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Development of a Dual-Energy Steam Boiler for Small-Scale Sterilization of Palm Fruit

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ABSTRACT

A dual-energy source steam boiler suitable for sterilization of palm fruit by small scale processors was developed. The machine was evaluated on electricity or biomass such as charcoal and firewood. Palm fruits were sterilized at 100ºC at various sterilization periods of 30, 45, 60, 75, 90, 105 and 120 minutes and at 60, 75 and 90ºC for 75, 90, 105 and 120 minutes respectively. The rate of digestion through liquid recovery was determined. Some physicochemical properties of the oil extracted using steamed palm fruit and fruit boiled in water were determined. Sterilization period at 100ºC was 60 min with charcoal, 75 min with firewood and electricity respectively. The average liquid recovery for the sterilization periods at 100ºC were 13.7, 16.9, 28.4, 29.5, 28.7, 29.7 and 30.0%, and the maximum after 120 mins sterilization at 60, 75 and 90ºC were 18.4, 20.8 and 28.1% respectively. The moisture content, the peroxide value and the free fatty acid contents were 0.1%, 8.0 O_2/kg, 3.2%; and 2.3%, 10.0 O_2/kg, 3.6% for the steamed and water-cooked fruits respectively. An improvement in the quality of oil produced from steamed fruits compared to fruits boiled in water was observed. The machine had a 98.9% boiling efficiency. The heating efficiency of cooking with biomass was 56.0% more than cooking with a pot of the same diameter. However, the cost of operating the machine with electricity was ₦4,320 ($28.8) for 8h/day/25days/month working time as against ₦9,600 ($60) and ₦15,250 ($101.6) respectively for firewood and charcoal for the same period. The cost of production of the boiler was ₦51,930 ($346.2).

Keywords: *Sterilization, boiler, quality, palm fruit, dual-energy*

1. INTRODUCTION

Palm oil in Nigeria is still produced majorly by traditional methods in small and medium scale through different extraction methods that vary from one locality to another (Ituen and Modo, 2000). There has been considerable advancement in palm oil extraction technology in the last few years especially in Asian countries such as Malaysia and Indonesia. Nigeria is yet to accelerate its pace of improvement and this explains why Nigeria has lost its premier position on the list of world major palm oil producers for the past two decades, Owolarafe *et al.*, 2007. The local demand for palm oil is substantial. It is estimated that for every five people in Nigeria, perhaps two litres of palm oil or more are consumed each month for cooking. However, it is on record that Nigeria presently import palm oil to supplement the domestic production which is estimated at about 800,000 tonnes per annum (MPOB, 2002; NEODA, 2007).

Lack of appropriate processing technologies constitutes the major obstacle to palm oil production in Nigeria, Owolarafe *et al.*, 2002. Nigeria has lagged behind not only in oil palm production but also in research into all aspects of oil palm production. A recent survey by a non-governmental organisation (The New Nigeria Foundation) shows that palm oil from the small and medium scale processors is non-competitive in the World market in terms of quantity and quality (Faborode, 2003). Apart from the poor quality, the production cost is high due to the labour intensive technologies being used. Optimisation of the processing technologies and/or machines will go a long way in improving palm oil extraction efficiency.

The FAO, 2002 established that sterilization (cooking) is one of the most important operations in palm oil processing. Conventional sterilization of Fresh Fruit Bunches (FFB) in the palm oil industry is a steam treatment process. It is carried out in cylindrical steel pressure vessels called sterilizers. The FFB is heated to a temperature of about 130 ºC under a pressure of 2.48 – 2.96 bar. The sterilization cycle lasts about 75 – 90 minutes. The focus of the sterilization process are – to inactivate the naturally occurring enzymes in the fruits which split the oil to form Free-Fatty Acid (FFA) and – preconditioning of the FFB for the next unit operation, (Tan, 2002). There are two conventional types of steam boiler namely: fire-tube boiler, in which water surrounds the steel tubes through which hot gases from the furnace flow. The second type is the water-tube boiler in which the water is usually inside tubes, with the hot furnace gases circulating outside the tubes. The objective of this work is to develop a steam boiler for medium scale oil palm processing.

2. DESIGN CONCEPTION OF THE MACHINE:

The concept of the machine is the combination of steam boiler principles and the traditional method of cooking palm fruits into a compact unit. Steam boilers are units in which steam is generated from boiling water; the source of energy could be biomass, oil or gas or geothermal. The traditional method of cooking palm oil is by pouring the palm fruits into a drum containing water and then boil. The machine combines these two principles in its operation. The steam generated by boiling water in a chamber, moves into another chamber where the palm fruits are cooked.

2.1 Functional Parts of Machine

The machine was a cylindrical unit similar in shape and size to drums used by local processors for cooking palm fruits. The parts as shown in Plate 1 show the upper (steam and water) chamber, the combustion chambers and the electrical part. The boiler was constructed with a mild steel of 0.9 mm thickness.

Plate 1 The dual-energy source steam boiler using firewood as a source of energy

Upper Chamber: The upper chamber comprises the water and steam chambers, consisting of an inner cylindrical barrel of 460 mm by 700 mm, and an outer (coating) chamber of 480 mm; giving a 20 mm allowance which was lagged with fibreglass to prevent heat loss.

Steam Chamber: The upper chamber is demarcated into two by a 20 mm wide strip of steel ring welded at 100 mm and 300 mm height of opposite ends of the cylinders from the base respectively; giving a slanting height and angle of 200 mm and 23.5^{o} respectively. The upper part is the steam chamber with 166.2 L capacity; where the palm fruits are held for steaming.

Upper Chamber Demarcation Plate: A steel plate of approximately 460 mm was cut to fit into the slanted demarcation ring to separate the water and steam chambers. The plate forms the base for holding the palm fruits for steaming. The plate is completely perforated for steam passage, and a perforated pipe welded in the middle for easy removal. The end tip of the plate terminates at the base of the discharge chute, so that material steamed flows by gravity when the discharge slide is opened.

Water Chamber: The base of the upper chamber is covered with a 460 mm steel plate on which six (6) pipes of 60 mm by 300 mm are welded and opening bored on the plate to open into the pipes. Hence, the water chamber consists of the inner barrel of the upper chamber at 100 mm height from the base and the water pipes. The total volume space for the water is 21.7 L.

Combustion Chamber: The combustion chamber is a cylindrical steel plate of 460 mm by 540 mm, covered at the base. Both the side and base are perforated for aeration and ash discharge respectively. The outer part of the water pipes projects into the combustion chamber and forms part of it. An opening of 140 mm by 300 mm was cut by the side of the combustion chamber and terminates at the base for feeding in of firewood. It is provided with a gate, hinged by the side and opened like a door. An 80 mm by 80 mm chute is provided at the top opposite side of the gate for feeding of charcoal, briquettes or any other biomass of small particle size.

Water Tubes: The water tubes, otherwise referred to as water pipes are the six 60 mm by 300 mm steel pipes (Plate 2) that form part of the water chamber in the (hollow) inside and part of the combustion chamber on the outside. It serves a dual purpose of increasing the volume capacity of the water chamber and increasing the heating surface area of the boiler in contact with fire.

Plate 2. The water pipes

Feed and Discharge Pipes: A 20 mm elbow pipe was fixed into the upper chamber at the lower end of the steam chamber for feeding in of water. The (6) water pipes were connected together at the base with 15 mm pipes. A 20 mm pipe was connected to one of the water pipes and extended outside with (2) elbow joints at the bend and tip. The elbow tip that projected out of the machine is fixed with a stop cork. This system was incorporated to provide flow of water within the pipes and the stop cork can be opened so that the system can be flushed after sometime to remove dirt.

Discharge Chute: A 100 mm by 80 mm opening with a slide gate cover was provided to correspond with the down tip of the upper chamber demarcation for the discharge of the palm fruit by gravity after steaming.

End Covers: The boiler was covered at the top with a 480 mm steel plate which is ringed for gripping and adequate covering. The cover is attached to the machine by a hinge for ease of opening. The base of the boiler is covered with a 460 mm steel plate, perforated for easy ash removal and disposal.

Support Components: The boiler was elevated from the ground by 60 mm with three (3) stud 20 mm × 20 mm squared pipes forming a tripod. Two (2) handles formed by folding a metal sheet into a 30 mm wide plate are welded by the sides of the machine for carrying.

Electrical Components: The electrical component comprises of heating elements, voltage regulator, contactor, thermocouple, indicator light, switch, and connecting wires. Three (3) heating elements of 1800 W capacity each were inserted into the water pipes and the tips (the conducting part) extended up and projected out from holes bored at the upper end of the water chamber and connected together to the electric circuit. A circuit box was formed from the 0.9 mm thick sheet into a 300 mm × 160 mm × 160 mm box. Grooves were made on the box surface with the dimensions of the electrical components coming into them. The voltage regulator, electrical contactor, indicator light, and the switch were fixed into the grooves and connected together. The voltage regulator, contactor and thermocouple were incorporated into the boiler in order to regulate the temperature to test the machine performance at temperatures below 100 ºC.

2.2 Thermal Efficiency of the Boiler

According to (Ballaney, 2005) boiler efficiency can be expressed as:

$$\eta_b = \frac{\text{Quantity of Heat Utilized}}{\text{Total Heat Supplied}} \times 100$$

$$= \frac{\text{Heat Supplied - Losses}}{\text{Total Heat Supplied}} \times 100$$

The contact surface area of the heating surface for biomass increases the heating efficiency by:

Surface Area of a circular cylinder, $A_{cs} = 2\pi r\,(h + r)$ …………. (3)

Where h = height and r = radius of the water tubes

For the six (6) water tubes, $A_{cs} = 2 \times 3.142 \times 0.06\,(0.3 + 0.06) = 0.8144\ m^2$

Area of the water tank base, $A_{wt} = \pi r^2 = 3.142 \times 0.46^2 = 1.4453\ m^2$

Increase in surface heating efficiency $= [A_{cs}/ A_{wt}] = [0.8144 / 1.4453] \times 100 \approx 56\%$

2.3 Machine test

The machine fabricated at the Department of Agricultural and Environmental Engineering, University of Ibadan was tested using electricity, firewood and charcoal. Palm fruits were purchased at the open market; from Ojoo market in Ibadan. Known weighed quantity of palm fruits were cooked at 100 ºC over varying period of time: 30, 45, 60, 75, 90, 105 and 120 mins, and also at temperatures; 60, 75, and 90 ºC for 75, 90, 105 and 120 min. respectively. The palm fruits were pounded, washed with warm water and reweighed to determine the rate of digestion. The experiment was repeated three times and average values taken.

2.4 Oil Extraction from Fruits Sterilized in Water and Steam

Two portions of 1.0 kg of the fresh palm fruits each were weighed and cooked in water and steamed at 100 ºC for 90 mins respectively. The samples were reweighed after boiling before pouring into a mortar and pounded until digestion (rupturing) was completed. The palm oil was extracted by hand pressing into a pre-weighed empty container and then weighed to obtain the extracted oil weight. The samples of extracted oil were analysed to determine the moisture content, the peroxide value and the FFA content using standard methods.

2.5 Costing

The monthly cost of using electricity, charcoal and firewood as fuel source was estimated using the current unit price in Nigeria of ₦4/kW-h for electricity, ₦12/kg and ₦28.6/kg for firewood and charcoal respectively.

3. RESULT AND DISCUSSION

3.1 Time taken by the energy sources to heat the water to 100 ºC

An average of 15, 20, and 35 min was observed to boil the water with firewood, charcoal and electricity respectively. This was as a result of the time taken to ignite the biomass materials completely. It was observed that the firewood ignited and burnt faster with visible flame than charcoal which takes time to ignite and reach its glow point. The water reaches 100 ºC with biomass faster than with electricity, because heat generated by the biomass was higher than that by the 5400 W electric power.

3.2 Sterilization time on using Charcoal for Steaming

From Fig 1, the fluid recovery increases steadily as sterilization time increases up to 60 minutes, beyond which increase was almost constant till it reaches 120 minutes. The fluid recovery at 100 ºC steaming temperature with charcoal was 29.1% at 60 min. sterilization time with a maximum of 30.2% at 120 min. sterilization time. Sterilization time of 60 min. was adequate when using charcoal to conserve energy; since there was no appreciable difference from 60 and 120 minutes sterilization. (Owolarafe and Faborode, 2008) observed that melting of oil globule commenced at sterilisation time as low as 30 min and then suggested the adoption of 60 min. sterilization time for small scale sterilization operation to conserve energy and preserve the quality of product.

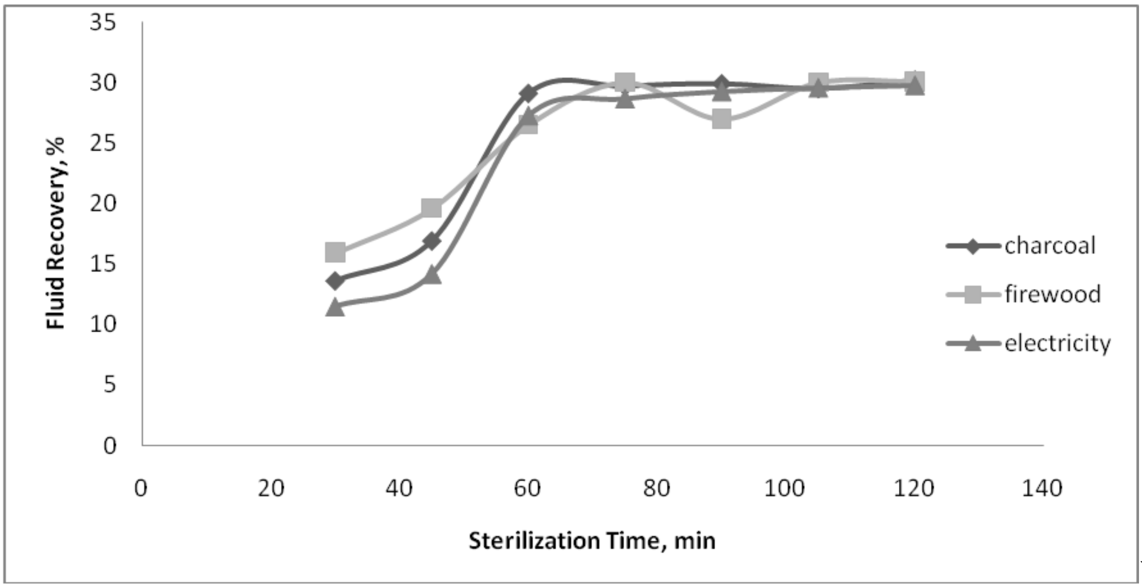

Fig 1. Fluid recovery at 100 °C Steaming

However, the fluid recovery time for firewood was 30.0 % at 75 min sterilization time with a maximum of 30.1 % at 120 min of sterilization.0.1%; and electricity was 28.7 % at 75 min sterilization time and maximum 29.8 % at 120 min sterilization. 1.1%.

Beyond 75 min sterilization with firewood or electricity, it is a waste of energy as the fluid recovery at 120 min is minimal. This corresponds with the lower limit of 75 – 90 min range recommended by Tan, 2002 for the heating of FFB at a temperature of about 130 °C at a pressure of 2.48 – 2.96 bar. Babatunde, *et al.* (1988) recommended steam sterilization temperatures of 100 °C and 130 °C at over 2·5 atmosphere of saturated steam pressure for sterilization time varying from 15 to 120 min.

3.3 Comparison of the Energy Sources

Fluid recovery at 100 °C steaming with firewood, charcoal and electricity became linear around 30% line at 60 – 75 min sterilization time. To maintain 100 °C sterilization temperature for 3 hours, it was observed that 12 kg and 8 kg of firewood and charcoal respectively were required to heat the system. From the calorific values, the power produced by the charcoal and firewood were 19.0 kW and 11.1 kW as against electricity of 5.4 kW, hence the 60 min and 75 min sterilization periods. The boiler achieved the 60 min sterilization period proposed by (Owolarafe and Faborode, 2008) and improved on the 75 – 90 min (at a temperature of about 130 °C at a pressure of 2.48 – 2.96 bar) recommended by Tan, 2002. It also met the temperatures of 100 °C and 130 °C at over 2·5 atmosphere of saturated steam pressure for sterilization time (varying from 15 to 120 min) recommended by Babatunde, *et al.* (1988).

The cost of electricity in Nigeria was ₦800 at ₦4/kW-h for 8 h/day and 25 days/month. Similarly, the cost of firewood and charcoal were ₦9,600 and ₦15,444 at ₦12/kg and ₦28.6/kg for the same period. It required 4 kg and 2.7 kg of firewood and charcoal respectively to heat the system for an hour. In terms of cost, it is cheaper to use electricity than charcoal and firewood. The time gained in using firewood and charcoal will be compensated for in terms of cost. However, in rural areas where this will be used, the cost of firewood will be negligible due to the fact that firewood is usually harvested directly from the farm. So in all, it will still be cost effective for the rural dwellers where there was no regular supply of electricity.

3.4 Sterilization Method and Oil Quality

Table 1 Some physicochemical properties of Palm Oil

Sample	Moisture Content (%)	Peroxide Value (O_2/kg)	FFA Content (%)
Cooked in water	8.5	14.0	8.0
Cooked with steam	5.0	10.0	6.8
Cooked in water for 90mins	2.3	10.0	3.6
Cooked with steam for 90mins	0.1	8.0	3.2

Table 1 showed the moisture content, peroxide value and the free fatty acid values of oil extracted from fruits cooked in water and steam respectively. The moisture contents of the fresh and boiled oil for cooked fruits were 8.5 and 2.3 % and for steamed fruits, 5.0 and 0.1 % respectively. This showed that moisture content of oil from fruits cooked in water was higher than that cooked in steam. The 0.1 % moisture of the oil from steamed fruit; and cooked after extraction was lower than 0.15 % given by *Gibon et al, 2007* as the moisture level at which both hydrolysis and oxidation are slowed.

The peroxide value of the fresh and boiled oil for cooked fruits were 14.0 and 10.0 (O_2/kg) and that for steamed fruits were 10.0 and 8.0 (O_2/kg) respectively. Indicating that the peroxide value of oil from fruits cooked in water was higher than that cooked in steam. The 8.0 (O_2/kg) for the oil cooked after extraction from the steamed fruits was within the limit of values of fresh oils to be less than 10 milliequivalents/kg (Wikipedia, June, 2004).

The free fatty acids of the fresh and boiled oil for cooked fruits were 8.0 and 6.8 % and that for steamed fruits were 3.6 against 3.2 % respectively. Both values for the steam oil were lower than 5 % given by (Ituen and Modo, 2000) as FFA standard by importing countries for oil quality, with financial penalties for exceeding this percentage. However, the boiled oil from the steamed fruits has the lowest FFA content of 3.2 %. This was within the range stated by *Gibon et al, 2007* which gave 3.5 % as the average value for FFA of commercial crude palm oil and FFA below 3.0 % as an indicator that the oil was produced from fresh un-ruptured palm fruits. These high values for the PV and FFA for fruits cooked in water may be related to the high moisture content as fatty acids are produced by the hydrolysis of the ester linkages in fat or biological oil, and the peroxide value of an oil or fat is used as a measurement of the extent to which rancidity reactions have occurred during storage.

The machine has a 98.9% boiling efficiency. The heating efficiency of cooking with biomass was 56.0% more than cooking with a pot of the same diameter. The total cost of construction was ₦ 51,930.

4. CONCLUSION

A dual energy source (electricity and biomass) steam boiler for sterilization of palm fruits was developed and evaluated using firewood; charcoal and electricity. It took 15, 20 and 35 mins for water to boil and 60, 70 and 75 mins of sterilization period to cook the fruits using firewood, charcoal and electricity respectively. The machine has a 98.9% boiling efficiency. The heating efficiency of cooking with biomass was 56.0% more than cooking with a pot of the same diameter using electricity. The total cost of construction was ₦ 51,930.

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