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Development and Cost Estimation for Sizing 5 Kw Palm Kernel Shell Steam Boiler

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***ABSTRACT*: *The aim of this study is to develop and estimate the cost of 5 kW Palm Kernel Shell (PKS) steam boiler. Design drawings were produced and used to fabricate PKS combusting unit. Other components needed for the design were selected based on functionality, durability, cost and local availability. Using the developed furnace, maximum combustion efficiency, steam temperature and pressure were estimated based on primary to secondary air supplied. The results showed that the primary to secondary air setting of (40:60) recorded highest combustion efficiency of 64.5% for a fuel feed rate of 17.3 kg/hr. The boiler's maximum steam temperature, pressure and mass flow rate recorded for 5 kW power rating were220 ^{o} C, 0.38 MPa and 0.023 kg/s respectively. The overall cost for sizing the boiler components is cheap (approximately $ 1,658.906) in comparison to similar design overseas ($ 2,223.56) and thus will serve as an alternative source of energy.*

KEYWORDS: *Cost, Furnace, Palm kernel shell, Power, steam generator*

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I INTRODUCTION

Agriculture remains one of the important sectors of the economy in Nigeria. It creates employment for about 70 % of Nigeria's populace and contributes about 40 % to the Gross Domestic Product (GDP) with crops production accounting for 80 %, while livestock and fishery account for 13 % and 4 % respectively [1]. One of the key agricultural crops in Nigeria is palm fruit which is found mostly in Southern Nigeria especially in the wet rain forest savannah belt. It also exists in the wet part of North Central Nigeria in areas such as Southern Kaduna, Kogi, Kwara, Benue, Niger, Plateau, Taraba, Nasarawa, Osun and Ondo States [2]. Solid wastes from palm tree comprise of Empty Fruit Bunches (EFB), Palm Press Fibre (PPF) and Palm Kernel Shell (PKS) . These solid wastes from palm tree accounting for 20-23 % of EFB, 12-15 % of PPF and 5-7 % of PKS based on its capacity [3]. However, much of these biomass wastes are left to decay in plantation areas or creating environmental nuisance [4]. Utilizing wastes, particularly PKS from oil palm industry for energy purposes could support the existing energy sector in Nigeria.

There are several technologies that enable oil palm mill to generate enough energy for its consumption and sometimes for export. Among them are fixed (1 kW- 50 MW), fluidized (5 MW- 100 MW) and dust technology (10 MW- 500 MW). Efficiencies of these technologies are dependent on fuel properties and the mixing quality between flue gas and combustion air [5]. Ninduangdee and Kuprianov [6] recorded high combustion efficiency and low emission performance in a fluidized bed combustion of palm kernel shell using optimized particle size, although the start up and running cost of operation associated with this technique make it difficult to be operated by small scale business. Remarkable improvement has also been recorded on design of large scale grate furnaces (fixed bed), yet additional work need to be done in small scale businesses in term of poor mixing especially when co-firing different fuel and high moisture fuel content for improve combustion and reduction of ash deposition on components of grate furnace [7]. The unique features of grate furnace are the tolerance of fuel type; positive movement of fuel down grates reduces blockages and well controlled air distribution lead to high combustion efficiency [8].These will increase combustion process and decrease ash deposition.Boiler design is a complex and time consuming procedure. Previously, emphasis was laid on primitive and probabilistic design processes which resulted in high cost of production. Dimensions of boiler for power generation often depend on fuel and vaporization efficiency; the mass balance, heat balance and heat transfer which has to be specified through empirical results and experiences. In this paper we aimed at design and estimate the cost of palm kernel shell combusting furnace for 5 kW power rating.

II MATERIALS AND EQUIPMENT

The basic materials for this study were palm kernel shells and additives (Al_2O_3, MgO and CaO) obtained from palm oil mill in Ogbomosho and Ilorin respectively. The equipment used include the air flow metre, Spectrophotometer, 12 points temperature channels recorder, air quality metre, X-ray diffractometer, muffle furnace, Gallen Kamp Bomb Calorimeter.

2.1 Furnace Operation and Development of Power Plant Components

The furnace under consideration was based on principle of water tube natural circulation. The main components of this furnace are steam drum, downcomer, riser tubes which represents the complete fluid flow loop. Water flows to the steam drum through downcomer riser loop. The riser tubes were situated inside furnace where heat of flue gases vaporizes the water into steam and back to the steam drum through steam header collection (Fig. 1). Due to the fact that steam water mixture inside riser tubes is less dense than the saturated water at inlet tube, fluid flows upwards in the riser tubes and back to the drum. The density difference between water at the inlet tube and steam-water mixture produces enough force to overcome friction and gravitational resistance to flow, therefore maintain a steam flow system [9]. The steam drum is partitioned into two zones. The lower section allows water intake to the drum while the upper section produces steam which flows from the top of the drum into the superheater tube. The superheated steam is expected to turn turbine to generate electricity

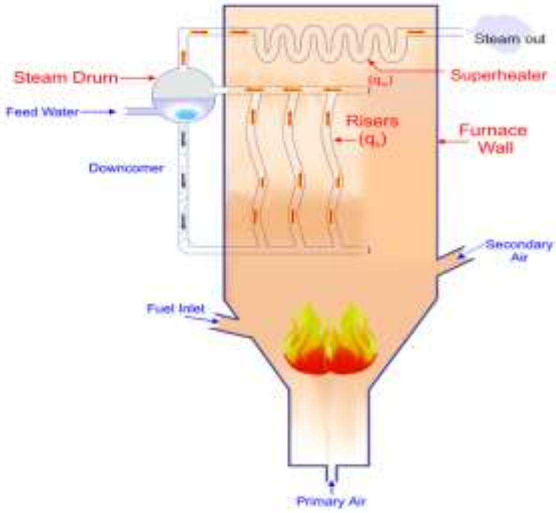


Figure 1. Schematic diagram describing water to Steam Circulation Loop

2.2 Refractory Brick Developed for Lining Furnace

The raw materials used in this study were kaolin, ball clay and hard wood sawdust. The sawdust in the mixture form uniform pores in order to allow heat energy stored in kaolin and it did not bloat while ball clay serves as binding agent. The kaolin was collected from Titibi in Awo, Osun State, Nigeria, while the ball clay and sawdust were collected from Orile – Igbon, Ogbomosho, Oyo State. The ball clay was soaked in water for five days to allow it to dissolve completely in orders to separate colloids from pebbles. The kaolin was milled to powder form using ball mill and then sieved to particle size of diameter 2.5 mm. The ball clay was sieved to 1.0 mm and similarly powders of sawdust of particle size 2.5 mm. The study carried out had a composition of kaolin as 60% by weight while ball clay and sawdust are 30% and 10% respectively according to [10]. The mixture of these powders with water was then rammed into a rectangular specimen with dimensions (275 mm×130 mm×60 mm) as shown in Fig. 2. The samples were sun dried for two weeks and then fired to 1200 ^{o}C in a kiln, a Pyrometric Cone Equivalent (PCE) was used to test the refractoriness of the bricks developed. About 80 sample formulations had a total of 300 g (180 g of kaolin, 90 g of clay and 30 g of sawdust).

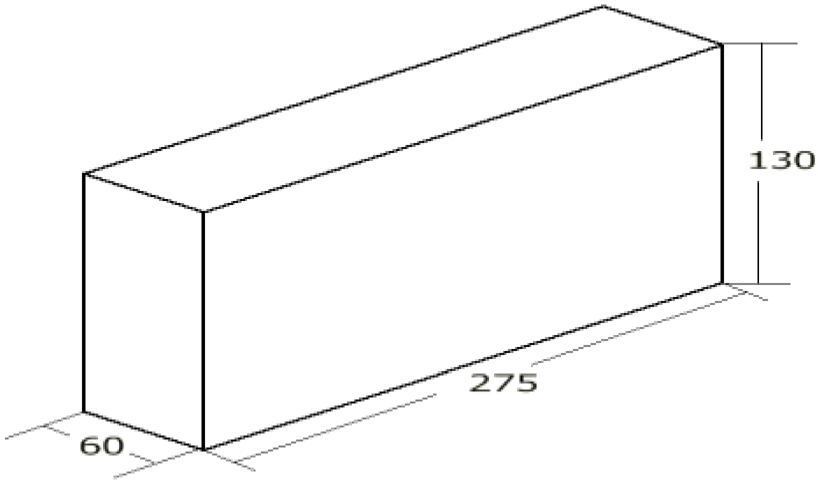
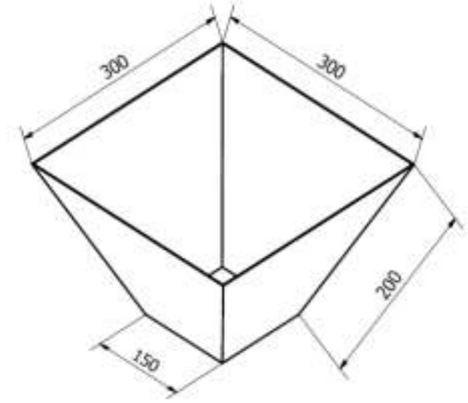
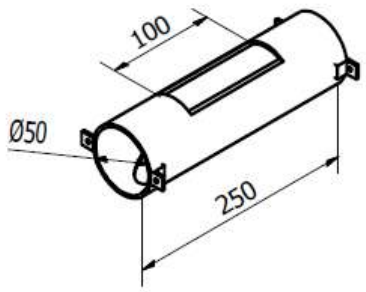
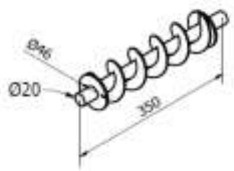


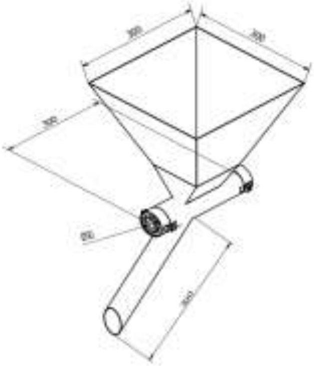
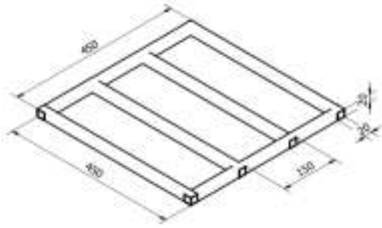
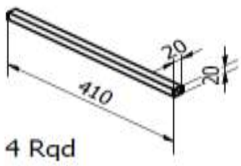
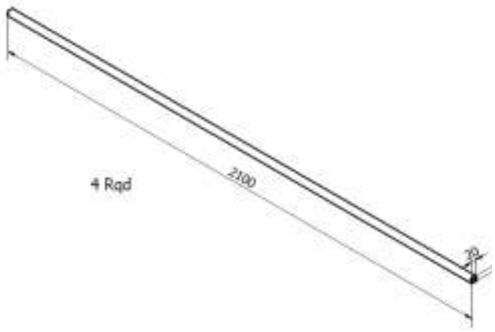
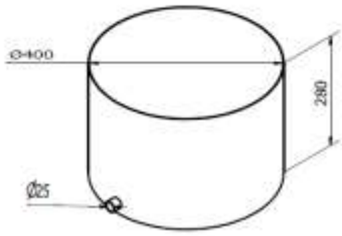
Figure 2. Refractory brick

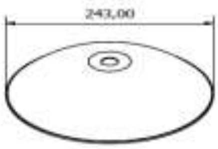
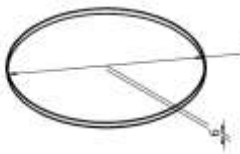
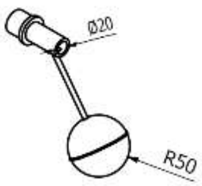
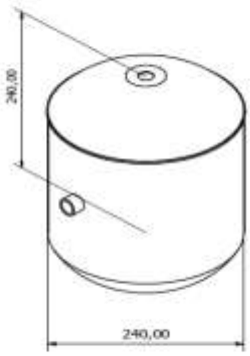
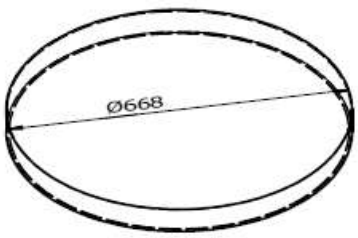
2.3 Fabrication Procedure and Assembly of Developed PKS Furnace

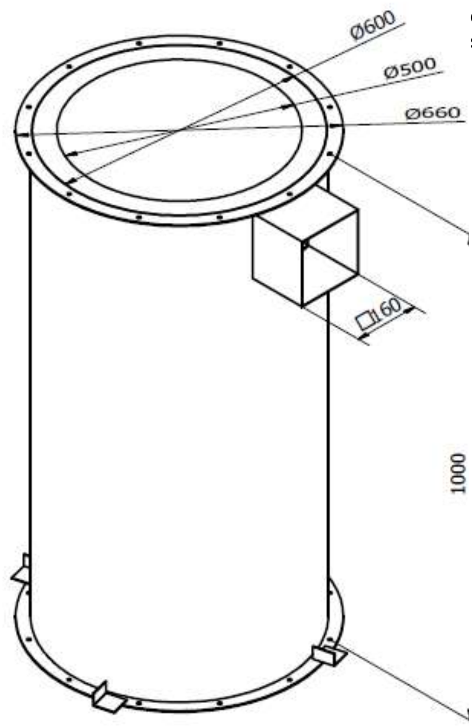
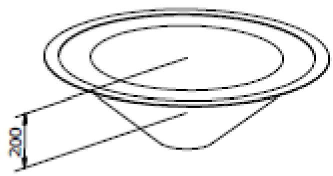
The components of the furnace developed are feeder, riser, water tank, steam drum, and furnace chamber. Each of the component's fabrication process, design and measurement, material selection and cost were shown in Table 1 according to Oladosu et al., (11). Fig. 3 shows the exploded view of the developed PKS combustion unit.

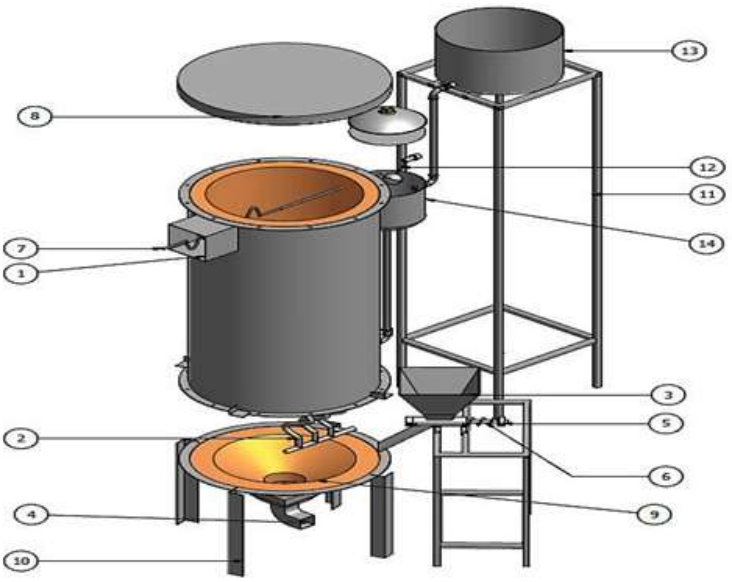
Table 1: Fabrication Processes of PKS Furnace

Component	Fabrication process	Component design and measurement	Material selection
Loading hopper	Cutting and welding steel plate		Steel plate, chisel, hammer, grinding disk and electrodes.
Auger housing	Boring of steel pipe		Chisels, ball and pine hammer, drill bits and half round files
Auger and screw conveyor	Cutting and welding		Chisels, cutting disc, hammer, hacksaw and electrodes
Bearing housing	Welding of housing bearing and flange		Files, chisels hammer and electrodes
Discharged pipe	Drilling and cutting of steel pipe		Drill bits, hacksaw, and files

Assembly of hopper, auger housing, bearing housing and discharge pipe	Assembly of hopper unit using welding machine		Electrodes, ball bearings
Water tank frame	Cutting and welding of square pipe		Vice, hacksaw and electrodes
Tank support	Cutting and welding of angle iron to hold up water tank and brazing		Vice, hacksaw and electrodes
Water tank	Cutting and welding of steel plate		Chisel, hammer, anvil, drlling machine and electrodes

Assembly of water tank and frame			Electrodes,try squares
Drum cover	Cutting and drilling of steel plate		Shear cutting machine, drill bit
Steam separator	Cutting of steel plate		Spinner, hammer
Inlet water pipe control valve	Cutting and external thread of shaft		Tap and die ,drill bit, and hacksaw
Assembly of drum cover, steam water separator and inlet water pipe control valve	Drilling and welding of drum using welding machine		Electrodes,
Furnace lid	Cutting and welding of flat sheet plate		Hand shear cutter, electrodes, chisel and hammer, mild steel

Furnace	Cutting and welding, stack up the developed bricks to the wall furnace of		Galvanized steel, mixture of kaolin, ball clay, sawdust, and water,
Furnace bottom	Cutting and welding of cone shape		Mild steel, divider, protractor



Item	Qty	Part list
1	1	Superheater exit port
2	3	Riser
3	1	Hopper
4	1	Primary air inlet
5	2	Ball bearings
6	1	Auger
7	1	Superheater
8	1	Furnace cover
9	1	Bricks
10	1	Furnace stand
11	1	Water tank stand
12	1	Water level control valve
13	1	Water tank
14	1	Drum

Figure 3. Exploded view of the developed PKS Combusting Furnace Unit

2.4 Experimental set up

The assembly of the furnace (Fig. 4) was designed in two sections: A conical section (0.25 m height with 45^{o} cone angle and 0.2 m inner diameter at the bottom plane) and cylindrical section (of approximately

0.4056 m^3 combustion volume and inner diameter of 0.6 m). The two sections had 0.5 m thick metal wall lined internally with refractory brick insulations of 0.25 mm thickness. Feed water was supplied to drum boiler and down comer risers loop connected to superheater tube. In addition, facilities for measurement were such as 12 points channel temperature recorder, air quality meter and air flow meters were used. The primary and secondary air flow was employed in the furnace for ensuring better mixing quality required for good combustion. Five K-type thermocouples with tips along the axis of combustion chamber for temperature measurement and air quality meters to detect CO, CO_2, and O_2, which were placed at different locations in the grate furnace (above the grate, core of the furnace, steam collection header, above steam header and exhaust port). Oladosu et. al., [12] reported the optimum mixture of PKS and selected additives for maximum combustion efficiency as [Al_2O_3 (2.5 %), MgO (0.0 %), CaO (5.0 %), PKS (92.5 %) and particle size (5.50 mm)]and the major operating variable, primary to secondary air ratio were selected for the test. The fuel feed rate was maintained to be constant (3.24 kg for every quarter an hour up to a maximum of 17.3 kg/hr. (in all combustion test).

Figure 4. Fabricated PKS Combusting Furnace

III RESULTS AND DISCUSSION

These are based on: evaluation of the furnace combustion efficiency based on primary to secondary air supply ratio, comparative view of results obtained with state properties of superheated steam generated for 5 kW power rating ease of maintenance, safety and health considerations and economic cost.

3.1 Evaluation of the Furnace Based on Combustion Efficiency when Firing PKS at Different Ratio of Primary to Secondary Air Supply.

Combustion efficiency based on primary (Pry) to secondary (Sec) air ratio, CO, CO_2 and temperature of flue gas were reported (Table 2). It was observed that air split ratio of 40:60 recorded maximum combustion efficiency (64.5%) and it is well comparable with the efficiency of biomass combustor for Agro-industry reported by Rogaume et. al. [8].

Table 2: Summary of test parameters on effect of the primary to secondary air supplied on combustion efficiency and gaseous emission

Pry: Sec air ratio	Fuel feed rate (kg/hr)	Temperature (^oC)	CO (ppm)	CO_2 (ppm)	$L_{thermal}$ (%)	$L_{chemical}$ (%)	Combustion efficiency (%)
30:70	17.3	760	301	7484	11.00	27.76	61.24
40:60	17.3	785	285	8497	11.03	23.49	64.58
50:50	17.3	673	372	7006	9.60	36.69	53.71
60:40	17.3	620	408	6875	8.71	41.01	50.28

3.2 Comparison of the results obtained with data sheet for steam turbine generator for 5 kW power rating

By way of validating these results, a search was done where PKS was used to generate steam for electricity production and from website V-FLO pump and system (www.V-FLO.COM). Power rated (5–45) kW requires maximum inlet temperature and pressure range of 400 ^oC and (0.45-4.2) MPa respectively and from this study, 5 kW requires maximum inlet temperature of 200 ^oC and pressure of 0.38 MPa, (Table 3). Assuming direct proportionality the results obtained is better or probably within the range.

Table3: Differences between the developed and imported 5 kW PKS Steam generator

Parameters	This study	V-FLO Pump and system www.V-FLO.COM
Power rated (kW)	5.00	5 – 45
Inlet maximum temperature (^oC)	220	400
Pressure (MPa)	0.38	0.45 - 4.2
Mass flow rate (kg/s)	0.023	

3.3 Cost Analysis

The materials and equipment used for the PKS combusting furnace design is shown in Table 4. The materials and equipment used are locally sourced and the overall cost for sizing the furnace component is approximately $ 1,658.906 (assuming ₦320 exchange rate to 1 dollar). The furnace (steam generator) is cheap in comparison to similar design overseas $ 2,223.6 (www.ecpush.com).This would greatly be interesting and be useful as energy back up in oil palm mill industry

IV CONCLUSIONS

The research was focus on the design and cost estimate of palm kernel shell combusting furnace for 5 kW power rating. The design philosophy is to alleviate unreliable energy supply in Nigeria which has left the rural dwellers socially backward with untapped economic potential. On completion and testing of the developed furnace it was observed that the primary to secondary air supply of (40:60) recorded highest combustion efficiency of 64.5% for a fuel feed rate of 17.3 kg/hr. The maximum steam temperature, pressure and mass flow rate recorded for 5 kW power rating were 220 ^{o}C, 0.38 MPa and 0.023 kg/s respectively. The overall cost for sizing the furnace component is approximately $ 873,857 assume **N** 320 exchange rate to 1 dollar. The furnace (steam generator) is cheap in comparison to similar design overseas $ 1350.6 (www.ecpush.com).This would greatly be interesting and be useful as an alternative source of energy

Table 4: Bill for Engineering Measurement and Evaluation

Materials	**Specification**	**Quantity**	**Cost (₦)**
1 mm steel sheet	Mild steel	3 sheets	16,000
1mm stainless sheet	Stainless	¼ sheet	8,000
Ø 50 mm × 1.2 mm steel pipe	Mild steel	Length	2, 500
25mm× 25mm × 3mm angle iron	Mild steel	3 lengths	4,500
25 mm× 25 mm^2 pipe	Mild 35steel	2 lengths	1,450
Ball bearings	Stainless	2 numbers	2,500
Ø 25 mm × 2 mm pipe	Stainless	3 lengths	12,000
Ø 25 mm × 1.6mm pipe	Stainless	½ length	4,000
Ø 500 mm × 1700 mm × 4 mm	Galvanised steel	1	18,000
Ø 40 mm × 600 mm shaft	Mild steel	1	1,900
15W reversible motor	1	1	4,500
Centrifugal blower 1horse power	1		5,500
Electrode	Stainless	1 dozen	1,500
Electrode	Mild steel	2 packets	4,500
Ball clay, kaolin and sawdust		Lot	8,500
Mold making		92 samples	3,500
Gas for firing bricks developed		20kg	14,000

6 points channel temperature recorder		1	33,500
Thermocouple		4	26,500
Transportation			45,500
Gas flow metre, gate valve and plumbing			55,000
Labour			75,000
Overhead cost			15,000
Turbine (5.5 kW))		1	125,000
Total			₦ 488,350

REFERENCES

[1]. S.O. Jekayinfa and A.I. Bamgboye, Energy use analysis of selected palm-kernel oil mills in south western Nigeria. *Energy*, 33, 2008, 81–90.

[2]. IPPA, (2010): African Case Study: Palm Oil and Economic Development in Nigeria and Ghana; Recommendations for the World Bank's 2010 Palm Oil Strategy. available from *http// www.ippanigeria.org*. (Accessed 10 April , 2014)

[3]. M. A. Nasution, T. Herawan and M. Rivani, Analysis of Palm Biomass as Electricity from Palm Oil Mills in North Sumatera. *Energy Procedia, 47*, 2014, 166 –172

[4]. T. O. Raji, O. M. Oyewola and T. A. Salau, New features for performance enhancement of experimental model bubbling fluidized bed combustor. *InternationalJournal of Scientific and Engineering Resarch, 3(1),* 2012, 217 – 226..

[5]. S. V. Loo and J. Koppejan, *Handbook of biomass combustion and co-firing* Earthscan, London 2008.

[6]. P. Ninduangdee and V. I. Kuprianov, Combustion of Palm Kernel Shell in a Fluidized Bed : Optimization of Biomass Particle Size and Operating Conditions. *Energy Conversion and Management*, 85, 2014, 800 – 808.

[7]. W. M. W. A. Najmi, A. N. Rosil and M. S. S. Izat, Combustion Characteristics of Palm Kernel Shells Using an Inclined Grate Combustor. *International Conference on Energy and Environment Organized by Universiti Tenaga Nasional, Bangi, Selangor, Malaysia*, 2007 *UiTM, Malaysia*,, 2006.

[8]. T. Rogaume, F. Jabouille and J. L. Torero, Effect of Excess Air on Grate Combustion of Solid Waste and on Gaseous Products. *International Journal of Thermal Science, 48(1)*, 2009, 165-173

[9]. K. J. Astrom and R. D. Bell, Drum – Boiler Dynamic *Automatica, 36*, 2000, 363-378

[10]. M. A. Akintonde, S. O. Abiodun and T. E Akinde, Clay, Clay Bodies and Strength: The Example of South – Western Nigeria, *Academic Resarch International, 5(3)*, 2014, 280-291

[11]. K. O. Oladosu, B. Kareem, B. O. Akinnuli, and T. B. Asafa, Application of ComputerAided Design for Palm Kernel Shell Steam Boiler, *Leonardo Electronic Journal of Practices and Tecchnologies, 30*, 2017, 87-104

[12]. K. O. Oladosu, B. Kareem, B. O. Akinnuli and A. O. Abass, Optimization of Ash Yield from the Combustion of Palm Kernel Shell and Selected Additives (Al_2O_3, CaO, MgO) Using D-Optimal Design, *Leonardo Electronic Journal of Practices and Tecchnologies, 28*, 2016, 9-18

k. O. Oladosu." Development and Cost Estimation for Sizing 5 Kw Palm Kernel Shell Steam Boiler."American Journal Of Engineering Research (AJER), Vol. 7, No. 6, 2018, PP.113-122.