Design and fabrication of a de-feathering machine with scalding tank

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Abstract: Manual de-feathering of poultry birds has been an age long practice which is time consuming and labor intensive for small scale poultry processors. This study designed and fabricated a de-feathering machine with scalding tank. The machine was evaluated in terms of machine plucking time, machine capacity and machine efficiency. The machine testing was carried out by using nine poultry birds made up of three birds each of broiler, layer and cockerel at 55ºC scalding temperature and at 7.54 m s^{-1} machine speed. The average machine efficiency for broiler, layer and cockerel were 93%, 92% and 89% respectively. The average machine capacity for broiler, layer and cockerel were 167, 155 and 139 birds hr^{-1} respectively. The machine capacity and machine efficiency decrease accordingly from broiler, to layer and to cockerel. The average machine plucking time for broiler, layer and cockerel were 22, 22 and 28 s respectively. The de-feathered birds appeared undamaged thereby preserving its market value.

Keywords: machine capacity, machine efficiency, machine plucking time

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1 Introduction

In most part of the world, manual de-feathering operation is done traditionally by the use of hand after it has been soaked in hot water of about temperature 80ºC – 85ºC which takes 40 – 50 seconds. More so, the traditional method of de-feathering birds has low output, time consuming, tedious and could lead to injury (Awotunde et al., 2018). Among the processes involved in processing poultry birds, feather removal is the most time consuming and risky next to eviscerating process especially when carried out manually. The planning and the building of a mechanical structure that will remove feathers of a poultry bird as reported by Awotunde et al. (2018), is the development of poultry de-feathering machine. The growth in the poultry farming mechanization has helped in meeting the daily demand of poultry products globally. The demand will keep increasing because of the health benefit of poultry product in terms of

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low fat and calorie content, chicken meat popularity among non-vegetarians all over the world, and to satisfy the world's dietary protein needs (Adefuye et al., 2021).

The different designs of de-feathering machine are classified as the drum style de-feathering machine and the horizontal de-feathering machine. The latter can also be called table-top plucker machine which is very risky because the poultry bird is held and gradually drop to the spinning fingers and manually move it around the machine. But for the former, the bird is lowered into the drum and allows the machine to do the whole job of de-feathering (Awotunde et al., 2018).

Despite the rise in production of poultry meat, there has been an increase in the number of processing plant for poultry and a lot of challenges were faced by producers due to high cost of input and mechanization of processing plant. Nevertheless, Poultry processing has been mechanized extensively during the past decades with manufacturers of equipment for poultry processing having to consider three priorities when designing and producing machines such as scalding tank, slaughtering cone, eviscerator, de-feathering machine, shackles, dunkers rubber fingers, e.t.c. must perform according to specifications, be safe and be hygienic during operation (Hupkes, 1996). There are a lot of the advantages of this machine such as human labour is greatly reduced; problem of boredom through manual removal of feathers is eliminated; avoiding scalding of the hand by hot water used in plucking is eliminated; uniformity of de-feathering is guaranteed (provided machine is in good condition) and minimize the spread of COVID, Ebola infections (Adefuye et al., 2021).

As for poultry meat, there is a need for mechanical de-feathering machine to meet the high demand for poultry meat production. To this end, a de-feathering machine with scalding tank was designed and fabricated.

2 Materials and method

2.1 Materials

The following materials were obtained for the fabrication and evaluation of the machine based on availability and relative cost which are:

Electric motor, de-feathering drum, live poultry birds, rubber fingers, solid shaft, heating element with a thermocouple/thermometer, scalding tank, water valve, and water source.

2.2 Method

2.2.1 Design concept

The isometric views of the conceptual design of de-feathering machine with scalding tank is shown in Figure 1 and the orthographic view of the design is shown in Figure 2.

2.3 Design calculation

2.3.1 Determination of driven pulley speed

$$N_1D_1 = N_2D_2 \quad (1)$$

(Smith and Wilkes, 1976).

Where: N_1 is speed of the prime mover, 1440 rpm;

N_2 is speed of the de-feathering shaft, rpm.

Using a speed reduction ratio of one third (1/3) to increase the torque of the shaft.

$$\frac{N_2}{N_1} = \frac{1}{3}$$

$$N_2 = \frac{1440}{3} = 480\ rpm$$

D1 is pulley diameter of the prime mover, 100 mm;

$$D_2 = \frac{N_1 \times D_1}{N_2} = \frac{1440 \times 100}{480} = 300\ mm$$

D2 is pulley diameter of the driven machine, 300 mm.

2.3.2 Determination of speed of shaft of the electric motor

$$V_1 = \frac{\pi N_1 D_1}{60} \quad (2)$$

Gbabo et al. (2013).

$$V_1 = \frac{\pi \times 1440 \times 100}{60} = 7.54\ m\ s^{-1}$$

$$V_2 = \frac{\pi N_2 D_2}{60} = \frac{\pi \times 480 \times 300}{60} = 7.54\ m\ s^{-1}$$

Where; V_1 is speed of shaft of electric motor (m s^{-1});

V_2 is speed of the de-feathering shaft (m s^{-1}).

2.3.3 Determination of angular velocity of the electric motor

$$w = \frac{2\pi N}{60} \quad (3)$$

Gbabo et al. (2013).

$$w_1 = \frac{2\pi N_1}{60} = \frac{2\times\pi\times1440}{60} = 150.80 rads^{-1}$$

$$w_2 = \frac{2\times\pi\times480}{60} = 50.27\, rad\, s^{-1}$$

Where: w1 is angular velocity of electric motor (rad s^{-1}); w2 is angular velocity of the de-feathering shaft (rad s^{-1}).

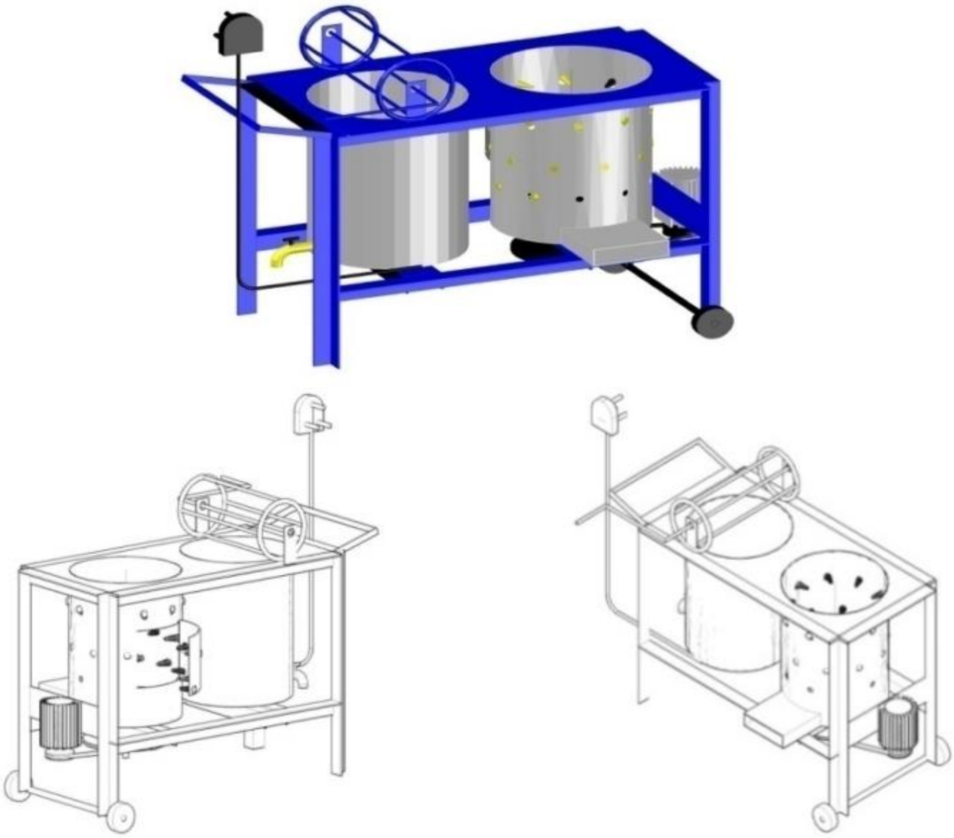


Figure 1 Isometric views of the conceptual design of de-feathering machine with scalding tank

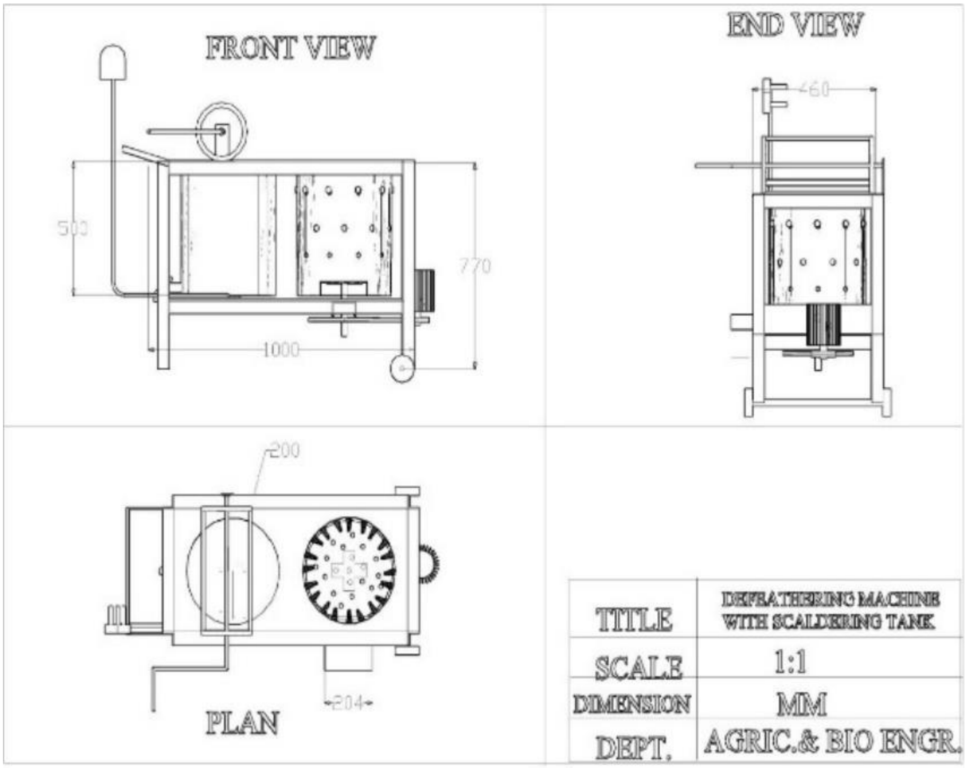


Figure 2 Orthographic view of the design

2.3.4 Determination of power requirement

Power delivered by the motor to the machine (kW)=Torque (Nm)×Angular velocity (rads^{-1}) (4)

Torque =Angular velocity (rads^{-1})×radius of the motor pulley(m) (5)

Hence,

$P_1 = {\omega_1}^2 R_1 = 150.80^2 \times 0.5 = 1137.03\ W =$ 1.137 kW

Where: P_1 is power delivered by electric motor; R_1 is radius of prime mover pulley.

$P_2 = {\omega_2}^2 R_2 = 50.27^2 \times 0.15 = 379.06\ W$

$= 0.379\ kW$

P_2 is power required for de – feathering;

R_2 is radius of the de-feathering machine pulley

2.3.5 Determination of torque acting on the drive shaft

$$\text{Torque} = \frac{\text{P} \times 60}{2\pi \text{N}_2} \quad (6)$$

$$Torque = \frac{379.06 \times 60}{2\pi \times 480}$$

$$Torque, T = 7.54\ Nm$$

2.3.6 Tangential drive load on the shaft

The tangential force on pulley drive (5)

$$F_D = \frac{Torque}{Pulleyradius}$$

$$F_D = \frac{7.54}{0.15} = 50.27\ N$$

Pulley radius = 150 mm = 0.15 m; Torque transmitted, 7.54 Nm.

But F_D was at 39.1° angle of contact/ lap of larger pulley to horizontal

Therefore, resolving this force horizontally;

$F_{Dh} = F_D \times \cos\theta_l = 50.27 \times cos39.1$= 39.01 N

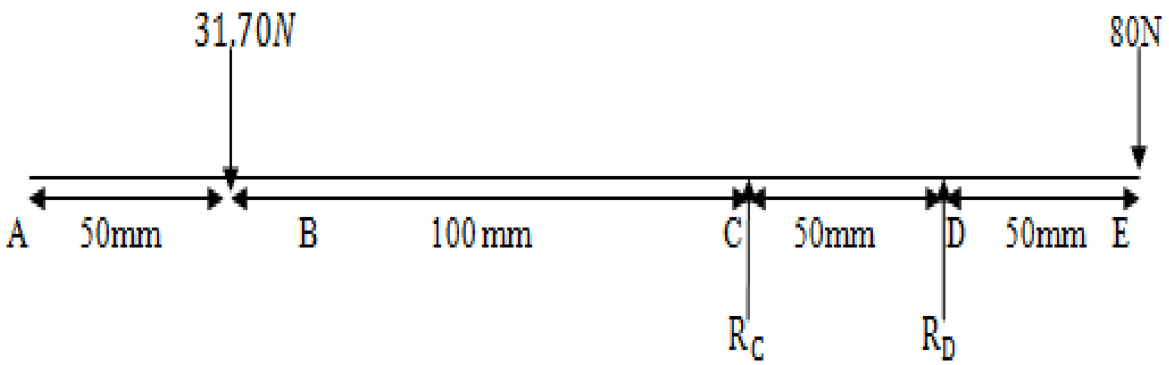


Figure 3 pulley and bearing arrangement on shaft

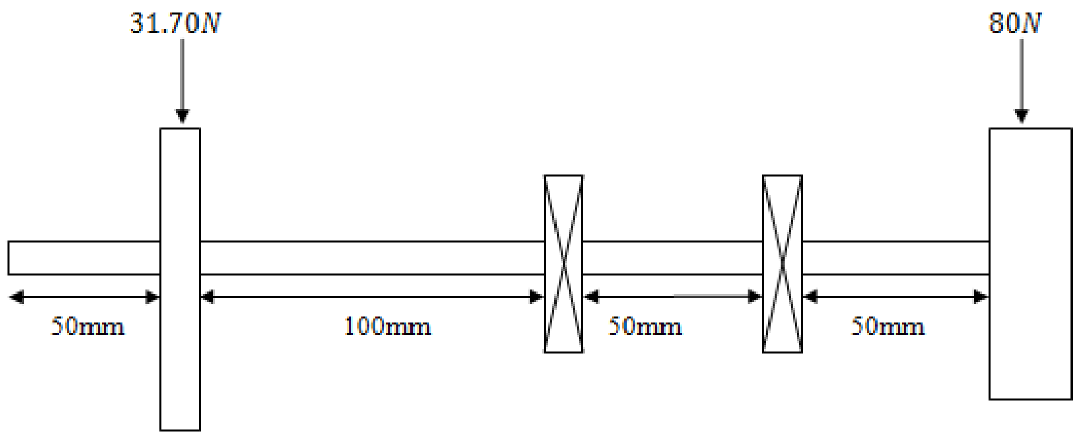


Figure 4 Vertical forces on shaft

Figure 3 and Figure 4 show pulley and bearing arrangement on shaft and vertical forces on shaft respectively.

Also, resolving this force vertically;

$F_{Dv} = F_D \times \sin\theta_l = 50.27 \times cos39.1 = 31.70\ N$

2.3.7 Bending moment in the vertical plane

$$R_C + R_D = 111.7 \quad (7)$$

Taking moment about the point R_C.

Take clockwise moment to be positive, the algebraic sum of moment equals zero.

Therefore, R_{D}=96.60 N; R_{C}=15.10 N

2.3.8 Bending moment on vertical plane

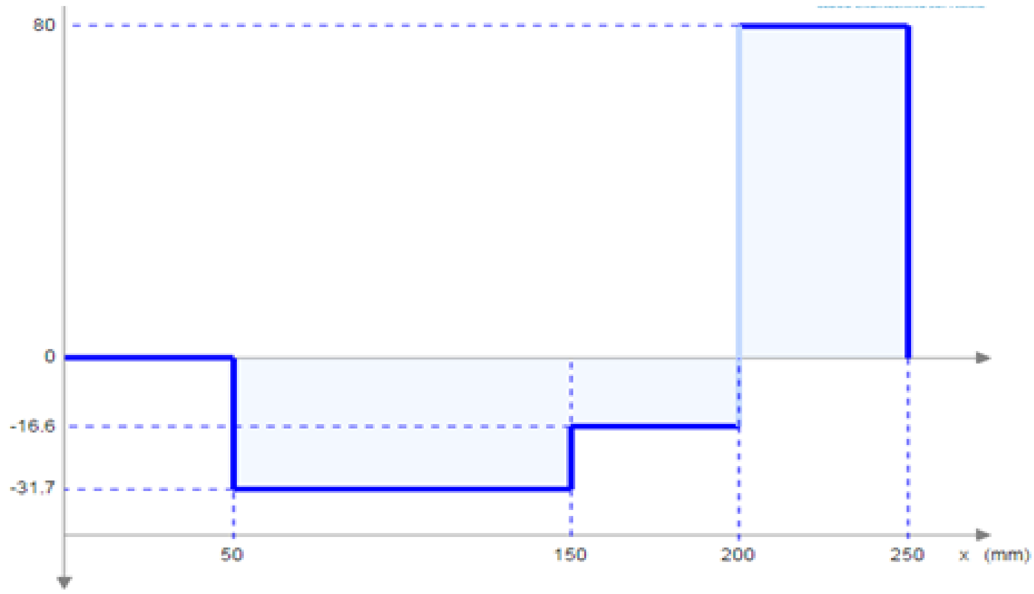
At A; $x = 0\ m$, $BM_A = 0$ Nm

At B; $x = 0.05\ m$, $BM_B = 0$ Nm

At C; $x = 0.15\ m$, $BM_C = -3.17$Nm

At D; $x = 0.2\ m$, $BM_D = -4.00$Nm

The shear force diagram for the vertical plane and bending moment in the horizontal plane are shown in Figure 5 and Figure 6 respectively.



At E; x=0.25 m, BM_E=0.00Nm

Figure 5 shear force diagram for the vertical plane

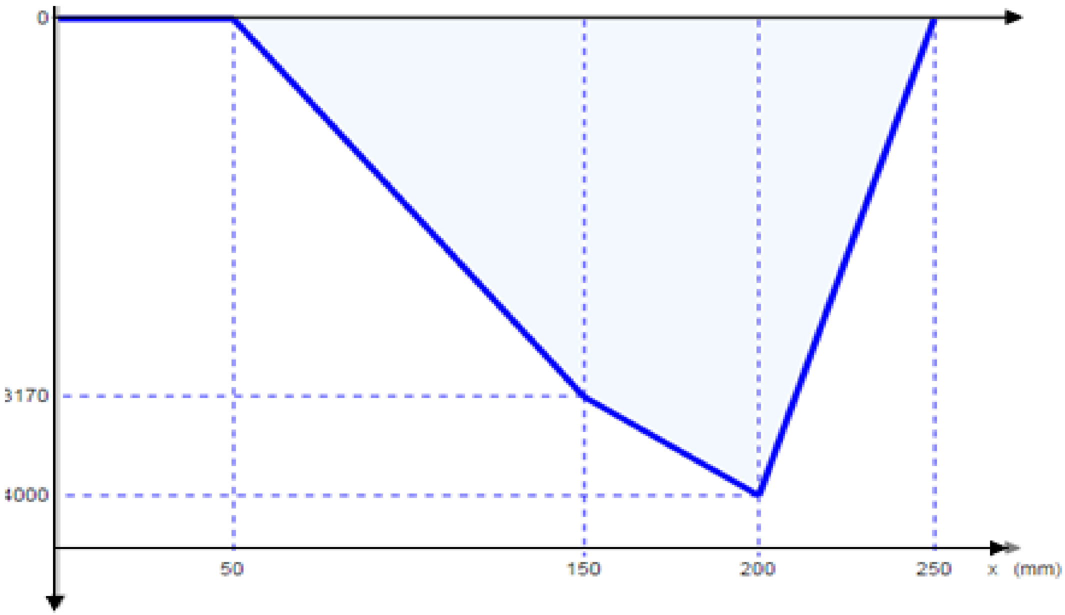


Figure 6 Bending moment diagram for the vertical plane

2.3.9 Bending moment in the horizontal plane

The horizontal forces on the shaft are shown in Figure 7.

$$R_C + R_D = 19.0\ N \quad (8)$$

Taking moment about the point R_C

Take clockwise moment to be positive, algebraic sum of the moment equals zero.

Therefore, $R_D = 81.98$N; $R_C = 37.03$N

2.4 Bending moment on horizontal plane

At A; $x = 0\ m$, $BM_A = 0$ Nm

At B; $x = 0.05\ m$, $BM_B = 0$ Nm

At C; $x = 0.15\ m$, $BM_C = -3.90$ Nm

At D; $x = 0.2\ m$, $BM_D = -4$Nm

At E; $x = 0.25\ m$, $BM_E = 0$ Nm

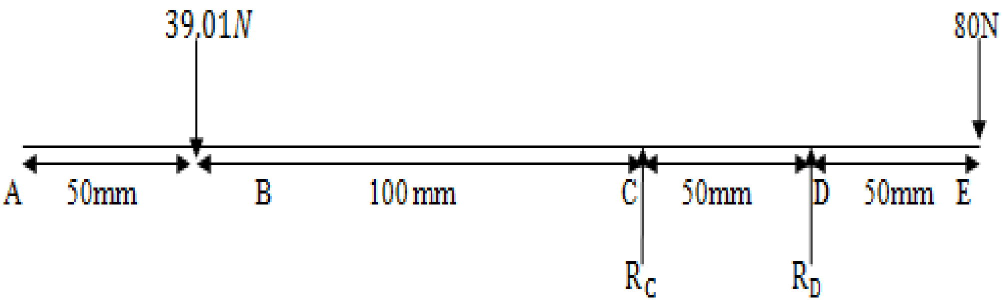


Figure 7 Horizontal forces on the shaft

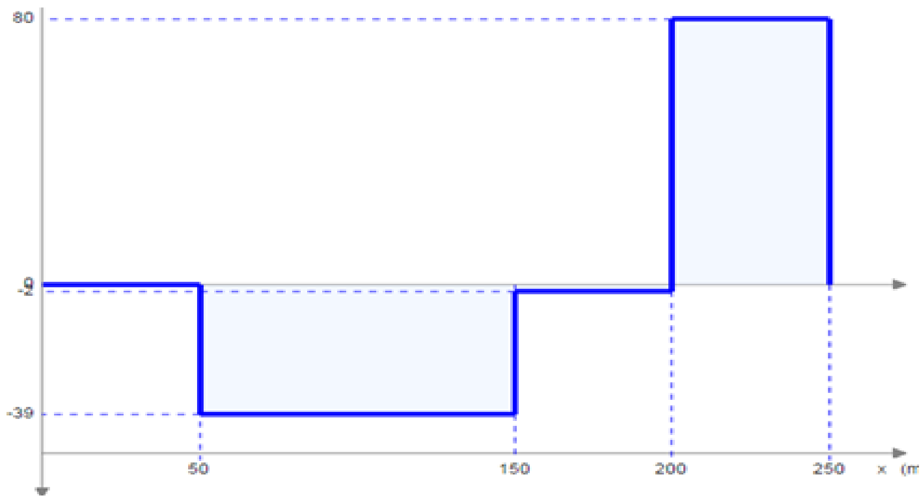


Figure 8 shear force diagram for the horizontal plane

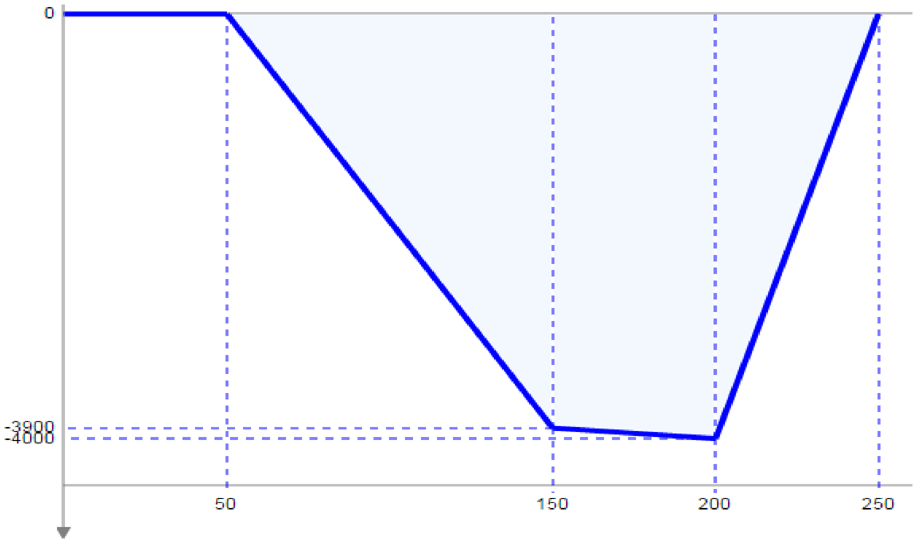


Figure 9 Bending moment diagram for the horizontal plane

The shear force diagram for the horizontal plane and bending moment diagram for the horizontal plane are shown in Figure 8 and Figure 9 respectively

2.4.1 Maximum bending moment

$$M_B = \sqrt{MB_V^2 + MB_H^2} \quad (9)$$

where,

MB_V is the maximum bending moment in vertical plan, 3.17 Nm^{-1};

MB_H is the maximum bending moment in horizontal plane, 3.90 Nm^{-1};

From Equation 9, M_B=5.03 Nm

2.4.2 Design of shaft

The shaft was designed on the basis of strength, rigidity and stiffness as it was subjected to twisting and bending moments. Khurmi and Gupta (2006), and Gbabo et al. (2013) reported that the formulae used for shaft design is given as;

$$d^3 = \frac{16}{\pi\tau_s}\sqrt{(M_bK_b)^2 + (M_tK_t)^2} \qquad (10)$$

Gbabo et al. (2013)

Where: d is shaft diameter (mm),

τ_s is the allowable shear stress for bending and torsion, 50 MPa or 50 MN m^{-2} for steel shaft with keyway, K_b is combined shock and fatigue factor applied to bending moment = 2.0 for minor shock, K_t is combined shock and fatigue factor applied to torsional moment =1.5 for minor shock

M_b is maximum bending moment, 5.03 Nm, M_t is torsional/twisting moment, 7.54 Nm, length of the shaft used was 250 mm.

From Equation (10)

d = 0.01155 m = 11.55 mm

The shaft diameter is 11.55 mm as calculated

In considering factor of safety, 20% was used as the factor of safety of the calculated shaft diameter which was added to the calculated shaft diameter. This was in accordance with Gbabo et al. (2013) who used 20% as factor of safety.

Therefore, the total shaft diameter = $11.55\text{ mm} + 2.31\text{ mm} = 13.86\text{ mm}$

20 mm diameter was chosen for the design by standard.

2.4.3 Design for torsional rigidity

$$J = \frac{\pi}{32} \times d^4 \qquad (11)$$

Khurmi and Gupta (2006).

$$\theta = \frac{TL}{JG} \qquad (12)$$

Khurmi and Gupta (2006).

Where: θ is torsional deflection on the angle of twist ; d is shaft diameter, 20 mm; T is twisting moment or torque on the shaft,7.54 Nm; J is polar moment of Inertia of the cross-sectional area about the axis of rotation, G is modulus of rigidity for the shaft materials, $84 \times 10^3\text{ N mm}^{-2}$.

L is the length of the shaft, 250 mm

From Equation 20, J = 15710 mm

From Equation 21, $\theta = 0.001428$ rad

2.4.4 De-feathering drum design

The volume of the drum was calculated using the Equation 13.

$$V = \pi r^2 l \qquad (13)$$

Where: V is volume of cylinder;

r is radius of cylinder, 200 mm

L is length of drum, 500 mm

From Equation 13,

$V = 62840000\, mm^3$(0.06284 m^3)

2.4.5 Design of scalding tank

2.4.5.1 Determination of volume of scalding tank

The volume of the scalding tank was calculated using the Equation 14.

$$V = \pi r^2 l \qquad (14)$$

Where; V is volume of cylinder

r is radius of cylinder ($200\, mm$)

L is length of cylinder ($500\, mm$)

From Equation 14,

V =62840000 mm^3=(0.06284 m^3)=62.84 *ltr*

2.4.5.2 Determination of power rating of heating element

The power rating of heating element was calculated using Equation 24

$$P = \frac{C_w \times V \times \partial\theta}{3600} \qquad (15)$$

(Elyse, 2017)

Where: Vis the volume of water = 62.84 ltr,

$\partial\theta is\ temperature\ difference = 80^oC$

c_w *is*specific heat capacity of water, 4.2 J$g^{-1}\, K^{-1}$

From Equation 15, P = 5.87 kwh

2.5 Machine description and working principle

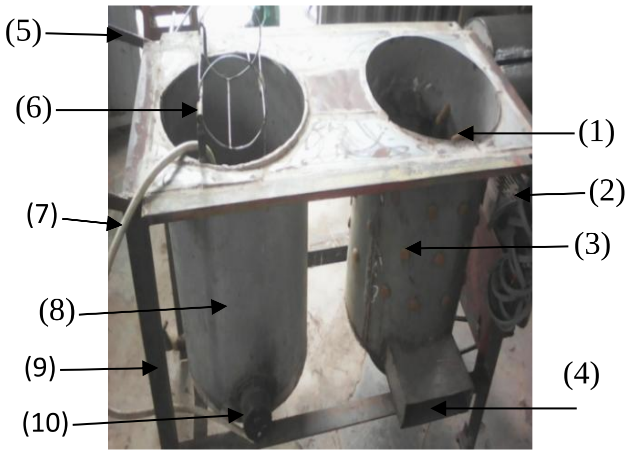
The machine was constructed and fabricated with an angle iron of 3 mm thickness (770 mm × $1000\, mm$) to provide support and rigidity. An electric motor of 2 hp is attached to the frame to transmit torque to the de-feathering disc.

The scalding tank and de-feathering chamber was made with stainless steel plate of thickness 2 mm and 1.5 mm respectively. An industrial immersion heater (3 – 6 kw) was attached to the basement of the scalding tank to supply heat to the water. A water valve is also attached to the scalding tank for drainage of water used for a number of scalding operations to avoid contamination which may reduce the quality of processed birds. The scalding tank also has a wheel and axle system attached to it for lowering the carcass into the scalding water. The de-feathering chamber has rubber fingers attached in helical arrangement to ensure proper contact with birds during de-feathering.

After the arrival of the poultry birds, the live weight of the birds were measured prior to slaughtering and the dead weight was also measure using a mechanical dial spring scale and the blood was allowed to drain completely to avoid contamination of scalding water. The slaughtered birds were mounted on the scalding tank with the use of a dunker/chicken hanger attached to a wheel and axle system used to lower the chicken into the scalding tank where scalding took place at a scalding temperature of 55℃ for the testing of the machine. The temperature was measured with the use of thermometer whose range is from $0\ to\ 100$℃ and regulated using a thermostat. The wheel and axle was swung up and down to ruffle the feathers to allow heat to reach the feather follicles under the skin.

After scalding, de-feathering operation was done immediately the bird was taken out of the scalding tank. The chickens were lowered into the de-feathering chamber where the rubber fingers remove the feathers. The removed feathers were collected from the feather outlet and the processed chicken was taken out.

The fabricated de-feathering machine with scalding tank is shown on Figure 10.



No	Component
1	Finger
2	Electric motor (2 HP)
3	De-feathering drum (0.06284 m^3)
4	Feather outlet
5	Handle
6	Wheel and axle
7	Wire
8	Scalding tank (0.06284m^3)
9	Frame
10	Immersion heater (5.87 kw)

Figure 10 Fabricated de-feathering machine with scalding tank

The birds were sourced from Kuto Market in Abeokuta, which is located approximately on latitude 7.1373° N and longitude 3.3515° E, Ogun State, Nigeria. The testing of the machine was carried out in November 15, 2021 at the Central Workshop of the College of Engineering, Federal University of Agriculture Abeokuta, which is located approximately on latitude 7.2297° N and longitude 3.4392° E, Ogun State, Nigeria.

The machine testing was carried out by using Nine (9) poultry birds made up of three (3) birds each of broiler, layer and cockerel. The parameters measured were live weight (kg), dead weight (kg), scalding time (s), machine plucking time (s), weight after plucking (kg), feather weight plucked by machine (kg), feather weight plucked by hand (kg) and hand plucking time (s). The performance indices were carried out using Equations 16 and 17.

$$i. Defeathering\ efficiency, e_m = \frac{W_m}{W_m + W_h} \quad (16)$$

Where: e_m is machine efficiency;

W_m is feather weight plucked by machine, kg;

W_h is feather weight plucked by hand, kg.

$$\text{ii. De} - \text{feathering capacity}, M_c = \frac{3600}{M_t} \quad (17)$$

Where: M_c is machine capacity, birds hr^{-1};

M_t ismachine plucking time, s.

2.7 Machine testing procedure

A1$\times$ 3 $\times$ 3 incomplete randomized experimental design was carried out with the following parameters; one scalding temperature (55°C) and three poultry breeds (broilers, cockerels and layers) at three replications at 7.54 m s^{-1} machine speed.

Analysis of Variance (ANOVA) was carried out on the effect of the poultry bird types on the machine efficiency and machine capacity at 55ºC using Minitab 21 Statistical Package.

3 Results and discussion

The machine was fabricated accordingly to the machine design carried out.

The parameters measured for the performance evaluation of the machine at 55ºC are shown on Table1. The machine plucking time for cockerel poultry bird was the highest among the other two poultry birds that had the same machine plucking time (Column 5). This shows that the force required to remove feathers from the poultry birds was highest in cockerel as compared with other two poultry birds that may likely required the same force to remove their feathers because they have the same machine plucking time. One of the factors that could affect the removal of feathers from poultry birds is scalding temperature as suggested by some researchers (Stadelman and Ziegler, 1955; Dickens and Shackelford, 1988). Other factors that could also affect the removal of feathers from poultry birds are bird maturity, breed, sex, killing method, length of time birds are held without feed and water before processing and delay after killing.

David (1999) stated that "it takes an average time of 5 minutes for a person to de-feather a bird while the machine processing takes about 40-50 seconds". For this de-feathering machine, the plucking time for poultry bird breeds ranged from 22 – 28 s at 55ºC. Therefore, the plucking time of this de-feathering machine was lower than the one given by David (1999).

The average values of performance indices of the machine at 55ºC for poultry bird breeds and at machine speed 7.54 m s^{-1} are shown in Table 2. The machine capacity and machine efficiency decrease accordingly from broiler, to layer and to cockerel (Columns 2 and 3 respectively). The number of birds that would be processed in a given time would be highest in broiler than any poultry bird tested. The machine capacity was affected by the machine plucking time of the poultry birds. This variation shows that cockerel with highest value of machine plucking time had the least machine capacity. Also, the machine efficiencies for the poultry birds were slightly different from each other which broiler had the highest value with 93%, followed by layers with 92% and finally layers with 89% (Column 3). The machine efficiency was affected by the feather weight plucked by machine and the feather weight plucked by hand but the difference in feather weight plucked by hand is negligible for the poultry birds tested. Therefore, the higher the feather weight plucked by machine the higher the machine efficiency.

The poultry bird type had no significant effect ($p \geq 0.05$) on the machine efficiency (Table 3). This means that any of the three birds tested (broiler, layer and cockerel) would have the same machine efficiency statistically as others.

Table 1 Parameters measured for the performance evaluation of the machine at 55ºC

Poultry bird breeds	Temperature at 55ºC							
	Live weight (kg)	Dead weight (kg)	Scalding time (s)	Machine plucking time (s)	Bird weight after plucking	Feather weight plucked by machine (kg)	Feather weight plucked by hand (kg)	Hand plucking time (s)
Broiler	1.67	1.60	48	22	1.45	0.22	0.02	23
Layer	1.20	1.15	30	22	1.05	0.15	0.01	20
Cockerel	1.63	1.58	52	28	1.53	0.12	0.02	66

Table 2 Average values of performance indices of the machine at machine speed 7.54 m s^{-1} for poultry bird breeds and temperature

Poultry bird breeds	Temperature (ºC)	
	55ºC	
	Machine capacity (birds hr^{-1})	Machine efficiency (%)
Broilers	167	93
Layers	155	92
Cockerel	139	89

Table 3 Analysis of variance for machine efficiency

Source	DF	SS	MS	F-Value	P-Value
Birds Type	2	21.56	10.778	2.85	0.135
Error	6	22.67	3.778		
Total	8	44.22			

The poultry bird type had significant effect ($p < 0.05$) on the machine capacity (Table 4). This means that at least two of the three birds tested (broiler, layer and cockerel) would have different machine capacity levels. The mean of machine capacity levels for broiler and layer are not significantly different from each other as well as the mean for machine capacity levels for layer and cockerel are not significantly different from each other too (Table 5). Also, the means for machine capacity levels for broiler and cockerel are significantly different from each other (Table 5). The number of birds that would be processed would be the same for broiler and layer, and layer and cockerel but would be different for broiler and cockerel.

Table 4 Analysis of variance for machine capacity

Source	DF	SS	MS	F-Value	P-Value
Birds Type	2	2016.0	1008.0	7.77	0.022
Error	6	778.0	129.7		
Total	8	2794.0			

Table 5 Separation of means by Least Significant Difference (LSD) for machine capacity

Birds Type	Mean
Broiler	167^{a}
Layer	155^{ab}
Cockerel	131^{b}

Note: Means with different letters are significant but means with the same letter are insignificant at 0.05

4 Conclusion

The following conclusions were reached:

The machine efficiency and machine capacity decrease accordingly from broiler, to layer and to cockerel.

The poultry bird types had no significant effect at $p \geq 0.05$ on machine efficiency while had significant effect $p < 0.05$ on the machine capacity.

Machine plucking time was highest in cockerel, followed by broiler and layer.

The machine was easy to use and less time consuming.

The machine was able to de-feather two smaller birds but performs better with one bird at a time.

The de-feathered birds appeared undamaged thereby preserving its market value in terms of skin quality.

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