System design, sustainable production and water quality research for Recirculating Aquaculture System (RAS)

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Abstract - *Fisheries are the primary source of livelihood for several communities. Fishing in India is a primary industry, employing 14.5 million people and contributing to 1.07% of the total GDP of India (2020, "Fishing in India - Wikipedia). Currently, most aquaculture systems are biofloc systems or pond farming setups. While wild fishing is slowly becoming unsustainable, aquaculture faces the problem of people using incorrect filtration methods, which leads to a high mortality rate. A 3-stage filtration system for freshwater aquaculture or recirculating aquaculture system (RAS) was built to tackle this problem. The RAS prototype was designed to satisfy compactness, efficiency, longevity, and financial requirements. The culture tank (main fish tank) has a capacity of 1000 L and is stocked with 100 fish. The stocking density comes out to be almost double as compared to bio floc systems. The three stages of filtration are mechanical filtration, biological filtration, and ultraviolet (UV) filtration. The fish used to test this prototype are mono-sex tilapia(200g) (GIFT)(2019, "An Excellent Candidate Species for World Aquaculture: A Review).*

Index Terms: aquaculture, Recirculating aquaculture system, fisheries, mono-sex tilapia

Abbreviations:

CAD-Computer Aided Design,

UV-Ultraviolet

RAS-Recirculating Aquaculture System

PVC-Polyvinyl Chloride

BOM-Bill of Material

DO-Dissolved Oxygen

1. INTRODUCTION

Recirculating aquaculture systems (RAS) are used for fish production where water exchange is limited, and biofiltration is required to reduce ammonia toxicity. Other types of filtrations and environmental control are often also necessary to maintain clean water and provide a suitable habitat for fish. The prime benefit of RAS is the ability to reduce the need for fresh, clean water while maintaining a healthy fish environment. Commercial RAS must have high fish stocking densities to operate economically, and many researchers are currently conducting studies to determine if RAS is a viable form of intensive aquaculture.

2. PROBLEM STATEMENT

Many fish farmers are using incorrect filtration techniques for recirculating Water Filtration, which results in a high mortality rate of fish and heavy losses. This project should increase the survival rate of fish to 90%. To design and develop a three-stage water filtration system in Recirculation Aquaculture System was to satisfy the following conditions: Compactness, Efficiency, Longevity, and Economical. The final result expected from this project was the "design of a three-stage water filtration system that can filter solid waste, biological waste and bacteria, and pathogens from the water." Additionally, understanding the primary goal of this project allowed it to be divided into many topics and sub-topics. These new topics were mainly divided into three stages of filtration. A THREE-STAGE WATER

FILTRATION SYSTEM

using CAD software was designed and modeled. Using the designed parts in the CAD software, the structure of the circular tank, mesh filter, stand, and biological filter was built.

ADVANTAGES AND CONSTRAINTS OF RAS

- The advantages of farming in RAS are:
- Fully controlled environment for the fish
- Low water use
- Efficient energy use
- Efficient land use
- Optimal feeding strategy
- Easy grading and harvesting of fish
- Full disease control

There are a few constraints in respect of infrastructure, feeds and staff:

- Availability of electricity 24/7
- Good water source, preferably bore-well
- Good fish feed quality, preferably high protein and fat extruded diets with high digestibility
- Technically skilled staff able to work in a medium-tech environment.

Recirculating Aquaculture System is the best option for locations close to or in cities, with good availability of electricity. Next, using RAS technology is the only possibility for farming tropical fish species indoors in moderate to cold climates.

3. . METHODOLOGY

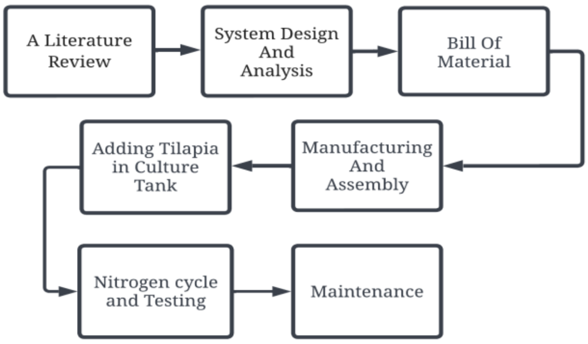

Fig 1: Methodology of the project

3.1. A literature review

With a survey of the literature, the project was begun. Many RAS industries near our area were visited. The technologies already in place were investigated, and areas to lower the mortality rate of tilapia fish were optimized. In RAS industries, the mortality rate for Tilapia fish is now close to 12%-15% (Howell, M., 2022). In order to learn more about the RAS systems, a lot of international research publications were studied.

3.2. System Design and Analysis

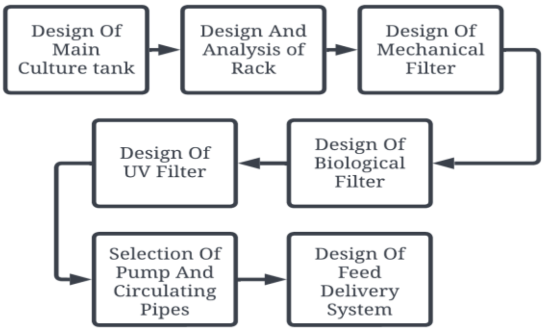

Fig 2: Flowchart of design and Analysis process

3.2.1. . Design of main culture water tank

RAS must be built to accommodate 100 fish, and the primary tank should have the required volume of water. The following calculations were performed to determine the precise volume of water in the culture tank: According to Purdue University, fish weighing 454 grams needs 7.6 liters of water (Thesis and Dissertation Office - Purdue University). A tank for 100 Tilapia fish was needed, and the weight of one fish was restricted to 500 grams. The maximum weight of 100 fish was thus 100 × 0.5, or 50 kg. In light of the calculations, 8.37 liters of water was required for 500 grams of fish. For safety, we considered 10 liters of water for a fish weighing 500 grams, and therefore a thousand liters figure was selected.

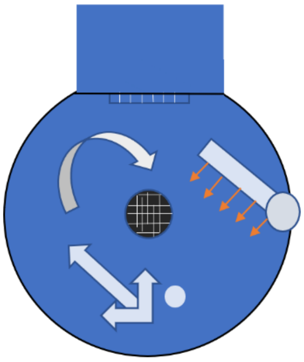

Fig 3: Cornell-Type tank design

When it comes to water filtration, the water tank's design is crucial. The Cornell-Type tank (Hydrodynamics of Octagonal Culture Tanks with Cornell-Type Dual-Drain System), in this instance, was chosen. The circular tank had an intake for tangential water flow at the top and a submersible pump at the bottom. This tank was white and covered in three defense layers against fungus. The tank had UV stabilization as well.

3.2.2. . Design and Analysis of rack

The rack, which will house all three filters, serves as the heart of our entire RAS system. Therefore, this rack's design was essential. In the initial design phase, the maximum combined weight of three filters, as well as the total amount of space needed for three filters was considered.

The rack should be separated into two tiers in accordance with the specifications. The mechanical filter will be at the top level, while the biological filter will be at the lower level. Extended room for the UV filter should be provided on the second level, maybe using a cantilever construction to move the UV filter a little bit farther away from the biological filter.

A slotted angle rack was chosen. It has four L-section slotted angles, a shelf, a nut bolt, and a reinforcing triangular plate are its four constituent parts. Now, we changed the following things to accommodate all three filters in place: The first shelf should be placed at the very top, the second one in the middle, and two additional shelves can be fastened immediately below it to create a cantilever construction. To provide the structure with stability, the final shelf is at the lowest position.

This slotted angle rack is made of galvanized iron. Whether it could sustain the weight of three filters was a difficulty. To ascertain such, we performed static structural analysis. The results of the analysis satisfied our needs. To stop the structure from rusting, we additionally painted it with red oxide and covered it with black paint. Now that we have this rack, we can use it in our tower tank design.

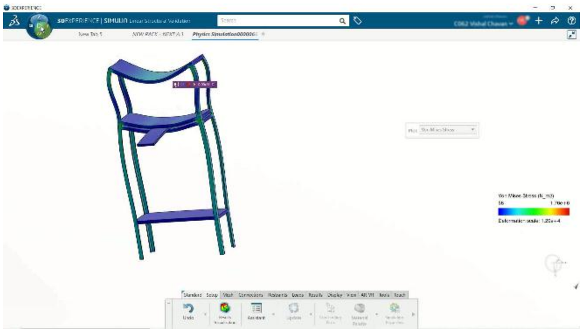

Fig 4: Analysis of Rack

Fig 5: Red oxide covered with black paint

3.2.3. . Design of mechanical filter

The recommended daily feeding rate for tilapia fish in recirculating aquaculture systems is 1% of their bodyweight (2019, "Tilapia RAS Farming). A daily need of 3% of their body weight was considered as a safety measure. Considering the maximum weight of fish to be 500 grams when designing the maximum filtration load, the daily feed requirement comes out to be 500 x 0.03 = 15 grams per fish. Total daily feed requirement for a hundred such fish is 100 x 15 = 1.5 kg.

Considering the food-to-waste conversion rate of 1:2, that is, if a fish eats 2 kg of food, then it will produce 1 kg of biomass ("FAO: Feed Formulation," FAO: Feed formulation). Thus, 1.5 kg per day of feed will produce 0.75 kg of biomass, which needs to be cleaned.

This biomass is of three types:

1. Sedimentary: composed of fish waste and uneaten food that settles out when water velocity is sufficiently low.

2. Suspended: Tiny food or waste particles that are neutrally buoyant—that is, they neither float or sink and are instead transported by the water flow.

3. Dissolved: They are dissolved, largely in the form of ammonia released by the gills or created by the mineralization of fish waste. Water can contain microbiological contamination.

In order to remove sedimentary and some suspended waste, a hybrid sedimentation type mechanical filter was designed. It consists of an 80-liter crate, 800-micron nylon mesh, 200-micron stainless steel mesh, 40-micron stainless steel mesh, aquarium sponges, and aquarium gravel.

The size of the mechanical filter, which is 80 liters, was determined by keeping in mind the filtration rate per day. The 800-micron mesh was set up to filter fish scales and uneaten food. A further 40 micron and 200-micron mesh will remove fish suspended biomass and relatively large amounts of waste. Sponges were kept to absorb dissolved biomass and relatively small amounts of suspended waste. Finally, gravel will remove any remaining suspended and sedimentary waste.

Fig 6: Mechanical Filter

3.2.4. Design of biological filter

Once the majority of the particles have been eliminated from the system, it is time to promote ammonification of any leftover suspended and dissolved materials in order to turn the ammonia produced into nitrites and eventually nitrates.

The colonization of the helpful bacteria that are essential to any recirculating aquaculture system is facilitated by the use of straightforward biological filters. The biofilter exposes the leftover particulates to the nitrifying bacteria when the fish tank effluent runs through it.

The decision to construct a moving bed biofilter was taken, by taking into account the capacity of the culture tank, the quantity of fish, and the water flow rate through the system. With 16 kg of bimedia, this biofilter can store up to 80 liters of water. Bio-Ceramic rings were the primary bimedia. Because of their efficiency and cost, their use was the best option.

A wavemaker was integrated in the biofilter to make it a moving bed type filter, ensuring that when water enters the biological filter it will be stirred about and will have sufficient time to react with the nitrifying and denitrifying bacteria present in the filter. Two air stones were added to the biological filter to oxygenate the water. The filter's efficacy was increased by the addition of activated charcoal.

The biological filter was configured to accept water input from the mechanical filter and output it to the UV filter.

Fig 7: Activated charcoal, Bio-ceramic rings, Wavemaker

3.2.5. Design of UV filter

In recirculating aquaculture systems (RAS), the microbiological safety of the intake water is crucial to guarantee that no diseases are introduced into the controlled environment, as it possesses a huge threat to the high value production that can lead to significant economic losses. Due to its vast number of advantages, ultraviolet (UV) disinfection is a commonly used method for protecting the intake water supply. By causing damage to their DNA and RNA, UV light renders bacteria inactive and stops them from proliferating and spreading illness. The product of UV light intensity, residence duration, and UV transmittance through water, the applied UV dosage (also known as fluence), which is commonly defined in terms of mJ/cm2 or J/m2, determines the capacity of UV to inactivate microorganisms. The germicidal range of 200–300 nm has strong DNA absorption, which will produce a successful initial disinfection at 254 nm (2022, "UV Disinfection System for Water Treatment - Alfaa UV). Cells have ways of repairing DNA and RNA damage. A microorganism's likelihood of undergoing photoreactivation (light-catalyzed repair) and dark space repair processes increases with decreasing UV dosage. However, using any popular UV lamp technology, there is essentially little chance for photoreactivation over a UV dosage of 15 mJ/cm2. In order to successfully disinfect the incoming water to the farm, it is essential to determine the desired UV dosage. Bacteria are often more UV-sensitive than the majority of other viruses.

Fig 8: Quartz glass circular tube

All these requirements were taken into consideration, and a four-watt UV tube was employed. Water will be exposed to UV radiation when it passes through a UV-transparent tube on its way from the biological filter to the UV filter input. The translucent tube's length and diameter were chosen to destroy most waterborne fatal microorganisms. The tube was 0.0127 meters in diameter and 0.02 meters in length. The material of the tube was important since it needed to be both sturdy enough to withstand water pressure and transparent to UV light. As a result, we used quartz glass in this instance to create a transparent tube. Extremely pure quartz glass can withstand severe temperatures in both the visible and infrared spectrums (Quartz Glass: What Is It? How Is It Made? Properties, Uses," Quartz Glass). It is suitable for permanent operation at temperatures up to 1100

°C—and even higher for brief operation—due to its excellent thermal shock resistance, low coefficient of thermal expansion, and good UV light transmission behavior.

3.2.6. Selection of pump and recirculation pipes

According to the design of the culture tank (Cornell type), the swirl effect causes the majority of solid waste to collect near the bottom of the tank. As a result, water for filtration should ideally be collected from the center of the base. A submersible water pump was used instead of altering the tank further for output. Requirements for the pump were very particular as it must work in accordance with the viscosity of waste water and pump that water further.

The pump has to be powerful, compact with substantial and rugged construction and be able to pass on the fish excreta without getting clogged. Thus an open-type pump was selected, which could readily lift the waste water without getting clogged. At least 1000 liters of water should be discharged each hour from the pump at a height of 2.18 meters. Due to its ability to meet all specifications, including a maximum discharge height of up to four meters and a maximum flow rate of up to 4,000 liters per hour, the "SUNSUN SUBMERSIBLE PUMP HQB 4500" was selected.

Half-inch class-2 UPVC pipes were selected for the flow and connection purpose due to the following reasons:

- Ability to maintain a 1000-liter-per-hour flow rate.
- High degree of inertness and resistance to corrosion.
- Free from biofilm contamination that can be a breeding ground for bacteria.
- Because it is used below its glass transition temperature (80 °C), PVC can be considered as a functional barrier, preventing any low molecular weight substances from migrating into culture tank water.
- The expected lifespan of a PVC pipe is 100 years or more for underground pipes.
- PVC water mains show a much lower failure rate than non-plastic materials.
- PVC pipes have clear environmental advantages over traditional materials. PVC is intrinsically a low-carbon plastic, as 57% of its molecular weight is chlorine derived from common salt.
- PVC pipes last a long time with a minimum of maintenance, and they are easily recyclable up to 10 times.
- Moreover, the ultra-smooth surface of PVC pipes reduces pumping costs and energy use, and their leak-free fittings eliminate water loss.

Fig 9: Half inch PVC pipe and Submersible pump

3.2.7. Design of feed delivery system

As per the calculations done during the design of the mechanical filter the 100 fish have a requirement of 1.5 kg of feed per day. An automated feed delivery system was designed to minimize human labor and dependency. It includes two compartments; each has a capacity of 400 grams for feed. There is a hopper (funnel) with a small vibrator at the top that can store additional feed and supply the compartments as needed. After 180 degrees of rotation, the culture tank can receive stored feed from the upper compartment through a bottom aperture. Following the rotation of the compartments, feed from the hooper is used to fill the second compartment, which has moved to the top, and the cycle is repeated as per the feeding times and requirements of the fish.

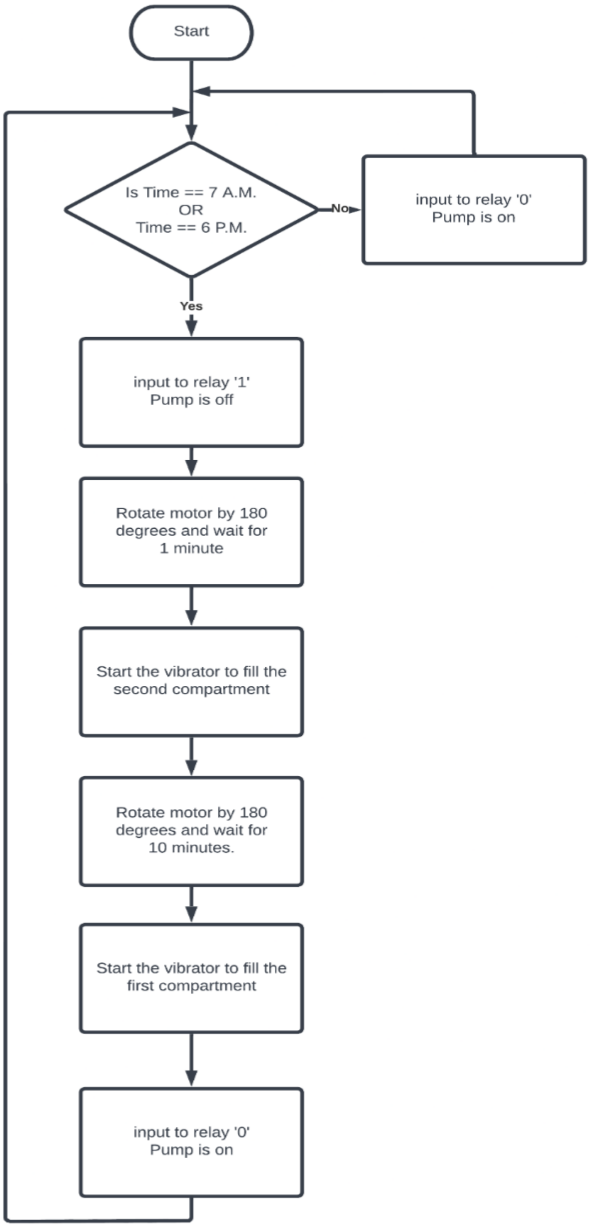

Fig 9: Flowchart of feed delivery system explaining entire process step by step

To ensure exact rotation of the compartments, NEMA17 (4.2 kg/cm) stepper motor was used as the prime mover. Arduino Uno microcontroller (Atmega328p) along with the Arduino Motor Shield (L293D) was utilized to regulate the time-to-time motion of this motor. During feeding, the filtration system was turned off so that the fish may consume their food in peace. This was facilitated by the use of a mechanical relay module which was connected to the submersible pump to act as a switch. In one day, the compartment has to rotate four times to meet the feed needs because each compartment can only hold 400 grams of feed. The feed is supplied in two portions, one in the morning and the other in the evening. Figure 9 shows the flowchart for the entire feed delivery procedure, and Figure 10 shows the code itself.

```
#include <AFMotor.h>     // including the dependencies
AF_Stepper motor(300, 1); // Connect a steppermotor with 48 steps/rev
AF_DCMotor vibrator(4);  // connect the vibrator in hooper
int i = 0;
int c = 1;
unsigned long watersettle = 120000;
unsigned long feeddelay = 20000;
unsigned long feedeat = 600000;
unsigned long finaldelay = 28800000;
void setup() {
  Serial.begin(9600);           // set up Serial library at 9600 bps
  Serial.println("Feed Delivery GO!!");
  pinMode(10,OUTPUT);
  motor.setSpeed(10);  // 10 rpm
  vibrator.setSpeed(200);
  vibrator.run(RELEASE);
}
void loop() {
  digitalWrite(10,HIGH);
  delay(watersettle);
  vibrator.run(FORWARD);
  for(int i=0;i<2;i++){
    motor.step(100, FORWARD);
    delay(feeddelay);
  }
  vibrator.run(RELEASE);
  delay(feedeat);
  digitalWrite(10,LOW);
  delay(finaldelay);
}
```

Fig 10: Code for feed delivery system in Arduino.cc

3.3. Manufacturing and Assembly

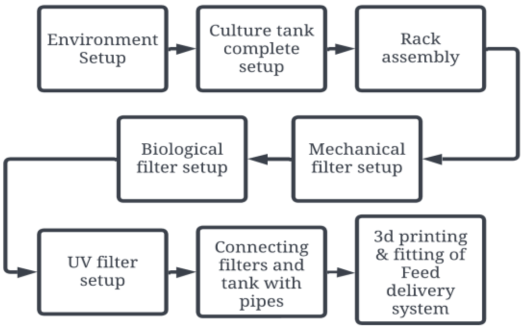

Fig 11: Flowchart from basic setup to the final stage of manufacturing

3.3.1. Environment Setup

In order to set up an RAS environment, it is necessary to choose an appropriate location, clean the region, create a temperature-controlled environment, ensure means of safeguarding the fish from predators, and make preparations for 24-hour electricity supply.

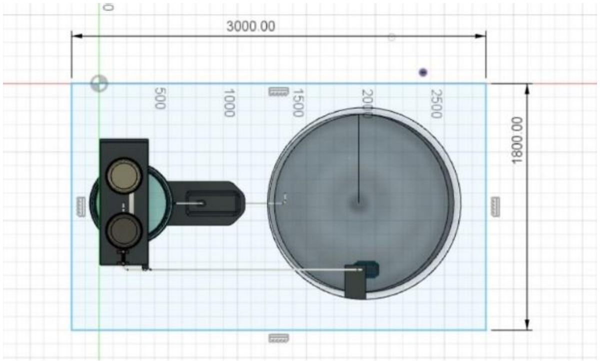

Fig 12: CAD analysis for environment setup

First, a basic estimate and analysis of the setup area was performed. Figure 3 depicts its dimensions (in mm). A room measuring 3m x 1.8m x 2.5m was constructed using 90% shade green net. This space allows us to keep the system at the right temperature while protecting the setup from most predators.

Fig 13: Creating best suitable environment for assembling the system

3.3.2. Culture Tank Setup

The tank type chosen above (Cornell-Type Tank (Hydrodynamics of Octagonal Culture Tanks with Cornell-Type Dual-Drain System)) was realized by converting a 1500-liter tank into a culture tank by removing its top cover. Perimeter reinforcement was provided using plywood strips to bolster lateral tank-wall strength. Additionally, the exterior of the tank was painted white, to arrest fungus growth and to maintain a cool temperature inside. The central-base area housed the submersible pump with an exclusion screen. Two air-pumps with three air-stones were added to the main tank, which ensured that the water had enough oxygen.

Fig 14: Modification of tank by removal of upper section and painting it white to maintain the system temperature

After adding 1000 liters of water, 200 milliliter of de-chlorinator liquid was added to the water in order to eliminate the chlorine & chloramine content present in water making it suitable for fish. Culture tank was covered with the 800-micron nylon net as a protection against biological creatures and wastes such as birds and leaves considering the requirement of the right amount of sunlight.

Fig 15: Setting up exclusion screen at water inlet and air pumps into the tank and covering it with 800-micron nylon net

3.3.3. Rack assembly

A slotted angle rack has four main components: G.I sheet shelves, reinforcing triangular plate, L-section slotted angles and nut-bolts (fasteners). To satisfy the requirements of the placement of the three filters, a cantilever structure was created in such a way that the first shelf was attached at the very top, the second and third in the center, the fourth shelf towards the bottom of the structure to provide stability. The fifth and last shelf was fixed in between the second and third shelf, forming a cantilever structure capable of supporting the ultraviolet filtration unit.

Fig 16: Assembled Rack for biological and mechanical filter setup

3.3.4. Mechanical Filter Setup

Water from the main tank was pumped into the mechanical filter using the submersible pump. It flows through the 800—200—40-micron mesh filter arrangement. The gravel and sponges at the bottom provide additional filtration via sedimentation of the waste particles. The bottom of this container offers gravel, which rests on top of the sponges that rest on top of a raised surface. The outlet of the filter is situated below the sponges, ensuring that the water passes through every stage of the filter before it can exit. The mesh arrangement guides the water through the 800-micron mesh, the 200-micron mesh, and the 40-micron mesh in this order respectively. Sizable metallic paper clips were used to secure the entire arrangement to the crate walls.

The output of the mechanical filter was in the form of two half-inch holes drilled into the bottom of the side-wall of the crate. UPVC pipes carried the filtered water to the biological filter for further treatment. In order to prevent gravel from exiting the mechanical filter, an additional exclusion screen was provided at the two half-inch outlets.

Fig 17: Mechanical Filter Setup at the center compartment of the rank

3.3.5. Biological Filter Setup

A 200-liter HDPE barrel was altered to make the biological filtration unit. The upper one-third portion was cut off and the periphery was covered with a rubber coating as a safety measure. A half-inch hole in the side of the barrel provided an exit for water. The outlets of the mechanical filter drop down to the bottom of the barrel. After adding 16 kg of bio-ceramic rings, the biological tank was filled with water until it just reached the exit hole. A wavemaker was placed at the bottom of the barrel to facilitate tangential flow. Activated charcoal was added in the biological filter to reduce the smell of water as well as to improve color (2013, "Advances in Pretreatment and Clarification Technologies).

Fig 18: Removing excess part of the tank and introducing bio media for setting up the biological filter

3.3.6. UV filter setup

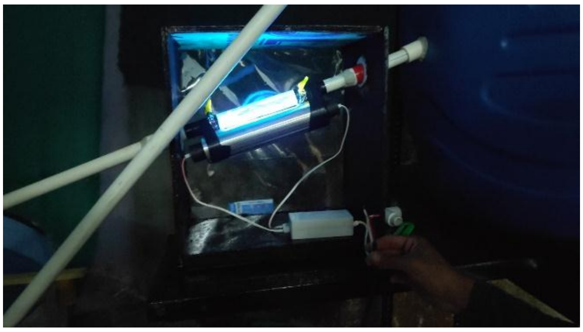

Fig 19: UV filter assembly

A wooden shell was created to house all the UV filter components (a two-side open cuboid). The position of the UV filter has to be at the right height and angle to fit between the biological filter and the culture tank. PLA (poly-lactic acid) connectors with the required hole inclination were designed and 3D printed on the Ender-3 3D printer. These connectors were used to connect the UV filter pipe and PVC pipe coming from the biological tank. To fit the quartz tubes into the connector, little UPVC pipes were connected to the ends of the tubes using hose clips. With this configuration, the 4W UV tube was attached to complete the UV filter.

Fig 20: Manufacturing of UV filter using conventional methods as well as modern CAD process

3.3.7. Pipe Connections

To prevent water leakage, "PVC cement solvent" was used to connect the pipes. All inner surfaces of the joints were coated with the cement solvent to ensure zero leakage. Supports were placed where possible to reduce the overhangs in pipes.

Fig 21: Entire setup of RAS system

3.3.8. 3D printing and fitting of feed delivery system

The automatic feed distribution system was designed and realized using the Ender-3 3D printer using PLA (poly-lactic acid). The stepper motor and the delivery flap were installed. The Arduino Uno board was stored in a box, coated with plastic wrap, along with the L293D stepper motor driver and a relay module. A one-inch cross section pipe was used to provide a pathway for feed to travel from the hopper to the container.

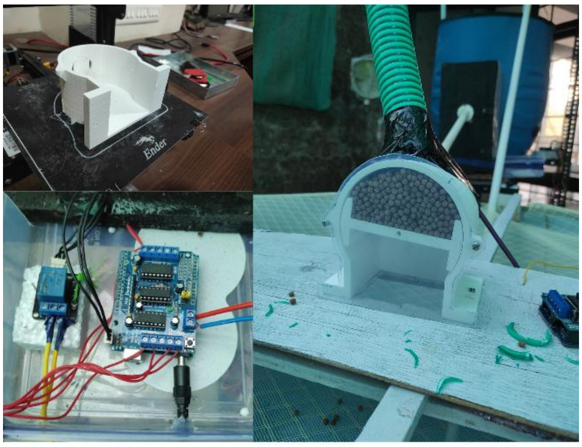

Fig 22: Manufacturing and assembly of feed delivery system

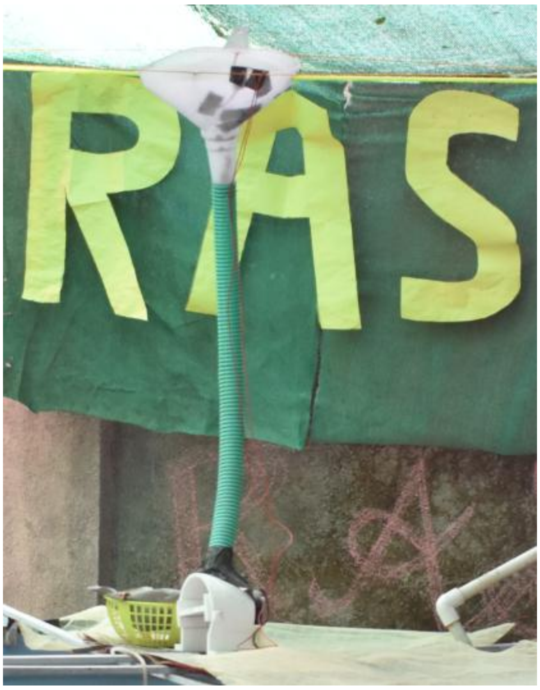

Fig 23: Complete setup of feed delivery system

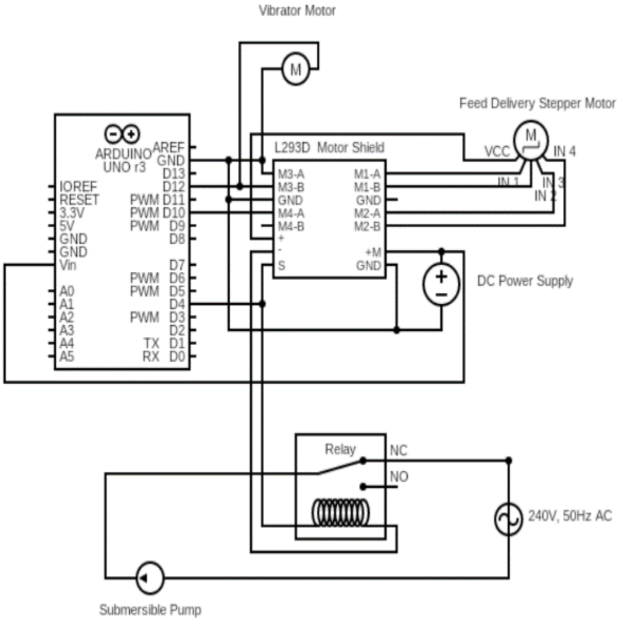

Fig 24: Circuit Diagram for feed delivery system and pump automation

4. Adding Tilapia in water

For the purpose of validating our RAS system, 100 fish, each weighing 200 grams were introduced to the system. Considering the time constraint fingerlings of tilapia were not used as they take time to grow up. 200g adult fish were the choice considering the extreme waste formation which would check the capacity of filters at the fullest. Salt water was introduced to the fish transport container. As osmosis attempts to equalize the salt content on each side of a semi permeable membrane, water is drawn out of the bacterium, fungus, and/or parasite's membrane or skin. Because the fish have greater water reserves and mass, the infections eventually succumb before their hosts do. Floating excreta was observed after a day because of sudden environment change while transferring fishes into tank and changed feeding conditions indicating the gases problem in fish. Metrogel-500 tablet was given along with the 4 days of starvation period and the gases problem was cured. Fish cornering the tank was observed once or twice indicating the less oxygen supply and higher ammonia levels. 20% water change was done for immediate reduction of ammonia. Extra air pump was introduced for improving DO level inside the tank.

Fig 25: Introducing 100 fish in culture tank

5. Nitrogen cycle and Testing

The nitrogen cycle is necessary for any biological filter to function. It was initiated just before the introduction of the fish. In order to reduce the cycle time, "Re-ocean Starter Bacteria", a ready to use bio-culture, was introduced to the biofilter. Our entire nitrogen cycle can be divided into three phases:(PPM)

Phase One (from 1 to 10 days):

Fish waste forms ammonia, which is highly toxic to most fish. Ammonia levels began rising from day 2.

Phase Two (from 11 to 18 days)

As nitrite-forming bacteria (Nitrosomonas) developed, ammonia was converted to nitrite, and while ammonia levels decreased, nitrite levels increased.

Phase Three (from 19 to 28 days)

As nitrate-forming bacteria developed (Nitrobacter), nitrite levels decreased, and nitrate levels increased.

When nitrates were produced, and ammonia and nitrite levels were zero, indicating that the tank was fully cycled, and the biological filter was fully functioning. At low levels, nitrates are not highly toxic to fish.

Fig 26: Day 05 – readings showing ammonia spikes in culture tank with maintained PH level

Fig 27: Day 28 – Result showing stable levels for ammonia, nitrite, nitrate, and PH

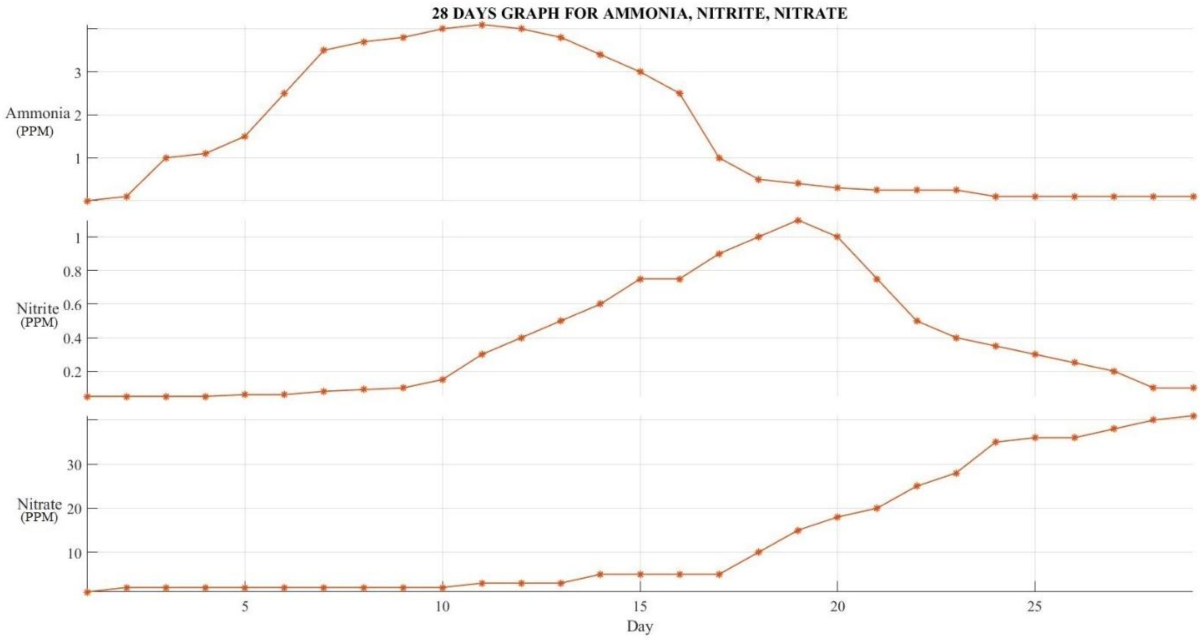

Fig 28: 28 Days graph for ammonia, nitrite, nitrate

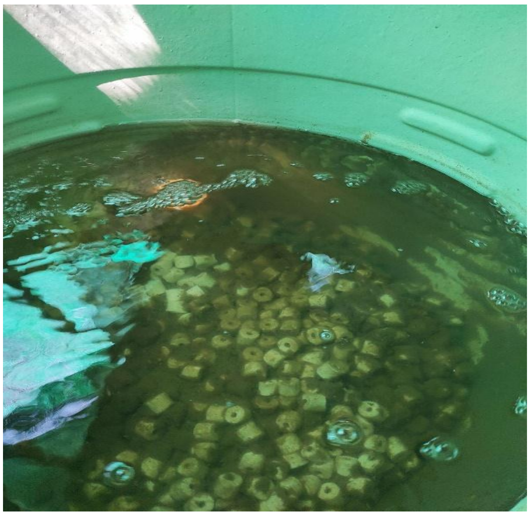

Fig 29: Clear water with bacteria colonization over biomedia

6. Maintenance

Maintenance included water exchange, topping up feed, cleaning mechanical filters, and regular inspection. In the summer, water has to be replenished more frequently than every two weeks due to increased evaporation. Every two days, cleaning was required for all three meshes and sponges in the mechanical filter.

7. FUTURE SCOPE

Introduction of temperature control devices and temperature sensors will improve the efficiency of the entire device by allowing us to maintain the water at an ideal temperature for fish growth as well as the biofiltration.

The design of the mechanical filter can be optimized to allow it to run for longer periods without the need of maintenance. Self-Cleaning mechanisms can be incorporated to reduce manpower dependency.

In a culture tank, hydroponics might be utilized to produce plants that provide fish food while simultaneously lowering ammonia levels (Aquaponics, G. G., 2022). The plants would provide the biofilter with additional surface area for the colonization of the bacteria.

8. CONCLUSION

Different mechanical and biological filter types were researched, and the right filter units were put into place.

The primary objective of this project was to design and develop a three-stage sustainable water filtering system for freshwater aquaculture. The whole RAS system was designed, manufactured, verified, and maintained in accordance with the structural criteria.

Ideation, market survey, product definition, design, prototyping and testing, were the product development stages followed during the course time.

Remarkable success in lowering the death rate - 91 fish were still alive after six months. In other words, we were able to limit the mortality rate to 10%.

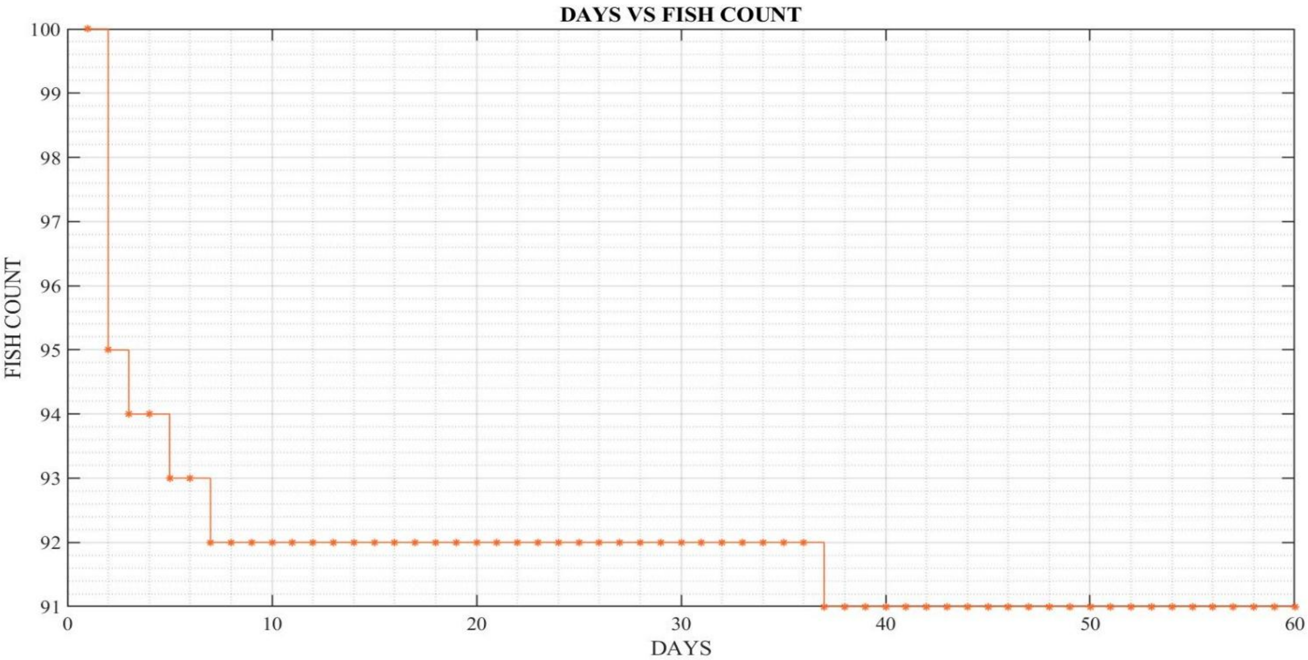

Fig 30: Fish vs Days count graph showing high mortality at the beginning and no mortalities afterwards

DECLARATIONS

Ethics approval (2020 Reporting animal research)

This article does not contain any studies containing animals performed by any of the authors. For clarification purposes, all procedures performed in the study were in accordance with the ARRIVE guidelines 2.0 and a full author's checklist has been submitted.

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Author contribution

All authors contributed equally to the study conception, design, analysis, results interpretation, and manuscript drafting.

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