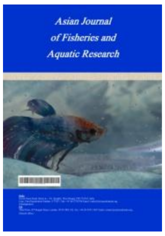

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Relevance of Water Recirculating System in Modern Aquaculture

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

The review of water recirculation in aquaculture practice presents the reality and benefits of a developed system for effective water re-use with optimum water quality, for intensive fish production. This advanced mechanism of adequate water re-use proves its relevance as it provides for intensive fish production, conservation of available water, conservation of available space, ease in site location, flexibility to locate production facilities near large markets, quick and effective disease control, complete and convenient harvesting, species and harvest diversity especially where available water for culture purpose is limited (considering how water intensive aquaculture is), and salvaging endangered species. The practice of recirculating aquaculture through Recirculating Aquaculture systems needs basic orientation for fish farmers especially in developing aquaculture practice areas, since it can be carried out at different intensities. Recirculating Aquaculture System is hence an optional technology for farming aquatic organisms that should be encouraged.

Keywords: Water; re-use; aquaculture; farming; fish; technology.

1. INTRODUCTION

There are three basic categories of culture systems: open, semi-closed and closed systems. Open system culture refers to fish farming either in natural bodies of water such as oceans, bays, estuaries, coastal lagoons, lakes or rivers. Semi-closed systems are those in which the culture

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water makes one pass through the system and is discharged. These are referred to as flow-through or once-through systems. The raceway falls into this category. Closed systems are those where the water is reconditioned and recirculated to culture units. These systems are also called the closed recirculating systems [1]. The closed recirculating systems is a mechanism for water recirculation and re-use. Water recirculation aquaculture is essentially a technology for farming of fish or other aquatic organisms by reusing the water in the production circle. 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 [2]. Recirculation technology is however primarily used in fish farming, and it is growing rapidly in many areas of fish farming sector, and systems are deployed in production units that vary from huge plants, generating many tones of fish per year for consumption to small sophisticated systems used for restocking or to save endangered species [3].

Aquaculture is faced with certain challenges concerned with how to successfully sustain a production, control the culture environment and maintain economic value, amidst the resulting competition for space, other resources, especially tolerable water physico-chemical parameters. These challenges are being met by tactically intensifying the culture processes and operations. The tendency to intensify the fish culture in a recirculating aquaculture systems (RAS), like other agricultural projects is an attempt to obtain higher yields for a given critical resource, which is water [4]. Aquaculture effluents contain various constituents that could cause negative impacts when released into the environment. The constituents include dissolved or particulate organics, and the impact on the environment depends on the amount, concentration, and the assimilative capacity of the environment for the particular constituent [4]. RAS is an effective and an environmentally friendly aquaculture method. This is because the RAS water treatment process is designed to minimise water requirements which leads to small volume of effluents. The effluents are accumulated into a sedimentation basin or tank which will facilitate treatment before discharging to the environment [4]. Water recirculation can be carried out at different intensities depending on how much water is recirculated or re-used. Some farms have 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 recirculating systems using around $3m^3$ new water per kilo of fish produced in a year [5]. Growing public demand for a healthy, tasty and affordable food is stimulating the boom in this industry, as the decline in wild fish populations resulted from over harvesting and increased water pollution has promoted the culture of farmed fresh fish that are grown in contaminant free in indoor tank systems [6].

RAS represents a new and unique way of farming. Instead of the traditional method of growing fish outdoors, in open ponds and raceways, this system rears fish at high intensities in indoor tanks with a controlled environment [6]. Recirculating systems filter and clean the water for recycling back through fish culture tanks. New water is added to the tanks only to make up for splash out and evaporation and for the water used to flush out waste materials. In contrast, many raceway systems used to grow Trout are termed ‘open' or ‘flow through’ systems because all the water makes only one pass through the tank and then is discarded. [6,7].

RAS has been developed for fish culture since the 1960’s. The application of RAS for commercial finfish production became more widespread between 1970 and 1980 [8]. However, during these years, many large commercial finfish producers that were using recirculating systems have also been notable in their failures [8]. Research and development to improve commercial recirculation systems continued and successful commercial systems have been reported [8]. Research on the development of RAS for commercial scale fish production has increased dramatically in the last two decades [9]. Researches have been done on unit process development and their integration into functional water re-use systems [8].

Fish grown in RAS must be supplied with the conditions necessary to remain healthy and continue growth. They need continuous supply of clean water at a temperature and Dissolved Oxygen (DO) content that is optimum for growth. A filtering (bio-filter) system is necessary to purify the water and remove or detoxify harmful waste products and uneaten feed. Fish must be fed a nutritionally complete feed on a daily basis to encourage fast growth and high survival rates.

The aim of this review is to provide knowledge and encourage intensive use of recirculating aquaculture systems for fish production especially even in draught areas with limited water resource. The review will also promote innovation in aquaculture, to reduce exploitation of wild fish resources, to increase abundance of fish resources for food and finally draw attention to RAS significance with relation to maximising concerned economies.

2. RAS COMPOSITION AND SIGNIFICANCE

A review on fish farming in RAS by Louis A. Helfrich and George Libey [10], and in the review by Jacob Brengballe's book on RAS, indicated that the functional parts of RAS include, but is not limited to the culture tanks, sump, oxygen injection chamber, and water circulation pump. Depending on the water temperature and fish species in question for culture, a water heating mechanism may be introduced.

2.1 Fish Culture Tanks in RAS

Fish can be grown in tanks of nearly every shape and size, though fish tanks are typically rectangular, circular, or oval in shape. Circular or oval tanks with central drains are somewhat easier to clean and circulate water through, than rectangular ones. Rectangular tanks are usually built with, or set upon inclined floors to facilitate cleaning and circulation.

Rearing tanks range in size from 500 to 500,000 gallons capacity. The size of the tank depends on a variety of factors including stocking rates, species selected, water supply, water quality, and economic considerations. The tank must be designed to correspond with the capacity of other components of the system, particularly size of the biofilter and sump, so that all parts of the system are synchronized.

Tanks can be constructed of either plastic, concrete, metal, wood, glass, rubber, and plastic sheeting, or any other materials that will hold water, not corrode, and are not toxic to fish. Smooth surfaces on the inside of the tanks are recommended to prevent skin abrasions and infections to the fish, and to ease cleaning and sterilisation.

Light weight, durable, plastic tanks are conveniently moved and readily cleaned when necessary, but they require special support to prevent stretching when filled with water. Stainless steel too is a good tank material, but it can be expensive. Marine-grade plywood tanks are inexpensive, but can leak if not properly sealed. They are not durable when compared with tanks of other materials. Concrete tanks may be the most economical to build, but they are relatively permanent and immovable structures once constructed. Concrete tanks can also leak with time, if building raw materials are not mixed with appropriate proportions during construction.

2.2 Biofilter Component of a RAS

The biological filter is the heart of the RAS. As its name implies, it is a living filter composed of a media (corrugated plastic sheets or beads or sand grains) upon which a film of bacteria grows. The bacteria provide the waste treatment by removing pollutants. The two primary water pollutants that need to be removed are fish waste (toxic ammonia compounds) excreted into the water and uneaten fish feed particles.

The biofilter is the site where beneficial bacteria remove (detoxify) fish excretory products, primarily Ammonia and nitrite which are toxic to fish. Ammonia in water occurs in two forms: ionized ammonium (NH_4^+) and unionized (free) ammonia (NH_3). The later (NH_3) is highly toxic to fish in small concentrations and should be kept at levels below 0.05mg/l. The total amount of NH_3 and NH_4^+ remains in proportion to one another for a given temperature and pH, and a decrease in one form will be compensated by conversion of the other. The amount of unionized ammonia in the water is directly proportional to the temperature and pH. As the temperature or pH increases, the amount of NH_3 relative to NH_4 also increases. In addition to ammonia, nitrite (NO_2) poisoning of fish is also an imminent danger in the RAS. In this case, Nitrite levels should be kept below 0.5 mg/l.

Ammonia is a poisonous waste product excreted by fish. Since fish cannot tolerate this poison detoxifying ammonia is fundamental to good water quality, healthy fish, and high production.

Detoxification of ammonia occurs on the biofilter through the process of nitrification. Nitrification refers to the bacterial conversion of ammonia (NH_3) to less toxic $N0_2$, and finally to non toxic NO_3. The process requires a suitable surface on which the bacteria can grow (biofilter medium), pumping and continuous flow of tank water through the biofilter, and maintaining normal water temperatures with good water quality.

Two groups of aerobic (oxygen requiring), nitrifying bacteria are needed for this job. Nitrosomonas bacteria convert NH_3 to NO_2 (oxidising toxic ammonia excreted by fish to less toxic nature), Nitrobacter bacteria convert NO_2 to NO_3 (oxidising toxic nitrite to largely non toxic nitrate).

Nitrification is an aerobic process and requires oxygen. For every 1 milligram of ammonia converted, about 5 milligrams of oxygen is consumed, and additional 5 milligrams of oxygen is required to satisfy the oxygen demand of the bacteria involved with this conversion [11]. Therefore, tanks with large numbers of fish, and production of large amount of Ammonia loads will require plenty Oxygen before and after the bio-filtration processes.

2.3 Sump Component of RAS

A sump is a low space that often collects undesirable liquids such as water or chemicals. In a RAS, the sump (clarifier tank) is used to prevent the excessive accumulation of fish excretory products and feed waste. Waste products increase the Biological Oxygen Demand (BOD), decrease the Dissolved Oxygen (DO) content, lower the carrying capacity (density of fish) that can be reared, and may result in off flavour in fish products. Accumulation and decomposition of waste material results in the production of toxic compounds such as (NH_4, NH_3, NO_2) and Hydrogen Sulfide (H_2S) that can be hazardous to fish health.

The clarifier tank is designed as a settling basin (large volume tank, with a slow flow rate to increase sedimentation). Its purpose is to concentrate and remove suspended solids (fish faeces, uneaten particles) before they clog the biofilter or consume valuable oxygen supplies. The clarifier should be a separate tank, isolated from the fish tank and the biofilter, so that it can be cleaned periodically (daily) as needed. To increase the efficiency of the clarifier, various filters (plastic filters, sand filters, metal screens) can be inserted into the Sump tank.

The size of the clarifier tank needs to be fully integrated with the size of the fish tank and biofilter, and also with the turnover rate of the system (pump size). The volume of the Sump and flow rates through the sump must be adjusted to maximise sedimentation of suspended particles.

2.4 Oxygen Management in a RAS

Successful fish production depends on good oxygen management. The addition of Oxygen in a pure form or as an atmospheric air (aeration) is essential to the survival (respiration) of fish held in high densities, the survival of aerobic nitrifying bacteria on the biofilter and for the decomposition (oxidation) of organic waste products. Supplying sufficient Oxygen to sustain healthy fish and bacterial populations and to meet the biochemical Oxygen Demand (BOD) for fish waste and unconsumed food is critical. Low Oxygen levels will reduce growth rate, feed conversion rates, and overall fish production.

The amount of Oxygen needed in RAS depends on a number of factors. Oxygen demand is directly correlated with the density of fish in the tanks, feeding rates, water temperatures, flow rates, and nitrification. It is also a function of physical conditions such as water temperatures and water volumes. Increasing Dissolved Oxygen concentrations through Oxygen injection, aeration, and increasing flow rates (turn over times) are ways to increase the density (carrying capacity) of fish that can be held in tanks of fixed size.

Atmospheric Oxygen can be added to the tanks by surface agitation with aerators or by large blowers. Surface aerators may not be cost effective or efficient in evenly distributing Oxygen throughout large commercial scale systems.

3. BENEFITS OF RAS

RAS offer fish producers a variety of important advantages over open pond culture. This makes fish farming interesting and convenient with considerable economic value from profit on sales return. These advantages include, but not limited to intensive fish production, conservation of available water and land (space), and ease in site/location selection. Others are fish species in ras, quick and effective disease control, complete and convenient harvesting.

a) Intensive Fish Production

It is predicted that more than an additional 40 million tonnes of aquatic food will be necessary by 2030 to maintain the current per capita consumption [12]. Producing more food from the same area of land while reducing the environmental impacts requires what has been called sustainable intensification [13]. RAS is an excellent alternative to open pond culture, where low densities (extensive culture) of fish are reared free, in large ponds, and are subject to losses from disease, parasites, predation, pollutants, stress, and seasonally sub optimal growing conditions.

RAS applies to the broiler house or swine barn concept, prevalent and effectively used in modern poultry and swine production systems. This encourages rearing large numbers of fish in a relatively small space. Indoor fish farming in tanks may revolutionalise fish production in the same way that confinement systems altered the swine and poultry farming industries.

b) Conservation of Available Water and Land (Space)

RAS conserves both water and land. They maximise production in a relatively small area of land and use a relatively small volume of water. For example, using a RAS it is possible to produce over 100, 000 pounds of fish in a 5,000 square foot building, whereas 20 acres of outdoor ponds would be necessary to produce an equal amount of fish with traditional open pond culture.

Similarly, since water is re-used, the water volume requirements in RAS are only about 20% of what conventional open pond culture demands. They offer a promising solution to water use conflicts, water quality and waste disposal. These concerns will continue to intensify in the future as water demands for a variety of uses escalate.

c) Ease in site/Location selection

RAS is particularly useful in areas where land and water are expensive and not readily available. They are most suitable for example in the northern areas of Nigeria, where a cold or cool climate can slow fish growth in outdoor systems and prevent or impede year round production. RAS provides growers for areas that are geographically disadvantaged because of a relatively short growing season (less than 200 days) or extremely dry (desert) conditions, a competitive, profitable, year-round fish production system.

They can be located close to large markets (urban areas) and thereby reduce hauling distances and transportation costs.

d) Fish Species in RAS

RAS are currently being used to grow catfish, stripped bass, tilapia, crawfish, blue crabs, oysters, mussels, and aquarium pets.

Indoor fish culture systems offer considerable flexibility to grow a wide diversity of fish species, rear a number of different species simultaneously in the same tank (polyculture) or different tanks (monoculture), raise a variety of different sizes of one or several species to another, depending on market demands or price.

RAS afford growers the opportunity to manipulate production to meet demand throughout the year, and to harvest at the most profitable times during the year. This flexibility in the selection of species and harvest time allows the grower to rapidly respond to a changing market place in order to maximise production and profitability. RAS permit the grower to competitively respond to market price and demand fluctuations by altering harvest rates and times and the species cultured.

e) Quick and Effective Disease Control

Disease control and pond management is easier in closed systems like RAS, since the culture environment is maintained at a high level of good hygiene practice. Generally in fish culture, the most common cause of disease is poor management practice.

f) Complete and Convenient Harvesting

Total harvest of fish in RAS is possible with little or no stress. Harvest could be graded based on fish size too, since even the harvest procedure is controlled and mechanised.

4. PRELIMINARY ECONOMIES FOR RAS

An investment in a commercial RAS farm has a similar level of risk and uncertainty as other fish farm enterprises that includes uncertain and risky operational characteristics, uncertain future market price, and uncertain input cost [12]. For RAS farms to be economical, they must produce a valuable fish. Currently, RAS are used to raise high value species, or species that can be effectively niche marketed, such as Salmon smolt, Yellow perch, Eel, Rainbow Trout, Wall eye, African Catfish, Channel Catfish and Arctic Charr. Marine RAS are being used to produce many species at both fingerling and table size fish including flounder, seabass, turbot, and halibut [13].

Financially, it is very important to have the accurate specification of all components because if the components are oversized, the system will function but not be cost effective. And for undersized equipment, the system will not be able to maintain the optimal environment for fish growth, resulting in lower production and financial loss [14]. It is very important for RAS farm operators to know the optimal environment for growth of the selected species, volume of market demand, size and shape of the fish product, required by the market and other factors that might influence and affect the farm operation [8].

A break even analysis can be carried out to determine the required quantity to cover production cost and required for profit and annuity payment. A simple break even analysis is the first measurement that could be made by using cost estimation and assumption of revenue [15]. However, the break-even analysis is not a formal method for measurement of profitability. The Net Present Value (NPV) assessment also enables comparison with alternative investments at different levels of risk [12].

Simulations of budgeting and assumption of revenue are used in evaluating investment opportunities. The likelihood of achieving profitability is estimated through obtaining a positive value of NPV [16]. The internal rate of return (IRR) is also used in profitability analysis. IRR is related to the NPV method since IRR is the rate when applied to the projected future cash inflows.

Finally, a sensitivity analysis can be used to determine how different values of independent variables such as cost of production, price, production quantity, and interest rate will affect the NPV, IRR and break-even quantity. Sensitivity analysis is used to predict the financial feasibility, if a situation turns out to be different from the assumption or estimation.

5. RAS AS A SUSTAINABILITY TRACK FOR AQUACULTURE

Some segments of the aquaculture industry are long overdue for reform. What is required is a paradigm shift in how we think about aquaculture, particularly its interaction with natural and social systems. This paradigm shift should be based on sustainable development. The management and conservation of the natural resource base, the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development conserves land, water, plant and genetic resources. Also, it is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable. In this case, sustainable aquaculture must consider the ecological, social, and economic aspects of development.

RAS is an alternative amidst other alternative factors to sustainable aquaculture includes ecological aquaculture, organic aquaculture, inland pond culture, polyculture, and integrated aquaculture. Concerns for water conservation and reduced waste discharges have prompted the increased use of closed RAS. RAS has less of an impact upon the environment because of their closed nature. In recirculating systems, wastes are filtered out of the culture system and disposed off in a responsible manner. Recirculating systems can be built just about anywhere, including in urban settings where they can use existing structures and be placed closed to markets, thereby reducing cost of transportation. Finally, RAS can be built to grow a wide variety of fish species year round, more-over in controlled environments.

6. CONCLUSION

In order for aquaculture to develop into an environmentally and socially responsible food production endeavor, more efforts should be made to improve RAS, and other closed and low discharge systems. Transition to the use of more closed systems and low discharge systems especially those that provide total containment of fish and recovery/re-use of wastes, funding agencies should place greater emphasis on further developing closed systems and other environmentally friendly aquaculture techniques e.g RAS. The government should also promote efforts to renovate or retrofit old factories or other existing structures for aquaculture purposes.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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