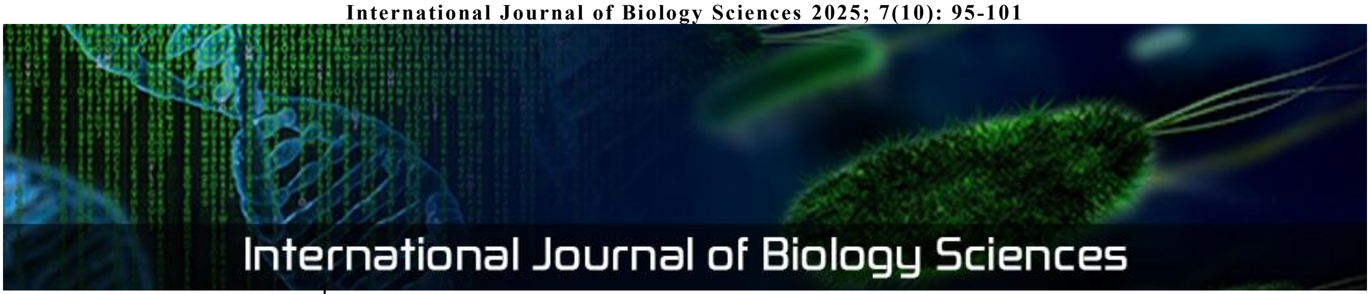
International Journal of Biology Sciences 2025; 7(10): 95-101



ISSN Print: 2664-9926
ISSN Online: 2664-9934
NAAS Rating (2025): 4.82
IJBS 2025; 7(10): 95-101
www.biologyjournal.net
Received: 08-07-2025
Accepted: 11-08-2025

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A Review of Re-circulatory Aquaculture System (RAS): Technologies, Challenges and their Scopes

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DOI: https://www.doi.org/10.33545/26649926.2025.v7.i10b.502

Abstract
The decline in capture fisheries raises the importance of culture fisheries sector. Aquaculture contributes greatly in food sector by compensating the rising demand. Particularly, Re-circulatory Aquaculture System (RAS) attracts significant attention due to its various benefits. RAS offer ways to enhance waste management, recycle nutrients, and use less water. Fish farming can be made environmentally sustainable through RAS. Thus, the purpose of this chapter is to provide an overview about RAS technology, system design, types, recent RAS developments along with scopes and challenges. The primary problems with RAS needs to be examined in order to provide farmers with improved solutions in the future. Potential areas for improvement and upcoming obstacles for the sector should also be noted for future research works.

Keywords: Aquaculture, Design, Filters, Fish growth, Recirculation

Introduction
Aquaculture is the world's fastest expanding food supply sector, contributing to global, regional, and local food security. Between 1990 and 2020, total global aquaculture output increased by more than 600%, with an average annual growth rate of 6.7%. The industry has a low carbon footprint as well as high protein and energy retention. Aquaculture's function in providing a healthy, lean protein source for the world's rising population is critical. Aquaculture's major mission is to efficiently supplement wild-caught fish options in order to improve the amount of seafood available globally. Recirculating aquaculture systems are a novel approach to fish farming. Rather to the usual way of rearing fish outdoors, this approach raises fish in large numbers in indoor tanks with a managed environment (Schaechter, 2009) [25]. Recirculating Aquaculture Systems (RAS) are intensive, typically indoor tank-based systems that accomplish high rates of water re-use through mechanical, biological, and chemical filtration, as well as other treatment stages. Aquatic species can be cultivated outside of their typical climatic range owing to precise environmental control, allowing operators to select production goals based on market, regulatory, or resource availability criteria. RAS technology can be useful when ideal sites are unavailable, when land or water space is limited, when water is in short supply or of poor quality, when temperatures are outside the optimum species range, or when the species is exotic, and when environmental regulation requires greater control of effluent streams and biosecurity (Murray *et al*. 2014) [20]. Additionally, the use of RAS technology enables the production of a variety of seafood products in close proximity to markets (Schneider *et al*. 2010), thus lowering the negative trade deficits associated with seafood imports from the EU and the carbon dioxide (CO_2) emissions linked to food transport (Martins *et al*. 2010) [18].

The necessity to make better use of the region's scarce water resources motivated the early scientific study on RAS, which was carried out in Japan in the 1950s and focused on biofilter design for carp production. In addition to these initiatives, scientists from Europe and the United States tried to adapt technology that was initially created for the treatment of home waste water (such as the sewage treatment activated sludge process, submerged and down-flow biofilters, trickling and various mechanical filtration systems). These early initiatives included study on marine systems for the production of fish and crustaceans. The majority of investigations, to the exclusion of other significant excretion difficulties, concentrated solely on the oxidation of harmful inorganic nitrogen wastes arising from protein metabolism, notwithstanding the pioneers' strong trust in the commercial potential of their work (Murray *et al*. 2014) [20]. Even though more nations are implementing RAS technology and despite its environmental benefits, it still contributes less to production than mariculture, flow-through systems, or ponds. The substantial initial capital expenditures required by RAS are a contributing factor in the slow acceptance of the technology (Martins *et al*. 2010) [18]. To be able recover investment expenses, high stocking densities and productivity are necessary. Concerns about welfare may consequently develop (Martins *et al*. 2005) [17]. However, RAS may also contribute to increased welfare because it is possible to keep a steady water quality (Roque *et al*. 2009) [23]. Thus, it is clearly understood that RAS is getting increased attention in more countries. Considering its importance, this chapter aims to summarize about RAS system design, operation, types along with future scope and challenges.

RAS Equipments

A) Tanks

The size of the aquarium is determined by the density of the fish. Three kinds of tanks are frequently utilized for RAS.

1. **Circular tank**: The culture of fingerlings and broodstock is dominated by a circular pattern. In the ras industry, the round tank is dominated by its hydrodynamic nature and natural structure. Stronger fiberglass or thin polyethene plastic are used to build the tank's walls. Its center bottom slopes, making it easy to remove solid trash.
2. **Rectangular tank**: Rectangular tanks are 20% more space-efficient and easier to harvest than circular tanks. Nevertheless, this tank's solid waste circulation is subpar. Waste particles accumulating on the tank floor cause a problem with the water quality. Thus, these waste particles are removed using the aeration system.
3. **Raceway tanks**: In marine culture, this kind of tank is frequently observed. Along the tank's length, a third wall is positioned to help regulate the water's circulation. Among the three tanks, it is the best.

B) Circulation units

The water pump or air blower that circulates the water in tanks is the main energy-consuming component of the RAS system. If this unit fails, there will be serious water issues. Airlift, axial flow, and centrifugal pumps are the three main pumping system types utilized in tanks (Tucker and Robinson, 1990) [30].

C) Carbon Dioxide Removal unit

A significant amount of carbon dioxide gas is produced by bacteria and fish in poorly managed RAS systems because carbon dioxide is much more soluble than oxygen. The high concentration of CO_2 causes the pH level to drop and the nitrifying bacteria to perform less effectively, which raises the ammonia level. CO_2 must be removed for improved production, and this is accomplished using either a blown air system or unpressurized packed columns (spray tower).

D) Solids removal

Fish, crustaceans, and other aquatic organisms expel solid waste after feeding. These solids disintegrate into fine particles that encourage the growth of bacteria, affecting the water's quality and odor. Swirl separators, screen filters, bead filters, sedimentation, and double drains are used to remove waste solids.

E) Biological filters unit

This unit uses bacterial action to aid in the disposal of solid waste. Dissolved organic material, including sugar, carbohydrates, fats, and proteins, that are expelled by aquatic culture organisms must be removed by the biofilter unit. The process of nitrification involves bacteria that are grown on filters in suspension or fixed-film attachment form, converting ammonia (a poisonous form of nitrogen) in the water into nitrate (a harmless form). A variety of filters, including rotating bio contactors, mixed bed filters, trickling filters, and fluidized bed filters, are used to remove waste from water (Luo *et al*. 2014) [16].

F) Aeration (oxygen addition) unit

The oxygen is transferred into the water by this device. Oxygen's limited water solubility makes it a limiting element in species culture. A colder RAS system operates at an oxygen concentration of 8 ppm, while a warm water RAS system operates at 5 to 6 ppm. Because fish and bacteria constantly demand oxygen, it is one of the most important components of the RAS system. If this unit is interfered with, cultured fish will completely die. Airstone diffusers, packed columns, down-flow contactors, low head oxygenators, U-tubes, and other devices are used to aerate the tanks (Lin *et al*. 2003) [14].

G) Disinfection unit

It is an essential recirculation process. This unit is primarily needed when there is a high risk of sickness and the stock is extremely valuable. A significant loss in output results from the frequent infection of water sources, fingerlings, and new stock with bacteria or other microbes. Water must therefore be disinfected, which is accomplished via ozone treatment and UV light because it is simple to install and use. UV radiation is mostly utilized for disinfection.

Types of filtration

1. Mechanical filtration

The only workable way to remove suspended organic and inorganic wastes from fish tanks is to mechanically filter the water that exits the tanks. The prepared diet given to the cultured animal is the source of nearly all solid wastes in RAS. The water quality may deteriorate as a result of the waste's long-term accumulation, stressing the animal. The partial gill suffocation and the increased growth of microorganisms that live in the suspended particles are the direct and indirect causes of this stress. Particularly concerning is the rise in biological oxygen demand that occurs as bacteria break down solid waste. In serial filtering design, the removal of this kind of waste is typically the initial step and is crucial to the process overall.

2. Drum filters

The design of the drum filter, which is by far the most often used kind of micro-screen, guarantees the delicate removal of particles.

Working principle of the drum filter

1. The drum receives the water to be filtered.
2. The filter components in the drum filter the water. The filtration process is powered by the difference in water levels inside and outside the drum.

3. The drum rotates, trapping solids on the filter components and lifting them to the backwash area.
4. Water from rinse nozzles is sprayed from the outside of the filter elements. The rejected organic materials are washed out of the filter elements into the sludge tray.

The sludge flows together with water by gravity out of the filter, escaping the fish, for external wastewater treatment.

The benefits of micro-screen filtering are as follows

- As suspended particles are eliminated from the water, the biofilter's organic load is decreased and the water becomes cleaner.
- Because the biofilter doesn't clog, the nitrification conditions are improved.
- The biofiltration processes are stabilized.

3. Rapid Sand Filters

A relatively simple and affordable way to remediate tainted water is using sand filtration. Sand filtration creates clean water that is completely safe for fish by using the filtering qualities of sand. Furthermore, this procedure is one of the finest options for water treatment for recirculating aquaculture systems because it requires little to no chemicals, replaced parts, or even little operator training, and it only requires a small amount of periodic maintenance. The water is usually allowed to flow through a bed of sand during this procedure, which causes the bigger suspended particles to sink to the upper layers of sand. Bacteria and other tiny creatures "stick" to the slime layers that form around the sand particles and consume the smaller organic sediment particles that are left in the sand filter. It is safe to reuse the clean water that goes through the filter.

4. Biofiltration

The finest particles will pass through the mechanical filter along with dissolved substances like nitrogen and phosphate, thus not all of the organic matter is eliminated. While nitrogen in the form of free ammonia (NH_3) is hazardous and must be converted into a non-toxic form in the bio-filter, phosphate is an inert chemical that has no harmful effects. Bacteria in the bio-filter carry out the biological process of breaking down organic waste and ammonia. Through the use of oxygen and the production of carbon dioxide and ammonia, heterotrophic bacteria oxidize or break down organic materials. Ammonia is changed by nitrifying bacteria into nitrite and then nitrate.

Usually made of plastic media, bio-filters or bio-balls have a large surface area per milliliter. The bacteria will cover a very big surface area on the media by growing as a thin layer. A well-designed biofilter should have a high surface area per cubic meter without being packed so densely that the organic stuff it is filtering won't block it. Therefore, a high percentage of free area for water to flow through, a decent overall flow through the bio-filter, and an adequate backwash method are all crucial. Depending on the load on the filter, these back-wash processes need to be performed at appropriate intervals, once a week or once a month. Organic debris is torn from the filter by causing turbulence with compressed air. Before the biofilter is reconnected to the system, the soiled water inside is drained and released. The biofilter is shunted during the washing process.

Design of Ras

Aquaculture systems created by RAS are infinitely scalable. Because waste streams can be managed in an environmentally responsible manner, there are no environmental restrictions on the size of the planned fish farm. Most likely the only feasible method that could be used is indoor aquaculture (Ebeling and Timmons, 2012) [8]. Large-scale production systems (above 1 million pounds annually), intermediate-sized systems (500,000 pounds annually), and small systems (50,000 pounds annually) are the different sizes of RAS. They can be used as hatcheries to produce eggs and fingerling sport fish for stocking and aesthetically pleasing fish for home aquariums, or they can be used as grow-out systems to produce food fish.

The ratio of recycled water to waste water which is more often expressed as the percentage of recycled water in the inflow water of the fish tank is an important design parameter. By recycling, say, 50% of the water flow and treating the water with simple solids removal and re-aeration technology, farm productivity can be usefully increased. More advanced and effective treatment methods are needed as the proportion of recycled to fresh water rises, which will have an impact on capital and operating expenses. Recirculated to replacement water ratios must typically be high (at least 95–99%) if biosecurity, complete control over environmental conditions, or minimal nutrient discharge to neighboring waters are the driving forces behind the use of RAS.

The water replacement rate, which is typically expressed as a percentage of the system volume changed daily, is a related indicator of water reuse. Around 1.2 times the volume of the tanks will be required in new inflow water over the course of 24 hours if, for example, a system has a 95% recirculated flow at a rate that effectively replaces the full volume in the tanks once per hour (120% replacement rate). With the same system, 99.8% of the tank discharge would be treated and returned to the inflow at a replacement rate of 5% per day (Timmons *et al*. 2002) [29].

According to Helfrich and Libey (1991) [9], a growing tank, sump of particulate removal device, biofilter, oxygen injection with U-tube aeration and water circulation pump are the common functional parts of a RAS. A water heating system might be required, depending on the fish species chosen and the water's temperature. Reducing organic and bacterial loads may also benefit from ozone and UV sterilization. The system engineering in RAS includes several unit processes where are shown in Fig. 1. From the central fish culture tank, the water is circulated through a series of systems that remove suspended and settleable waste solids, remove fine and dissolved solids, change ammonia into nitrate, take out carbon dioxide and add oxygen, and, if necessary, disinfect the water before reintroducing it to the culture tank. All of these procedures are managed by the monitoring and control system, which also sets water quality set points and sounds an alarm when they deviate from allowable bounds. To avoid losses from external disease introduction, a biosecurity program and procedure must be strictly applied to the entire farm and process.

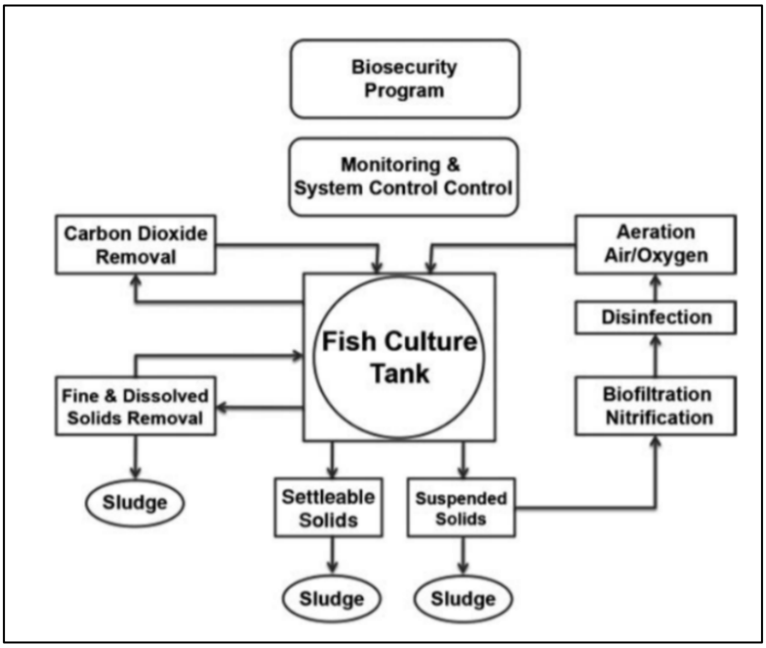

Fig 1: Unit processes in a Recirculatory Aquaculture System

New developments in RAS

The most important factor that contributes to developmental stages in RAS is feed. Feed is having a greatest impact in framing and expanding RAS technologies. Research on feed development's connection to the aquaculture industry's increased sustainability is ongoing. Reducing the feed conversion ratio (FCR) is the first step towards lessening the environmental effects of aquaculture systems. In a trout farm, a 30% decrease in FCR translated into a nearly 20% reduction in the environmental impact worldwide, excluding energy use (d'Orbcastel *et al*. 2009) [6]. The RAS offers year-round ideal environmental conditions, enhances fish welfare, and reduces the FCR, which increases feed efficiency (Losordo, 1998) [15]. If feed digestibility does not decline, feed impact on the environment can also be minimized by selecting low trophic level and locally sourced ingredients (e.g., proteins and lipids from phytoplankton instead of fish).

Apart from feed, waste treatment in RAS attracts attention. RAS waste water possesses a flow rate that is 10–100 times lower and 10–100 times more concentrated (Blancheton *et al.,* 2007) [3]. This makes treatment easier and more affordable. The environmental impact of converting flow-through trout farms into RAS, including waste management, was also demonstrated by Pedersen *et al*. (2008) [22]. The removal efficiencies in RAS ranged from 85% to 98% for suspended solids and organic matter, and from 65% to 96% for phosphorous. Lower TSS removal efficiency values have also been reported. Davidson and Summerfelt (2005) [7] reported 40–45% removal with drum filter. In another study, 22% removal with drum filter and 66% removal by swirl separators were reported by Couturier *et al*. (2009) [5]. Various treatment processes and setups were being implemented in both freshwater and marine aquaculture farms. A series of water treatment units at various locations were implemented at all the farms in order to obtain (1) sludge with more than 15% dry matter, which can be valorised as fertilizer directly or after composting, (2) supernatant water from the backwash water tank, which can be treated through constructed wetlands, thereby alleviating the load of suspended solids and the biological oxygen demand, and (3) filtered water (recirculating water low in suspended solids) that returns to the fish tanks. Filtered water from flow-through systems is typically not treated. However, total ammonia nitrogen (TAN) concentrations can rise to levels that demand treatment based on fish biomass, water flow rate, and regulatory measures. Due to the high water flow rate (50–100 m3/kg fish produced) and low nutrient concentrations (e.g., approximately 1 mg TAN/L) in the effluent, this presents a significant economic challenge (Metaxa *et al*. 2006) [19]. Enhancing waste management and collaborating with extractive species cultures could potentially mitigate the ecological consequences of fish farms. The answer might lie in integrated multi-trophic aquaculture (IMTA), in which the waste products (by-products) of one species are used as inputs for other co-cultured species (Hussenot, 2006) [10].

Wetlands and algal ponds have drawn a lot of attention lately as RAS water treatment units since they aid in the system's water reuse. The medium strength municipal waste water that is typically treated in artificial wetlands is 20–25 times more diluted than the wastewater from fish tanks, ponds, or raceways (Vymazal, 2009) [31]. After the wastes are concentrated, wetlands are primarily used to treat aquaculture effluents, and at that point, they are regarded as an affordable and practical biological treatment method (Sipaúba-Tavares and Braga, 2008) [28]. The effluent from an intensive African catfish operation was treated directly by passing it first through carp ponds and then through ponds that had been turned into wetland (Kerepeczki *et al*. 2003) [12]. Removal rates of TAN, PO_4, and organic suspended solids in this pond-wetland system were found to be above 90%, while those of inorganic nitrogen compounds, TN, and TP, were found to be between 65% and 80%. 38% of the NO_3 was removed. The kind of sediment and the type of plants present have a significant role in how well artificial wetlands are treated. Compared to plants that form fibrous roots, rhizome-forming plants are less effective at eliminating TAN and NO_3 (Cheng *et al*., 2009) [4]. According to Naylor *et al*. (2003) [21], plants primarily influence the removal of organic matter and N species, whereas sediments like limestone or steel slag are great at removing P. Compared to concentrated effluents, the nutrient removal efficiency of nonconcentrated aquaculture effluents in constructed wetlands is typically lower. Using a hydraulic retention time of 7.5 hours, trout raceway effluents in a constructed wetland had an average removal of 68% of COD, 58% TP, and 30% of TN (Schulz *et al*. 2003; Schreier, 2010) [26] [27].

RAS-suitable species

- Cobia (Rachycentron canadum) and baramundi/Asian seabass/bhetki (Lates calcarifer)
- Pearl spot/Karimeen (Etroplus suratensis), tilapia (Oreochromis niloticus), and silver/Indian pompano (Trichinotus Blochii/Trichinotus mookalee)
- The pangasius, also known as pangasianodon hypophthalmus,
- Rainbow trout (Oncorhynchus mykiss), particularly in areas with hills and cold water

There are numerous considerations that determine whether raising a particular species of fish in recirculation is appropriate, including biological suitability, environmental issues, and profitability. Various fish species have been categorized in the tables below based on whether it is commercially feasible to raise them in a recirculating system. Recirculation is always advised for small fish since they grow more quickly and are therefore better suited to a regulated environment until they are large enough to continue growing.

A number of criteria, including biological suitability, environmental concerns, and economics, influence the species' selectivity for culture in RAS tanks. Since small fish grow more quickly and their environmental conditions can be readily managed until they reach their ideal size, small fish are always advised for RAS (Zhang *et al*. 2011; Saran Kumar, 2023) [24] [32]. Fish species are divided into many groups based on their commercial viability of growth, which are explained below:

Following fish have excellent biological performance and acceptable market condition

Common name	Scientific name	Optimum temperature for survival
Arctic char	*Salvelinus alpines*	14 °C
Atlantic salmon	*Salmo salar*	14 °C
Eel	*Anguilla Anguilla*	24 °C
Grouper	*Epinephelus spp*	28 °C
Rainbow trout	*Oncorhynchus mykiss*	16 °C
Seabass / Seabream	*Dicentrarchus labrax /Sparus aurata*	24 °C
Sturgeon	*Acipenser spp.*	22 °C
Turbot	*Scophthalmus maximus*	17 °C
Whiteleg shrimp	*Penaeus vannamei*	30 °C
Yellowtail amberjack	*Seriola lalandi*	22 °C

Challenges And Future Scope

A significant reported limitation of RAS pertains to the requisite investment and the extended pay-back durations, which typically span eight years. Generally, RAS are not economically viable; "encouraging technology" is inevitable, but there needs to be a good reason, considering the system from an overall "market-need" perspective, which guarantees technical feasibility as a precondition for being economically viable. In order to plan a reasonable and attainable production goal and meet the actual demand, a thorough market or social research is required. Thus, low operating costs come in second and dependable operation is the first requirement. In order to recover from the initial investment more quickly, both requirements must be met: the first must result in stable production and profits; the second must offer a larger margin for return (Badiola *et al.,* 2012) [2]. Other suggestions include less use of energy in RAS. For example, less energy will be required if the pumping head is reduced and the biofilter performs better (Jokumsen and Svendsen, 2010) [11]. Recovering wastewater from the drum filter backwashing, for example, by employing flocculants will lessen the quantity of intake water, minimizing the effect on the environment and pumping expenses. Next, the addition of new technologies can minimize the challenges for a successful raceway system. Creation of new compartments for aquaponics and algae farming in order to reduce environmental output, maximize nutrients and detritivores by utilizing produced byproducts like carbon dioxide and produce secondary products that become a significant economic input. Further, Azim and Little's (2008) [1] proposed that the application of hybrid technology with biofloc and RAS will increase the functional profit. A more recent study revealed that by lowering the feed cost, biofloc technology could contribute to the economic and environmental sustainability of RAS (Kuhn *et al*. 2009) [13]. Thus, proper knowledge about RAS should be disseminated to gain potential candidates. The systems are complicated since it takes a lot of knowledge to understand how they should be operated in a given situation; their performance depends on a number of parameters that depend on each other. According to the participants in the interviews, those in charge of overseeing recirculation systems should receive functional skill training as part of university curricula, as well as additional practice or internships in research and/or participatory production firms.

Advantages

- Increased longevity of equipment and tanks
- The benefit of obtaining high-quality fish is the decreased reliance for antibiotics and other medications.
- Decrease in direct operating expenses related to parasites, feed, and predator control.
  Eliminate the possibility of parasites leaking into recipient waters.
- Risk decrease as a result of disease, parasites, and climate factors
  RAS production can encourage flexibility in terms of farming location and market accessibility.
- Allow a wide variety of species to be produced regardless of temperature requirements.
- The ability to closely monitor feeding for a full day significantly improves feed management in RAS.
- Predation, unfavorable weather, unfavorable temperature, and external pollution are some of the elements that can lessen the exposure of stock to stress on RAS.
- Allow for the safe production of non-endemic species.
- Make judicious use of land and water resources.
- Has a lower water requirement than ponds.
- It can be found in additional places.

- Its intensity is high (culturing more fish in a smaller area), and it is highly environmentally friendly.

Disadvantages
- A steady, uninterrupted power source is necessary; in the event that the electric power fails, a backup supply of electricity is needed.
- Starting a recirculating aquaculture system requires more capital than ponds or raceways.
- Component failure, poor water quality, stress, and illnesses are prevalent in poorly maintained.
- RAS systems. All of these things need to be maintained by experts.
- A catastrophic loss of fish in RAS could result from an electrical failure.
- Chemicals used to treat illnesses have the potential to harm biological filters.
- Setting up new RAS technology requires a large initial capital commitment.

Conclusion
The most likely and practical way to meet the growing market demand for aquatic products is through aquaculture. It offers a consistent and dependable supply of fresh seafood that is safe to eat, wholesome, and reasonably priced. Many experts predict that intensive fish farming will be the future trend in the aquaculture sector. RAS provides an efficient solution to overcome the demand in food supply chain. It is eco-friendly and can be placed in different locations. Considering this, a detailed review on RAS system, design, types, operation, challenges and scope were provided in this chapter. Even though RAS technology provides success, still there are shortcomings associated with capital cost and production strategies. This should be addressed with better solutions in future studies.

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