DESIGN CONSIDERATION OF BIOFLOC PRODUCTION SYSTEMS

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Introduction

Biofloc production systems were developed to improve environmental control over intensive production. In places where water is scarce or land is expensive, more intensive forms of aquaculture must be practiced for cost-effective production and biofloc technology seems to be the solution. Biofloc technology has become a popular in farming of Pacific white shrimp, P. vannamei and now it is used in other shrimp and fish as well. It is now a very popular system of semi-intensive and intensive shrimp and fish farming with low or no water exchange. It is comparatively much profitable and bio-secured system of aquaculture. A basic factor in designing a biofloc system is waste treatment. Biofloc systems work best with species that are able to derive some nutritional benefit from the direct consumption of floc. At its core, biofloc is a wastewater treatment system and was developed to mitigate the introduction of diseases into aquaculture facilities or farms from incoming water (water exchange, typically used in prawn farming). Biofloc systems employ a counter-intuitive approach to more traditional aquaculture designs. Where more traditional aquaculture designs seek to remove suspended solids, bio-floc systems allow and encourage solids and the associated microbial communities to accumulate in the water. Assuming sufficient aeration and amalgamation in order to maintain an active "floc" in suspension, water quality can be maintained and controlled. Bioflocs' may also have probiotic effects in some species. Essentially, bioflocs' provide two very critical services, which also helps a little to understand how they work. They treat wastes from feeding and provide nutrition from floc consumption.

Specifications and design of biofloc systems

"Flocs" are a supplementary food resource that can be consumed between feeding times (pellet use). One of the benefits of biofloc systems is it capacity to recycle waste nutrients via microbial protein into fish or prawns. The main component of biofloc is nitrogen that is incorporated into bacterial cells. One other benefit of biofloc systems is the benefit of improved feed conversion ratios derived from the consumption of microbial protein. It should also be noted that bi-floc systems are generally implemented as pond based systems as they add the most benefits to pond based aquaculture. Additionally, biofloc is not suitable for just any species and works best with species that are able to derive nutritional benefit from the direct consumption of "floc". Implementing biofloc technology to culture shrimp in ponds and recirculating systems could offer several advantages, including improvement of water quality and animal nutrition.

Basic types of biofloc systems

Few types of biofloc systems have been used in commercial aquaculture or evaluated in research. The two basic types are those that are exposed to natural light and those that are not. Biofloc systems exposed to natural light include outdoor, lined ponds or tanks for the culture of shrimp or tilapia and lined raceways for shrimp culture in greenhouses. A complex mixture of algal and bacterial processes control water quality in such "greenwater" biofloc systems. Most biofloc systems in commercial use are greenwater. However, some biofloc systems (raceways and tanks) have been installed in closed buildings with no exposure to natural light. These systems are operated as "brown-water" biofloc systems, where only bacterial processes control water quality.

Based on the waste treatment, there are two primary biofloc technology systems that can be considered for shrimp culture.

(i) in-situ biofloc systems, where biofloc form in the culture pond/tank along with the shrimp.

(ii) ex-situ biofloc systems, in which effluent waters are diverted into a suspended-growth biological reactor where biofloc are generated and subsequently can be used as an ingredient in shrimp feed.

In-situ systems are currently in use, and ex-situ systems are in the developmental stage. Each option (in-situ versus ex-situ) has unique benefits and limitations. For example, in-situ biofloc systems, under proper conditions, can assimilate ammonia directly into microbial proteins, thereby preventing the accumulation of nitrate (from nitrification). Additional benefits are that the biofloc provide nutrition directly to the shrimp. However, the downside is lack of control regarding manipulation of biofloc nutritional profiles. Furthermore, in-situ biofloc systems exert a high oxygen demand because oxygen is being used by both biofloc and shrimp. With ex situ biofloc systems, one has better control of floc nutritional profiles and can manage the demand for oxygen by floc and shrimp in separate tanks.

Design consideration

Bioflocs production systems are either of ponds, tanks, raceways and RAS indoor or outdoor

Pond design-outdoor

Aquaculture ponds are dynamic and complex ecosystems, which will only produce the targeted cultivable production, if nutrient cycling and waste decomposition are properly managed. A number of physical, chemical and biological methods used in treating this kind of problem, management practices influencing the load and decomposition rates in ponds include water exchange, sediment removal, aeration, fallowing period between crop cycles, liming etc. Ponds are designed so that it may be possible to maximise the viability of a low water exchange and maintenance of microbial floc system. These specifications include pond shape to maximise active suspension and oxygen distribution, maximum and minimum depths, drainage capability, and lining. The influence of pond design on system viability has not been fully researched and at present different designs is being adopted at different places. The basic requirements for biofloc system operation include high stocking density and high aeration with correct paddlewheel position in ponds. Ponds must be lined with concrete or high density polyethylene (HDPE). An intensive BFT pond has to be planned bearing in mind the need to provide proper aeration to all parts of the pond, mixing the water to minimize anaerobic sludge accumulation and to enable periodic drainage of the sludge both during the crop and between crops. Additionally, designs should facilitate efficient harvest and easy feeding. General rules and demands of pond design should be followed in designing BFT systems also. But as per the site condition it needs to be modified

Pond shape

The classical design BFT ponds is based upon a round pond concept with aerators inducing radial water flow, or otherwise square or rectangular ponds where water flow is sort of radial, mostly in parallel to the pond dykes. In such cases, corners are rounded or cut to minimize stagnant areas. Round ponds are the most common design for small ponds, used in hatcheries and some production units. Building larger round ponds is more difficult (digging, utilizing land, lining) and rectangular or similar are more common.

Pond Size

Intensive ponds should not be too large. The biomass in the ponds is high, controlling large volumes of water is difficult, harvesting of too high biomass is complicated and the risk of holding dense fish or shrimp populations in very large reservoirs may be too high. In addition, the risk of losses if something goes wrong in large intensive ponds is very high. The typical size range of intensive ponds is normally in the range of 100-1,000 m^2 while the typical size of intensive BFT shrimp ponds is 1,000 – 20,000 m^2 (0.1-2ha).

Pond depth

The depth of ponds is in the range of 1-2 m. The advantage of deep ponds is their high heat buffering capacity, which helps to avoid over-heating or over-cooling during the diurnal cycle. In addition, the deeper water column minimizes contact of the surface water to pond bottom anaerobic conditions and allows a deeper water column for feeding and biological processes. However, constructing deeper ponds demands a higher investment and in cases of limited gradient to the drainage base makes drainage and harvest more of a problem.

Pond lining

BFT ponds are most always lined. It could be lined with Concrete, Bricks, Fiberglass, Wood, Plywood, HDPE, PVC, EPDM. Lining of ponds is usually done with High Density Polyethylene (HDPE) sheets of about 1 mm (30-40 mil). Cheaper alternatives may be constructing a pond bottom with compacted laterite soil (or laterite crushed stones). Laterite, the red soil commonly found in tropical regions, makes a stable pond bottom upon compaction. However, in this case, the banks should also be covered with plastic sheets. Another possibility is to line the pond with a soil cement mixture. In sandy soils one can mix cement with a top layer of soil and obtain a stable lining. The bottom should be smooth to ease draining and cleaning. The relatively fast water movement within the pond (10-30 cm/sec) may induce a significant erosion of earthen banks. Boyd and others (Boyd, 1995) found that such eroded material constitutes a large portion of the accumulated sludge and causes difficulties in pond maintenance. Avnimelech and co-workers (1986) found that a soft clay dominated pond bottom becomes highly anaerobic due to the mixing of organic matter with the clay and the very limited oxygen diffusion into the deep bottom layer. Additional advantages of lining are the ease of cleaning pond bottom in between cycles and possibly more efficient utilization of feed residues sinking to the bottom. It is interesting and important to note that the nature of organic matter accumulating on the pond bottom differs between lined and earthen bottoms. In earthen ponds, the organic residues mix with the soil, forming a rather stable complex, in comparison to highly degradable, unstable and bio-reactive organic residues that accumulate adjacent to the lining. This difference affects pond management: in earthen ponds, organic matter accumulates over a period covering several cycles and has to be periodically removed. In the case of lined ponds, organic deposits do not accumulate, yet due to the high reactivity they affect chemical and biological processes in the pond vigorously and may cause a real problem for production in the pond. One very clear example of the difference between earthen and lined ponds is demonstrated by following phosphorus interactions. In earthen ponds, the soluble phosphorus interacts with soil components and is, to a large extent adsorbed. In lined ponds, such interaction does not take place and excessive phosphorus remains, mostly as soluble phosphorus in the water (Avnimelech and Ritvo, 2003).

Central drainage system

In recent time there is a noble concept of shrimp toilet or central drain applied by aquaculturists are showing interest in establishing shrimp pits or shrimp toilets or central drain at the center of the culture pond. For this purpose, they are utilizing about 5- 7% of the total surface area of pond. Ideally, the pond size should be about 1000-5000 m^2 for the establishment of shrimp toilet. Establishments include 7-10 feet concrete cement with a smooth slope to the center where there will be a small well of about 2-3 feet depth. Smooth and slope surface (25-30^o) at center allows fast movement of waste toward the central pit with the additional advantage of lesser requirement of water with concentrated organic waste removal. By the continuous movement of water by intensive aeration all the waste materials will be dragged in to well. This waste can be removed using a siphoning motor or submersible or floating pump (power of about 2 hp) for every week so that there will not be any sludge. Natural gravitational force can also be used for draining the organic waste like in central drain. In the recent time, there is an addition to shrimp toilet concept is an HDPE and rubber parabola cover (2.5 meters in diameter), placed over the central drain of a pond. The purpose of the keeping parabola is to extend the area of sludge removal. The achievement of thorough drainage is very important in extensive BFT ponds, where a very good exposure to the air and drying are essential. In CIBA, under NFDB project biofloc based *P. vannamei* culture is being undertaken in lined central drainage ponds at Muttukadu experimental station.

Prefabricated ponds/tanks

A new and interesting approach is the installation of pre-fabricated ponds. Such ponds are produced presently in both Mexico and Colombia (possibly else-where as well), are relatively inexpensive and can be installed within a few days. The ponds (tanks) are relatively small (up to about 150 m2) and can be used as a starting technology for individual farmers. Such ponds are suitable for the production of dense fish biomass (shrimp in special cases, to provide fresh shrimp) and can easily be placed in green-houses. Organic residues are always produced and their accumulation as bottom sludge is an unavoidable problem. The basic solution to this problem is to concentrate the sludge in limited points in the pond (sludge traps) and design for the capacity to drain out the sludge, during the production cycle and between cycles.

Race ways – outdoor and indoor

A raceway usually consists of rectangular basins or canals constructed of concrete and equipped with an inlet and outlet. A continuous water flow-through is maintained to provide the required level of water quality, which allows animals to be cultured at higher densities within the raceway. Most raceways are made of reinforced concrete, though some earthen raceways are also built. Earthen raceways with plastic liners cost little and are easy to build, but cleaning and disinfecting them is difficult and plastic linings are fragile. Reinforced concrete is more expensive, but is durable and can be shaped in complex ways. Raceway tanks can also be built from polyester resin. A raceway is most often a rectangular canal with a water current flowing from a supply end to an exit end. The length to width ratio is important in raceways. To prevent the fish stock from swimming in circular movements, which would cause debris to build up in the centre, a length to width ratio of at least six to one is recommended. If the width is too large this could result in a feeble current speed which is not desirable (see below). The length of a raceway unit is usually constrained by the water quality or by how much stock a unit can hold for ease of management. The average depth of a raceway for fin fish, such as rainbow trout, is about one meter. This means each section in a raceway should be about 30 m long and 2.5–3 m wide. The landscape should sloped to one or two percent, so the flow through the system can be maintained by gravity. The raceway should not be curved, so the flow will be uniform.

Generally the water should be replaced about every hour. This means a typical raceway section requires a flow rate around 30 liters per second. However, the optimum flow through rate depends on the species, because there are differences in the rates at which oxygen is consumed and metabolic wastes are produced. The flow rate necessary to maintain water quality can also change through the year, as the temperature changes and the cultured species grow larger. For reason such as these, continuous monitoring of water quality is important, including measurements of water flow rates, pH levels and temperature, as well as the levels of dissolved oxygen, and suspended and solid waste material

Closed raceway

Another BFT system design is the closed raceway approach. The closed raceway is based upon a linear rather than a radial water movement pattern. Closed raceway units can be constructed as such, when all walls and flow partitions are built as an integral part of the system (e.g. walls and partitions built of concrete). A cheaper and easier mode is to put in a partition, dividing the pond the rectangular pond into a closed raceway. It is important to note that the flow partition is separating two sides having the same water head and that the separation does not have to be tight. Thus, a partition made of simple plastic sheets placed in position supported by poles may be sufficient. Aerator placement is generally parallel to the raceways. Sludge tends to accumulate in closed raceways at the ends of the flow partitions where water flows around the baffle and relatively dead volumes are created. The linear flow mode of the closed raceways seems to enable the operation of long ponds. Pond length can be as long as there are enough aerators along the pond (and as long as you can have all pond length sloping toward the outlet). The width of the raceway should be such that enable smooth water flow and easy access. A width of about 10-30 m seems to be appropriate.

Mr Adam Body in the Northern Territory, Australia operated a shrimp farm that included four 2.5 ha ponds, 500 m long and 50 m wide (Chamberlain, 2000). The ponds were divided into 2 raceways, about 25 m wide by earthen baffles. The ponds were each equipped with 4 long arm paddle wheel aerators. Such ponds seem to have many advantages, are relatively inexpensive and simple. Yet, more experience in planning and operating closed BFT raceways is required.

Green house

Greenhouses are framed or inflated structures covered with transparent or translucent material large enough under partial or fully controlled environmental conditions for the shrimp or fish culture. In India use of greenhouse technology started only during 1980's and it was mainly used for research activities for agriculture and horticulture purposes. The National Committee on the use of Plastics in Agriculture (NCPA-1982) has recommended location specific trials of greenhouse technology for adoption in various regions of the country. Greenhouse structure of various types are used. Although there are advantages in each type for a particular application, in general there is no single type greenhouse, which can be constituted as the best. Different types of greenhouses are designed as per the location based on shape, utility, material and construction:

The green house can be of wooden framed or pipe framed structure or truss framed structure. The type of covering material as

- Glass glazing.
- Fibre glass reinforced plastic (FRP) glazing
    - Plain sheet
    - Corrugated sheet.

- Plastic film
    - UV stabilized LDPE film.
    - Silpaulin type sheet.
    - Net house.

Different greenhouse designs are available, ranging from small ponds (a few hundred m) up to structures covering large ponds. Stability of these structures during strong winds may be a problem, calling for a solid and expensive structure. In all cases, ventilation is needed, to enable release of heat and allow better temperature control.

Greenhouse raceways for shrimp

Building upon the intensification of lined, outdoor shrimp ponds, member institutions of the former U.S. Marine Shrimp Farming Consortium developed biofloc technology in intensive lined raceways in standard greenhouses (100 feet long × 25 feet wide). These greenhouses can be sited inland to avoid expensive coastal land and in areas with a temperate climate if supplemental heat is provided. Experimental or nursery-scale raceways (40 to 50 m3) and commercial-scale systems (250 to 300 m3) are constructed to fit in a standard greenhouse.

Raceways are shallow (about 50 to 100 cm) and typically include a central baffle or partition to improve internal circulation. Water movement is provided by banks of air-lift pumps that draw water from the tank bottom and release it at the tank surface or by pumps that inject water through nozzles designed to provide aeration. Water is directed to flow along the tank in one direction and in the opposite direction on the other side of the partition. Raceways also have an extensive network of diffused aeration to maintain biofloc in suspension. At the highest intensities and standing crops, oxygen may be injected for a short time after feeding or continuously as needed.

Biofloc solids concentration is managed with settling tanks. Settling tank volume is less than 5 percent of system volume. Some systems include foam fractionation to capture fine solids and foam. Best operation occurs when settleable solids are 10 to 15 mL/L; best shrimp feed consumption occurs at the low end of that range.

Shrimp (SPF) juveniles are stocked at 300 to 500 PL per m2 (up to 750 to 1,000 PL per m2). Yields of 3 to 7 kg/m2 are typical, with yields of 10 kg/m2 possible with pure oxygen supplementation. Water use is about 200 to 400 L/kg. In addition to shrimp grow-out, biofloc technology can be used in commercial nursery systems. The relatively small and shallow raceway is physically suitable for intensive nursery culture. Importantly, juvenile shrimp may be able to take better advantage of the nutritional benefits of biofloc than larger shrimp.

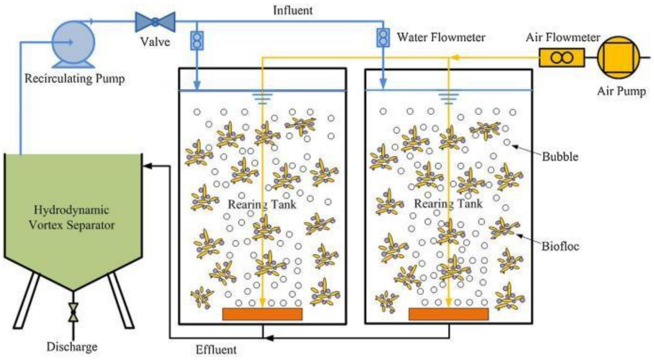
Greenhouse raceway for shrimp (Clemson system)

A variation of a shrimp biofloc system in a greenhouse has been evaluated at Clemson University. The system consists of three shrimp rearing tanks, each of which is 250 m$_2$, containing 150 m^3 of water. The system is operated with a solids concentration of 200 to 500 mg/L (15 to 50 mL/L). Water from rearing tanks flows to a primary solids settling tank where it is allowed to become anoxic. Denitrification and some alkalinity recovery occur here under those conditions. Water then passes to an aerated tank stocked with tilapia, which provide filtration (polishing) and nutrient recovery. Next, water flows into an intensively mixed tank with dense biofloc (1,000 to 2,000 mg/L) that serves as a biofilter to oxidize ammonia. Water then flows to a tank for solids settling before returning to the rearing tank. Settled solids are recycled to the suspended-growth biofilter. The main difference between this and the previously described system is the use of a dense suspension of biofloc separate from the shrimp as a biofilter. The Clemson system is also different in that it includes an anaerobic component in the treatment loop. The system has produced 2.5 to 3.5 kg/m$_2$ in a 150- to 180-day growing season. Sustainable feeding rates in excess of 1,000 kg/ha and peak

Fig 3. Raceway culture system

RAS and Recirculatory Biofloc system - RBFT

A different approach, recirculating aquaculture systems, RAS, is based upon the treatment of water quality in a separate compartment using mechanical solids separation, biofilters of different types and often water sterilization,



The basic components of RAS are unique, irrespective of the aquatic species. The capacity of RAS is decided, based on the biomass and feed rate. The important processes in RAS are waste solids removal, biofiltration, degassing, aeration and disinfection.Recirculation can be carried out at different intensities depending on how much water is recirculated or re-used.

Design considerations

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Solid waste removal

Solids removal is very important in RAS. The solids in the form uneaten feeds and excreta must be removed as soon as possible, because it may result in biofouling, NH_3 production, oxygen depletion, high microbial load and eventually occurrence of disease within the system. There are different techniques being employed for solids removal i.e. sedimentation/settling tank, screens, granular media filters, porous media filters, hydrocyclones and later on foam fractionation and ozonation for fine and dissolved solids removal. The use of the above mentioned treatments are specific to the size of solids and may be used in combination.

- **Sedimentation** – Settling tank, Tube settler is used for sedimentation of large particles.>100 µm particles can be removed by this process. The drawback is low hydraulic loading and only 40-60 % solids removal is possible.
- **Granular media filters** – Rapid sand filter, Pressure sand filter, Bead filter etc. comes under this category. About >20 µm paricles can be removed by granular media filters. They have moderate hydraulic loading rate and 60 – 90 % solids removalis possible. The disadvantage is high head loss in the filtration.
- **Screen** – Coarse screen, Micro screen, Drum filter can be used to segregate particles of >60 µm size. These equipments have negligible head loss and high hydraulic loading. About 5-50 % solids removal is possible.
- **Porous media filters** – DE filter, Cartridge filter comes under porous media filters. These are used in micro-particles removal. Upto 0.1 µm particles can be separated used cartridge filters. They have moderate head loss andaverage hydraulic loading rate. About 90% solids removal is possible with porous media filters.
- **Hydrocyclones** –Swirl separators are used in old times. They are very simple in construction and capable of separating large particles of >200 µmsize. The disadvantage is very high head loss and low hydraulic loading.
- **Foam fractionation** - fine and dissolved solids are removed in protein skimmer. About <30 µm size particles are separated by foam fractionation.

Selection of method/equipment for solids removal is based on hydraulic loading rate, head loss, fine solids removal efficiency, water loss and resistance to biofouling. The method can be used alone or in combination based on the size of particles to be removed.

In RBFT system each tank, there is an annular air diffuser (porous rubber with an external diameter, 16 mm andinternal diameter, 8 mm, length, 650 mm each) and a 2-Hp aerator (Blower) to provide air and to keep the solids suspended. The recirculating pump offered the power to make sure the recirculation of RBFT system, which results in a velocity of the inlet water (the regulation of water inlet velocity is based on valve and water flowmeter). The inlet velocity greatly changed the flow pattern of the rearing tank, which could affect the distribution of biofloc particles, just like the size of bubble supplied by aerator. To a certain water inlet velocity and bubble size, the rearing tank could obtain a homogenous distribution of biofloc. According to the homogenous distribution, the TSS of rearing tank would decrease to an expected level because HDVS could discharge the biofloc particles effectively and exactly.

RAS has numerous advantages over the other conventional farming systems. In RAS aquatic animals can be grown in controlled conditions that influence their growth and can better manage economic and production performance. RAS uses only upto 10% of water exchange daily, and thus, the animals can be grown in places where limited water is available with efficient use of water resources. Indoor aquaculture through RAS creates high density farming and thus, reduction in land area compared to traditional pond based systems. Bio-security can be maintained through RAS.

Conclusion

High-density rearing typically requires some waste treatment infrastructure. At its core, biofloc is a waste treatment system. Biofloc systems were also developed to prevent the introduction of disease to a farm from incoming water. Shrimp farming began moving toward more closed and intensive production where waste treatment is more internalized. Super-intensive shrimp culture systems require a unique set of engineering and management criteria. Many of these issues are still being explored by the scientific community as well as by the aquaculture industry. The future surely holds a place for super-intensive biofloc systems or some adaptation of this technology if responsible aquaculture development is to progress.

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