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DESIGN AND FABRICATION OF DOWNSIZED PALMFRUIT DIGESTER

BY

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DECLARATION

Candidate's Declaration

I, **NII-ASHIEDU DARIUS,** declare that this dissertation, with the exception of the quotations and references contained in published works which have all been identified and acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere

SIGNATURE: ………………………………….

DATE: …………………………………………..

Supervisor's Declaration

I hereby declare that the preparation and presentation of this dissertation were supervised by me in accordance with the guidelines on supervision of dissertation laid down by the School of Research and Graduate Studies of the University of Education, Winneba, and recommended it for acceptance for the award of the Degree.

SUPERVISOR: …………………………………………………………………….

SIGNATURE: ……………………………………………………………………….

DATE: ……………………………………………………………………………….

DEDICATION

This work is dedicated to the Almighty God who has given me wisdom and has seen me through my educational life. Also, to my mother Beatrice Borley-fio for her motherly love.

My children Jared Nii-Ashiedu, Caleb Nii-Ashiedu and Elijah Nii-Ashiedu. Pastor Timothy Acquaah of The Apostolic Church Ghana, Bechem for his spiritual support.

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ABSTRACT

A downsized oil palm fruit digester was designed, fabricated and tested. The materials for fabrication were sourced locally. The machine was tested for throughput capacity (Dc) and efficiency (η). Average throughput capacity of 0.030 kg/sec and efficiency of 70.8% was 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 made of the stand which serves as the main frame of the machine.

It has a hopper which serves as the inlet of the machine.

It also has a digestion chamber with a set of beaters welded to a shaft.

It is powered by a 6.5HP engine and has a low fuel consumption.

The machine is driven by a v-belt on a v-pulley.

The machine is simple to operate and maintain, it is cost effective and mobile.

CHAPTER ONE

INTRODUCTION

1.1 Background of study

Palm oil, a kind of edible vegetable oil, which is derived from the pulp of the fresh palm fruit in its various forms, has become the leading vegetable oil produced globally, accounting for one quarter of global consumption and nearly 60% of international trade in vegetable oils (World Bank, 2010). The increase in consumption is due to its multiple uses in both food industry and non-food sectors. It also has many competitive advantages over other competing oils, such as having low cost of production, high yield, and being free from trans-fatty acids (Oil World, 2008). Oil palm commercially cultivated on about 12 million hectares of land in the humid tropics. Major producers are Malaysia and Indonesia (85% of global output). Other smaller but significant producers include Nigeria, Colombia, Costa Rica, Ecuador, Honduras, Cote d 'Ivoire, Ghana, Cameroon, Papua New Guinea, and Thailand (World Bank, 2010).

According to (Ayodele 2010), the palm oil industry in Ghana since independence has been geared towards meeting domestic demand and thus reducing import bills, (i.e. it has largely been an import substitution industry). The growth in oil palm cultivation from the 1970s was in response to the increase in domestic demand as a result of growth in population, urbanization and industrialization. The structure of the palm oil industry in Ghana has been shaped by the presence of two different markets: home consumption and industrial use in domestic manufacturing (Fold & Whitfield, 2012). As a result, Ghana's industry has two sub-sectors which are largely separated. The industrial use sub-sector consists of medium and large scale oil palm plantations and mills. Processing mills under large scale sub-sector process more than 10 tonnes fresh fruit bunches (FFB) per hour while installations that process between three and eight tonnes FFB per hour are termed medium scale

(Poku, 2002). Large sub-sector is characterized by more efficient technology, economies of scale, higher productivity on farms (in terms of yields of oil palm bunches) and in mills (in terms of quantity of oil extracted). It also produces better quality of crude palm oil and further refined palm oil products, which are sold to companies for use in manufacturing. The small scale sub-sector, however, consists of household processors (who process manually and private smallholder oil palm cultivators, who largely sell their fruit bunches to small scale mechanized mills (Processing units handling up to two tonnes of fresh fruit bunches (FFB) per hour) (Poku, 2002). The small scale sub-sector is characterized by low-yielding oil palm variety, low productivity of farm and mill, and low quality crude palm oil which is sold in the village or at small town markets (Fold & Whitfield, 2012).

The palm oil industry in Ghana is expanding in recent times, as current total area under oil palm production is put at 360,000Ha up from 289,170Ha in 2003 (MoFA, 2011). The expansion in oil palm plantation is significantly accompanied by processing of palm fruits into edible oil, especially among women in many rural communities in Ghana where palm plantations are common. Statistics of crude palm oil (CPO) production in Ghana from 2002-2010 indicates that the small scale palm oil processing industry, mostly dominated by women, produced the greater portion (MoFA, 2011). For instance, out of the total of 402,473.00mt of crude palm oil produced in 2010, the small scale and the private holdings contributed 80% (MASDAR, 2011). Government has identified the palm oil sector as holding tremendous potential to create jobs and reduce poverty among the rural poor especially women and the development of the economy. Recent trends in world price suggest that crude palm oil when properly nurtured could easily become a major foreign exchange earner for the country. As result, Ghana has recently signed an agreement worth $21.6 million with Chyuan Chya Food and Beverages Limited (CCFB), and the China-Africa Economic Trade Limited. Under the agreement, Ghana will export 36,000 metric tonnes of palm oil to China every year (Essabra-

Mensah, 2010). Although the deal would create over 100,000 jobs, the palm oil to be exported will be mainly sourced through small and medium scale palm oil producers in Ghana. That is however, dependent on the ability and efficiency of small and medium scale producers to increase production. To be able to raise the productivity of small scale palm oil producers to ensure the realization of this deal, there should be proper management and efficient utilization of resources in the sector.

Processing of palm fruits into edible oil as primary economic activity of women in many communities in Ghana where palm plantations are common is no exception in the Assin North Municipality (ANM) and Assin South District (ASD) of Ghana. Efforts to improve the livelihoods of women in such communities could be targeted at such cottage industries as their efficient operation holds the key to poverty reduction among venerable households. According to Ekine & Onu (2008), determinants such as cost of palm fruits, cost of hiring equipment, transportation of the palm bunches, availability of labour, price of palm oil among others are crucial in the industry because the survival of the enterprise is highly dependent on these important variables since they influence the level of Gross Margin (GM) obtained by the processors.

Processing of oil palm among the rural folks is characterized by labour intensiveness with low production yields. The method of processing is usually by traditional means which is mostly done manually. Most of the small scale processors happens to be women who will have to hire young men with much energy to take care of the labour intensive aspect of their work. In recent times, various machinery has been developed to help make processing less drudgery with high productivity but with high price making it difficult to afford.

To make various processing machines more affordable and accessible to the rural palm oil processors, this downsized palm fruit digester was designed and developed.

1.2 Problem Statement

Palm oil, in its various forms, has become the leading vegetable oil produced globally accounting for one quarter of global consumption and nearly 60% of international trade in vegetable oils (World Bank, 2010). In 2007/2008, the world consumption of palm oil reached almost 40 million tonnes and in 2050, it is forecast to reach 93.256 million tonnes, depending on the edible oil substitute demand (Oil World, 2008). In recent decades, the domestic consumption of palm oil in West Africa has also increased more rapidly than its production. After centuries as the leading producing and exporting region, West Africa has now become a net importer of palm oil (Olagunju, 2008). Ghana has a long history of palm oil production. It was its primary export in late part of the 19th century and the early part of the 20th century (Ayodele, 2010). Like other countries in the region, Ghana has failed to take palm oil production beyond mere potential. This is due to the use of traditional methods of production coupled with the low quality of palm oil produced which could not make Ghana to meet up with the rising global and domestic demand. Its current annual production is put at 120,000MT down from 128,000 in 2008 (FAOSTAT, 2010). The domestic consumption level is estimated to be around 230,000MT per annum. The shortfall is being filled by import at great cost to the country.

In a bid to address the demand-supply gap various processing machinery have been developed to help reduce the drudgery associated with palm oil processing and also to increase productivity. But with the influx of the numerous processing equipment, most of the rural small scale processors still depend on the traditional methods which makes their work more labour intensive with low production. This is due to the high prices of the machines. This project work seeks to come up with very affordable equipment that would be very accessible to the small scale farmers in the rural areas.

The current method of processing palm oil is fraught with problems such as:

1. It requires more labor when using the traditional approach (mortar and pestle) in producing the palm oil.
2. The efficiency of the traditional approach is low.
3. Low production rate.
4. Traditional producers carry the palm fruits through long distance.
5. Insufficient funds to purchase the palm oil producing equipment.

1.3 Aim of study

This project is aimed at designing and fabrication of downsized palm fruit digester for the production of palm oil by the traditional processors who are unable to purchase bigger equipment due to financial constraints.

1.4 Objective of the Project

The broad objective of the project is to reduce the hindrance affecting the traditional palm oil producers.

The specific objectives of the study are to:

1. Reduce drudgery in the traditional way of palm oil production.
2. Increase the efficiency in the oil palm production.
3. Increase productivity.
4. Fabricate a mobile palm fruit digester.
5. Make the equipment affordable for the traditional producers

1.5 Guiding questions

1. What is the main aim of fabricating the palm fruit digester?
2. What is the efficiency of the traditional way of producing palm oil?
3. Are the traditional processors able to do more production?
4. What is the main objective of the project?
5. Would the palm oil processors be able to acquire the equipment?

1.6 significance of the project

1. The work will add new information to already existing knowledge

2. The study will serve as a reference document for further research.

3. The research work ultimately is to make known the problems people in the study area encounter, so as to help find lasting solution to them

1.7 Delimitation of the project

The study could have discovered two or more alternative machines but due to time and financial constrains it is limited to only downsized palm fruit digester machine

1.8 limitations

The limitation of this project includes inadequate resources like, time and finance. The other limitation was lack of adequate basic tools at the facility.

1.9 Organization of the project

The thesis is organized into five chapters. Chapter one presents introduction, problem statement, aim, research question, objectives of the study, significance and concluded with the delimitation of the study. It is followed by Chapter two, which constitutes extensive review of relevant literature on the palm oil industry in Ghana, palm oil processing, related studies on palm oil production, profitability, constraints and technical efficiency.

Research methodology involving the materials, method, and results are described in Chapter three. Chapter four presents result and discussion of the study while summary, conclusions, recommendations and suggestions for further research is provided in Chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature relevant to the study. Overview of the oil palm industry in Ghana (colonial era and post-colonial era), the production trends of actual crude palm production in Ghana, Palm oil processing, Palm oil characteristics and usage, returns from palm oil production, Economic importance of palm oil processing, and a review of related studies on palm oil production, and Technical efficiency in small scale palm oil processing have been provided

2.2 The Oil Palm Evolution in Ghana

2.2.1 Oil Palm Industry in Ghana during Colonial Era.

Oil palm plantations were not very much considered by the dominant British colonial administration in Ghana. The Dutch were the first to introduce the plantation system in Ghana about the beginning of the eighteenth century. Dickson (1969) reports the establishment or attempted establishment of several Dutch plantations near the coast during the eighteenth and nineteenth centuries. Other plantations included those established by German, British, and other European interests about the end of the nineteenth century and in the early decades of the twentieth century, particularly after the passing of the Oil Palm Ordinance of 1913, when "Numerous oil palm plantations including those at Butre, Sese, and Winneba were made" (Carrere, 2010). The Ordinance empowered the government to grant a mill operator the exclusive right to extract oil, by mechanical means, from the pericarp of palm fruits produced within 16 km of the mill. According to Fold (2008), the plantation system failed to gain a significant hold, partly because of the internal political insecurity engendered by inter-tribal warfare and by rivalry among the European powers seeking territorial hegemony. In addition, the negative attitude towards the system by the British Crown, which, from about 1850 onwards, gained the upper hand in the European struggle to colonize Ghana, also contributed to the failure of the plantation system in pre-colonial era (Dickson, 1969 & Howard 1978).

2.2.2 Oil palm industry in Ghana after independence

Things changed after 1957, during the post-independence period, when there was a policy change involving greater emphasis on the plantation system centered on oil palm and rubber. The policy change, up to the time of the 1966 military coup d‘etat, encouraged state-owned and state-operated plantations. However, mainly because of capital constraints, political interference, poor planning, mismanagement, and the rigidity of the centralized state control system; these state-owned farms did not prove economically viable (Carrere, 2010). They succeeded only in worsening rural living conditions by dispossessing the peasants of their most fundamental natural resource, the land, with little or no compensation and by the deforestation and other forms of ecological and economic disturbance associated with the removal of natural vegetation to make room for monoculture plantations. Subsequently, some of the state plantations were sold. Others were abandoned, sometimes after felling of the palms, a practice that invariably left behind derived savanna or even grass in place of the original forest cover. Attempts were made to reorganize the remaining plantations into viable economic units under decentralized state control (Carrere, 2010).

After the 1981 coup d'etat and the subsequent liberalization of the economic system, a new policy sought to promote plantations through private enterprise, foreign aided government ventures, and joint government-private projects. The resultant plantations include the three major ones established by the government-owned but foreign-assisted, Ghana Oil Palm Development Co. (GOPDC) located around Kwae in the Eastern Region; the government/privately owned Twifo Oil Palm Plantations Ltd. (TOPP) located around Twifo Praso/Ntafrewaso in the Central Region; and the government/privately owned Benso Oil Palm Plantations Ltd. (BOPP) located around Benso/Adum Banso. They were to grow oil palms for producing oil from the fruit of the palm, "probably the heaviest producer of vegetable fats". This agro-industrial crop, which has a wide variety of uses, was a leading foreign exchange earner for Ghana, mainly based on small-scale peasant production in an oil-palm belt near the littoral, from about the mid-nineteenth century to the beginnings of the twentieth century (Gyasi, 1992).

According to Carrere (2010), the three major new palm plantations (GOPDC, TOPP, and BOPP); were established on land compulsorily acquired from peasant farmers by the government in the humid tropical environment of the interior. In addition to developing the acquired areas into palm plantations, the companies involved were to encourage palm fruit production among the peasants in the plantation hinterland through the nucleus estate system to help sustain their huge palm-oil-processing mills located inside the plantations (Carrere, 2010).

Since 1977, when they started, the three plantations have developed rapidly and contributed significantly towards the expansion of Ghana's oil-palm hectares from 18,000 to 103,000 between 1970 and 1990. This growth of 24 % per annum has resulted in the re-emergence of the oil palm as a major commercial crop and has served as a basis for the fast-developing palm oil and other agro-industrial processing industries; and rendered the country more than self-sufficient in palm-oil production (Fold, 2008). Table2.1 shows major stakeholders in the oil palm industry in Ghana.

Table 2.1: Major Stakeholders in the Oil Palm Industry in Ghana

Company	Location
Benso Oil Palm Plantation (BOPP) Ltd.	Benso, Western Region
Twifo Oil Palm Plantation (TOPP) Ltd.	TwifoPraso, Central Region
Ghana Oil Palm Development Corporation Ltd. (GOPDC).	Kwae Via Kade, Eastern Region
National Oil Palm Plantation (Juaben Oil Mills Ltd).	New Juaben, Ashanti Region
Norpalm Ghana Ltd. (Prestea Oil Palm Plantation)	Prestea, Western Region
National Oil Palm Plantation. (Ayiem Oil Mills Ltd).	Ayiem, Western Region.
Golden Star Oil Palm Ltd	Bogoso, Western Region
Small Scale and Private holders	Scattered in the country

Source: Gyasi, 2008 & MoFA, 2011

2.2.3 President Special Initiative on Palm oil

As part of the Government's strategy to revamp the oil palm industry in the country, a Presidential Special Initiative (PSI) on Palm Oil Plantation and Exports was launched around 2004. About US$3.4 million was invested in the initiative. Under the programme, about 100,000 ha of oil palm plantations were planned to be cultivated over a 5-year period in six regions in the country, together with the establishment of 12 nurseries to raise about 1.2 million high-yielding seedlings for supply to farmers. The Oil Palm Research Institute (OPRI) of the CSIR (Council for Scientific and Industrial Research) was given the task to produce two million high-yielding seedlings annually (Gyasi, 2008).

By 2008 only about 30,000 hectares had been put under cultivation due to insufficient funding (Government of Ghana, 2009). The already established farms are not properly maintained and consequent attacks by pests leading to low yields. This scenario was the norm across all the regions where the plantation took place. The nurseries established to produce seedlings for farmers are no more functioning due to lack of funding and lack of political will to continue the project after change of Government in 2008 (Asante, 2012).

2.3 Oil Palm Production in Ghana

2.3.1 Land under Oil Palm cultivation

According to Poku (2002), oil palm plantations in Ghana covered 304,000 hectares in 2002. In 2004, around 285,000 hectares of oil palm were cultivated (Carrere, 2010).

Smallholders cultivated nearly 88% of the total area under production but produced only 72% of the oil palm fresh fruit bunch (FFB). The remaining 28% was produced by the private estates cultivating less than 12% of the total area. The existing plantations operate based on a nucleus estate with associated smallholder schemes and independent outgrowers. The out-growers own and cultivate oil palm on their land, receive planting material and other inputs and technical advice from the companies (usually on credit) to which they are contractually obliged to sell their production (Fold, 2008). Total land under oil palm as given by the Statistics, Research and Information Directorate (SRID) of the Ministry of Food and Agriculture in 2010 is 360,000 hectares (MoFA, 2011).

2.3.2 The production trend of actual crude palm oil production in Ghana

According to Fold (2008), the total volume of palm oil production in Ghana is unknown due to a significant amount of household-based production for self-consumption or petty trade. He stressed that the greater quantity of total production for industrial use however, is produced in four large-scale plantations managed and controlled by three foreign companies (BOPP, TOPP, GOPDC, and Norpalm). MoFA categorized palm oil processing industry in Ghana into three main sectors, namely large scale, medium scale and small scale. Based on the production figures of MoFA, the actual quantity and projections of CPO produced by these sectors from 2002-2010is presented in Table 2.2.

Table 2.2: Actual Crude Palm Oil Production (MT) in Ghana from 2002-2010

Year	Large scale	percentage	Medium scale	Percentage	Small scale	percentage	Total output
2002	67,188.90	27.50%	5,729.00	2.30%	171,366.00	70.20%	244,283.90
2003	69,749.90	26.37%	6,301.00	2.38%	188,503.00	71.25%	264,553.90
2004	75,346.40	26.00%	6,932.00	2.40%	207,353.00	71.60%	289,631.40
2005	78,595.80	25.00%	7,625.00	2.43%	228,089.00	72.57%	314,309.80
2006	82,400.10	24.12%	8,387.00	2.45%	250,888.00	73.43%	341,675.10
2007	66,451.30	18.90%	9,225.70	2.62%	275,976.80	78.48%	351,653.80
2008	66,668.32	17.53%	10,148.07	2.67%	303,572.32	79.80%	380,388.71
2009	75,415.00	18.74%	10,836.00	2.69%	316,222.00	78.57%	402,473.00
2010	70,444.00	17.72%	10,836.00	2.73%	316,222.00	79.55%	397,502.00

Source: (MoFA, 2011)

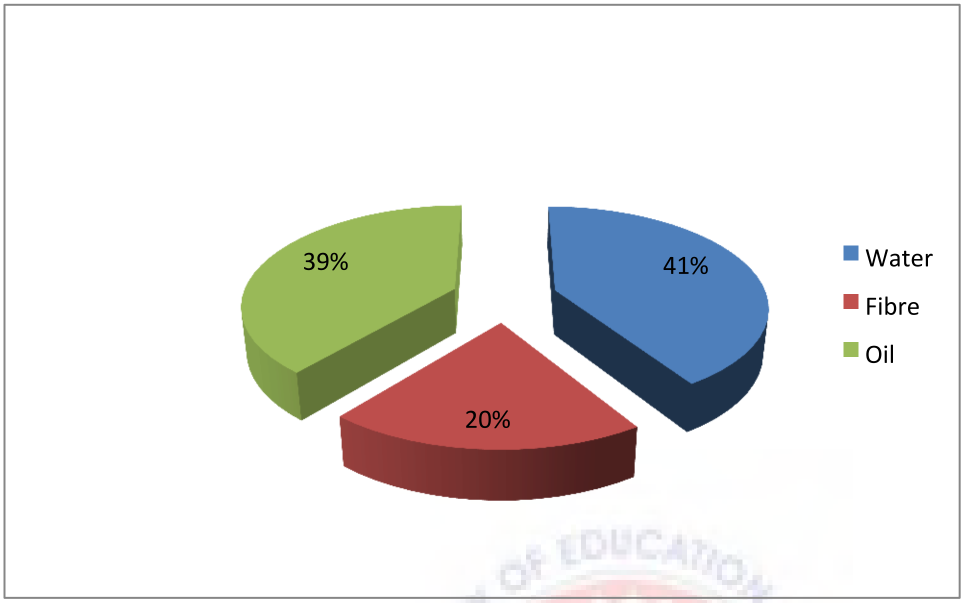
Statistics of crude palm oil (CPO) production in Ghana from 2002-2010 in Table2.2 indicates that the small scale palm oil processing industry produced the greater portion of the total output. For instance, out of the total of 402,473.00mt and 397,502.00mt crude palm oil produced 2009 and 2010 the small scale and the private holdings contributed 78.57% and 79.55% respectively and the situation is not different from the rest of the years. The contribution of the small scale palm oil processing sector is significant to the palm oil processing industry and the economy of Ghana at large. Women also dominate the small scale sector with few men giving technical assistance (MoFA, 2011).

2.4 Palm Oil Processing

The fruits of the oil palm are small (weighs about six to 20 g) and occur in bunches of about 10 to 40 kg. Naturally a bunch holds about 200 fruits; however, some cultivars of oil palm can have bunches with up to 4000 fruits (Rehm & Espig, 1991). The fruit is orange-red in colour (due to a high content of carotene) and it comprises a kernel enclosed in a shell (endocarp) surrounded by pulp (mesocarp). Two types of oil can be obtained from the oil palm fruit: palm oil from the fibrous mesocarp (only two mesocarp oils are available commercially, the other is olive oil) and palm kernel oil from the kernel.

The ratio of produced palm oil and palm kernel oil is about ten to one (MPOC, 2011). The composition of oil palm fruit meesocarp is shown in Figure 2.1

Figure 2.1: Composition of Oil Palm Fruit Mesocarp



Source: Bockisk, 1998

Palm oil production can be divided into three stages, namely plantation, transportation to the mill and milling (Yusoff & Hansen, 2007). Hence, the production involves three sectors: agriculture (plantation stage), transport and industry (milling stage).

When establishing an oil palm plantation, the land needs to be cleared. In Ghana, this is commonly done by burning. Before planting, the land is prepared by ploughing and weeding (Clay, 2004). About four or five years after planting the oil palm is mature enough to produce fruit (Rehm & Espig, 1991). After this, the fruit bunches are cut down by hand. At larger plantations, harvesting is done with the help of mechanical lifts; otherwise, knives are attached to long bamboo-sticks. Oil palms grow tall and after about

25-30 years, harvesting becomes very difficult and the plantation is renewed (Rehm & Espig, 1991). Transportation of the fruit bunches to the mill needs to be done as fast as possible. Within 24 hours after detachment the fresh fruit bunches have to be processed if high quality and value is to be obtained (Rehm & Espig, 1991). This partly explains why; palm oil mills are normally located close to the plantations.

The procedure for extracting oil from the oil palm fruit is complex and can be summarized as follows: It involves the reception of fresh fruit bunches from the plantations, sterilizing and threshing of the bunch to free the palm fruit, digestion (mashing the fruit) and pressing out the crude palm oil. The crude oil is further clarified to purify and dry it for storage and export (Poku, 2002). At a refinery, the Crude Palm Oil (CPO) is further treated (deodorized, freed from pigments, free fatty acids and phospholipids) to produce refined, bleached, and deodorized (RBD) palm oil. The palm cake obtained from pressing is sent to a kernel-crushing plant where the fibre is removed from the nut, the nut is cracked and the endocarp separated from the kernel. The kernel is further processed (e.g. pressed) to obtain crude palm kernel oil (CPKO) (Subramaniam *et al.*, 2010).

2.4.1 Processing Activities and Practices of Small-Scale Palm Oil Processors

The major operating activities carry out at the processing centres include removal of spikelets from the bunch, storage of the fruit containing spikelets, fruit removal from spikelet and storage, boiling/steaming of fruits, digestion and pressing of fruits clarification of the CPO and separation of nuts from the fibre. Digestion and pressing of fruits are fully mechanized while removal of fruits from the spikelet and separation of nuts from fibre are partly mechanized in some of the centres.

2.4.2 Removal of Spikelet from Bunches.

This process involves cutting of the fruit containing spikelet from the fruit bunch using either a cutlass or an axe. This is usually done by men due to its strenuous nature. Cutting of the spikelet from the bunch is done on the bare floor in most the processing centres while few of them perform it on a raised cemented platform. This activity usually results in fruit bruises which lead to reaction within the oil cells thereby increasing the free fatty acid content of the oil (Owolarafe *et al.,* 2008; Ngando *et al* ., 2011).

2.4.3 Storage of Spikelet Containing nuts, Removal and Storage of Fruits from Spikelet

Storage of spikelet containing nuts is done with the view of facilitating easy loosening or removal of nuts from the spikelets (Adjei-Nsiah *et al.,* 2012). Spikelets are usually heaped and covered with plastic sheets for a period ranging from three to five days. Heaping the spikelets cause the tissue attaching the fruit to the bunch or spikelet to wilt with time thereby causing the fruit to detach from the spikelet or the bunch. Removal of fruits from the spikelets is usually done manually by women and children. This activity employs a large number of the unemployed women in the rural communities. Majority of the processing facilities visited use this method to remove nuts from the spikelets. This method of fruit picking from spikelets usually delays fruit processing and promote fermentation of fruits resulting in high FFA and oil of low quality (Adjei-Nsiah *et al.,* 2012). This activity is partly mechanized in some of the centres by using equipment called Fruit thresher. Sometimes, after picking the fruits from the bunch or spikelets, processors further heap the fruits for a period ranging from one to two weeks causing the fruits to ferment or grow mouldy. About 41% of the processors store their fruits beyond one week before processing. However, to produce palm oil with low free fatty acids (FFA) content, Poku (2002) recommended that palm fruits should be processed within 48 hours after harvesting. This is to arrest lypolytic enzymes and stop the production of free fatty acids as poor and lengthy storage of fruits lead to a considerable increase in free fatty acids that will affect the quality of palm oil produced from these fruits (Owolarafe *et al* ., 2008; Ngando *et al* ., 2011). Processors outline three major reasons for which they store fruits before processing into oil. These reasons include difficulty in removing fruits from the bunch immediately after harvest before boiling, expectation of higher oil yield and reduced effluent resulting from processing. According to the processors, storing the fruits reduce the moisture content of the fruits which consequently leads to high quantity of palm oil. Some processors also erroneously believe that storing the fruits leads to increase in the oil content. They also argue that storing the fruits cause the mesocarp to become soft and easy to press for the release of oil. This practice also leads to low quality of oil as FFA level increases with fermentation (Tan *et al.,* 2009). However, the number of days' fruits are stored before processing depends on whether the processor is processing for food and non-food uses. Fruits processed food uses are usually stored for a duration not exceeding one week while fruits processed for non-food uses are stored beyond one week.

2.4.4 Sterilization/Boiling of Fruits

One of the major operations in the processing of palm fruits is fruits boiling or sterilization. The objectives of fruit boiling are: inactivation of enzymes, softening of fruit, conditioning of nuts and coagulation of proteins (Babatunde *et al.,* 2003). During fruit boiling, the heat inactivates lipase, an active hydrolytic enzyme presents in the mesocarp of the fruits. The most popular method for fruit boiling among small scale processors is the use of metal drum, fruit boiler or big cooking pots over an open fire. Fruits are boiled in metal containers ranging from 200-1000 litres in volume. The fruits are then covered with a jute sack. The metal container is placed on metallic tripod stove or tripod made from big stones/blocks with a lot of firewood placed under it. Bamboo is the source of firewood for almost all the centres visited. They supplement the bamboo with the dried fibre especially in the dry season. Most of the heat generated is lost to the environment thus requiring a lot of firewood. Heating may last for one to three hours depending on the volume of the fruits and the burning efficiency of the fuel. Recently, steam fruits boilers have been designed by the Ghana Regional Appropriate Technology Industrial Services (GRATIS) foundation which uses steam to sterilize the fruits and use less firewood and water (Adjei-Nsiah *et al.*, 2012). This equipment is used by few community processing centres supported by NGOs.

2.4.5 Digestion and Pressing of Fruits

Digestion is the process of releasing the palm oil in the fruit through the rupture or breaking down of the oil-bearing cells. This operation is highly mechanized in all the processing centres visited. After the fruits are digested, the digested material is pressed to release the oil. This involves separating the crude oil from the mash. This process is done by male operators managing the processing facilities.

2.4.6 Nut and Fibre Separation

Nut and fibre separation is another activity carry out in the processing centres. A process where the nut is picked manually from the fibre after the oil is squeezed out from the fibre and the nut. The fibre separated from the nuts is re-pressed with hand screw press to squeeze out any oil left in the mixture as result of the presence of nuts in the mixture. The nuts obtain is dried for one to weeks weeks and sold for processing. This activity is done manually by women. It is also mechanized in a few of the processing centres visited with a machine propel by diesel-powered engine.

2.4.7 Clarification

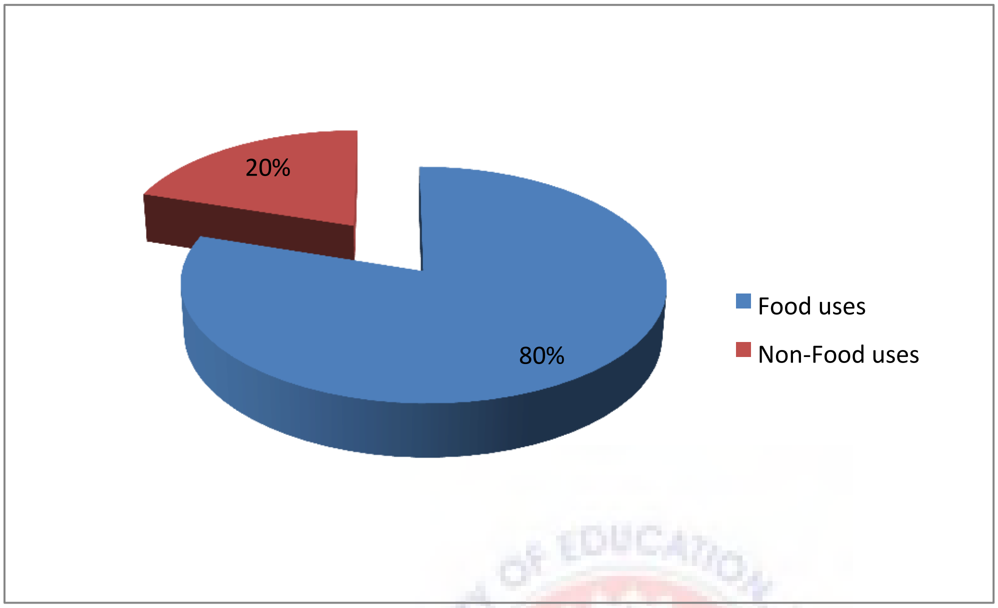
The main purpose of clarification is to separate the oil from its entrained impurities (Poku, 2002). The fluid coming out of the press is a mixture of palm oil, water, cell debris, fibrous material and non-oily solids. The clarifying process is not mechanized in any of the mills visited. After pressing, the oil is poured into a metal container and placed on a fire and heated for a period ranging from one to two hours till there is no water in the boiling oil at the top layer. The oil is then removed gradually into metal bucket or pan till there is only a thin layer of oil on the water. CPO aimed at soap making and other nonfood purposes is not clarified. Such oil may contain high moisture levels which will increase FFA content of the oil during storage as a result of autocatalytic hydrolysis (Ngando *et al.,* 2011) making such oil unhealthy for human

2.5 Characteristics and uses of Palm Oil

Both palm oil and palm kernel oil are used in a variety of products (Figure 2.3). The two oils are however chemically and nutritionally unrelated. According to Teoh (2002), there are equal proportions of saturated and unsaturated fatty acids palm oil, while palm kernel oil contains mostly saturated fatty acids. Palm oil has a good resistance to oxidation due to its high natural content of the antioxidants carotenoids and vitamin E (MPOC 2011 & Edem, 2002). Both CPO and CPKO can be fractionated into liquid (palm/palm kernel *olein*) and solid (palm/palm kernel *stearin*) components used for different purposes
(MPOC, 2011).

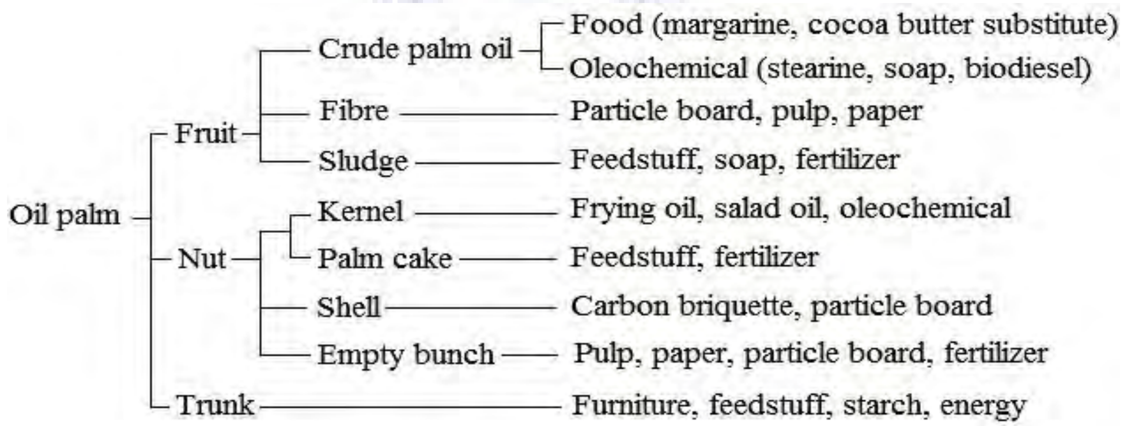
Palm oil and palm kernel oil have a wide range of applications; about 80% are used for food applications while the rest is feedstock for a number of non-food applications (Salmiah, 2000).

Figure 2.2 Food and Non-Food Uses of Palm Oil



Source: Salmiah, 2000

Figure 2.3 Uses of Palm Oil



Source: Adapted from Fairhurst & Mutert, 1999

Palm oil for food purposes

The oil palm provides one of the leading vegetable oils produced globally, accounting for one-quarter of global consumption and approximately 60% of international trade in vegetable oils (World Bank 2010). An estimated 74% of global palm oil usage is for food products and 24% is for industrial purposes (USDA, 2010). Palm oil has been criticized for being unhealthy (Lam *et al.*, 2009), but according to the Malaysian Palm Oil Council (MPOC), palm oil is highly suitable as edible oil because of its many nutrients and vitamins (MPOC, 2011). Basiron & Weng (2004) argued that palm oil is healthy edible oil and about 80% of the world's produced palm oil is used for food purposes. Since palm oil is resistant to oxidative deterioration it is good as frying oil. Potato chips, fries and doughnuts are often fried in palm oil (Sumathi*et al.,* 2008). Palm oil is also a major component of shortenings and margarines, and is commonly used in products such as reduced fat spread, ice cream, coffee whiteners, whipping cream, filled milk, mayonnaise and salad dressings, palm-based cheese and coconut milk powder (Basiron & Weng 2004). Natural palm oil is trans-fat free and hence often blended with other oils producing transfatty acid formulations (Gee, 2007).

Palm oil in non-food products

Oil palm is among the most productive and profitable of tropical crops for biofuel production. High-yielding oil palm varieties developed by breeding programmes can produce over 20 tonnes of fresh fruit bunches/ha/year under ideal management, which is equivalent to five tonnes oil/ha/year (excluding the palm kernel oil) (Poku, 2002).Basiron & Weng (2004) stressed that the non-food application of palm oil and palm kernel oil is only about 20 % but adds a high economic value. The oils form 10 per cent of the total dry biomass produced by the palm, but the 90% left might be a source of fibre and cellulosic material for second-generation biofuel production (Basiron 2005). As indicated in Figure 2.3 Palm oil can be used in soap and other personal care products such as many cosmetics and toiletries; and is also used in lubricants and greasers, printing ink, drilling mud and as an inert ingredient in pesticide formulations (Mekhilef *et al.*, 2011). Basiron (2005) furthermore stressed that palm oil is used as biofuel. Refined palm oil can either be converted into methyl ester and then be directly used as biodiesel, or be blended with petroleum diesel obtaining diesel fuel (Mekhilef *et al.*, 2011).

Other products from the oil palm

As shown in Figure 2.3, several products can be obtained from other parts of the oil palm. For every kilogram of obtained palm oil, approximately fourkg of dry biomass is also produced (Sulaiman, 2010). A third of this biomass is found in the fresh fruit bunches (FFB) and the other two thirds constitute trunk and frond material (Sulaiman, 2010).

When replanting, about 75 tonnes of dry matter per hectare is produced (Basiron & Weng, 2004). Normally the empty fruit bunches are burned to produce energy, or used in mulching as a fertilizer (Subranamian *et al.*, 2010a). The pressed palm cake and the sludge that is left after clarifying CPO are used as fertilizer or as animal feedstuff Figure.2.3. According to Fairhurst & Mutert (1999) about 25 % of the palm biomass can be returned to the field as nutrient rich mulch.

2.6 Returns from Palm Oil Production

According to Oil World (2008), palm oil uses less land than crop-based oilseeds. Only 0.26 hectares of land is required to produce one tonne of oil from palm oil, while soybean, sunflower and rapeseed require 2.2, 2 and 1.5 hectares, respectively, to produce one tonne. Palm oil generates nearly 10 times the energy it consumes, compared to a ratio of 2.5 for soybeans and three for ripe oilseed. Oil World (2008), highlighted that Production of palm oil is more sustainable than crop based vegetable oils such as soybean and rapeseed. It consumes considerably less energy in production, uses less land and generates more oil per hectare. Modern high-yielding varieties of palm, under ideal climate conditions and good management are able to yield five tonnes of palm oil per hectare, annually. Oil palm has the highest yield of any oil seed crop, averaging tree to four tonnes of mesocarp oil per ha per year in the major palm oil producing countries (Wahid, 2005). Through the analysis of rattan, rubber, and palm oil in East Kalimantan, Indonesia, Belcher, *et al* (2004) computed the net present value and other financial viability indicators of each commodity. The study was conducted to look at the changing use and management of forest product in East Kalimantan because the traditional land-use was under pressure by a range of factors, including government policy. The results showed that palm oil gives the best of the land use options, when considering the profitability per unit of land compared to rattan and rubber. Goenadi (2008) suggests that, because of the growing climate in Indonesia, palm oil yields may potentially be as high as six to seven tonnes per hectare. However, in 2008, Indonesia was averaging between three to four tonnes of palm oil per hectare. Increasing the yield of palm oil production gives Indonesia the potential to increase the production without requiring additional land conversion. Land-use returns from oil palm are significant as compared with many other forms of land-use. In 2007, a report prepared for the Stern Review estimated the return from palm oil land-use as ranging from $US960/ha to $US3340/ha. This was in comparison with smallholder rubber, rice fallow, cassava, and one-off timber harvesting which yielded $US72/ha, $US28/ha, $ US19/ha and $US1099/ha, respectively (Goenadi, 2008). Compared to other major oil crops, palm oil has lower production costs and produces more oil from less land (Yusoff & Hansen, 2007). They argued that returns on land, capital and labour produce substantial revenues both for individual producers and the country as a whole. Thoenes (2006), also held the same assertion that palm oil production has the lowest production costs per unit, when compared to other oils, for example soybean oil, which, although cheap, has 20 % higher production cost (the labour costs taken into account) per unit than palm oil.

2.7 Economic Importance of Palm Oil Processing

The economic importance of oil palm crops in developing countries is enormous. Generally, palm oil industry is considered to be labour intensive and therefore, able to provide jobs for local inhabitants and improve employment levels (Casson, 1999). Jobs are provided for thousands of villagers in Ghana who otherwise may not have employment prospect (MASDAR, 2011). Palm oil provides developing countries and the poor a path out of poverty. Expanding efficient and sustainable agriculture such as Palm Oil Plantations provides small and large plantation owners and their workers with a means to improve their standard of living (World Growth, 2011). The World Bank (2010), with its mission to reduce poverty, sees this commodity as one which can play an important role in furthering economic development in these countries as well as securing a rising standard of living for the rural poor when the full range of environmental, social, economic and governance risks are addressed, and contributing to global food security.

According to the World Bank (2010), the sector directly employs up to three million people in Indonesia and up to six million worldwide. The economic contribution of palm oil and other plantation commodities provided the assurance of a remunerative source of income and unlimited employment opportunities throughout the year for the people of Malaysia

(Basiron, 2011). Basiron (2011) noted that a day's work of harvesting oil palm fruits can provide a person with an income of more than US $30. In a country where two meals per day would cost only US $4, such an income is rather remunerative. Nobody should be deprived of a better life or even resort to begging as long as he or she is willing to put in a few hours of work in a day in our oil palm or rubber plantations (Sulaiman, 2010). Malaysia enjoys almost full employment, which also means that labour shortages exist especially in the plantation (MPOC, 2011). Generally, women in the villages are responsible for the processing and sale of farm produce. Small scale agro-processing seems to hold the key to rural poverty reduction and the prolific oil palm tree provides the best raw material for starting rural industries (Poku, 2002). According to him, palm oil processing provides sustainable employment and means of livelihood for women in rural communities of Africa. In Indonesia, 1.7 to two million people work in the oil palm sector (Wakker, 2006; Zen *et al.*, 2006). Looking at wider benefits, it is estimated by the industry players that the oil palm sector benefits around 6 million people, many of whom have been rescued from poverty (Goenadi, 2008).

2.8 Related Studies on Small Scale Palm Oil Production

According to Poku (2002), small scale does not necessarily mean a significant decrease in efficiency. It does, however, mean a reduction in working capital and operating costs. The small mills can be placed at the heart of local communities, minimizing reliance on vehicular transport that is normally unavailable in rural communities, given the poor condition of road networks and other infrastructure (Poku, 2002). The small scale sector is a means of helping farmers to get easy access to mills to avoid post-harvest losses. The development of small scale or even portable mills would allow communities and companies to plant and process oil palm fruit in remote areas (Jekayinfa & Bamgboye, 2007). However, they shared a different view in terms of efficiency of these mills as compared to the large mills. They highlighted that the large mills process at least 30 tonnes of fruit per hour, more profitable and require less energy per unit of oil produced than the current generation of small mills.

Omoti (2004) noted that obsolete equipment is mostly used in small scale palm oil processing activities. He indicated that among small scale producers, palm oil is principally processed by traditional or semi- mechanized methods whose system is highly inefficient. Omoti's study revealed that methods used by the small scale processors are laborious, time consuming and inefficient. It also yields very low oil, often of poor quality and more often about 25 -75% of potential palm oil is lost during processing. High cost of processing equipment is a serious problem faced by processors in Nigeria and according to Omoti (2004) this problem has discouraged intending processors from establishing their own mills. Therefore, majority of the processors resort to hiring of processing equipment and this has resulted in delay in processing of the palm fruits. Ekine & Onu (2008) examined the economics of small scale palm oil processing and noted that the quantity and amount of revenue realized by the processors are usually under estimated mainly due to inadequate recording and improper accounting procedures. They also indicated that the level of gross margin of small scale palm oil processors is negatively influenced by several factors, which include cost of palm fruits, cost of hiring equipment, transportation of the FFB, availability of labour, and price of palm oil among others.

2.9 Profitability Analysis in Small Scale Palm Oil Processing

Ibekwe (2008) analyzes the role of women in oil palm fruit processing and marketing. The cost and return analysis showed that palm oil processing is profitable since BCR was 2.13. Ibekwe (2008) pointed out that the larger cost components of the industry were cost of palm fruit, labour, extraction and transportation. Olagunju (2008) also conducted a study on economies of palm oil processing in south western Nigeria and reported BCR of

1.29. The study also revealed the rate of return computed as Gross Ratio and Expenses Structure Ratio to be 0.29, 0.77 and 0.423 respectively. These financial indicators show that the enterprise is profitable. Olagunju (2008) noted that with increased capital, improved technology, improved road network and skilled labour, the processors profit would increase substantially.

In their study of technological and financial assessment of small scale palm oil Production in Kwaebibrem District of Ghana, Adjei-Nsiah *et al.* (2012) reported that in the peak fruit production period of April-May, processors make a loss of 38% of every cedi invested in the palm oil processing business and that the production of palm oil can be a profitable venture only during the lean fruit production season (from September – December) when oil is relatively scarce. According to Adjei-Nsiah *et al.* (2012) processors obtained BCR value of 1.26 in the lean season which quite similar to the BCR value (1.29) obtained by value obtained by (Olagunju, 2008).

Alufohai & Ahmadu**,** 2012) studied economics of processing fresh fruit bunches (FFB) into palm oil and reported that palm oil processing was a profitable business venture. This is evidenced by the gross margin and net profit per 20-litre of palm oil of N2, 080.51 and N1, 613.11 respectively. The Return on Investment (ROI) of 66% and the Benefit-Cost Ratio of 1.66 showed that the business was viable (Alufohai & Ahmadu**,** 2012). The value-added computation showed that it is more advantageous to process the Fresh Fruit Bunches before selling since the value of the product could be increased significantly

(Alufohai & Ahmadu**,** 2012).

2.10 Constraints to Small Scale Palm Oil Processors

According to Fold & Whitfield (2012), the impediments in the small scale palm oil sector in Ghana include low-yielding oil palm variety, low productivity of farm and mill, low quality of crude palm oil, lack of access to finance (including working capital and capital investments) as many of the small scale processors have poor financial records with the banks. Efficient utilization of resources; and training and retaining skilled workers are also problems in the sector. The assertion made by the (FAO, 2005) that, many of the small scale processors do not attempt to find out what their production costs are, because they believe that it is too complicated or too difficult and this affects their output is not much different from that of Fold & Whitfield (2012) as they all point to inefficiencies in the sector leading to low productivity. Ibekwe (2008) has studied the role of women in palm fruit processing and marketing and identified lack of access to capital, limited access to extension services, lack of ownership of land, high processing cost, price fluctuations and women domestic activities as problems militating against the small scale palm oil sector in Nigeria.

Ayodele (2010), in his study on palm oil and economic development in Nigeria and Ghana reported that the main problems that hinder increased palm oil production, to at least meet the local demand, includes land acquisition, infrastructure, finance and out of date production techniques. According to Ayodele (2010), 73% of palm oil producers in Nigeria and Ghana rank higher poor infrastructure and lack of access to finance as their biggest challenges in the sector. Olagunju (2008) also stressed that factors such as lack of access to improved infrastructure and finance are major downsides of the palm oil industry. The assertions made by Olagunju (2008) on the constraints facing the small scale palm oil processors are in consonance with that of (Ayodele, 2010).

Ekine and Onu (2008) also studied economics of small scale palm oil processing in Nigeria and reported that inadequate fund is the major problem faced by palm oil processors hence most of them could not establish their own processing mill. Omoti (2001) stated that Nigeria has enormous potential to increase her production of palm oil and palm kernel primarily through application of improved processing techniques which are limited in the sector. Alufohai & Ahmadu (2012) affirmed that major problems confronting the small scale palm oil processors in the Edo State, Nigeria were inadequate capital/lack of credit (88%), high cost of labour (58%) and lack of transportation facilities (50%).

CHAPTER THREE

METHODOLOGY

3.1 Materials, Equipment and Methods

3.1.1 Materials

Material selection for this work is based on service requirement, fabrication requirement and economic requirement as reported by Oyejide & Salisu, (2018). The service requirement involves the properties a material should have, to serve the purpose for which it is designed for and some of these properties include; corrosion resistance, strength, toughness, resistance to heat, maintainability, safety among others (Oyegide & Salisu,2018). Fabrication requirement necessitates workable properties a material should have and they include; machinability, forgability, malleability, ductility, weldability, castibility, among others, the economic requirement entails the affordability of the material for fabrication and commercialization of the product (odinikuku&salisu,2018). table 3.1 and 3.2 shows the summary of the choice of materials and equipment used in the work.

Table 3.1: Summary of the choice of materials selected

Part	Material	Justification
Digester drum	Mild steel	• It is cheaper • Ease of fabrication • High resistance to deformation • Availability
Frame stand	Mild steel	• for strength, toughness, withstand shear force and compression
bearing	High carbon steel	• resistance to wear and corrosion, hard, tough and high strength
Main shaft	Mild steel	• can easily be machined • it is cheaper and readily available • it is hard
hopper	Mild steel	• it cheaper • easy to fabricate • availability

Table 3.2: Summary of the choice of equipment selected

Part	Equipment choice	Justification
Power source	6HP	• Low cost and reliable • Low vibration and noise • Less fuel consumption

3.2 Methods

The following methods were adopted in this project work.

3.2.1 Design consideration

The following factors were considered while designing the machine

- The environment
- The load capacity
- Material properties
- Reliability of the machine
- Maintenance strategy

3.2.2 Design alternatives

Table3.2: depicts different design alternative that could be selected for the research work

Table 3.3: Design alternatives

consideration	A	B	C	D	SELECTION
Prime mover	Petrol engine	Diesel engine	Electric motor	Steam engine	A
Frame stand	Pipes	Angle bar	Flat bar	wood	B
Drum	Stainless steel	Mild steel	Iron	Aluminum	B
Shaft	Steel	Mild steel	Iron	wood	C
Hopper	Stainless steel	Mild steel	iron	Aluminum	B
Beaters	Flat bar	iron	Angle bar	Stainless steel	A

Thus, a petrol engine, angle bar, flat bar, mild steel, and Iron were selected**.**

3.2.3 Design determination

According to Osoiro & Udu,(2013), having considered the primitive method of digestion and mechanized rotary action of the oil palm fruit digester, a lot was taken to determine the development of the machine.

- Higher capacity compared to the traditional/primitive method of the palm fruit digestion.

- Reduction in drudgery associated with the traditional/primitive method.
- Strength of material should withstand the force acting on the various components of the rotary palm fruit digester.
- Simplicity and complexity of the digester should suit the intended user(s) and has no side effect on him and his environment
- The general configuration of the machine and the factors of safety administered for effectiveness and efficiency.
- The power ratings of the engine to be used.
- The configuration and operation techniques of the machine when in operation.
- Ease of operation, choice of material and machine affordability.

3.2.4 Design requirements

The following functional parameters and component parts are required in this research work:

- High strength (tensile and compressive) material
- Density and weight of boiled palm nuts.
- Power required: petrol engine
- Main shaft diameter
- Digester arm diameter
- Selection of bearing for shaft

3.2.5 Design consideration

The following were the considerations made in designing the machine

- Volume of the drum
- Full load condition
- Power determination
- Machine Torque
- Petrol engine
- Bearing selection

3.2.6 Detailed design

Below are some calculations made to determine details of parts of the machine

a. Volume of the drum

The volume of the drum is given by Equation (1).

$$V=\pi r^2 h \qquad (1)$$

where,

h= height of drum

r= Internal radius of the drum

di= Internal diameter=194mm,

ri =194/2 = 97mm

de= external diameter= 200mm

h= 610mm

V=3.142× (97) ²x610

V=18031139.619mm

V=18031.14mm³

V=0.018m³

b. Required load

The density of boiled palm fruit is given by Equation (2).

ρ=m/ v (2)

where,

m= mass of boiled fruit

v= volume of the drum

ρ = 12/18031.14 =0.00067kg/m³

c. Power determination

In accordance with the American society of Agricultural Engineers (ASAE), the rupture strength of palm fruit sterilized at 100°C under atmospheric pressure for a period of 45 minutes is 1.082N/mm² (Agbonkhesse & Omoikolo, 2018). Using the above value, the rupture force can be determined as follows;

SR = FR/ AM (3)

where,

SR = rupture strength

AM = area of palm fruit mesocarp (mm^2)

FR = rupture force (N)

Assuming that the palm fruit is a sphere, the area can be determined as follows;

$$AM = 4\pi (Rm)^2 \quad (4)$$

d. Machine torque

Torque transmitted per digester arm is given by Equation (5).

$$(Td) = FR x LD \quad (5)$$

where,

LD = Length of digester arm

Thus, total torque in the digester

$$(T) = TD \times n \quad (6)$$

where, n = Number of digester arm

$FR = m\omega^2 LD$

The angular speed of shaft (ω) is determined from Equation **(7)**

$$\omega = \sqrt{(FR/ mLD)} \quad (7)$$

FR = mg

m= FR g

Therefore,

$\omega = \sqrt{(g/ LD)}$

$Pd = T\omega$ (8)

where,

Pd=Power required of the digester

T = Torque

ω = Angular velocity

The area of palm fruit mesocarp (mm^2)

$AM = 254.5mm^2$

The rupture force is calculated as shown;

$FR = 1.082 \times 254.5$

$FR = 275.37N$

Torque transmitted per digester arm (Td) = FRxLD

$Td = 275.37 \times 0.07 = 19.28Nm$

Total torque in the digester $T = Td \times n = 19.28 \times 20 = 385.6Nm$

$FR = m\omega^2 Ld$

$\omega = \sqrt{(10/ 0.07)}$

$\omega = 11.95rad/sec$

Pd = Tω

Pd = 11.95 x 385.6

Pd = 4600w

Pd = 1863.6w /746w = 6.1hp

3.2.7 Description of the oil palm fruit digester

The machine is made up of the following major components; petrol engine, digester barrel/drum, main shaft, beater arms, discharge end, frame stand, ball bearings, hopper and bolt and nuts.

a. Petrol engine

The petrol engine is the prime mover present in the machine. It is powered by petrol which then drives the main shaft connected to it. It helps in reducing the noise, vibration and stress other prime movers might induce in the system. In this research work, 6hP engine was used.

b. Digester barrel/drum

The digester barrel is the part that houses the main shaft which carries the beater arm; the petrol engine is mounted on the digester stand /table when in operation. Parboiled oil palm fruits are fed into the digester barrel through the feed hopper. The petrol engine serves as the prime mover which powers the shaft and beater arms for turning or digesting. It is a simple 200mm cylindrical drum shape and it is placed horizontally with a hopper on the top. The bottom part of the digester is the discharge end where the digested fruits passes out.

c. Main shaft

The main shaft is made from a mild steel rod with a dimension of 35mm diameter and length of 920mm. The beater arms are attached at its sections, centrally located in the digesting barrel and is supported at both ends by a sealed ball bearing.

d. Frame stand

The frame stand is a base which provides rigid and skeletal support of length 560mm x 350mm and a height of 500mm for the entire machine system. It consists of compartments for both the digesting chamber and the prime mover (petrol engine). The frame is made of mild steel angle bar (45mm x 45 mm, 4mm thick) which is joined by welding to provide a very rigid joint. The frame is attached to the digesting barrel by bolts and knots.

e. Beater arms

The beater arms are elements attached vertically to the main shaft

f. Bearings

Pillow bearings are used in this machine. They are located at both ends of the main shaft in order to reduce friction between the contacting parts and increase shaft speed.

g. Hopper

The hopper was made with of 2.0mm mild steel sheet. The shape of the hopper is triangular and provides a doorway to the digestion chamber. The hopper is mounted on the digestion Chamber and has square shape at throat region for easy flow of the palm fruit.

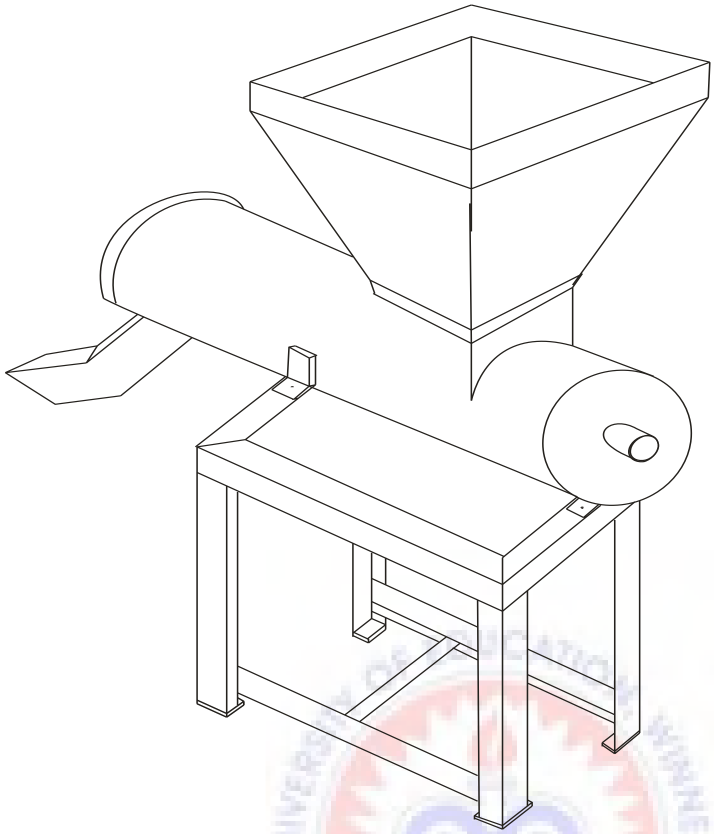


Figure 3.1. Isometric view of the downsized palm fruit digester

3.2.8 Fabrication location

The place of fabrication is Rural Technology Facility (RTF) Bechem. RTF is a mechanical workshop in the Tano south municipality in the Ahafo Region. The workshop is situated off Kumasi to Sunyani road. RTF could be described as an engineering workshop equipped with metal working machines for technical training and the development and promotion of appropriate technology to micro and small-scale enterprises (SMEs) in the municipality.

The major functions of the Centre are as follows:

- Train traditional apprentices
- Train technical apprentices
- Train students (polytechnics, technical institutions, universities) on attachment

- Provide technological support services
- Repair services

3.2.9 Fabrication process

The fabrication process involves using the selected materials and constructing the product based on the design and the desired dimension. The various methods used during the fabrication of the machine from start to finish include; measuring, marking, cutting, joining, drilling and finishing. This was done part by part before assembly of each component

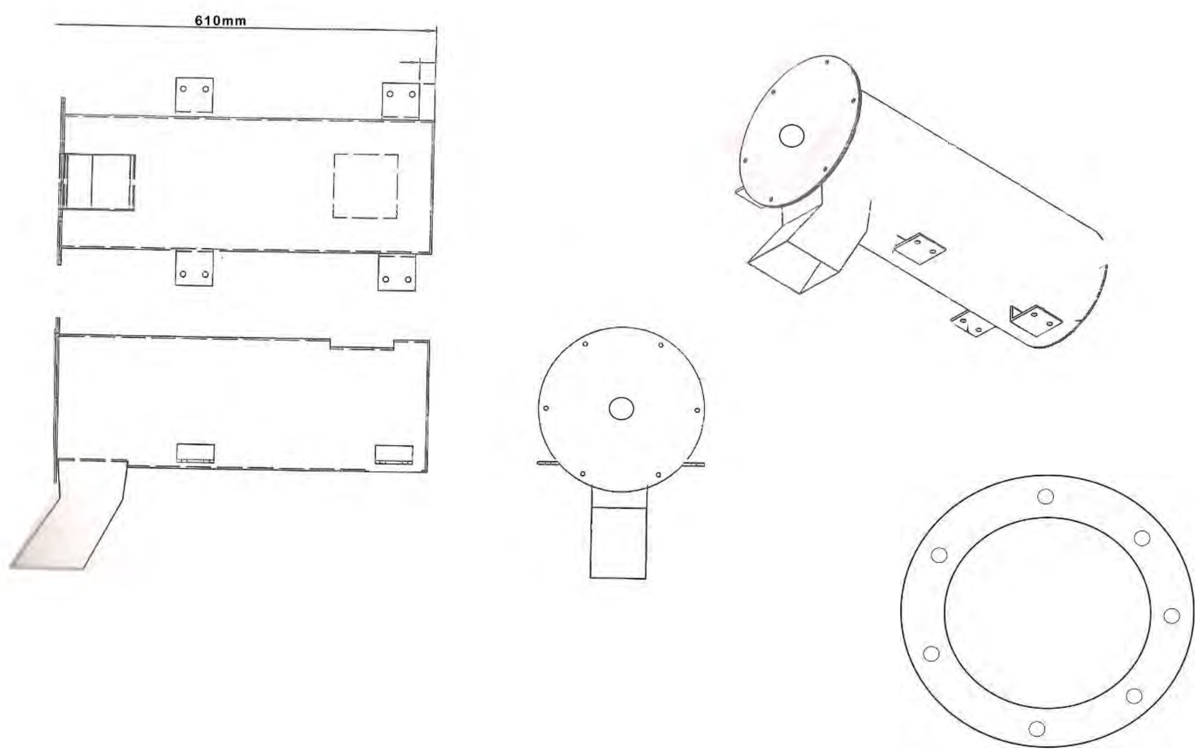


Figure 3.2. view of the digester drum

Materials needed to form the digester drum are as follows:

- 6mm mild steel plate – to be rolled to form the cylindrical shape
- Grade 10 mild steel electrodes – for welding
- Bolts and nuts – to fasten the flange to the drum
- Try square – to check the angles
- Scriber – for marking out

Steps involved in fabricating digesting chamber/drum

The following were the basis steps that were followed in fabricating the drum

- The diameter of the digester drum is 200mm and the length is 610mm. in order to get the size of the plate to form the diameter, we use the formula for finding the circumference which is Circumference= πd or 2πr where d= the diameter and r=radius.
- Using πd, we have 3.14x200mm=628mm. the 6mm mild steel plate is marked to the size of 628mm x 610mm. The tools used for the marking out are the try square, scribe and a straight edge.
- With the use of the shears, the plate was successfully cut.
- The plate was then sent to the rolling machine to be rolled and get the cylindrical shape.
- The ends were successfully joined by welding them together.
- A plate of the same thickness and diameter was drilled in the middle on the Centre lathe machine with a drill size of 27mm.
- After that it was welded to one end of the cylinder
- Two plates of the same thickness were cut round to a diameter of 280mm.

- Inside one of the round plate was another circle constructed at a diameter of 200mm.
- With the use of the Centre lathe machine, the inner circle was machined off leaving a round space of the same diameter as the cylinder formed
- Six holes of diameter 10mm are drilled on the plate to make way for bolts and nuts of the size 17.
- The round plate was welded at the open end of the drum. The hole in the plate fits exactly at the end of the drum since they are of the same diameter. The plate welded to the drum is called the flange.
- A hole of diameter 27mm was drilled in the Centre of the other round plate to make way for the digester shaft.
- Holes were drilled at the same positions as flange to make it possible for fastening by the use of bolt and nuts
- Space was cut under the cylinder for the discharge (the outlet of the machine) to be fixed. A space of 120mm square was also created to make way for the hopper (the inlet of the machine).
- The two ends of the digestion chamber were drilled in order to make way for the digester shaft into the bearing. Beneath the holes are well positioned and welded 40mmx40mm angle iron to serve as a seat for the bearing. The shaft that fits a bearing of the size 205 is 25mm shaft.

The hopper fabrication

The hopper is the inlet of the machine and it is placed on the digestion chamber.

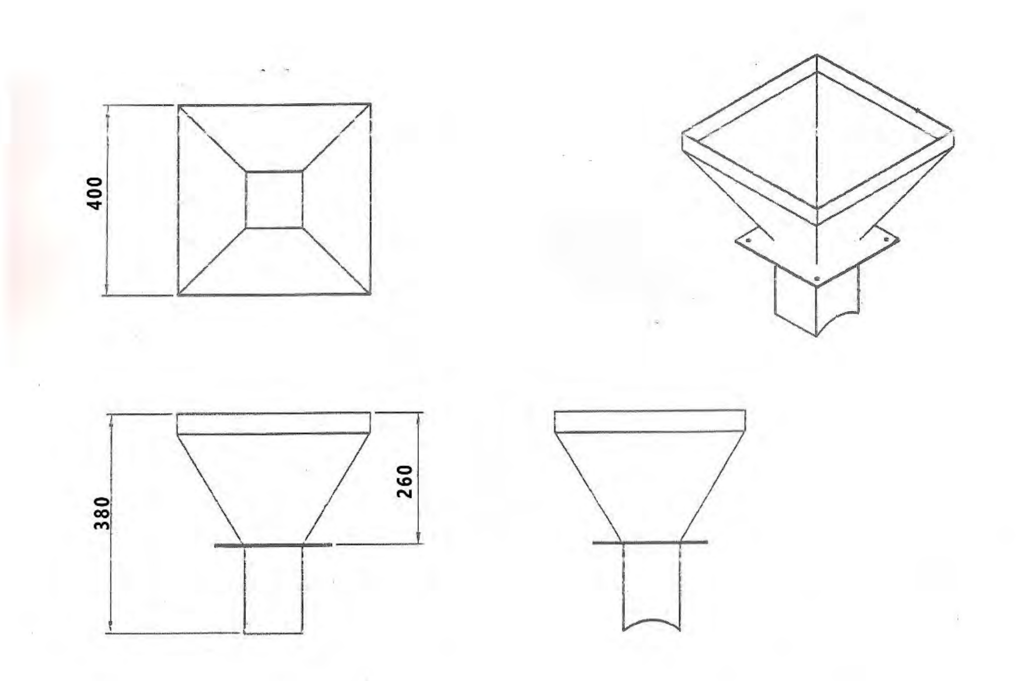


Figure 3.3 the views of the digester hopper

Materials needed to form the digester drum are as follows:

- 2mm mild steel plate – to be rolled to form the cylindrical shape
- Grade 10 mild steel electrodes – for welding
- Try square – to check the angles
- Scriber – for marking out
- Tape measure- for measurement

The hopper has four parts with the same measurements; however, we will be going through one part since the other three follows the same procedure. In some cases, we can use one part as a pattern to mark the other three parts so save time.

The main material used for the fabrication of the hopper is the 2mm mild steel plate. The hopper has a height of 260mm and the top is 400mm and has a base of 120mm.

To realize the shape, we go through the following procedure:

- By the use of the tape measure, try square and scriber, we mark the plate at 400mm x 260mm.
- From the top of the plate to down, we mark 50mm at both edges.
- The down part of the plate also measures 400mm, but the neck of the hopper is 120mm. to be able to get the base, we subtract 120mm from the 400mm which gives us 280mm. and we divide it by 2. Which is 140mm.
- We measure and mark 140mm from each end of the base of the plate.
- From the top where the 50mm mark is, we construct a straight line to join the 140mm mark is, thus giving a triangular shape on the plate.
- With the use of the shear the shape was cut out of the parent plate.
- Same procedure was followed to cut the other three parts.
- Grade 10 electrode was used to tack all the four parts together.
- A 3mm thick plate was cut at a measurement of 160mm square.
- With the use of a cold chisel, the inside of the 3mm thick plate is chopped off at a measurement of 120mm square and filed to avoid sharp edges.
- The base of the formed hopper was tacked to the space created on the 3mm plate serving as the seat for the hopper. Diameter 7mm drill bit was used to drill the four corners of the base plate to make space for bolts and nuts.

The stand

The stand of the digester is the part of the machine that carries the other parts such as the digestion chamber and the petrol engine and are attached to the to the table by bolts and nuts for easy disassembling during transportation and servicing. The table has a rectangular shape of 56ommx350mm. with four legs with a height of 500mm.

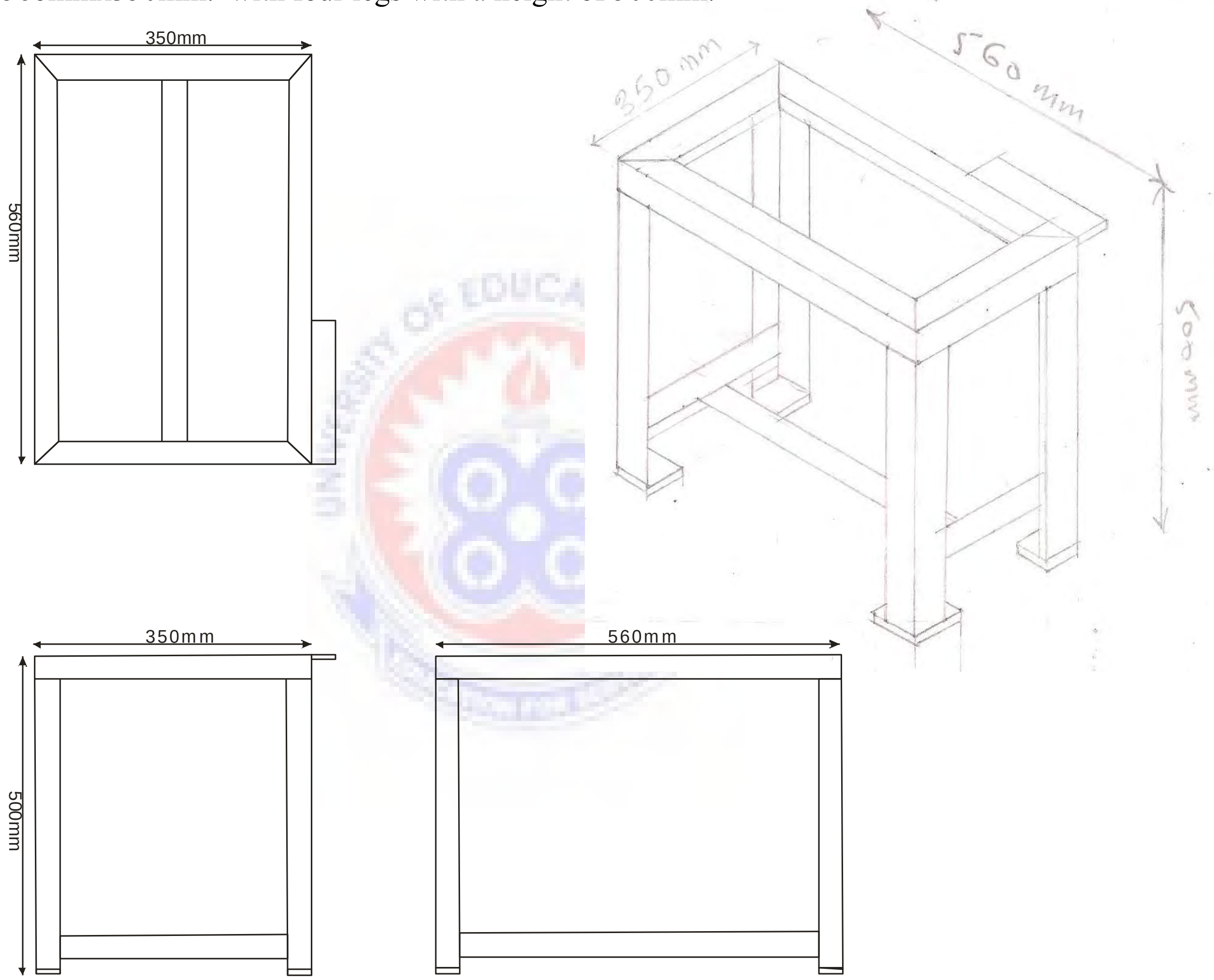


Figure 3.4 the views of digester stand

Below are the materials required for the fabrication of the stand followed by the fabrication procedure.

Materials needed to form the digester drum are as follows:

- 45mm x 45mm angle iron
- Grade 10 mild steel electrodes – for welding
- Try square – to check the angles
- Scriber – for marking out
- Tape measure- for measurement

Fabrication procedure

- The tape measure was used to take a measurement of 560mm(two) and 35omm(two)
- With the help of the try square, the scriber was used to do the marking
- The cutting tool the was used cut the angle iron is the hacksaw (the cutting were done at a mitre, so after joining two faces, angle of 90° is attained)
- The table has a height of 500mm with four legs
- This time around the cutting was done at an angle of 90°
- With the use of the electric arc welding machine, the legs were attached to the table.
- To make the table more robust, an angle was welded at two opposite sides of the legs and then another is welded to join the two.

The digester shaft

The main digester shaft is made from mild steel shaft with a diameter of 27mm and a length of 860mm.the beater arms are attached at its section, centrally located in the digestion chamber and its supported at both ends by e sealed pillow bearing.

The beaters are attached to the central shaft to provide the size reduction effects on the palm fruit. On one end of the shaft is the v-pulley, fitted to the hammer shaft to provide the drive from the petrol engine via the v-belt.

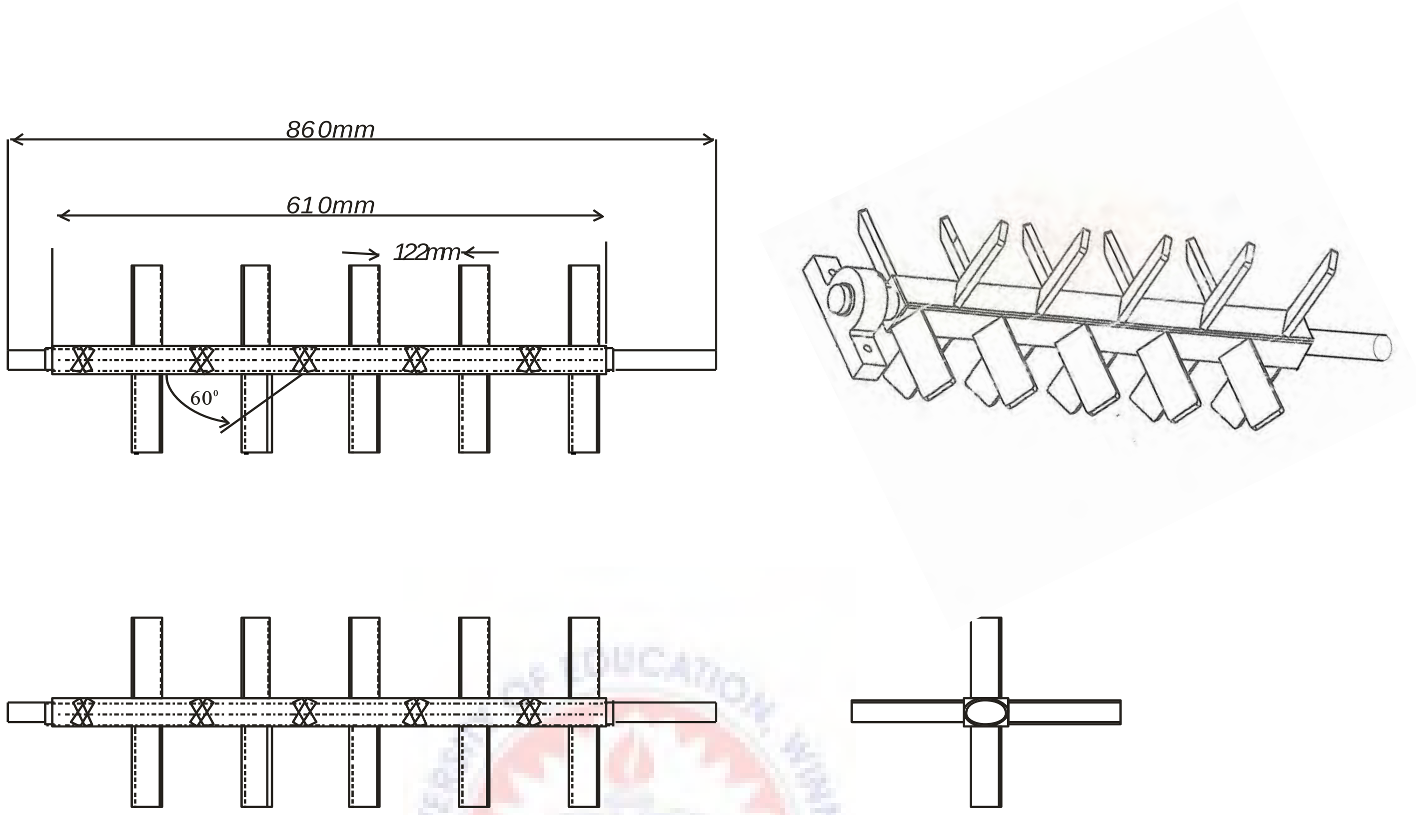


figure 3.5 the views of the digester beaters

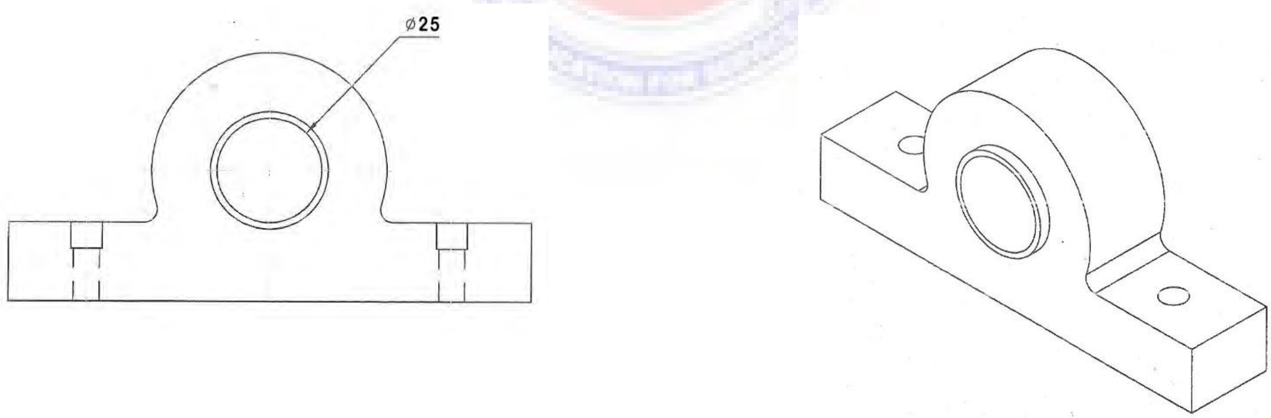


figure 3.6 views of the digester bearing

Materials required for the fabrication of the digester shaft

- 40mmx40mm angle iron –welded around the round shaft to provide flat surface for the beaters

- Diameter 27mm round iron shaft – that serves as the main digester shaft
- Hacksaw – for cutting
- Tape measure – for taking measurement
- Scriber – for marking out
- Flat bar – serve as the beaters
- Electric arc welding machine
- Grinding machine – for cutting of the flat bar

Fabrication process

- The 40mmx40mm angle iron was cut at measurement of 600mm (two pieces) by the use of the hacksaw
- With the help of the welding machine, the two angle irons were welded together to form square open ends
- The flat bar was cut into 20 pieces with one measuring 50mmx70mmx10mmthick by the use of the cutting disc.
- The length and diameter the shaft is 860mm and 27mm respectively.
- The shaft from one end is measured at 160mm and from the other end 100mm.
- The shaft was sent to the lathe machine and both marked ends are machined down to a diameter of 24mm. this was because the diameter of the 205 bearing 25mm.
- The reason why one machined end is longer than the other is that, the shorter end only takes the pillow bearing while the longer machined end takes both the bearing and the pulley.

- On the end that measures 150mm is a keyway that locks the pulley to the shaft with the help of a key.
- After subtracting the turned ends from the length, the middle portion will measure 600mm.
- The formed angle iron is welded around the portion that was not machined
- The flat bar which serves as the beaters are welded to all the four sides on the angle iron. The interval between them is 122mm. the drawing will show more details on the arrangement of the beaters.

Working principle of the machine

The horizontal digester machine designed consists of a cylindrical vessel (drum) that is fitted to a central rotating shaft carrying a number of beater arms, feed hopper which serves as the intake chute for the parboiled palm fruit. With the aid of the rotating beater arms by a prime mover (petrol engine, the fruit is being digested. The horizontal oil digester works on the rotary impact principle. It consists of the hopper, digester barrel, bearings, main shaft, beater arms, discharge end, 5.5hp petrol engine and the table/stand. The digester barrel carries the hopper and the shaft assembly which lies in the central position of the barrel. The shaft assembly is made up of twenty beater arms which are arranged specifically at angles and distances strongly welded to the shaft in the vertical position. When connected to a reliable source of power, the petrol shaft is set in motion which is connected to the beater shaft by a key and bolts and nut. This sets the digestion process in motion. The boiled palm fruits are macerated for some time and then the discharge allows the digested fruits to come out to come out for pressing.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The palm fruit of about 9kg was sourced from a local market in Bechem, Tano South, Ahafo Region. The fruits were washed and cleansed for dirt and other impurities before being boiled for approximately 600 seconds using a gas cooker and a stop watch to accurately measure the time. The mass of the palm fruit after boiling was weighed to be 12kg. After proper assembly and installation of the digester machine, the digestion chamber of the machine was carefully inspected, washed and cleaned to prevent any health hazards. The palm fruits were weighed using a spring mass weighing scale. The total weight was approximately 12kg and was split into three parts of 4kg each. Table 4.1 shows the various mass of boiled palm fruits.

Table 4.1: Various masses of boiled palm fruits

Test	Mass of palm boiled fruit(kg)	Time taken(s)
1	4	120
2	4	130
3	4	150
Σ	12	400
Average	4	133.33

4.2 Mass output

Mass of boiled palm fruit (input) = 12kg

Mass of palm fruit not properly mashed = 3.49kg

The mass output was obtained as the difference between boiled palm fruit and mass of un-macerated palm fruit.

The mass output = Mass of boiled palm fruit – Mass of un-macerated palm fruit= 12 – 3.49 = 8.51kg It is observed that the time taken for each mass of palm fruit to be digested increases except the first mass. This was due to the fact that not all the palm fruit are been digested. Thus, when it was discharged, the unmacerated ones are being separated and poured back into the drum. This test was repeated twice while the time increases as the palm fruit increases inside the drum. Also, the un-macerated fruit is known as the ERROR test and it is being subtracted from the total mass of boiled fruit to give the output.

4.3 Efficiency of the machine

From the three tests carried out. A total mass of 12 kg of boiled palm fruits was taken, split into three sections of two kg each and fed through the hopper when the machine was in operation. The mass of palm fruits not properly macerated was separated and weighed to be 3.49kg. The efficiency is thus calculated as follows;

Efficiency = (Output/Input) × 100%= (8.5/12) × 100%= 70.8%

Thus, the machine is 70.8% efficiency. The machine through-put capacity is calculated from Equation

(13) (Orhorhoro & Ikpe, 2016).

$$MTC = M/T \qquad (13)$$

Where,

MTC = Machine throughput capacity M = Mass of processed of palm fruit T = Processing time

Thus,

MTC =

4/ 133.33

= 0.030kg/sec

With an average machine throughput capacity of 0.030kg/sec, the machine performance is satisfactory.

Table 4.2 shows the results of detailed design of the fabricated downsized oil palm fruit digester machine. The rupture force was calculated as 275.37 N. Power required of the digester were determined by the expression which states that the power is the product of torque (T) and angular velocity (ω). A 6hp petrol engine was selected to give the required torque in the digester. Torque transmitted per digester arm and total torques in the digester was obtained as of 19.28 Nm and 385.6Nm respectively. The volume of the drum was obtained as 0.018m³.

Table 4.2: Results of detailed design

SN	Parameters	Value	Unit
1	Volume of drum	0.018	m^3
2	Density of boiled fruits	0.00067	Kg/m^3
3	The area of palm fruit mesocarp	254.5	mm^2
4	Rapture force	275.37	N
5	Torque transmitted per arm	19.28	N/m
6	Total torque in the digester	385.6	N/m
7	Required power	6	Hp
8	Bending moment on the digester arm	19.28	N/m

CHAPTER FIVE

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

A downsized palm fruit digester was designed, fabricated and performance evaluation carried out. The test result revealed that the machine has an efficiency of 70.8%. The machine is made up of simple components that can be easily assembled. It is designed so that local users can purchase and easily carry out maintenance and at the same time operate the machine with ease for palm oil production.

5.2 Conclusion

The palm fruit digester so far developed is easy to operate. Testing and performance evaluation of the system showed that the system can reduce the labour force since it does not require many hands in its operation. Therefore, manufacturers should take up this innovation of the oil palm fruit digester and implement it in the mass processing of red oil palm fruit for export, domestic and industrial uses.

The use of the petrol as the prime mover makes it possible to eliminate the problems associated with power outages.

5.3 Recommendation

To develop the area of agriculture and industrial raw material development as well as food security and employment, government should take advantage of this innovation.

Short- and medium-term loans should immediately be granted to farmers to enable them adopt this important innovation for mass production of red oil palm in order to meet the growing demand of the nation's industry, local consumption and for export.

Oil palm fruit farmers and local oil palm fruit processing industries are encouraged to patronize this innovation and to increase their profit. The use of this innovation other than the commonly used manual type will attract youths and more investors in this sector as drudgery and tedium has been removed.

Optimization of the oil palm digester to determine its optimum performance parameters is recommended because many operational parameters of this affect its performance differently at the same level.

Since the efficiency is above average, thus., the downsized palm fruit digester machine is highly recommended for end users in palm oil processing

5.4 Suggestions for future research

There are a number of ways in which this study can be extended. This study only focused on the digestion of the palm fruit. However, a comparative project could be done to add screw press to eliminate too much boiling of the soup before scooping the palm oil from the top. In addition, future study should examine the economic efficiency in the small scale palm oil processing industry.

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