Aquatic Feed Extrusion Technology : An Update

P. Vijayagopal
Scientist (SS), Physiology, Nutrition and Pathology Division
Central Marine Fisheries Research Institute
Marine Fisheries P.O.
Mandapam Camp - 623 520, Tamil Nadu

In an article published in Fishing Chimes (Oct. 92) entitled "Pelletisation and extrusion in aquatic feed technology", a comparative account of feed pelletisation vis-a-vis extrusion was discussed. This article, compiled from various sources for teaching post-graduate students in mariculture, is an attempt to provide a deeper understanding in aquatic feed extrusion technology, which would be of use to current and potential users of extrusion equipment. Extrusion today is also seen as a cheaper alternative to conventional animal protein production which requires investment in crores of rupees in the Indian context.

Extruders are basically screw pumps through which feed mix is forced and in that process is subjected to heat, pressure and shear forces. Extrusion is a process, which combines several unit operations including mixing, cooking, kneading, shearing, shaping and forming. The two factors that most influence the nature of the extruded product are the operating conditions of the extruder and the rheological properties of the food. The most important operating parameters are the temperature, pressure, diameter of the die apertures and shear rate.

The range of machines available is mind boggling due to their applications in food industry in general; and the array of value added food produced through their use are limitless.

Terminology: Extrusion with steam preconditioning is known as wet extrusion and extrusion without steam preconditioning is called dry extrusion. Dry extruders were solely designed for processing soyabeans, which inherently had sufficient oil to act as a lubricant during extrusion. Later, steam preconditioning prior to extrusion was shown to improve the processing efficiency and product versatility. This led to what is technically called 'retro-fitting' of dry extruders with steam conditioners. Thus, a clear distinction between dry and wet extrusion is not there now.

Extruders can also be classified according to the method of operation (cold extruders or extruder cookers) and the method of construction (single-or twin-screw extruders).

Twin screw extruders: Twin screw extruder is a better design where one screw wipes out the cavity of the other screw thus ensuring positive displacement of feed materials through the barrel thereby preventing burning out of products prevalent in single screw extruders. Moreover, a single screw extruder requires elaborate drying, utilising higher higher energy. In a twin-screw extruder, lower moisture content in feed ensures less moisture in the extrudate requiring no or short time drying.

Applications: There are several applications of extrusion, including aquaculture feed preparation.

The water adsorptive capacity of the starch can serve as an empirical test of the degree of gelatinization. However, care is needed when applying this test because some extrusion processing conditions further change the structure of starch known as dextrinization.

Dextrinization is said to be a stage beyond gelatinization at which the starch molecules begin to break down into smaller molecules such as dextrin, which are polysaccharides of intermediate chain length. These smaller molecules dissolve in cold water rather than adsorbing it. Normally extrusion at moderate temperature and moisture levels results in reasonable levels of gelatinization and low levels of dextrinization. If the temperature level is gradually raised and the moisture addition rate is reduced, both gelatinization and dextrinization will start to increase. If this process of raising temperature and lowering moisture is continued, a point is reached at which all the starch is gelatinized and some of it is dextrinized. From this point onwards dextrinization increases and the amount of gelatinized starch will begin to fall as the free starch molecules continue to be broken down into dextrins and other small molecules.

The effect of all the above is that water adsorptive capacity and solubility increases in line with extrusion conditions of rising temperature and falling moisture until a point is arrived at which solubility continues to rise but adsorptive capacity starts to fall. The properties of extruded starch can thus be manipulated by varying processing conditions.

Extrusion effects denatured protein and undenatured protein in different ways. Denatured proteins are those that have been pre-cooked to a degree where some of the amino acid chains have been broken up into individual amino acid units or into shorter chains (meat meal, fish meal, extracted soyabean meal). These proteins are incapable of gel formation during extrusion. Thus they do not contribute to the binding properties of the raw material mix.

Undenatured proteins are those that have not previously been heat-treated. Their amino acid chains are undamaged and under certain extrusion conditions they are capable of gel formation in much the same way as starch is. These materials can act as a binder, in fact textured vegetable protein (TVP) can be made using this material as virtually the only constituent. Undenatured protein can also complex with starch to form water stable products. However, if the extrusion conditions are too severe, the undenatured protein will pass through the gel state and revert to an inert denatured form within the extruder barrel.

It is often desirable to deliberately denature a protein by extrusion. Mild breakdown of the protein structure improves digestibility. Many proteinaceous constituents inhibit normal digestion or reduce the shelf life of products. For example, urease in soyabeans is an undesirable enzyme (proteinaceous), which is readily inactivated by extrusion. Other enzymes such as lipases in rice bran are also undesirable because they accelerate the development of rancidity in the oil content of this material. Lipase can also be denatured by extrusion.

When extruding proteinaceous material, if reducing sugars are also present in the mixture being extruded, indigestible Maillard reaction compounds may be formed by the interaction of these two feed components during processing which can reduce the nutritional value of the final product.

Extrusion has little effect on fibre. However, the bulk density of the fibre content seems to be increased by extrusion. This is probably a consequence of the mechanical action of the extruder breaking up and compressing the fiber strands. Extruding fibrous material in conjunction with a strong alkali such as sodium hydroxide may improve the digestibility of these materials in the context of ruminant feeding.

Extrusion has little effect on fats, but fats have an important physical function in the extrusion process in that they act as a lubricant and tend to limit expansion. When fats are extruded in combination with carbohydrates, they tend to form a loose complex, which reduces the solubility of the fat in ether. This must be taken account of in analyzing extruded products for fat content by applying acid hydrolysis prior to conventional fat determination. The formation of a starch/fat complex may be desirable because a product can be produced that has textural and palatability characteristics suggestive of a lower fat level than are actually present and fat digestibility is not affected.

Most minerals are inert in the context of extrusion processing. Vitamins A, C, thiamin, niacin and some other are heat sensitive and a portion of these vitamins that passes through the extruder will be destroyed. This can be adjusted by adding overages prior to extrusion or by adding these vitamins post extrusion.

Many feed additives such as flavours, mould inhibitors and other stabilizers are sensitive to the effects of extrusion. For example, flavours may be broken down within the extruder creating a totally different taste to the one intended and in any case much of the flavour may be flashed off with steam on exit from the machine.

Reclamation of wet organic by-products by extrusion: In most countries increasingly restrictive laws are being enacted to govern the disposal of by-products from the animal production and food processing industries. This is adding to the problems and costs associated with discarding these materials and consequently recycling techniques are becoming more and more viable.

Many animal by-products are potentially valuable sources of nutrients. Rendering is the most widely used reclamation process but the equipment needed is often too large in scale and too high in capital cost as pointed out earlier, to be within the reach of smaller scale operators.

Waste treatment systems based on extrusion now offer a cheaper small-scale alternative to conventional rendering as mentioned earlier. In this context true dry extruders can stand alone. Steam preconditioners are not needed. Such dry extrusion systems have the potential to reclaim by-products such as:

1. *Fish/Crustacean residues:* Whole fish, shells, heads, entrails, fins, tails etc.
2. *Poultry by-products:* Whole hens, hatchery waste, offal, heads, feet, feathers.
3. *Abattoir by-products:* Offal, hair, blood.
4. *Food processing residues:* Dairy waste, bakery by-products, confectionery waste, etc.

Extrusion and wet waste processing: The heat and pressure generated within a dry extruder has the capacity to inactivate bacteria (both gram positive and gram negative), as well as moulds and viruses. Extrusion has been shown to significantly reduce the levels of some bacterial and fungal exo-toxins. However, adequate temperatures and pressures must be attained during processing and extrusion contamination avoided. Thus, extrusion can serve to sterilize waste material.

On exiting the extruder much of the intrinsic moisture of a product is lost to the atmosphere as steam. This is a consequence of the high temperatures attained during the process coupled with the instantaneous pressure drop experienced by material leaving the extruder die. Thus, dry extrusion can also serve to dehydrate material.

Since the material passing through an extruder is subjected to heat only for a very limited time (less than 30 sec), in comparison to the dwell time required in a conventional rendering plant batch cooker (up to 1 hr or more), it is argued that extrusion causes less damage to nutrients such as the amino acid lysine resulting in a finished product of higher biological value.

Limitations: Only up to a maximum of 50% of the total moisture content of the material being processed is actually lost on leaving the machine. Dry extruders generate heat as a result of friction and shear and it is difficult to achieve adequate processing temperatures if the total moisture content of material being fed into the machine is higher than 30%. High fat levels can also create problems. In practice, to produce a shelf stable finished product, the initial moisture content of the raw material should be below 22% - 24%. Thus extrusion can be very cost effective to produce a finished product such as a fish feed or a pet food utilizing a wet waste as one of the raw mateirals.

Potential of extrusion in aquaculture feed manufacture: The production of feeds for aquaculture is the fastest growing sector in the global feed industry. Although a large amount of aquatic feed is still produced by conventional pelletizer technology, extrusion is being utilized to a larger extent because it has several advantages over pelletizing which include the following:

* Buoyancy can be controlled, thus floating and slow sinking feeds can

be produced;

* Extruded feeds are usually capable of carrying higher fat levels than pelleted feeds;
* For many species extrusion increases carbohydrate availability;
* Extrusion can aid in the destruction of micro-organisms and some other contaminants;
* Extruded pellets generally have greater physical integrity and produce less fines;
* Under some circumstances greater water stability can be achieved with extruded feeds;
* Wet materials such as fresh minced fish can be readily incorporated into extruded products.

The above factors indicate that extruded feeds are generally utilized more efficiently, thus improving feed conversion ratios and reducing water pollution. Despite all these advantages it should be borne in mind that extrusion is a more expensive process than pelletizing and that for species such as shrimp it is often debatable which technology is the most appropriate. Experience with shrimp farming suggests that dry type extruders have a role to play in small-scale low output plants (less than one ton per hour).

Raw materials: Basic raw materials common to the manufacture of most extruded aquacultural feeds include cereals (maize, wheat etc.), cereal by-products (wheat flour, corn gluten, wheat gluten etc.), fish meal, squid meal, shrimp meal, meat meal, blood meal, poultry by-product meal, soyabean meal, full fat soyabean meal, other vegetable protein meals, fats and oils (including fish oil), vitamin and mineral premix, salt, stabilizers and binders. This list is not exhaustive, but it should serve to illustrate that the raw materials used are similar to those employed in the manufacture of other types of animals feeds.

The manufacture of aquaculture feeds is more complex than conventional feed manufacture. Hardness, size, buoyancy, durability and water stability must all be taken into account. Dedicated plants to serve the aquaculture industry are often recommended.

Buoyancy and Water Stability: Achieving the buoyancy and water stability characteristics of aquaculture feeds by manipulating processing and formulation variables is very important. This is explained here under.

Buoyancy: To produce a 4-6 mm pelleted feed that will completely float in freshwater, a final product bulk density of around 550 gm/l or less is reported. Above 650 gm/l, this type of product tends to sink and between 550 gm/l and 650 gm/l partial floatation or slow sinking is achieved. These bulk density figures are again reported to differ with different pellet sizes.

Varying the degree of expansion of the product controls bulk density. Including starch in the formula can only produce an expanded pellet as mentioned earlier. Normally, the higher the percentage of starch in the formula, the easier it is to produce an expanded pellet that will float. In practice, around 20% or more starch is normally required to produce floating pellets. Raw rice and potato starch tend to expand more readily than maize or wheat starch. Fine grinding of the starch assists gelatinization and expansion.

Fat in the extruded mixture tends to retard expansion, partially because it acts as a lubricant and partially because it complexes with the starch inhibiting the gel forming characteristics of this material. In practice, it is advisable to hold fat levels in the extruded mix down to 6% or less if a floating pellet is desired. If higher fat levels are needed for nutritional reasons then additional fat is sprayed after extrusion.

The expansion produced by extrusion is created by moisture trapped within the mixture vapourizing into steam as material exits the die. One gm of water heated to 150° C within the extruder will vapourize to about 385 cm^3 of steam. This puffs out the elastic starch gel, which then dries, and sets. If the moisture content of the mix is too high, (25% or more) then the starch gel will set slowly and will tend to contract. This can produce a tough skinned pellet with a hard mouth feel that will sink. To maintain the expanded state attained and prevent shrinkage, it is therefore best to extrude at lower moisture content (20% - 25%).

Generally thick dies tend to reduce the degree of expansion in the finished product, principally because the material has the chance to expand longitudinally in the die. Thick dies are therefore more appropriate for sinking feeds (shrimp feeds) and thin dies are more appropriate for floating feeds.

The higher the degree of open die area on the die plate, the less the expansion produced. This is because using more or bigger holes tends to reduce the final pressure in machine within the die. Higher pressure is reported to create greater expansion.

Although floating fish feeds can be produced on a dry type extruder wihout steam conditioning of the raw material mix, processing can be difficult, slow, extremely power consuming and very unforgiving of changes in the material mixture or formulation. Steam conditioning vastly improves the process. It is strongly recommended by experts that a steam conditioner be fitted to these machines if floating fish feed production is contemplated.

Recently sophisticated twin paddleshaft preconditioners have been developed for use with dry type extruders. These preconditioners prolong product dwell time in the conditioning chamber and help to maximize moisture penetration and ensure that it is uniform. Such preconditioners are ideal for the production of aquaculture feeds and are hence strongly recommended.

Fairly high finished product moisture content is required for floating pellets. Thus, drying is always necessary to stabilize the product.

Water Stability: If starch is extruded at a high temperature and low moisture content, a high degree of dextrinization will occur and the product will tend to dissolve fairly readily in water. The first rule for achieving water stability is to extrude fairly wet (20%-25% moisture content) and fairly cool (120° C).

Wheat gluten has proved to be an ideal binder for imparting water stability. But it must be considered that wheat gluten acts as a binder primarily because it is a unique undenatured protein. If extruded at too high a temperature, the gluten will be denatured within the machine and will lose its binding characteristics before the pellet is formed. It is best to extrude cool and wet and then set or post-condition the gluten in the drier. This will produce a water stable pellet.

Larval feed production through extrusion: This is another area where sphereizer-agglomeratin systems are in place leading to the production of larval feeds. Sinking, floating and slow-sinking feeds of requisite particle size (as small as 250 microns) are produced for a highly specialized international market. Three production oriented methods are reported in this area: (1) Production of large pellets and crumbling (2) direct extrusion of small diameter feeds and (3) spheriezer-agglomeration systems.

Production of large pellets and crumbling requires no further explanation. However, advantages of this conventional method are, high levels of production, lwo cost per unit production and easo in raw recipe preparation. Disadvanatages are: low plant yields of the wrong size, requires final product sifting, poor final appearance, poor water stability, limited to sinking feed production and sharp pellet edges causing mortality.

Direct extrusion processing is accepted as a stand alone process where, sinking feeds of 0.6, 0.8 and 1.2 mm and floating feeds of 0.6 and 0.8 mm could be produced using a single screw extruder. Advantages are, pasteurization of feed, excellent appearance, internal addition of oil and good pellet stability, and disadvantages are high cost per unit production, and requirement of final product sifting and low production, apart from having a dedicated product line. A 'vented head technology' is used here which means that the extruder barrel has an opening allowing loss of moisture and pressure, facilitating this micro-feed production process.

In the sphereizer-agglomeration system (SAS); a uniformly mixed and pulverized formulation is passed through a low shear and low temperature extrusion process where it is conditioned with steam, water and other possible liquid additives and compressed through a special die to form extruded strands. These strands, when transported into a sphereizer by cyclonic motion, sizes and shapes the strands into pellets with lengths about the size of the strand diameter. Through SAS™, feeds in the size range of 0.3 to 1.2 mm can be produced. Low processing temperature minimizes nutrient damage and favours production of medicated feeds and utilization of other temperature sensitive ingredients. However, the main disadvantages pointed out are, no pasteurization and capability to produce only sinking pellets.

Conclusion: With regard to extrusion, the only cautionary note is that extruder operation is a fairly difficult skill to master. Product quality is heavily dependant on the skill of the operator and adequate operator/technical staff training is an area often neglected when Companies/Institutions consider the purchase of extrusion equipment. It is recommended that extruder suppliers provide technical support as well as the equipment itself.

The answer of Dr. Warren Dominy, a renowned aquatic feed technologist to a query on the acceptability of extrusion technology worldwide in the aquatic feed processing sector is thought provoking in this context. He said. "I have estimated shrimp feed processing to be 10% extruded and 90% pelleted. I don't have the estimates from China, which could be significant. A top shrimp feed producer in Asia recently told me that he knew of no extruded shrimp feed in Thailand, Indonesia, Malayasia, India, Vietnam and/or the Philippines. May be in China, where they are just starting to make feeds and some extruder expert sold a machine. I think that the ratio may be something like 98% to 2%, the 2% being specialized feeds, i.e., maturation diets with cold extrusion (Japan) and companies just entering the business".

Suggested further reading

HICKEY, R. Introduction to extruding aquafeeds. URL: www.sprout-matador.com

KEARNS, J.P. and NEASE, T. (2001) Larval feeds: Small diameter aquatic feeds by extrusion cooking. International Aquafeed pp 26-29.

VIJAYAGOPAL, P. (1992) Pelletization and extrusion in aquatic feed technology. *Fishing Chimes*. Vol (**7**).

WINNOWISKI, T.S. (1995) Factors that affect pellet quality and trouble shooting the pelleting process. American Soyabean Association. MITA(P) No. 083/12/94 Vol. (FT **23**-1995) URL: www.pacweb.net.sg/asg.

WOODROOFE, J.M. (1995) Dry extrusion application in the feed industry. American Soyabean Association. No. 083/12/94 (Vol.FT 33-1995) URL: www.pacweb.net.sg/asa.

Index to Full Page Advts