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Implementation of Heat Exchanger Palm Fruit Cooker for Optimum Production of Palm Oil

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ABSTRACT: Palm oil as a product of palm fruit, is currently in high demand in Nigeria. The demand for the product is far higher than the supply. With this increase in demand, the price of the product is significantly in the increase. There is need to develop ways of efficiently producing the product from the available palm fruit. The heat exchanger palm fruit cooker designed has two chambers; the inner and outer chamber, the outer is for water content and the inner for the palm fruit to undergo the cooking process. The component has heat energy requirement of 46kJ with use of 45kg of fuel (firewood) to cook the palm fruit. It is made up of mild steel consisting of 6mm for the outer chamber and 2mm for the inner chamber for easy conduction of heat from the boiled water in the outer chamber. The study concludes by showing the economic benefits of constructing the cooker which produces more oil than the normal cooking pots in use.

KEYWORDS: Heat Exchanger, Palm Fruit cooker, Heat Energy, Firewood, Boiled Water.

I. INTRODUCTION

The oil palm (Carrere, R., 2010) is one of the most popular tree crops in Nigeria, West Africa and some part of Asia like Malaysia. Palm trees generally has lots of agricultural and economic important and application. The stem is used for building construction, furniture and firewood. Other parts are used for home cleaning apparatus as broom, cooking, etc.

The palm oil produced is extensively used for cooking which provides some ingredient to our food and it is inevitable in our day-to-day life concerning our foods for survival (Omoti, U., 2001). As a matter of fact, every part of the tree has economic value presently (Olatunbosun, D. et al 2014). It is reported that 338 billion pounds was generated from the cultivation of oil palm thus amounting to about twice the level of production of any other fruit crop, making oil palm by far the world's number one fruit crop. Report by (Ibitoye, S.J., 2014) has showed that the palm oil and palm kernel oil have a wide range of applications, about 80 percent of the palm oil produced finds its way into food products while the rest is feedstock for a number of non-food application (Ekpo, D. D. et al 2012). The by-products of oil palm fruit processing such as empty bunches and fibres can further be process as raw materials for potash fertilizer, fibre and pulps (Diji C. J. et al 2013).

Palm oil has been one of the major raw materials in our industries today (Olagunju, F.I., 2008). It is widely used for the production of soap, cream, deodorant and reagent for chemical industries. Presently, the demand for palm oil in Nigeria has been on the increase, especially with the closure of the border by the present administration, the demand has been on the increase, in which the demand is higher than the supply (Ekpo, D. D. 2012). As such there is need to improve on the process of its production to minimize wastage of the product. That is to say with the available palm fruit, higher quantity of palm oil could be derived from it than the normal way it used to be (Ekpo, D. D. 2019). Research showed it that the major point in which palm fruit losses palm oil is when it is being cooked directly with water. That is pouring the palm fruit into a pot of water and setting fire to heat the water for it to be fully cooked. On this process, the palm fruit losses a significant quantity of the oil to the water (Diji, C. J et al 2013). This is obvious as the water completely changes colour from the colourless substance to deep black and reddish colours in most cases.

The palm fruit cooker constructed is based on the water steam boiler technology which will reduce economic waste and improve the quantity /quality of output (Okpo, et al 2021). It will also reduce the percentage of oil loss while processing, and cut down on previous processing time while upgrading the safety standard for its users and people near-by (Nkan, et al 2023). The introduction of this machine will increase the level of palm oil production by reducing the rate of oil loss while processing. Figures 1 and 2 shows the palm fruits and the traditional method of heating the fruits.

Figure 1: Palm oil fruits

Figure 2: A woman preparing to make fire for traditional palm oil cooker

II. MATERIALS AND METHODOLOGY

The criteria for material selection for the various components of the machine was based on the type of heat that would be generating on them, the work they are expected to perform, the environmental condition in which they will function as well as their useful physical and mechanical properties (Ekpe, et al, 2024). The cost, toxicity of materials and their availability in the local market also influenced the choice of material. Basically, over 90% of the heat transfer components are made of mild steel plates of various thicknesses depending on their location on the machine and the heat they are expected to transfer. Steel was used because of its thermal properties which make it a perfect for fabricating the palm fruit cooker (Udoh, et al, 2024). For the steel plates used in this work, 2mm weighed 15.7kg/m2, 4mm weighed 31.4kg/m2 and the 6mm plate weighed 47.1kg/m2. This means that the plates exhibit different heat fluxes depending on their densities thus allowing flexibility in deployment on different parts of the cooker. Another factor in favour of steel is the heat transfer coefficient - the proportionality constant between the heat flux and the thermodynamic driving force for the flow of heat (i.e., the temperature difference, ΔT) which is 7.9 W/(m^2-K) for mild steel (for water it is 11.3 and in steam it's 1050). Though it also depends on whether the fluid is moving, if so, the velocity. The bottom of the inner chamber of the boiler is made of 6mm steel plate. This is to enable it withstand heat since it will be directly in contact with the flames from the combustion chamber. The wall of the inner chamber is made of 2mm steel plate so as to hasten the transfer of heat from the boiling water to the fruits inside. The outer casing of the boiler is fabricated with a 4mm steel plate to reduce heat loss outward and enhance rigidity.

III. HEAT TRANSFER MECHANISMS

The heat transfer mechanism occurred into process; the conduction and convection processes

Conduction occurs within solids on a molecular scale without any motion of solid matter relative to one another. The basic equation for conductive heat transfer is given by Fourier's law. The negative sign in the equation indicates that the heat flows from the higher temperature side to the lower temperature side.

$$\dot{Q} = -k\left(\frac{dT}{dx}\right) \quad 1$$

where, dT = temperature difference across a thickness of dx, Q = rate of heat transfer across material thickness of dx, k = thermal conductivity of material. So, for a material of thickness Δx with different temperatures T1 and T2 at its two faces, are as shown

$$\dot{Q} = -k\,\frac{(T_2 - T_1)}{\Delta x} \quad 2$$

For the Convection process which is defined as the transfer of heat by motion of or within a fluid. It may arise from temperature differences either within the fluid or between the fluid and its boundary, or from the application of an external motive force.

$$N_u = \frac{h_c L}{k} \quad 3$$

Here, L = length of solid surface

hc = convective heat transfer coefficient

k = thermal conductivity of fluid

The palm oil steam boiler was built in a circular shaped tank; the standard formula for volume was applicable. Thus, for the circular shaped palm fruit cooker, the capacity is determined by the expression below; Capacity [C] = 2πd2 h, where'd' = diameter, & 'h' = height and the perimeter of a circle, [p] = 2πr, where 'r' = radius. This expression was used in the construction of the cylindrical tank. Here, heat is transferred from the combustion chamber to the 6mm bottom plate of the outer chamber by conduction which heats up the water inside it. Once the water gains heat, it transfers the heat to the inner chamber through conduction and convection. Heat is transferred through to the 2mm inner chamber through conduction, and then, convection when the water boils which provides steam from the heated water which moves into the inner chamber through the perforation at the upper sides of the inner chamber. It obeys the first law of thermodynamics by transferring heat which is used to cook the palm fruits and losses some percentage of heat to the environment through the outer chamber illustrating the second law of thermodynamics.

IV. RESULTS AND DISCUSSION

The progression of events during operation can be mathematically expressed as follows: The volume of the chambers (both outer and inner) can be given by: pi x radius^2 x height. Thus, the outer chamber measures 610 x 610mm Hence; 3.142 (pi) x 610mm x610mm = 1169138.2mm,1169m^3+102,155m^3 = 1271m^3. For the inner chamber. The computation was done in two parts, first the topmost part was divided from the bottom part at the point of first inclination. Using the formula $\pi x r^2$ the volume for this part is 715m^3. For the bottom part, the formula $v=1/3\pi r^2 h$ was used to derive the volume as 85m^3. Then total volume of the inner chamber = 800m^3. This chamber holds about 800kg of fruits, while the space between the two chambers holds about 110 liters of water. The heat energy required to change the temperature of water (the water has to boil in order to transfer heat to the inner chamber through conduction) is gotten by the formula.

Energy=specific heat capacity of water x mass of water x changes in temperature

Thus, energy = 4.184K^{-1}g^{-1} x 110000g x 99 = 46024J = 46kJ

About 45kg of fuel (firewood) was needed to achieve this level of energy, time required for the water to boil was 90 minutes and another 60 minutes was required to cook the fruits properly. Thus, total time required for a full cycle of operation is 150 minutes. If we consider that the boiler during operation will have a higher temperature than its surrounding, we find out that there will be a transfer of heat from the system to the surrounding.

This heat transfer is given by the formula:

Where L = length, K = thermal conductivity, r1 = inside radius, r0 = outside radius, (T2 – T1) = change in temperature.

$$Q = \frac{2\pi KL(T_2 - T_1)}{In(r_o/r_1)}$$

$$Q = \frac{2 \times 3.142 \times 43 \times 0.609 \times 95}{In\left(\frac{0.305}{0.241}\right)}$$

$$Q = \frac{15633.12}{0.235}$$

$$Q = 66{,}382.59J = 66KJ$$

Hence, energy lost to the surrounding (away from the boiler) = 66kJ

Transfer of energy (heat) by conduction (when the combustion heats up the bottom of the outer casing which has direct contact with the fire) is given by:

Q = kA (T hot – T cold) t / d 4

Where k is the thermal conductivity of the material, A = cross sectional area, T hot = the higher temperature, T cold = the lower temperature, t = time taken and d = thickness of the material.

Thus, Q = 43 x 12-3 x (87) x 150 / 6mm = 1122300J

So, energy conducted by the bottom of the outer casing to the water = 112.2kJ

Heat transfer by convection (when the water in-between the two chambers boil to produce steam which enters the inner chamber through the perforations at the top to quicken the boiling of the fruits) is given by the formula = HcA (T hot – T cold). Where Hc = the heat transfer coefficient, A = area, (Thot - Tcold) =change in temperature Hence, Q = 4020 x 0.2 x 99 =79,596J Thus the heat conducted by steam into the inner chamber = 79kJ. The design specification of the boiler is shown in figure 3, while figure 4 shows the sections of the boiler.

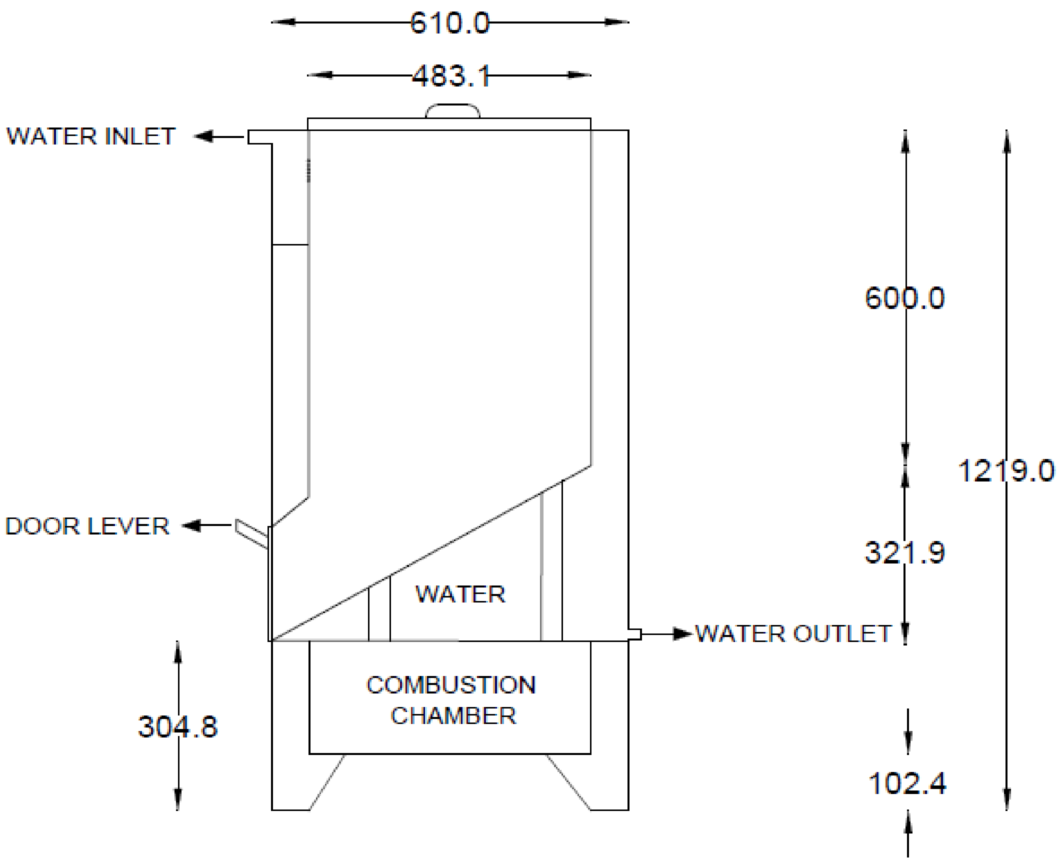

Figure 3: Design Specifications of the cooker

Figure 4: Pictorial view of the cooker and some sections

V. DISCUSSION

The palm fruit steam cooker consists of an internal and external chamber, The internal chamber sits in the external casing which is the main housing and which has a lid, chimney, combustion chamber, water inlets and outlets. Water is filled in the space between the two chambers through the water inlets. Fuel is added in the combustion chamber. The fuel could be charcoal, firewood or palm fruit chaff. Here, the palm fruit chaff is recommended as it is easily and cheaply acquired and burns readily for longer periods. One bunch of palm fruit weighs an average of 23-27kg and typically yields 1 liter of oil after being cooked using the old method of open pot boiling, but using the steam boiler, it produced 1.5 liters (an extra 0.5 liters). Table 1 below, further explains the amount of oil retrieved per bunch cooked.

Table 1 - Showing amount of fruits cooked using the steam boiler versus the old method and yield in liters.

No. of bunches	New method Yield (liter)	Old method yield (liter)
1	1.5	1
5	7.5	5
10	15	10
15	22.5	15
20	30	20

Though the technology of palm oil production has advanced in recent years with new technological innovation to produce palm oil and palm kernel oil of superior quality, survey

VI. CONCLUSION

On test-running and in subsequent operations, the boiler worked as predicted. The combustion chamber was particularly impressive as it allows easy flow of air through it and the compacting effect the chamber pulls on the fuel made the combustion almost effortless. Boiling 1500 kilograms of fruits took about a 30 to 45 minutes and there was no stress from smoke and other effects as compared to the older traditional method of boiling. It should be noted that less manpower is needed to operate this machine and even less skill is required from the few needed staff.

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