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Some Engineering Properties of Fish Feed Pellets

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ABSTRACT

Study was carried out to investigate some physical and mechanical properties such as length, diameter, 1000 unit mass, bulk and true densities, surface area, static and dynamic coefficient of friction, angle of repose and crushing load of fish feed pellets and also to establish a database for engineering properties of fish feed pellets. There is paucity of information on some engineering properties of fish feed pellets that is useful toward understanding the behavior of the product during the processing operations, transporting, packaging and storage processes. Average actual diameter and expansion rate of the fish feed pellets were 2.47 ± 0.10 mm, 4.05 ± 0.12 mm, 4.86 ± 0.22 mm and 7.09 ± 0.18 mm and 17.89 ± 1.54%, 23.78 ± 2.2%1, 16.89 ± 1.14% and 14.75 ± 1.32% for pellet diameter of 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm respectively. Bulk and true densities, durability, dynamic and static coefficient of friction and crushing load increased with increasing in feed pellet size. Plywood had the highest dynamic and static coefficient of friction amongst the three surfaces. Stainless steel provided lowest dynamic and static coefficient of friction for fish feed pellets. Stainless steel as construction material in the manufacture of process components is therefore recommended for better productivity..

Keywords: *True density, static coefficient of friction, angle of repose, sphericity, physical properties.*

INTRODUCTION

Aquaculture industries play a major role in most developing countries such as Nigeria because it enhances higher income, higher nutritional value, and broader employment opportunities (Kannadhason *et al*., 2008). Aquaculture feed is quite expensive and this can be attributed to the cost of raw ingredient and machinery involved in production and processing of the feed. Sometimes the cost of aquaculture feeds can be up to 30% to 60% of total operational costs for aquaculture production (Kannadhason *et al*., 2009). The recent upsurge in the interest in the aquaculture feed industry can be attributed to the modern technology employed as the world's population continues to grow exponentially (Razzaq *et al*., 2012).

There are basically two types of aquaculture feed namely floating feeds and sinker feeds. Most commercially produced feeds are floating type feeds using extrusion cooking process. The extrusion processes involves; cooking, sterilization, expansion, texturization, and product shaping (Liu and Rosentrater, 2011). This processing technique is embedded with unique advantages such as enhanced food conversion ratio, control of pellet density, higher feed stability in water, better production efficiency (Razzaq *et al*., 2012, Delgado-Nieblas *et al*., 2012 and Forsido *et al*., 2011). During the extrusion process, starch is gelatinized, which plays an important role in the final extrudate properties (Chevanan *et al*., 2008). Rosentrater *et al*., 2009 reported the importance of binder such as starch in feed digestibility, expansion, water solubility and particle binding. Majority of aquaculture feeds used in the country is imported. There is an urgent need for the development of fish feed pelleting machines for indigenous fish farmers and feed manufacturing industry in Nigeria.

For agricultural mechanization to be successful in Nigeria it must be based on indigenous design, relatively affordable, simple in operation and less energy free flow (Tabil 2010, Jekayinfa, 1995 and 2003, Odigbo 1999 and 1997). One of the major problems faced with the production of pelleted aquaculture feeds in Nigeria is that, aquaculture feeds are produced within feed mills majorly designed and geared towards the manufacture of poultry and livestock feeds. Some of these feed mills lack the required capacity for fine grinding. The cost of equipment procurement and energy consumption for fine grinding is quite enormous (Koh, 2007 Arora, 2007, Tabil *et al*. 2010 and Rolf, 2007).

There is paucity of information on the engineering properties of fish feed pellets which provide essential database and unique understanding for the design of equipment for handling operations, conveying, packaging, floatability, separation, drying, storage and process for optimum efficiency by engineers, food scientists and processors. The objective of this study is to investigate some engineering characteristics of fish feed pellets of different sizes.

Materials and Methods

The four different sizes of extruded fish feed pellets was bought in Port Harcourt, Rivers State, Nigeria. Moisture content was determined based on ASABE, (2003).

$$W_2 = W_1 \times \left[\frac{M_1 - M_2}{100 - M_1}\right] \quad (1)$$

where, W_1 and W_2 are mass of the sample and distilled water (g), and M_1 and M_2 are initial and final moisture contents (% drying basis) respectively.

For this experiment, 100 fish feeds were randomly picked, the linear dimension such as length and diameter were measured using a digital Vernier caliper with a reading of ±0.01 mm. Surface area and volume of the fish feeds were calculated according to Mohsenin, 1980, McCabe *et al.*, (1986), Koocheki *et al*. (2007), Milani (2007) and Galedar *et al*. (2008). This was achieved by measuring the height (h) and radius (r) of 100 feed pellets for each category and using the following relationships as follows:

$$\text{Surface area (SA)} = 2\pi r(h + r),\ \text{mm}^2 \quad (2)$$

$$\text{Volume} = 2\pi\, r^2 . h\ ,\ \text{mm}^3 \quad (3)$$

The static and dynamic coefficient of friction was determined for fish feed pellet with respect to three structural materials namely: galvanized iron sheet, plywood sheet and stainless steel in accordance with ASAE (1987), Ghazavi *et al*. (2008) and Davies and Mohammed (2011). The angle of repose was determined based on the method used by Davies and El-Okene (2009). The mean crushing load require to initiate rupture in fish feed pellets in the horizontal and vertical axes were measured using an Instron Testing Machine equipped with a 5 kg load cell at a compressive rate of 30 mm min^{-1}.

Bulk and True Density

The bulk of fish feed pellets were poured into a container of predetermined mass and volume (250 ml) from a height of 100 mm at a constant rate (Garnayak *et al.*, 2008). The bulk density (ρ*b*) of fish feeds were determined by filling an empty glass container of predetermined volume and known weight with fish feeds were poured from a constant height, striking off the top level and weighing. The true density (ρ*t*) of fish feed pellets was determined using the water displacement method (Mohsenin, 1986 and Kabas *et al*. 2007). The ratio of the mass (M) and volume (V) was expressed as bulk density.

$$\rho b = \frac{Mb}{Vb} \quad (4)$$

$$\rho t = \frac{M}{V} \quad (5)$$

Result and Discussion

The average diameter, expansion rate and as well as standard deviation and coefficients of variation of fish feed pellets were shown in Table 1. It was revealed that the average actual diameter and expansion rate of the fish feed pellets were 2.47 ± 0.10, 4.05 ± 0.12, 4.86 ± 0.22 and 7.09 ± 0.18 mm and 17.89 ± 1.54, 23.78 ± 2.21, 16.89 ± 1.14 and 14.75 ± 1.32% for pellet diameter of 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm respectively. This is an indication that pellet feeds after being forcibly ejected from the die of extrusion machines expanded. Expansion rate is irrespective of pellet sizes. Highest and lowest expansion rate corresponded to 3.0 mm and 6.0 mm die diameter. The coefficients of variation of the actual diameter and expansion ranged between 0.05 (2.0 mm) and 0.09 (6 mm) and 0.06 (2.0 mm) to 0.10 (6.0 mm) respectively.

According to Khater *et al*. (2014) reported the actual diameter and expansion rate of pellets fish feed value ranged from 1.51 to 4.55 mm and 33.31 to 40.94% for die diameter of 1.0 mm, 1.5 mm, 2.2 mm and 3.0 mm.

Table1. *Mean actual diameter and expansion rate of fish feed pellets.*

Die diameter (mm)	Statistic	Actual diameter (mm)	Expansion rate (%)
2mm	Mean	2.47	17.89
	SD	0.10	1.54
	CV	0.05	0.06
3mm	Mean	4.05	23.78
	SD	0.12	2.21
	CV	0.07	0.09
4mm	Mean	4.86	16.89
	SD	0.22	1.14
	CV	0.05	0.08
6mm	Mean	7.09	14.75
	SD	0.18	1.32
	CV	0.09	0.10

The mean length, surface area and standard deviation of the fish feed pellets were 2.49 ± 0.11, 3.78 ± 0.22, 4.88 ± 0.37 and 6.15 ± 0.94 mm and 24.57 ± 2.45, 61.95 ± 8.08, 98.26 ± 7.78 and 196.41 ± 9.52 mm^2 for 2.0, 3.0, 4.0 and 6.0 mm pellets sizes respectively. The coefficient of variance for length corresponded fish pellet sizes 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm were 0.13, 0.05, 0.07 and 0.05 respectively. The coefficient of variance for surface area corresponded fish pellet sizes 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm were 0.09, 0.12, 0.07 and 0.14 respectively. The surface area of pellets fish feed value ranged from 10.57 to 71.13 mm^2. The volume of pellets fish feed 4.04 to 79.09 mm^3 (Khater *et al*., 2014). The floatability characteristic of fish feeds improved with size of the feeds. The average diameter of fish seed pellets ranged between 95.71± 0.042% for 2.0 mm pellet size to 98.53 0.028% for 6.0 mm pellet size. The mean volume, mass and standard deviation of the fish feed pellets were 9.14 ± 1.57, 37.68 ± 7.71, 83.85 ± 19.33 and 211.23 ± 40.34 mm and 0.021 ± 0.004, 0.037 ± 0.008, 0.103 ± 0.029 and 0.229 ± 0.027 mm^2 for 2.0, 3.0, 4.0 and 6.0 mm pellets sizes respectively. The coefficient of variance for length corresponded fish pellet sizes 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm were 0.15, 0.17, 0.20 and 0.16 respectively. The coefficient of variance for mass corresponded fish pellet sizes 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm were 0.16, 0.21, 0.37 and 0.13 respectively. The volume of pellets fish feed value ranged from 4.04 to 79.09 mm^3 (Khater *et al*., 2014).

Table2. *Physical properties of locally produced fish feeds*

Pellet size	Parameters	Sample No	Minimum	Maximum	Mean	Standard Deviation	Coefficient variation
2.0 mm	Length (mm)	50	2.49	3.00	2.74	0.113	0.130
	Surface area (mm^2)	50	24.57	29.49	26.67	2.469	0.092
	Volume (mm^3)	50	9.14	12.26	10.46	1.57	0.147
	Mass (g)	100	0.019	0.026	0.021	0.004	0.164
	Floatability (%)	20	93.95	98.39	95.71	0.042	0.051
3.0 mm	Length (mm)	50	3.78	4.21	4.05	0.217	0.054
	Surface area (mm^2)	50	61.95	77.93	67.92	8.075	0.117
	Volume (mm^2)	50	37.68	52.79	42.54	7.714	0.174
	Mass (Kg)	100	0.029	0.045	0.037	0.008	0.214
	Floatability (%)	20	94.17	97.34	96.12	0.047	0.069
4.0 mm	Length (mm)	50	4.88	5.23	4.49	0.370	0.076
	Surface area (mm^2)	50	98.26	113.82	106.46	7.784	0.073
	Volume (mm^2)	50	83.85	119.98	89.98	19.33	0.197
	Mass (Kg)	100	0.047	0.089	0.103	0.029	0.366
	Floatability (%)	20	97.51	98.07	98.75	0.031	0.053
6.0 mm	Length (mm)	50	6.15	8.03	7.09	0.940	0.051
	Surface area (mm^2)	50	196.41	266.10	227.70	0.152	34.91
	Volume (mm^2)	50	211.23	291.62	256.90	40.34	0.159
	Mass (Kg)	100	0.175	0.229	0.201	0.027	0.134
	Floatability (%)	20	96.96	99.48	98.53	0.028	0.035

The average angle of repose for fish feed pellets of sizes 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm were 25.4±3.21°, 28.7 ±2.10°, 32±1.76 ° and 35±3.45 ° (Fig. 1). This is an indication that angle of repose increases with increasing in the size of fish feed pellets. Similar observation was reported on mean angle of repose by Khater *et al*. (2014) for fish feed pellets size of 1.0 mm, 1.5 mm, 2.2 mm and 3.0 mm. The static coefficient of friction and angle of repose is pertinent for the design of conveyor and hoppers for planting machines

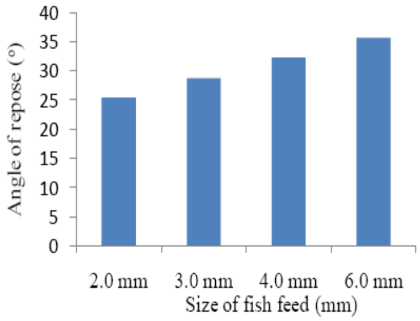

Fig1. *Angle of repose of repose*

Figure 2 revealed the average durability of fish feed pellets of sizes 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm were 97.45±5.43%, 95.61±3.87% 92.81±6.13% and 90.50±8.34%. This is an indication that durability increased with increasing in the size of fish feed pellets. Similar observation was reported on mean angle of repose by Khater *et al*. (2014) for fish feed pellets size of 1.0 mm, 1.5 mm, 2.2 mm and 3.0 mm.

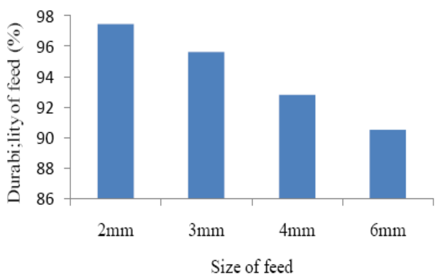

Fig2. *Durability of fish feed*

Bulk and true densities of fish feed pellets was presented in Figure 3. It was showed that the average bulk and true densities of the fish feed pellets were 494±12.63 kgm^{-3}, 501±17.92 kgm^{-3} 570±19.3 and 586±14.93 and 785±21.47, 858±29.39, 894±16.28, 963±21.38 for 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm respectively. This is an indication that increases in pellet size leads to increasing in bulk and true densities for all the four pellet sizes studied. Bulk and true densities are important in designing of separating and cleaning processes for grains, sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes (Heidarbeigi *et al*., 2009).

The average crushing load values were 63.53±8.38, 67.09±10.36, 74.80±9.83 and 78.3±6.49 N in horizontal position for 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm fish feed pellets respectively (Fig. 4). The mean crushing load were 75.70±12.10, 86.31±13.20, 89.5311.05, and 101.93 ±10.73 N for 2.0 mm, 3.0 mm, 4.0 mm and 6.0 mm feed pellets respectively. It was revealed from the result that the crushing load increased with the increasing with the size of the feed pellets in both vertical and horizontal positions. Other researchers observed that crushing load increased with the pellet size in both vertical and horizontal position. Bahnasawy and Mostafa (2011) reported the mean crushing load of 454.13±81.19, 177.89±17.12, 90.74±18.23 and 91.99±14.48 N in vertical position for the large animal, rabbit, poultry grower and finisher feed pellets respectively. Also, in horizontal position, mean crushing load of were reported 348.35±93.49, 32.20±9.88, 29.50±5.09 and 31.08±4.13 N for the large animal, rabbit, poultry grower and finisher feed pellets respectively. According to Khater *et al*. (2014) reported that crushing load increased from 6.13 ± 0.33 to 24.98 ± 1.15 N with increasing in pellet size from 1.0 to 3.0 mm

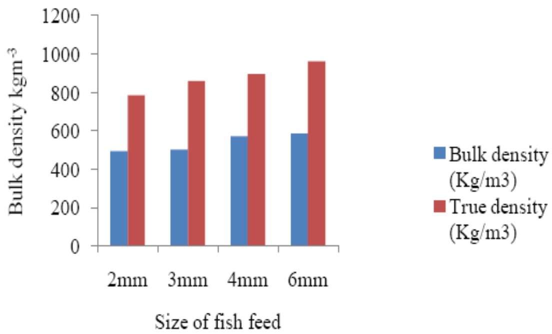

Fig3. *Bulk and true densities of fish feeds pellets*

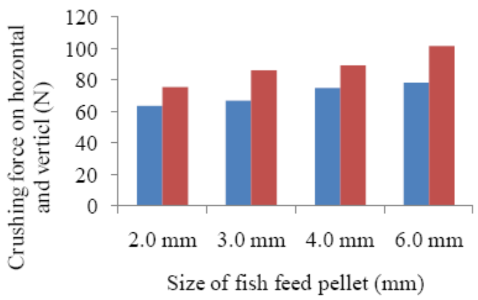

Fig4. *The mean of crushing force of pellets feed fish.*

The static coefficient of friction varied between 0.424±0.027 (6.0 mm and stainless steel) and 0.573±0.037 (2.0 mm and plywood) for all the fish feed pellets size and studied surfaces (Table 3). Dynamic coefficient of friction varied between 0.490±0.057 (6.0 mm and stainless steel) and 0.405±0.011 (2.0 mm and plywood) for all the fish feed pellet sizes and structural surfaces. Dynamic and static coefficient of friction increased with increasing in pellet sizes. Plywood and had the highest dynamic and static coefficient of friction amongst the three surfaces. Stainless steel recorded lowest dynamic and static coefficient of friction.

Structural Surfaces	Statistic	Static Coefficient of Friction				Dynamic Coefficient of Friction			
		2mm	3mm	4mm	6mm	2mm	3mm	4mm	6mm
Plywood	Mean	0.573	0.537	0.529	0.502	0.490	0.448	0.439	0.417
	SD	0.037	0.042	0.038	0.044	0.057	0.026	0.043	0.041
	CV	0.032	0.042	0.010	0.031	0.019	0.013	0.061	0.043
Galvanized iron	Mean	0.524	0.511	0.480	0.460	0.425	0.421	0.419	0.410
	SD	0.082	0.032	0.056	0.035	0.043	0.061	0.033	0.032
	CV	0.041	0.035	0.027	0.011	0.024	0.013	0.017	0.035
Stainless steel	Mean	0.489	0.457	0.431	0.424	0.418	0.317	0.338	0.405
	SD	0.043	0.031	0.023	0.014	0.011	0.013	0.016	0.011
	CV	0.014	0.021	0.012	0.027	0.019	0.015	0.010	0.017

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