Development of a Metal Kiln for the Production of Charcoal from Waste Wood

ODESOLA I.F., N. NDEKWU & E.O. IGE

Department of Mechanical Engineering, University of Ibadan, Ibadan
Email: if.odesola@mail1.ui.edu.ng

Abstract

The need for preservation of fresh fish for commercialization purposes has attracted research efforts especially from fish scientists. There are a number of energy sources utilized for fish processing, such as electrical and wood. Due to the abundance of vegetation in the university community, there abound waste woods from felling of aged timbers; this offers potential for wood charcoal production. The focus of this study is to develop a pilot plant for wood-charcoal kiln to be employed for fresh fish processing. Relevant mathematical formulations were employed for determination of kiln model dimensions prior to fabrication of kiln parts. The wood charcoal produced in the kiln was used for fresh fish processing and the combust emission was analyzed at peak carbonization stage. Mathematical computation of Heat transfer analysis of the charcoal-making process in the kiln was undertaken using MATLAB. The wood average mass of 35 kg was combusted in the kiln to make charcoal to obtain a minimum and maximum wood conversion efficiency of 0.105 and 0.314 respectively were obtained. Maximum carbonization temperatures in the range of 350–400°C were also observed. Computational results agreed with experimentally observed data and revealed that incorporation of an insulating material would have an adverse effect on the carbonization process. The study established that the design upon modification would be environmentally safe, viable and an economic alternative for processing fish farm produce.

Keywords: Production, Smoking, Charcoal, Kiln, Design

Introduction

The need for energy sources in the processing of aqua-produce is increasing with the recent awareness in fish farming. These sources include electrical, wood and the traditional sun-drying methods. With the predicament of epileptic power supply in the developing world and the abundant presence of vast wood products in the university community, the reason for wood as a choice energy source for processing of aqua-based produce seems researchable. However, the flavours exhuming from wood-dependent smoke method results in an incomplete combustion process; this is because wood contains phenolic, carboxyl and some poly-nuclear aromatic hydrocarbons, which according to Eyo (2001) can be carcinogenic. The flavour enhancing components of smoke are guaicol and syringol which are phenolic esthers. It also produces soot on the body of smoked fish which can make the end products unattractive to consumers. However, the charcoal-powered smoking process produces complete burning of wood by the principle of pyrolysis with less smoke, because most of the volatile compounds would have vaporized in the production stages of charcoal (Horner, 1992; Braigs, 2007). The afore-mentioned justified the production of charcoal from wood as a mechanism to improve smoke exhaust content and improve nutritional value of the smoked fresh fish.

Carbonization of charcoal can only be achieved in an enclosed environment such as a kiln where control can be exercised over air entry to ensure that the wood does not merely burn to ashes, but that it decomposes chemically to form charcoal. Wood matter consists basically of cellulose, lignin and water. The process of charcoal production is summarized as follows. Wood pieces are stacked within the kiln and set on fire with air initially permitted to flow into the charcoal making kiln. The temperature of the burning wood rises as the wood pieces ignite, and water vapour, usually observed as white smoke begins coming out from the kiln. As the temperature rises to about 280°C, the wood constituents begin to break down chemically to produce charcoal, water vapour, methanol, acetic acid and more complex chemicals, chiefly in the form of tars and non condensable gas consisting mainly of hydrogen, carbon monoxide and carbon dioxide (Kammen & Lew, 1985). These gases are usually observed as a dark grey or bluish grey smoke issuing out of the kiln.

Earth kilns

Earth kilns are usually rectangular shaped pits dug in the Earth. The wood pieces to be converted to charcoal are stacked inside the pit. After stacking, the pit is covered up, usually with layers of leaves and sand, leaving small openings for gas flow. The wood pieces are then ignited. As burning proceeds, air entry into the pit is regulated by plugging or unplugging the openings. A single charcoal production cycle using earth kilns can take up to five days, depending on the pit size and charcoal quantity. Major drawbacks associated with Earth kilns are low wood conversion efficiency, limited control over gas flow, they require constant attendance, they are difficult to operate in wet conditions, and the charcoal output is usually mixed with sand (Wartluft & White, 1983). A common variation of the Earth Kiln is the Mound kiln. In mound kilns, rather than employing a pit, the wood pieces are stacked and arranged in a mound which is subsequently covered before the stack is lit up.

Brick kilns

Brick kilns are made of bricks, usually built up into a hemispherical shape. For larger brick kilns, sizes can be up to 6m diameter and 3m height. Brick kilns have two diametrically opposite doors, usually made of steel. One door is for loading the kiln with wood pieces while the other is for unloading charcoal. Like all charcoal kilns, brick kilns incorporate holes for air regulation. For brick kilns, ventilation holes are usually evenly spaced holes at the bottom part of the kiln and an 'eye' or smoke outlet at the top.
The main advantages of brick kilns are: they have a high charcoal producing efficiency, they are not easily damaged, not easily harmed by overheating, they can stand unprotected in the sun and rain without corrosion or ill effects and have a useful life of about 5 to 8 years, they can be built in medium and large sizes, control of burning is relatively simple, they require very little steel during construction (FAO, 1999).

The main disadvantages of brick kilns that make it an unviable consideration for this project are the fact that construction is costly and labour intensive, they require expertise for fabrication, cannot be relocated, they are not portable and are not appropriate for small scale charcoal production.

Metal kilns

There are numerous designs of metal charcoal making kilns, and so a single description may not suffice to illustrate the construction and operation of metal kilns. All metal kilns are however made of metal sheets fabricated into a closed structure with moveable openings to exercise control over air and gas flow. Design specifics of metal kilns are determined by factors such as desired scale of charcoal production, frequency of kiln transportation, desired kiln working life etc.

The major advantages of metal kilns are: Total or near total control can be exercised over gas flow into and out of the kiln if properly constructed, they can be easily transported if properly constructed, unskilled personnel can be easily trained in their usage, carbonization of wood using metal kilns requires minimal supervision; they can be easily constructed in a metal workshop; they can be operated in areas of high rainfall; mean conversion efficiencies of up to 24% can be consistently achieved; and with maximum control of the process, a wider variety of raw materials can be carbonized (FAO 1999).

In Africa, Nigeria and at the University of Ibadan campus in particular, there are a lot of waste wood resources. The university fish farm may produce its own charcoal for smoking of fresh fish using waste wood resources within the university environment. This work is therefore aimed at designing and fabricating a metal charcoal making kiln. The proposed plant will solve the problem of excessive expenditure on charcoal in the fish farms. This will also provide a means of utilising abundant waste wood resources in the university community.

Methodology

Design analysis and considerations

Charcoal is made through the pyrolysis of wood, which is essentially the thermal decomposition of organic matter under inert atmospheric conditions or in a limited supply of air, leading to the release of volatiles and formation of char. Pyrolysis of wood is typically initiated at around 150 °C and lasts till 300-450 °C, depending on the species of wood (Cengel, 2003). A charcoal making kiln is a structure designed with the ability to withstand the high wood carbonization temperatures while permitting the control of air inflow or otherwise into the system. Numerous methods and kiln types for charcoal production exist, like the earth, brick, cement or masonry, metal and retort kilns. In this work, metal kiln was used; this is due to the its ability to be constructed in any desired shape, its high portability and high wood conversion efficiency, near total control over air and gas flow, relatively long useful working life and moderate fabrication cost.

In the design process, certain specifications were used; the charcoal-fired kiln for fish-meat processing was developed for a maximum heat transfer rate of $850Wm^2K^{-1}$ following the mathematical formulations in Ayo, (2009). Also, mass flow rate of air into the chamber of 3.142x10^{-2}kg/s Ayo, (2009); and a local design condition of kiln height at 0.65m. Thereafter, the metal fish kiln was fabricated using the following design criteria: The kiln was for small charcoal production scale, air tightness, air flow control, gas emission expulsion, heat exchange between the kiln and the environment, mode of firing the kiln, protection of the kiln from adverse weather conditions, durability, minimal maintenance requirements, and ease of operation. The materials selected for the kiln were determined by considering the following criteria: thermal properties, strength, acquisition costs, and projected weight of the kiln.

Determination of area of combustion chamber

Using Tran & White, (1992); the mass flow rate of charcoal is given as: $m' = [c \times (\dot{m}'') \times \mathrm{a}]$ (1)

where; m' is the mass flow rate of charcoal, $\dot{m}''$= mass flow rate of air into the chamber= $3.142 \times 10^{-21}\ kg/s$, and a = area of the charcoal feed chamber, c is a constant given by Tan & White, (1992) as 14.

The burning rate of charcoal is 9.8×10^{-5}kg/s; if it burns for 1 hour, then the mass flow rate will be $3.53 \times 10^{-1} kg$. This mass flow rate therefore requires an area of $0.2290m^2$ and, hence a diameter of $0.54m$.

Determination of area of air opening

The volume of air in the combustion chamber of a kiln is defined as

$$V_{air} = \dot{m}_{air} \times \rho_{air} \quad (2)$$

Where: $\rho_{air} = \text{Density of air}$, and $\dot{m}_{air} =$ mass of air in a kiln combustion chamber. According to Ramakrishna, (1992) mass of air in a kiln ($\dot{m}_{air}$) is defined as

$$\dot{m}_{air} = \left[\left(\frac{\dot{A}}{F_{actual}}\right) \times \dot{m}\right] \tag{3a}$$

where $F_{actual} = \text{Actual Stochiometry Fuel},\ A = \text{Stochiometry},$ and $m = \text{mass of fuel}$

Substituting eqn. (3) in eqn. (2), we obtained

$$V_{air} = \left[\left(\frac{A}{F_{actual}}\right) \times \dot{m}\right] \times \rho_{air} \tag{3b}$$

Given that $\frac{A}{F_{actual}} = 5.5328$ (as given in the design specification) and, density of air (ρ_{air}) at a temperature of T_m ($^{\Delta T}/_2$) of 175°C is 1.182kg/ms; hence V_{air} will be 0.799 Kg/hr.

Area of opening for air inlet A_{air} is given by Ramakrishna, (1992) as;

$$A_{air} = \left[\frac{V_{air}}{23.6 * \sqrt{h}}\right] \tag{4}$$

The local height h of the chamber is 0.65m; therefore, the area A_{air} is $0.04204m^2$ that exposes air inlet into the chamber.

Determination of surface area for heat transfer $\boldsymbol{A_{ht}}$

The surface area of heat transfer (A_{ht}) is defined as

$$A_{ht} = \frac{\dot{q}}{h\Delta T} \tag{5}$$

where h is the heat transfer coefficient, ΔT is the temperature difference and it is given in terms of Nusselt number (Nu) as:

$$h = \frac{Nu * K}{d} \tag{6}$$

where, Nu is the Nusselt Number, K is the thermal conductivity of the air, d is the diameter of the kiln combustion chamber.

$$Nu = 0.48 * [Gr * Pr]^{0.25} \tag{7}$$

In eqn. (7),

Pr= Prandtl number = 0.744at 175 ^{o}C ; and Gr is Grasshoff number, and is given as: $Gr = \frac{(g * \beta * \Delta T) * d^3}{\vartheta^2}$ (8)

In eqn. (8), g = acceleration due to gravity =9.81m/s^2; β = the volumetric expansion coefficient at STP which is $3.7 \times 10^{-3\,\diamond}C$, ΔT = heat conduction of air K at 175 $^{\circ}C$=1.401, and ϑ = kinematic viscosity of air at 175 $^{\circ}C$ =1.182*$10^{-5}Kg/ms$

Substituting in equations (6), (7) and (8) into equation (5) the dimension of the surface area needed for charcoal combustion is obtained as 2.18m^3. The obtained parameters were used to select metal sheets for the proposed plant.

The proposed kiln

The Isometric, Orthographic and pictorial views of the proposed Kiln are presented in Figs 1, 2 and Plate 1 respectively. For the part list of Fig. 1 see table 1.

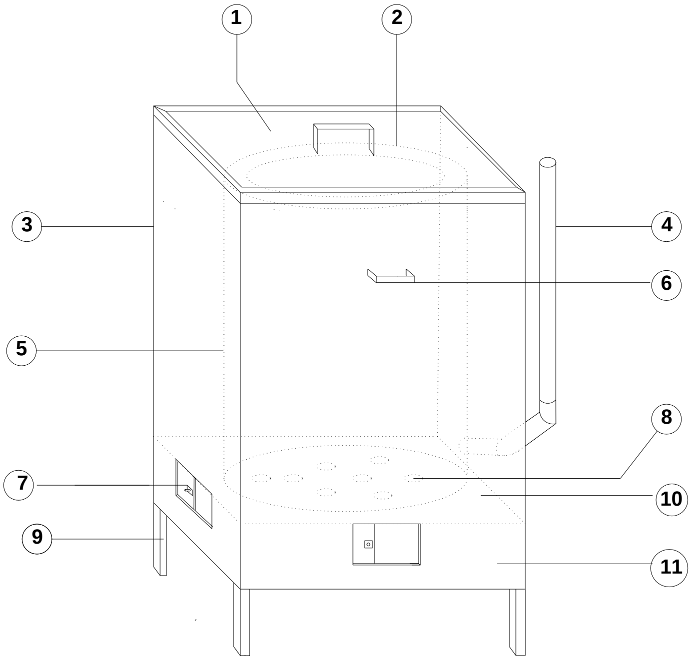

Fig.1 Isometric view of charcoal-fired kiln

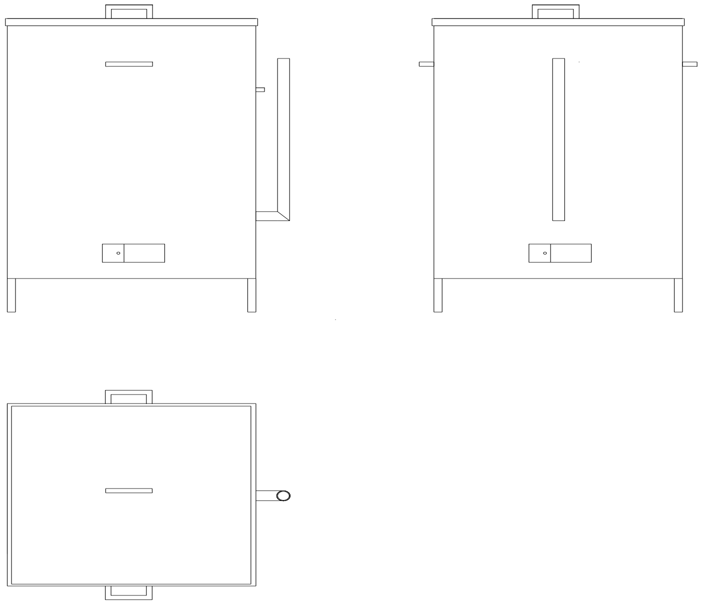

Fig 2.Orthographicview of the charcoal-fired kiln

Plate 1: Pictorial view of the fabricated charcoal-fired kiln

The fabrication processes involved a number of operation sequences ranging from bench work to lathe and milling machining to welding operations, thereafter, parts were assembled. The parts of the proposed kiln are shown in Table 1.

Table 1: Kiln parts list

S/N	Component	Dimension (M)	Qty.	Material
1	Kiln outer cover	0.61 x 0.61	1	Aluminum
2	Carbonization chamber cover	0.54 diameter	1	Stainless Steel
3	Kiln outer body	0.6 x 0.6 x 0.91height	1	Stainless steel sheet
4	Chimney	0.63 height x 0.05 diameter	1	Stainless pipe
5	Carbonization chamber	0.64 height x 0.55 dia.	1	Stainless Steel diesel drum
6	Kiln handle	0.02m diameter	2	Cast iron
7	Air flow control slot	0.1 x 0.18	4	Mild steel sheet
8	Ventilation Holes	0.02 diameter	8	-
9	Kiln stand	0.004 thick angle iron	4	Cast iron
10	Carbonization chamber base plate	0.6 x 0.6	1	Inert Refractive Bed Plate
11	Kiln firing chamber	0.6 x 0.6 x 0.15	1	-

Modeling of kiln

Mathematical formulations

Modeling of the charcoal making process is necessary in order to have an idea of the pattern of heat transfer during wood carbonization. Ideally, pyrolysis models are made up of chemical kinetics, mass transfer and heat transfer models (Sinha et al., 2000). However, only a heat transfer model was developed in this work. A lumped heat transfer model with the kiln treated as a composite walled arrangement with heat being generated radially outwards from the core or center of the kiln where the wood was being carbonized.

Assumptions

The following assumptions were made for this investigation:

- The wood undergoing pyrolysis within the carbonization chamber is considered as a single bulk material at an instantaneous uniform temperature.
- The carbonization chamber is at the uniform instantaneous temperature.
- The burning wood and the walls of the cylindrical carbonization chamber are at the same instantaneous uniform temperature during wood carbonization.
- The air space between the carbonization chamber and the kiln's outer body is at the uniform instantaneous temperature.
- The convective heat transfer coefficients for air, air space between the inner and outer chambers of the kiln, and the outside air are both remain constant during the carbonization period.
- Heat transfer from the inner carbonization chamber to the kiln outer body is only by convection.
- The cross section of the kiln's outer body is assumed to have a circular section.
- Heat transfer occurs only in the horizontal plane.

Based on these assumptions, during wood carbonization,

- Convective heat is transferred through the small air space between the inner drum and outer kiln body;
- Conduction heat is transferred through the thin wall of the outer kiln body;
- Convective heat transferred from the outer walls of the outer kiln body into the surrounding air.

The composite walled heat flow model adopted in this work is depicted in Figs. 6 and 7; while the heat flow circuit diagram is shown in Fig.8.

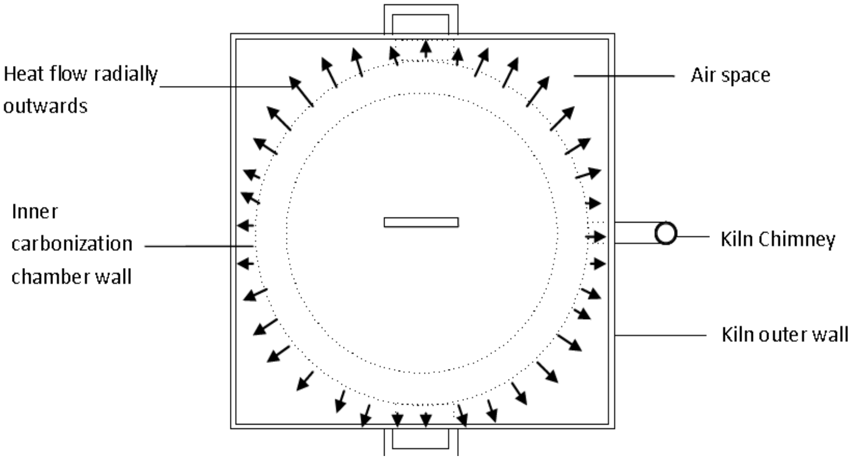

Fig. 5 The kiln plan view

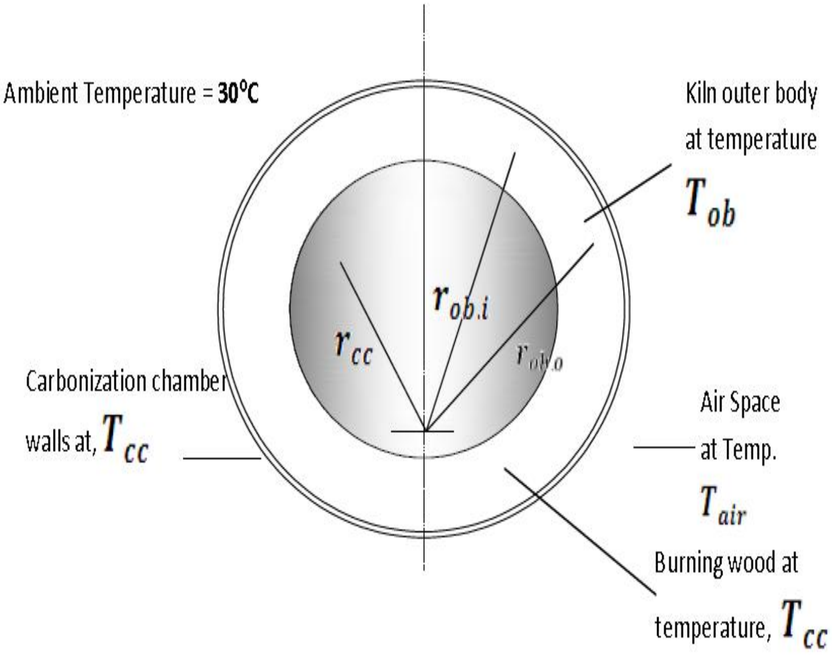

Fig. 6 Assumed kiln section for composite heat flow model

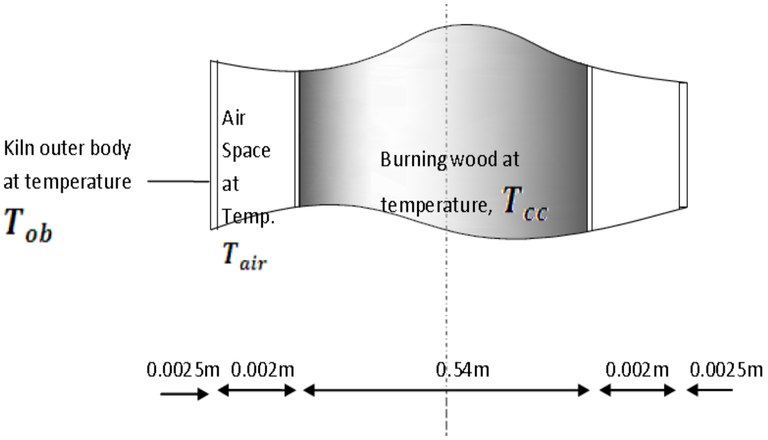

Fig. 7 Side view of the kiln section

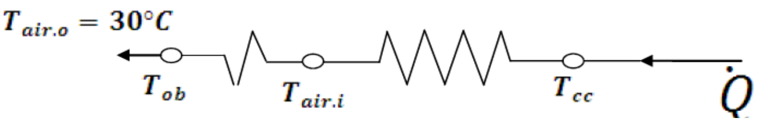

Fig. 8 Kiln heat transfer circuit diagram

The governing heat transfer equation for the carbonization process (Kammel et al.) is therefore

$$T_{cc} - 30^0C = \dot{Q} \times \left(\frac{1}{2\pi r_{cc} L_{cc} h_{air.i}} + \frac{1}{2\pi k_{ob} L_{ob}} \ln \frac{r_{ob2}}{r_{ob1}} + \frac{1}{2\pi r_{ob} L_{ob} h_{air.o}}\right) \quad (9)$$

Therefore, the recoverable heat Q being generated due to wood combustion inside the kiln at any time, *t* is therefore given by

$$\dot{Q} = \frac{T_{cc} - 30^C C}{\left(\frac{1}{2\pi r_{cc} L_{cc} h_{air.i}} + \frac{1}{2\pi k_{ob} L_{ob}} \ln \frac{r_{ob2}}{r_{ob1}} + \frac{1}{2\pi r_{ob} L_{ob} h_{air.o}}\right)} \quad (10)$$

where, T_{cc} = Temperature of the inner carbonization chamber; T_{ob} = Temperature of the kiln outer body. $\dot{Q}$ = Heat transfer rate at any time, t, r_{cc} = Radius of the carbonization chamber or drum, r_{ob} = Radius of the kiln outer body, L_{cc} = Height of the carbonization chamber, L_{ob} = Height of the kiln outer body, $h_{air.i}$ = Heat transfer coefficient of inner air space, $h_{air.o}$ =

Heat transfer coefficient of outer air, k_{ob} = Thermal conductivity of the kiln outer body material (Mild steel).

The solution of eqn.(10) for various values of ΔT = $(T_{cc}$ - 30°C) gives the heat generation profile for the combustion of wood inside the charcoal making kiln over the carbonization period of each test process. The values of ΔT = $(T_{cc}$ - 30°C) are obtained from the temperature readings taken during wood carbonization and are as shown in the last columns of tables 2 to 4.The quantities in eqn. (10) have the following values: r_{cc} = 0.27m, r_{ob} = 0.3 m, L_{cc}= 0.64m, L_{ob} = 0.91m, k_{ob} = 46 W/m. °C, $h_{air.i}$ = 10W/m^2.°C, $h_{air.o}$ = 15W/m^2.°C

To determine the influence of the inclusion of an insulating material, we need to know the temperature of the outer body, T_{ob} when insulation is used as compared with T_{ob} when no insulation is used. This will give an idea of how much heat is trapped or stored within the system during carbonization. To obtain the temperatureT_{ob}, the heat transfer eqn. (10) becomes:

$$T_{cc} - T_{ob} = \dot{Q} \times \left(\frac{1}{2\pi k_{ins} L_{ins}} in \frac{r_{ins2}}{r_{ins1}} + \frac{1}{2\pi * k_{ob} L_{ob}} in \frac{r_{ob2}}{r_{ob1}} \right) \qquad \textbf{(11)}$$

The only unknown in eqn. (11)is T_{ob}. The values for the carbonization chamber temperature, T_{cc} and the heat generation rate, Q remains the same as for the case of no insulation. Eqn. (11) is solved using MATLAB over three test carbonization processes to give the results in tables 2, 3 and 4.

Table 2: Input temperatures for test 8 matlab code

TIME	TEMPERATURE		
	Carbonization Chamber (°C)	Kiln Outer Body (°C)	ΔT = T_{cc} - 30°C
12:30pm	184	104	154
1:00pm	289	85	259
1:30pm	225	74	195
2:00pm	201	80	171
2:30pm	189	74	159
3:00pm	182	77	152
3:30pm	175	75	145
4:00pm	171	79	141
4:30pm	160	78	130
5:00pm	145	70	115
6:00pm	160	76	130
7:00pm	153	81	123
8:00pm	134	61	104
9:00pm	126	57	96
10:00pm	97	45	67

Table 3: Input temperatures for test 9 MATLAB code

TIME	TEMPERATURE		
	Carbonization Chamber (°C)	Kiln Outer Body (°C)	ΔT = (T_{cc} - 30°C)
12:30pm	279	97	249
1:00pm	292	121	262
1:30pm	307	127	277
2:00pm	284	118	254
2:30pm	194	120	164
3:00pm	230	90	200
3:30pm	226	89	196
4:00pm	160	79	130
4:30pm	152	70	122
5:00pm	145	68	115
6:00pm	150	71	120
7:00pm	132	62	102
8:00pm	110	56	80
9:00pm	87	51	57
10:00pm	78	49	48

Table 4: Input temperatures for test 10 MATLAB code

TIME	TEMPERATURE		
	Carbonization Chamber (°C)	Kiln Outer Body (°C)	ΔT = $(T_{cc}$ - 30°C)
12:30pm	190	92	160
1:00pm	250	110	220
1:30pm	298	107	268
2:00pm	272	96	242
2:30pm	210	83	180
3:00pm	180	78	150
3:30pm	175	80	145
4:00pm	160	75	130
4:30pm	152	69	122
5:00pm	140	62	110
6:00pm	137	63	107
7:00pm	130	59	100
8:00pm	101	51	71
9:00pm	85	46	55
10:00pm	71	42	41

Results and discussion

The performance evaluation of the fabricated kiln was carried out at the university fish farms. Ten different charcoal making processes were performed. Each process involved loading the kiln with a specified weight of wood pieces of approximately the same size. The wood stack was then sprayed with petrol and ignited. Subsequently, the burning of the wood was monitored by varying the amount of air flow into the kiln at different times until at the appropriate time, all air inlets were closed and the wood carbonization was completed. A complete burning process took an average of 24 hours. The recorded input and output data for the ten test carbonization processes are as shown in Table 5. The efficiencies of the ten test charcoal making processes are shown in Figs.9 and 10.

Table 5: Recorded data from ten test carbonization processes

Test Run	Wood Input (kg)	Charcoal Output (kg)	Mean Wood Size (L x W.) (m)	Cycle Time (Hours)	Air Inlet Time (Hours)		Efficiency
					Through top cover	Through open slots	
1	20	2.1	12 X 5	22	2	4	10.5%
2	37	8.5	11 X 4	21	1½	3	22.9%
3	35	9.5	12 X 4	21	1½	3	27.1%
4	40	10.4	12 X 3	21	1½	3	26.3%
5	39	11.1	11 X 4	16	1½	3	28.5%
6	37	9.2	11 X 4	21	1½	3	24.8%
7	40	10.5	11 X 4	22	1½	3	26.2%
8	36	11.3	11 X 4	20	1	2½	31.4%
9	35	10.2	12 X 5	21	1	2½	30.8%
10	39	9.7	12 X 5	24	1	2½	24.8%

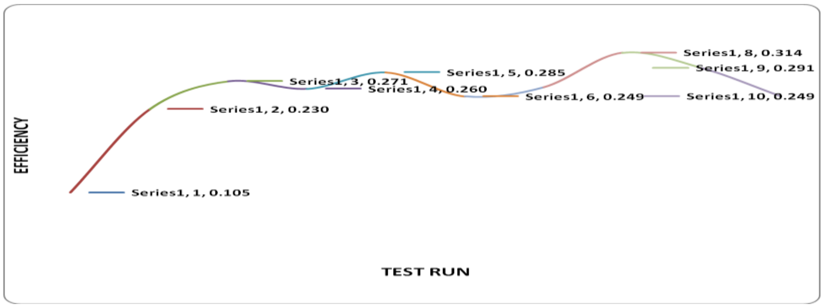

Fig. 9: Wood conversion efficiencies for ten test charcoal making processes using a metal kiln

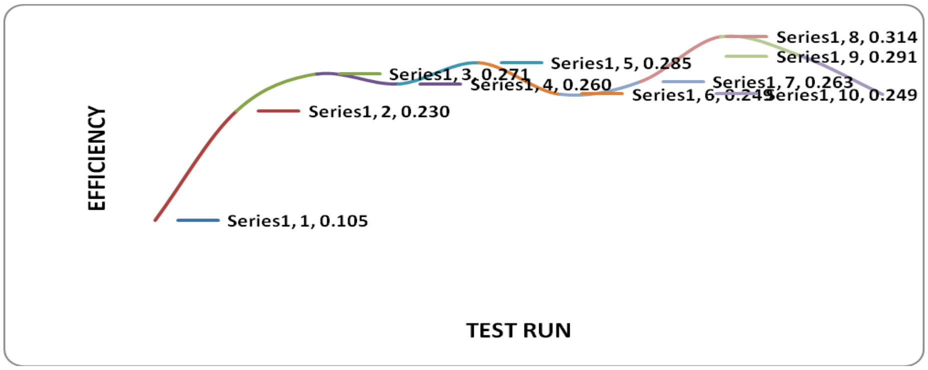

Fig 10 Wood conversion efficiencies for ten test charcoal making processes using a metal kiln

Factors for maximizing wood conversion efficiency

From comparison of the results of the ten test carbonization processes, it was observed that the main factors which significantly affected charcoal output quantity and quality were:

Air inlet timing

It was necessary to permit some initial inflow of air into the kiln to ensure that there was enough air to aid combustion during the initial phase of carbonization. The timing of air entry into the kiln during wood carbonization was found to significantly affect charcoal output. Longer initial air entry times of up to 3–4 hours tended to produce low charcoal yields with a high ash content as observed from the results of test 1. Lower air entry times of between 1–2 hours resulted in higher charcoal yields. This observation was attributed to the low moisture content of the wood which resulted in rapid combustion of the wood pieces during air inflow into the kiln.

Wood piece size

The usage of smaller wood pieces of about 0.3m length x 0.1m diameter usually resulted in higher useful charcoal yields. Usage of large wood pieces resulted in partially carbonized wood and low useful charcoal yield. The wood pieces loaded into the kiln also had to be similar in size otherwise incomplete carbonization of larger wood pieces or burning to ashes of smaller wood pieces would result.

Overall process timing

The timing of the overall process, that is, from the point of ignition to the point of charcoal unloading was found to affect charcoal output. Longer overall process times were found to result in low charcoal yields and high ash content, the size of wood and air entry time being constant. Based on the foregoing and with respect to the model in the present study, it can be stated that the best conditions for the maximization of charcoal output are a combination of low air inflow periods, smaller wood piece sizes of about 0.27m length x 0.1m diameter and lower carbonization process timing.

Temperature readings

Temperature readings were taken at different points of the kiln during wood carbonization to establish a pattern of heat flow through the kiln. Temperatures were taken from the kiln's outer body, the inner carbonization drum and the chimney draft. The results from the last two charcoal making processes are contained in the Figs. 11 and 12.

Gas analyzer readings

Analysis of the gas emissions from the kiln during wood carbonization was performed using a gas analyzer. The readings from the gas analyzer were taken at the peak of carbonization and showed the percentage content of various gases in the smoke emitted from the kiln. Other data recorded from the gas analyzer were the wood combustion efficiency during carbonization, excess air content of the smoke emissions and temperature of the smoke emissions. The readings are as shown in Tables 6 and 7.

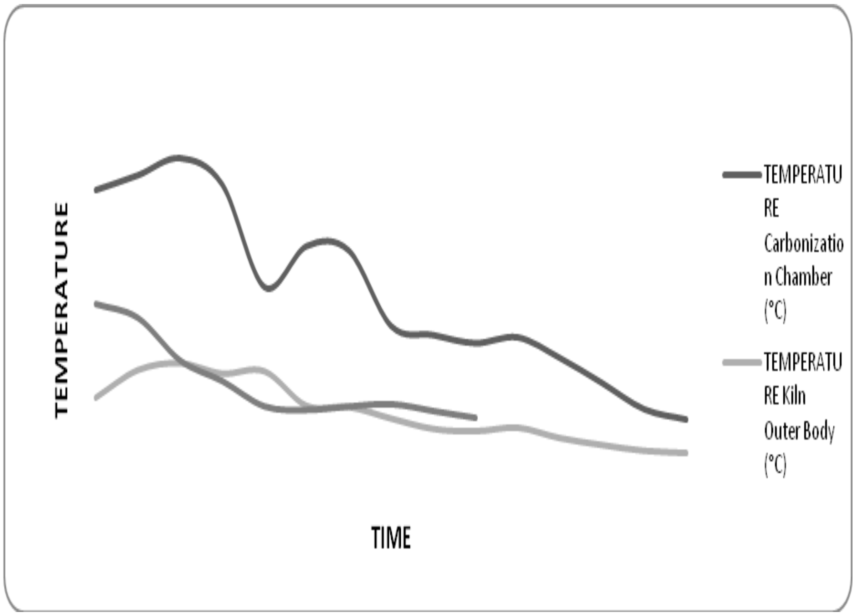

Fig.11 Temperature at different kiln points during wood carbonization (Test 8)

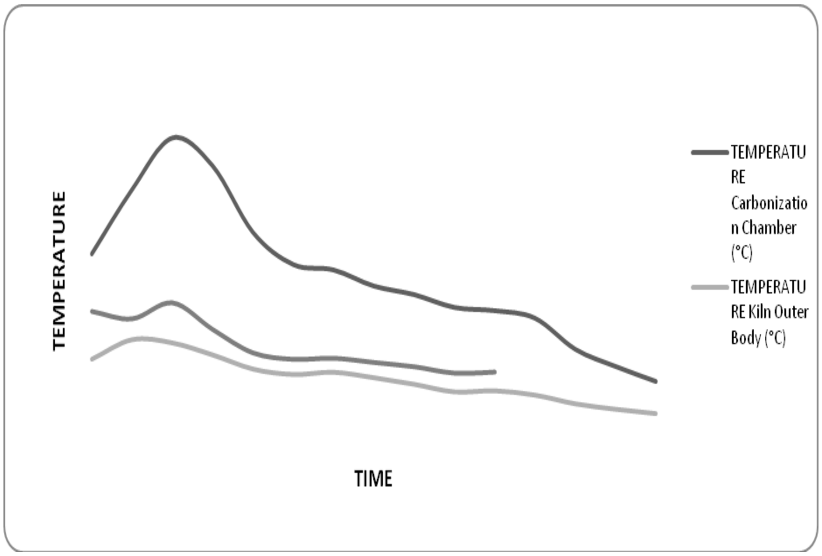

Fig. 12 Temperature at different kiln points during wood carbonization (Test 9)

Table 6: gas analyzer reading 1

Parameters	*Value*
O_2	4.9%
Combustion Efficiency	87.5%
CO_2	15.6%
Stack Temperature	82°C
Air Temperature	37.8 °C
Excess air	29.7%
NO	3ppm
SO_2	129ppm
NO(6)	3ppm
$SO_2(6)$	120ppm

The first reading showed predominance of CO_2 and O_2 in the carbonization exhaust emissions with 4.9% ofO_2 and 15.6 % ofCO_2 . Other gases had a much lesser percentage such as NO with just 3 parts per million of smoke particles and SO_2 with 129 parts per million of smoke particles. The reading also showed an instantaneous combustion efficiency of 87.5% and an excess air content of 29.7%.

Table 7: Gas analyzer reading 2

Parameter	*Value*
O_2	10.1%
Combustion Efficiency	85.4%
CO_2	10.6%
Stack Temperature	86°C
Air Temperature	40.5 °C
Excess air	89.1%
NO	3ppm
SO_2	129ppm
NO(6)	3ppm
$SO_2(6)$	120ppm

The second gas analyzer reading also shows predominance of CO_2 and O_2 in the carbonization exhaust emissions with 10.1% of O_2 and 10.6 % of CO_2. Other gases have a much lesser percentage such as NO with just 3 parts per million of smoke particles and SO_2 with 129 parts per million of smoke particles. The second gas analyzer reading shows an instantaneous combustion efficiency of 85.4% and an excess air content of 89.1%.

The above gas content analysis showed CO_2 as the only prominent environmentally harmful gas in the kiln's gaseous emissions. Considering the small charcoal production scale, it was concluded that the gaseous emissions from the kiln had minute impact on the environment. Also, provided that the kiln is operated in a well-ventilated environment, CO_2 poisoning is hardly a factor.

Undesirability of the inclusion of insulation materials

The temperature profiles for the kiln outer body temperature over three carbonization test processes show virtually no deviation from the ambient temperature of 30°C, see Figs. 13 and 14. This can be physically interpreted to mean that none of the heat generated during carbonization flows through the insulating material to the kiln's outer body and so the temperature of the outer body is virtually the same as the ambient. This conclusion has been verified practically. It is thus concluded that the inclusion of insulating material leads to a zero heat transfer condition wherein all the heat generated during combustion is trapped within the carbonization chamber. Such a situation will lead to excessively high temperatures within the kiln and more rapid wood combustion such that process times may need to be drastically reduced.

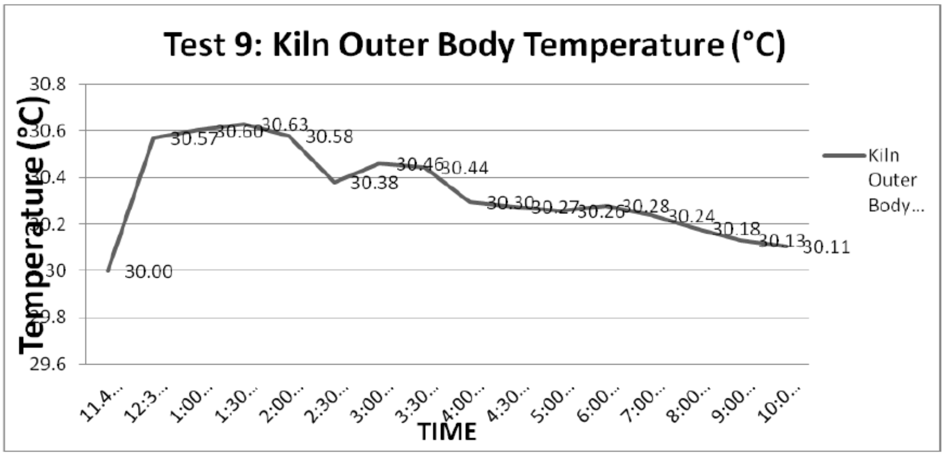

Fig.13: Profile of recoverable heat generated (kW) during carbonization

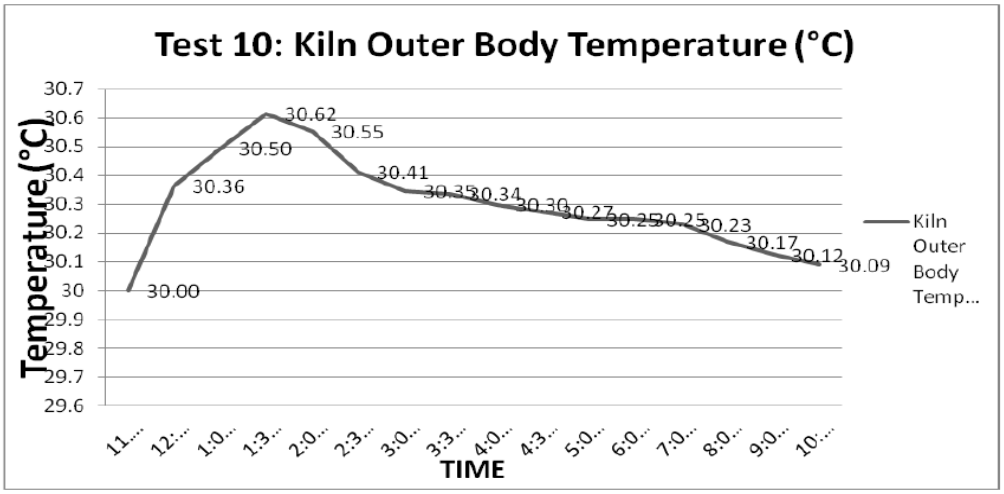

Fig.14: Profile of recoverable heat generated (kW) during carbonization

Production cost of the proposed Kiln:

Table 8 gives the production cost of the proposed kiln.

Table 8: Kiln fabrication cost

ITEM	*COST*
1.2 x 2.4m 14 gauge standard steel sheet	N10,500
0.6 x 1.2m Mild steel sheet	N7,000
1m length 0.05m dia. 10-gauge Iron pipe	N20,000
1m length 10-gauge Angle iron	N1000
Used diesel drum	-
Fabrication workmanship	N6,500
TOTAL	**N45,000**

.

Conclusion

A charcoal making kiln was fabricated in this work and performance evaluation was carried out by undertaking ten charcoal making or carbonization processes. Factors which maximized wood conversion efficiency were found to be a combination of lower air entry periods, less process times and smaller wood sizes. A mathematical heat transfer model of the carbonization process was developed and it revealed maximum recoverable heat rates of the order of 2kW from the charcoal kiln during wood carbonization. The same model also revealed that the inclusion of an insulation material was undesirable for the particular kiln designed, fabricated and tested in this work.

The total cost of fabrication of the metal Kiln is ₦45, 000. This project is highly feasible economically and will largely improve the economy of the fish drying process at the University fish farms. It was thus concluded that the charcoal kiln designed, fabricated and tested in this work would serve as an economically viable, safe and efficient means of utilizing the waste woods in the university community.

References

Ayo, S. A. (2009). Design, Construction and Testing of an Improved Wood Stove *AU J.T* 13(1): 12-18.

Braigs, J.L. (2007). Smoke Detectors, Carbon Monoxide Detectors and charcoal.Arch. J. Smoke Detectors, 41:3-18.

Cengel, Y.A. (2003). Heat Transfer Approach: A Transfer Approach. McGraw Hill, 2nd Edition.

Eyo, A.A. (2001). Fish Processing Technology in the Tropics, pp: 38, 153-163.

FAO, (1999). Food and Agriculture Organization.World Production of Fish, Crustaceans and Molluscs by Major Fishing Areas. Fisheries Information and Statistics Unit (FIDI). Fisheries Department, FAO; Rome.

Horner, W.F.A., (1992). Preservation of Fish by Curing: Fish Processing Technology. Chapman and Hall, London, pp: 125-128.

Kammen, D.M. and D.J. Lew (2005). *Renewable and Appropriate Energy Laboratory Report: Review of Technologies for the Production and Use of Charcoal.*

Ramakrishna, J. (1992). Preliminary results of the EWC/FWD global survey of improved cookstove programs. Indoor Air Pollution from Biomass Fuel, Working Papers from a WHO Consultation, 8 June 1991, pp. 135-146, World Health Organization (WHO),Geneva, Switzerland.

Sinha, S., A. Jhalani, M.R. Ravi and A. Ray (2000). Modeling of pyrolysis in wood: A review, SESI Journal, Vol. 10(1): 41-62.

Tran, H.C., and R.H. White (1992). Burning rate of solid wood measured in a heat release ratecalorimeter. Fire & Materials 16(4): 197-206.

Wartluft, J.L. and S. White (1983). *Comparing Simple Charcoal Production Technologies for the Carribean.* VITA News, pp.8-11.