Open Access Library Journal
2018, Volume 5, e5032
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Development and Performance Evaluation of Palm Kernel Shells Fueled Stove Converting Waste to Energy

Basil Olufemi Akinnuli[1], Oluwaseun Oluwagbemiga Ojo[2], Olutosin Olufisayo Ilori[2]

[1]Federal University of Technology, Akure, Nigeria
[2]Adeleke University, Ede, Nigeria
Email: ojo.oluwaseun@adelekeuniversity.edu.ng

How to cite this paper: Akinnuli, B.O., Ojo, O.O. and Ilori, O.O. (2018) Development and Performance Evaluation of Palm Kernel Shells Fueled Stove Converting Waste to Energy. *Open Access Library Journal*, **5**: e5032.
https://doi.org/10.4236/oalib.1105032

Received: November 5, 2018
Accepted: December 18, 2018
Published: December 21, 2018

Abstract

Oil palm (*Elaesis guineensis* Jacq.) is an indigenous forest product of West Africa. The natural groves usually have palms that bear ordinary fruits. These fruits emerged hard-kernelled shell (*dura*) and thin-kernelled shell (*tenera*). These kernels were found useful as fuel by researcher due to its high calorific value. The existing fuels such as kerosene, gas, are out of reach to an average Nigerian due to its scarcity and high cost. Other means of fuels like charcoal, wood are not hygienic and also not easy to get due to high rate of deforestation, hence the development of kernel-fuel stove. This was possible after preliminary investigation of its calorific value which was found to be 16.9 MJ. The major components of the kernel-fueled stove are the: frame, blower, miner plate, pot carrier and burning chamber. The capacity of the stove is 22.4 kg of kernel shell; its performance evaluation was carried out by comparing the developed stove with other stoves fueled by sawdust, charcoal, gas, kerosene and electric cooker, and it was discovered it got the shortest time for boiling 3 liters of water in 2.30 minutes.

Subject Areas

Bioengineering

Keywords

Performance Evaluation, Palm Kernel, Stove Development, Calorific Value, Fuel

1. Introduction

In Nigeria, agriculture has remained one of the important sectors of the economy. It generates employment for about seventy percent of Nigeria's population and contributes about forty percent of the gross domestic product (GDP) with crops production accounting for eighty percent, livestock thirteen percent, and fisheries four percent [1] [2]. The Council for Renewable Energy of Nigeria (CREW) estimates that power outage brought about a loss of 126 billion NGN (984.38 Million USD) annually [3] [4]. The predominant energy resources for domestic and commercial uses in Nigeria are fuel, wood, charcoal, palm kernel shell, palm fibre, kerosene, cooking gas and electricity [5]. Other sources, though less common, are sawdust, agricultural crop residue of cornstalk, cassava stick, and in extreme cases, cow dung.

Development and utilization of renewable energy should be given a high priority especially in the lights of increased awareness of the adverse environment impact of fossil and based generation. The need for sustainable energy is rapidly increasing in the world. A wide spread use of renewable energy is important for achieving sustainability in the energy sector in both developing and industrialized countries [6] [7].

[8] studied combustion characteristic of palm kernel using an inclined grate combustor. The inclined grate fixed bed combustion chamber used to burn the palm shell exhibits low capability with conversion rate of twenty percent to thirty two percent of its calorific value. Main design faults were identified for the combustion-air distribution system as well as fuel and distribution. [9] [10] conducted a review on electricity generation based on biomass residue in Malaysia.

[11] performed economic analysis of diesel-fuel replacement by crude palm oil in Indonesian power plants. Their analysis was basically on the needs to find an alternative fuel to substitute diesel in their power plants in order to reduce the use of non-renewable energy sources in Indonesia.

[12] studied progress and challenges in utilization of palm oil biomass as fuel for decentralized electricity. His findings revealed that generating electricity such as biomass power would help transform the entire economic activity and large part of rural population would be able to use the energy for various basic needs. [13] [14] compared the combustion efficiency of palm waste such as palm fibre, palm kernel shell (PKS) and empty fruit bunches in a fluidized bed and spouted bed. The result showed that for combustion of palm fibre and palm kernel shell, the fluidized bed has higher combustion efficiency compared to spouted bed.

[15] [16] presented a comprehensive review of biomass resources and biofuel production potential in Nigeria. The review shows that a variety of biomass resources exist in Nigeria and that there is also immense opportunity for their conversions for various types of biofuel using different biomass conversion technologies that are currently available.

Stove is an enclosed space in which fuel is burned to provide heating, either to heat the space in which the stove is situated, or to heat the stove itself and the item placed on it. Table 1 shows the summary of available stoves with their pictures, description, efficiency and price range where available.

Table 1. Overview of current available stove, [17].

Picture	Description	Efficiency	Price range
Three Stone Open Fire 	Most common Stove. Free. Very smoky and wasteful in fuel utilization.	11% - 15%. As low as 8% in household cooking testing	Free
Metal stove 	Health risk to women and children. Made of scrap sheet metal. Life time of 2 - 4 years. Easily available in the market and urban alternatives to 3-Stones. Portable and easy to carry. Low cost.	20% - 27%	3 - 5
Vehicle Rim 	Made from used vehicle rims. Very robust. Heavy to carry. Lifetime: 5 - 7 years, the reverted model 3 - 5 years Replacement of support after 3 years	20% - 27%	3 - 10
Self-made Mud Stove 	Made from mixture of clay, cow dunk and rice straw. Supported by 3- stones. Easy to build with local material and labour. Needs frequent maintenance by owner Adaptable to cooking needs and family own pot. Big variation in designs and quality.	15% - 25% Efficiency gains uncertain	Free
Clay Stove with Chimney 	Made from mixture of clay, cow dunk and rice straw. Has metal grate as support and requires clay bricks. Smokeless due to chimney. Easy to build with local materials and labour Adaptable to cooking needs, but only fits a specific pot size	Savings of 20% compared to 3-stone open fire	12 - 20

Continued

Toyola Fire Wood Stove 	Made of scrap metal with ceramic liner. Requires high degree of ceramic expertise, quality clay and assess to kiln. Portable. Liner can also be used for fixed or portable clay stoves and are built into e.g. larger multi pot institutional stoves	Saving up to 60%	Approximately 9
Metal Stove 	Made up of sheet metal Not yet in circulation but is tested in Northern Ghana by the NGO, New Energy Need for laboratory and field test. Can also be used with saw dust	n/a	N.a.
Envirofit B-1100 	Industrial improved firewood stove Lunched in India but on its way to several African countries. Envirofit is an NGO based in Colorado, US. Development supported by the shell foundation and Colorado State University. Portable, all biomass types can be used. Produced in China	Savings up to 50%	Cost from 10 - 20 USD (from 500 - 100 Indian rupees)
Philips Smokeless Stove. 	Industrialized improved firewood Stove. Lunched in India by Philips in 2008 for a trial. Electronically controlled fan forces air through the stove leading to better fuel to air ratio. Usable for small pieces of wood. Very low fuel consumption. Smoke free and portable. Produced in China.	Savings Up to 80%	N.a.

In order to determine which type of heating fuel is the best value, four different variables were considered in literature which are: the type of heating fuels (solid, liquid, electricity, or gas); the unit cost of heating fuels (amount of money cost by unit measure); per unit content of fuel (measured in Btu's); and annual fuel utilization efficiency (AFUE).

Table 2 shows the demerits in the existing stoves.

Table 3 demonstrates the different types of fuels used by stoves and their comparison of entropy constant.

2. Methodology

The method used in this research covered: identification of required components of the proposed stove design, analysis of each component, components material selection, engineering drawing of the stove, components' production and their assembly, test of the stove and comparison with the existing ones to evaluate its performance.

Components: the components are pot holder, air inlet plate, centrifugal fan, outlet plate, top plate and the frame.

Table 2. Different types of stoves and their demerits.

S/N	Stove	Demerit(s)
1	Kerosene Stove	1) High fuel cost 2) Ventilation required 3) Spillage of fuel that can cause fire 4) Burn risk is possible
2	Firewood Stove	1) Large quantity of firewood is required 2) Cooks food slowly 3) Gather smoke in the kitchen 4) Makes the kitchen utensils dirty 5) Makes pot black with sooth 6) Smokes from wood may be life threatening
3	Natural Gas Stove	1) Expensive to buy and install 2) Dangerous due to the possibility of gas leakages 3) Give off humid heat rather than the dry heat required for effective roasting 4) Gas leaks cause rooms and building to be filled with toxic, flammable gas
4	Electric Stove	1) Coils take longer time to heat up, which can slow down cooking process 2) Heat from stove tends to radiate through the entire kitchen which can make it uncomfortable to cook at times 3) There is need for constant supply of electricity 4) Cost of operating it is very high
5	Propane Stove	1) Produced instant heat, but sometimes produces offensive odour 2) Frequently has been causing carbon monoxide poisoning when used indoor or poorly ventilated areas 3) Denser than air, if a leak in propan fuel occurs, the gas will have a tendency to sink into any enclosed area and thus poses a risk of explosion and fire
6	Anthracite Coal	1) Dirty 2) More attention to fire and furnace is necessary 3) Heat in fuel is difficult to realize 4) Like all fossil fuels, burning anthracite coal emits deadly carbon monoxides therefore a good chimney is a necessity

Table 3. Different types of fuels used by stoves and comparison of entropy constant.

Types	BTU/Unit	Kilocalories/Unit
Kerosene (No 1 fuel oil)	134,000/gallon	8921/liter
Burner fuel oil (No 2 oil)	140,000/gallon	9320/liter
Electricity	3413/kWh	860/kWh
Natural gas	1,000,000/thousand cord	7139 cubic meter
Propane	91,600/gallon	6098/liter
Anthracite coal	27,800,000/ton	6,354,286/tonne
Hardwood (20% moisture)	24,000/cord	1,687,500/cubic meter
Pine (20% moisture)	18,000/cord	1,265,625/cubic meter
Wood pellets (pellet stoves)	36,000,000	8,228,572/tonne

Design Analysis of the Component

1) Design Analysis of the Frame Support

The PKS stove was designed for maximum strength load it can carry.

Mass of water and the pot used is 45 kg (4.413 KN);

Length (L) of the full cross bar = 860 mm;

Load is to be uniformly distributed over the support.

Support reaction

$$R_A = R_B = \frac{wl}{2} = 2.207\,\text{KN/m} \tag{1}$$

The shear force S_x at section

$$S_x = \frac{wl}{2} - W_x \tag{2}$$

The maximum shear force $S_{x(\max)}$

$$S_{x(\max)} = S \cdot F = \frac{WL}{2} = 1.90\text{KN} \tag{3}$$

The maximum bending moment (B_m) of the support

$$B_m = \frac{wl}{2} \times \frac{1}{2} - \frac{w}{2} \times \left(\frac{1}{2}\right)^2 \tag{4}$$

B_m = 0.41 KNm.

Design Analysis of the Fuel Chamber

$$\text{Volume } (V) = \pi r^2 h \tag{5}$$

$V = 0.04\ \text{m}^3$.

Mass density of palm kernel shell = 560 kg/m^3;

Calorific value of palm kernel shell = 16.9 MJ/kg.

Therefore, the mass of fuel in the stove = mass density of palm kernel shell × volume of the fuel chamber

$$F_m = f_d \times C_v \tag{6}$$

= 22.4 kg

$$\text{Available energy } (E_{av}) = C_v \times F_m \quad (7)$$

= 378.6 MJ

2) Design Analysis of the Blower

a) Propeller Fan Design

The design power (*P*) of the fan is 100 W while working under a head (*H*) of 600 m at running speed, *N* of 2000 rpm.

Diameter of impeller (*d*) is 0.03 m;

Blade thickness at the inlet (b_1) is 40 mm;

Blade thickness at the outlet (b_2) is 15 mm;

Inlet blade angle (β_1) is 22.5˚;

Outlet blade angle (β_2) is 50˚;

Mass density of air (γ_a) is 1.0 kg/m.

Figure 1 demonstrates the inlet and outlet velocity diagram.

Blade velocity at inlet V_{b1}

$$V_{b1} = \frac{\pi D_1 N}{60} \quad (8)$$

where D_1 is inlet diameter and *N* is fan speed in revolutions per minute V_{b1} = 1.591 m/s.

Blade velocity at outlet V_{b2}

$$V_{b2} = \frac{\pi D_2 N}{60} \quad (9)$$

V_{b2} = 3.142 m/s.

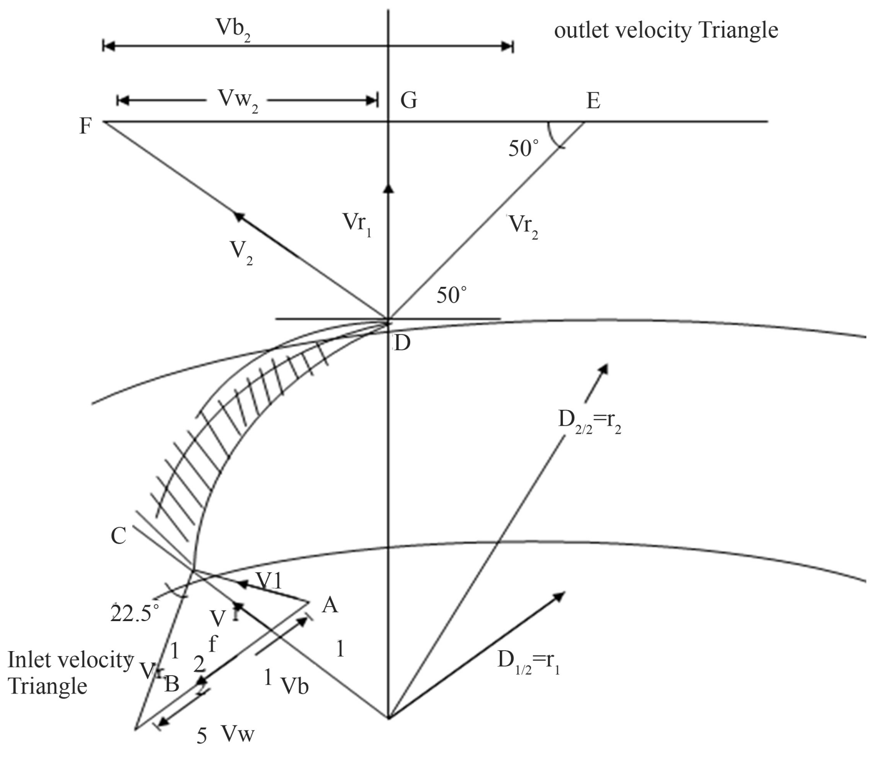


Figure 1. The inlet and outlet velocity diagram.

b) Quantity of Air Delivered (Q)

$$Q = \pi D_1 b_1 V_{f1} = \pi D_2 b_2 V_{f2} \tag{10}$$

But velocity of flow at inlet V_{f1} is expressed as

$$V_{f1} = \frac{Q}{\pi D_1 b_1} \tag{11}$$

The Q *i.e.* the required discharge to produce power

$$Q = \frac{P}{\rho g H} \tag{12}$$

$Q = 0.034\ \text{m}^3/\text{s}$.

Hence, V_{f1} = 18.02 m/s [velocity of flow remains constant throughout the runner *i.e.* V_{f1} = V_{f2}]

The flow rate τ is given by the ratio of the velocity of flow at the inlet to the theoretical velocity

$$\tau = \sqrt{2gH} \tag{13}$$

$\tau = 5.25$ m/s.

The speed ratio $\varnothing$ is given by the ratio of the blade velocity at the inlet V_{b1} to the theoretical velocity

$$\varnothing = \frac{V_{b1}}{\sqrt{2gH}} \tag{14}$$

$\varnothing = 0.5$.

Table 4 explains the ultimate analysis of palm kernel shell.

c) Determination of the Quantity of Heat Released

Figure 2 shows a solid cylinder of radius r, insulated with an insulation thickness ($r_2 - r_1$).

Where L is length of the cylinder, T_1 is the surface temperature of the cylinder; T_{air} is temperature of air; h_o is heat transfer coefficient at the outer surface of the insulation and K is thermal conductivity of the insulating material.

The rate of heat transfer from the surface of the solid cylinder to the surrounding is given by

$$Q = \frac{2\pi L\left(T_1 - T_{\text{air}}\right)}{\frac{\ln\left(r_2/r_1\right)}{K} + \frac{1}{h_o r_2}} \tag{15}$$

$Q = 39.2$ W/m.

$$Q_i \text{ (without insulation)} = h_o \times 2\pi r_1 \left(T_1 - T_2\right) \tag{16}$$

$Q_i = 22.6$ W/m.

d) Minimum Insulation Thickness (T_m)

$$T_m = r_c - r_1 \tag{17}$$

where T_m is minimum insulation thickness, r_c is critical radius of insulation, and r_1 is radius of the fuel chamber.

Table 4. Ultimate analysis of palm kernel shell.

Element	% of constituent
Carbon	57.01
Oxygen	31.8
Nitrogen	0.5
Hydrogen	11.11

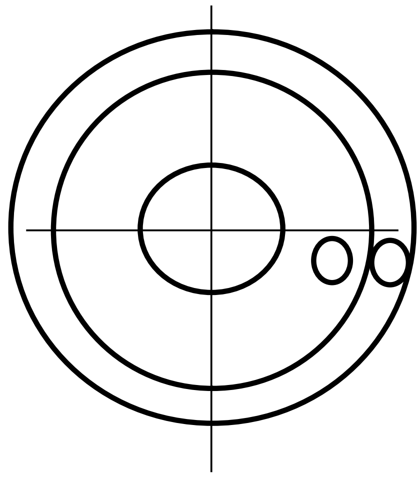


Figure 2. An insulated solid cylinder.

Note $r_c = k/h_o$, $T_m = 0.644$ mm.

e) Percentage Increase in Head Dissipation (H_d)

$$H_d = \frac{Q_2 - Q_1}{Q_1} \times 100 \tag{18}$$

$H_d = 73.5\%$.

The required drawing to this developed stove is found in the Appendix.

3) Developed PKS stove Performance Evaluation

The palm kernel shell stove performance is evaluated by observing its efficiency in cooking relative to other forms of heat source using a stop watch for time taken. Other materials used are thermometer, aluminum pots, sawdust stove, charcoal stove, electric stove, gas cooker, kerosene stove and the PKS stove.

Procedure

a) 3 litres of water are measured into the pot.

b) Light up the stove and allow proper combustion to circulate round before placing the water pot carrying the 3 litres of water with thermometer on the fire.

c) Watch and record the time required for water to attain its boiling point.

d) Repeat the same action on the remaining five sources of heat.

3. Results and Discussion

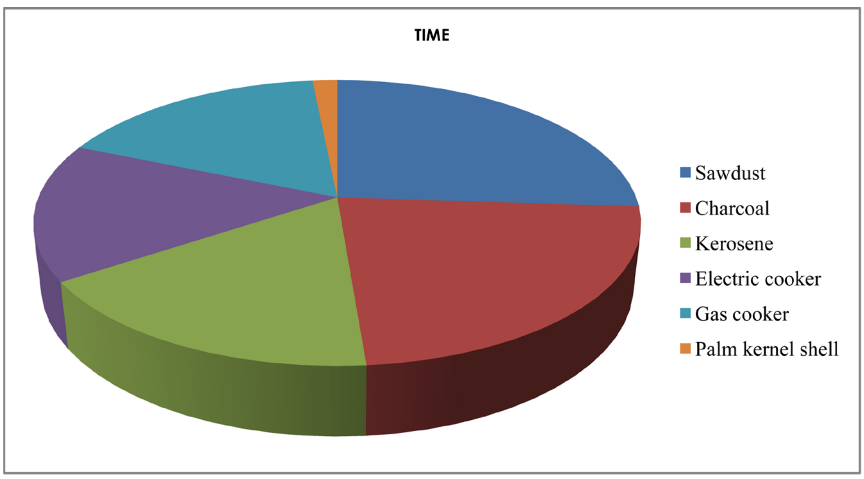
The palm kernel shell stove has been successfully developed having frame of shear force of 1.90 KN, maximum bending moment of 0.41 KNm, fuel chamber of 0.04 m^3 and available energy of 378.6 MJ with the blower capable of delivering 0.034 m^3/s of air. The rate of heat transfer from the surface when insulated to the surrounding is 22.6 w/m having a minimum insulating thickness of 0.644 mm while the percentage increase in dissipation is 73.5%.

Evaluating the performance of the stove compared with the other five types of different source of fuel (gas, kerosene, sawdust, electric cooker and charcoal). Sawdust has the highest time for the three liter of water to boil. The results to this experiment in descending order are: Sawdust, 38.35 min; charcoal, 33.45 min; kerosene, 25.00min; electric cooker, 23.00 min; gas cooker 25.28min; and palm kernel shell stove, 2.30 min. This experiment shows that palm kernel fueled stove is the fastest due to its short time of 2.30 min followed by gas fueled stove of time 15.28 min.

Figure 3 shows the fuel performance chart.

4. Conclusions

The design and fabrication of the Palm kernel shell stove has been achieved successfully as well as performance evaluation on the stove. Its performance evaluation was carried out by comparing the developed stove with other stoves fueled by sawdust, charcoal, gas, kerosene and electric cooker, and it was discovered it got the shortest time for boiling 3 liters of water in 2.30 minutes. The kernel shells are always available in bag which can last for several months with only five hundred naira (₦ 500) which are equivalent in dollar rate to more than one US dollar (US$1.43) compared with the cost of other fuels.



Source of Fuel	Time
Sawdust	38.35
Charcoal	33.45
Kerosene	25
Electric cooker	23
Gas cooker	25.28
Palm kernel shell	2.3

Figure 3. Performance evaluation results on a pie chart.

Palm kernel shells are attractive renewable energy resource that has been utilized in agricultural industries as a secondary energy source. Due to certain physical characteristics, palm shells are a relatively hard-to-burn biomass fuel, and the combustion chamber design as well as the combustion process should be optimized to enhance combustion efficiency.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Jekayinfa, S. and Bamigboye, A.I. (2008) Energy Used Analysis of Selected Palm Kernel Oil Mill in South Western Nigeria. *Journal of Energy*, **33**, 81-90. https://doi.org/10.1016/j.energy.2007.08.008

[2] Al-Kayiem, H.H. and Yunus, Y.Md. (2013) Drying of Empty Fruit Bunches as Wasted Biomass by Hybrid Solar-Thermal Drying Technique. *Journal of Mechanical Engineering and Sciences*, **5**, 652-661. https://doi.org/10.15282/jmes.5.2013.12.0063

[3] Council for Renewable Energy (CREN) (2012) Nigeria Electricity Crunch. http://www.reneablenigeria.org

[4] Noor, M.M., Wandel, A.P. and Yusaf, T. (2013) Design and Development of MILD Combustion Burner. *Journal of Mechanical Engineering and Sciences*, **5**, 662-676. ttps://doi.org/10.15282/jmes.5.2013.13.0064

[5] Famuyide, O.O., Adebayo, O., Bolaji-Olutunji, K.A., Awe, F., Owoeye, A.Y., Awodele, D.O. and Adeyemo, A. (2013) Assessment and Sustainable Management of Non-timber Forest Products Used as Food and Medicine among Urban Dwellers in Oyo State, Nigeria. *Global Science Research Journals*, **5**, 186-193.

[6] Sunday, O. (2012) Energy and Sustainable Development in Nigeria: The Way Forward. *Journal of Energy Sustainability and Society*, **2**, 15. https://doi.org/10.1186/2192-0567-2-15

[7] Ghobadian, B., Najafi, G. and Nayebi, M. (2013) A Semi-Empirical Model to Predict Diesel Engine Combustion Parameters. *Journal of Mechanical Engineering and Sciences*, **4**, 373-382. https://doi.org/10.15282/jmes.4.2013.2.0035

[8] Noor, M.M., Wandel, A.P. and Yusaf, T. (2014) The Simulation of Biogas Combustion in a Mild Burner. *Journal of Mechanical Engineering and Sciences*, **6**, 995-1013. https://doi.org/10.15282/jmes.6.2014.27.0097

[9] PhanBinh, M.Q., Duong Long, T., Nguyen Viet, D., Tran Trong, B., Nguyen My, HH., Nguyen Luong, H., Nguyen Duc, A. and LuuLoc, C. (2014) Evaluation of the Production Potential of Bio-Oil from Vietnamese Biomass Resources by Fast Pyrolysis. *Biomass and Bioenergy*, **62**, 74-81. https://doi.org/10.1016/j.biombioe.2014.01.012

[10] Hassan, M.B.H. (2012) A Review on Electricity Generation Based on Biomass Residue in Malaysia. *Renewable and Sustainable Energy Reviews*, **16**, 5879-5889. https://doi.org/10.1016/j.rser.2012.06.031

[11] Petr, P. and Vladimír, H. (2018) Economic Analysis of Diesel-Fuel Replacement by Crude Palm Oil in Indonesian Power Plants. *Energies*, **11**, 504. https://doi.org/10.3390/en11030504

[12] Bridgwater, A.V. (2012) Review of Fast Pyrolysis of Biomass and Product Upgrading. *Biomass and Bioenergy*, **38**, 68-94. https://doi.org/10.1016/j.biombioe.2011.01.048

[13] Gharehghani, A., Hosseini, R. and Yusaf, T. (2013) Investigation of the Effect of Additives to Natural Gas on Heavy-Duty Is Engine Combustion Characteristics. *Journal of Mechanical Engineering and Sciences*, **5**, 677-687. https://doi.org/10.15282/jmes.5.2013.14.0065

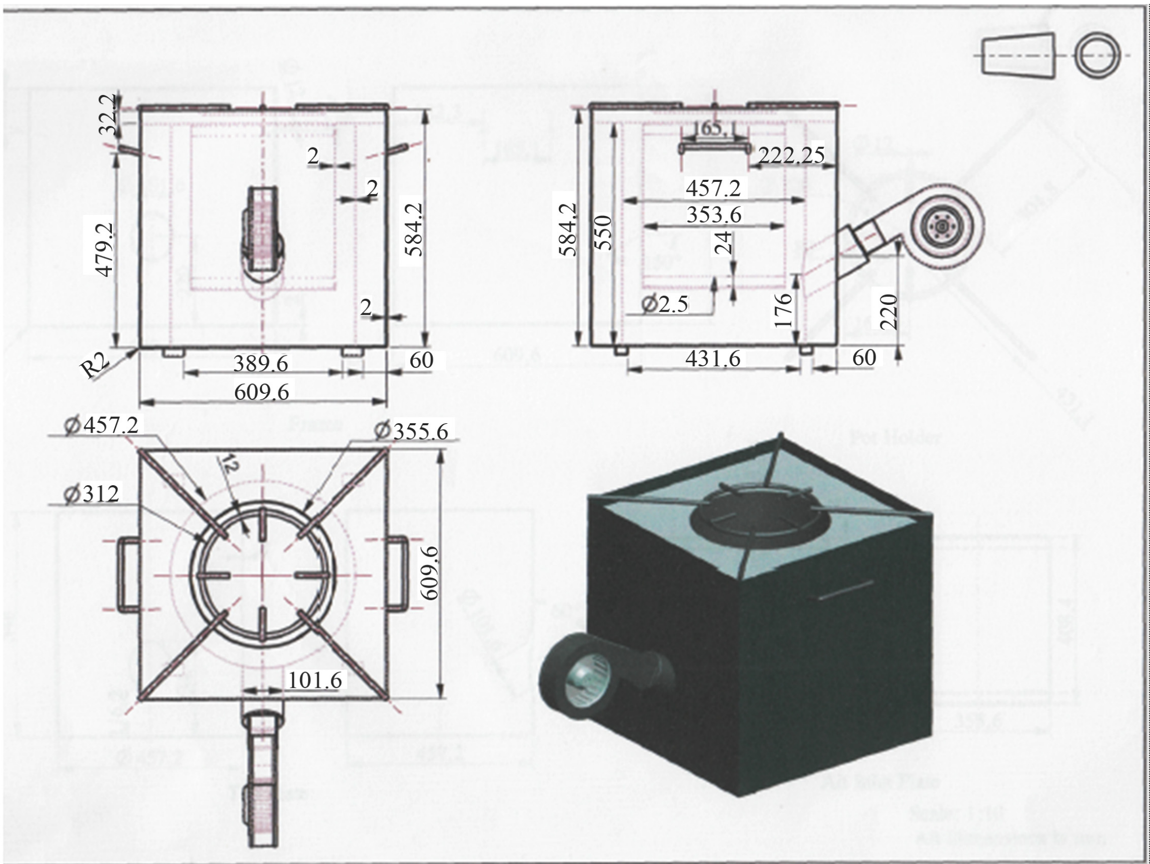
[14] Ibrahim, M.F., Aziz, S.A., Razak, M.N.A., Phang, L.Y. and Hassan, M.A. (2012) Oil Palm Empty Fruit Bunch as Alternative Substrate for Acetone-Butanol-Ethanol Production by Clostridium Butyricum EB6. *Applied Biochemistry and Biotechnology*, **166**, 1615-1625. https://doi.org/10.1007/s12010-012-9538-6

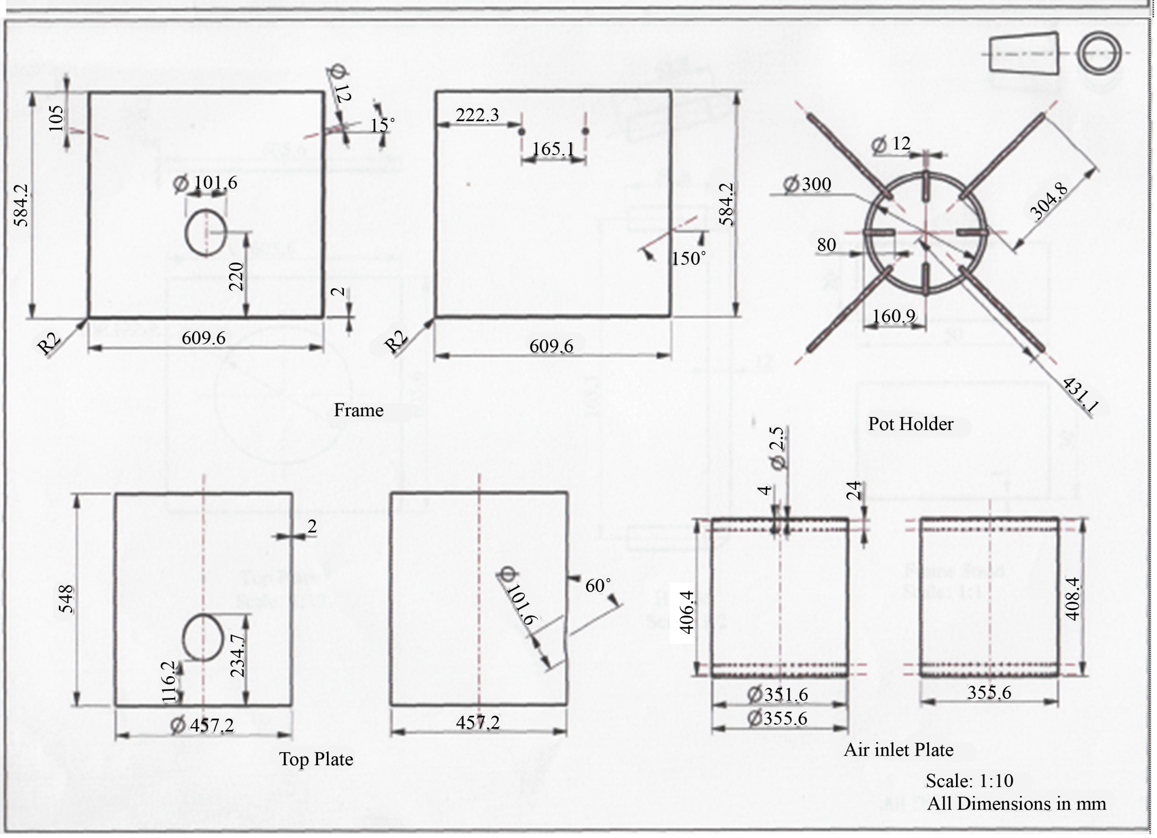
[15] Agbro, E.B. and Nosa, A. (2013) A Comprehensive Review of Biomass Resources and Biofuel Production Potential in Nigeria. *Research Journal in Engineering and Applied Science*, **13**, 149-155.

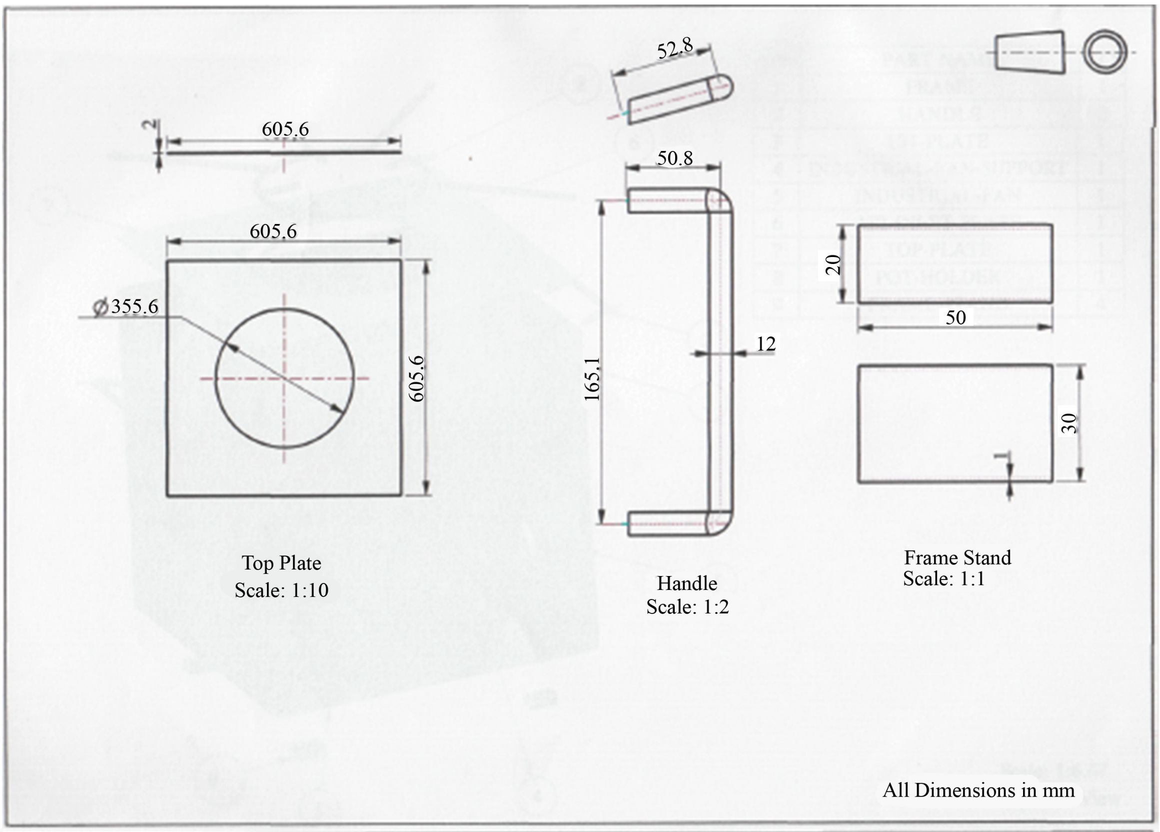
[16] Simonyan, K.J. and Fasina, O. (2013) Biomass Resources and Bioenergy Potentials in Nigeria. *Renewable and Sustainable Energy Reviews*, **8**, 4975-4989.

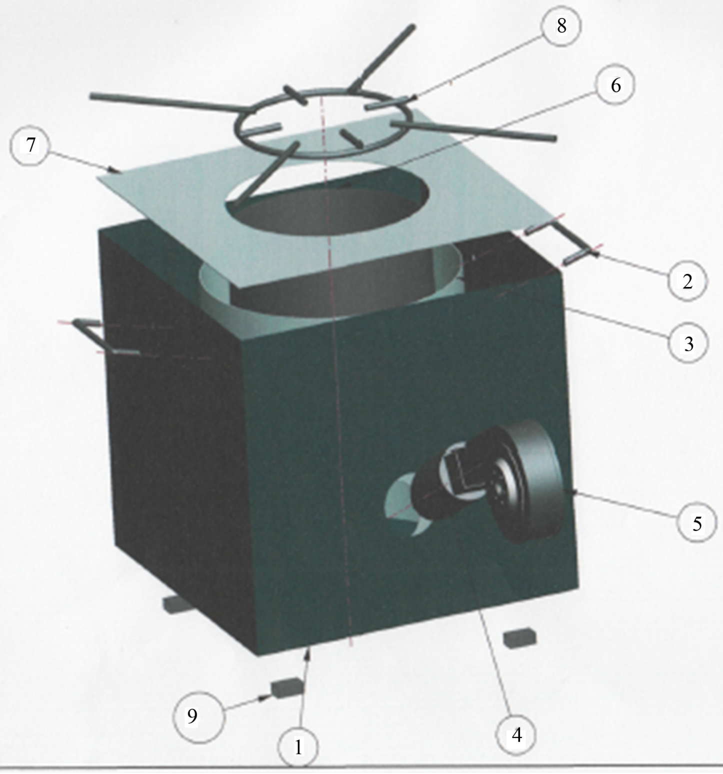
[17] Luangkiattikhun, P., Tangsathitkulchai, C. and Tangsathitkulchai, M. (2008) Non-Isothermal Thermo-Gravimetric Analysis of Oil-Palm Solid Wastes. *Bioresource Technology*, **99**, 986-997.

Appendices




Frame
Pot Holder
Top Plate
Air inlet Plate
Scale: 1:10
All Dimensions in mm





S/N	PART NAME	QTY
1	FRAME	1
2	HANDLE	2
3	1ST-PLATE	1
4	INDUSTRIAL-FAN-SUPPORT	1
5	INDUSTRIAL-FAN	1
6	AIR-INLET-PLATE	1
7	TOP-PLATE	1
8	POT-HOLDER	1
9	FRAME-STAND	4

Scale: 1:6.67
Exploded View