ENGINEERING AND BIO-TECHNOLOGIES IN AQUACULTURE

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Contents

Summary

A large variety of technologies are involved in production and processing in fish culture. Some are engineering technologies dealing with all physical aspect of production and mechanics; others are dealing with biology, the so-called "bio-technologies." There is a continuum in the complexity of technologies, which is related to a continuum in the complexity of production systems and in the degree of domestication of the species and the expertise of the farmer. The most widely distributed production system is the extensive aquaculture in ponds with fish feeding on

the endogenous food produced by the aquatic ecosystem. It usually deals with simple technologies mostly based on know-how and few domesticated species (carp for instance) and was empirically elaborated by generations of fish farmers based in trial-errors. Sophisticated technologies are more based on knowledge resulting from a strong research effort made by developed countries. In the North, input of technologies resulted in successful complex intensive production systems and commodity chains; attempts of transfer to developing country often result in failures. Technologies have to be adapted to the local socio-economic context, to the capacity of the social corpus to handle them, to availability of local expertise, and to the degree of domestication of the cultivated species.

1. Introduction

Over the past decades the aquaculture showed qualitative changes in the production and uses of aquatic products. New paradigms have developed such as the production of fish for stocking rivers and lakes, either for commercial or recreational fisheries or for ornament. Fish culture technologies allow gene conservation of endangered species via the breeding of captive brood stock. A large range of products is offered on the market including non-alimentary products such as fish skin leather or drugs and chemicals. One of the main problems faced recently by the fish and prawn-farming industry was the environmental constraints requiring new equipments and technologies for preventing the discharge of farm effluents in the wild or at least minimizes the discharge of pollutants into the environment. There is now a tendency to remove the aquaculture facilities from the natural environment i.e. not depending on open water in the wild (integral water recirculation systems in raceways or in pond farm systems). A large variety of technologies are involved in the culture and processing of fish. Some are engineering technologies dealing with all physical and mechanical aspects to handle water and organisms; others are dealing with the biology of ecosystems (including bio-manipulation by introduction of fish) or the biology of cultivated organisms (the so-called “bio-technologies”). More recently technologies of the agro-industry were involved in the processing of some cultivated species. There is a continuum in the complexity of technologies, which is related to a continuum in the complexity of production systems and in the degree of domestication of the species. There are consequently a large variety of technologies, which can be identified as specific for each production systems.

2. Engineering Technologies

2.1 Culture of Juvenile in Hatcheries

Simple wooden incubators and troughs and small raceways with running spring water, Zug jars for carp, paddlewheel for catfish are still operating in hatcheries dating back from the fifties. Circular spawning and hatching tanks are extensively used in China and in others Asian countries for the propagation of Chinese carps. More sophisticated hatcheries are found now for most cultivated species: salmon sea bass, sea breams, turbot, abalone, and oysters. They operate often on recycling system usually with partial renewal of water. The costs are high but such systems produce valuable seed products ensuring economical profitability. The possibilities of thermo-regulation allow an early reproduction in the season and the production of larger fry so that the marketable size can be reached earlier. Some equipment for larvae rearing was recently designed offering clean water and high survival rate. Some technologies such as airlift pumps; bio filters used in aquariology have been transferred to intensive fish culture of rainbow trout fry.

2.2 Culture of Mollusks and Algae in Open Water

Extensive systems for the production of mollusks, mainly oysters, mussels and clams, are most commonly applied in coastal areas, which are suitable for spat collection and on growing. These systems are depending largely on wild seed and natural food mostly phytoplankton. Various spat collection devices have been developed, which provide surface area for the attachment of spat. One of the most common collectors consists of scallop or oyster shells strung on a rope or wire, which suspend from rafts, long lines or bamboo frames. Although spat collection from the wild is still dominant in commercial culture of mollusks, hatchery seed production has also been developed and being practiced by increasing number of producers. The simplest, though less efficient production system for grow-out of mollusks is bottom culture, when human intervention is limited to the provision of spat, and protection from pests and predators. During the past decades, major emphasis has been given to off-bottom culture, when the mollusks are grown on specially designed structures, which facilitate the use of the available sites and enable the better utilization of primary productivity for the nourishment of mollusks. Ratts, racks, stakes, trays and long lines are commonly used nowadays in commercial systems in open waters, but few land-based systems involving raceway and pond have also been developed. In typical rack culture systems, rafts of different designs are used to suspend trays or strings carrying the seed. In areas with heavy wave action, long lines anchored at both ends and supported by floats are used for hanging the strings or trays. The traditional trays were made of wood and wire mesh, however rubber, plastic coated wire mesh, polypropylene, special metal alloy were also used recently. By the application of new materials and special coatings, the unwanted bio fouling could also be reduced. Although the culture of mollusks still involves a lot of handwork, mechanization has also been introduced to facilitate the handling of seed strings and crop harvesting with transport to depuration and processing plants (see *Marine Aquaculture and Shelled Mollusks*).

Seaweeds (mainly red, brown, and green algae for human consumption) contribute a substantial proportion (more than 20 %) of the total world aquatic production. Besides human consumption in Asia, seaweeds are also used as fodder, and in the manufacture of agar, carrageenan, alginates, mannitol, and iodine. Seaweeds are most commonly cultured in Asia, particularly in Japan, China and Korea. The culture principle is similar to that of mollusks, when the “seed,” in case of seaweeds the monospores, are collected by substrates (bundles of bamboo; rocks; concrete blocks; net with large mesh size; and split bamboo strung with ropes; etc.), which are transferred then to suitable sites, such as inshore areas near estuaries for grow-out. Raft and rack culture in open sea are widely practiced in Japan and China, but seaweeds are also grown in ponds applying similar procedures than in pond fish culture (see *Growing of Algae*).

2.3 Culture in Ponds

Ponds are earthen (sometime concrete or cover with liners) impoundments holding fresh water or seawater. This is the most common land based aquaculture system particularly developed for cyprinids, catfish and prawns. Their sizes show great variety from few square meters to several hectares. The production may be extensive based (yielding 100–500 kg/ha/year in temperate zones to several t/ha/year in tropical zones), depending on the intensity of fertilization, which stimulates the food web and supplemental feeding. The basic civil engineering technologies are involved: dams levee and spillway and construction, hydraulics works, harvest basin monks and sluices. Standard technologies for building catfish ponds were set up in the USA in order to lower the cost. Technologies for the measurement of water composition alkalinity, hardness, and ion concentration are also available.

Water is usually added to compensate for seepage and evaporation; gravity water is commonly used but in some case water has to be pumped from the nearby sea, river or lake or from underground. Pumping technologies are well established but they are costly and sometime not profitable. In the Danube Delta in Romania large pond farm based only on pumped water had to be closed down after the "revolution" because the true pumping costs appeared too high and the production was not economically profitable. Another common oxygenation technology used in pond farming is the aeration, using simple paddlewheel systems or more elaborated aerators. Pumping systems with propellers (circulators) are also used to mix water in ponds in order to avoid thermal stratification. A large range of equipment is used in pond fish farming: demand feeders, boats for feeds or fertilizers distribution, and for cutting macrophytes, etc. Fishponds may not be only production facilities but they can have an important role in integrated water management. Besides the conventional function of the ponds being used for fish production, the well managed fish ponds can also serve as nutrient trap and nutrient processing unit, when the high organic material content of the inflow water (from farms, processing factories, waste water and treatment plants, etc.) is removed from the water and partly turned into fish flesh. The possible integration of pond fish production with other activities, including the provision of habitat for water related animals and plants is getting more attention as population grows and water resources becomes limited.

2.4 Culture in Raceways and Tanks

Raceways are commonly used for intensive production in monoculture in continental water especially for the rainbow trout culture. Basically, water brings oxygen and eliminates the feces and metabolic products excreted by the fish. Technologies have been introduced to intensify production in the same volume of water by introducing oxygen via various type of aerator or more recently liquid oxygen. As the waste water is discharged in rivers, resulting in alteration of the water quality below the fish farms, legal regulations have been recently established limiting the discharge of suspended matter and appropriate equipment were developed such as filtration and sedimentation systems. These are examples of the so-called "eco-technologies" or environmental engineering. In intensive culture system, technologies are also developed to offer the fish the optimum physical environmental conditions in term of flow rate, mixing water and by a better design of the hydrodynamics of culture tanks. Feeding is a major issue in intensive culture and technologies help to ensure feed processing and quality of pellets (use of Near Infrared Reflectance), and a better distribution of the feeds (various type of feeders, some taking into account the nutritional requirement of the animals).

2.5 Culture in Cages or Enclosures

Fish culture in cages or enclosures is commonly practiced in various water bodies with simple (bamboo, wood) or more elaborated (steel, plastic) sub-structures. Cage culture is practiced for growing fish (salmon, sea bass) and for larvae rearing with original technologies such as illumination to attract zooplankton in case of marine species and coregonids. Cages require underwater observations usually made by divers but the remote operated vehicle (ROV) carrying video cameras may provide pictures of fish for automatic image analysis. One problem faced in cage culture is the turgidity of water which is so high (for example in the Niger River) that the fish cannot see and catch the pelleted food; at feeding time the fish have to be trained to come at the surface of water so that they can see the feeds thrown by hand and could catch them before they sink.

2.6 Fish Production in Closed System

Technologies for water denitrification and purification recycling and controlling some parameters such as dissolved oxygen and water temperature have been refined. One objective is to offer the fish optimum environment conditions for growth, reproduction, survival, health, and flesh quality. Temperature is often a major constraint in temperate zone as the true growing period is restricted to 100–150 days/year for fish in ponds. Another objective is to limit the fish farm discharges in open waters (sea, river, and lake) (see *Environmental Impact of Aquaculture*).

Hatcheries for the production of juveniles offer an example of operational intensive production units with recycled water using mechanical filtration and bio filters but the renewal rate of water is still important, up to 10% per day (semi closed systems). This shows that the present technologies in use are not efficient enough to recycle entirely the water of the units. Culture in entirely recycled water is a new approach for fish production. This would contribute to solve several of the above-mentioned problems regarding environment and water temperature variation. In this system the fish farmer owns the water as the farmer owns the land. The amount of water used is limited and it is not released in the wild. It should be possible to adapt the quality of the water to the needs of the growing fish (temperature, oxygen, and pH) and to have a better control of the growth. Such intensive recirculating production systems can also solve the problem of the shortage of sites available for aquaculture operations. Integral recirculation systems are not yet fully elaborated for growing on fish; they are still at an experimental/pilot scale. A first experimental unit included 2 tons carrying capacity in 20 m^3 water with a water residence time up to 50 h. Water goes through a mechanical filter, UV lamp, nitrifying bio filter, CO_2 stripping column and is buffered by caustic soda (NaOH). Pure oxygen is distributed by a computerized supply system with permanent oxygen recording in the tanks connected to security system. The 20 m^3 unit yielded 1160 kg of sea bass biomass i.e. 5.2 m^3 seawater/kg of fish.

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Biographical Sketches

Roland Billard was born in 1934 in France and graduated from Lyon University in 1965. He received his Doctorate d'Etat at the Paris P & M. Curie University. He has worked as Assistant and Director of research at the National Institute of Agronomic Research (INRA) and was Director of the Fish Physiology Laboratory in this institute from 1970 to 1984. Since 1986 he is Professor at the "Muséum National d'Histoire Naturelle" in Paris and Director of the Laboratory of General and Applied Ichthyology. His main research interest is fish reproduction, spermatogenesis (structural and quantitative aspects, endocrine regulation) and physiology of spermatozoa with application to the control of reproduction and spawning, gamete preservation and artificial insemination. He also showed interest on the production systems in aquaculture. He has published more than 300 scientific articles and 200 technical papers and published or edited a dozen books. He is member of the French Academy of Agriculture, foreign member of the Romanian Academy of Agriculture and member of the Academia Georgofilli (Italy).

Laszlo Varadi was born in 1948 in Hungary and graduated from Godollo Agricultural University in 1972 as mechanical engineer in agriculture. He received a second diploma from the same university in agricultural water management in 1975. He has been working in the Fish Culture Research Institute, Szarvas, Hungary since 1975, where his experience has included research on the mechanization of pond fish farms and the development of intensive fish production systems. He has also been involved in the design and operation of aquaculture facilities and in training in aquaculture engineering. He regularly works for international organizations as aquaculture engineering consultant in developing countries. He has published more than 70 scientific and technical papers. Since 1992 he has been appointed as director of the Fish Culture Research Institute, Szarvas, Hungary.