Design and Development of an Integrated Palm Fruit Juice Machine

Abstract

A palm fruit juice extracting machine comprising an outer tub, inner tub, shaft, pulley, electric motor, belt, band heater, agitator and lagging material was developed and tested. The test conducted based on its performance showed that the juicer performed at a throughput capacity of 0.8kg/mins with an efficiency of 93.7% . The juicer was powered with 1HP electric motor. All the materials used in the fabrication of this machine were sourced locally and the estimated cost of producing one unit is fifty-five thousand, six hundred and fifty naira (₦55, 650.00). This concept design of an integrated palm fruit juice machine has significantly improved ease of extracting juice from palm fruits and drastically reduce intensive labour with improved hygiene. This machine is therefore highly recommended over the traditional method.

Comment [A1]: Abstract must contain introduction, importance and necessity and objective of the study, materials and methods, and results in brief. Avoid stating unimportant information here.

Keywords: palm fruit juice, integrated machine, throughput capacity, efficiency, hygiene

1. INTRODUCTION

Palm fruit grows on a unique species of oil palm tree (*Elaeis guineensis*) which grows near the equator. Each oil palm tree produces ample quantities of fresh fruit bunches throughout the year. The bunches can weigh up to 50 pounds each and have 1000 to 3000 fruitlets per bunch. Each fruitlet consists of a hard kernel surrounded by a fleshy mesocarp or pulp, enclosed in a shell endocarp. Oil palm (*Elaeisguineensis*) yields the highest oil per unit area compared to other oil bearing crops (Akinoso and Igbeka, 2011; Murshed *et al*, 2020). This palm bears its fruits in bunches which contain many individual fruits similar in size to a small plum. An individual palm fruit is made up of the pericarp (fibrous oil matrix pulp) and a central nut. The pulp (monocarp and exocarp) contains the palm oil while the nut consists of a shell (endocarp) and kernel which contains palm kernel oil (Kwasi, 2002; Sharmila *et al,* 2014).

Extraction of Palm fruit Juice from Palm fruit for the purpose of cooking soup or stew is traditionally done using man-power effort which consist of washing the palm fruits vigorously to remove all traces of dirt, boiling the nuts for 15-20 minutes on medium heat or until the nuts soften, after which the palm fruits will be transferred to mortar and pestle manually to de-husk the outer shell when the temperature of the moisture content is still high. The Palm fruit juice is extracted by using bare hands to squeeze together with a sieve to separate the Palm nut from the palm nut juice. This method is done manually in Nigeria (Ganiru, 2022; FAO, 2005). Efforts to mechanize and improve this traditional manual procedure have been undertaken by some research bodies, development agencies, and private sector Engineering companies, but these activities have been piecemeal and uncoordinated.

The high demand in banga soup and stew for consumptions in homes, cannot be met by this conventional method of extraction only, which is solely produced individually at homes, hotels and in occasions and at a slow pace. Meanwhile the process is purely unhygienic and always contains some levels of impurities in it. Asoiro and Udo (2013) designed and developed a motorized oil palm fruit rotary digester comprising of a feed hopper, hammers, axle, screening plate, v-belt, 2hp electric motor, digesting chamber and frame using standard and locally sourced materials. The machine is designed to extract Palm oil from Palm nut and the Palm nut juice. Adepoju *et al*. (2017) developed and did a performance evaluation of an oil palm fruit digester, the machine was tested for throughput capacity and efficiency. Average throughput capacity of 330.91 kg/h and efficiency of 62.35% were obtained. Rate of digestion increased with the increase in mass of the digesting palm fruits while the efficiency of the oil palm fruit digester decreased with increase in mass of the digesting palm fruit in some cases. The machine is simple to operate and maintain but it was developed to extract Palm oil from Palm fruit and not the Palm fruit juice.

Thus the need to develop a small scale palm fruit digester that will address the issue of extraction of Palm fruit juice from the Palm fruit for the purpose of cooking *banga* soup or stew. The design is conceptualized to reduce material handling in Palm fruit juice production for hygienic purposes and to reduce the issue of impurities, increase productivity and as well as save time and energy at homes and in commercial areas. Hence, this project is aimed at design, develop and performance test of a palm nut juice extractor.

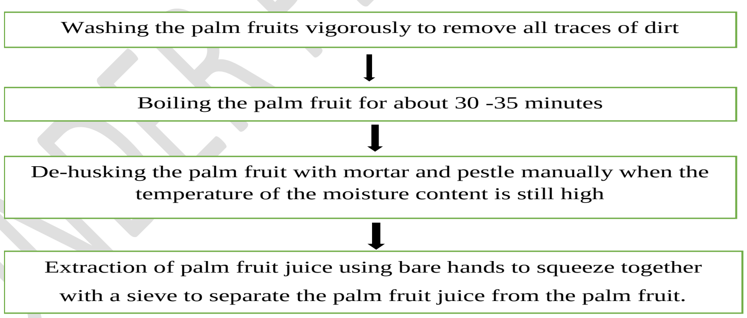

Fig. 1: Flow diagram of a conventional palm fruit juice production process.

2. MATERIALS AND METHODS

2.1. Description of the developed palm fruit juice extractor

The major components of the developed palm fruit digester for palm fruit juice extraction shown in Figure 2 are outer tub, inner tub, shaft, pulley, electric motor, belt, heater element and agitator. The Palm fruit digester works on the principle of centrifugal and centripetal force. The Palm fruit digester process is electrically controlled, such as the agitator, electric motor and the heating element. The inner tub was drilled with numerous holes to allow for passage of water in and out of the tub and also it creates grater on the wall of the inner tub.

The machine is loaded vertically with a well washed palm fruit, cold water is added into the machine, this then fills both drums up. The heating button is selected to boil the palm fruit using the heating element to the required temperature, the electric motor button is selected to cause the agitator to go in a rotational movement, mixing up the palm fruit, agitating them against the grating wall of the inner drum to help remove the exocarp and the endocarp of the palm fruit respectively. After this process, the drain button is used to drain out the palm fruit juice of the drums. Clean water is introduced again into the drums and the agitator rotates again to rinse the palm nut from any remaining palm fruit juice. This palm fruit juice goes out through the screen in the inner drum into the outer drum then to the orifice for collection.

2.2. Design analysis of the machine

2.2.1. Design considerations

The design, material selection and development of the palm fruit juice extractor was based on the following considerations:

1. The availability of materials locally to reduce cost of production and maintenance.
2. The criteria for selecting materials for the various components of this machine were based on the work they are expected to perform and the environmental condition in which they will function.
3. It is desired that there should be an optimal performance in the digestion of the palm fruit therefore, the motor and the pulley were carefully designed/selected to meet the required speeds for the rotation of the agitator.

2.2.2 Inner and outer tub design

The inner tub was designed to be cylindrical with volume capacity of 18.5litres.

The cylinder: Volume of the inner tub is expressed as *0.01858493*m^3 using equation (1); Therefore, the volume in liter is 18.5liters

$$V = \pi {r_1}^2 h \qquad (1)$$

While the volume of the outer tub is expressed *0.02474325m³* using equation (2)

$$V = \pi r_2{}^2 h \qquad (2)$$

Therefore, the volume in liter is approximately 25liters

Where $r_1 = inner\ radius = 0.13m, r_2 = outer\ radius = 0.15m\ and\ h = height\ of\ the\ tub = 0.35m$

2.2.3. Selection of material and heater element for the fabrication

Stainless steel (316 food-grade) was selected for the fabrication because it is a variety that is used more often in commercial food production as it has better corrosion resistance. This is because it contains more of the element nickel than its counterpart. The wrap band heater selected for the juicer was constructed of stainless steel. The lead wires are insulated with polymer materials. The materials used in the heater construction are rated to handle the maximum application temperatures to which they are being subjected. The heater also was designed to handle the application environment, which include high humidity or wash down maintenance conditions.

2.2.4. Selection of pulley, belt and determination of the speed

The machine requires two pulleys with one keyed on the electric motor shaft and one mounted on the agitator shaft and a belt connecting the two pulleys. Due to its availability, cost and performance, plastic pulleys were selected. The speed ratio of the driver to the driven pulley for the electric motor shaft and the agitator shaft is approximately 8:1. The rated speeds of the primary drivers (motor) is 1800rpm. The speed of the driven agitator shaft pulley was determined as 227rpm using the following relation in equation 3 (Kurmi and Gupta, 2005).

$$N_1 D_1 = N_2 D_2 \qquad (3)$$

Where N_1 is the drive pulley speed, rpm; N_2 is driven pulley speed, rpm; D_1 is diameter of drive pulley = 160mm while D_2 is diameter of driver pulley = 20mm. The centre distance, C between the two pulleys were determined as 110mm using Equation (4);

$$C = \frac{1.5D_2}{VR^{1/3}} \qquad (4)$$

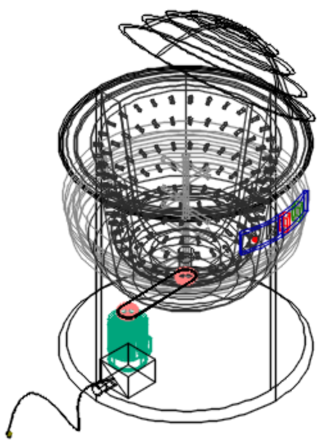

Fig.2: Wire Diagram of the Palm Fruit Digester

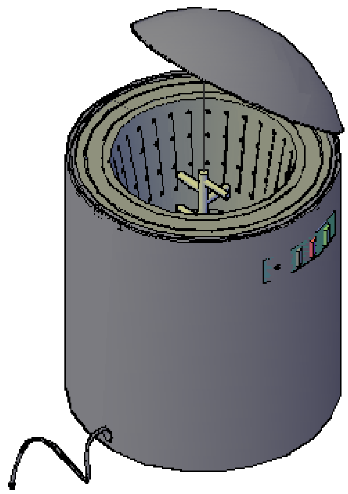

Fig.3: Block Diagram of the Palm Fruit Digester

Where VR is velocity ratio.

The length *L* of the belt required were calculated as 523mm from Equation (5)

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C}$$

(5)

The length derived from the equation was compared to what is available in the standard table, and the closest is 645mm, C = center distance between drive and driven pulley. Type "A" V-belt was selected, therefore, based on IS: 2494-1974, belts of standard pitch lengths of 645mm were selected for the motor shaft. Consequently, the exact centre distances between the two pulleys used in the fabrication of the machine were also determined using Equation (5) as 166mm.

Thus, the angle of lap, θ of the pulley were computed as 137.43 (2.39 rad.) using the following relationship

$$\theta = \left[arcsin\left(\frac{D_2 - D_1}{2C}\right)\right] \quad (6)$$

The belt speed for the drive were determined as 1.9m/s for the motor shaft using the following relation given as.

$$v = \frac{\pi N_2 D_2}{60} \quad (7)$$

2.2.5. Determination of belts tensions

The mass per unit length, of the selected belt were obtained from standard table as 0.375kg/m for the A-645mm belt [16, 17]. The tensions on the tight side, T_i of the belts for the drive is given as

$$T_i = T_{max} - T_c \quad (8)$$

where $T_{max} = \delta a$, $T_c = mv^2$

T_{max} = Maximum tension of the belts T_c = Centrifugal tension Thus, T_i was computed as 198.6N for the motor shaft. Consequently, the slack side belt tensions T_j were determined as 109.2N for the motor shaft using Equation 9 (Sharma and Aggarwal, 2006).

$$2.3 log \frac{T_i}{T_j} = \mu\theta cos\beta \quad (9)$$

Thus, the tensions in the slack and tight sides of the pulley are 109.2N and 198.6N respectively.

2.2.6. Selection of electric motor

The power, P required for driving the agitator shaft of this machine were determined as 0.3234Kw using Equation 10 (Cornish, 1991) given by

$$P = (T_i - T_j)v \quad (10)$$

Taking care of 10% possible power loss due to drives friction, the power required to drive the agitator shaft were computed as 0.3234kW (0.4337HP). Therefore, a standard 1HP electric motor were selected to drive the agitator shaft of this machine.

2.2.7 Torque T on the vertical shaft

The torque on the vertical shaft was determined as 144723.4625Nm using equation (11)

$$\frac{T}{j} = \frac{G\theta}{l} \quad (11)$$

Wherel = length of the shaft = *0.32m*

G = modulus of rigidity = $77.2\ X\ 10^9 N/m^2$

Θ = Angle of twist = 2.39rad

j = polar moment of inertia = *2.51 X 10^-7*

2.2.8 Torsional stress τ on the vertical shaft

Torsional stress on the vertical shaft was calculated as 11577877000N/m^2 using equation 12

$$\frac{\tau}{r} = \frac{T}{j} \qquad (12)$$

where r = 0.02m

2.3. Performance testing procedure

The palm fruit juice extractor capacity, C and efficiency were evaluated using ten (10) experimental runs. Each test involved operating the machine at a rotational design speed of 39rpm for five (5) minutes. The total weight of palm fruit digested during each test was recorded. The weight of well digested palm fruit, and the weight of partially digested were also recorded. Palm fruits with its pulp removed completely were taken to be well digested palm fruits while the partially digested are palm fruits that still have some amount of pulp remaining on it. The weights were measured with a weighing scale. Thereafter, the throughput capacity and efficiency of the machine respectively were computed in each case using the following relations:

$$\eta(\%) = \frac{N_g}{N_T} X \frac{100}{1} \qquad (11)$$

$$C = \frac{Total\ mass\ of\ palm\ fruit\ fed\ into\ the\ digester}{Time\ \ taken\ to\ complete\ operation} = \frac{P_f}{t} \qquad (12)$$

$where\ t = time\ of\ the\ opeation = 5minutes,$

$N_g = mass\ of\ \ well\ digested\ palm\ fruits$

$N_T = \ total\ mass\ of\ digested\ palm\ fruit$

$C = throughput\ capacity$

3. Results and Discussion

Comment [A2]: This section deals with all data analysis followed by different Tables and Figures to illustrate explicitly the results and their comparisons with others. So, this section needs to be rewritten again.

The result of the performance test of the developed palm fruit juice extractor is as contained in this section. The total mass of palm fruit juiced was 4kg. It was observed that mass of well digested palm fruit was 3.75kg while 0.25kg was partially digested. Thus, the efficiency of the machine was calculated using equation (11) and 93.75% was obtained. Thereby indicating a high efficiency for the developed machine. In addition, the machine throughput capacity (kg/min) was obtained by expressing the mass of both proper and improper processed palm fruit per unit time. From equation (12), a throughput capacity of 0.8kg/min was obtained the developed machine with test process time of 5mins per run at rotor speed of 227rpm. Lastly, the overall cost of production was put at fifty-five thousand, six hundred and fifty naira (N55, 650.00). Thus, making it affordable.

4. Conclusions

A moveable palm fruit juicer was designed, fabricated and tested at Abia State Polytechnic, Aba, Nigeria for palm fruit juice extraction. This machine which boil, digest and extract palm fruit juice. The test conducted on its performance showed that the juicer performed at a throughput capacity of 4000g in 5mins with an efficiency of 93.7%. This integrated system, reduced material handling in Palm fruit juice production for hygienic purposes, increases productivity and as well as save time and energy at homes and in commercial productions. Again, it is affordable due to its low cost of production because it was fabricated with locally sourced materials. The estimated cost of producing one unit of the juicer is fifty-five thousand, six hundred and fifty naira (N55, 650.00). It is therefore recommended for mass production by any manufacturer/investor for availability in the production of palm fruit juice for banga soup and *ofe akwu.*

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