

Soft Moist Extruded Aqua Feeds

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Understanding the Extrusion Process: Basic Concepts

The extrusion process has been used for many years in the food and feed industries. In the aquaculture industry, extruders have been used to produce a great variety of products, but most of the products produced in extruders today fall in the sinking or floating categories. To understand how extruded aqua feeds are produced we must first understand how the extruder works. The extruder can be defined as a bioreactor where the raw materials are subjected to high temperature and pressure over a relatively short time. Because of this extruders are referred to as High-Temperature-Short Time bioreactors. The heat is produced by the mechanical energy input provided by the rotation of the screws and the friction between feed particles with feed particles, feed particles with the screw, and feed particles with the barrel of the extruder. During the process the materials are moved forward to the exit or die and depending on the open area of the die the pressure can be as high as 200 or more atmospheres. The material under high pressure and temperature becomes a fluid-like plastic, also referred as an amorphous melt. This molten phase of material contains water that is intrinsic to the ingredients or added in the mixer, preconditioner, or even in the extruder. At high pressures the water contained in the feed particles or the water added to the mix is in the solid phase; how-



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ever, as the melt exits the die it is exposed to the atmospheric pressure. This sudden drop in pressure causes the water in liquid phase to change to the gaseous state producing what is known as expansion. As the steam escapes the molten phase leaves small voids which determine the cellular structure of the extrudate. The more cells the final product has, the less dense it becomes, and hence becomes a floating feed. If the cellular structure is more compact the final product is denser; therefore, heavier and can be considered a sinking feed. Floating feeds have a density that is usually below 450 g/l, while sinking feeds have densities above 550 g/l and is preferred that they be > 600 g/l.

Energy Input in the Extrusion Process

During the extrusion process electrical energy is converted to mechanical energy and this is transferred to the formula mix. A good way to characterize the extrusion process is by knowing the amount of mechanical energy input per unit of mass. This is known as *Specific Mechanical Energy* or SME and can be defined as the total Energy input divided by the mass flow rate, W/m . The units for SME are Watts/kg, W/Metric Ton, or MJ/kg.

Shear Rate and Shear Stress

One way to characterize the extrusion process is by the amount of shear that is applied to the product. In other words the rate at which the product is deformed during the process. Most of the shear occurs in the screws and depends on the geometry (channel depth and angle) of the screw and the speed at which it rotates. The shear rate is denoted by the following formula:

$$\lambda^0 = \frac{dV}{dh} \approx \frac{D\omega}{2H} = \text{sec}^{-1}$$

Where dV/dh is the change of velocity with respect to the height (channel), and $D\omega/2$ is the maximum tip speed velocity of the screw and H is the height of the flight or channel depth.

The term $\dot{\lambda}$ is of importance in understanding how extruders are classified. Table 1 (Mercier et al., 1989) presents the extruder classification based on shear rate. Of interest to us is the low shear cooking extruder. In this type of extruders the processing temperature of the dough can reach 150 C, the feed moisture can be as high as 28%, product moisture (out of the extruder) 25%, screw diameter to flight height is 7-15, the shear rate is between 10-30 sec⁻¹ (reciprocal seconds), and the SME between 0.25 to 0.36 MJ/kg. Note that there are noticeable differences when compared to other extruder types. For instance, Pasta Extruders operate at lower shear rate, lower mechanical energy input, and lower dough temperatures than the low-shear cooking extruders. On the other end of energy input we can see that high-shear extruders operate at much higher temperatures, net mechanical energy inputs, higher screw speeds (rate of shear is greater), and much lower product moisture.

Table 1. Extruder Classification Based on Shear Rate

Measurement	Type of Extruder			
	Pasta	High Pressure Forming	Low-Shear Cooking Extruder	High Shear Extruder
Mix moisture, %	32	25	28	15-20
Product moisture, %	30	25	25	4-10
Product temperature, °C	52	80	150	180-200
Screw diameter to flight height	3-4	4.5	7-15	7
Screw speed, sec ⁻¹	4.5	6.5	10-30	60-70
Shear rate in screw, sec ⁻¹	5	10	20-100	165
SME input, MJ/kg	0.11	0.14	0.14	0.40

Source: Mercier C., Linko P., Harper J.M.: 1989: *Extrusion Cooking*, American Association of Cereal Chemists. pp 4-5.

Therefore, to produce soft moist products the formula mix needs to be wetted in the mixer, preconditioner, or in the extruder. The extruder must have a screw profile with mostly forward conveying elements that are long pitch, and are rotated at low screw speeds to impart low SME (Figure 1).

Softmoist Feed Formulation

In semi-moist feeds water acts as a lubricant and plasticizing agent. As a lubricant it reduces the mechanical energy input, which results in a lower temperature process. Because the temperature and pressure are low the drop in pressure as the dough exits the die is not drastic and this results in little expansion of the product. Therefore, the product may end up with moisture content of around 20% but in most cases as high as 28%. At this moisture levels the major concern is to prevent microbial growth and this can only be achieved by controlling the water activity (Aw). Water activity is a measurement of free water or water not bound to the food particles that can be used for microbial growth. Keeping Aw as low as possible and below 0.65 is important to prevent microbial growth and extend the shelf life and freshness of the product.

Soft-moist feeds include 10-15% of humectants or ingredients that have the property to bind water. Such ingredients include

sugars, salts, propylene glycol, honey, corn syrups, disaccharides, glycerin, and maltodextrins. The humectants in the liquid form can be added in the mixer, or metered in the pre-conditioner and/or extruder. If the extruder is a single screw it is preferred to add the humectants in the mixer or preconditioner. Single screws are not good mixers as compared to twin-screws which have very good dispersive mixing capabilities.



Fig 1. Long pitch conveying screw that facilitates low shear in an extruder.

Another way to control mold growth in the final product is by reducing the pH. Acids such as lactic, propionic or phosphoric can be used to reduce the pH. Also mold inhibitors are used in the formula. A common ingredient used as mold inhibitor is potassium sorbate (0.2-0.3% inclusion).

Forming Die

The die serves the purpose of shaping the dough into the final shape. The most common shape of an aquatic soft moist feed is the cylindrical shape known as pellet. Die design affects the final product. The more open area the die has, the lower the pressure and hence less expansion. More restriction causes increase in pressure, temperature, and expansion. Therefore, to control the amount of expansion and keep it as low as possible, the formula must include the appropriate amount of humectants, the screw speed must be low, and the die design should provide enough open area to decrease as much as possible the pressure drop. Also the orifice geometry of the die can have a great impact on the shear rate. For cylindrical orifices the shear rate in the die can be measured as follows:

$$\dot{\lambda} = \frac{4Q}{\pi r^3}$$

Where Q is the volumetric flow rate per orifice and r is the radius of the orifice. Note that as the orifice diameter is decreased the shear rate increases considerably. And the shear rate can also be used to estimate the drop in pressure by the following formula:

$$\Delta P = \frac{2L\eta\dot{\lambda}}{R}$$

Where L is the land length of the dies orifice, η the viscosity of the melt (difficult to determine), and R is the radius of the orifice. Note that as the R term increase the drop in pressure also decreases. Therefore, to avoid excessive expansion and high temperatures it is important to have adequate die open area. For most dies it is recommended between 600-700 square millimeters of open area per metric ton of feed (flow rate.

Cutting the Product

Immediately after exiting the die the product is cut. The length of the product and to some extent the shape can be affected by the speed of the cutter and the knife design. For soft moist feeds it is recommended to use flex blades with very sharp cutting edge.

Conveying, Cooling, and Storage

Once the pellets are cut to the right size they must be conveyed to the cooler and finally to the packaging for storage and shipping. Soft-moist products require conveying systems that can

handle the product gently. Therefore, the recommended type of conveyor is the belt conveyor. During conveying and handling the product should not be piled up or keep the bed depth as low as possible to avoid damaging the soft pellets with its own weight.

Since the product must remain soft, it is not dried but rather cooled to minimum of 10C above ambient temperature. The preferred unit for cooling soft moist products is a horizontal unit, to prevent product packing and damage. Because the product may have a low pH and the condensation that can occur inside the cooler it is recommended to build it of stainless steel. In some cases the horizontal coolers are designed with moisture control units to prevent excessive loss of moisture from the material.

After exiting the cooler the product must be conveyed to the packaging area by gentle handling equipment. In the packaging area the product must be stored in horizontal bins with a maximum bed depths of 2 meters, again to prevent product packing and damage.

Product Attributes and Applications

Soft-moist feeds can have several advantages over the dried pelleted feeds. For one, the soft product may be more easily consumed by the crustaceans. To eat, crustaceans take a pellet in their front claws and shred it into small pieces. As it shreds, the other legs make or knead the shreds into a ball that is guided to its mouth. If the pellets are too hard the shrimp will need to wait until it has expanded by the water action to consume it. In some cases the shrimp takes it but after trying to consume it without being successful it drops it to look for another one. This dropped pellet can become a contaminant and a source of organic matter that contributes to water quality degradation. Also, if the pellets are too hard the shrimp may expend too much energy trying to shred and consume them. Soft moist feeds could also have better water stability than regular pelleted feeds or other extruded feeds. In the pelleting process the binding of the particles occurs as the feed is heated and wetted in the long retention time pre-conditions or by the action of synthetic binders. With high shear extruders the starch is degraded, or sheared to the point that it loses its binding ability and this is exacerbated by an increase in its water absorption capacity to the point that when the pellet is submerged it swells and disintegrates. In contrast, the low shear rate of the soft-moist extrusion process involves the right conditions of moisture (high), shear (low), and temperature (above gelatinization) to produce a pellet that is soft and has high water stability.

The soft moist extrusion process can permit the inclusion of higher volumes of liquids, such as hydrolysates, and solubles than what can be incorporated, due to moisture addition limitations, in the pelleting process. In the case of liquid ingredients such as hydrolysates and solubles with low pH, their higher inclusion could contribute to prevent mold growth.

Soft moist feeds can also be easily manipulated to produce rounded shapes using vibratory equipment. The latter cannot be done with the traditional pelleting press because the product is already too hard. The equipment that can impart the sphericity to the soft moist feed is known as a marumerizer or spherizer.

Soft moist feeds will also have applications in feeding fish. They can be used in weaning wild-caught broodstock of carnivorous fish that eat only live prey or a feed high in fresh fish. They can also be used to feed species that eat slow and prefer a feed with soft texture.

Conclusions

Soft-moist extrusion process can offer an option for the production of highly water stable and nutritious shrimp and fish feeds. Feeds produced with a medium shear forming extruder are subjected to temperatures high enough to sterilize the product. And because the extruder can handle higher volumes of moisture (25-30% vs 17% for traditional pelleting) it is possible to include other ingredients high in moisture content such as solubles and hydrolysates.

Continued from page.15

Effect of canola oils as alternative lipid resources in diets for juvenile red seabream (*Pagrus auratus*). B.D. Glencross, W.E. Hawkins & J.G. Curnow. 2003. *Aquaculture Nutrition* 9:305-315. (Corresponding author e-mail: bglencross@fish.wa.au)

This study evaluated crude and refined canola oils and refined soybean oil as potential fish oil substitutes in red seabream. Each of the oils was used to replace 25%, 50%, 75% and 100% of added fish oil in the diet. The diet had 60% fishmeal, 10% total lipids and 4% added oil. A negative control diet containing no added oil and a positive control diet containing 8% added fish oil were also included. A significant reduction in growth was observed when the fish oil was replaced with 100% crude canola oil. Reduction in growth was observed with the negative control diet as well. The positive control diet gave the best growth. No other significant growth effects were observed. The growth data showed that the red seabream utilized the plant oils.

There was a considerable effect of the dietary treatments on fatty acid composition of the fish. Significant increases in 18:2w6 (linoleic acid) and 18:3w3 (linolenic acid) were observed with the inclusion of plant oils. There were some, but not dramatic decreases, in the levels of long chain HUFA when plant oils were included. A sensory evaluation study compared the cooked fillets of fish fed the 100% canola oil, 100% soybean oil and 100% fish oil treatments. It rated the canola oil fed fish the highest in overall acceptability.

Restoration of the fatty acid composition of red seabream (*Pagrus auratus*) using a fish oil finishing diet after grow-out on plant oil based diets. B.D. Glencross, W.E. Hawkins & J.G. Curnow. 2003. *Aquaculture Nutrition* 9:409-418. (Corresponding author e-mail: bglencross@fish.wa.au)

Three months ahead of the study, three groups of red seabream were reared on a fish oil based diet or diets where the fish oil (FO) had been replaced with canola (CO) or soybean oil (SO). After three months, some of the fish that had been fed with CO or SO were put on FO while other fish were continued with the dietary treatments they had been receiving for three months. All fish were fed for another 32 days. There were no significant differences between the dietary treatments except for a slight growth improvement in fish on SO switched to FO. The fatty acid composition of the fish switched from CO or SO to FO changed significantly. Levels of 18:2w6 (linoleic acid) and 18:3w3 (linolenic acid) decreased while the levels of long chain PUFA, 20:5w3 (EPA) and 22:6w3 increased when the fish were returned to FO. The study demonstrated that it is possible to reverse the fatty acid changes in red seabream that has been fed plant oil based diets, by feeding them with a fish oil based diet.