Photo courtesy: Dr. George W. Chamberlain

This article discusses technology options available for extruded shrimp feed production.

Modern Extrusion Systems for Shrimp Feed Production

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Shrimp feeds are processed by extrusion cooking systems to develop desirable physical product characteristics. Starch gelatinization, sinking rates, and pasteurization are critical properties that impact nutritional and environmental considerations. Starch gelatinization of shrimp feeds is important as it may affect feed digestibility and contribute to water stability. Feed not immediately consumed must be water stable to protect water quality. Feed buoyancy affects feed efficiency through proper presentation for consumption. Final product bulk density is a major factor in determining buoyancy (Table 1.)

Fast sinking feeds are required for shrimp. Bulk densities are high and pellet sizes are usually small in diameter (<3mm). These feeds require a faster sink rate to also avoid competition from birds, but a major requirement for fast-sinking properties is due to the method of feeding. Feed is sometimes placed on a "feeding tray" and slowly lowered into the water until it rests on the bottom of the pond or other body of water. The feed must sink rapidly and not hesitate at the surface or it could be displaced from the tray and could be lost in the mud at the bottom of the pond.

There are many factors that influence buoyancy and these include surface tension at the interface between the feed pellet and the water, pellet displacement, and water temperature and salinity. The adjustment of process parameters can be used to control bulk density; but may unfavorably impact other process parameters such as system capacity. However, several hardware tools are available to process shrimp feed to the desired bulk density while allowing optimum process parameters such as extrusion moisture to be employed.

Table 1 Final Product Bulk Density Correlation with Float/Sink Properties

Feed characteristics	Sea water @ 20℃ (3% salinity)	Fresh water @ 20℃
Fast sinking	>640 g/l	>600 g/l
Slow sinking	580-600 g/l	540-560 g/l
Neutral buoyancy	520-540 g/l	480-500 g/l
Floating	<480 g/l	<440 g/l

Hardware tools

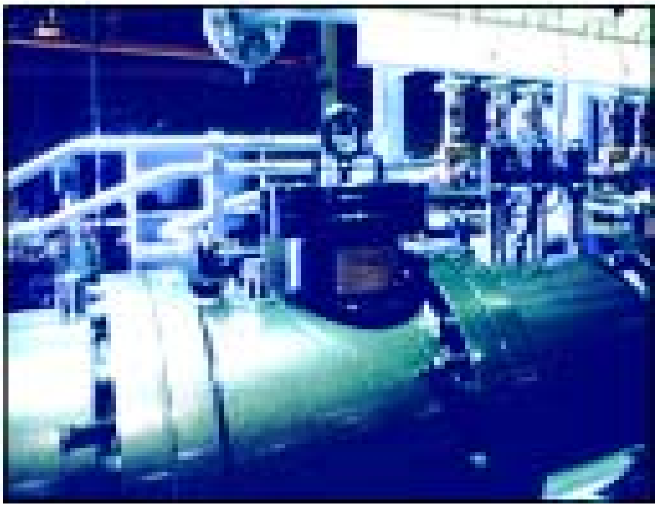
There are several hardware tools available in the industry that can be used to control product bulk density:

- Vented extruder barrel with or without vacuum assist
- Separate cooking and forming extruders where the product is vented between the two units
- Back pressure valve and pressure chamber at extruder die

Vented Extruder Barrel

The extruder barrel is normally closed and the extrudate subjected to an environment of increasing pressures until it exits the die orifice resulting in some expansion. Where higher product densities are required for shrimp feeds, the extruder barrel can be configured to include a vent which releases process pressure and reduces product temperature through evaporative cooling (Figure 1).

Figure 1. Extruder barrel with the vent port closed



A vacuum assist can be added to the vented barrel (Figure 2) to increase the product density even further by more evaporative cooling and de-aeration of the extrudate. Vacuum assist (up to 0.7 bar) will improve pellet durability, increase piece density, and reduce extrudate moisture. Disadvantages of a vacuum-assisted, vented extruder barrel include the following:

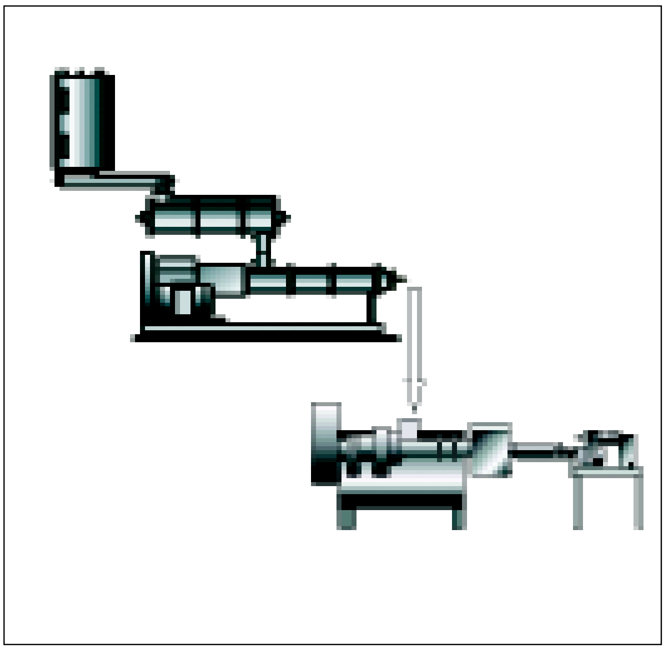
- Increased investment for hardware
- Potential capacity of extruder reduced 25 to 50 percent
- Disposal of product fines from vent and water from vacuum pump (These waste streams can be recycled back into the system as shown in Figure 2.)
- Control of SME (specific mechanical energy) inputs are reduced

Separate Cooking and Forming Extruders

Another hardware tool utilized by the manufacturers of both floating and sinking aquafeeds is a dual extrusion process (Figure 3).

Figure 2. Extruder barrel vent with vacuum assist

Figure 3. Cooking Extruder and PDU (Product Densification Unit) Forming Extruder



In this process, the first extruder is used in solo for the production of expanded or floating aquafeeds or it can be used as a cooking extruder for the two-stage cooking/forming process. The second forming extruder (PDU or Product Densifying Unit) is used only when processing very dense, fast-sinking shrimp feeds. This processing system has the advantage of being able to operate both extruders at their maximum rate potential. When only one extruder is used to produce a very dense pellet, the extruder may have to be operated at lower throughputs to prevent expansion. Adding the second forming extruder (PDU) can allow an aquafeed manufacturer to produce a wide range of feed densities from highly expanded, floating feeds with one extruder, or very dense, 100 percent sinking shrimp feeds with the cooking extruder and PDU.

Back Pressure Valve and Pressure Chamber

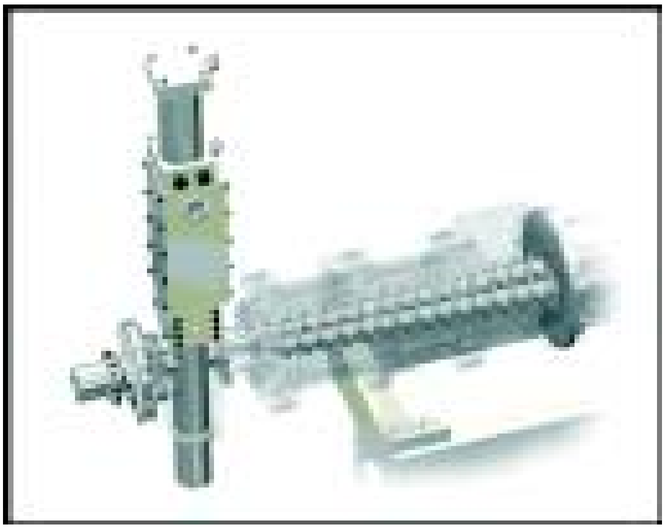
Final product characteristics can be controlled by extruder die restriction. One device commonly used by aquafeed manufacturers is termed a "back pressure valve" (BPV) which is used to adjust die restriction while the extrusion system is in operation. The variable-opening BPV is mounted on the end of the extruder prior to the final die assembly (Figure 4).

Specific mechanical energy (SME) and extrusion pressure are process parameters controlled by valve positioning. The BPV provides internal control of shear stress and SME for regulation of important product properties:

- bulk density
- size and uniformity of cell structure
- starch gelatinization
- shape definition
- water and fat absorption

The extrusion process for aquafeeds is reported to be more stable with a BPV and preconditioning/extrusion process temperature requirements are lower resulting in improved nutrient retention. The BPV eliminates the need for altering extruder configurations between different product families (floating, slow sinking, and sinking aquafeeds). An integral part of the BPV is a by-pass feature to divert product from the die/knife assembly (and pressure chamber) and product conveyor for service and startup/shutdown procedures which improves sanitation in this area.

Figure 4. Back Pressure Valve Mounted on a Twin Screw Extruder



Another device available in the industry today is an enclosed chamber which surrounds the die/knife assembly and permits control of pressure external to the extruder and die. Desired pressures are maintained in the knife enclosure by a special airlock through which the product discharges. Compressed air can be used to generate the required pressure in the chamber. As pressure increases, the water vapor point increases which reduces product "flash-off expansion" and thus increases density (Table 2).

Table 2. Effect of Increasing Pressure in Chamber

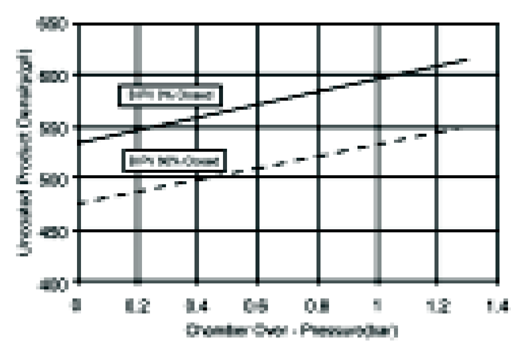
Over-pressure in chamber (bar)	Boiling point of water (°C)	Expected increase in product density (%)
0	100	0
0.5	112	10.0
1.0	121	18.3
1.5	128	25.0
2.0	134	28.3

The pressure chamber can be coupled with a BPV to provide excellent process control:

- adjust SME on-line for control of critical product properties
- divert off-spec product during startup from the pressure chamber
- accurate control of product density external to the extruder and die
- no extruder configuration changes required to make floating and sinking aquafeeds
- increase extruder capacity over vented configurations by 25 to 50 percent

The combined impact of a pressure chamber and a BPV is illustrated in Figure 5. The BPV can be used as an independent tool to alter product density and other critical properties or can be used in conjunction with a pressure chamber to further alter product density.

Figure 5. Effect of Chamber Pressure and BPV Closure on Bulk Density of Uncoated Aquafeed



Comparison of Hardware Systems for Shrimp Feed Process

(See Table 3)

1) Vented extruder barrel with or without vacuum assist (single or twin screw systems):

a) Twin screw system will cost 1.5-2 times more than the single screw system for owning and operating costs per ton. Twin screw system can process through die sizes as small as 0.6 mm while single screw is limited to 1.0 mm for smallest die hole size.
b) Vented head section for density control system makes the process very sensitive to screw wear, partially blocked dies, and high rates. Any of these items can increase barrel fill and will cause product to discharge from the vented head even with the vertical stuffing device.
c) Vacuum system required for density control has a water discharge stream that must be managed. This stream will likely contain suspended feed particles which limits disposal options. There will also be a maintenance burden associated with the vacuum system and stuffing device.
d) Vented head limits process control of cook and SME inputs for management of product quality.

2) PDU (product densification unit) with a single or twin screw system)

a) Low maintenance costs and high throughput capabilities.
b) Maximum recipe flexibility with ability to handle very high starch recipes. Product is cooked and then cooled before final sizing to reduce stickiness of the high starch diets.
c) PDU produces dense products with 100% sinking properties.
d) Excellent process control as cooking step is independent of the densifying process and therefore cook can be controlled independently of density.
e) No vacuum pumps, rotary airlocks to deal with and maintain.
f) PDU system is easier to operate than vacuum-assisted vented extruders or pressure chamber systems.

3) BPV (back pressure valve) coupled with pressure chamber device

a) The high starch recipes will easily expand creating floating product even with the pressure chamber device. Small diameter products (1mm) do not respond well to this densification technique due to small product mass. This technique works better for products that are 2mm and larger.
b) High starch recipe will stick together and clump easily in the pressure chamber creating problems with large amount of "overs" and clumped product.
c) Pressure chamber contains rotary airlock and control devices that will have maintenance issues.
d) Systems lack the process control necessary for ingredient flexibility especially at high rates.

Table 3 Comparison of Shrimp Feed Extrusion Systems

Processing System	Rate Potential Index for given extruder size	Index of Maximum Density Achieved	Maximum Typical Water Stability (hrs)	Recipe Flexibility
Open vent in extruder barrel	1.0	1.00	20	Best for low starch (<15%) and high protein (=36%)
Open vent in extruder barrel with vacuum assist	1.1	1.03	22	Best for low starch (<15%) and high protein (=36%)
Closed vent and BPV and pressure chamber used at die	1.5	1.10	24	Best for low starch (<15%) and high protein (=36%)
Closed vent and PDU	4.0*	1.20	12	Best for high starch (=15%) and low protein (<36%)

* Maximum rates of up to 15 ton/hour for one system.

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In business since 1935, Wenger Mfg. is the major supplier of extrusion and dryer process hardware and technology for the aquatic and pet food industries. Wenger Mfg. supplies "the whole product" through augmented product services such as training programs, process engineering, and development of concepts into manufacturing processes.