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CHAPTER 2

DESIGN, FABRICATION AND AUTOMATION OF A PALM OIL MILLING MACHINE FOR SUSTAINABLE PALM OIL PRODUCTION

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Introduction

Palm oil is an edible vegetable oil derived from the reddish pulp of palm fruits. It is naturally reddish in colour because of its high beta-carotene content (Reeves *et al.*, 1979). Palm oil is one of the few highly saturated vegetable fats and is semisolid at room temperature. It is a common cooking ingredient in the tropical belt of Africa, Southeast Asia and parts of Brazil. It has a widespread use in commercial food industries because of its affordability and saturation of the refined product when used for frying. A large proportion of the oil is also consumed in the manufacture of soaps including native black soap, candles and lubricants. The folklore nutritional and healing properties of palm oil have been recognized for generations.

Red palm oil has been the remedy of choice for nearly every illness in many parts of Africa. Palm oil milling is the process of obtaining edible palm oil from ripe palm fruits. The milling process involves the reception of fresh fruit bunches from plantations, threshing of bunches to free palm fruits, sterilization of the threshed palm fruits, digestion and edible oil extraction from the crude palm oil. The extracted oil is further purified and dried for storage and export.

The two major methods employed during the milling of palm fruits into palm oil are the manual/traditional method and the mechanized/ modern method. While the former is employed by peasant women and small processors using mortars in Nigeria and most other West African countries, the latter is employed in the cities and involves the use of machines in carrying out some units operations involved in the palm oil milling process. Though the mechanized method is a great improvement on the traditional method, it still has some shortfalls as evident in the great amount of manpower required for operation. Hence the initiation of automation in the palm oil milling process.

A. Traditional Palm Oil Processing at Oritamerin, Arulogun-road, Ojoo, Ibadan, Nigeria

The milling process is a true reflection of the traditional method of palm oil processing as illustrated in Figs. 1(a) - d). Peasant women harvest palm fruit bunches which they cut into sections and keep in heaps for days to ferment. A day is often scheduled for the actual processing and this date is communicated to everyone expected to be involved.

On the scheduled day, the real processing begins very early in the morning. The peasant women with their children start off by washing the fermented fruits to remove dirt. Another group of women prepare the firewood while the fruits are being washed. The washed fruits are then boiled in large pots with clean water until they are very soft for pounding. The male children help their mothers in the pounding process which is done in large wooden mortars with wooden pestles until a mixture of nuts and crushed pulp is obtained. The hot pounded mixture of crushed pulp and nuts are pressed using warm water to separate the fibre, pulp and nuts from the oil/water mixture after which local sieves are used to filter out the fibre and nuts. The crude oil obtained is re-boiled until the oil flows to the top with water and other impurities remaining at the base of the pot. The oil/water mixture is then left to cool and the palm oil is skimmed from the top with small bowls for drying. The dry oil is poured into kegs of various litre sizes ready for consumption and sale.

(a)

(b)

(d)

(c)

(d)

Fig 1: (a) Loosening (b) Boiling (c) Pounding (d) Pressing processes

B. Tertiary Education Union (TEU) Palm Oil Prototype

A par-boiler or steamer steams palm fruits until the outer layer (exocarp) is weakened. Steam escapes through a perforated pipe included in the design of the steamer. A digester or crusher then pounds steamed nuts into mash. Beating action through centrifugal force propels mashed product into a chute to be collected in a reservoir. Steam is introduced and oil is squeezed out through the perforated holes. The product will contain some amount of water and impurities. The difference in the specific gravities of water and oil separates the mixture with the lighter oil floating at the top. The lighter oil sips into an inner funnel placed at its level for collection through a spout. The residual water in the clarified oil is removed via evaporation in a dryer and clean oil is collected as the final product.

Methodology

The design involves three major sections: a steaming section comprising a steamer, a de-hulling section comprising a de-huller and a boiling section comprising a boiler. Cone shape was chosen in the design of the steamer and boiler to allow their respective contents flow easily by gravity into the next section. A process schematic which specifies material flow paths and transformations in the design is shown in Fig. 2.

The fabrication of the design of the three basic sections in the prototype was achieved via welding, cutting, forming and machining of the various materials involved with mechanical tools. The fabrication was carried out at the mechanical workshop in the University of Ibadan, Ibadan. Some of the materials involved in the design fabrication are mild steel sheet, galvanized steel sheet, angle iron, pillow bearings, pulleys, thread pipes, fibre glass, stainless rod, flat bar, bolts, nuts, metallic clips and mild steel welding electrodes. Some of the mechanical tools engaged are welding machine, shear/cutting machine, drilling machine, rolling disc and grinding machine.

The fabricated design was automated through control algorithms on a Peripheral Interface Controller (PIC). PIC was chosen because of its availability, moderate instruction set, fast processing speed and the memory capacity of its RAM. Embedded C language was used to write the codes because of its flexibility. Some of the electrical components involved in the automation include PIC microcontroller, solenoid valves, relay switches, electric motor, thermocouple, step down transformer, bridge diodes, resistors, regulators, core flexible cables, Vero board, Liquid Crystal Display (LCD), keypad and soldering lead. The algorithms involved in automating the fabricated design are illustrated by the flow diagram in Fig. 3 and the circuit diagram is shown in Fig. 4.

The control principles for each of the three major sections of the fabricated design are illustrated by the process control loop in Fig 5.

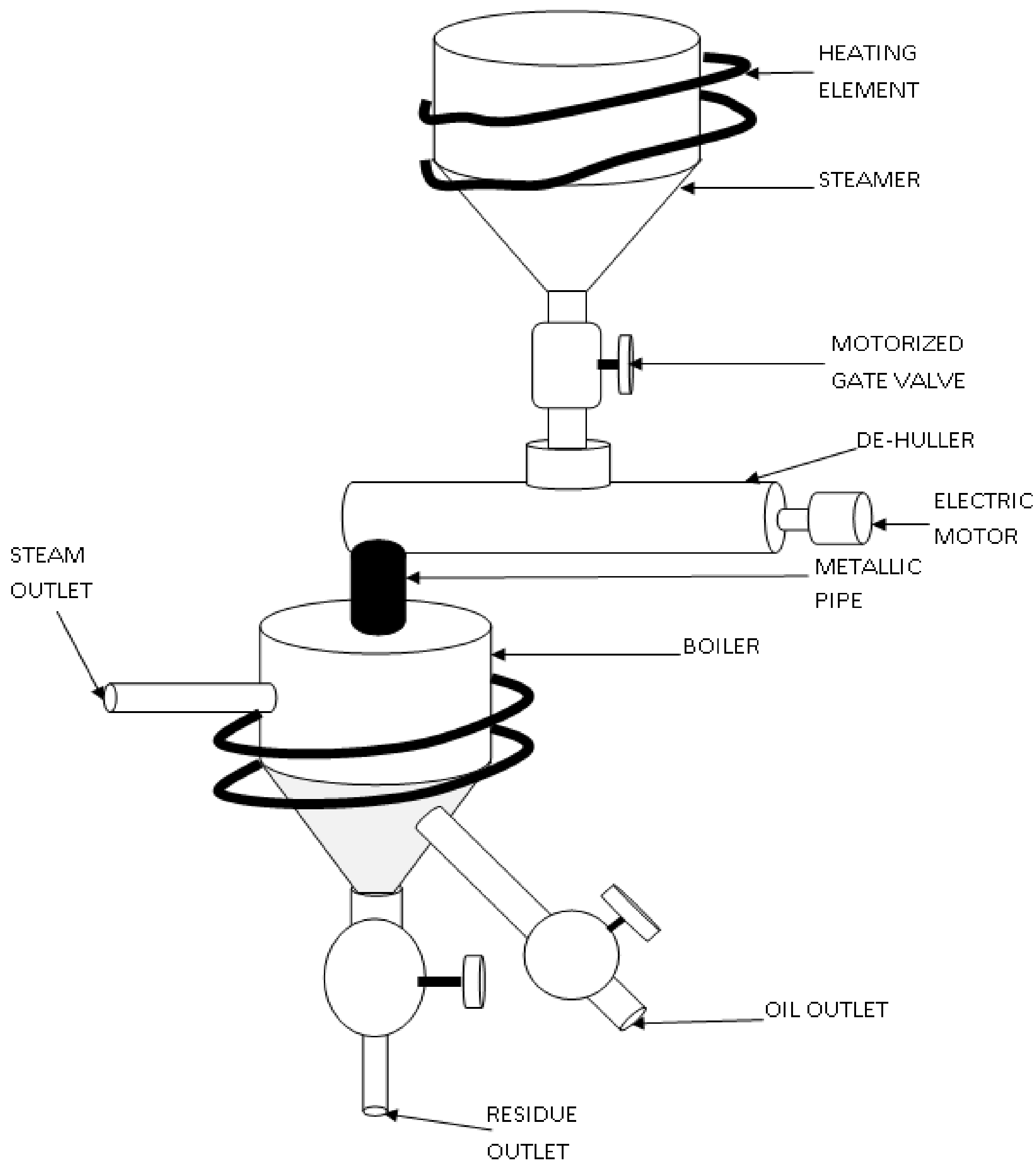

Fig. 2 Process Schematic

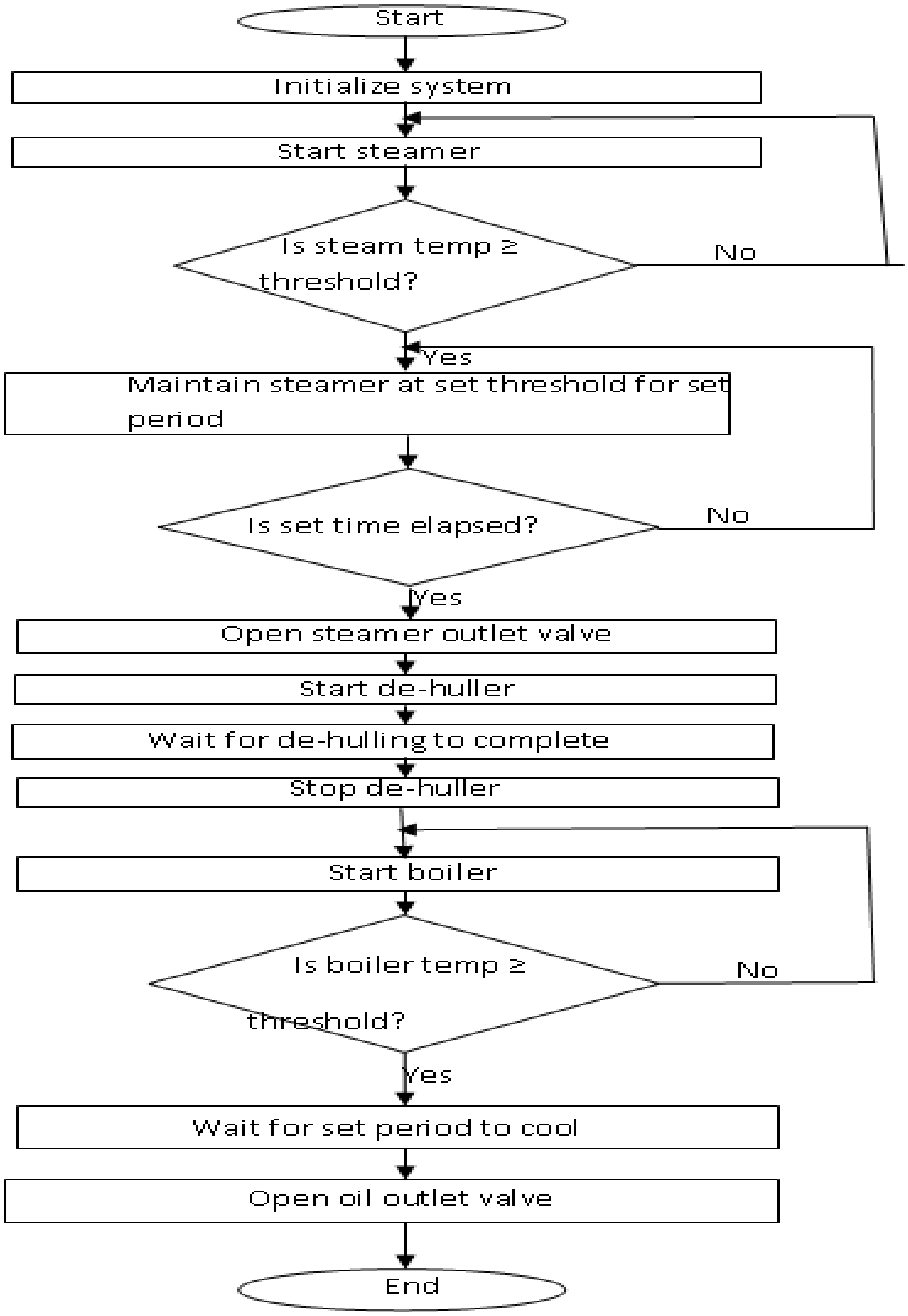
Start
Initialize system
Start steamer
Is steam temp ≥ threshold?
No
Yes
Maintain steamer at set threshold for set period
Is set time elapsed?
No
Yes
Open steamer outlet valve
Start de-huller
Wait for de-hulling to complete
Stop de-huller
Start boiler
Is boiler temp ≥ threshold?
No
Yes
Wait for set period to cool
Open oil outlet valve
End

Fig. 3 Process Flow Diagram

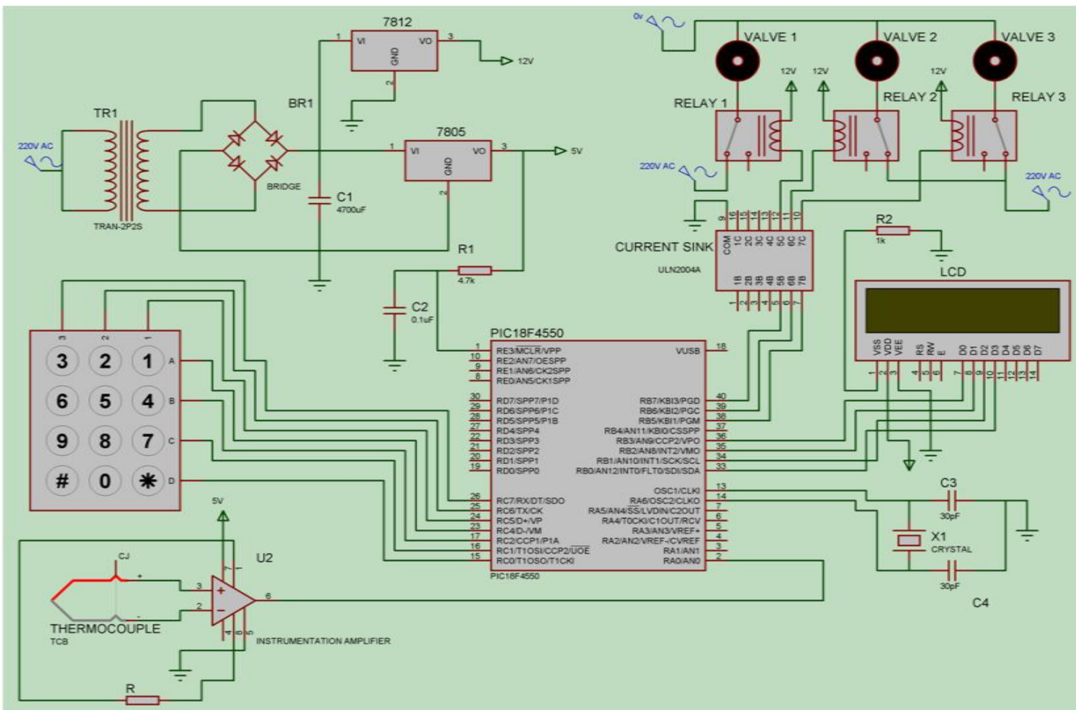

Fig. 4 Circuit Diagram

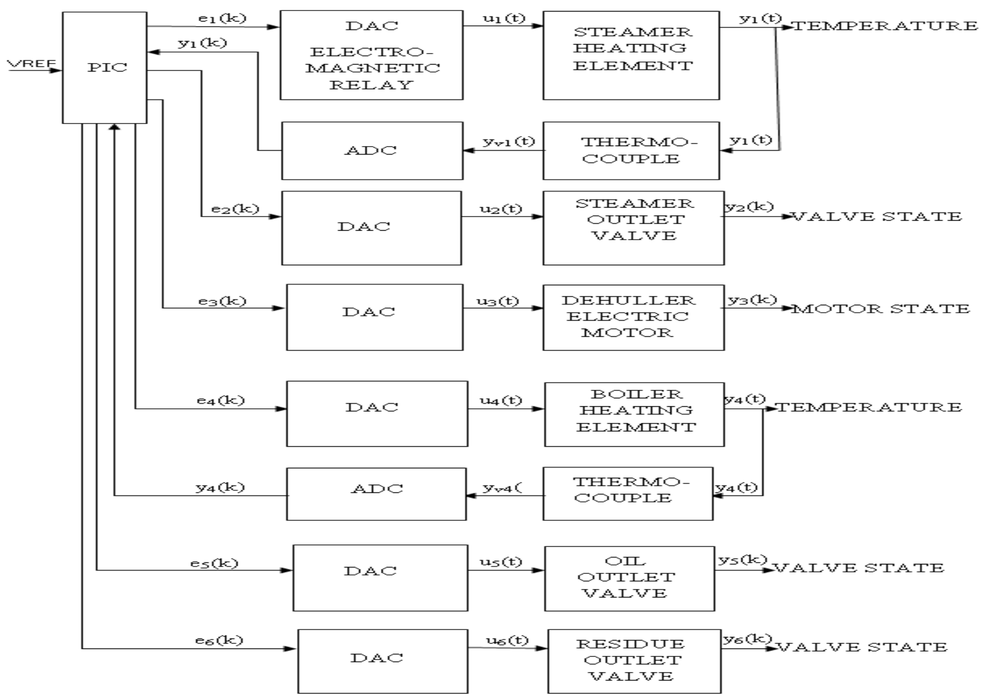

Fig. 5 Circuit Diagram

Heat Exchange Equations

Heat is a measure of the thermal energy transferred from one point of higher temperature to another point of lower temperature in a system. The heat content, Q, of an object depends upon its mass, m, its specific heat capacity, C, and its temperature change, $\Delta\theta$. It is given by the heat transfer equation below:

$$Q = mc\Delta\theta \text{................................ (i)}$$

Where Q- heat content in joules

m- mass in kilograms

c- specific heat capacity in joules per kilograms per Kelvin

$\Delta\theta$- temperature difference in Kelvin

The heat exchange equations were calculated based on the assumption that there was no loss in the volume of water and palm oil in the steaming and de-hulling sections. Also, the heat equation was assumed to have been evaluated before the evaporation of water due to fractional distillation in the boiling section.

In the steaming section, the mixture of palm fruits and water are initially at room temperature (25^0C) before the application of heat via the heating elements. The heating elements increased the temperature of the mixture to 70^0C and sustained it at this temperature for about 5 minutes. Thus, the temperature undergone by the mixture of palm fruits and water is calculated as:

$$\Delta\theta_{palm\ fruits} = \Delta\theta_{water} = 70^0C - 25^0C = 45^0C \ldots\ldots\ldots\ldots \text{(ii)}$$

The heat transfer equation to determine the amount of heat absorbed by the water from the heating element is computed thus:

$$Q_{water} = m_{water} c_{water} \Delta\theta_{water} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

The mass of water applied to steam the palm fruits was measured as 10Kg and the specific heat capacity of water is $4.2J/g^0C$. The quantity of heat absorbed by the water is thus:

$$Q_{water} = (10000g)(4.2J/g^0C)(45^0C) = 1890000J = 1.9MJ \ldots\ldots \text{(iv)}$$

The quantity of heat absorbed by the palm oil in the palm fruits can be calculated in a similar manner. The specific heat capacity of palm oil is $1.988J/g^0C$. A single palm fruit weighs an average of 15Kg and since about 20% of the palm fruit is composed of palm oil trapped within its fibers, the mass of palm oil content of in a single palm fruit can be obtained as:

$$\frac{20}{100} x 15g = 3g \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(v)}$$

Since about 50 palm fruits were steamed along the water in the steamer during testing, the total mass of the palm oil within the fibers of the palm fruits is derived as:

$$50 \times 3g = 150g \ldots\ldots\ldots\ldots\ldots\ldots \text{(vi)}$$

The quantity ofheat absorbed by the palm oil trapped in the palm fruits is thus obtained as:

$$Q_{palm\ oil} = m_{palmoil} c_{palmoil} \Delta\theta_{palm\ oil}$$

$$= (150g)(\ 1.988J/g^0C)(\ 45^0C) = 13.42KJ \ldots\ldots\ldots \text{(vii)}$$

In the de-hulling section, the water was observed to have lost about 12^0Cto attain a new temperature of 58^0Cwhile going through the de-hulling stage. Thus, the quantity of heat lost by the water is calculated as:

$$Q_{water} = (10000g)(\ 4.2J/g^0C)(12^0C) = 504{,}000J = 0.5MJ \ldots\ldots \text{(viii)}$$

The steamed palm fruits spend a longer period in this stage and thus lose more temperature to the metal chassis of the de-huller. This drop in temperature was measured to be approximately 21^0C thus resulting in a new temperature of 49^0C. The quantity of heat lost by the palm oil in the fruits thereforecalculated as:

$$Q_{palm\ oil} = = (150g)(\ 1.988J/g^0C)(\ 21^0C) = 6.26KJ \ldots\ldots\ldots \text{(ix)}$$

In the boiling section, the quantity of heat present in the water and palm oil on arrival at the boiler stage is obtained as:

$$Q_{water} = 1.9MJ - 0.5MJ = 1.4MJ \ldots\ldots \text{(x)}$$

$$Q_{palm\ oil} = 13.42KJ - 6.26KJ = 7.16KJ \ldots\ldots \text{(xi)}$$

The oil and water mixture is then heated up to 21^0C to perform fractional distillation on the mixture. The quantities of heat absorbed by the water and palm oil in this stage areevaluated as:

$$Q_{water} = (10000g)(4.2J/g^0C)(100^0C - 58^0C)$$

$$= (10000g)(4.2J/g^0C)(42^0C) = 1.764MJ \ldots\ldots\ldots \text{(xii)}$$

$$Q_{palm\ oil} = (150g)(1.988J/g^0C)(100^0C - 49^0C)$$

$$= (150g)(1.988J/g^0C)(51^0C) = 15.2KJ \ldots\ldots\ldots \text{(xiii)}$$

Results and Discussion

The mild steel used in the fabrication of the steamer was malleable enough to be shaped, drilled, welded and cut into pieces. However, it was susceptible to corrosion due to high proportion of iron to carbon. Provision was therefore made to protect the mild steel by galvanizing its outer covering. The complete steamer set-up is shown in Fig.6.

The pillow bearing employed to fasten the inner cylinder to its stand in the de-hulling section was discovered to have high fatigue strength, low thermal expansion, elasticity and bonding properties. The complete de-huller set-up is shown in Fig. 7.

The heating element employed in heating the boiler content was discovered to have high specific resistance, high melting point and high mechanical strength. The complete boiler setup is shown in Fig. 8.

The complete set-up of the processing plant comprising the boiler unit, de-huller unit and boiler unit is shown in Fig 9.

Fig. 6 Complete steamer set-up

Fig. 7   Complete de-huller set-up

Fig. 8   Complete boiler set-up

Fig. 9 Complete set-up of processing plant

Conclusion and Future Work

The various materials involved in the fabrication were apt for their respective purposes. The mild steel sheet used for the fabrication of the steamer and boiler were good conductors of heat. The angle iron used in fabricating the frame of the entire set-up was strong enough to withstand their weight. The response times of the PIC, thermocouple, heating element and relays were quick and the level of de-hulling was adequate. In all, the fabricated design gave a quality oil output when operated both manually and automatically.

This project work has established the need for automation in small scale palm oil processing. It has been established that automation in palm oil processing helps to save labour, energy, materials and also improves the quality, accuracy and precision of the various processing steps. In the end, good quality palm oil is produced for domestic and commercial usage.

It is recommended that future work be considered for greater efficiency of the processing plant and a cleaner oil output.

References

Ataga, D.O., Ilechie, C.O., &Omoti, U. 1993. *Small-scale Palm Oil Processing Technology in Nigeria.*

Cha Sooky, Robert SP, Joy ES (2002). Availability and vitamin A value of carotenes from redpalm oil assessed by an extrinsic isotope reference method. *Asia Pac. J. Clin.Nutr.* 11 (57): 5438-S442.

Edem D.O (2002). Palm oil: biochemical, physiological, nutritional, hematological and toxological aspects: a review. *Plant Foods Hum, Nutr.* 57(3-4): 319-41.

Kwasi (2002).“Origin of oil palm”.Small-Scale Palm Oil Processing in Africa.Agricultural Services Bulletin 148.Food and Agricultural Organization.ISBN 92-5-104859-2.

May, Choo Yuen (September 2012). “Malaysia: economic transformation advances oil palm Industry”.aocs.org. American Oil Chemists’ Society.

Modebe, S. (19780. The Feasibility Study of OlumoAgro-Allied Farm.

Reeves, James B.;Weihrauch, John L. (1979). Composition of foods: fats and oils. Agriculture Handbook 8-4. Washington D.C, U.S. Dept. of Agriculture, Science and Education sAdministration.p.4.

Usoro, E.J. (1974. “The Nigerian Oil Palm Industry”.Ibadan: Ibadan University Press. P. 15.