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RESEARCH ARTICLE

DEVELOPMENT OF A FISH OIL EXTRACTING MACHINE

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ABSTRACT

This study aimed to develop a fish oil-extracting machine. An electric-motor powered screw press machine was used for extracting oil from fishes. The machine is made up of a feed hopper, upper casing, screw drum, perforated screen, shaft, oil trough, cake tray, and frame. The total weight of the machine is 82 kg with height of 132 cm. The components of the machine were fabricated using locally available materials which include mild and galvanised steel, that were sourced from the local market. The extractor was tested with fish at cooking times of 10, 15 and 20 minutes and cylinder speed of 80, 100 and 120 rpm. Minced Atlantic mackeryspecie of fish was used for the evaluation of the machine performance. Fish oil yield and physio-chemical/biological (micro) analysis were performed. It was observed that the oil yield increased with increasing cylinder speeds at all the heating times investigated. The best oil yield (20.9 %) was obtained for 120 rpm speed and 15 minutes cooking time and the lowest oil yield was obtained at 80 rpm and 20 minutes cooking time. Analysis of variance showed that cylinder speed, cooking time and their interaction made significant effects ($p \leq 0.05$) on the parameters evaluated and the separation of means using F-LSD also showed significant difference at $p \leq 0.05$. Analysis of Variance (ANOVA) at $p \leq 0.05$ showed significant difference in the extraction loss at all the speeds investigated for the 10 and 15 minutes cooking times but there was no significant difference at the speeds of 80 rpm and 100 rpm for the 20 minutes cooking time. The extraction reduces with increasing cylinder speed at each of the cooking time. The value of free fatty acids (FFA) in the extracted fish oil was found to be 2.3%, which is within the standard value of 2% to 5% for fish oil. The iodine value was 168 I_2/100g which is which is within the standard value of between 160 to 190 I_2/100g. The peroxide value (PV) was 11.4 meq/kg, which is well below acceptable limit of 20 meq/kg oil. This indicated that the fish oil extracted had low lipid oxidation rate. The saponification value was187 mgKOH/g which is within the range of 165-195 mgKOH/g for fish oil. The microbiological analysis of the extracted oil showed that the total coliforms count was 6.0×10^3CFU/ml of oiland the faecal coliforms count was 0.25 CFU/ml of oil which are safe for human consumption. The combination of cooking time of 15 minutes and cylinder speed of 120 rpm provided the best combination for the developed fish oil extraction machine using oil yield as the main criterion.

INTRODUCTION

Fish is one of the most popular food items for human consumption throughout the world. Fish oils have gained much more importance because of the presence of health beneficial omega-3 fatty acids in them. These polyunsaturated fatty acids (PUFA) especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) play a crucial role in the prevention of atherosclesis, heart attack, depression, stroke, diabetes, obesity, premature ageing, hypertension, cancer and improve the vision power and memory (Chin and Dart, 1995). Generally, fish oils are more complex than land-animal oils or vegetable oils due to long – chain unsaturated fatty acids. Fish oils are unique in the variety of fatty acids of which they are composed and their degree of un-saturation (Ackman *et al*, 1982). Refined fish oils are rich in polyunsaturated fatty acids of the linolenic acid family. Current medical research suggests that these fatty acids might have a unique role to play in prevention of coronary artery disease and the growth of different types of cancers. The oil is industrially used in leather tanning, production of soap and glycerol, and other products. Fish meal is a ground solid product that is obtained by removing most of the water and some or all oil from fish or fish by-products and is mainly used for the production of animal feeds (Ruiter, 1995). Oil extraction is the process of recovering oil from oil-bearing agricultural products through manual, mechanical, or chemical extraction. The processing techniques involved in commercial production of edible fats and oils vary according to the type of raw material. Fish reduction to produce oil and fishmeal, except for solvent extraction, generally employs the same principles, techniques and equipment common to the production of the other edible

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fats and oils. In general, fish are processed by the wet reduction method in which the principal operations are cooking, pressing, separation of the oil and water with recovery of oil, and drying of the residual protein material.
The traditional method of processing fish into its valuable components has been in existence for ages. Hot water floatation is probably the simplest method and is still used in many rural areas. The ground material is placed in boiling water and simmered for several hours. On removing from the fire and cooling the oil floats to the surface and is skimmed off. In general the oil is then heated in a shallow pan to drive off the last traces of water. This improves the keeping quality of the oil as water has a catalytic role in the development of rancidity in oils. The extraction efficiency is generally low, and problems often occur with the formation of oil-water emulsions which makes the final separation difficult. In some cases salt is used to break such emulsions.

In the present world of technological advancement, different types of machines have been developed using modern methods for oil extraction from various oil sources. In spite of the efficiency associated with solvent extraction, the cost of its plants demands a higher capital and operating investment schedule. The complex and hazardous systems found in solvent extraction plants require that these plants must be carefully designed for safety. Most of the solvents used in solvent extraction burn or explode very readily. One of the disadvantages of the extraction is that the solvent extracts some no triglycerides (Williams, 2005). Another serious problem is the presence of volatile organic impurities in the final product, which can compromise the quality and go against the new profile of consumers who are seeking for natural products aiming to have a healthier diet (Michulec and Wardencki, 2005). Some of the solvents have also been found to create poisonous products. In addition, cake from this extraction system may be of little or no food value and becomes wasteful in livestock feed formulation (Anna *et al*, 2012). Therefore, it has become necessary to provide for an extraction method appropriate enough to cater for the needs of small and medium scale fish oil processors. This study was aimed at developing fish oil extraction alternative to cater for both the small and medium scale fish oil processors. The study takes into account the limitations of the traditional methods and introduces improved concepts into its design, to achieve acceptable capacity, simplicity of operation and ease of repairs and maintenance using locally available materials.

MATERIALS AND METHODS

Description of the Machine

The principal components of the developed fish oil extracting machine are feeding hopper, interrupted screw drum, cylindrical casing, cake outlet, oil outlet, and frame. The screw drum is housed in the cylindrical barrel at a clearance of 5 mm between the screw diameter and inner diameter of the barrel. In operation, minced fish is introduced into the machine through the feeding hopper and the machine crushes, grinds, presses and conveys the fish inside the cylindrical casing with the aid of the screw drum enabling oil to squeeze out of the fish. The oil extracted flows through the perforations in the casing and is collected in a trough underneath the crushing cylinder. The residual cake after the oil is extracted exits out of the cake outlet in form of flakes. The machine is powered by a 5 hp single phase electric motor and has a production cost of Ninety Thousand Naira (₦90,000 ≈ $536.00). Figure 1 is the isometric drawing of the machine while figure 2 is the photograph of the machine. Figures 3 and 4 are the orthographic and exploded drawings respectively.

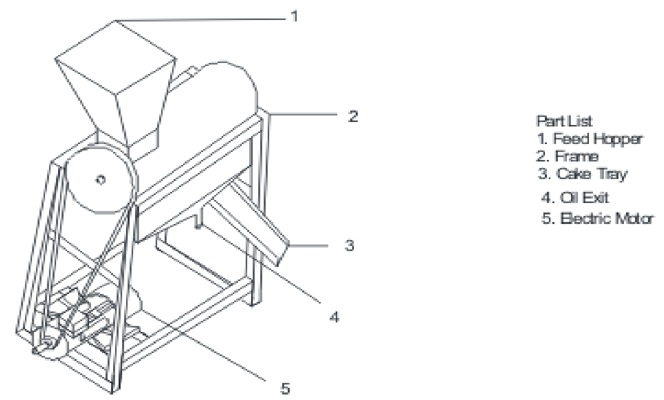

Figure 1. Isometric drawing of the fish oil-extracting machine

Figure 2. Photograph of the Fish Oil Extracting Machine

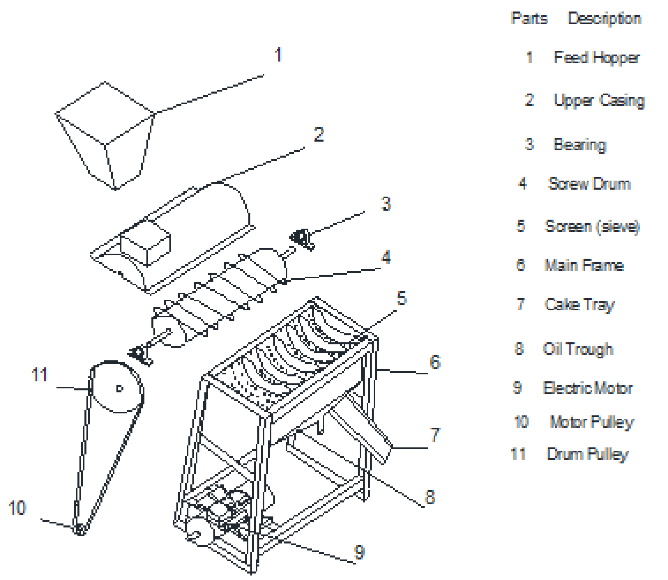

Figure 4. Exploded Drawing of the Fish Oil Extracting Machine

Design Analysis

The Principle of the Fish Oil Extraction Process

The extraction process is to operate in a continuous system. The extraction is facilitated by the mincing of the fish. The minced fish material is introduced into the expeller through the hopper. The screw moves and presses the material for the oil expression.

Dimensions and Design of the Extraction Unit

The extraction unit consists of the concave screen and the pressing drum. The concave sieve is 340 mm in diameter and is made of 2 mm thick metal sheet of 640 mm length. The drum is made up of rectangular bars of length 700 mm, width 4 mm and height 50 mm welded to form flights round the length of the cylinder of length 650 mm, thickness 2 mm and diameter 230 mm.

Screw Pitch of the Pressing Drum

The pitch of a thread is the distance from a point on one thread to the corresponding point on an adjacent thread. Thus for a drum auger of length L and M number of flights, the pitch is given by;

$$P = \frac{L}{M} \quad \text{(Khurmi and Gupta, 2005)} \qquad 1$$

Where:

L = Length of drum
M = Number of flights

Shear Failure Analysis of Pressing Drum

The shearing stress of the pressing drum is defined by;

$$\tau = \frac{16M_t}{\pi d^3} \quad \text{(Khurmi and Gupta, 2005)} \qquad 2$$

For belt drive, the torque was calculated as follows:

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

Where:

τ = Shearing stress, M_t = Torsional moment, d = Core diameter of pressing drum, mm,
T_1 = Tension in tight side, N, T_2 = Tension in loose side, N, R = Radius of drum pulley, mm.

Area of Screen

Perforated screen was selected because perforated screens generally have the advantage of being an inexpensive material that can be changed out with minimum labour. Perforated screens generally have 20% to 25% open area and 3 mm to 4 mm perforation sizes (Kataria, *et al*., 2011).

Design of Shaft

The shaft is made from wrought iron. It carries combined load of bending moment and torque which is given as:

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad \text{(Khurmi and Gupta, 2005)} \qquad 4$$

Where:

S_S = Maximum permissible shear stress,
K_b = Combined shock and fatigue factor applied to bending moment,
K_t = Combined shock and fatigue factor applied to torsional moment,
M_b = Maximum bending moment, Nm,M_t = Torsional moment, Nm.

Table 1. Results of design calculations

DESCRIPTION	RESULT
Volume of hopper	0.01536 m^3
Volume of hopper material	0.000576 m^3
Weight of hopper	44.41 N
Weight of pressing drum	156 N
Screw pitch of pressing drum	93 mm
Shearing stress of pressing drum	90700 N/m^2
Area of screen	0.342 m^2
Open area of screen	0.086 m^2
Weight of screen	40 N
Shaft diameter	32 mm

Physiochemical Properties of the Fish Sample

The physiochemical properties of the fish sample were carried out using the method described in AOCS, 1992. The parameters determined were water content, protein content, oil content, ash content, carbohydrates, density, coefficient of friction, angle of difference and shear strength.

Evaluation and Statistical Analysis

Selection, Preparation and Pre-treatment of Test Materials

Oily fish species (Atlantic mackery) was obtained fresh from the market in Makurdi. Prior to analysis, the internal organs were removed and the fish was washed to remove the residual blood. The fish was cut into small pieces. The minced fish was heated to 95-100 °C for approximately 10-20 minutes. This process coagulates the proteins and disrupts the cell membranes thus allowing the leakage out of bound water and oil (Adesoji *et al*, 2013).

Machine Evaluation Procedure

The expeller powered by a 5hp electric motor was set into operation and known weights (6000 g) of each prepared sample were fed into the machine through the feeding hopper. The interrupted helical screw drum conveyed, crushed, squeezed and pressed the fishes in order to extract the oil. The oil and water phases (containing water-soluble proteins as well) are separated from the solid phase (press cake). The fluid extracted and the press cake were collected and weighed separately. Clarification was done to separate the oil from its entrained impurities. The fluid extracted out of the press is a mixture of fish oil, water, cell debris, and non-oily solids. The fluid was allowed to stand undisturbed to settle by gravity so that the oil, being lighter than water, will separate and rise to the top. The clear oil was decanted into a reception container, sieved and heated to remove moisture in the oil. From the values obtained, oil yield was calculated according to Olaniyan and Oje (2007, 2011), and Adesoji *et al* (2013) as:

$$O_y = \frac{100\, W_{OE}}{W_{FE} + W_{RC}} \% \qquad 5$$

Where; W_{OE} = Weight of oil extracted,
W_{FE} = Weight of fish extract,
W_{RC} = Weight of residual cake.

Experimental Design and Statistical Analysis

The experimental design for the statistical analysis follows a two-treatment effect (cylinder speed and cooking time) in a split-plot factorial design with Completely Randomized Design (CRD) involving a two-way classification with three replications per experimental unit. The experimental unit comprises two factors; three cylinder speeds (80, 100 and 120 rpm) in each of the three levels of the cooking times (10, 15 and 20 minutes) giving a nine treatment combinations for the experiment as cylinder speed versus cooking time. The cylinder speed in the combination forms the levels of factor 'A' while the cooking time forms the levels of factor 'B'. All data collected were subjected to analysis of variance (ANOVA) to test for significant effects at 95 % confidence limit using the procedure recommended by Steel and Torrie (1980). When significant difference was observed, treatment means were separated using the F-LSD.

Analysis of Fish Oil Quality

Chemical methods

The physicochemical properties of the oil were determined to assess its quality and purity. Four oil quality indices were used to determine the quality of the extracted oil. They are the free fatty acid content, saponification value, iodine value and peroxide value. The level of free fatty acids (FFA), saponification value (SV), iodine value (IV) and peroxide value (PV) were determined by titration according to the Official Methods and Recommended Practices of the American Oil Chemists' Society (AOCS, 1992).

Microbiological Analysis

Microbiological analysis was conducted for aerobic plate count method (Standard Plate Count agar) with four dilution and incubated at 37°C for 24-48 hours. Count was carried outusing hand lens. The colony forming unit (g/mL) was calculated according to Vanderzant and Splittstoesser, 1992from the equation;

$$Cfu = \frac{N}{VD} \qquad 6$$

Where; N= number of colonies, V= volume of diluents, D= dilution factor.

RESULTS AND DISCUSSION

Machine Evaluation

Characterization of Fish

Results of the characterisation of the fish sample are presented in table 2. Proximate composition included moisture, lipid, protein, ash and carbohydrate contents. The moisture content was found to be 55.7%. The protein contentand ash content were 15.6 and 1.5%. Carbohydrates composition estimated in the samples analysed was 0.4% and the lipid content was found to be 26.8% in this study. According to Ackman (1989), fish can be grouped into four categories according to their fat content as lean fish (< 2%), low (2-4%, medium (4-8%) and high fat (> 8%). In terms of the lipid content, fish species examined can be considered to be in the high fat fish category. The density of fish sample was found to be 25° and 0.466 respectively. The shearing strength of fish sample was found to be 3578 N/m^2.

Table 2. Characterisation of Fish Sample

Parameter	Test Value
Proximate Composition	
Water content	55.7%
Protein content	15.6%
Oil content	26.8%
Ash content	1.5%
Carbohydrates	0.4%
Physical Properties	
Density	950 Kg/m^3
Coefficient of friction	0.466
Angle of repose	25°
Mechanical Properties	
Shear strength	3578 N/m^2

Effect of Cylinder Speed and Heating Time on the Oil Yield

Table 3. Analysis of variance of the effect of cylinder speed and heating time on oil yield (%)

Sources of Variation	Df	SS	MS	Observed F	Required F (5%)
Treatment combinations	8	29.52			
Cylinder Speed (S)	2	20.17	10.09	126.06*	3.55
Heating Time (T)	2	7.02	3.51	43.88*	3.55
Interaction (S×T)	4	7.02	1.76	21.94*	2.93
Error	18	1.47	0.08		
Total	26	30.99			

* - significant

Table 4. Effect of cylinder speed and heating time on the mean oil yield (%)

Heating Time (min)	Cylinder Speed (rpm)		
	80	100	120
10	17.5 [a]	18.1 [b]	19.7 [c]
15	18.2 [d]	18.8 [e]	20.9 [f]
20	17.5 [g]	18.0 [h]	18.7 [i]

Means having the same letter in the same row are not statistically different from each other at P ≤ 0.05 using F-LSD.

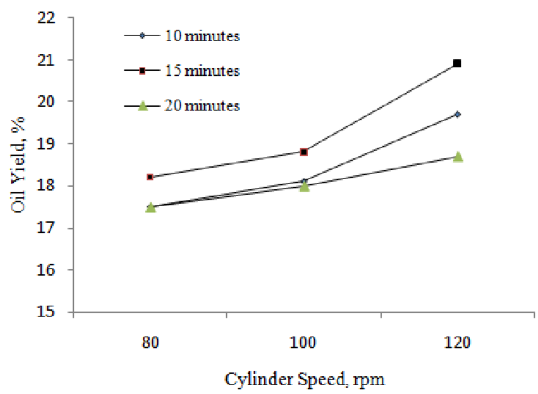

Figure 5. Effect of cylinder speed and heating time on the mean oil yield (%)

The Analysis of variance (ANOVA) of the effect of cylinder speed and heating time on the oil yield (%) at P≤ 0.05 is presented in table 3, and the Means using F-LSD is presented in table 4. Moreover, Figure 5 shows the effect of cylinder speed and heating time on the mean oil yield. From the ANOVA (Table 3) there is a significant difference in the cylinder speed, cooking time and their interaction. There was significant difference in the oil yield at all the speeds investigated for the entire cooking times. The best oil yield (20.9 %) was obtained for 120 rpm speed and 15 minutes cooking time. The lowest oil yield was obtained for the conditions of 80 rpm and 20 minutes cooking time. It was observed from table 4 that the oil yield increased with increasing cylinder speeds at all the heating times investigated. This is in agreement with the statement of Bamgboye and Adejumo, (2007) who reported that a reduction in speed of rotation of the shaft, for example, could reduce the oil yield, increasing the oil content in the cake and solids in the oil. Akinoso *et al*. (2009) while evaluating the effects of compressive stress, feeding rate and speed of shaft screw press on palm kernel oil yield observed same trend of increase inoil yield with increased speed.

Effects of Cylinder Speed and Heating Time on the Percentage Extraction Loss

The effects of the cylinder speed and heating time on the percentage extraction loss is presented in table 5. The Analysis of Variance (ANOVA) at $p \leq 0.05$ is presented in table 6.

Table 5. Replicated results of total machine loss (%) of the fish oil extracting machine at three different heating time and three cylinder speeds

Cooking Time (mins)	Replications	Cylinder Speed (rpm)			Total
		80	100	120	
	1	21.67	21.33	17.50	60.5
10	2	24.17	20.00	18.33	62.5
	3	25.00	19.67	15.00	59.67
Total	-	70.84	61.00	50.83	182.67
	1	21.67	16.67	13.33	51.67
15	2	20.00	18.00	13.00	51.00
	3	20.00	17.67	10.00	47.67
Total	-	61.67	52.34	36.33	150.34
	1	30.00	27.50	19.17	76.67
20	2	27.50	28.33	18.33	74.16
	3	29.67	29.17	19.83	78.67
Total	-	87.17	85.00	57.33	229.50
Grand Total	-	219.68	198.34	144.49	562.51

Table 6. Analysis of Variance of the Effect of Cylinder Speed and Heating Time on Total Machine Loss (%)

Sources of Variation	Df	SS	MS	Observed F	Required F (5%)
Treatment Combination	ts-1=8	712.79			
Cylinder Speed	s-1=2	333.65	166.83	102.35*	3.55
Heating Time (T)	t-1=2	352.02	176.01	107.98*	3.55
Interaction (S×T)	s-1(t-1)=4	352.02	88.01	53.99*	2.93
Error	ts(r-1)=18	29.32	1.63		
Total	tsr-1=26	742.11			

The graph of the effect of cylinder speed and heating time on the mean total machine loss is shown in figure 6. From the ANOVA (Table 6) there is a significant difference in the cylinder speed, cooking time and their interaction. There was significant difference in the extraction loss at all speeds investigated for the 10 minutes and 15 minutes cooking times. There was no significant difference in the extraction loss at the speeds of 80 rpm and 100 rpm investigated for the 20 minutes cooking time. The total extraction loss reduces with increasing cylinder speeds at each of the heating times (Figure 6).

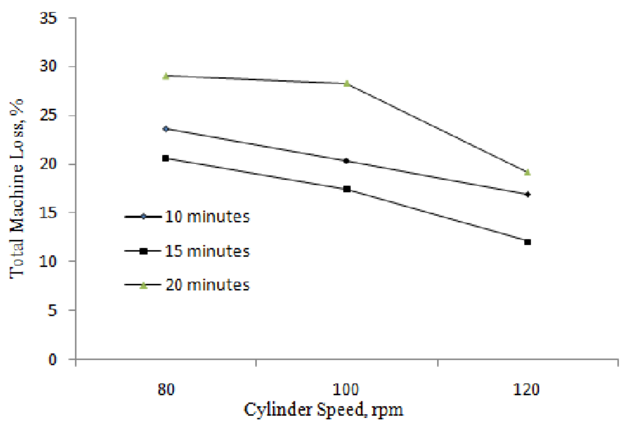

Fig. 6. Effect of Cylinder Speed and Heating Time on the Mean Total Machine Loss

The lowest extraction loss, 12.11%, was obtained for cylinder speed of 120 rpm and 15 minutes cooking time. The highest extraction loss, 29.06%, was obtained for cylinder speed of 80 rpm and 20 minutes cooking time.

Quality of the Extracted Fish Oil

In order to determine the stability and quality of the extracted fish oil, some quality assessment was conducted. As presented in table 7, it was observed that all the results obtained were tolerable to the standard values.

Table 7. Analysis of the Extracted Fish Oil Quality

Parameter	Unit	Test Value	
		Crude Oil	Refined Oil
Physiochemical Properties			
Free Fatty Acid Value	%	2.3	0.28
Saponification Value	mgKOH/g	187	132
Iodine Value	Iodine/100g	168	105
Peroxide Value	$mEqO_2/kg$	11.4	2.5
Microbiological Measurement			
Total Coliforms Count	CFU/ml	-	6.0×10^3
Faecal Coliforms Count	CFU/ml	-	0.25

The value of free fatty acids (FFA) in extracted fish oil was found to be 2.3 %, which is within the standard value of 2 % to 5 % for fish oil. The iodine value was found to be 168 I_2/100g of the sample was within the standard value of between 160 to 190 I_2 /100g of the sample. Bimbo (1998) has reported that peroxide value (PV) of crude fish oil was between 3 and 20 meq/kg. In this study, the PV was found to be 11.4 meq/kg, which is well below acceptable limit of 20 meq O2/kg oil. This indicated that the fish oil extracted had low lipid oxidation rate. Saponification is the process of breaking down a neutral fat into glycerol and fatty acids by alkali treatment. The Saponification value (SV) of fish oil obtained in this study was within (187 mg KOH/g) the standard value range for fish oil (165-195 mg KOH/g), given by Bimbo (1998). According to Middle brooks *et al* (1988), mackerel stored at 0, 15, and 30°C have counts of about 10^6 CFU/g of flesh. The results of the microbiological analysis of fish oil showed that the total coliforms count was 6.0×10^3 CFU/mL of oil and the faecal coliforms count was 0.25 CFU/mL of oil. The reduction in the coliforms counts is as a result the use of heat in the oil extraction process.

Optimization for Optimum Performance

The concept of optimization was used to choose the optimal combinations between the two variables; cooking time and cylinder speed that provided the optimal performance of the fish oil-extracting machine. The combination that guaranteed the highest oil yield and extraction efficiency and the least extraction loss was considered optimal. The combination of cooking time, 15 minutes and cylinder speed, 120 rpm provided the best combination the fish oil extractor should be operated using the oil yield as the main criterion. At this variables combination, the highest oil yield, 78.11% and the least extraction loss, 12.11% occurred.

Conclusion

The results obtained from the developed machine shows that mechanical extraction is a suitable method for extracting fish oil because of its high yield and high oil purity. Also, the use of an electric motor to operate the extractor produces less noise thereby reducing the cost of abating pollution. This process also generates little or no waste since the fish cake can be used as animal feeds thereby reducing cost of waste disposal. From the output of the machine it can be concluded that design and installation of a commercial plant is viable. However, further studies on this machine should investigate the effect of other operational parameters such as cylinder-concave clearance on the quantity and quality of the extracted fish oil.

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