2nd International Engineering Conference (IEC2017)
Federal University of Technology, Minna, Nigeria

Development of an Extruder for the Extraction of Fish Oil From Fish Based Stock

*Ayuba A. B[1], Olugboji A.O[2], Adedipe O[3]. & Babawuya A[4].

[1]Fish Product Development and Engineering Department, National Institute for Freshwater Fisheries Research, P.M.B 6006 New Bussa, Niger State Nigeria.

[2]Mechanical Engineering Department, Federal University of Technology,P.M.B 65 Minna Niger State, Nigeria

*Corresponding author email:abk4sure@gmail.com, +2348039749606

ABSTRACT

Fish oil are mostly used in the food, soap, medical and pharmaceuticals industry for the production of, oil for cooking, toilet soap and drugs. The objective of this work is to develop a technology for the extraction and processing of fish oil, from Cat Fish (*clarias gariapinus*) and Trunk Fish (*mormyrus delicious*); to design and fabricate, assemble the component and testing of the extruder, based on the design specification. While in designing and in material selection, consideration was given to the social – economic status of the intended user of the machine. The functional part of the machine includes worm shaft, cylindrical barrel gear box, oil outlet, cake outlet, and hopper The modification of the machine involves consideration on the process of extraction, time taken to extract, quality and quantity of oil recovered from the fish. The worm shaft is at increasing diameter while the screw system is at a decreasing pitch; these in turn give rise to a maximum pressure for oil extraction and fish cake extrusion process. In operation, the gradually built-up pressure along the worm conveys, crushes, grinds, presses and squeezes oil out of the pre-heated fish into the oil outlet. The fish residue is also extruded out through the fish cake outlet inform of flakes. The extruder was tested and result showed a reasonable oil yield and extraction efficiency, it is Powered by a 5 hp single phase electric motor. It is design to extract and recover about 80% oil from the whole body of the fish.

Keywords: *cylindrical barrel gear box , pulley and Worm shaft,*

1 INTRODUCTION

The development and advancement of science and technology coupled with the present economic situation has brought about increasing challenges for the development of different machines and devices to meet peoples demand. The concern of Engineer and Technologist is the motive of meeting such need at an affordable price and to reduce the burdens and problems experienced in using crude method. Similarly, the global marketplace has fostered the need to develop new products at a very rapid and accelerating pace hence efficient design of products is a vital tool to compete in such market (Ullman, 2010). The finding is based on scientific knowledge which involves research and development, design, manufacture and production. Over the years mechanical expression which is the mechanical deliquoring of compressible solids has been the best method of obtaining liquid from a liquid-solid medium (Dahlstrom et al, 1999). Particularly, Saravacos and Kostaropoulos (2002) observed that mechanical expression is used in the separation of fish oil from fish stock to preserve the biochemical components of fish oil. process and is chemical free extraction process brought about the development of a technology for the extraction and processing of fish oil. An automated extruder is a machine that uses mechanical means to extract fluid, typically fish oil from fresh fish. Cat fish (*Clarias garapinus)* and Trunk Fish (*Mormyrous delicious*)

Fish oil is different from other oils mainly because of the unique variety of fatty acids it contains including high level unsaturated fatty acid (Oega-3FFA and Omega-6FFA) which are essential to the body. This is known as the eicosapentaenoic acid (EPA) and the docosahexaenoic acid (DHA). (Pigot, 1967).

2 METHODOLOGY

2.1 MACHINE OPERATIONAL PRINCIPLE:

The raw materials used in this research work are the two types of fish species that were readily available.

i. Catfish or mud fish (*Clarias gariepinus)*
ii. Trunk Fish (*Mormyrous delicious*

Figure 1 below shows the flow chart of the operational principle.

Raw material (fish)

Hopper

↓

Cylindrical Barrel

(Grinding + Pressing + Expelling)

↓

Press Liqour outlet + Cake outlet

Collection

↓

Filtration of the press Liqour

↓

Oil and Water Separation using Separating funnel

↓

Refining and Packaging of the Oil

Figure 1 Flow Chart Showing Operational Principle of the Fish Oil Extruder

2.1.1 DESIGN ANALYSIS/CALCULATION

Design for the power requirement of the Extractor:

The power required to drive the extractor was calculated using a modified fomular from Olaniyan et al. (2007) as: shown in eqn. (1) below.

$$P_e = 4.5 \; x \; Q_v \; x \; I_s \; x \; \rho \; xg \; x \; F \qquad (1)$$

P_e= (4.5) x (0.1) x (1.1) x (1054) x (9.81) x (0.5)

P_e = 2559.80 W

746 watts = 1 H.P

Therefore 2739.81 W = $\frac{2559.80}{746}$ =3.43 H.P

$P_m = \frac{Pe}{\square} = \frac{2559.80}{0.75}$ = 3.4 KW

Where P_m is the power of the electric motor and ∩ is the drive efficiency. Given that 75% or 0.75; hence P_m =3.4 KW. Therefore, a 5.0 H.P Single - phase electric motor was selected to drive the extruder.

The torque (T) generated by the motor is given by the relation;

$$T = \frac{P}{\omega} \qquad (2)$$

P = 5.0 x 746 = 3730 W

$\omega = \frac{2 \; x \; \pi \; x \; N}{60}$

N = Rotational speed of electric motor = 1,450 rev/min

$\omega = \frac{2 \; x \; \pi \; x \; 1450}{60}$ = 151.7 rad/s

$T = \frac{P}{\omega} = \frac{3730}{151.7}$ = 24.58 Nm

2.1.2 The Belt and Pulley System

Selection of belt type: Based on the power calculated (3.730 KW) and according to the indian standards (IS: 2494- 1974), belt type B was selected (R.S. Khurmi 2011)

The torque supplied by the belt drive to the shaft is given by;

$$T = (T_1 - T_2) R \qquad (3)$$

$R = \frac{0.017}{2}$= 0.0085m

from equation (3)

Where torque is calculated as 24.56 Nm or 24.56x10^3 N/mm

24.56 = $(T_1 - T_2)$ x 0.0085

$(T_1 - T_2) = \frac{24.56}{0.0085}$

$(T_1 - T_2)$ = 2889.4 N

The ratio of the tight tension (T_1) to the slack side tension (T_2) is given by Budynas, R.G. and Nisbeth, J.K. (2011).;

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\left(\frac{\mu\alpha}{\sin \square/2}\right)} \qquad (4)$$

$$T_c = mv^2 \qquad (5)$$

Where m = mass per unit length of belt =

$m = \rho A \; = 1140 \; X \; 143 \; X \; 10^{-6}$ = 0.16 kg/m

But density (ρ) of belt material (Rubber) was found to be 1140kg/m^3

A = Cross- sectional area of the V- belt was calculated to be 143 x 10^{-6} m^2

V = Velocity of belt = ωr,

But ω = $\frac{2\,\pi\,N}{60} = \frac{2\,x\,3.142\,x\,1450}{60}$ =151.9 rad/sec

V = 151.9 x 0.0085 = 1.29 m/s

T_{C} = mv^2 = 0.16 x $(1.29)^2$ = 2.7 N

Angle of wrap (α) is gotten from the relation;

α_1= 180 – $2\sin^{-1}\left(\frac{R-r}{C}\right)$ (6)

α_2 = 180 + $2\sin^{-1}\left(\frac{R-r}{C}\right)$ (7)

R = Radius of big pulley = 0.027 m

r = radius of small pulley = 0.017 m

α_1= 180 – $2\sin^{-1}\left(\frac{0.027-0.017}{0.5}\right)$

α_1= 177.7^0 = 3.10 rad

α_1 = 3.10 rad

α_2 = 180 + $2\sin^{-1}\left(\frac{0.027-\,0.017}{0.5}\right)$

180 + $2\sin^{-1}(0.02)$

α_2 = 3.2 rad

θ = 30^0

μ = Coefficient of friction between belt and pulley = 0.3

From equation (4)

$\frac{T_1-2.7}{T_2-\,2.7}=e^{\left(\frac{0.3\,X\,3.1}{\sin 30/2}\right)}$

$\frac{T_1-2.7}{T_2-\,2.7}=e^{\frac{0.93}{0.2588}}$

$\frac{T_1-2.7}{T_2-\,2.7}$=3.6

T_1 = 3.6T_2 – 9.72 + 2.7

T_1 = 3.6T_2 – 7.0

$(T_1\ -\ T_2)$ = 2889.4

3.6T_2 – 7 -T_2= 2889.4

T_2 = $\frac{2896.4}{2.6}$ = 1114 N

T_2 = 1114 N

From equation 4

T_1 - T_2 = 2889.4

T_1 = 4003.4 N

Total force exerted in large pulley by the belt is;

T_1 + T_2 = 4003.4 + 1114

T_1 + T_2 = 5117.4 N

2.1.3 Determining the Diameter of the Shaft

According to American Society of Mechanical Engineering (AMSE) code for solid shaft with combine torsion and bending load; it is given by:

$d_o{}^3$= $\frac{16}{\pi\,\tau\mathrm{max}}\sqrt{(K_m\,x\,M)^2\,+(K_t\,x\,T)^2}$ (Khurmi R.S *et al*, 2011) (8)

T_e = $\sqrt{(K_m\,x\,M)^2\,+(K_t\,x\,T)^2}$

T_e = $\sqrt{(1.0\,x\,3832.8)^2\,+(1.5\,x\,24.56)^2}$

T_e = 3832.98 N/m

Torsional loading due to the applied torque by the belt is given below

τ = $\frac{\mathrm{Tro}}{\mathrm{J}}$

J = $\frac{\pi\,x\,do^4}{32}$

d_o = external diameter of shaft (m) = 0.038 m

J = $\frac{\pi\,x\,(0.038)^4}{32}$ =2.0473429 x 10^{-7} m^4

J = 2.0473429 x 10^{-7} m^4

τ_{max}= $\frac{24.56\,\mathrm{x}\,0.019}{2.0473429\,\mathrm{x}\,10-7}$= 2279246.92 N/$m^2$

$d^3{}_o$= $\frac{16}{3.142\,x\,2279246.92}$ x 3832.98

= 2.234202924 x10^{-6} x 3832.98

d_o= $\sqrt[3]{8.563655124\mathrm{x}10-3}$

d_o = 27 mm

The calculated value obtained is less than the shaft diameter (38 mm). This implies that the shaft will have sufficient resistance to the torsional and bending stress acting on it.

2.1.4 DETERMINATION OF THE GEAR SPEED

The pulley was designed by considering the power to be transmitted between the electric motor and the extruder screw shaft. The ratio of the pulley to the extruder shaft is 1:21 and the speed of the big pulley was calculated using the fomula given by (olaniyan *et al*, 2007) as $N_1D_1=N_2D_2$ 9

D_1 = diameter of large pulley 27 mm

D_2 = diameter of small pulley 17 mm

N_1 = speed of electric motor 1450 rpm

N_2 = speed of big pulley

$\therefore \quad N_2 = \frac{D2\ x\ N1}{D1} = \frac{0.017\ x\ 1450}{0.027} \quad N_2 = 912.96$ rpm

2.1.5 DESIGN FOR CAPACITY OF THE EXTRACTOR

The theoretical capacity of the extractor was determined using a modified form of the equation given by Olaniyan *et al*. (2007) as;

$$Q_e = 60 \text{ x } \frac{\pi}{4} D_s^2 - d_s^2 P_s N_s \rho \varphi \quad (10)$$

D_s = diameter of worm shaft = 38 mm, d_s = diameter of the base worm shaft = 20 mm

P_s = worm pitch = 18 mm, N_s= rotational speed of the worm shaft = 44 rpm

ρ = density of fish = 1080 kg/m^3, φ = filling factor = 0.8

From equation 10

$Q_e = 60 \text{ x } \frac{\pi}{4} \text{ x } (0.038)^2 - (0.02)^2 \text{ x } 0.018 \text{ x } 44 \text{ x } 0.8 \text{ x } 1080$

Q_e = 370 kg/h

Hence the design capacity of the extractor is 370 kg/h

2.1.5 Volume of the Hopper

Assuming radius of upper opening, is 53mm; radius of lower opening, is 37.5 mm; vertical height of the hopper, h, is 200 mm,

$$\text{Volume} = \frac{1}{3} \text{ x } (h(R^2 + Rr + r^2) \quad (11)$$

$V = \frac{1}{3} \text{ x } 200\ x(6202.8)$

V = 413520.0 mm

The volume of the hopper is calculated to be 413.50 m^3

2.1.6 MATERIAL SELECTION

In choosing the materials for the component parts of the machine, proper care was taken to ensure good and lasting construction

Machine Description

The machine consists of the feeding chamber (hopper), expelling unit, discharge units, frame and electric motor. The hopper is pyramidal in shape and made of 1mm gauge galvanized iron sheet. The expelling unit consists of a screw shaft with a perforated barrel outer casing. The screw is divided into three sections; the feeding, milling and discharge sections as it tapers. The friction and pressure produced by the screw on the barrel causes the mass to heat up, thus facilitating oil extraction as the screw grinds and presses the fine mass against the expelling chamber. The oil flows through the perforation in the casing and is collected beneath the expeller chamber while the residue (cake) is extruded from the unit through the cake discharge outlet.

The frame supports the machine and is firmly fastened together with bolts and nuts to allow easy dismantling for transportation. The prime mover is a (5hp) electric motor of 1450rpm speed with belt and pulley arrangement.

The table i: below shows the machine part that was used for the development of the extruding machine.

2.1.7 EXPERIMENTAL PROCEDURE

The fishes were thoroughly washed in order to remove dirt that might get stuck to the body after undergoing a de-freezing process, the head and the tail of the fishes were removed completely. The rest of the fish are cut into strips, to enhance a speedy preheating process that will last for 10 minutes at a temperature of 90 – 100 ^{0}C.

The cooked mass of the fishes was fed into the extruder hopper to be pressed in other to separate the fat-free dry solids and the liquid (oil & water) and the machine was switched on. The fat-free dry solids are further processed into fish meal. Fish meal is commonly used in animal feed. After five minute of operation, the liquid (oil & water) which is called press liquor is further processed to separate the oil and water using separating funnel. The press liquor was sieved using a muslin sack and washed with hot water of measured quantity before pouring into the separating funnel, for further separation of oil and water

The final stage of oil processing is calling polishing using centrifuging machine in other to removed impurities before storage inside the containers. The sketch of the fish oil extruding machine is shown below in Figure i. and plate i is showing how oil and water are been separated, plate ii shows the fish extract while plate iii shows samples of oil extracted.

2.2 FIGURES, TABLES AND PLATES

Table i: Machine part consideration and material used

S/N	COMPONENT	MATERIAL USED	SPECIFICATION (mm)	QUANTITY
1	Angle bar (frame)	Galvanized steel	50 x 50	3 Length
2	U – Channel	Galvanized steel	430 x 65 x 35	1
3	Shaft	Mild steel	□38 x 70	1
4	Inclined rod	Galvanized steel	□12 x 10	1 Length
5	Gear box	Mild steel	□ 27	1
6	V – belt	Rubber	IS:2494 B1974	2
7	Bearing	Cast and steel iron	□ 38	2
8	Barrel	Mild steel	5 x 90 x 45	1 Length
9	Pan	Mild steel	18gauge	1 Sheet
10	Bolt and Nuts	Mild steel	M10,M13	10
11	Electrode		Gauge 12	½ packet
12	Machining			
13	Paint			½ Gallon

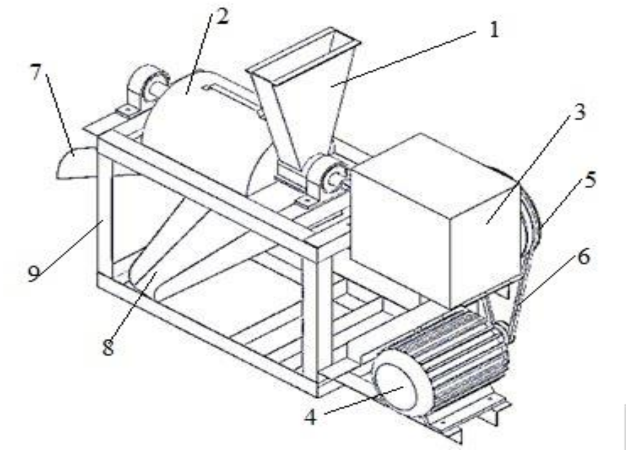

Figure i. Diagram of the fish oil extruding machine

1.Hopper, 2. Cylindrical barrel cover, 3. Gear box, 4. Electric motor, 5. Pulley, 6. Belt, 7. Fish cake outlet, 8. Fish oil outlet, 9. Frame.

Plate i Showing oil and water separation technique

Plate ii. Fish extract/fish meal.

Plate iii. Samples of extracted fish oil

3 RESULTS AND DISCUSSION

Machine Evaluation

Table ii-iii shows the extraction data obtained during the extraction process

TABLE II: SUMMARY OF THE PERFORMANCE OF THE FISH OIL EXTRACTION DATA FOR CAT FISH IS SHOWN BELOW

Weight of fsh before extraction (kg)	Weight of fish after filleting O_l (kg)	Weight of Press liqour extracted, O_e (kg)	Weight of maximum oil extracted, O_{me} (kg)	Weight of residue, O_R (kg)	Oil yield, Oy (%)	Extraction Efficiency of machine, Ee (%)
1	0.85	0.22	0.08	0.50	10.4	94.0
2	1.87	0.70	0.19	0.90	10.4	95.1
3	2.75	1.05	0.30	1.05	10.9	87.2
4	3.80	1.60	0.25	1.25	10.5	85.5

Table ii shows the performance of the fish oil extraction data for catfish. As 0.85kg of cat fish was pressed, 0.08kg of oil was recovered with a machine extraction efficiency of 94%. Also 1.25kg of oil was recovered as 3.80 kg of cat fish was pressed with a machine extraction efficiency of 85%. Hence as the weight of the fish increases during pressing the rate of oil yield also increases.

TABLE III: SUMMARY OF PERFORMANCE THE FISH OIL EXTRACTION DATA FOR TRUNK FISH

Weight of fsh before extraction O_l (kg)	Weight of fish after filleting O_l (kg)	Weight of Press liqour extracted, O_e (kg)	Weight of maximum oil extracted, O_{me} (kg)	Weight of residue, O_R (kg)	Oil yield, Oy (%)	Extraction Efficiency of machine, Ee (%)
1	0.90	0.30	0.93	0.45	10.3	94.4
2	1.85	0.85	0.21	0.70	11.3	96.2
3	2.80	1.15	0.35	1.20	12.0	95.7
4	3.70	1.40	0.45	1.53	12.1	91.3

As can be seen above Table iii shows the performance of fish oil extraction data for trunk fish. As 0.90kg of trunk fish was pressed, 0.45kg of oil was recovered with a machine extraction efficiency of 94.4%. Also 1.53kg of oil was recovered as 3.70 kg of trunk fish was pressed with a machine extraction efficiency of 91.3%. Hence as the weight of the fish increases during pressing the rate of oil yield also increases**. T**able iii also shows that trunk fish has more oil than cat fish when fish of the same quantity was pressed. The oil yield obtained from 1kg of cat fish was 0.08kg with extraction efficiency of 94% when compared to that of (Ngwu 2013) which is 0.045kg for 1kg of catfish oil yield with 87% extraction efficiency.

Table iv: T-test showing the difference between the average oil yield values of trunk fish and cat fish

Fish oil yield	N	Mean	SD	SE	T-Statistic	DF	P-Value
Trunk fish	4	11.425	.83016	.41508	2.15	6	0.75
Cat fish	4	10.325	.63300	.31650			

From table iv, the calculated probability value (0.75) is greater than the level of tolerance (0.05) at the degree of freedom of 6. This means that there is no significant difference between the oil yield of Trunk fish and Cat fish.

Table v: T-test showing the difference between the average machine efficiency values of trunk fish and cat fish

Efficiency of machine	N	Mean	SD	SE	T-Statistic	DF	P-Value
Trunk fish	4	94.4	2.2015	1.1008	1.494	6	0.186
Cat fish	4	90.4	4.8059	2.4029			

The result in table v, shows that the calculated probability value (0.186) is greater than the leveal of tolerance (0.05) at the degree of freedom 6. This implies that there is no significant difference between the efficiency of the machine during cat fish and trunk fish oil extraction.

Table iv and v shows that there exits no significant difference between the two fish speciecs (cat fish and trunk fish) oil yield. (P > 0.05). It was also found from the analysis obtained in table iv and v that there exist no significant different in efficiency of the machine during cat fish and trunk fish oil extraction. (P > 0.05).

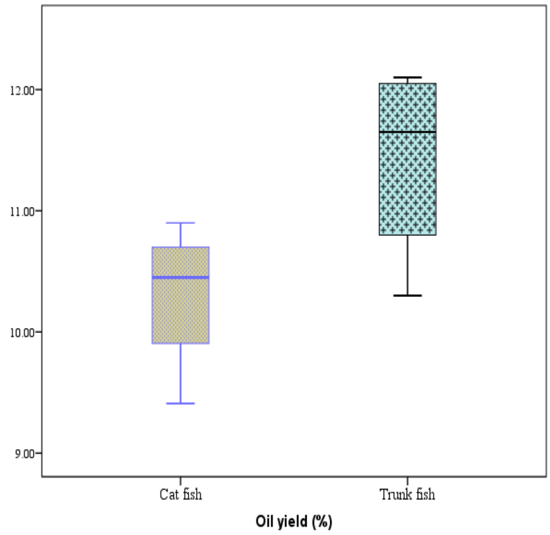

Figure 6. A Box plot showing variation between cat fish and trunk fish oil yield

The graph above reveals that the mean oil yield of trunk fish and cat fish were 11.42 and 10.30 respectively

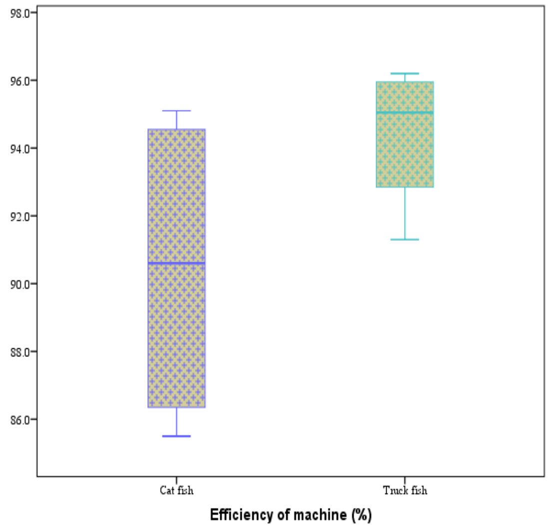

Figure 7. A Box plot showing variation between cat fish and trunk fish machine efficiency

From figure 7 above, the machine efficiency value for trunk fish and cat fish were 94.0% and 90.45% respectively.

4 CONCLUSION

Performance test was carried out on the extruder. It was tested and found to be efficient in the extraction of oil from Cat fish (*Clarias gariapinus)* and Trunk Fish (*Mormyrous delicious*). The extruder was simple enough for local fabrication, operation, repair and maintenance. Powered by a 5 hp single phase electric motor, the extruder has average extraction efficiency of 90.40% the high efficiency Generally the performance parameter of the machine increase with increase in the machine speed. (Olaniyan and Oje 2007) used these criteria for castor oil extraction. There is no significant difference between the two speciecs oil yield of cat fish and trunk fish.The extruder can be used for small and large scale oil extraction in the rural and urban communities across the country. This machine can provide employment for at least two persons at the same time produce fish oil and fish cake for agricultural, domestic and industrial used. The data obtained from the experiment shows that the extruder was able to extract some quantity of oil from the two fish species but there is still plenty of scope for improvement.

REFERENCE

Adesoji M. O., Kamaldeen A. Y., Adebayo L. W., and Kunle K. A. (2007). Design, development and testing of a screw press expeller for palm kernel oil extraction. *Journal of Agricultural Engineering and Technology*,56-59

Aidos I, van-der-Padt A, Boom RM, and Luten JB, 2003. Quality of crude fish oil extracted from herring by-products of varying states of freshness. *Journal of Food Science*. 68, 458-465.

Brennan, J.G., Butters, J.R., Cowell, N.D and Lilly A.E.V (2003), *Food Engineering Operations* Second Edition, Published by Applied Science Publishing Limited, Lodon.

Budynas, R.G. and Nisbeth, J.K. (2011). Shigley's Mechanical Engineering Design Ninth Edition, McGraw-Hill Companies, Inc., New York. 1082p.

European Food Safety Authority (EFSA), 2007. Scientific Opinion on Fish Oil for Human Consumption. *The EFSA Journal* 2010;8(10):1874

Khurmi R.S and J.K. Gupta (2011). A Textbook on Machine Design, Fourteenth Edition, Eurasia Publishing House (Pvt.) Ltd. Ram Nagar, New Delhi. 1230p.

Ngwu E.O, Ayuba, A.B.., Adelowo, E.O., (2013). Design and fabrication of a Screw Press for fish oil extraction. *National Institute for Freshwater Fisheries Research Annual Report* pg 53-54

Olaniyan, A.M., and Oje, K.,(2007). Development of mechanical expression rig for dry extraction of shear butter from shear kernel. *Journal of food Science and Technology*, 44(5), 465-470

Pigot, G.M. (1967). *Production of Fish Oil*, In: "Fish Oils," M.E Stanby Edited. Avi Publishing Company, Westport, Connecticut, pp 183-192.

Saravacos, G.D. and Kostaropoulos, A.E. (2002). Handbook of Food Processing Equipment. Springer Science+Business Media LLC, New York, 698p.

Ullman (2010) *The Mechanical Design Process*, Fourth Edition McGraw-Hill Companies, Inc New York, 450p

United Nation Development Organization (UNIDO) (1987), *Small Scale Oil Extraction from Groundnut and Copra* UNIDO Edition