



Recirculating Aquaculture Systems (RAS): Principles, Components and Applications in Sustainable Fish Farming

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ABSTRACT

Recirculating Aquaculture Systems (RAS) are an advanced method of fish and shellfish farming in which water is continuously collected, filtered, treated, and reused within a closed or semi-closed production system. In comparison with conventional pond-based and flow-through aquaculture systems, RAS allows fish to be cultured at high stocking densities while requiring very little water exchange, often less than 10% of the total system volume per day. This helps to reduce overall water consumption and minimize the release of aquaculture effluents into the environment. This article reviews the major components of RAS, including mechanical and biological filtration, aeration and oxygenation, disinfection, and waste management, along with their basic operating principles. The major benefits of RAS, such as efficient use of land and water, improved biosecurity, and reduced dependence on geographical and climatic conditions, are also discussed. However, the technology has certain limitations, including high initial investment, considerable energy requirements, technical complexity, and the possibility of rapid and serious losses in case of system failure. Overall, despite these economic and operational challenges, RAS has considerable potential as a sustainable aquaculture technology for increasing production and meeting the growing global demand for fish and other aquatic food resources.

KEYWORDS

Recirculating Aquaculture System, RAS, bio filtration, sustainable aquaculture, water quality management

Introduction

The global demand for fish and other aquatic food products is continuously increasing due to population growth and rising fish consumption per person. Aquaculture has become an important source of aquatic food and now contributes more than half of the fish available for human consumption globally (FAO, 2022). However, conventional aquaculture practices, including open pond culture and net-pen systems, are associated with several environmental and management problems. These include high water requirements, nutrient-rich effluent discharge, disturbance of surrounding ecosystems, disease transmission, and sensitivity to changes in environmental conditions (Ahmed & Thompson, 2019).

Recirculating Aquaculture Systems (RAS) have been developed as an alternative approach to address many of these limitations. RAS are controlled aquaculture systems in which culture water is continuously treated and reused through a combination of mechanical filtration, biological filtration, aeration, oxygenation, and other water-treatment processes. This technology allows fish to be cultured at relatively high stocking densities while reducing water consumption and environmental discharge (Timmons & Ebeling, 2013). Since RAS facilities can be established indoors and do not necessarily depend on nearby natural water bodies, production can be located close to major markets and population centres. This may reduce the distance required for transporting live fish and fresh products and can improve the efficiency of the production and supply chain (Martins et al., 2010).

Principles of RAS

The basic principle of a Recirculating Aquaculture System (RAS) is the continuous treatment and reuse of water to maintain suitable conditions for the growth and survival of cultured aquatic organisms. During feeding and metabolism, fish consume dissolved oxygen and release metabolic wastes, particularly ammonia, along with solid faecal matter. In an RAS, water from the culture tank is continuously circulated

through different treatment units, where solid wastes are removed, toxic nitrogen compounds are converted, carbon dioxide is reduced, and oxygen is replenished before the treated water is returned to the culture tank (Losordo et al., 1998; Timmons & Ebeling, 2013). Through this continuous circulation and treatment process, RAS can achieve very high water reuse, considerably reducing the requirement for fresh water compared with conventional flow-through systems (Martins et al., 2010).

The major water quality parameters that need to be carefully monitored and controlled in RAS include:

- Dissolved oxygen (DO): Maintained at suitable levels through aeration systems or the addition of pure oxygen to support fish respiration and biological filtration.
- Ammonia and nitrite: These toxic nitrogen compounds are controlled mainly through biological filtration, where beneficial nitrifying bacteria convert ammonia into nitrite and subsequently into the less toxic nitrate.
- Carbon dioxide (CO₂): Produced through fish respiration and microbial activity and removed using degassing or aeration units to prevent harmful accumulation.
- Total suspended solids (TSS): Fish faeces, uneaten feed, and other particulate materials are removed using mechanical filtration units such as drum filters, screen filters, or sedimentation systems.
- pH and alkalinity: Maintained within appropriate ranges because stable pH and sufficient alkalinity are essential for fish health and for the effective functioning of nitrifying bacteria.
- Temperature: Carefully controlled according to the cultured species because temperature directly influences metabolism, feeding activity, growth, oxygen demand, and overall production performance (Timmons & Ebeling, 2013).

Key Components of a RAS

A Recirculating Aquaculture System (RAS) consists of several interconnected units that work together to maintain suitable water quality and provide a healthy environment for cultured organisms. Each component performs a specific function, such as removing solid and dissolved wastes, maintaining oxygen levels, controlling gases, and reducing the risk of disease.

Culture Tanks: Culture tanks are the primary units where fish or other aquatic organisms are reared. They are commonly designed in circular or octagonal shapes to promote effective and uniform water circulation. The circular movement of water helps concentrate faecal matter and uneaten feed toward the central drain, making the removal of solid waste easier and improving the self-cleaning ability of the tank (Timmons & Ebeling, 2013).

Mechanical Filtration: Mechanical filtration is used to remove larger suspended particles, such as uneaten feed, faeces, and other solid materials, from the circulating water. Early removal of these wastes is important because their decomposition can increase the organic load and negatively affect water quality. Drum filters, screen filters, and settling units are commonly used for this purpose. Continuous or regular operation of mechanical filtration helps prevent excessive accumulation of solids within the system (Timmons & Ebeling, 2013).

Biological Filtration (Bio filter): The biological filter is one of the most important components of an RAS because it controls toxic nitrogenous compounds produced from fish metabolism and waste decomposition. Beneficial nitrifying microorganisms convert ammonia first into nitrite and then into nitrate through the nitrification process. Different types of biofilters are used in RAS, including moving bed biofilm reactors (MBBR), trickling filters, and fluidized-bed filters. Effective biofiltration is essential for maintaining safe ammonia and nitrite concentrations in the culture water (Ebeling & Timmons, 2012).

Aeration and Oxygenation: High stocking densities in RAS can result in considerable

oxygen consumption by fish and microorganisms. Therefore, maintaining an adequate dissolved oxygen concentration is essential for fish health, growth, and proper functioning of the biofilter. Aeration devices, diffusers, oxygen cones, and pure oxygen injection systems may be used to supply additional oxygen when normal aeration is insufficient (Timmons & Ebeling, 2013).

Degassing Units: Carbon dioxide (CO₂) is continuously produced through the respiration of fish and microorganisms and can accumulate in a recirculating system. Excessive CO₂ concentrations can negatively affect fish respiration and overall performance. Degassing units are therefore used to remove excess CO₂ from the water. Packed-column degassers, cascade aerators, and other gas-exchange systems are commonly used for this purpose (Timmons & Ebeling, 2013).

Disinfection: Disinfection systems help reduce harmful microorganisms and improve biosecurity within RAS facilities. Ultraviolet (UV) irradiation and ozone treatment are commonly used to reduce pathogen and microbial loads in the circulating water. When properly designed and operated, these systems can improve water quality and reduce disease risks without leaving the same type of persistent chemical residues associated with some conventional disinfectants (Summerfelt, 2003).

Sludge and Waste Management: Solid wastes collected by mechanical filtration systems need to be regularly removed and properly managed. The collected sludge can be dewatered and either disposed of safely or further processed for beneficial uses, such as soil amendment or agricultural fertilizer, depending on its composition and local regulations. Proper waste management reduces environmental impacts and can contribute to circular approaches in aquaculture by recovering useful nutrients from aquaculture wastes (Martins et al., 2010).

Advantages of RAS

Recirculating Aquaculture Systems (RAS) offer several important advantages over conventional aquaculture systems. These

benefits are mainly related to efficient water use, better environmental control, biosecurity, and higher production efficiency.

Water Conservation: One of the major advantages of RAS is the efficient use of water. Since water is continuously treated and recirculated, only a small quantity of new water is generally required to replace losses and maintain water quality. Depending on system design and management, RAS can reuse a very high proportion of the available water, making the technology particularly useful in areas where freshwater resources are limited (Badiola et al., 2012).

Improved Biosecurity: RAS provides a more controlled production environment than open aquaculture systems. Because the culture water is treated and the system has limited contact with external water sources, the introduction and spread of pathogens, parasites, and other unwanted organisms can be reduced. This makes RAS suitable for controlled production and health management, particularly for valuable fish species (Martins et al., 2010).

Better Environmental Control: Important environmental conditions such as temperature, dissolved oxygen, pH, water chemistry, and photoperiod can be monitored and adjusted according to the requirements of the cultured species. As a result, fish can be maintained under relatively stable conditions throughout the year, with less dependence on seasonal and external environmental changes. This can support consistent growth and production performance (Timmons & Ebeling, 2013).

Efficient Use of Land: RAS allows fish to be cultured at relatively high stocking densities, resulting in greater production from a comparatively small land area. This makes RAS especially useful where suitable land for conventional ponds is limited or expensive. Vertical and indoor production approaches can further improve the efficiency of land use (Badiola et al., 2012).

Flexible Location of Production: Unlike many conventional aquaculture systems, RAS facilities do not necessarily need to be located near large natural water bodies. They can be

established close to cities, markets, or processing facilities. Producing fish closer to consumers can reduce transportation requirements, shorten distribution time, and potentially improve product freshness (Martins et al., 2010).

Better Effluent Management: In RAS, waste products are concentrated and removed from the circulating water rather than being continuously released into the surrounding environment. Solid waste and nutrient-rich water can therefore be collected, treated, and, where appropriate, reused or further processed. This provides opportunities for better nutrient recovery and contributes to more sustainable and circular aquaculture practices (Martins et al., 2010).

Challenges and Limitations

Although RAS provides several environmental and production benefits, its operation also involves significant technical and economic challenges.

High Initial Investment: The establishment of an RAS facility requires considerable initial investment. Costs are associated with culture tanks, pumps, mechanical and biological filtration units, oxygenation equipment, monitoring instruments, buildings, and control systems. Therefore, the initial investment can be substantially higher than that required for some conventional aquaculture systems (Badiola et al., 2012).

High Energy Requirement: RAS depends on continuous operation of pumps, aeration and oxygenation systems, filtration equipment, temperature-control units, and other electrical components. Consequently, energy consumption can represent a major part of operating costs. High energy demand may also increase the environmental footprint of RAS when electricity is generated from fossil fuels (Martins et al., 2010).

Technical and Operational Complexity: RAS is a highly integrated system in which the failure or poor performance of one component can affect the entire production process. Skilled personnel are required to monitor water quality, maintain biofilter performance, operate

mechanical equipment, and respond quickly to changes in dissolved oxygen, ammonia, pH, temperature, and other parameters (Timmons & Ebeling, 2013).

Risk of Rapid System Failure: Because fish are generally maintained at high stocking densities, any major failure of pumps, aeration, oxygenation, or electrical systems can rapidly deteriorate water quality. In particular, a prolonged power failure can cause oxygen depletion and may result in severe fish mortality within a short period. Therefore, backup power, emergency oxygen supply, alarms, and continuous monitoring are important components of RAS management (Martins et al., 2010).

Off-Flavor Problems: Off-flavor is another potential problem in RAS production. Compounds such as geosmin and 2-methylisoborneol (MIB) may be produced by microorganisms within the system and can accumulate in fish tissues, resulting in undesirable taste or odor. Depending on the severity of the problem, fish may require a depuration period in clean water before harvest to reduce these compounds and improve product quality (Timmons & Ebeling, 2013).

Applications and Species Suitability

RAS technology has been applied to the production of a wide range of freshwater and marine species. Common examples include Atlantic salmon (*Salmo salar*), tilapia (*Oreochromis spp.*), African catfish (*Clarias gariepinus*), barramundi (*Lates calcarifer*), and several ornamental fish species. The technology is used for different production stages, including hatchery operations, nursery rearing, broodstock management, juvenile production, and grow-out culture (Dalsgaard et al., 2013).

RAS has received particular attention in Atlantic salmon production, especially for land-based farming. The controlled conditions provided by RAS can reduce dependence on marine net-pen environments and help address concerns associated with sea lice, disease transmission, escapes, and nutrient discharge. RAS can also provide greater control over water

quality and production conditions, making it an attractive technology for intensive fish farming (Dalsgaard et al., 2013).

The suitability of a species for RAS depends on several factors, including its tolerance to high stocking density, oxygen requirements, growth rate, temperature preference, feeding behaviour, market value, and ability to adapt to controlled culture conditions. Therefore, RAS is not equally suitable for every species, and system design should be matched to the biological and production requirements of the target species (Timmons & Ebeling, 2013).

Conclusion

Recirculating Aquaculture Systems (RAS) are an important technological development in modern and sustainable aquaculture. These systems support intensive fish production while reducing water consumption, improving biosecurity, and providing better control over environmental conditions compared with conventional aquaculture methods. However, the high initial investment, considerable energy requirements, and need for skilled management continue to limit their wider adoption. Recent developments in efficient filtration systems, automation, monitoring technologies, and the use of renewable energy are helping to overcome some of these limitations and improve the overall feasibility of RAS. With the increasing demand for seafood and growing pressure on land and water resources, RAS has strong potential to become an important part of future sustainable aquaculture, particularly in areas where water and suitable land are limited.

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