An introduction to Re-circulating AQUACULTURE SYSTEM

Shubhadeep Ghosh

Introduction

Recirculation aquaculture is essentially a technology for farming fish or other aquatic organisms by reusing the water in the production. The technology is based on the use of mechanical and biological filters, and the method can in principle be used for any species grown in aquaculture such as fish, shrimps, clams, etc. Recirculation technology is, however, primarily used in fish farming. Recirculation is growing rapidly in many areas of the fish farming sector, and systems are deployed in production units that vary from huge plants generating many tonnes of fish per year for consumption to small sophisticated systems used for restocking or to save endangered species.

The earliest scientific research on recirculatory aquaculture system was conducted in Japan in the 1950s focussing on biofilter design for carp production, which was driven by the need to use locally-limited water resources more productively. Denmark was one of the first countries to use recirculating aquaculture system technology for commercial European eel aquaculture in 1980s. Recirculating systems are now used to produce both fresh- and saltwater species, including rainbow trout, whiteleg shrimp, and turbot. The Monterey Bay Aquarium Seafood Watch's "best choices" list includes several species farmed in recirculating tanks, a farming method that, it says, can minimize disease and the discharge of pollutants with wastewater treatment. Charoen Pokphand Foods of Thailand aims to produce its entire whiteleg shrimp with indoor recirculating aquaculture system by 2023. Other recirculating aquaculture system ventures currently planned include a US $500-million Atlantic salmon farm in Maine that is expected to produce about 30,000 tonnes of fish annually and a $152-million Atlantic salmon farm in Japan that produce 10,000 tonnes of fish annually.

Operational Scale

Recirculation can be carried out at different intensities depending on how much water is recirculated or re-used. Some farms are super intensive farming systems installed inside a closed insulated building using as little as 300 litres of new water, and sometimes even less, per kilo of fish produced per year. Other systems are traditional outdoor farms that have been rebuilt into recirculated systems using around 3 m^3 new water per kilo of fish produced per year.

Principle of Recirculation

In a recirculation system it is necessary to treat the water continuously to remove the waste products excreted by the fish, and to add oxygen to keep the fish alive and well. A recirculation system is in fact quite simple. From the outlet of the fish tanks the water flows to a mechanical filter and further on to a biological filter before it is aerated and stripped of carbon dioxide and returned to the fish tanks. This is the basic principle of recirculation. Several other facilities can be added, such as oxygenation with pure oxygen, ultraviolet light or ozone disinfection, automatic pH regulation, heat exchanging, denitrification, etc. depending on the exact requirements.

Need for Recirculation

Fish in a fish farm require feeding several times a day. The feed is eaten and digested by the fish and is used in the fish metabolism supplying energy and nourishment for growth and other physiological processes. Oxygen (O_2) enters through the gills, and is needed to produce energy and to break down protein, whereby carbon dioxide (CO_2) and ammonia (NH_3) are produced as waste products. Undigested feed is excreted into the water as faeces, termed suspended solids (SS) and organic matter. Carbon dioxide and ammonia are excreted from the gills into the water. Thus fish consume oxygen and feed, and as a result the water in the system is polluted with faeces, carbon dioxide and ammonia. These harmful substances seriously affect the quality of aquatic products, so water treatment equipment is needed to remove these substances, add oxygen (O_2) to the water and adjust the temperature of the water to ensure a high-quality environment for fish survival. Recirculation aquaculture uses equipments for physical filtration (e.g. solid–liquid separation equipment, microscreen drum filter and foam fractionator) that could remove suspended solids during the water treatment; and equipments for biological filtration (e.g. fluidized sand biofilter (FSB), moving-bed biofilm reactor (MBBR) and rotating biological contactor (RBC)) that could remove ammonia nitrogen, nitrite and other hazardous substances from wastewater; and equipments for water disinfection and sterilization, O_2 addition, CO_2 removal and temperature control.

Global Context of Marine Recirculatory Aquaculture Systems

In the saltwater arena, it appears that recirculating systems play an important role in the production of healthy, properly sized fingerlings for stock out in netpens or ponds. Recirculating systems are very compatible with the complex nature of reproduction in marine species and the broodstock fecundity of most marine species diminishes the impact of waste processing costs. The high values associated with fingerlings and marine ornamentals will also promote adoption of recirculating technologies. The higher market prices of marine fishes make this an attractive niche for recirculating systems.

The first example is a recirculatory aquaculture system for salmon smolt production marketed by the Norwegian company Akva (through a buy-out of the Danish firm Uni-Aqua). This features a double loop which treats the full recycled flow with solids filtration, UV disinfection and degassing, with only a proportion of the flow treated through moving bed bio-reactors (MBBR). Oxygenation is carried out at the tanks using cone injectors. The second example is an experimental scale marine recirculatory aquaculture system designed at the Centre of Marine Biotechnology, University of Maryland, USA. The system components include: 0.3 m^3 microscreen drum filter, 0.4 m^3 pump reservoir, 0.9 m^3 CO_2 stripper, 1.5 m^3 protein skimmer, 8 m^3 nitrifying moving bed bioreactor (MBB), 1 m^3 low head oxygenator, 0.6 m^3 pump reservoir, 0.15 m^3 conical sludge collection tank, 0.5 m^3 sludge digestion tank, 3 m^3 denammox fixed-bed up-flow biofilter, 0.02 m^3 biogas reactor with gas collection. Tank water was used to backwash organic solids from the microscreen drum filter.

Benefits of Recirculation

- Longer average life of tanks and equipment (versus nets, boats) allowing for longer amortisation periods. However, serious attention needs to be applied in building infrastructure for marine species due to highly corrosive atmosphere that ensues when trying to maintain optimum temperatures in a temperate / northern climate.
- Reduced dependency on antibiotics and therapeutants generate marketing advantage of high quality ‘safe’ seafood.
- Reduction of direct operational costs associated with feed, predator control and parasites.
- Potentially eliminate release of parasites to recipient waters.
- Risk reduction due to climatic factors, disease and parasite impacts - provided the recirculatory system design has fully taken into account local climate, ambient air / water temperature conditions, incoming water treatment and bio-security.
- Head-starting species where it could be beneficial to lengthen the amount of time young ones are raised in recirculatory aquaculture system before being transferred to cages. This reduces the amount of time the fish are exposed to the risks of the ocean growing environment, as well as potentially reducing total production times by optimizing the growing conditions.
- Recirculatory aquaculture system production can promote versatility in terms of location for farming, proximity to market and construction on brown-field sites. However, they still need to be in close proximity to source water supplies and consideration needs to be given to local water quality and aesthetics since recirculatory aquaculture system farms resemble industrial buildings.

- Enable production of a broad range of species irrespective of temperature requirements; provided costs of temperature control beyond ambient are energy efficient.

- Enable secure production of non-endemic species.

- Feed management is potentially enhanced in recirculatory aquaculture system when feeding can be closely monitored over 24h periods. The stable environment promotes consistent growth rates throughout the production cycle to market size – provided the operator and recirculatory aquaculture system design has taken into account the diverse range of water quality management issues. Optimum environmental conditions promote excellent FCRs with some high value marine species achieving market size in 50% of time taken in sea cages.

- The advantages of recirculatory aquaculture system in terms of feed management assumes the operator has the capability to accurately control and record fish biomass, mortality rates and movements across the farm. Efficiency in these tasks becomes increasingly important with increasing farm size.

- Due to increased growth rates and superior FCRs that can be secured in recirculatory aquaculture system farms, energy savings related to feed use may partially compensate for increased energy costs associated with pumping and water purification.

- Exposure of stock to stress in recirculatory aquaculture system farms can be reduced with respect to some factors such as adverse weather, unfavourable temperature conditions, pollution incidents and predation.

Challenges of Recirculation

- Lack of suitably experienced recirculatory aquaculture system managers and operators. Former cage or hatchery managers are not necessarily sufficiently well qualified to operate commercial scale recirculatory aquaculture system farms without minimum 6-10 months training on the job. Poor awareness in terms of the broad range of water quality variables that require 24h in-line monitoring – especially in marine recirculatory aquaculture system.

- While recirculatory aquaculture system farms enable operators to avoid any release of particulate solid or dissolved nutrient waste into recipient waters it is questionable as to how many investors take this issue seriously or appreciate the costs of implementing waste management into the production programme.

- Investors in recirculatory aquaculture system technology, even those with aquaculture experience, generally know little about water quality control, sea water chemistry and waste management at the industrial scale. Equally, recirculatory aquaculture system technology suppliers often know little about aquaculture and / or have a weak biological background.

- Investors fail to prepare adequately when identifying an appropriate recirculatory aquaculture system technology package – hence the large number of commercial failures
- Conclusion about economic viability of a recirculatory aquaculture system project is often based on assumptions and variables related to expected market price, utilization of the waste stream, product quality, optimal and maximum densities achievable, energy costs and costs relating to depreciation and interest on loans. Some of these criteria are subject to change and where if assumptions are based solely on small pilot or research projects, then even greater caution is required.
- Production of species preferring warmer water (20-25 ^{0}C) can be advantageous both from a growth rate standpoint but also in terms of energy conservation.
- Species selection for recirculatory aquaculture system production is a critical issue. Irrespective of sustainability arguments for recirculatory aquaculture system production, the farm still needs to make a profit. Production of a commodity species in recirculatory aquaculture system which has to compete with the same product either imported or farmed using a lower production cost method requires serious risk assessment.
- Dependency on securing a premium price for a recirculatory aquaculture system farmed product justified by sustainability criteria may not always hold true. This is particularly so in terms of energy demand, energy source and associated carbon footprint.
- Reducing operational costs of recirculatory aquaculture system farms through utilisation of farm waste for value added products is perfectly feasible but is often over-played by developers. Recirculatory aquaculture system farm effluent takes the form of a mobile sludge and dissolved nutrient streams which can be readily recycled into value added products such as composts, micro-algae and polychaete worms. The management of recirculatory aquaculture system farm sludge is a very real issue which few developers seem to properly appreciate at the outset of the project.
- The utilisation of RAS farm waste for on-site energy production is also feasible and the potential contribution in trial studies indicates this approach could be useful. However, the investment in anaerobic digesters and equipment for conversion of gases to usable energy needs to be carefully balanced against the potential savings in power consumption.