

**Development of a preconditioning system for FUTA floating fish feed
extruder**

ABSTRACT

The need to enhance the quality of fish feed produced in Nigeria was the major consideration in the design and development of a preconditioning system. The machine consists of two insulated cylindrical barrel, set of arranged paddles on a shaft, frame, hot water and feed mash inlet, discharge chute, chain and sprocket. It was powered by a three-phase 15hp electric motor which transmits power to the machines shaft and set of paddles via chain and sprocket. The performance characteristics of the machine; mixing efficiency and throughput capacity were evaluated using NIOMR feed formulation at feed mash particle sizes of 900 μm , 550 μm , 520 μm and paired paddle rotating speed of the lower and upper chamber at (96.8; 145.2), (122.6; 183.2) and (174.5; 260.8) rpm respectively. The throughput capacity of the preconditioner is 650 kg/hr. The results showed increase in temperature and moisture content level of the particles as the machine speed decreases. The optimum mixing efficiency that gave best uniformity of mix was attained when Paired paddle speeds were (96.8; 145.2), (122.6; 183.2) with an average Biot numbers of 0.1.

KEYWORDS: Design, preconditioner, mixing efficiency, throughput capacity, Biot number.

1. INTRODUCTION

Fish feed is a nutritional formulation which consists of different classes of food in the right proportion that aids fish growth. Fish feed can be classified into natural and artificial diet (Craig

23 and Helfrich, 2002). Natural fish feeds are sourced from natural waters or well-fertilized ponds
24 which are balanced diet that help fishes grow strong and healthy. Examples of this food source
25 are microscopic plants (phytoplankton), microscopic animals (zooplankton), insects,
26 crustaceans, copepods and molluscs (Bolorunduro 2002). Artificial feeds can be complete or
27 supplementary diets. Complete diets supply all the ingredients (protein, carbohydrates, fats,
28 vitamins, and minerals) necessary for optimal growth and health of the fish in the right
29 proportion. Most of this complete diet are formulated with protein (18-50%), lipid (10-25%),
30 carbohydrate (15-20%), ash (< 8.5%), phosphorus (< 1.5%), water (< 10%), and trace amounts
31 of vitamins, and minerals. While supplementary diet is used only to support the natural feeds
32 with energy-based food in form of carbohydrate, proteins and fats & oil, but does not contain
33 minerals and vitamin (Craig and Helfrich, 2002). They can be used in all fish culture system.
34 Artificial feeds also known as commercial fish diets can be manufactured using well-
35 compounded mixture of feedstuffs and can be extruded (floating or buoyant) or pelleted (sinking)
36 feeds (Craig and Helfrich, 2002). The estimated quantity of imported fish feed from European
37 countries into Nigeria annually stand at 4000 tons (AIFP, 2004), this reduces the country's
38 foreign exchange earnings as few manufacturers that have ventured into production of fish feed
39 in the country produce low quality feeds, import most of the key equipment used, which are very
40 expensive and costly to maintain. It was evident in the submission of FAO (2005), that the
41 fishery industry has not achieved its goal of employment and social peace because the system is
42 not operating in a sustainable and efficient manner. In commercial fish feed production, certain
43 steps are taken to achieve extruded or pelleted feeds. They are selection of ingredients, grinding,
44 mixing, preconditioning and extrusion, cooling and drying (Woynarovich *et al.*, 2011).
45 Preconditioning which is one of the unit operations in fish feed production is neglected by most

manufacturers in Nigeria in order to reduce cost of production. The goal for preconditioning is to hydrate, pre-heat and mix powdery raw materials with injected fluids (steam, water and potentially oil or slurries) to obtain a homogeneous pre-cooked product that is best adapted to the next stage in fish feed production line. This operation improves extruder efficiency and reduces energy consumption, equipment wear and maintenance cost (Bailey *et al.*, 1995). Preconditioning systems allow greater flexibility in controlling process parameters like temperature and moisture which extruders lack that affects the quality of the feed (Vijayagopal, 2004). With no known report on any existing preconditioning system for fish feed production developed in Nigeria, this research to develop a preconditioning system for fish feed production was conceptualized with the aim of improving the feed quality produced by the newly developed FUTA fish feed extruder which can be adopted to suit other extruders in Nigeria.

2. METHODOLOGY

2.1 Design considerations

The preconditioner was designed based on the following considerations:

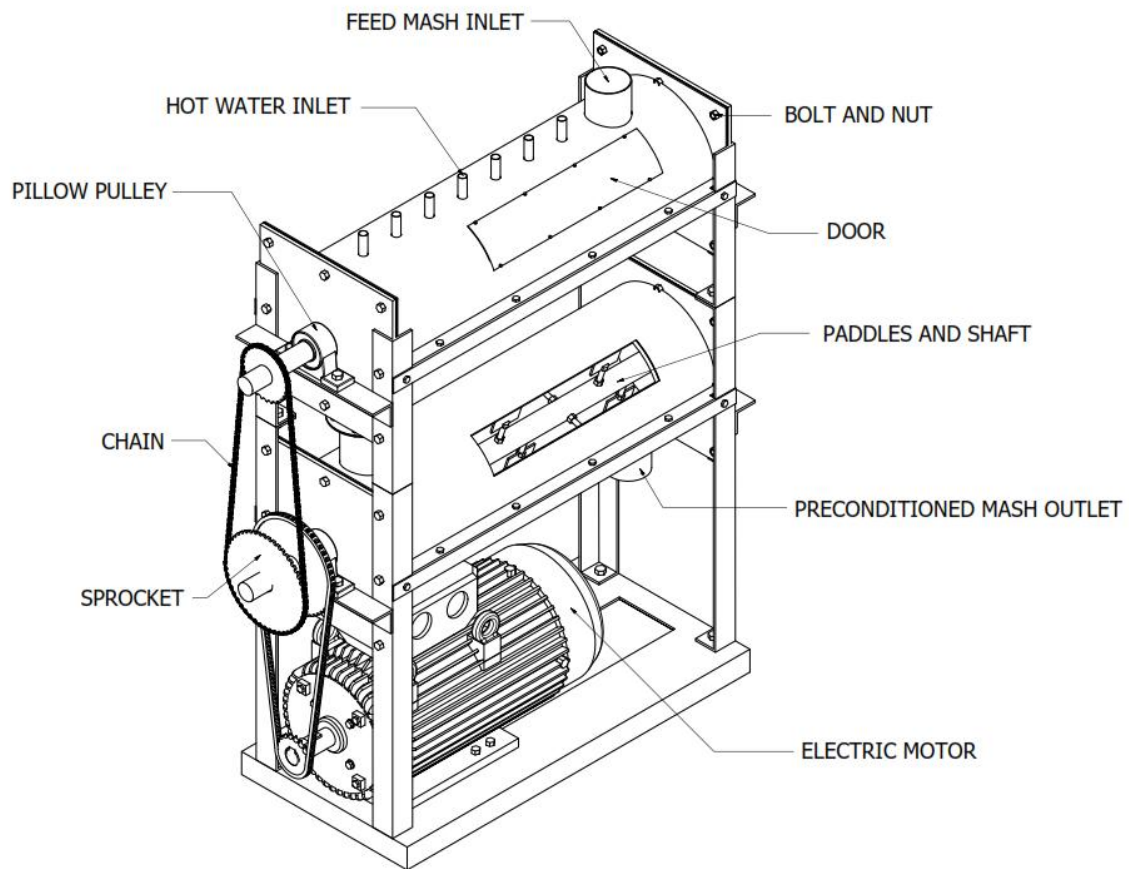
- i. The choice of materials used was based on their quality, availability, durability, efficiency, workability, desired goal and their suitability for construction.
- ii. Preconditioner technology requires injection of heat and moisture in a closed system, so proper insulation material was used on the body frame of the equipment to retain heat inside the mixing chamber which reduces heat loss and burns to the user.
- iii. Aesthetics was considered for the equipment to be appealing to consumers.
- iv. The paddles were designed to achieve uniform mixing efficiency.
- v. The assembly of the machine was made simple for easier maintenance.

2.2 Description of machine

The preconditioner as shown in Figures 1 and 2, consists of the paddles and shaft arrangement made of stainless steel for mixing and conveying the preconditioned feed mash. The internal cylindrical barrels (upper and lower chambers) are made of stainless steel and insulated with a Polyurethane foam to retain heat during mixing and held in place by a removable cover. They are supported by a frame made of 75 × 75 mm mild steel angle iron to withstand tensional and vibrational stress. The machine is powered by 15hp electric motor operating at speed of 1460rpm. A reduction gear of ratio 5:1 which transmits power to the chain and sprockets that rotates the two shafts carrying the well-arranged sets of paddles. The different components of the preconditioner were designed and selected using standard engineering principle.

2.3 Operational principle of the fish feed preconditioner

The feed mash and hot water were introduced into the upper chamber of the machine through the feed mash and hot water inlet pipes simultaneously. The feed mash was hydrated, heated and conveyed radially into the lower chamber at high speed before being transferred to the discharge chute at reduced speed to increase retention time for adequate mixing of feed. The paddle angle between the two rotating shafts were configured such that though the shafts moved in the same direction, the feed mash were conveyed in the opposite direction.



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86 Figure 1: Isometric view of the fish feed preconditioner

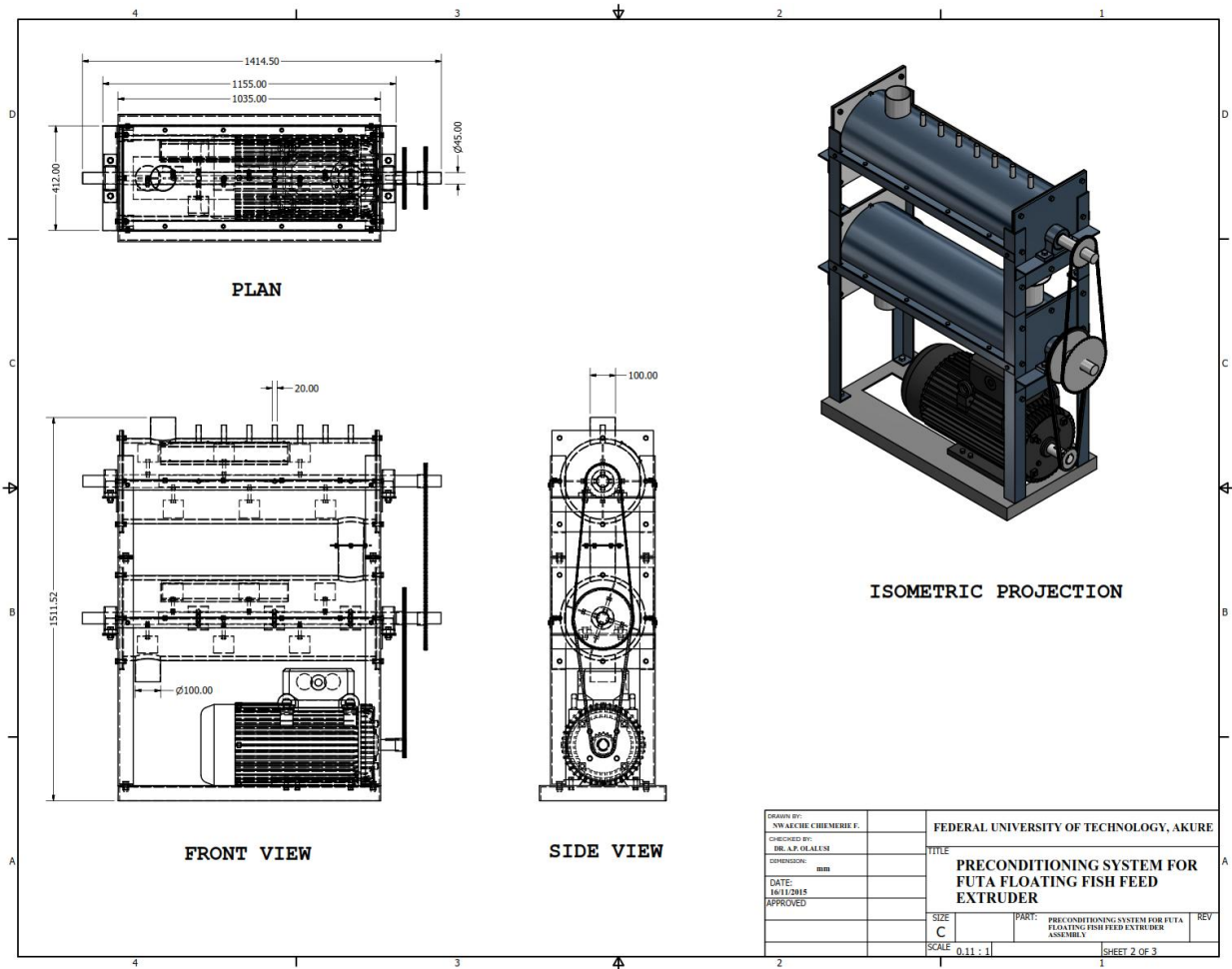


Figure 2: Orthographic projection of the machine

2.4 Design calculation

Determination of the upper chambers internal surface area

The chamber is made up of stainless steel. The chamber and other parts welded on it, is cylindrical in shape.

Let the surface area of the cylindrical parts is given by

$$C_A = 2\pi r(r + h) \quad (1)$$

95 Surface area of the inlet and outlet unit on the upper chamber

$$96 \quad C_B = 2\pi r(r + h) \times 2 \quad (2)$$

97 Surface area of the hot water inlets (7 in number) on the upper chamber

$$98 \quad C_C = 2\pi r(r + h) \times 7 \quad (3)$$

$$99 \quad \text{Total area, } T_A = C_A + C_B + C_C \quad (4)$$

100 ***Determination of the lower chambers internal surface area***

101 The chamber is made up of stainless steel. The chamber and other parts welded on it, is
102 cylindrical in shape. The dimension used in the upper chamber for C_A and C_B was also used for
103 the lower chamber.

$$104 \quad \text{Total area, } T_A = C_A + C_B \quad (5)$$

105 ***Determination of the volume and mass of the upper internal chamber***

$$106 \quad \text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad (6)$$

$$107 \quad \text{Density of stainless steel} = 7930 \text{ kg/m}^3$$

$$108 \quad \therefore \text{Volume} = \text{Area} \times \text{Thicknes}(C_A + C_B + C_C) \quad (7)$$

$$109 \quad \therefore \text{Mass} = \text{Volume} \times \text{Density} \quad (8)$$

110 ***Determination of the volume and mass of the lower internal chamber***

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

111 Density of stainless steel = 7930kg/m³

112 $\therefore Volume = Area \times Thicknes(C_A + C_B)$ (9)

113

114 ***Design of Chain and sprockets***

115 The chain drive system of this machine is made up of two chain and sprocket assemblies. One
116 connecting the drive and lower chamber and the other connecting the lower and upper chamber
117 of the machine. Based on investigation of existing preconditioners a rotational speed ranging
118 from 150 – 400 rpm was selected for both chambers.

119 A moderate shock service condition with service factors (K_s) was selected from the
120 manufacturer's catalogue.

121 $K_s = K_1 \times K_2 \times K_3$ (Khurmi and Gupta, 2005)

122 where, K_1 is load factor = 1.25, for mild shock

123 K_2 is lubrication factor = 1.5, for periodic lubrication

124 K_3 is rating factor = 1, for 8 hours per day

125 ***Lower and upper chamber chain drive system***

126 Velocity ratio of a chain drive is given by

127 $V.R = \frac{N_1}{N_2} = \frac{T_2}{T_1}$ (Khurmi and Gupta, 2005)

128 Where N_1 is speed of rotation of driving sprocket

129 N_2 is speed of rotation of driven sprocket

130 T_1 is number of teeth on the larger sprocket

131 T_2 is number of teeth on the smaller sprocket

132 Design power = rated power $\times$ service factors

133 ***Determination of pitch circle diameter of the driving and driven sprockets***

134 $d_1 = \frac{P}{\sin\left(\frac{180}{T_1}\right)}$ and $d_2 = \frac{P}{\sin\left(\frac{180}{T_2}\right)}$ (Khurmi and Gupta, 2005)

135 Where d_1 and d_2 is pitch circle diameter of driving and driven sprocket respectively

136 P is chain pitch

137 T_1 and T_2 is number of teeth of the driving and driven sprocket respectively.

138 ***Pitch line velocity of the driving sprocket***

139 $V_1 = \frac{\pi d_1 N_1}{60}$ (Khurmi and Gupta, 2005)

140 Where d_1 is pitch circle diameter of driving sprocket

141 V_1 is pitch line velocity

142 N_1 is speed of rotation of driving sprocket

143 Total load on the driving side of the chain, W

144 $W = \frac{\text{rated power}}{\text{pitch line velocity}}$ (Khurmi and Gupta, 2005)

145

146 Design of power transmitted on the basis of breaking load, W_B

147 Breaking load $W_B = 106p^2$ (in Newton) for roller chains. (Khurmi and Gupta, 2005)

148 Where p is chain pitch

149 Safety factor, $n = \frac{W_B}{W}$ (Khurmi and Gupta, 2005)

150 Power transmitted, $P = \frac{W_B \times V_1}{n \times K_s}$ (Khurmi and Gupta, 2005)

151 Chain velocity, $V = \frac{T_1 P N_2}{60}$ (Khurmi and Gupta, 2005)

152 Where T_1 is number of teeth in the driving sprocket

153 N_2 is speed of rotation of the driven sprocket

154 P is chain pitch

155 Tangential driving force,

156

157 $F_T = \frac{\text{power transmitted (in watts)}}{\text{speed of chain in m/s}}$ (Khurmi and Gupta, 2005)

158 Centrifugal tension in the chain, $F_C = mv^2$ (Khurmi and Gupta, 2005)

159 Tension in the chain due to sagging, $F_S = Kmgx$

160 Where m is mass of the chain per metre

161 x is centre distance

162 g is acceleration due to gravity

163 K is constant (Khurmi and Gupta, 2005)

164 Total tension on the driving side of the chain, $T_T = F_T + F_C + F_S$

165 ***To calculate the centre distance between the sprockets***

166 The minimum allowable centre distance between the driving and driven sprocket should be 30 to
167 50 times the pitch. Thus, for this model 30 times the pitch is selected.

168 $30p = 30 \times 25.4$

169 In order to accommodate initial, say in the chain, the value of centre distance is reduced by 2 to
170 5mm

171 Correct centre distance, $x = 762 - 4$

172 (Khurmi and Gupta, 2005)

173 ***To calculate number of chain links***

174 $K = \frac{T_1 + T_2}{2} + \frac{2x}{P} + \left[\frac{T_2 + T_1}{2\pi} \right]^2 \frac{P}{x}$ (Khurmi and Gupta, 2005)

175 ***To calculate chain length***

176 $L = K * P$ (Khurmi and Gupta, 2005)

177 **Design of shaft**

178 ***Lower and upper chamber shaft design***

179 Maximum bending moment

180 $M_b = \sqrt{M_v^2 + M_H^2}$ (Khurmi and Gupta, 2005)

181 Torsional moment M_t for the shaft

$$M_t = \frac{P \times 60}{2\pi n} \quad (\text{Khurmi and Gupta, 2005})$$

Where P is the design power in watts and n is the speed of rotation in rpm for the driven sprocket.

Diameter of the shaft

The diameter of the shaft is given by

$$d^3 = \frac{16}{\pi S_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (\text{Khurmi and Gupta, 2005})$$

Where K_b and K_t are combined shock and fatigue factors applied to bending moment and torsional moment.

S_s is allowable stress for shaft with key way = 42MN/m²

K_b and K_t are 1.5 and 1.0 respectively for rotating shaft.

Shaft is usually subjected to axial bending and torsional loads

For solid shaft

$$\text{Tensile stress} = \frac{4f_a}{\pi d^2}$$

f_a is the reaction at bearings close to the chain and sprocket on the shaft of the upper and lower chambers

Bending load for lower and upper chamber shaft

$$\text{Bending stress} = \frac{32M_b}{\pi d^3}$$

197

198 2.3 Preliminary test

199 The composition of the feed mash ingredient used and volume of water added in the mixture
200 during preliminary test were according to suggestion proposed by Nigerian Institute for
201 Oceanography and Marine Research (NIOMR). The Table 1 below shows the percentage
202 composition by mass of the different ingredients used.

203 **Table 1. Fish feed mass formulation used**

S/N	Ingredient	Percentage composition by mass (%)
1.	Cassava flour	39
2.	Soymeal	20
3.	Groundnut Cake	20
4.	Fish meal	20
5.	Fish premix	0.5
6.	Nitox Antimould	0.5

204

205 **Source:** Nigerian Institute for Oceanography and Marine Research (NIOMR)

206 The machine was tested by varying feed mash particle sizes of 900, 550 and 520 μm . The
207 machine paddle speed were in pairs of (96.8; 145.2), (122.6; 183.2) and (174.5; 260.8) rpm. The
208 first and second values in the bracket represents the paddle speed of the lower and upper

chamber respectively. The initial moisture content and temperature of the formulated fish feed were taken before each run. Hot water at 100 °C and feed mash were introduced into the preconditioner simultaneously at rate of 2 litres per 13kg batch. At the discharge, the weight of the final temperature and moisture content of the preconditioned feed were all determined. The thermal conductivity and volumetric heat capacity was determined using a single instrument called KD2 Pro which has 30 mm dual-needle sensor that was inserted into the feed mash which measures and displays its reading. Each run was repeated three times and their average was used for analysis. The throughput capacity and mixing efficiency were determined to calculate the performance indices of the machine.

Throughput capacity T_p , was determined using equation (6) below.

$$T_p = \frac{W}{t} \dots\dots\dots (6)$$

Where, T_p is throughput capacity (kg/h)

W is weight of the feed mash collected (kg)

t is time taken for preconditioning (min)

Determination of mixing efficiency of the preconditioner

The mixing efficiency of the preconditioner was determined using the dimensionless Biot number Bi that is generated after mixing; when the Biot number (Bi) is less than 0.1 it means the preconditioner mixes poorly, intermediate when is approximately 1 and good mixing when the Biot number is greater than 10. Biot number is given by

$$Bi = \frac{\lambda r}{\alpha} \dots\dots\dots (10)$$

229 where $\lambda = h_{fp}$ which is heat transfer coefficient ($\text{W}/\text{m}^2/^\circ\text{C}$)

230 α is thermal conductivity ($\text{W}/^\circ\text{C}/\text{m}$)

231 r is radius sphere of the feed mash particle (m) (Urmas *et al.*, 2015)

232 $\therefore h_{fp} = \frac{Q_{fp}}{A\Delta T}$ (11)

233 where A is total area of the particles in the control volume

234 ΔT is temperature difference between fluid and particle temperature ($^\circ\text{C}$)

235 (Tor, 2013)

236 $\therefore Q_{fp} = Q_{fluid} - Q_{paste}$ (12)

237 where Q_{fp} is heat flow from the fluid to the particles (W)

238 Q_{fluid} is convective heat flow of the fluid into the particles (W)

239 Q_{paste} is convective heat flow out of the paste (W)

240 $Q_{fluid,paste} = mcp(\theta_1 - \theta_2)$ (13)

241 where cp is volumetric heat capacity of the particles (MJ/m^3)

242 θ_1 is initial temperature of the particles and water ($^\circ\text{C}$)

243 θ_2 is final temperature of the particles and water ($^\circ\text{C}$)

244 m is mass of the fluid and particles (kg)

245 Substituting equation (13) in (12)

$$Q_{fp} = mcp(\theta_1 - \theta_2) - mcp(\theta_1 - \theta_2) \dots (14)$$

3. RESULTS AND DISCUSSION

The graphs below show the effect of the paired paddle speed on final moisture content and temperature of the preconditioned feed mash, residence time and mixing efficiency.

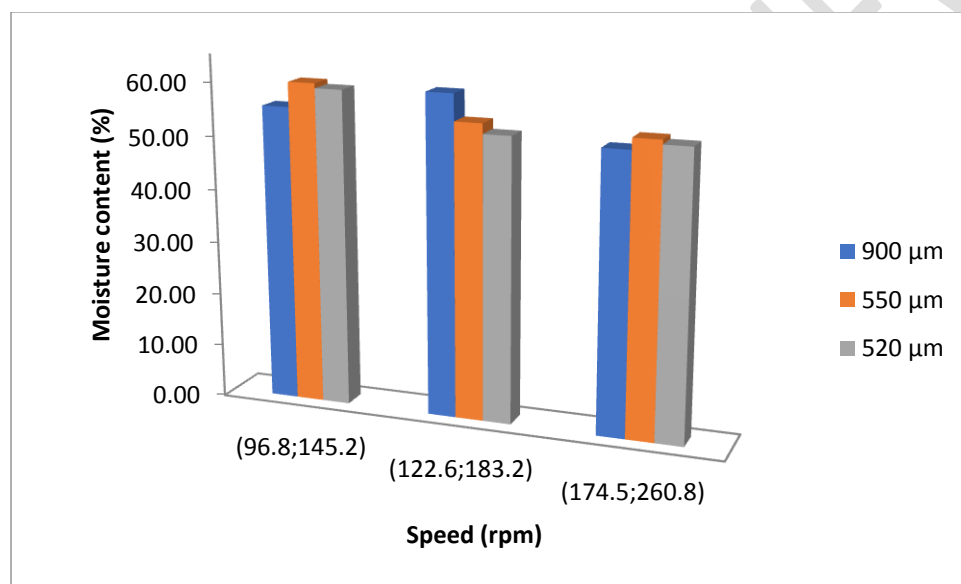


Figure 3: Variation in the moisture content with paired paddle speed in rpm and particles

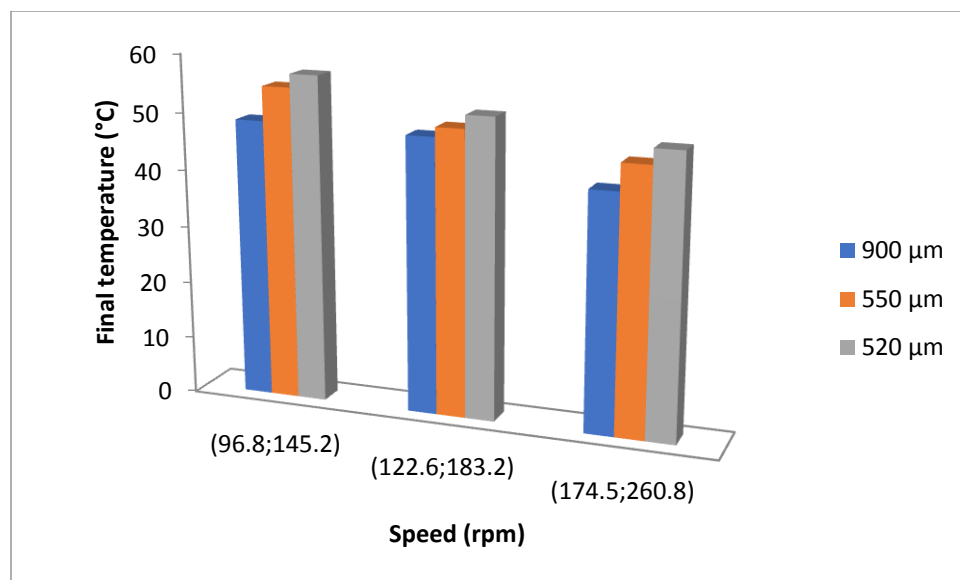


Figure 4: Variation in final temperature with paired paddle speed in rpm and particles

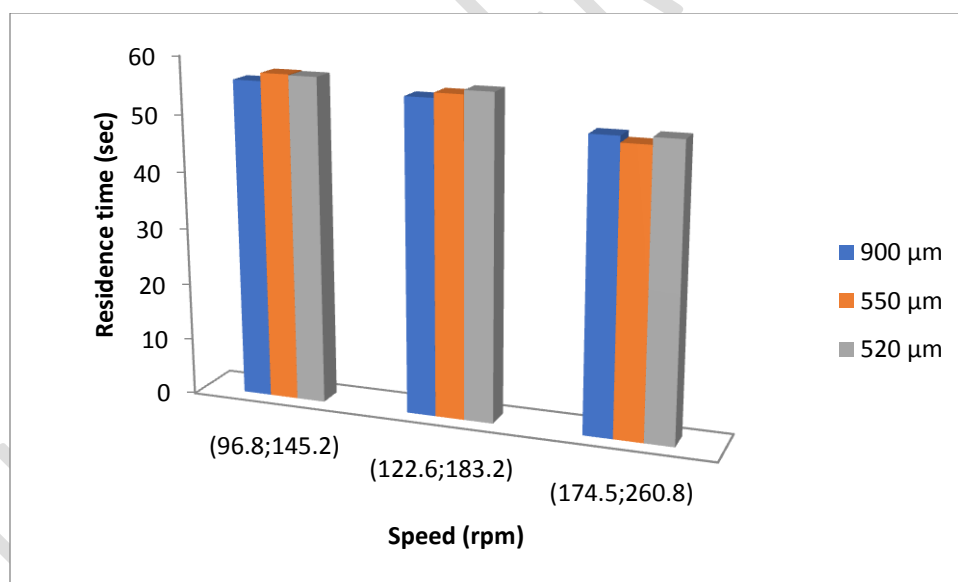


Figure 5: Variation in residence time with paired paddle speed and particles

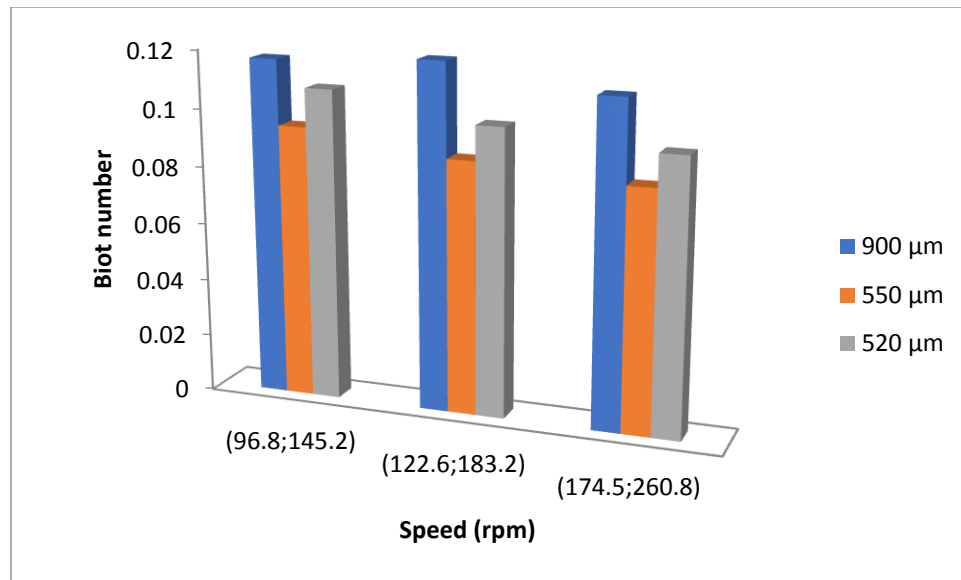


Figure 6: Variation in Biot number with paired paddle speed in rpm and particles

Figures 4, 5 and 6 shows that at paddle speed 174.5 and 260.8 rpm, the average retention time for all the particles was 49.9 seconds. At this speed the feed mash discharged at a low temperature and moisture content level. The average temperature and moisture reading were 44.3 °C and 52.2 %, respectively. At paddle speed 122.6 and 183.2 rpm, the average retention time for all the particles was 55.46 seconds. This showed slight increase in temperature and moisture content level readings which averaged 47.6 °C and 55.1 % respectively due to increase in retention time. There were significant increase in temperature and moisture content reading at paddle speeds of 96.8 and 145.2 rpm. The average temperature and moisture content readings were 52 °C and 58.8%, respectively and an average retention time of 57.12 seconds for all the particles. This showed that all the particles absorbed more moisture and heat as the paired paddle speed of the preconditioner reduces with increasing retention time. This agrees with report by Eugenio (2004), that higher residence time improves the hydration and heat absorption rate of the preconditioned feed mash.

Figure 6 shows that, at paddle speed of 174.5 and 260.8 rpm, the average Biot number of all the particles was 0.09. However, at paddle speed of (122.6 and 183.2 rpm) and (96.8 and 145.2 rpm) the Biot number of all the particles was 0.1. This implies that the Biot number increases as the paddle speed is reduced for all the particles.

Previously reported by Eugenio (2004), this result shows that the evaluated preconditioner performed poorly at the selected speeds. However, it can be improved by further reducing the speed and increasing the retention time to obtain higher Biot number and hence higher mixing.

4. CONCLUSION

The preliminary evaluation of the machine in terms of mixing efficiency and throughput capacity indicates that it has high potential in improving the quality of feeds produced in Nigeria. Though, the mixing efficiency obtained from the test was low, further improvement on the operating conditions of the preconditioner will definitely increase the mixing efficiency of the system.

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