Design, Construction and Management of a Recirculating Aquaponics System

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Publication Date: 2026/07/09

Abstract: This study discuss on the design, construction and management of a re-circulatory aquaponics system. The system is made up of four culture tanks of 2ft by 1ft by 1ft (Lx b x h) dimension each. These tanks are supported on a platform with an outlet leading to growing pipes of 3''size where water flows through. These pipes are in three numbers for each treatment and are suspended on a platform and carries water out to the sedimentation tank of same size 2ft by 1ft by 1ft (Lx b x h) through a flow through pipes of ¼ size. The growing pipes consist of eleven holes that support the planting of crops. The sedimentation tank consist of the sharp sand that filters the dirt and allow for easy cleaning of the pond water, on the sand is laid the granites and oyster shells that also assist in the purification of the water. The activated charcoal is arranged in a small porcelain sack to allow for cleansing of the purified water which is pumped back into the rearing tank. Also in the sedimentation tank is situated the small pumping tank of ¼ hp to pump the purified water from the sedimentation tank to the rearing tank. 80 pieces of (*clarias gariepinus)* fish were cultured with 20 pieces assigned to each tank and fed 5% of their body weight per day. The water temperature, ph, Do2, and turbidity were monitored everyday to prevent oxygen depletion and ph fluctuation of the circulatory water. The water management is strictly followed and monitored. The sedimentation tank is clean every week by washing all the materials and flushing in clean water into the sedimentation tank to neutralize the ph and increase the oxygen level of the water so as to support the fish growth and also the growth parameters of crops planted in the planting pipes are monitored weekly.

Keywords: *Design, Construction, Management, Re- Circulatory, Aquaponics.*

How to Cite: Fakunmoju F. A.; Tijani E. K.; Dickson P. O. (2026) Design, Construction and Management of a Recirculating Aquaponics System. *International Journal of Innovative Science and Research Technology*, 11(6), 2959-2667.
https://doi.org/10.38124/ijisrt/26jun967

I. INTRODUCTION

The increasing global population, while staying within the planet's ecological limits, hinges on the sustainability of future agricultural systems (*Rackstrom et al.,* 2009). These systems must be designed to yield more while utilizing fewer resources and generating lower emissions compared to current practices. To address these challenges, it is crucial to intensify food production and integrate it with existing farming methodologies (*Tyson et al.,* 2011). Aquaponics combines aquaculture and hydroponics, creating an integrated system in which fish and plants thrive together (Yep & Zheng, 2019). This interaction cultivates an optimal environment for growth, often leading to higher productivity than traditional methods (*Zidni et al., 2013*; *Turnsek et al*., 2020). The aquaponic system enhances sustainability by utilizing plant root systems to absorb waste from fish culture water (Yang & Kim, 2019; Dauhan & Suparmono, 2014). Moreover, intensive recirculation aquaculture systems (RAS) are recognized as one of the most sustainable approaches to producing animal protein (*Martins et al.,* 2010). By recycling process water in RAS, we can conserve precious resources such as water and energy. Additionally, the system efficiently concentrates and manages animal waste, facilitating better treatment, disposal, or recycling options (*Blacheton et al.,* 2007).

One of the most effective approaches to warm water aquaculture using re-circulating aquaculture systems (RAS) is found in the production of African catfish, *Clarias gariepinus*. This method supports stocking densities of 200–350 kg per cubic meter of water, making it feasible even in limited spaces (*Palm et al.,* 2018). However, the environmental conditions within a RAS can pose challenges for the fish, as the accumulation of nutrients from feed and input water increases over time (*Elies et al.,* 2017). Recent findings indicate that the intensity of African catfish production in RAS significantly influences the buildup of nutrients in the system (*Palm et al.,* 2018). To mitigate the impact of nutrient emissions, researchers are exploring the integration of commercial plant production systems that reuse process water, a concept known as aquaponics (*Palm et al.,* 2018). The nutrient-rich process water contains beneficial elements derived from unabsorbed fish feed

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun967

nutrients (*Palm et al.*, 2018). The high rate of water reuse characteristic of RAS enhances the concentration of essential nutrients for plants, such as nitrate, phosphate, and potassium (*Delaide et al*., 2016). In this setup, plants are cultivated in a hydroponic system where their roots are immersed in water (Johnson et al., 2017). These plants act as biofilters, effectively breaking down harmful substances into harmless compounds for the fish, while also supplying essential oxygen to the water used in fish care (*Zidni et al.*, 2019b).

Aquaponics is on the rise, driven by the increasing scarcity of land and water for traditional fish farming. This innovative system makes efficient use of water as a growing medium, which is crucial for maintaining high water quality in fish and shrimp farming, including catfish, thereby enhancing overall productivity (Gichana, 2019; *Pinheiro et al*., 2020). One effective way to uphold water quality in an aquaponics setup is through the use of filters (Danner, 2019; Lennard, 2012; *Darmayanti et al.,* 2011). These filters can be a variety of materials, such as plants, bioballs, gravel, coconut husks, sponges, or even a combination of different types (Samsundari & Wirawan, 2013; Kushayadi, 2018; Alam, 2019). Unlike hydroponics, which solely depends on nutrient supplements, aquaponics merges a re-circulating aquaculture system (RAS) with hydroponics by utilizing nitrogen-rich fish waste as natural fertilizer (*Pantanella et al.*, 2010; Blidariu and Grozea, 2011; *Love et al.*, 2015). To enhance the economic viability of aquaponics, it is essential to improve profitability and minimize operational costs (Klinger and Naylor, 2012; *Goada et al.*, 2015). One potential solution for lowering these costs could be reducing the water recirculation period. Environmental factors, such as excessive light intensity, have been noted as significant influences on nitrate uptake in vegetables (Liang and Chien, 2013). While moderating light intensity is important for plant growth (Santamaria, 2006), it can also impact nutrient absorption. Thus, the aquaponics production system is viewed as one of the most efficient and environmentally sustainable farming methods of the 21st century (FAO, 2014; *Oladimeji et al*., 2020). By combining RAS and hydroponic systems, it effectively alleviates some of the negative environmental impacts associated with these practices (Tyson et al., 2011; *Zou et al.*, 2016). This combination allows for the efficient use of nitrogen-rich fish waste as an organic fertilizer for plants (Blidariu & Grozea, 2011; *Love et al.*, 2015; *Pantanella et al.*, 2010), while the cleaned wastewater from the plants is recirculated for fish rearing (*Zou et al.*, 2016). Overall, aquaponics offers an innovative, reliable, and cost-effective way to enhance food production and address land-use conflicts. However, there remains a lack of information to firmly establish the effectiveness of this system compared to conventional methods of fish and vegetable production. The growing interest in aquaponics, which combines aquaculture and hydroponics, highlights its potential as an eco-friendly, bio-integrated food production system (*Colt et al.*, 2022), with the primary objective of repurposing nutrients released from fish waste for plant growth.

Re-circulating aquaculture and hydroponics present promising pathways for boosting production while also being kinder to the environment. Nonetheless, these systems come with their own set of challenges that can hinder efficiency and profitability. In re-circulating aquaculture, for instance, it's crucial to regularly monitor water quality, and wastewater must be discharged periodically to keep the water in peak condition. On the other hand, hydroponic systems face issues as plants absorb nutrients and chemical changes in the solution necessitate the removal of water, which then requires replacement with fresh nutrient solution. While this approach is less damaging to the environment compared to traditional agricultural methods that lead to nutrient leaching, managing the nutrient-rich wastewater can pose difficulties for producers and impacts the overall water conservation effectiveness of the system (*Baiyin et al.*, 2021). This is where aquaponics shines, as it combines aquaculture and hydroponics to tackle the hurdles that conventional agricultural methods experienced.

➢ *Justification of the Study*

This study aims to address a significant knowledge gap in the field. While there are multiple studies exploring the effectiveness of different aquaponic designs for various plant species (*Baiyin et al.*, 2021; *Baßmann et al.*, 2020; Paudel, 2020), many opportunities in this area remain untapped. Specifically, there has been insufficient focus on how aquaponic systems are constructed and maintained to achieve optimal results.

II. MATERIALS AND METHODOLOGY

➢ *Construction Site:*

The project is taking place at the Fisheries Departmental, Hatchery Unit of Lagos State Polytechnic, Ikorodu.

➢ *Construction Materials:*

- *Pebbles (Stones)*

Pebbles are natural stones with a size range of 4 to 64 millimeters, as classified by the Krumbein phi scale. They are larger than granules (ranging from 2 to 4 millimeters) but smaller than cobbles (which measure between 64 and 256 millimeters). A rock formation composed primarily of pebbles is called a conglomerate. These stones can vary in color and texture and may feature streaks, or veins, of quartz and other minerals. While pebbles typically exhibit a smooth surface, their encounters with the sea can leave marks from contact with other rocks or pebbles.

- *Activated Charcoal*

Activated charcoal is a lightweight black carbon residue created by subjecting wood (as well as other plant and animal materials) to significant heat in an environment with limited oxygen. This process, known as pyrolysis, effectively removes moisture and volatile constituents from the material. Typically, heat is generated by burning a portion of the original material.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun967

- *White Stone*

White stone is a transparent imitation gem, similar to rhinestones, designed to resemble diamonds.

- *Oyster Shell*

Oyster shells are the protective outer coverings of oysters. They can be processed into products like calcium supplements for human use or for laying hens.

- *PVC (Polyvinyl Chloride)*

Polyvinyl chloride, often referred to simply as PVC, is the third most widely produced synthetic plastic polymer globally, following polyethylene and polypropylene. PVC is available in two primary forms: rigid (RPVC) and flexible.

- *Surface Pumping Machine*

Surface pumps are engineered to draw water from surface sources such as springs, ponds, tanks, or shallow wells. Our selection of surface pumps mainly includes diaphragm and rotary vane pumps, which can operate directly with solar power for cost-effective functionality.

- *Pipes and Fittings*

Fittings or adapters are essential components in pipe systems, serving to connect straight sections of pipe or tubing, adapt to varying sizes or shapes, and regulate fluid flow. These fittings play a crucial role in plumbing, facilitating the movement of water, gas, or liquid waste in both residential and commercial settings.

- *Tangit-Gum*

Tangit is a solvent-based adhesive formulated with tetrahydrofuran (THF) for stability. It is specifically designed for applications involving pressure pipes, such as those carrying drinking water and gas, as well as for bonding PVC drain pipes and cable conduits.

➢ *Duration:*

The research was conducted over a period of two months.

➢ *Design Equations:*

In accordance with the relevant standards and findings from related studies, the design for the recirculatory pond system was established using the following equation: $$Q_{av} = \frac{V}{t \cdot S}$$ Where Q_{av} denotes the average flow [m^2/day], t represents the retention time [days], V indicates the volume [m^3], and S signifies the surface area of the tank.

➢ *System Construction:*

The system is designed with four culture tanks, each measuring 46.5 cm by 30.9 cm by 23.8 cm, along with purification units that include sedimentation, filtration, and pumping capabilities. Each tank is individually positioned on a stable platform that supports both the rearing tanks and the associated plant pipes. The rearing tanks connect to the plant pipes through ¼-inch pipes, which are equipped with control valves to manage the water flow between the tanks and the plant pipes. The planting pipes consist of 3-inch perforated tubing, with holes spaced 15 cm apart. Both ends of the plant pipes are capped with stoppers to retain water within the system. Small sections of the ¼-inch pipe, cut to 5 cm lengths, are inserted into each hole along the 3-inch pipe to provide support for the plants. At the lower end of the third 3-inch pipe, an outlet is positioned near the stopper to minimize water loss from the system. A coupling connects the 3-inch pipes to facilitate movement from one pipe to the next using additional ¼-inch sections. Three 3-inch pipes are arranged in parallel and linked with ¼-inch pipes, ultimately connecting to a longer ¼-inch pipe that returns any overflow from the 3-inch pipes back to the purification tank. The purification tank performs three essential functions: sedimentation, filtration, and pumping. It contains layers starting with sharp sand at the bottom, followed by granite or white stone, oyster shell, and activated charcoal. As water flows into the purification tank, these processes work effectively to clean the water. A small pumping machine with the capacity of 12kva draws water from the purification tank and directs it back into the rearing tanks. Once the fish are placed in the rearing tanks, the water is released into the planting pipes, allowing the plants to absorb nutrients from the water discharged from the cultured tanks.

- *Calculating Water Flow in a Recirculating Pond System*

To design an efficient water flow system in the rearing tank, we need to calculate the rate of water flow using a straightforward formula: $$V = A \times h$$ In this equation:

- ✓ V represents the volume of water in the planting system pipe (in cubic meters, m^3).
- ✓ A is the cross-sectional area of the planting pipe (in square meters, m^2).
- ✓ h denotes the height or depth of the rearing tank (in meters). This can also be expressed as: $$V = \Pi \frac{d^2}{4} \times h$$

Where:

- ✓ d is the diameter of the planting system pipe (in meters). To find the discharge rate (Q) in m^3/sec, we can use the equation: $$Q = \frac{\text{Volume discharged}}{\text{Time taken}}$$

The volume of discharge can also be derived from the area of the velocity of the discharge pipe: $$\text{Area of discharge pipe} = \Pi \frac{d^2}{4}$$ According to Bernoulli's Equation, the energy exerted by the moving fluid (water) at a height above a reference point is expressed as: $$\text{Pressure head} + \text{Velocity head} + \text{Potential head} = \text{Total head}$$ Where: - The pressure head from the planting pipe can be calculated using the formula: $$\text{Pressure head} = \frac{P}{pgh}$$.

In this formulation:

- ✓ P is the pressure (in N/m^2) at the reference point, -
- ✓ p is the density of the water flowing in the culture pond (in kg/m^3), -

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun967

- ✓ g represents the acceleration due to gravity. Thus, the velocity head can be expressed as: \[\text{Velocity head} = \frac{V^2}{2g} \] With: - p as the water density, -
- ✓ h as the height of the bio-tower tank. For fluid pressure, it was measured at 21582 N/m², while atmospheric pressure was noted as 1.01325 N/m². The total pressure before discharge can be found by summing the static pressure (Ps) and the atmospheric pressure (*Fakunmoju et al.*, 2021).

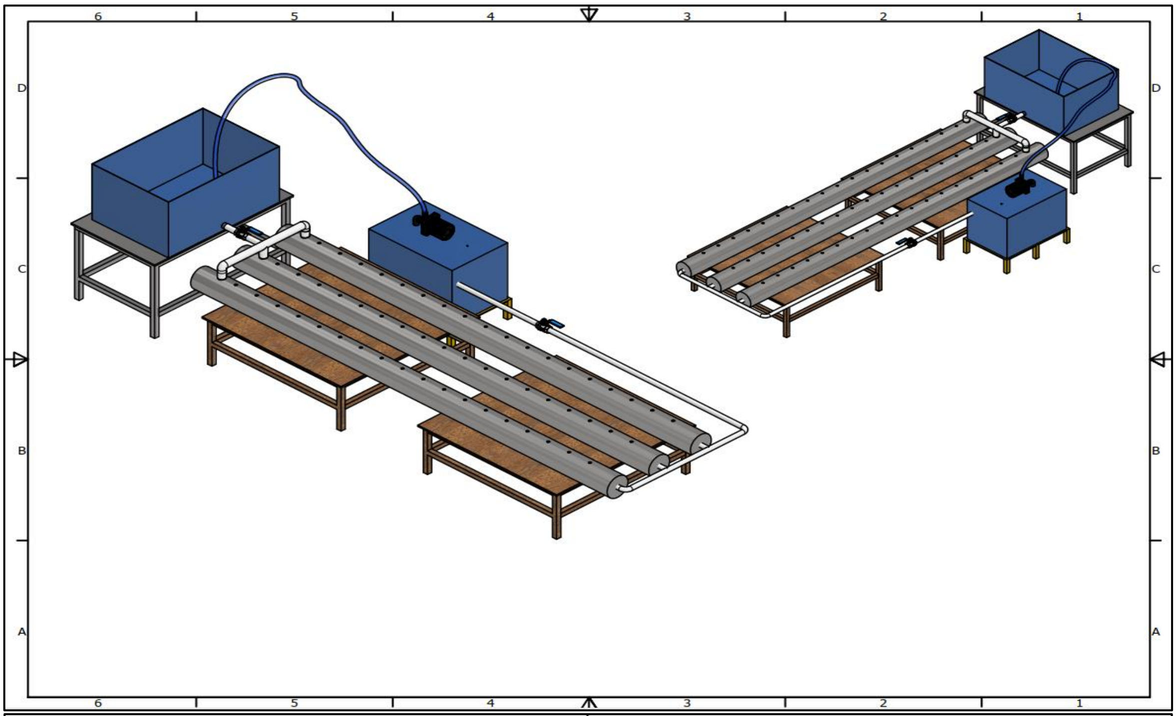
Plate 1 Planted Vegetables Introduced to the Aquaponics System

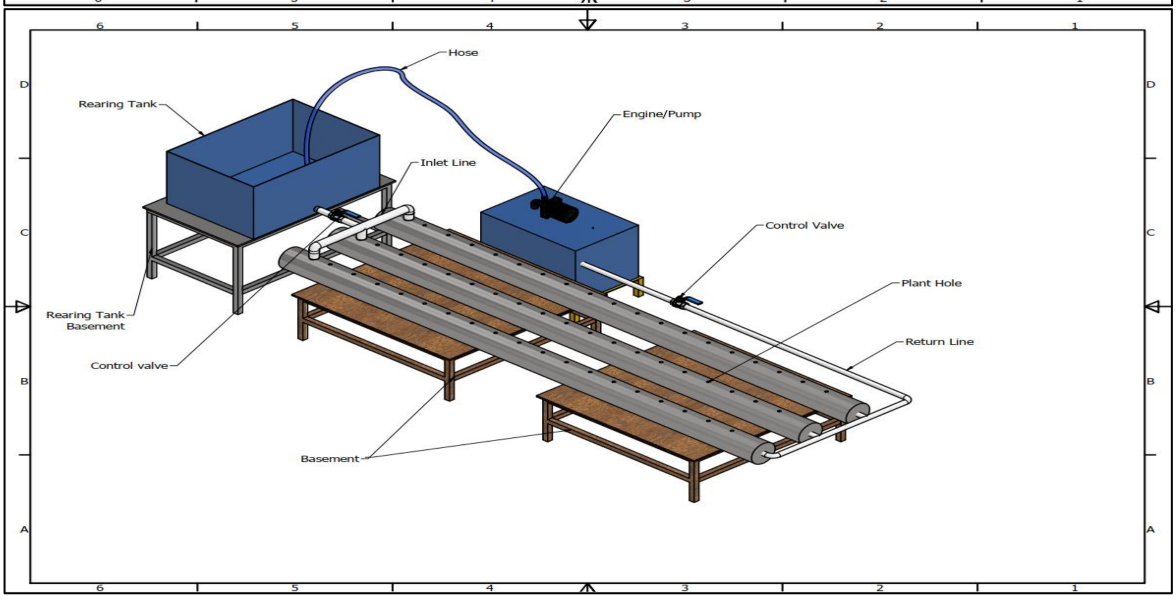
Plate 2(a) The Constructed Aquaponics System

Plate 2(b) Planted Vegetables and Cultured Fish Introduced to the Aquaponics

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun967

Fig 1(a) Showing the Four Tanks in the Re-Circulatory Aquaponics System





ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun967

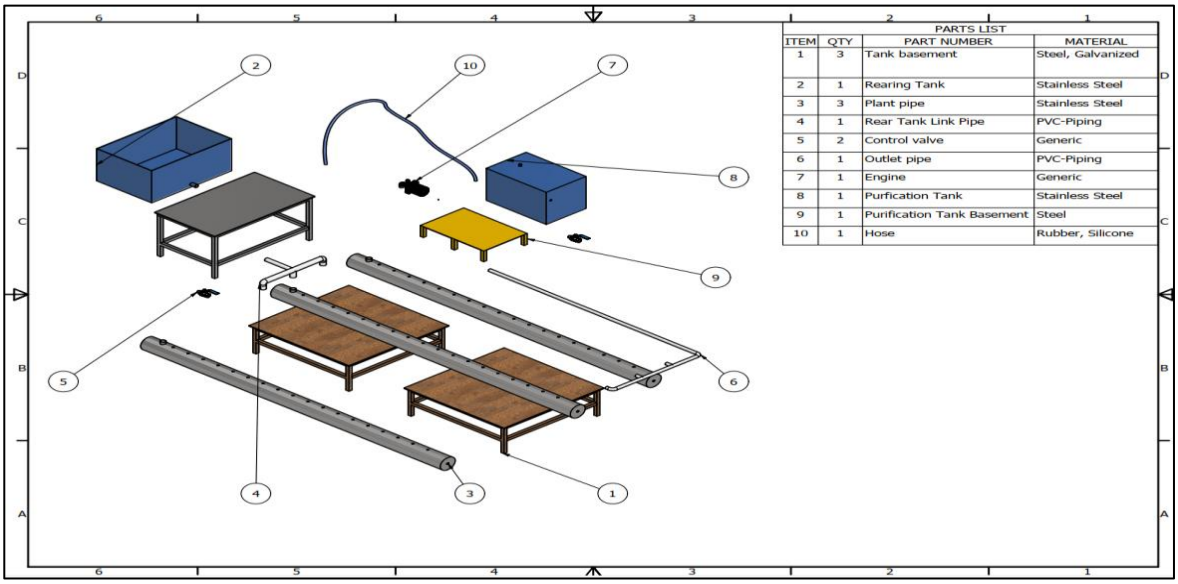


Fig 2 (a) Diagram Showing Different Parts of the Aquaponics Re-Circulatory System

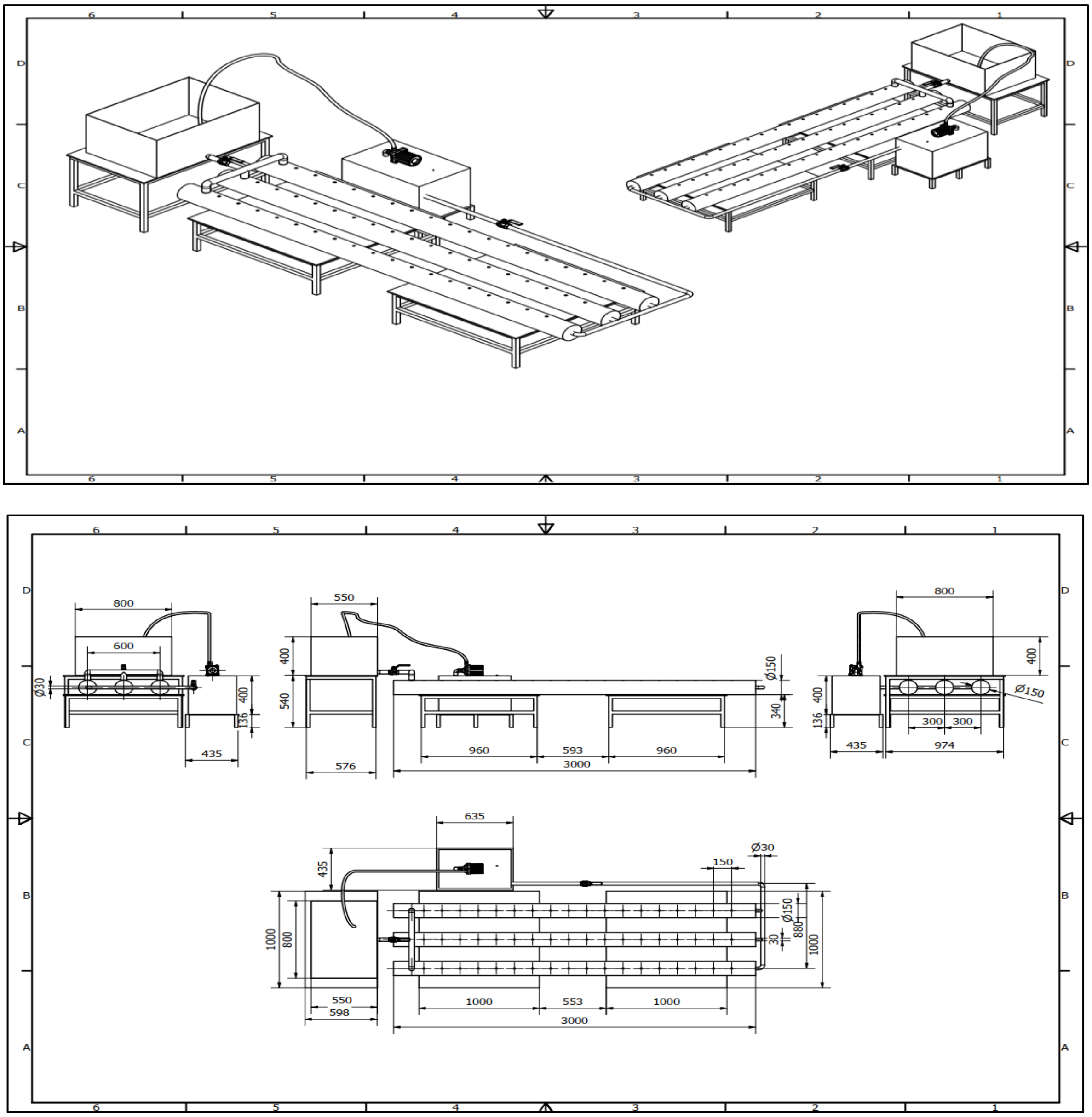


Fig 2(b) Showing the Dimension of the Re-Circulatory Aquaponic System.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun967

III. RESULT AND DISCUSSION

A. Results

➢ *Management of Re-circulatory Aquaponics System*

The management of the constructed re-circulatory aquaponics system begins with the maintenance of the water going or passing through the outlet. The waste water from the fish in the rearing tank passes through an outlet that is protected with a sieve net to prevent the passage of larger particles into the planting pipes. The water moves through the outlet guided with net into the planting pipes which are in three (3) set. The passage of the water into the planting pipe is controlled using the control valve to prevent an overflow of water into the planting pipes. When the waste water gets into the planting pipes it gets to a certain level that the planting pipe cannot accommodate it again, it then overflows through an outlet pipe connected to each of the planting pipe through a return pipe into the purification tank where the water sediment, filtration and pumped back with an engine, through a hose into the rearing tank.

The waste water in the planting pipe is being utilized by the plants planted in the planting holes. While in the purification tank, the sediment from the waste water is being absorbed by the sand and then filtered using activated charcoal. When there are excess sediments in the tank the water in the purification tank is changed with fresh water and all other materials like the sand, granite and the activated charcoal bag are washed and raised with clean water to remove the dirt/sediments before clean water is added and then allowed to be pumped into the fish rearing tank to get mix up with the residual water in the rearing tank and the planting pipes. The waste water from the fish in the rearing tanks are removed by removing the seine net at the outlet of the tank and raise thoroughly before been replaced.

The layout of the rearing unit and the planting pipes designed or constructed is presented in fig. 1. Four sets of culture tanks were constructed with a capacity of 25litres. These four sets of tanks have the capacity to hold at least twenty-five juvenile fishes from inception to maturity.

These three tanks are placed on a platform and each of them is connected to 3 different sets of 3” pipe of 10ft in length. Each tank is attached to 3 sets of 3” pipe perforated at interval of 15cm from each other.

Each of these holes consists of 5cm (1/4”) pipe to allow for upright placement of planted crops. Each of these 3” pipes have an inlet from the top of the pipe that allows the water to flow into it. The inflow of water is controlled by the control valve placed at the end of the outlet from the culture/ rearing tank.

Each cultured tanks have two types of flow lines (the inlet and outlet) as illustrated in Plate. 1. The supply line operation at a maximum system flow width of 0.8m/s with a minimum slope of 0.20%. The slope is to allow the free flow of water from the culture tank to the planting pipes and also allow flow of water from the planting pipes to the purification tank (sedimentation, filtration and pumping). The culture tanks have an inlet and the outlet line.

The inlet tank to the culture tank has a diameter 0.3m each connected directly to the outlet of the pumping machine. In this process the water picked from the purification tank by the pump is discharged into the rearing tank thereby allowing the atmospheric air to mix with it.

The engine has a capacity of 12KVA with an ability to fill a tank of 500 litres faced down in the purification tank to pick the purified water from the purification tank and send it back to the rearing tank. The culture tank contains the cultured fish that are used for experiment purpose to determine the effectiveness of the aquaponics.

The tank consists of an outlet located at the bottom of the tank carrying the ¼ sized pipe to allow for drainage and every movement of water down to the planting pipes.

The outlet carriers the control valve of ¼ size that controls the movement of water down to the planting pipes. The excess water passes through the connected pipes to the purification tanks.

The purification tanks serve as the (sedimentation, filtration and pumping tank) which also contains sharp sand placed at the bottom of the tank followed by the granite and the oyster shell and later by the activated charcoal. All these substances help in breaking down of nitrogenous waste from the water and some unhealthy elements.

B. Discussion

The re-circulating aquaponics system designed was primarily an indoor setup. The water flows through its components via gravity, as they are strategically positioned at varying elevations to optimize the water movement (*Fakunmoju et al.*, 2021). A pumping unit transfers water from the purification tank, as previously detailed by Akinwole & Faduroti (2007). Our system features an ideal pipe diameter to radius ratio of 5 cm^2, ensuring efficient flow dynamics. The purification tank is designed to promote the removal of settle able solids, giving the fish a more natural living environment. The effectiveness of using a rectangular tank has been supported by various studies (Tomiwa *et al*., 2008; *Losardo et al.*, 2008). As water is re-circulating, the system requires only a modest addition of new water about half its volume each week. Different filtration methods are incorporated within a framed enclosure, according to what Akinwole and Faduroti (2007) reported, where the filtration chamber utilizes diverse materials. Water aeration can be achieved simply by allowing water to flow from the pump back into the culturing tank through a return hose. This approach, which includes disinfection and oxygenation of the water, has been endorsed by *Losordo et al.* (2008). Considering how water flows from the inlet into the culturing tank, down through the planting pipes, and through the filtration unit, was found was effective and adaptable according to the design (Morey, 2009). The purification processes involving sedimentation and filtration play a critical role in managing the input feed and waste output, helping to maintain optimal water quality. Additionally, the plants placed within the planting pipes positively impact water quality by effectively reducing levels of accumulated nitrate, nitrite, and nitrogen. Overall, the re-circulating aquaponics system demonstrates the potential to support a slight increase in fish stocking density while maintaining a relatively low mortality rate among cultured fish.

IV. CONCLUSION AND RECOMMENDATION

➢ *Conclusion*

In summary, the re-circulatory aquaponics system stands out as the most effective method for integrating fish culture and crop planting within aquaculture systems. This approach significantly minimizes water usage, reduces the costs associated with pumping water at regular intervals, and allows for efficient land use for planting. Furthermore, it is evident that the re-circulatory aquaponics system not only accelerates the growth cycle for both fish and crops but also yields superior quality products in a shorter timeframe, making it the ideal choice for both producers and consumers in the market.

➢ *Recommendation*

It is highly recommended that recirculatory aquaponics system be adopted by large scale farmer in other to meet the market demand of the fish/ crops buyers in the shortest possible time.

REFERENCES

[1]. Alam, T. (2019). Regulation of the cytochrome P450 enzyme system in fish. Aquatic Toxicology 24: 1-19.
[2]. Akinwole AO, Faduroti EO.(2007). Biological Performance of African Catfish (Clarias Garipinus) Cultured in recirculatory system in Ibadan Agriculture Engineering 2007; 36:18-23.
[3]. Baiyin, M.A., van der Steen, N.P., Hooijmans, C.M., Gijzen, H.J., (2021). Nitrogen mass balances for pilot-scale biofilm stabilization ponds under tropical conditions. Bioresour. Technol. 102, 3754–60.
[4]. Babmann, M.; Mendiola, D.; Bostock, J.(2020). Recirculating Aquaculture Systems (RAS) analysis: Main issues on management and future challenges. Aquac. Eng. 2020, 51, 26–35. [CrossRef]
[5]. Blidairu, H., and Grozea, M. (2021). Kinetics of nutrient uptake by roots : responses to global change. New Phytol. 147, 155–169.
[6]. Blancheton, J.P., Attramadal, K.J.K., Michaud, L., D'Orbcastel, E.R., Vadstein, O., (2013). Insight into bacterial population in aquaculture systems and its implication. Aquac. Eng. 53, 30–39
[7]. Blancheton, J.P., Attramadal, K.J.K., Michaud, L., D'Orbcastel, E.R., Vadstein, O., (2013). Insight into bacterial population in aquaculture systems and its implication. Aquac. Eng. 53, 30–39.
[8]. Blancheton, J.P.; Piedrahita, R.; Eding, E.H.; Lemarie, G.; Bergheim, A.; Fivelstad, S.; Roque D'Orbcastel, E.(2007). Intensification of landbased aquaculture production in single pass and reuse systems. In Aquacultural Engineering and Environment; Bergheim, A., Ed.; Research Signpost: Trivandrum, India, 2007; pp. 21–47. ISBN 9788130801995.
[9]. Coombs, A.(2014). Defining the anthropocene. Front. Ecol. Environ. 2014, 12, 208.
[10]. Colt, R.; König, B.; Villarroel, M.; Komives, T.; Jijakli, M.H.(2022). Strategic points in aquaponics. Water 2022, 9,182. [CrossRef]
[11]. Delaide, B.; Goddek, S.; Gott, J.; Soyeurt, H.; Jijakli, M.H.(2016). Lettuce (Lactuca sativa L. Var. Sucrine) growth performance in complemented aquaponic solution outperforms hydroponics. Water 2016, 8, 467. [CrossRef]
[12]. Darmayanti, A.; Gommek, B.S.; Gatty, J.K.; Ambigot, M.; Jajikio, K.H.(2011). Lettuce (Lactuca sativa L. Var. Sucrine) growth performance in simple aquaponic systems outperforms hydroponics. Water 2011, 8, 467. [CrossRef]
[13]. Danner, S.(2019). Aquaponics-Integration of Hydroponics with Aquaculture; ATTRA: Melbourne, Australia, 2019.
[14]. Dauhan, S and Suparmono, M .(2014). Aquaponics mixed with Hydroponics as an integration of Aquaculture; MARRA: Melbourne, Australia, 2014.
[15]. Elies, R.; (2017). (Fischgut Nord eG/PAL Anlagenbau GmbH & Co. KG, Abtshagen, Germany). Personal communication, 2017.
[16]. Fakunmoju FA, Babalola AO and Adesina BS.(2021). Design and construction of a Prototype Aquaculture Pond Re-Circulatory system using locally sourced materials (Wood and PVC Blind), International Journal of Fisheries and Aquatic Studies 2021; 9(3): 180-185
[17]. FAO (2014). The future of food and agriculture: Trends and challenges; 2014.
[18]. Goada, C.; Davidson, J.; Welsh, C.; Brazil, B.; Snekvik, K.; Summerfelt, S. (2015). The impact of water exchange rate on the health and performance of rainbow trout Oncorhynchus my kiss in water recirculation aquaculture systems. Aquaculture 2015, 294, 80–85. [CrossRef]
[19]. Gichana, D. (2019). The Development of Sustainable Saltwater-Based Food Production Systems: A Review of Established and Novel Concepts. Water 2019.
[20]. Klinger, U. and Naylor, H.W.(2012). Effects of fish biology on ebb and flow aquaponical cultured herbs in northern Germany (Mecklenburg Western Pomerania). Aquaculture 2012, 466, 51–63. [CrossRef]
[21]. Kushayadi, D. J. (2018). The status and prospects of renewable energy for combating global warming. Energy Econ. 2018, 33, 584–593.
[22]. Lennard, C.I. (2012). The effect of recirculating aquaculture systems on the concentrations of heavy metals in culture water and tissues of Nile tilapia Oreochromis niloticus. Food Chem. 2012, 126, 1001–1005. [CrossRef]
[23]. Liang, A. and Chien, B.S..(2011). Lettuce (Lactuca

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jun967

sativa L. Var. Sucrine) growth performance in simple aquaponic systems outperforms hydroponics. Water 2011, 8, 467. [CrossRef]

[24]. Losordo TM, Maner MR, Rkocy J.(2008). Recirculatory Aquaculture Tank Production system. An overview of critical consideration. Southern Regional Agriculture center. Publication 2008; 459:6.

[25]. Love, F.; Landry, J.-S.; Plouffe, D.; Seufert, V.; Rowhani, P.; Ramankutty, N.(2015). Urban agriculture: a global analysis of the space constraint to meet urban vegetable demand. Environ. Res. Lett. 2015, 9, 64025.

[26]. Martins, C.I.M.; Eding, E.H.; Verdegem, M.C.; Heinsbroek, L.T.; Schneider, O.; Blancheton, J.P.; Roques d'Orbcastel, E.; Verreth, J.A.J.(2010). New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. Aquac. Eng. 2010, 43, 83–93. [CrossRef]

[27]. Morey RI.(2009). Design Keys of a recent recirculatory built in chile operation with fluidized biofilter. Aquaculture Engineering 2009; 41:85- 90

[28]. Oladimeji O.T., Osilesi O.O., Onajobi F., Adebawo O.O., Oyedemi S.O., and Afolayan A. J. (2013). "Stability study of smoked fish, Horse Mackerel (*Trachurust rachurus*) by different methods and storage at room temperature". *African Journal of Biochemistry Research,* 7 (6): 98-106.

[29]. Palm, H.W.; Knaus, U.; Appelbaum, S.; Goddek, S.; Strauch, S.M.; Vermeulen, T.; Jijakli, M.H.; Kotzen, B.(2018). Towards commercial aquaponics: A review of systems, designs, scales and nomenclature. Aquac. Int. 2018, 26, 813–842. [CrossRef]

[30]. Pantamella, H.W.; Knaus, U.; Wasenitz, B.; Bischoff, A.A.; Strauch, S.M.(2010). Proportional up scaling of African catfish (Clarias gariepinus Burchell, 1822) commercial recirculating aquaculture systems disproportionally affect nutrient dynamics. Aquaculture 2010, 491, 155–168. [CrossRef]

[31]. Paudel, H.W..(2020). Significant factors affecting the economic sustainability of closed aquaponic systems. Part II: Fish and plant growth. AACL Bioflux 2014, 7, 162–175.

[32]. pinhenro, C. I. M.; Eding, E. H.; Verdegem, M. C. J.; Heinsbroek, L. T. N.; Schneider, O.; Blancheton, J. P.; d'Orbcastel, E. R.; Verreth, J. A. J.(2020). New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. Aquac. Eng. 2020, 43, 83–93.

[33]. Rackstrom, E., Kling, P., Gunnarsson, L., Larsson, D. G. J. and Förlin, L. (2009). Proteomic analyses indicate induction of hepatic carbonyl reductase/20[beta]-hydroxysteroid dehydrogenase B in rainbow trout exposed to sewage effluent. Ecotoxicology and Environmental Safety 68: 33-39.

[34]. Samsundari, M. J. and wirawan, J. T. (2013). Toxicology and genetic toxicology in the new era of "toxicogenomics": impact of "-omics" technologies. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis 499: 13-25.

[35]. Tomiwa MA, Ogunsanmi A, Yunusa A.(2008). Studies on growth performance and feed utilization of two clarid catfish and their hybrid reared under different culture system. European Journal of Scientific Research 2008;23(2):252 -260.

[36]. Turnsek, Y., Csanaky, I. L. and Klaassen, C. D. (2020). Quantitative-profiling of bile acids and their conjugates in mouse liver, bile, plasma, and urine using LC-MS/MS. Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences 873: 209-217.

[37]. Tyson, G. T., Daston, G. P., Degitz, S. J., Denslow, N. D., Hoke, R. A., Kennedy, S. W., Miracle, A. L., Perkins, E. J., Snape, J., Tillitt, D. E., Tyler, C. R. and Versteeg, D. (2011). Toxicogenomics in regulatory ecotoxicology. Environmental Science & Technology 40: 4055-4065.

[38]. Yep, N. W.; Zhang, P. H. (2019). Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada. J. Clean. Prod. 2019, 17, 362–373.

[39]. Zou, R., Raffaele, M. and Nicklas, P. (2016). Pharmaceuticals in STP effluents and their solar photodegradation in aquatic environment. Chemosphere 50: 1319-1330.