufacture the horizontal animal feed mixer from low cost local material to be suitable for Egyptian farms.
- Optimize some operating parameters affecting the performance of the manufactured mixer (batch size and mixing time).
- Evaluate the manufactured mixer from the economic point of view.

MATERIALS AND METHODS

The main experiments were carried out through years of 2013 and 2014 in a local factory in Alexandria Governorate to study the effect of some operating parameters on the performance of the horizontal animal feed mixer.

1. Materials

1.1. Experimental feed formula composition

The experimental feed formula composition for the manufactured mixer under different batch sizes is tabulated in Table (1)

1.2. The Manufactured Mixer

A local mixer, suitable for mixing animal feed, was manufactured from low cost local material to overcome the problems of high power and high cost requirements under the use of the imported mixers. The local mixer was manufactured specially for this work and constructed at a small workshop in Alexandria Governorate. The manufactured mixer has a full capacity of 1200 kg.

Table (1): The experimental feed formula composition

Composition	Batch size, (kg)			
	550	**700**	**850**	**1000**
Soybean meal 44%, kg	104	140	160	190
Yellow corn, kg	30	50	60	75
Barley, kg	55	70	85	100
Coarse wheat bran, kg	140	150	180	200
Fennel and caraway straw, kg	94	133	154	173.5
Fenugreek seed meal, kg	12	20	25	30
Alfalfa dehydrated meal, kg	70	76.5	105	130
Rice bran, kg	30	40	55	70
Salt, kg	2	3	4	5
Lime stone, kg	7	10	13	16
Non - Food additives, kg	6	7.5	9	10.5

The manufactured mixer consists of the following main parts:

- feed formula transfer gates:

Three gates at the top of the mixer are used to allow animal feed formula to flow through them to the mixer. Another gate at the bottom of the mixer is used to collect the output mixed material.

- Mixing trough:

The mixing trough is a combination of rectangular top and a cylindrical base. The rectangular top dimensions are 355 cm length 110 cm width and 140 cm height. The cylindrical base dimensions are 355 cm length and 55 cm diameter. The mixing trough is made of milled steel with a thickness of 8 mm. Mixing trough corners are fillet welded. The total volume of the mixing trough is 7.15 m^3 while its mass is 100 kg.

- Mixer shaft

The shaft is a rotating member of circular cross section which transmits power. Two opposite screws as well as a set of blades are mounted on the mixer shaft to mix the batch. The shaft is made of iron steel and supported by two rolling bearings. The shaft is operated at a speed of 0.11 m/s (26 rpm) by means of pulley and belt powered from the electric motor. The shaft length is 370 cm.

- Bearings

The shaft is supported by two rolling bearings. The manufacturer's catalogue is used to select the suitable type of the rolling bearings. According to the manufacturer's catalogue, the anti friction ball bearing is selected.

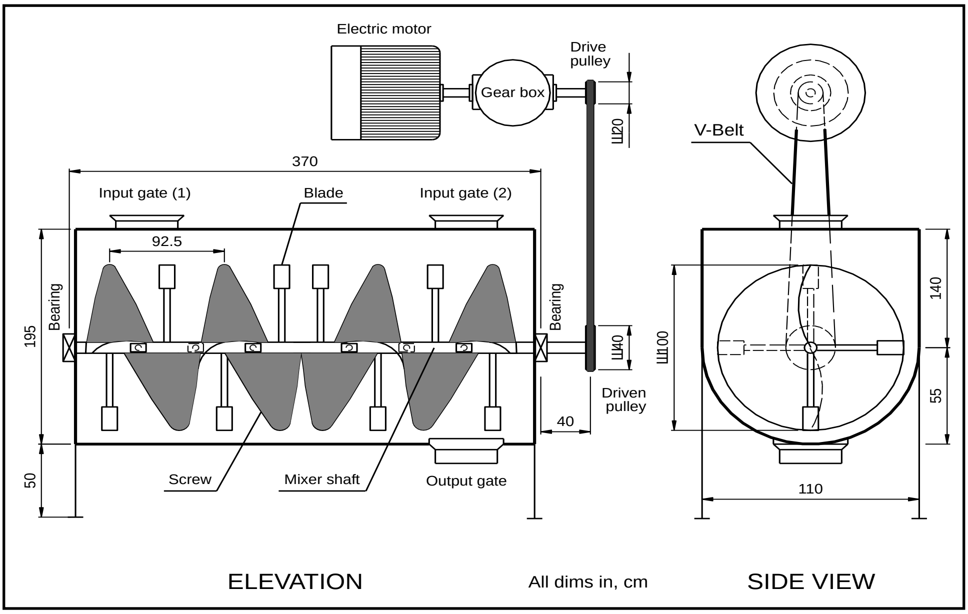

Fig.(1): Schematic views of the developed mixer

- Mixer frame

The mixer frame, which carries all the mixer parts, is made of heavy structural steel (I) section of 12 mm thickness to prevent any vibration during the mixing operation. Mixer supports are, welded to mixer body, providing reasonable working clearance underneath.

- The power source

The manufactured mixer was powered by an electric motor 22 kW (30 hp) at a rated speed of 1480 rpm.

- The transmission system

The mixer shaft is operated by means of mixer pulley (400 mm diameter) and belt powered from the electric motor pulley (150 mm diameter). The power is transmitted from the motor pulley to the machine shaft by gearbox with different speed ratios.

2- Methods

Experiments were carried out to evaluate the performance of the manufactured horizontal animal feed mixer to optimize values of the main operating parameters during animal feed processing.

2.1. Design of mixer shaft

The mixer shaft is supported by two bearings. A belt of V- shape is fixed on the pulley in the end of the shaft to transport load (F1). Another distributed load due to the shaft mass, screw mass, blades mass and material mass (F2) is applied to the same shaft. The two loads are not in the same plane and direction (Fig. 2).

The shaft in this case is subjected to combine torsion and bending stresses. Shafts stressed in torsion and bending are calculated on the combined stress. The diameter of mixer shaft in this case can be calculated according to the maximum shear stress theory as follows **(Khurmi and Gupta, 1984)**:

$$\tau_{\max} = \frac{1}{2}\sqrt{k_m^2\sigma_b^2 + k_t^2\tau_{tor}^2}$$

$$\tau_{\max} = \frac{1}{2}\sqrt{k_m^2\left(\frac{32M}{\pi d^3}\right)^2 + 4k_t^2\left(\frac{16T}{\pi d^3}\right)^2}$$

$$\tau_{\max} = \frac{16}{\pi d^3}\sqrt{k_m^2M^2 + k_t^2T^2}$$

Where:

- τ_{max} - Maximum shear stress, τ_{max} = 5500 N/cm^2,
- σ_b - Bending stress, N/cm^2,
- τ_{tor} - Torsion stress, N/cm^2,
- M - Maximum bending moment, N.cm,
- T - Maximum torque, N.cm,
- d - Diameter of shaft, cm,
- K_m - Shock factor for bending, K_m = 1.0,
- K_t - Shock factor for torsion, K_t = 1.0.

To determine both M (maximum bending moment) and T (maximum torque), the forces F_1 and F_2 (distributed load) acting on the shaft must be calculated.

- Determination of F_1

Force F_1 represents tension forces on the pulley, this force acts at 15^0 to the vertical direction as shown in Fig. 2. Force F_1 can be calculated as follows:

$$F_1 = T_1 + T_2$$

Where:

T_1 - Maximum tension on the pulley, N

T_2 - Minimum tension on the pulley, N

Maximum and minimum tensions on pulley can be calculated according to the following equations **(Khurmi and Gupta, 1984):**

$$2.3 \text{ Log } T_1/T_2 = \mu\ \Phi \cos\alpha$$

$$T = (T_1 - T_2)\ r$$

Where:

μ - Coefficient of friction,

$\mu = 0.54 - 42.6 / (152.6 + V)$

$\Phi = (180 - 2\alpha).\ \pi/180$

2α - Groove angle of the pulley (32 deg),

T - The maximum torque transmitted by the pulley, N. cm

r - Radius of driven pulley, cm ($r = 40$ cm).

The maximum torque transmitted by the pulley can be calculated using the following equation **(Khurmi and Gupta, 1984):**

$$P = 2\pi\ N\ T / 60$$

Where:

P - Motor power, kW, ($P = 22$ kW)

N - Speed of driven pulley, rpm, ($N = 26$ rpm)

$T = 37.5$ kN.cm

By using the above equations T_1, T_2, F_1 were calculated and found to be with the following values:

$T_1 = 2025$ N

$T_2 = 150$ N

$F_1 = 2025 + 150 = 2175$ N

Resolving F_1 into vertical and horizontal components

The vertical component = $F_{1v} = F_1 \cos 15$

The horizontal component = $F_{1h} = F_1 \sin 15$

The vertical loading on the shaft = $F_v = F_{1v} - W$

Where: W - Pulley weight, W = 100N.

$F_v = 2175 \cos 15 - 100 = 2000N$

The horizontal loading on the shaft = $F_h = F_{1h} = 563$ N

$F_h = 2175 \sin 15 = 563$ N

- Determination of F_2

Force F_2 represents distributed load due to the material weight, shaft weight, screw weight, and blades weight. This force acts on the vertical direction.

$F_2 = W_1 + W_2 + W_3 + W_4$

Where:

- W_1 - Weight of material, N,
- W_2 - Weight of shaft, N,
- W_3 - Weight of screw, N.
- W_4 - Weight of blades, N.

$F_2 = 10000 + 250 + 200 + 50 = 10500$ N

- Determination of reactions

The shaft is subjected to vertical and horizontal loads.

By using the vertical loading diagram (Fig. 2), the reactions R_{1v}, R_{2v} can be calculated to be as follows:

$R_{1v} = 5466$ N

$R_{2v} = 3034$ N

By using the horizontal loading diagram (Fig. 2), the reactions R_{1h}, R_{2h} can be calculated to be as follows:

$R_{1h} = 61$ N

$R_{2h} = 624$ N

- Determination of maximum bending moment

From the resultant bending moment diagram (Fig. 2), the maximum bending moment was found to be as follows:

M = 527.6 kN.cm

- Determination of maximum torque

The maximum torque can be calculated using the following equation **(Khurmi and Gupta, 1984):**

$T = (2025 - 150) * 20$

$T = 37.5$ kN.cm

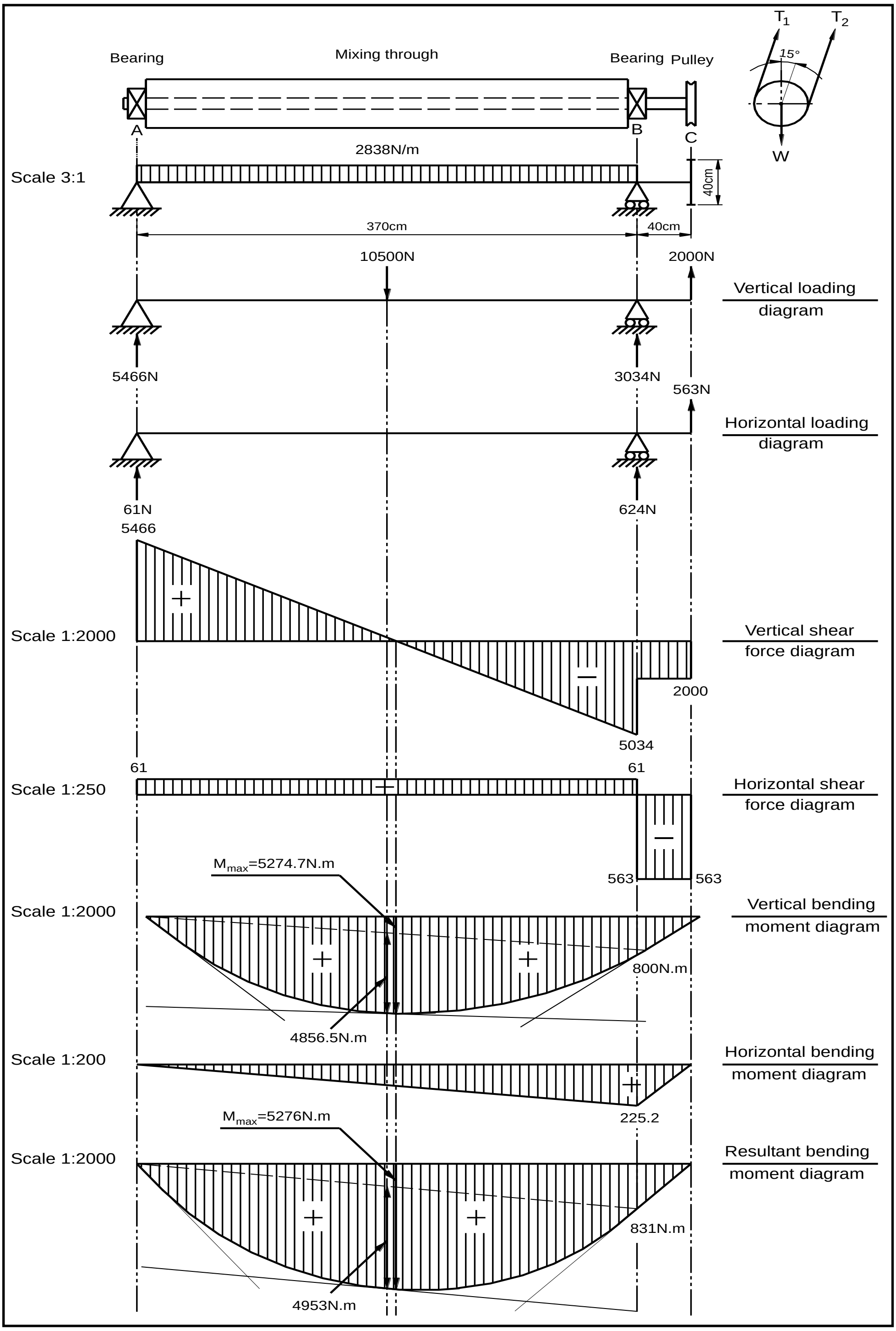

Fig. (2): Resultant bending moment diagram of mixer shaft.

- Then the maximum shear theory is applied:

$$\tau_{\max} = \frac{16}{\pi d^3}\sqrt{k_m^2 M^2 + k_t^2 T^2}$$

$$5500 = \frac{16}{\pi d^3}\sqrt{(527.6)^2 + (37.5)^2}$$

So, from the above equation, d = 78 mm

Then the mixer shaft is designed at a diameter of 80 mm.

2.2. Experimental conditions

The performance of the manufactured horizontal animal feed mixer was experimentally measured under the following parameters:

- Four batch sizes of 550, 700, 850 and 1000 kg.
- Four mixing times of 10, 15, 20 and 25 min.

2.3. Measurements and determinations

Performance evaluation of the manufactured mixer was based on the following indicators:

- The mean:

The mean is the average value of a population. It can be calculated as follows:

$$\bar{X} = \frac{\sum x}{n}$$

Where: $\bar{x}$ - The mean,

Σ x - Sum of samples,

n - Number of samples.

- Coefficient of variation (C.V.):

The coefficient of variation is an expression for sample variability relative to the mean. It is defined as follows:

$$C.V. = \frac{S}{\bar{X}} \times 100, \quad \%$$

Where: S - Standard deviation.

The standard deviation is the amount of variation in the sample population. It is defined as follows:

$$S=\sqrt{\frac{\sum X^2-\frac{(\sum X)^2}{n}}{n-1}}$$

- Mixing homogeneity:

Sufficient samples were taken from the top, middle and bottom of the mixer. Homogeneity is calculated by determining both maximum and minimum assay, then calculating the deviation between maximum assay and mean and also between minimum assay and mean then the greater value is divided by mean and multiplying by 100. It can be also explained as following:

- Determine maximum assay.
- Determine minimum assay.
- Deviation between maximum and mean.
- Deviation between minimum and mean.

$$Mixing\ homogenity=\left(1-\frac{The\ greater\ of\ step\ (3)\ or\ (4)}{Mean}\right)\times 100$$

- Mixer productivity:

Mixer productivity was calculated from the following relation:

$$Mixer\ \ productivity\ (Mg/h)=\frac{W_P}{T}\times 3.6$$

Where: Wp - Mixed mass, kg,

T - Consumed time, s.

- Required power

The following formula was used to estimate the motor power **(Kurt, 1979):**

$$P=\sqrt{3}\times\cos\varphi\times I\times V/1000$$

Where:

P - Power required, kW,

I - Current intensity, Ampere,

V - Voltage, (380 V),

$\cos\varphi$ - 0.7

- Specific energy

The specific energy for the mixing operation can be calculated as follows:

$$Specific\ energy\ (kW.h/Mg) = \frac{Required\ power\ (kW)}{Batch\ size\ (Mg/h)}$$

- Mixing cost

The mixer hourly cost is estimated according to the conventional method of estimating both fixed and variable costs. While mixing cost was calculated using the following formula:

$$\text{Mixing cost(L.E./Mg)} = \frac{\text{Mixer hourly cost(L.E./h)}}{\text{Batch size (Mg/h)}}$$

RESULTS AND DISCUSSIONS

The discussion will cover the obtained results under the following heads:

1. Effect of mixing time and batch size on the coefficient of variation and mixing homogeneity

Representative coefficient of variation (C.V.) and mixing homogeneity values versus mixing time are given for various batch sizes in Figs. 3, 4.

Concerning the effect of mixing time on the coefficient of variation and mixing homogeneity at both batch sizes of 550 and 700 kg, results show that increasing mixing time from 10 to 15 min, decreased C.V. values from 8.5 to 4.5 % for 550 kg batch size and from 9.5 to 6.0 % for 700 kg batch size, while increased mixing homogeneity from 90 to 95 %, and from 88 to 93 % under the same previous conditions. Any further increase in mixing time more than 15 min up to 20 min, the C.V. values will increase from 4.5 to 7.5 % and from 6.0 to 8.5 %, while homogeneity will decrease from 95 to 91 % and from 93 to 90 % under the same previous mentioned conditions. The more increase in mixing time up to 25 min, coefficient of variation will decrease while the vice versa was noticed with mixing homogeneity.

Relating to the effect of mixing time on the coefficient of variation and mixing homogeneity at batch size of 850 kg, results show that increasing mixing time from 10 to 20 min, decreased C.V. values from 12.5 to 4.0 %, while increased mixing homogeneity from 87 to 97 %. Any further increase in mixing time more than 20 min up to 25 min, the C.V. values will increase from 4.0 to 5.5 %, while homogeneity will decrease from 97 to 93 % under the same previous conditions.

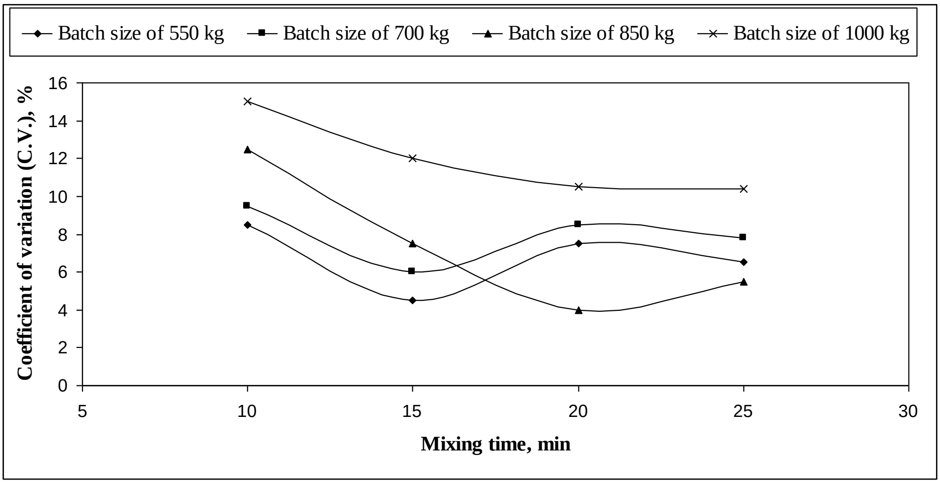

Fig. (3): Effect of mixing time and batch size on coefficient of variation

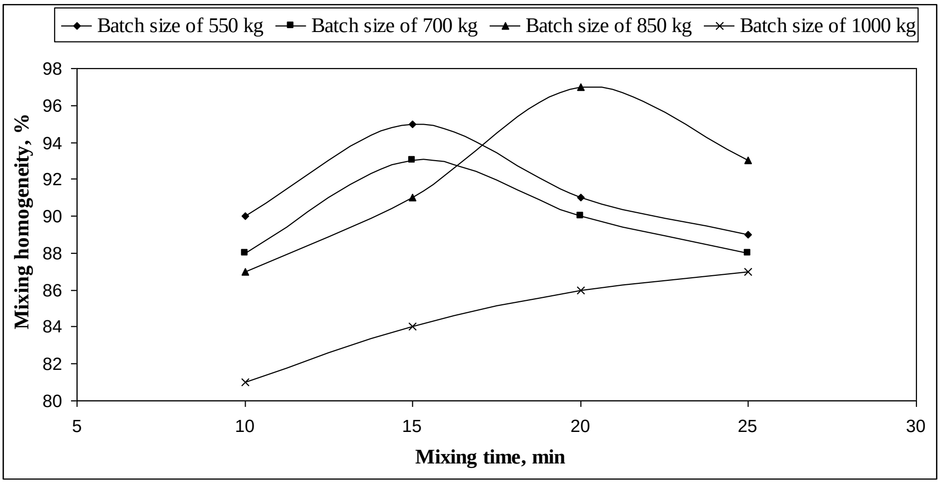

Fig. (4): Effect of mixing time and batch size on the mixing homogeneity

As to the effect of mixing time on the coefficient of variation and mixing homogeneity at batch size of 1000 kg, results show that increasing mixing time from 10 to 25 min, decreased C.V. values from 15.0 to 10.4 % while increased homogeneity from 81 to 87 %.

The coefficient of variation under 10 % is considered excellent, of between 10-15 % is good, of between 15-20 % is fair. While with value more than 20 % is poor as reported by **(Coates and Tanaka, 1992)**. So, the obtained results show that the mixing time of between 15 to 20 min is recommended (As these mixing times recorded minimum values of C.V.). Because increasing mixing time more than 20 min leads to separate active materials from carrier materials, moreover the increase in mixing time more than the recommended values, increase temperature and as a result, vitamins will be broken. Results also show that batch size of between 700 to 850 kg are recommended as they recorded minimum values of C.V. and maximum values of mixing homogeneity. This attributed to the smaller size of vacuum in the mixer (about 70 % filling ratio), which led to more efficient mixing.

2. Effect of mixing time and batch size on mixer productivity

Fig. 5 shows the effect of both mixing time and batch size on the mixer productivity. The obtained results show that increasing mixing time from 10 to 25 min, the mixer productivity decreased from 3.3 to 1.3, from 4.2 to 1.7, from 5.1 to 2.0, and from 6.0 to 2.4 Mg/h at batch sizes of 550, 700, 850 and 1000 kg, respectively.

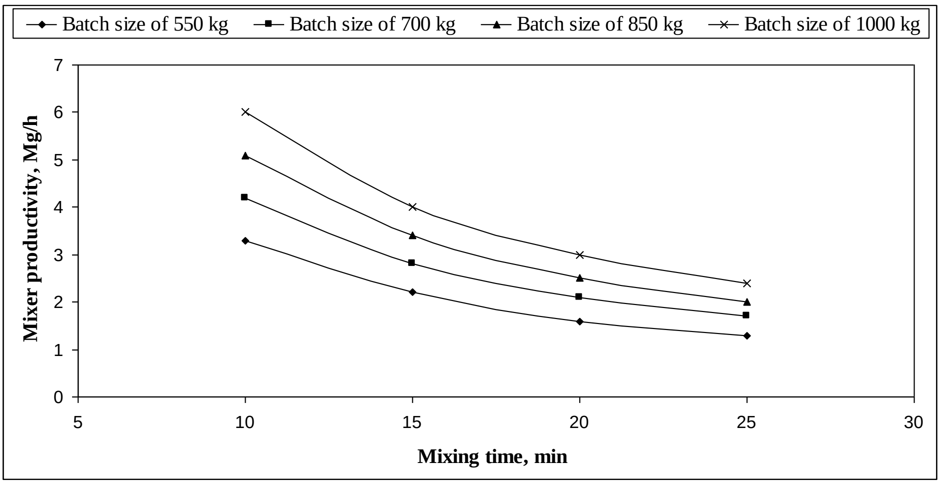

Fig. (5): Effect of mixing time and batch size on mixer productivity

The decrease in mixer productivity by increasing mixing time is attributed to the long time required for mixing the same feed formula.

3. Effect of mixing time and batch size on specific energy

Fig. 6 shows the effect of both mixing time and batch size on the specific energy. Considering the effect of mixing time on the specific energy, results show that increasing mixing time from 10 to 25 min, the specific energy increased from 5.6 to 15.0, from 5.0 to 13.5, from 4.5 to 12.0, and from 4.0 to 10.5 kW.h/Mg at batch sizes of 550, 700, 850 and 1000 kg, respectively.

Relating to the effect of batch size on the specific energy, the obtained data show that increasing batch size from 550 to 1000 kg, decreased the specific energy from 5.6 to 4.0, from 7.7 to 5.4, from 10.5 to 7.5, and from 15 to 10.5 kW.h/Mg at mixing times of 10, 15, 20 and 25 min, respectively.

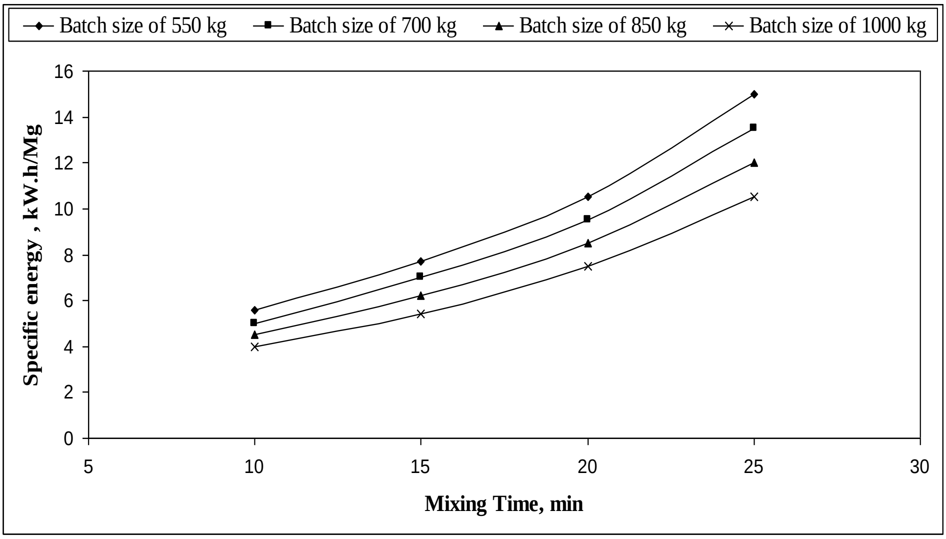

Fig. (6): Effect of mixing time and batch size on specific energy

The increase in specific energy by increasing mixing time is attributed to the increase in the consumed power to complete the mixing process. While the decrease in specific energy by increasing batch size is due to the increase of mixer productivity.

4. Effect of mixing time and batch size on mixing cost

Fig. 7 shows the effect of both mixing time and batch size on mixing cost. Considering the effect of mixing time on mixing cost, results show that increasing mixing time from 10 to 25 minutes, increased mixing cost from 29 to 76, from 25 to 63, from 21 to 53, and from 16 to 24 L.E./Mg at batch sizes of 550, 700, 850 and 1000 kg, respectively.

Relating to the effect of batch size on mixing cost, the obtained data show that increasing batch size from 550 to 1000 kg, decreased mixing cost from 29 to 16, from 42 to 24, from 58 to 33, and from 76 to 44 L.E/Mg at mixing times of 10, 15, 20 and 25 minutes, respectively.

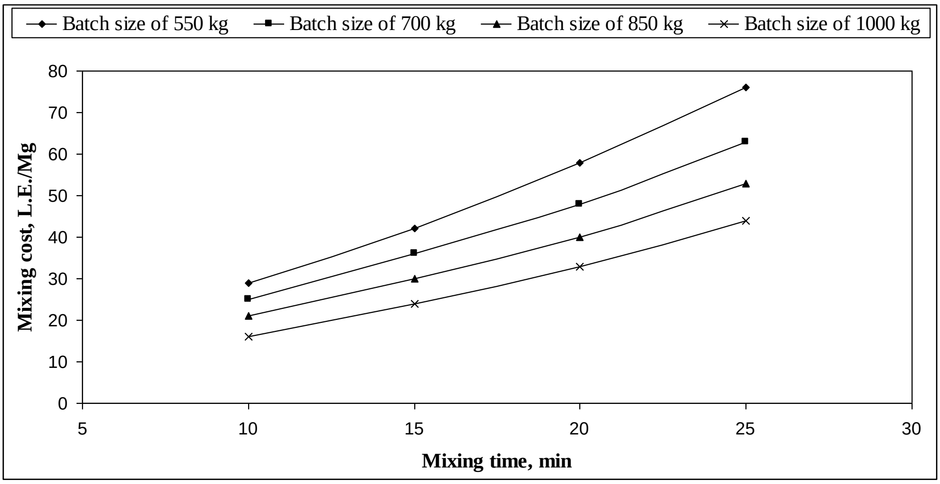

Fig. (7): Effect of mixing time and batch size on mixing cost

Increasing mixing cost by increasing mixing time was due to the increase in the consumed power to finish the mixing operation. While the decrease in mixing cost by increasing batch size is due to the increase of mixer productivity.

CONCLUSIONS

- Batch size as well as mixing time are considered very important variables affecting the performance of the manufactured animal feed horizontal mixer.
- The mixer shaft is designed according to the maximum shear stress theory. Accordingly, the diameter of the mixer shaft was calculated and was found to be of not less than 80 mm.
- The mixing time of between 15 to 20 minutes and batch size of between 700 to 850 kg are recommended to control the performance of the manufactured mixer.

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الملخص العـربــي

تصنيع وتقييم أداء خلاط أفقى محلى لخلــــط وتصنيــع أعــــــلاف الحيوانات

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أجريت هذه الدراسة بمصنع لإنتاج الأعلاف بمدينه الإسكندرية لدراسة العوامل المؤثرة على إنتاج وتصنيع الأعلاف بواسطة خلاط تم تصنيعه خصيصا لهذه الدراسة وكذلك تحديد أنسب الظروف للوصول إلى أعلى جودة للمنتج تحت عوامل التشغيل المختلفة. وكانت أهداف الدراسة هي:

- تصنيع خلاط محلى بغرض إنتاج أعلاف حيوانية ذات جودة عالية لتحقيق الهدف المنشود منها في تحسين إنتاج الثروة الحيوانية.
- تحديد أفضل عوامل التشغيل للحصول على أعلى كفاءة تشغيل للخلاط المصنع.
- تقييم أداء الخلاط اقتصادياً.

هذا وقد تم تصميم عمود الإدارة بالخلاط باستخدام نظرية الإجهادات العظمى للوصول الى القطر المناسب لهذا العمود لكى يستطيع مقاومة الاجهادات الواقعة عليه دون أن ينكسر.

ثم تم إجراء مجموعة من التجارب لاختبار الخلاط المصنع تحت عوامل تشغيل مختلفة:

- أربع أزمنة للخلط وهي (١٠، ١٥، ٢٠ و ٢٥ دقيقة)
- أربع تشغيلات مختلفة الأحجام وهي (٥٥٠، ٧٠٠، ٨٥٠ و ١٠٠٠ كجم).

وقد تم تقييم المعاملات السابقة أخذاً في الاعتبار كلاً من:

- تجانس المواد المخلوطة
- إنتاجية الخلاط
- الطاقة اللازمة لعملية الخلط
- التكاليف الكلية لعملية الخلط.

أظهرت النتائج التجريبية أن تجانس المواد المخلوطة يكون أعلى ما يمكن فى حين تكون الطاقة اللازمة للتشغيل والتكاليف الكلية فى أنسب قيمها تحت ظروف التشغيل الآتية:

- يجب أن يصنع عمود الإدارة بالخلاط بقطر لا يقل عن ٨٠ مم.
- أن يتراوح زمن الخلط ما بين ١٥ الى ٢٠ دقيقة.
- تلقيم المواد المراد خلطها بكمية تتراوح بين ٧٠٠ – ٨٥٠ كيلوجرام.

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