Review Article

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Design of experiments optimisation study on the fat coating machine for extruded fish feed

Abstract

Background: The fat coating machine has been evaluated in several studies evaluating its impact on production. The question remained as to what speed the various components of the fat coater should be operated at to optimize performance. Therefore the influence of coating speed (10, 13, 16 rpm) at different time (5, 10, 15, 20, 25, 30, 35, 40 minutes), on extruded fish size (3, 4, 6, 8 mm) was studied using fat coating machine. This article presents the results of an optimisation study conducted on a fat coating machine showing that an increase in pellet size resulted in a decrease in oil absorption and an increase in coating time and speed resulted in an increase in oil absorption. Extrudates size and coating time were the two factors that significantly affected the oil absorption rate of the extruded feed. The optimum point of oil absorption was achieved after 33 minutes using a 3 mm extrudates size, resulting in a machine efficiency of 99.8%. The coated extrudates were checked for physical parameters. The equipment performance was carried out to demonstrate the efficiency of the equipment and ended with satisfactory results.

Keywords: speed, time, size, absorption, efficiency

Volume 2 Issue 6 - 2018

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Received: October 31, 2018 | **Published:** November 29, 2018

Introduction

Fish feeding is one of the most important factors in commercial fish farming, as the feeding regime can have an impact on both the growth efficiency and the food waste.[1,2] Over the past decade, the use of extruded diets for feeding fish has increased dramatically. These diets have superior water stability, better floating properties and higher energy than pelleted diets.[3,4]

Extrusion has become the major processing method for food and feed industries, and it is rapidly evolving from an art into a science. The major reason for this is that extrusion is a versatile process that offers several advantages over the traditional cooking and processing methods. Extrusion offers energy savings, flexibility, controllability, product shaping, continuous production, and very little effluent during processing. One possible adverse effect of food and feed processing through extrusion is the destruction of vitamins. These vitamins can lose 20% of their activity at the lowest expander temperature and shortest residency time. At the expander's highest temperatures and longest resident times, these same vitamins lose at least 65% of their original activity.[5–7] Hence, a way out or substitute is needed for compensating and making up for the denaturing to avoid poor feeding of the fish is through fat coating.[8]

The addition of the fats and oils to the pellet or fish feed to achieve the improvement is done by in various ways such as before or after pelletizing, but the quantity or degree of application varies such that the volume of addition before pelletizing should not be more than 3% of the production, or it will lead to the production of pellets of loose character.[9] This method of application is not suitable for extruded feed pellets production, but it has low-level technical demand for the process equipment. The maximum fats/oils adding volume can be 8% after pelletizing, which is the fat/oil coating.[7] It improves the productivity without affecting the solidness of pellets; it works well for producing extruded animal feed, and having high-level standard of the equipment.[10] Oil has then been known to be one of the best carriers of micronutrients and that it also increases the energy value of the feed.[11] To this end, it serves as the easiest way to add again the lost nutrients and increase the energy level of the feed.

Due to the fact that not much has been worked on the effect of coating speed, coating time and pellet size on the oil absorption rate of an extrudates. The norm is that the coating is done either by hand mixing only or by any specialized method. In addition, no measurements or experiments are made to confirm the required coating speed and coating time. Optimization is an essential part of quality assurance; it involves the systematic study of systems, devices, and processes that aim to determine whether they perform their intended functions adequately and consistently as specified.[12] The established device optimization requirements are determined based on the available machine parameter historical data of that device. The aim is to provide a method for the performance of fat coaters by examining the effect of various parameters such as coating time and speed when mixing different extrudates sizes.

Methods

Extruded feed of various sizes (3, 4, 6, 8 mm) was collected from the factory (Fexod Fedek Ventures Ibadan, Nigeria) after production from the extruder (Fexod 330A) and dried in a fluidized bed dryer. Five (5) kg of the extrudates were then measured using a balance (ULTRA-75), oil was added to the weighed pellet and then coated using an existing fat coating machine (Fexod K787M). The machine is made of galvanized steel and the coater is suspended by angled arms. It is driven by a 0.75 horsepower electric gear motor via a pulley system that connects the coater to the gear motor. The fat coating machine has a maximum loading capacity of about 60 kg extrudates per batch and the maximum rotational speed is 16 rpm. The electric motor is in turn regulated by a 3-phase voltage converter with the maximum voltage of 400 volts. A stopwatch was used to track the coating time, and a photo tachometer (Lutron, DT-2236B, Taiwan) was used to measure the speed of rotation of the grease coating machine.

Oil holding capacity (OHC) was performed and calculated according to Chakraborty[13] with minor modifications. Five (5) kilograms of fish feed pellets were weighed into a plastic container for emptying into the fat coating machine. For each sample, 130.9 ml (0.15 kg) of refined soybean oil (density = 0.9165 to 0.9261 g/ml at 20° C) was added and mixed with the sample in the fat coater.

For the first speed, the machine is running at the highest speed due to the speed of the electric motor rotating the mixer and also the ratio between the driver and the driver. The voltages to reach the required speed can be calculated as follows:

The normal speed of the electric motor is 48 rpm. The ratio of driver to driver is 1: 3;

The speed is calculated using the formula:

$$S_C = \frac{D_n}{D_r} \times S_{EM}$$

Where:

S_c= Speed of the coater (rpm)

D_r = Diameter of the pulley on the electric motor (cm)

D_n = diameter of the pulley on the coating machine (cm)

S_{EM} =Speed of the electric motor (rpm)

The remaining speeds are updated by varying the voltage of the electric motor. This was done using the variable voltage converter (Hossoni, TSGC2-9kVA, Japan) to obtain a speed of 13 rpm and 10 rpm, respectively.

At a power of 24 kilowatts with 60 ampere current, the speed of the fat coating machine was 16 rpm, then the initial voltage can be calculated as follows:

$$P = I \times V$$

Where:

P= power (watts)

I= current (Amperes)

V= voltage (volts)

Therefore,

$$V = \frac{P}{I}$$

To calculate the required tension for the remaining speeds we apply this formula:

$$\frac{V1}{V2} = \frac{S1}{S2}$$

Where:

V_1 = initial voltage

V_2 = final voltage

S_1 = initial speed

S_2 = finial speed

The statistical analysis of the data collected was done using Design Expert 9.0.6. Design–Expert offers comparative tests, screening, characterization, optimization, robust parameter design, mixture designs and combined designs.

Results

The results of coating the extrudates with various considerations are shown in Table 1. The result shows that an increase in extrudates size resulted in a decrease in oil absorption and an increase in coating time and coating speed resulted in an increase in oil absorption. In the coating time range of 25 to 40 minutes of coating 3 mm extrudates size and 4 mm extrudates size, an optimum oil absorption point (24 to 28 g/g) was obtained. For larger extrudates sizes (6mm and 8mm) this was not the case, oil absorption was optimal for coating times of 22 minutes. Extrudates size and coating time were the two factors that significantly affect the oil absorption rate of the extruded feed.

The efficiency was also considered as an answer in the evaluation of the performance of the fat coating machine, and from the statistical analysis package, it was found that in terms of efficiency, the relationship between the extrudates size and the coating speed was significant ($p \leqq 0.05$).

Table 1 Optimal design experiments and experimental results

	Variables			Response	
S/N	Pellet size (mm)	Coating time (mins)	Coating speed (rpm)	Oil absorption (g/g)	Efficiency (%)
1	3	15	10	26	99.61
2	3	30	16	2	97.28
3	3	25	10	28	99.81
4	3	10	10	8	97.86
5	3	30	10	-16	95.53
6	3	35	10	0	97.09
7	3	20	13	22	99.22
8	3	0	13	28	99.81
9	3	15	13	28	99.81

Table Continued

	Variables			Response	
S/N	Pellet size (mm)	Coating time (mins)	Coating speed (rpm)	Oil absorption (g/g)	Efficiency (%)
10	3	0	16	28	99.81
11	3	40	10	22	99.22
12	3	35	13	20	99.03
13	3	5	10	0	97.09
14	3	5	13	-4	96.70
15	3	10	16	6	97.67
16	4	20	10	18	98.83
17	4	5	16	22	99.22
18	4	20	16	28	99.81
19	4	25	13	20	99.03
20	4	30	13	20	99.03
21	4	30	16	28	99.81
22	4	0	16	28	99.81
23	4	10	16	28	99.81
24	4	5	13	18	98.83
25	4	15	13	20	99.03
26	4	40	10	16	98.64
27	4	15	10	18	98.83
28	4	35	16	12	98.25
29	4	35	10	16	98.64
30	4	40	13	22	99.22
31	4	0	10	30	100.00
32	6	15	16	22	99.22
33	6	40	13	26	99.61
34	6	15	10	28	99.81
35	6	20	16	28	99.81
36	6	35	16	22	99.22
37	6	25	16	2	97.28
38	6	10	13	2	97.28
39	6	25	10	14	98.45
40	6	15	10	26	99.61
41	6	40	13	28	99.81
42	6	40	13	-8	96.31
43	6	0	10	28	99.81
44	6	35	13	-4	96.70
45	6	0	13	28	99.81
46	6	5	16	6	97.67
47	6	30	13	-4	96.70
48	6	40	16	-10	96.12
49	8	5	10	18	98.83

Table Continued

	Variables			Response	
S/N	Pellet size (mm)	Coating time (mins)	Coating speed (rpm)	Oil absorption (g/g)	Efficiency (%)
50	8	5	16	28	99.81
51	8	5	16	20	99.03
52	8	15	13	18	98.83
53	8	0	13	28	99.81
54	8	40	16	10	98.06
55	8	0	16	28	99.81
56	8	35	10	18	98.83
57	8	40	10	14	98.45
58	8	25	13	22	99.22
59	8	20	10	28	99.81
60	8	20	13	22	99.22
61	8	25	10	16	98.64
62	8	10	13	26	99.61
63	8	10	10	26	99.61
64	8	5	16	-76	89.71
65	8	30	10	14	98.45

Figure 1 show that with a extrudates size of 8 mm, the efficiency of the machine decreased from 98.9% to 98.1% with increasing coating time, whereas with extrudates size of 3 mm the efficiency steadily increased. At 5 minutes coating, the efficiency was relatively constant over all extrudates sizes, which were about 98.7%, while at 40 minutes coating, the efficiency increased steadily with decreasing extrudates size. Contour plot shown in Figure 2 further established this relationship that from a coating time of 24 minutes and above, the machine efficiency was optimal for extrudates sizes between 3 mm and 5 mm.

Discussion

The relationship between coating speed and extrudates size shows that with smaller extrudates sizes and high coating speed, the efficiency is optimal, as shown in Figure 3. The relationship between coating speed and coating time showed no significant effect on the efficiency, but according to Figure 4 we observe that with a higher coating time and a higher coating speed, the efficiency reaches the optimum efficiency.

The statistical analysis package expressed that there was a significant relationship between extrudates size and coating time. This could be due to the fact that there are more ways to achieve an optimum point for the machine by varying the coating time and extrudates size.

It was observed that the highest coating speed using small extrudates sizes and relatively high coating time resulted in high oil absorption and in the middle the oil absorption was optimal. All variables can be attributed to the fact that at the lowest speed the cohesive force is caused by the centrifugal force generated by the coating chamber, it is sufficient to optimize the oil absorption, while at a higher speed the reverse case of the centrifugal force occurs, the force and therefore the oil was applied to the feed more quickly that the 3 mm and 4 mm feed absorbs the oil faster than the larger extrudates, this could be due to the fact that they have a higher bulk density than the 6 mm and 8 mm extrudates which, in turn, absorb the extrudates because of the higher ratio of extrudates volume compared to the larger extrudates sizes, which have a lower ratio of pellet number to oil volume, more oil in less time.[14–17]

Conclusion

Smaller extrusion feeds (3-5 mm) tend to coat better and faster within 19 to 40 minutes coating time because of the bulk density which is greater than that of the much larger pellet sizes (6-8 mm). The optimum point of oil absorption (25 g / g) was therefore reached with longer operating time (about 33 minutes); Time was an important factor in the study. The efficiency of the machine was about 99.8% (optimal) with a longer coating time (about 20 to 33 minutes), while a smaller pellet size (3 to 5 mm) was used

Funding details

Nil

Acknowledgments

The authors also want to thank Fexod Fedek Ventures, Ibadan, Nigeria for their support with the equipment in caring out this work.

Conflicts of interests

Authors declare that there is no conflicts of interest

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