Full Length Research Paper

Design and construction of fish smoking kiln

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The design and construction of fish smoking kiln was undertaken with the aim of improving the existing fish smoking kiln. The kiln consists of metal frame made of angle iron on which the entire component was assembled. The handle controls the speed of the ventilation fan through chain and sprocket. The charcoal housing is made of perforated metal sheet to allow for proper ventilation. The kiln is operated manually by turning the handle which drives the fan to augment natural ventilation. The machine performance was evaluated using fish samples (African mud Fish) smoked to an average moisture content of 11.46% within an average time span of 5 h, and the average final weight of the dried fish was 0.9827 Kg. It was found that the fish can be kept for at least two months before showing the sign of spoilage.

Key words: Fish, kiln, moisture content, smoke charcoal.

INTRODUCTION

Fish is one of the most diverse groups of animals known to man with more than 20,500 species in existence. According to FAO (1985), the World fish production from capture fisheries and aquaculture has reached 121 tones. A decline in fish availability will have a detrimental effect on the nutritional status of the citizenry particularly in places where fish contributes significantly to the protein intake of the people such as Nigeria where fish constitutes 40% of animal intake Olafunde (1989). Efforts should therefore, be geared towards increased fish production through improved resource management matched with effective post-harvest handling, preservation and processing to prevent spoilage.

Most of the fish harvested in the tropics is used for direct consumption but a great deal is processed into fish meal for use in compounding feeds (Eyo, 2001). Also according to Eyo (2001), a significant quantity is lost as a result of the absence of adequate technology to prevent post harvest losses. An estimated 20 to 50% of the fish produced in the remote and hinter lands of many tropical countries perish before these get to the consumers (Olafunde, 1989). Also, according to Eyo (2001), is due to poor handling, preservation and processing practices adopted by the artisanal fishermen, fish farmers and fish entrepreneurs.

In most developed countries, canning or freezing methods are used for fish preservation to improve the shelve life of fish. However, in underdeveloped and developing countries, traditional smoking kiln is still practiced, especially, in the tropics due to the sophisticated nature, erratic power supply and costs of the equipments. Consequently, there is the need to develop a more efficient and affordable equipment to enhance fish processing and reduce drudgery associated with traditional method.

RESEARCH METHODOLOGY

The smoking kiln was designed and constructed with the aim of fulfilling the following objectives; safe operation, general maintenance and servicing, low initial and operating costs, efficient and effective performance among others.

Design calculations

Volume of the kiln: the capacity of the kiln is directly related to the

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volume of the fish tray (vf) and is calculated as:

$$Vf = l \times b \times h \tag{1}$$

Where l = length of the tray = 49 cm
b = width of the tray = 29 cm
h = height of the tray = 5 cm

$$\therefore Volume = 49 \times 29 \times 5 = 7105 \, cm^3$$

Volume of the Charcoal Tray (Vc): is calculated as;

$$Vc = L \times b \times h \tag{2}$$

Where: L = Length of Charcoal Tray = 49 cm
b = width of Charcoal Tray = 29 cm
h = height of charcoal tray = 10 cm

$$\therefore Vc = 49 \times 29 \times 10 = 14210 \, cm^3$$

Diameter of kiln handle

Moments (m) of force = force (f) x length (height)   (3)

Where f = maximum of a man (500 N) and that of a woman (300 N)
h = height of handle = 0.16 m
f = 300 N (force of a woman)

$$m = 300 \times 0.16 = 48 \, Nm$$

The diameter of the kiln handle can be calculated as

$$(\delta) = \frac{m}{w} \tag{4}$$

Where: $\delta = working \ stress = \dfrac{\delta ult}{K}$ (5)

δult = 552 Mpa
K = Safety factor = 2
$$\delta = \frac{\delta ult}{K} = \frac{552}{2} = 276 \, Mpa$$
M = moment of force
W = Resistance moment = $0.1d^3$
Where d = diameter of the kiln handle (mm)

$$\delta = \frac{m}{0.1d^3}$$

$$276 = \frac{48}{0.1d^3}$$

$$d = \sqrt[3]{\frac{48 \times 10^3}{0.1 \times 276}}$$

$$d = 12 \, mm$$

According to Khurmi and Gupta (2003), the speed ratio may be determined from the expression below:

Speed ratio (V.R)

$$V.R. = \frac{N_1}{N_2} = \frac{T_2}{T_1} \tag{6}$$

Where N_1= and N_2 = number of revolutions of the smaller and larger sprockets (rpm) respectively
T_1 = number teeth on larger sprocket = 48
T_2 = number teeth on smaller sprocket = 20

$$V.R. = \frac{48}{20} = 2.4$$

Pitch Circle diameter of the smaller and larger sprockets (d_1 and d_2)
Pitch circle diameter of the larger sprocket (d_2)

$$d_2 = \frac{P}{\sin\left(180^0 / T_2\right)} \tag{7}$$

Where P = pitch = 1.3 (from Table 1)
d_2 = 20 cm
Pitch circle for the smaller sprocket (d_1)

$$d_1 = \frac{P}{Sin\left(180^0 / T_1\right)} \tag{8}$$

d_1 = 8 cm

Determination of speed of chain

$$p = [(wb \times v)/k] \times Ks \tag{9}$$

Where;
P = power developed by man = 0.1 Kw (Onwuala et al., 2006).
v = velocity of the chain in m/s
K = safety factor
Ks = Service factor
Wb = breaking load = 300 N

$$Ks = K_1.K_2.K_3 \tag{10}$$

Where;
K_1 = Load factor = 1 (for constant load)
K_2 = Lubrication factor = 1.5 (for periodic lubrication)
K_3 = rating factor = 1.25 (for 16 hours per day)
K_s = 1.875
Now

v = (P.K.K$_s$)/W$_b$ (11)

$$V = 0.1 \times 10^3 \times 2 \times 1.875 / 300$$

$$V = 1.25 \, m/s$$

Determination of number of revolution of the larger and smaller sprockets

$$v = \frac{\pi DN}{60} \tag{12}$$

Where

v = Velocity = 1.25 m/s
D = Pitch circle diameter (mm)
N = Number of revolutions (rev)

From Equation (12) number of revolutions of the larger sprocket (N_2) is given as

$$N_2 = \frac{V \times 60}{\pi D}$$

Where
D = 20 cm = 0.2 m
V = 1.25 m/s
N_2 = 119 revolutions

Similarly from equation (12) number of revolutions of the smaller sprocket (N_1)

$$N_1 = \frac{V \times 60}{\pi D}$$

Where
D = 0.08 m
N_1 = 298 revolutions

Torque on the shaft

$$T = \frac{P \times 60}{2\pi N_2} \qquad (13)$$

T = Torque (Nm)
P = Power (0.1 Kw)
N_2 = Number of revolutions of the larger sprockets = 119

$$\Rightarrow T = \frac{0.1 \times 60}{2\pi \times 119} = 8.03 \; Nm$$

Fan speed
Fan speed is given by the speed of gear multiplied by the velocity ratio

Fan speed = N_2 × V.R   (14)
        = 119 × 2.4 = 286 rpm
Fan air density (ρ) is given as

$$\rho = 1.325 B/T \qquad (15)$$

Where
B = atmospheric pressure = 760 mmHg
T = absolute temperature of air at room temperature
  = 35 + 273^{0}K = 308^{0}K
ρ = 13.25 x 760/308 = 3.30 Kg/m^3

Fan capacity Q is given as

$$Q = \frac{Q_x P_x}{P} \qquad (16)$$

Where
Q_x = Volume flow rate (m^3/s)

Q = Fan capacity

$$\rho_x = fan \; air \; density \; at \; plane \, X \; (Kg/m^3)$$

$$Q_x = 1097 A_x \sqrt{\frac{P_{vx}}{\rho_x}}. \qquad (17)$$

Where
P_{vx} = velocity pressure at plane X
A_x = Area of the larger sprocket (m^2)

$$A_x = \frac{\pi d_2{}^2}{4} = \frac{3.142 \times 0.2^2}{4}$$

$$A_x = 0.031 \; m^2$$

Where d_2 = pitch circle diameter of the larger sprocket
Velocity pressure (P_{vx}) = force/Area
Where
F = 300 N

$$\Rightarrow P_{vx} = \frac{300}{0.03} = 9677 \; N/m^2$$

Now $Q = \dfrac{Q_x \rho_x}{\rho}$; $\rho_x = \rho = 3.30 \; Kg/m^3$

Q = Q_x = 1836 m^3/s

Heat transfer by conduction is obtained as:

$$q = \frac{KA(T_1 - T_2)}{L} \qquad (18)$$

Where
K = Stainless steel conductivity = 30 Wm/K
A = Area of the fish tray = L x b = 0.142 m^2
L = distance between the fish tray and the charcoal tray = 0.1 m
T_1 = Temperature of the inside = 40°C (assumed)
T_2 = Temperature of the outside = 30°C (assumed)

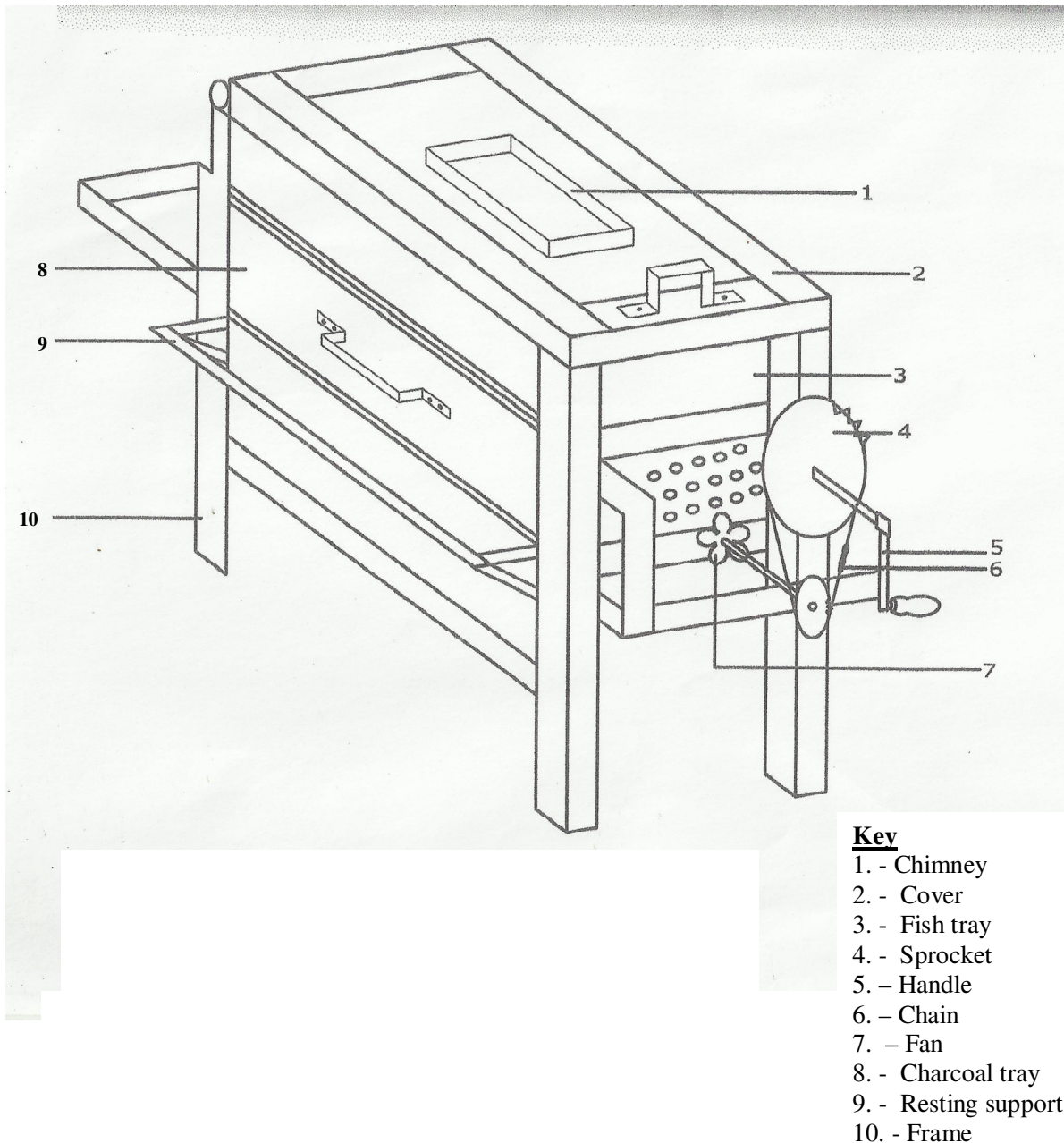$$\Rightarrow q = \frac{30 \times 0.142 \times 10}{0.1} = 426 \; J/m^2$$

Materials and construction

A mild steel metal sheet was used for the construction of charcoal tray and fish tray and general cover. While angle bar iron was used for the construction of the frame which formed the main support and the shaft was made using steel rods.

Construction of components

The important components of smoking kiln are

Frame: made up of angle iron of 25 x 25 mm. The angle irons were cut and welded together to form the mounting support for the kiln with 570 mm x 300 mm x 580 mm as the length, width and height respectively (Figure 1).

Key
1. - Chimney
2. - Cover
3. - Fish tray
4. - Sprocket
5. – Handle
6. – Chain
7. – Fan
8. - Charcoal tray
9. - Resting support
10. - Frame

Figure 1. The Assembled smoking kiln

Fish Tray: This is the container into which the fish is loaded and smoked. It is constructed from metal sheet and wire mesh with length 4980 mm, width 290 mm and height 50 mm.

Charcoal Tray: This is the container for burning the charcoal to provide energy for smoking the fish. It is constructed from metal sheets of 1 mm thick. It has the dimension of 490 mm x 290 mm x 100 mm.

Rotating Handle: The rotating handle was constructed from steel rod. This handle controls the speed of the fan which provides air for effective burning of the charcoal.

Axial Fan: The axial fan of 20 mm diameter with five blades and thickness of 1 mm was chosen. The fan was screwed to the shaft attached to the smaller sprocket and directly facing the charcoal tray which is situated 10 mm below the fish tray.

Machine assembly

The various components of the machine were either fastened using bolts or nuts or welded. The completed assembly of the kiln is shown in Figure 1.

Operational techniques

Fish to be smoked are fed into the fish tray and covered. The

Table 1. Performance evaluation results.

S/No	Initial weight (Kg)	Time taken to smoke the fish (h)	Final weight (Kg)	Final moisture content (%)
1.	1.2	5.0	1.0727	10.60
2.	1.3	5.0	1.1527	11.33
3.	0.82	4.0	0.7127	13.08
Mean	1.11	4.66	0.9827	11.46

charcoal is lit and the burning charcoals supplies the heat which dries the fish and smokes that envelope the fish serves as a preservative. The handle is rotated from time to time to drive the fan which supplies air to facilitate the burning. The ashes dropout through the perforation at the base of the tray. To control the heat transfer to the fish, the charcoal tray can be pulled out to rest on support.

Performance evaluation

Three sets of fish samples (African Mudfish) were obtained from Jimeta main market; the samples were thoroughly washed and salted, then allowed to dry for an hour under the sun.

The charcoal in the charcoal tray was first ignited with the help of kerosene, the ignited charcoal was allowed to burn for 10 to 15 min to allow the kerosene odour to be exhausted. More charcoal was added to the burning charcoal.

The first set of the sun dried fish was then weighed (Initial weight) and put into the burning tray. As the charcoal was burning, the fan is operated to supply a fairly constant heat. During the smoking, the sides of the fish facing the burning charcoal are changed routinely by pulling out the burning tray and then turning the fishes upside down then pushing the tray back. Similarly the weight of the fish is determined intermittently whenever the position of the fish is to be changed and the corresponding moisture content is determined. This is continued until the final weight and hence the final moisture content is determined. The final moisture content that is, safe moisture content (10 to 15%) (Ikenweiwe et al., 2010) is calculated using Equation (19) when there is virtually no further reduction in the moisture content. The time taken for the smoking was the total time taken including the time for the intermittent determination of moisture content and that of changing the position of the fish. The result is given on Table 1. After smoking and determination of final moisture content, the fish is allowed to cool and kept in plastic bucket, well covered carton and polythene bag to determine its storage life. These containers were selected because they are among the common storage media used for handling fish in Adamawa State. The determination of the storage life was done between the months of August to October, 2010.

$$mc_{db}(\%) = \frac{Initial\,weight - Final\,weight}{Final\,weight} \times 100 \qquad (19)$$

Where
Mc_{db} = Moisture content dry basis in percentage
Initial weight = Weight of sun dried fish (Kg)
Final weight = Weight of smoked fish (Kg)

RESULTS AND DISCUSSION

The assembled machine was rigid and operates smoothly with little effort needed to operate the fan.

The smoking kiln was tested with three sets of fish in the month of August, 2010; the result of the test is given in Table 1.

Table 1 above shows that within the time frame of averagely five (5) hours, the moisture content of each set of the fish was reduced to a safe moisture content this is similar to the result obtained in Ikenweiwe et al. (2010). The time taken for smoking as stated earlier depends on the weights/sizes of fish, the initial moisture content, the fat content of the fish and the uniformity and intensity of heat supplied. The use of this machine is found to be efficient when compared to the local method of smoking fish that takes almost 24 h in addition to the other labour stresses.

During the storage period, the fish were checked on weekly basis. At the end of the tenth week it was found that the fish in the carton maintains its normal colour, odour and taste but has some problems of insect and fungal attack (Table 2). While the fish in the plastic bucket and polythene bag were found to be in their normal characteristics up to the eighth week. Though in the ninth and tenth week there were no problems of insect attack, but traces of fungal attack (the formation of mold) was observed. This implies that storing in cartons need to be accompanied by the use less harmful insecticides that is, insecticides that can be exhausted within the storage period. While fish to be stored in plastic buckets and polythene bags, must be well dried. In general stored fish need to be checked at least once every two weeks, though frequency of opening may give room for absorption of moisture and penetration of insects. The storability of fish could also depend on the atmospheric weather condition.

The machine was found to be affordable by the local farmers as shown in Table 3. At the end of testing the machine it was cleaned, movable parts were oiled and the machine was well covered and kept under shed.

Conclusion

A smoking kiln that is easy to operate, cheap, portable and easily maintained was designed and constructed. The kiln was tested using one of the most available types of fish in the area. The smoking kiln performed efficiently by drying the fish to safe moisture content (10 to 15%) within five hours. The storability of the fish was found to be about two month. However, the duration of storage

Table 2. Characteristics of the fish stored under different conditions.

Week	Storage media		
	Carton	Plastic Bucket	Polythene bag
1st week	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste
2nd week	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste
3rd week	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste
4th week	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste
5th week	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste
6th week	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste
7th week	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste
8th week	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste
9th week	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste	Normal colour, normal odour and normal taste
10th week	Normal with traces of insect and fungal attack	There are traces of fungal attack	There are traces of fungal attack

Table 3. Cost analysis.

Item	Cost (₦)
Metal sheet	1000
Angle bar iron	1000
wire mesh	200
Steel rod	1000
Axial fan	1000
Shaft	500
Sprockets	500
Charcoal	500
Paint	400
Labour	1000
10% Miscellaneous	710
Total	7810

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could be increased in the dry season because of lower atmospheric humidity. It can also be concluded that fish that should be stored in cartons should be accompanied by the application of less harmful insecticides (those that are exhausted within the storage period). The overall production cost is eight thousand Naira (₦8000). This can be affordable by the local fish farmers. The machine can also be used for roasting meat and corn like maize. However the machine requires attention during operation to regulate or control the smoking process to avoid damage of the fish.

It is therefore recommended that the fan should be driven by d. c. motors for uniform blowing of air, constant heat energy supply and to further reduce drudgery to minimum.