Design of a Process Plant for the Production of Poundo Yam

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Abstract

This paper explicitly gives the details of the design of an integrated process plant for poundo yam production. The paper covers the deign analysis of each machine involved in the production process of the process plant. Viz a viz peeling and slicing machine; parboiling machine; conveyor; sieving machine; drying machine and grinding machine. It explained the material required for the fabrication of each part of the machines used in the process plant and the cost analysis. A simulation was done to confirm the workability of the design for fabrication purpose. The plant has a capacity of converting 23tubers of yam(discorea alata) into 250Kg of poundo yam in 7hrs.

Keywords: Design , Process Plant, Manufacturing, Poundo Yam

1. INTRODUCTION

High post harvest food losses, arising largely from limited food preservation capacity are a major factor constraining food and nutrition security in the developing countries of West Africa, where seasonal food shortages and nutritional deficiency diseases are still a major concern [1]. It is estimated that about 50% of perishable food commodities including fruits, vegetables, roots and tubers and about 30% of the food grains including maize, sorghum, millet, rice, cowpeas are lost after harvest in west Africa. The factors responsible for post harvest food losses in West Africa are ineffective or inappropriate food processing technology, Careless harvesting and inefficient post harvest handling practice, Poor transportation media, Bad market practice and Lack of storage facilities. In essence to reduce post harvest food losses traditional foods have to be improved using technological food processing techniques. One of these techniques is processing of yam into instant yam flour.

The slow progress in upgrading traditional food processing and preservation techniques in the country, contributes to food and nutrition insecurity. Simple low cost traditional food processing techniques are the bedrock of small scale food processing enterprises that are crucial to rural development, employment opportunity, rural-urban migration and associated social problems. Regrettably, small scale food industries in the country are hampered by adoption of inefficient and inappropriate technologies, poor management, inadequate working capital, limited access to banks and other financial institutions, high interest rates and low profit margins.

Yam, Dioscorea (spp), a dicotyledonous perennial plant, is an important source of carbohydrate for many people of the sub-Saharan region especially in the yam zones of West Africa. Several

species of yam are grown in the in the tropics and temperate zones of the world since it grows easily, it has large yield and is little affected by disease and pests. It is the second most important root/tuber crop in West Africa after cassava, with production reaching just under one third the level of cassava. Some are grown for medicinal purposes and other for edible purposes. The most common of the edible species are *Dioscorea alata L*; (known as the greater yam), *Dioscorea cayenensis lam*; (the yellow yam) *Dioscorea rotundata poir*. *Dioscorea esculenta* (white yam) [2]. Yam has an energy content of about 30 billion kcal with a corresponding protein content of 0.66 million ton [3].

Yam is a source of carbohydrates in human diet being processed into pounded yam for human consumption. The tubers of yam cannot be stored much longer after harvest before decaying, and so processing follows immediately after harvesting. Poundo yam which is also referred to as instant pounded yam flour (IPYF) is a processed white powdery form of yam (dehydrated yam flour) which is produced desiccating machine. It is a fast means of making pounded yam which is done by pouring a measured quantity of the yam flour into boiling water, which is stirred continuously until the required texture and taste is achieved. Yam processing leading to size reduction includes peeling, slicing, parboiling, grating, drying, drying and sieving [4]

2. LITERATURE REVIEW

Yam can supply a substantial portion of the manganese and phosphorus requirement of adults and to a lesser extent the copper and magnesium. The tubers can grow up to 2.5 meters in length and weigh up to 70kg (150pounds) [3]. The vegetable has a rough skin which is difficult to peel but which softens after heating. The skin varies in color from dark brown to light pink. Nigeria has been adjudged as the top producer of yam with a value of 26.6million metric ton [3]. Table1shows the output of top yam producers in 2005.

S/n	Country	Production (million metric ton)
1	Nigeria	26.6
2	Ghana	3.9
3	Australia	3.2
4	Cote d' Ivoire	3.0
5	Benin	2.3
6	Togo	0.6
7	Colombia	0.3
	World total	39.9

TABLE1: Yam Output 2005 (Top Producers as at 2005)   [2]

Design and Construction of a yam pounding machine has been developed in which the machine consists of a shaft, pulleys, belt, bearings, electric motor and yam beaters [5]. The existing design works have been on different separate entity of process. But the present research or design work has integrated all the processes into an entire production plant process.
The production process of instant pounded yam flour consist of simple operations which can be mechanized. These unit operations can be summarized as follows
*Yam Selection and Weighing***:** This involves the selection of suitable varieties of yam, considering the size and shape of the tubers. The wholesome tubers are then weighed.
Washing: The selected tubers are washed properly to remove adhering sand. The essence of the washing is to ensure that the peeling is done effectively.
Peeling and Slicing: The washed tubers are carefully loaded into a yam peeling and slicing machine for peeling the bark of the yam. The pilled tubers are then mechanically sliced to desirable thickness in a slicing machine made of stainless steel.
Parboiling: The yam slices are blanched in boiling water (parboiling) for some minutes, depending on the thickness of the slices
Drying: The parboiled yam slices are dried in a dryer at specified drying temperature for few hours. The dried yams chips are stored in air tight containers
Grinding: The dried yam chips are grinded directly into flour of uniform particle size distribution.

Sieving and Packaging*:* The yam flour is sieved and packed into air tight, moisture proof packaging materials
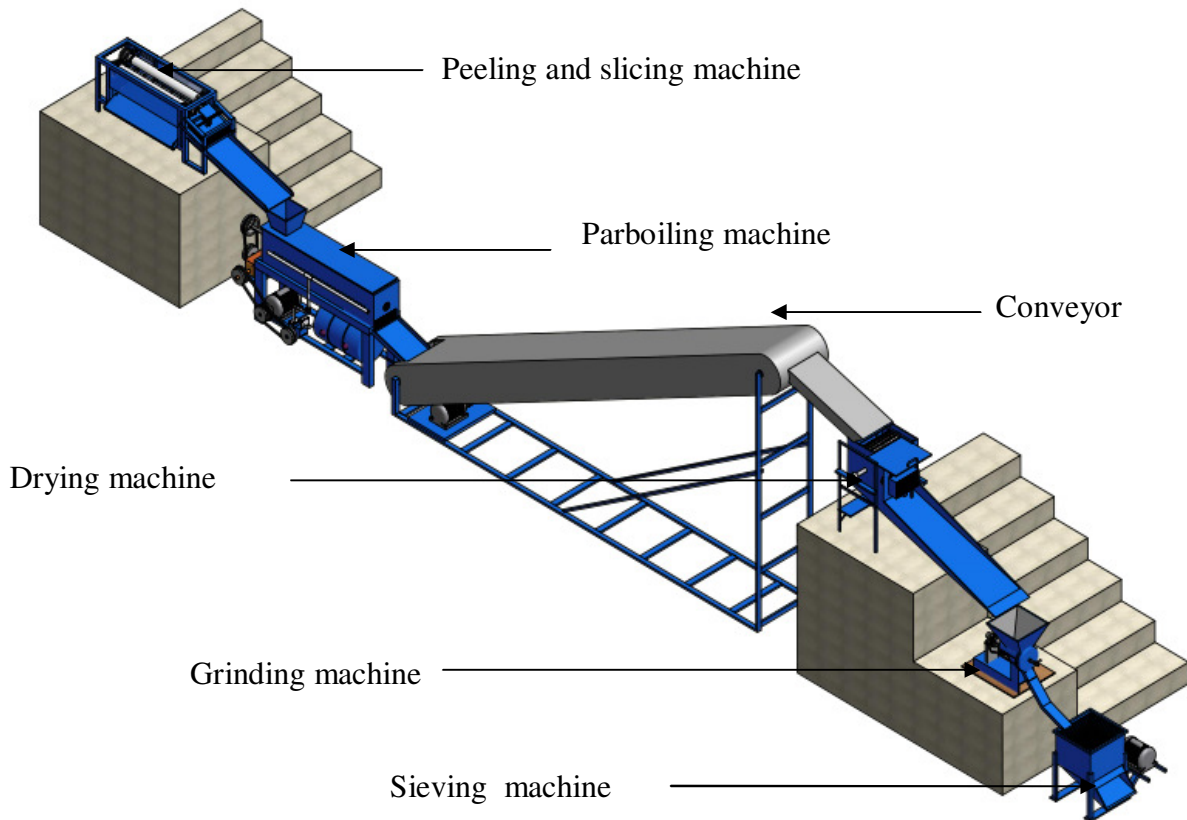

FIGURE 1 : The designed product plant for poundo yam production

3. MATERIALS AND METHODS

The production of poundo yam is a continuous process production. It involves the production of continuous stream of instant yam flour. The type of equipment layout suitable for plant is a process layout. In a process layout the equipments are arranged in such a way that they satisfy the production stages of the product. The plant is made up of various machines which the yam must pass through before getting to the final product. These machines are peeling and slicing machine, parboiling machine, drying machine, grating machine, sieving machine and the conveyor. These are as shown in figure 1.

The component part of each machine was designed. The arrangements of the plant at designed level is as shown in figure 2.
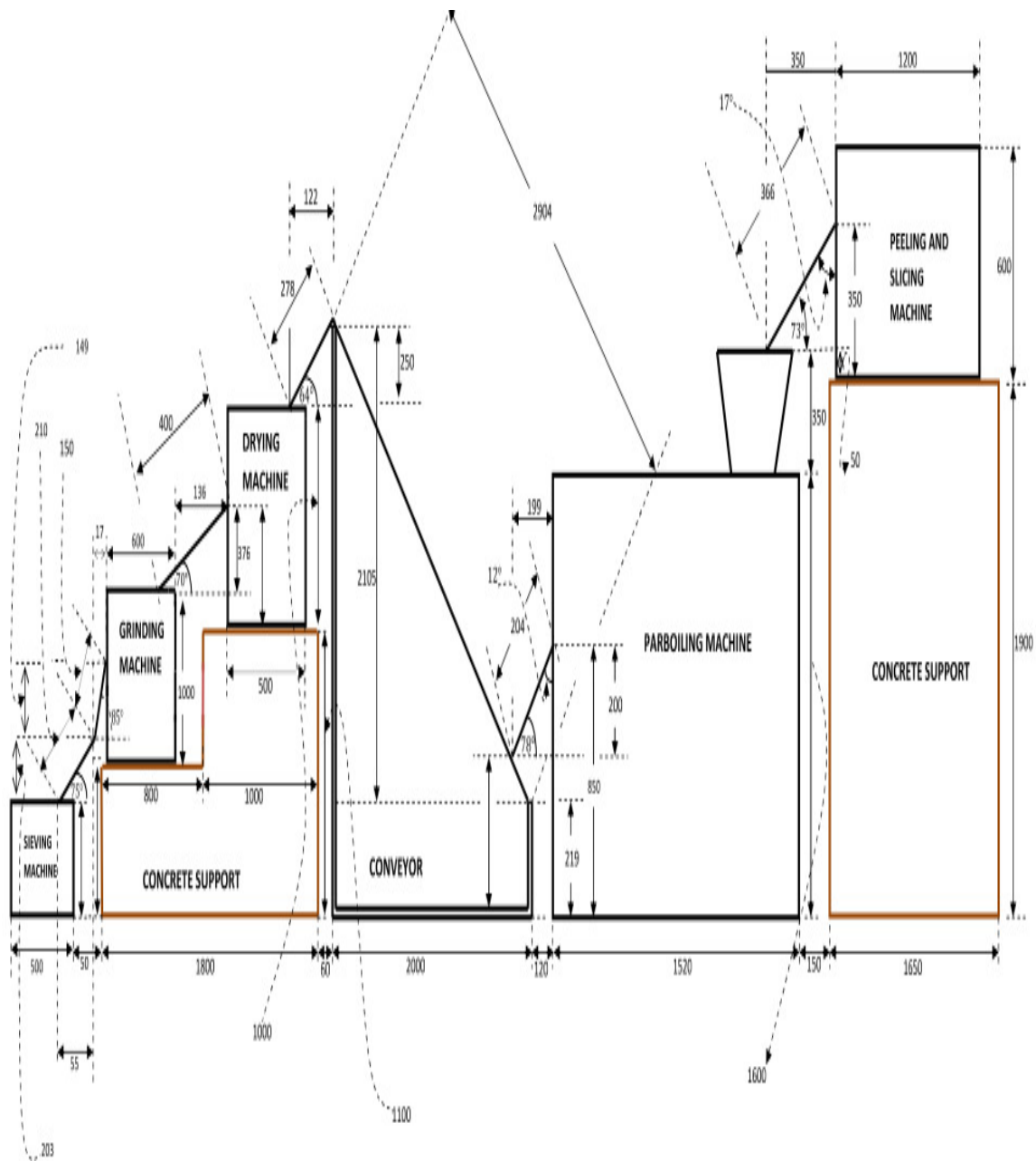
FIGURE 2: Schematic diagram of the process plant showing angle of repose of the delivery chutes and the distance separating the machines

The diameter of the peeling shaft and auger shaft was determined using the below empirical equation [4].

$$d^3 = \frac{16}{\pi S_s} \sqrt{\left\{ (K_b M_b)^2 + (K_t M_t)^2 \right\}} \qquad (1)$$

Where ;
d = diameter of the shaft (m); S_s = Allowable shear stress N/m^2
K_b = Combined shock and fatigue factor applied to bending moment
K_t = Combined shock and fatigue factor applied to torsional moment
M_b = Bending moment (Nm); M_t = Torsional moment (Nm)
The length of belt transmitting power between two pulleys of dissimilar diameters was derived [6].

Lenght of belt $L = \sqrt{4x^2 - (D_2 - D_1)} + \frac{1}{2}(D\theta_2 - D\theta_1)$ (2)

Where $D\theta_2 = \frac{\theta_2}{360} \times \pi D_2$

and $D\theta_1 = \frac{\theta_1}{360} \times \pi D_1$

Where:
D_1 and D_2 are the diameters of the pulleys
x = center distance between the two shafts
θ_1 and θ_2 are the angle of lap of the belts on the pulley
When the pulleys are of the same diameter the length of belt is obtained.

$$L = \pi \left\{ \frac{D_4}{2} + \frac{D_3}{2} \right\} + 2C + \frac{(D_4 - D_3)^2}{2} \qquad [8] \qquad (3)$$

Where:
L = Length of the belt
D_4 and D_3 are the diameters of the two pulleys attached to the peeling and auger shaft respectively. C is the center distance between the two pulleys.
The volume of the hopper in the parboiling machine was obtained as stated below [9].

$$V_{hopper} = V_{wholepyramid} - V_{cutawaypyramid} \qquad (4)$$

$$V_{hopper} = \{0.5 \times L_{b1} \times L_{b2} \times H_p\} - \{0.5 \times L_{c1} \times L_{c2} \times H_c\} \qquad (5)$$

Where:
$L_{b1} = L_{b2}$ = length of the top shape of the hopper which is considered to be a square.
$L_{c1} = L_{c2}$ = length of the base shape of the hopper which is considered to be a square.
H_p = vertical height of the pyramid; and H_c = vertical height of the cut away pyramid
The water horse power (WHP) is the power output of the pump and it is stated as

$$WHP = \omega QH_m \qquad \text{where } H_m = \text{manometric height} \qquad (6)$$

$$WHP = \rho g QH_m \qquad [10] \qquad (7)$$

Where ρ ang g are the density of water and acceleration due to gravity respectively.
The efficiency of the pump is obtained as

$$\gamma_{pump} = \frac{WHP}{SHP} \qquad [10] \qquad (8)$$

Where SHP = Shaft horse power = The power input to the pump from the electric motor
The volume of the parboiling chamber V_{pc} was obtained as

$$V_{pc} = H_r.B_r L_r + 0.5\left(\frac{\pi B_r^2 L_r}{4} \right) \qquad (9)$$

Where:
H_r = Height of the rectangular section of the parboiling chamber
B_r = Breadth of the rectangular section of the parboiling chamber = diameter of the cylindrical section
L_r = Length of the rectangular section of the parboiling chamber = length of the cylindrical section
The internal pressure of the parboiling chamber 'P_{ch}' was obtained to from

$$P_{ch} = \rho(L_r - 0.3) \times 100 \qquad (10)$$

Where ρ and L_r are the density of water and length of the rectangular section of the parboiling chamber.
The hot water reservoir used in the parboiling machine is made from plate material. The thickness of the plate material t_{hwr} was determined from:

$$t_{hwr} = \frac{P_{hwr} D \times 10^3}{2 f_{hwr} J} + C \qquad [10] \qquad (11)$$

Where:

P_{hwr} = The internal pressure of the hot water reservoir

D = Diameter of the hot water reservoir; f_{hwr} = Permissible stress in the hot water reservoir

J = Joint efficiency; and C = Corrosion allowance

The Euler's theory for crippling and buckling load 'W_{cr}' under various end conditions was used to determine the buckling load on the machine, and it is given as:

$$W_{cr} = \frac{c \pi^2 E A}{\left(l/k \right)^2} \qquad (12)$$

Where C is the constant representing the end conditions of the column or end fixity coefficient of 4 for welded and bolted joints

E and A = Young's modulus of elasticity for the material of the column and cross sectional area respectively.

l and k are the length of column and least radius of gyration of the cross section respectively.

Where: $k = \sqrt{\dfrac{I}{A}}$ such that I is called polar moment of area.

The Schematic diagram of the designed dryer is shown in figure 3. The volume of the drying drum was derived from:

$$V_{dr} = \frac{\pi D_{dr}^2 L_{dr}}{4} \qquad (13)$$

Where:

L_{dr} = length of the drying drum ; and D_{dr} =diameter of the drying drum

The number of holes 'n_h' on the metal plate was obtained as

$$n_h = \frac{\pi D_{dr} \times L_{dr}}{0.0004} \qquad (14)$$

The volume of each hole 'V_h' is determined using :

$$V_h = \frac{\pi D_h^2 t_{dr}}{4} \qquad (15)$$

Where D_h = diameter of the hole and t_{dr} = thickness of the metal plate from which the drying drum is made .

Hence the total volume of all the holes V_{Th} as obtained using

$$V_{Th} = n_h V_h \qquad (16)$$

$$V_{Th} = n_h \left\{ \frac{\pi D_h^2 t_{dr}}{4} \right\} \qquad (17)$$

The total volume of the materia 'V_{mT}' assuming there is no hole in it can be obtained from:

$$V_{mT} = \pi D_{dr} \times L_{dr} \times t_{dr} \qquad (18)$$

Hence the volume of the material 'V_m' when there are holes in it was obtained from

$$V_m = V_{mT} - V_{Th} \qquad (19)$$

The thermal energy input to the dryer in KJ/hr was obtained from

$$H_{in} = C_{h-in} \times \left(T_{in} - T_{amb} \right) \qquad [12] \qquad (20)$$

Where; H_{in} = the thermal energy input, C_{h-in}, the specific heat of humid air and T_{in} and T_{amb} are the input temperature and ambient temperature respectively.

The amount of moisture removed from the yam (M_r) during the drying operation was estimated using:

$$M_r = \frac{M_i(M_o - M_f)}{100 - M_f} \qquad\qquad [12] \qquad\qquad (21)$$

Where :
M_i = initial mass of the yam = mass of yam at maximum volume of drying drum = dryer capacity
M_o = initial moisture content of the yam
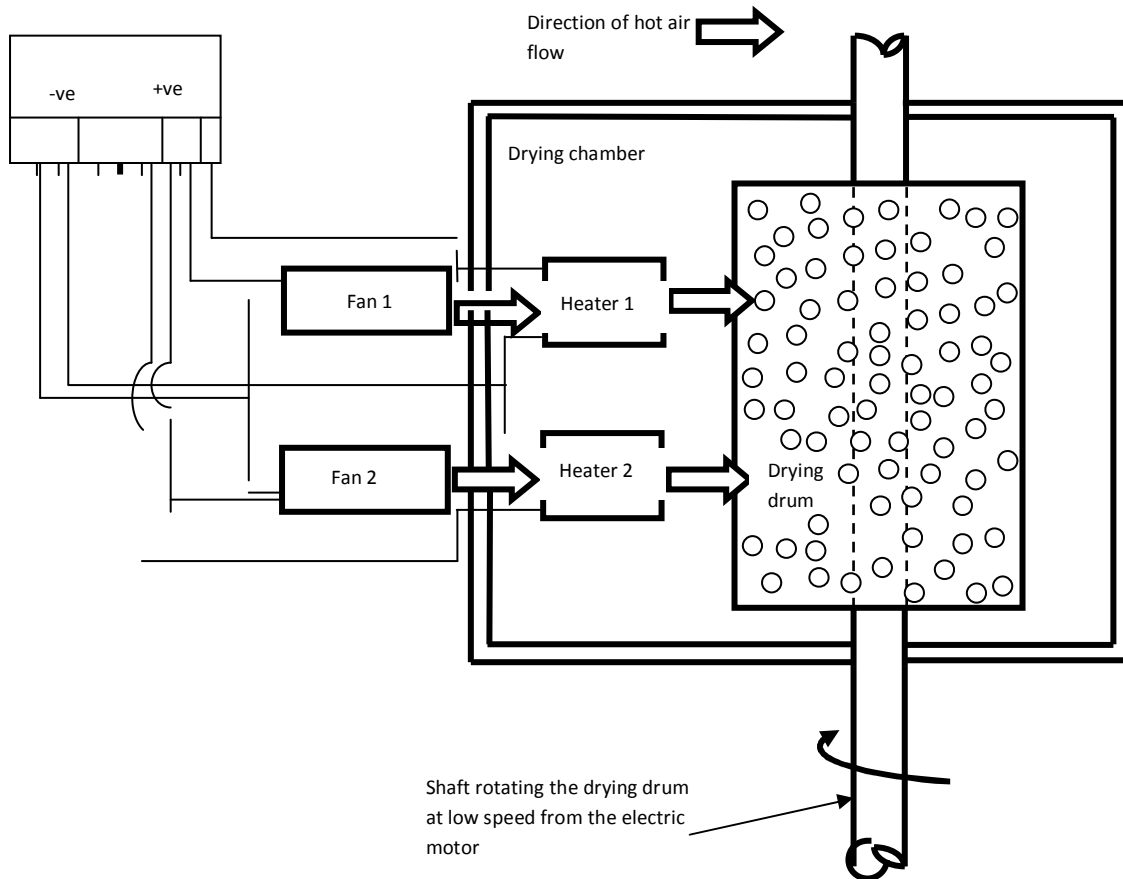M_f = final moisture content of the yam.

FIGURE 3: Schematic Diagram of the Dryer

Figure 4 shows the isometric view of the sieve frame made from wood. The volume of wood V_{wood} was obtained using

$$V_{wood} = 2L_{CD}{}^2(L_{DE} + L_{AB}) \qquad\qquad (22)$$

The sieves are two and they are of the same size, then the total volume of the wood can be obtained as $\quad V_{Twood} = 2 \times V_{wood} = 4L_{CD}{}^2(L_{DE} + L_{AB}) \qquad\qquad (23)$
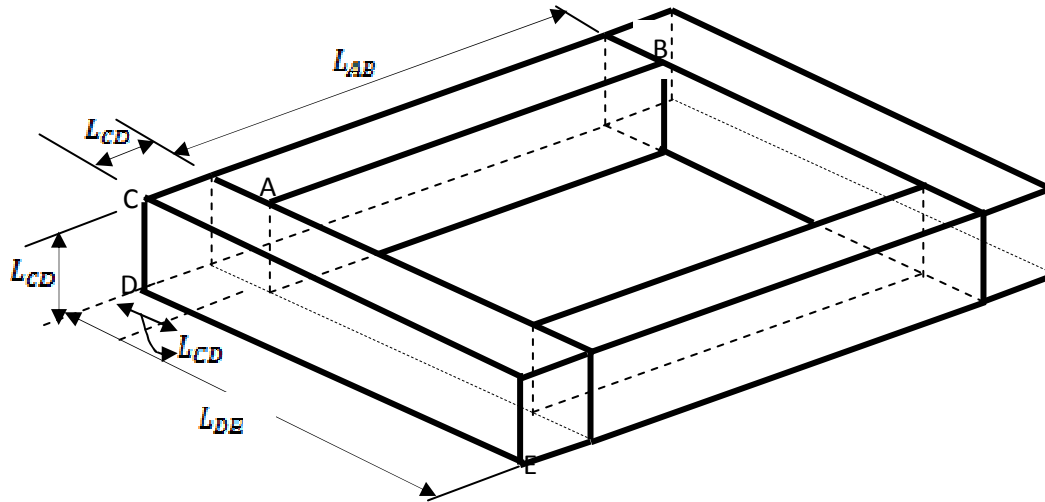
FIGURE 4: Sieve Frame

The volume of the sieving chamber V_{sc} was obtained from:

$$V_{sc} = 2\{(L_{DE} - 2L_{CD})\} \times L_{AB} \times L_{CD} \qquad (24)$$

The time, velocity, and acceleration of the follower at return stroke and out-stroke are tabulated as follows

$$t = \frac{\theta}{\omega_{cam}} \qquad (25)$$

$$V = \frac{\pi \omega_{cam} S}{2\theta} \qquad (26)$$

$$a_o = \frac{\pi^2 \times \omega_{cam}{}^2 S}{2\theta^2} \qquad [8] \qquad (27)$$

Parameters/motion	Return stroke motion	Out- stroke motion
Time (s)	0.05	0.03
Velocity (m/s)	9.40	6.23
Acceleration (m/s^2)	884	395

TABLE 2: Values for Follower Motion

The rated life of the bearing supporting the auger shaft of the grinding machine was derived as

Rated life $L = \left(\dfrac{C}{p}\right)^3 \times 16^6$ *revolutions*

Where:
C = load rating; and P = dynamic equivalent load [8]
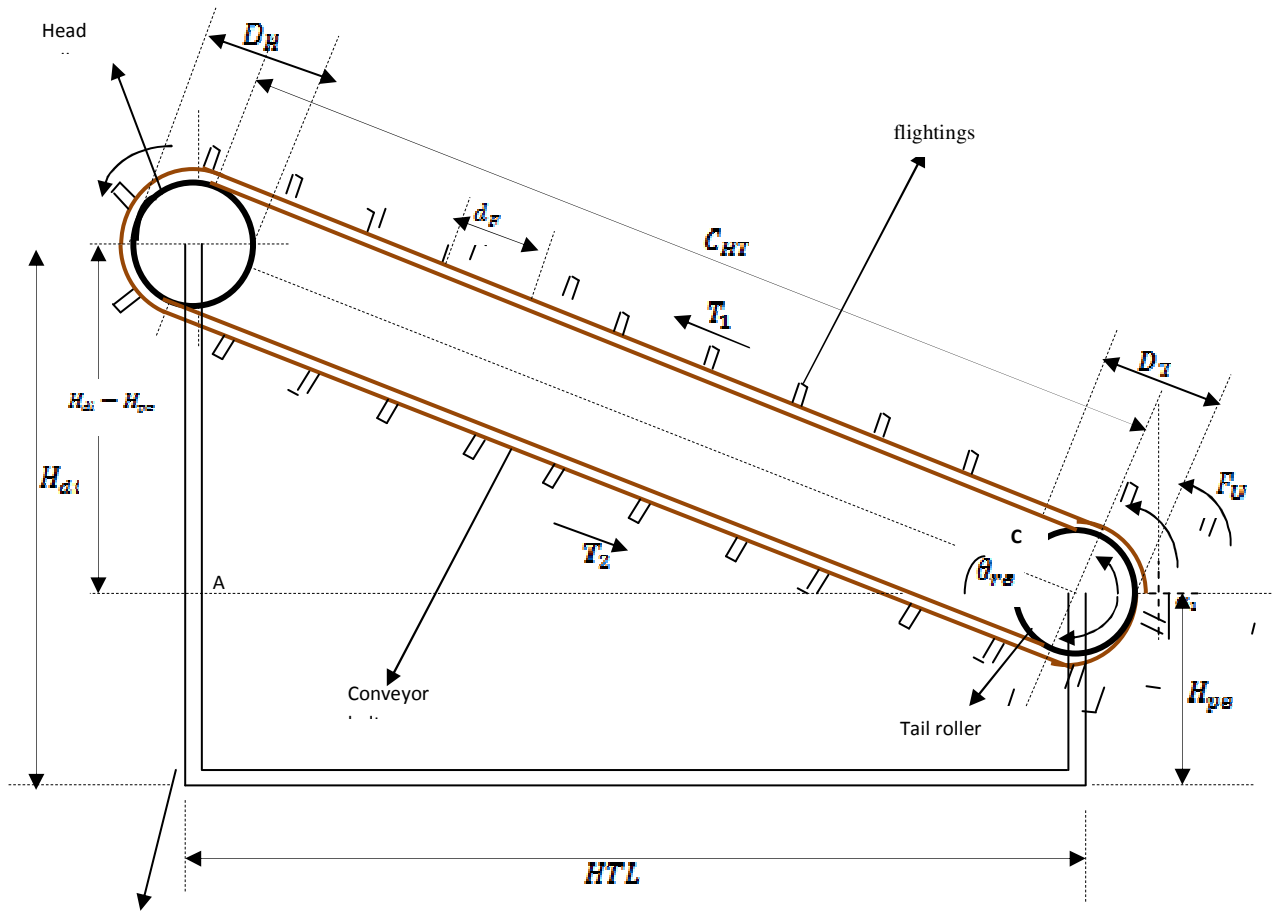Figure (3) shows the schematic diagram of the conveyor used in the process plant.

FIGURE 5: Diagram of the conveyor used in the poundo yam process plant

Where

D_H = Diameter of the head roller which is equal to the diameter of the tail roller

d_f = Distance between two flights on the belt

C_{HT}=Center distance between the head and tail roller = conveying length

θ_{re}= Angle of elevation of the rollers

H_{pe} = Height of the parboiling machine exit to the ground

HTL = Horizontal travel distance between the parboiling machine and the drying machine

H_{di} = Height of the drying machine exit to the ground

α= angle of wrap on the rollers

$T_1 = Tension$ in the tight side of the belt

T_2 = Tension in the slack side of the belt

The center distance between the head and tail roller (which is the conveying length) is obtained from:

$$C_{HT}{}^2 = HTL^2 + \left(H_{di} - H_{pe}\right)^2 \qquad (28)$$

The length of the conveyor belt L_{CB} was obtained from:

$$L_{CB} = 2\left(CHT + \frac{\alpha}{360}\pi D_r\right) \qquad (29)$$

The number of Flights on the belt was obtained from:

$$n_f = \left(\frac{L_{CB}}{d_f}\right) \qquad (30)$$

The load stream volume Qv (which is defined as the conveying capacity of the conveyor) was obtained from

$$Qv = 3600 \, Av \ (m^3/hr) \qquad [13] \qquad (31)$$

Where :
A and v are the cross sectional area of the load stream and the belt speed respectively.
The mass of load stream which the conveyor can move at a time is called the capacity of the conveyor and it was derived accordingly.

$$Q_{m} = \rho_m \, Q_v \ \ (tons/hr) \qquad (32)$$

Where ρ_m is the density of the material conveyed. The bulk density of yam, $\rho_m = 1104 \, Kg/m^3$ [11]
The power required at the drive sprocket is the summation of the power for empty conveyor and load over the horizontal distance (p_1) and the power required for lift (p_2).

$$P_T = P_1 + P_2 \qquad (33)$$

Where :

$$p_1 = \left(\frac{C_B v + Q_m}{C_L + k_f} \right) \qquad (34)$$

Where
C_L= length factor of the belt ; C_B= width factor of the belt; and k_f = working condition factor

Where:
$$p_2 = \left(\frac{H_{di} - H_{pc}}{367} \right) Q_m \qquad (35)$$

The material selected for each component part of the machine in the process plant is analyzed in Tables 3 to 8.

S/n	Machine Component	Criteria for Selection	Material used for the Design	Suitable Material	Reasons for Selecting the Material
1	Machine Frame	Strength, firmness, and rigidity	Angle bar (Mild Steel)	H- Beam	It is cheap and readily available
2	Peeling Shaft	Strength, resistant to shock and torsional deflection	Galvanized steel.	Stainless steel	It is cheap and readily available
3	Auger Shaft	Strength, resistant to shock and torsional deflection	Galvanized steel.	Stainless steel	Cheaper and readily available
4	Electric Motor	optimal functionality	8.4 Hp and speed of 2000rpm	8 Hp and speed of 2000rpm	Most suitable
5.	Slicing Blades	strength and must be corrosion free	Stainless Steel	Stainless Steel	strong resistance to corrosion and cheaper

TABLE 3: The materials selected for the key component parts of the peeling and slicing machine

S/n	Machine Component	Criteria for Selection	Material used for the Design	Suitable Material	Reasons for Selecting the Material
1.	Auger spiral/coiled plate	Strength, resistant to shock, torsional deflection, and corossion free	Mild Steel	Stainless Steel, galvanized steel, and mild steel	Strong resistance to corrosion and cheaper
2.	Hot water reservoir (Tank)	Non corrosive, light weight and ability to hold hot water.	Tin sheet Ready made drum	Stainless Steel sheet	It is cheaper suitable, readily available and corrosion resistance
3.	Electric Motor	High efficient 20 Horsepower with medium range speed.	Continuous running electric motor; 20 hp with speed of 2000 rpm	Continuous running electric motor; 22 hp with speed of 2500 rpm	Most suitable
4.	Hot Water Pump	High efficiency, medium range speed with good and appreciable discharge rate.	Rotary pump with brass meshed gear.	Pump with stainless impeller.	It is suitable, cheap and resistance to corrosion
5.	Insulation	It must possess a very low thermal conductivity, light weight and durable.	Wood-saw dust.	Glass wool, Fibre glass and asbestos insulation wool.	It is suitable very cheap and readily available.

TABLE 4: The materials selected for the key component parts of the parboiling machine

S/n	Machine Component	Criteria for Selection	Material used for the Design	Suitable Material	Reasons for Selecting the Material
1.	Machine Frame	Strength, firmness, and rigidity	Angle Bar (Mild Steel)	H-Beam or U-Channel	It is suitable, cheaper and readily available.
2	Sprockets	strength and ability to avoid wobbling.	Mild Steel	Forged Steel	Most suitable and cheaper
3	Conveyor Belt	Strenght, corossion or contamination free material.	Rubber	Leather, cotton or fabric, balata	Most suitable and cheaper
4	Rollers	Strenght, smoothness and concentricity to avoid wobbling.	Mild Steel	Forged Steel	Most suitable and cheaper

TABLE 5: The materials selected for the key component parts of the conveyor

S/n	Machine Component	Criteria for Selection	Material used for the Design	Suitable Material	Reasons for Selecting the Material
1	Drying Drum	No contamination, strength	Galvanized steel	Stainless steel, Galvanized steel	Low cost, Availabil`ity, Durability
2	Drying chamber	Lightness	Mild steel	Stainless steel, Galvanized steel, Mild steel	Low cost, Availability
3	Heating box	Good conductivity	Aluminium	Steel, Aluminium, Teflon	Low cost, Availability
4	Insulator	Low thermal conductivity, stability at high temperature	Hardboard	Fiber glass, plywood, hardboard, sawdust, carton	Low cost, Availability
5	Heaters	Good electricity-heat conversion			Availability Suitability
6	Fan	Good air current, minimum power consumption			Average cost, no need for D.C – A.C conversion

TABLE 6: materials selected for the key component parts of the drying machine

S/n	Machine Component	Criteria for Selection	Material used for the Design	Suitable Material	Reasons for Selecting the Material
1	Hopper	The material must not contaminate the dried cubes of yam put into it.	Galvanized mild steel	Mild steel, aluminum stainless steel, Galvanized mild steel	Low cost, Availability Suitability
2	Grating Drum	Strenght, and ability to withstand the distributed vibration.	Mild steel sheet	Stainless steel sheet	It is cheaper suitable and readily available
3	Grating Disc	It must be strong enough to withstand shock without torsional deflection, shearing and bending. It must not contaminate the food substance	Mild Steel	Stainless Steel	It is cheaper suitable and readily available.
4	Delivery Chute	Contamination Free, strength	Galvanized mild steel	Mild steel, aluminum stain- less steel, galva- nized mild steel	Low cost, Availability Suitability

TABLE 7: Materials selected for the component parts of the grinding machine

S/n	Machine Component	Criteria for Selection	Material used for the Design	Suitable Material	Reasons for Selecting the Material
1	Sieve	Corrosion resistance, lightness, surface finish, cost	Wood	Wood, cast iron mild steel	Lightness corrosion resistance
2	Cam	Strength, machinability	Mild steel	Mild steel stainless steel	Strength cost
3	Delivery Chute	No contamination, strength	Galvanized mild steel	Mild steel, aluminum stainless steel, Galvanized mild steel	Low cost, Availability Suitability

TABLE 8: materials selected for the key component parts of the sieving machine

4. RESULTS AND DISCUSSION

To determine the time required for the grinding operation, let the grinding machine produce $10000mm^3$ of grounded poundo yam for every revolution of its auger shaft. Then it is necessary to

determine the number of revolution of the auger shaft that will produce the total volume of dried cubes of yam put into its hopper.

The total volume of the dried cubes put into the grinding machine is 0.154m^3 = 154000000mm^3.

Hence the auger requires $\left(\dfrac{154000000}{10000}\right)revolutions$ to completely grind the volume of dried cubes put into its hopper.

If the auger shaft of the grinding machine rotates at 342.86 *rpm* then the time required for the grinding operation (t_g) can be obtained as :

$$t_g = \left(\frac{154000000}{10000}\right)revolutions \div 342.86 rpm$$

t_g = 45 mins

Since the sieving operation and grinding operation are designed to operate simultaneously, then the total time required by the plant per batch is obtained as:

$T_{batch} = t_{ps} + t_p + t_g$ (38)

T_{batch} = 427.4 *mins* = 7.12 hrs = 7*hrs*

5. CONCLUSIONS

The critical role that mechanization of traditional food processing techniques plays in national development cannot be overemphasized in Nigeria, because high-post harvest food losses arise largely from limited food preservation capacity. In essence small scale food industries that involve lower capital investment and that rely on traditional food processing technologies are crucial to rural development in the country. By generating employment opportunity in the rural areas small scale food industries reduce rural-urban migration and the associated social problem. They are vital to reducing post harvest food losses and increasing food availability. hence a poundo yam process plant will serve as a means of reducing post harvest food loss of yam in the country.

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