ENVIRONMENTAL AND ENERGY REQUIREMENTS FOR DIFFERENT PRODUCTION DENSITIES OF NILE TILAPIA (*Oreochromis niloticus*) IN RECIRCULATING AQUACULTURE SYSTEMS: LABORATORY AND COMPUTER SIMULATION STUDIES

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Environmental and Energy Requirements for Different Production Densities of Nile Tilapia (O*reochromis niloticus*) in Recirculating Aquaculture Systems: Laboratory and Computer Simulation Studies

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

I dedicate this thesis to my late mother, Mrs. Margaret Wambua, for bringing me up with love and instilling good and strong virtues in me which help me which to date, have shaped my daily life. To my father, William Wambua, for educating me and teaching me the importance of reading, what good reading means, and further, for his continued support counsel, counsel, and good advice. To my wife, Ms. Jackeline Mbula and our sons Samuel and Joshua for the motivation and the trust, they have shown in me. In a special way, baby June who happened to be a blessing just a few days to my Thesis defence.

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LIST OF ABREVIATIONS AND ACRONYMS

DO	Dissolved oxygen
EC	Electrical conductivity
pH	Potential hydrogen
RAS	Recirculating aquaculture system
SSA	Specific Surface Area
TAN	Total Ammonia Nitrogen
Hp	Horse power

LIST OF NUMENICLATURES

Symbol	Definition	Units
$\mathbf{NH_3}$	Ammonia	mg/L
$\mathbf{NH_4^+}$	Ammonium	mg/L
$\mathbf{NO_3^-}$	Nitrate	mg/L
$\mathbf{NO_2^-}$	Nitrite	mg/L
ρ	Density	kg/m^3
Q	Flow rate	m^3/s or L/min
V	Volume	L or m^3
g	Acceleration due to gravity	N/kg or m/s^2
$\mathbf{VO_2}$	Specific Oxygen Consumption	$mgO_2/kg.hr$

ABSTRACT

A Recirculating Aquaculture System (RAS) attempts to provide sustainable utilization of the available water resources by reducing water pollution and water acquisition costs. Improper matching of RAS components yields inflated cost of production and consequently leads to system failure. The significant challenges in RAS are to maintain favourable water quality for the fish and create conducive conditions that minimize the cost of energy required. In Kenya, many Recirculating Aquaculture Systems have not been able to strike a balance between the optimal levels of water parameters and the cost of energy required to run the system. This study, therefore, aimed at evaluating environmental and energy requirements for different production densities of Nile tilapia (*Oreochromis niloticus*) in a RAS. In this study, both production density and water flow rates were varied, and water quality parameters namely Dissolved oxygen, ammonia, pH, EC, and temperature monitored. Tilapia stocking densities were varied between 2.3 kg/m^3 and 10 kg/m^3 while flow rate was varied from 2.0 L/min and increased at intervals of 1 L/min to a flow rate of 10 L/min. The energy consumed for the different stocking densities and flow rates was also monitored using installed electricity meters. Crushed pumice rock packed in a 1000L tank was used as the biofilter. A RAS prediction model, model based on physical, chemical, or biological laws and theories, was developed using the Matrix laboratory (MATLAB) app-designer programming environment. Purification efficiency (PE) was computed as a proportion of the amount of ammonia removed from the RAS water by the biofilter. The study showed that ammonia removal was reduced with an increasing flow rate. The Purification Efficiencies (PE) of the pumice rock biofilter ranged from 79.18% at 2.0 L/min to 9.79 % at 10.0 L/min. Both pH and Electrical conductivity increased with increasing flow rate at all stocking densities. Dissolved oxygen increased with flow rate. The energy demand by the pump and the aerators increased progressively with flow rate from 0.5 kWh at 2.0 L/min to 2.3 kWh at 10.0 L/min. The developed RAS model made predictions of energy and water quality for different stocking densities and flow rates. An evaluation of the model prediction accuracy by comparing the observed data and the model predicted data gave R^2 values for ammonia, pH, dissolved oxygen,

electrical conductivity, and energy as, 0.95, 0.89, 0.23, 0.87 and 0.85 respectively. The study showed that environmental parameters of a RAS are greatly affected by variations in stocking densities and flow rates ($P<0.05$). Energy consumption increased from as low as 0.4 kWh at 2.0 L/min to as high as 2.3 kWh at 10.0 L/min for each stocking density. The developed RAS model demonstrated sufficient capability to predict environmental requirements for different stocking densities. From the study, we recommended that to maintain good RAS water quality and increased production and profits among farmers using RAS in Kenya, the right combination of stocking density, energy, and water flowrate should be utilized in RAS practices. More similar studies on RAS should be carried out for other fish species such as African catfish as well as with other biofilter media other than pumice to develop suitable biofilter materials for use in RAS for increased fish production.

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Recirculating Aquaculture System (RAS) is a system that employs the principles of efficient water utilization and conservation to maximize production of the target organism while minimizing pollution and water costs (Lekang, 2013). Demand for RAS has been brought about by the increasing need for white meat around the world, Kenya included. The fish harvesting from natural water bodies has been on the decreasing trend (FAO, 2016). The ever-reducing water and land resources present a situation where aquaculture systems with little water and land requirements are needed. These can be achieved through systems such as RAS that take up less space and need less water to produce aquatic organisms (Avnimelech, 2006).

With RAS, fish can be produced in the home backyards, and the family white meat demands met at low costs and additionally, provide a source of income through the sale of the surplus. The most limiting issues in RAS production systems must be addressed in order to achieve the efficiency of the RAS production systems (Avnimelech, 2006; Pillay & Kutty, 2005). The two most limiting issues that pose a significant challenge to individuals willing to utilize the RAS for fish production are, (i) water quality and (ii) cost of energy. These come in as a result of the farmers using improperly designed RAS to match their production goals (Crab et al., 2007). Improper matching of RAS components such as pipes, aerators, pumps and production density may lead to the inflated cost of production and ultimately result in the system failure. These RAS design challenges make the production of fish using RAS very expensive with some farmers incurring huge losses while others were taking up to eight years before the system pays back (Badiola et al., 2010).

Fish stocking density must be matched with the water recirculation rates in order to address the issue of water quality in aquaculture. The biofilter material which is the home

to the nitrifying bacteria facilitates the conversion of ammonia into the non-toxic forms of nitrogen before the water is pumped back into the production system (Badiola et al., 2010; Gutierrez-Wing & Malone, 2006). Unfortunately, in Kenya, there are no developed specifications and standard designs for various RAS stocking density.

Most farmers in Kenya practising fish production using the RAS, use locally available inert materials such as sand and charcoal for the bacterial films to grow and remove ammonia in the RAS water. Sometimes these materials can be combined with live plants for the uptake of the nitrates upon conversion from ammonia and nitrites (Obwanga, Lewo, & Bolman, 2017).

1.2 Statement of the Problem

Fish farming in Kenya is an industry which has not found much advancement among farmers as well as those supporting it (Ngugi, Bowman, & Omolo, 2007). RAS is one type of the various modes of aquaculture practised in Kenya (Munguti et al., 2014). The biggest challenge in intensive fish production is to maintain favourable water quality for the fish to thrive and at the same time embrace systems that minimize the cost of energy required for pumping and aeration (Pillay & Kutty, 2005). Most of the existing Recirculating Aquaculture System in Kenya have not been able to strike a balance between the conducive levels of water quality parameters and the cost of energy required to run the system (Timmons & Joseph, 2010).

Most of the farmers practising inland fish farming use the pond and raceway systems majorly due to availability of water to refill the system. With these old systems, it is cheaper to get new water and release the polluted water instead of treating it and returning it into the system (Obwanga et al., 2017). Nevertheless, water sources are decreasing day by day from competing needs while the amount of land available for setting up large fish ponds with little fish stocking is diminishing due to land fragmentation. RAS provides an answer to the problems of reducing water and land requirements for fish production. However, the attendant costs of water treatment and pumping for water recirculation and

reuse must be considered. This research aimed at determining the energy and environmental requirements for different RAS production densities.

1.3 The Objectives

1.3.1 Main Objective

The main objective of this study was to evaluate environmental and energy requirements for different production densities in a Recirculation Aquaculture through laboratory and computer simulation studies.

1.3.2 Specific Objectives

The specific objectives of this study were to:

1. Determine the variation of environmental parameters with Nile tilapia (*Oreochromis niloticus*) production density and water flow rates in Recirculation Aquaculture Systems.
2. Determine the energy requirements for environmental control of different production density in Recirculation Aquaculture Systems
3. To develop and evaluate a prediction computer model for management of Recirculating Aquaculture System.

1.4 Research Questions

The research questions for this study were:

1. How do the different environmental parameters of water vary with flow rate and production density in Recirculating Aquaculture Systems with Nile tilapia (*Oreochromis niloticus*)?
2. What are the energy requirements for the different production densities in Recirculating Aquaculture System?
3. How accurate can the RAS prediction model predict energy and water quality parameter for different production densities?

1.5 Justification

With a small portion of land, one can raise a considerable number of fish in tanks where the water is well aerated, and contaminants are continuously removed. RAS provides a conducive environment for fish growth with little water requirements and the possibility of high productivity as compared to pond and raceway systems (Pillay & Kutty, 2005). Moreover, with RAS, the outlet water is cleaned and used again, which means that the amount of new water added can be reduced (Lekang, 2013). However, the main challenge in RAS is to remove ammonia from water and create a conducive environment for the fish to thrive while keeping the system profitable at the same time (Avnimelech, 2006).

Up to date, no research in Kenya has been dedicated to producing standards for RAS system with different stocking densities. As a result, those practising RAS continue to make avoidable losses (Munguti et al., 2014). With no standardization of RAS in the country, most of the farmers practising this intensive system end up developing systems which lead to losses through fish deaths. High flow rates lead to unnecessary expenses on energy and inadequate removal of ammonia and other contaminants (Obwanga et al., 2017). Since the inception of devolution and devolvement of agriculture, most counties especially those endowed with adequate water and land resources have focused on aquaculture to increase food production, generate incomes for individual, eradicate poverty and spur the growth of the devolved units. However, most of the aquaculture interventions used to achieve the above objectives are tied to the less effective aquaculture production methods which require ample space and vast volumes of water. These, therefore, bring in the need to adopt such aquaculture production systems such as RAS that utilize water and land resources in such a manner to spare the same resources for other agricultural purposes.

An 8 m by 15 m and 1 m average depth pond holds approximately 120 m^3 can carry approximately 400 kg of fish at maturity which translates to 3.3 kg/m^3. An average RAS has the capability of carrying more than 7 kg/m^3. This more than halves the quantity of water required to produce the same quantity of fish.

1.6 Scope and Limitations of the Study

The study involved the design of a RAS that constituted a set of three production tanks with a shared mechanical and biological filter for the management of ammonia. Only flow rates and stocking densities were varied during the study. For the different flow rates and stocking densities, the environmental parameters such as ammonia, pH, dissolved oxygen, temperature, electrical conductivity and energy consumption for pumping and aeration were measured. The study was a laboratory-scale set-up that allowed for close monitoring of the RAS processes. The experiment was set-up at Jomo Kenyatta University of Agriculture and Technology (JKUAT) main campus. A predicting model was developed to help in the management of RAS water quality and energy for RASs of different stocking densities.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Overview

Recirculating Aquaculture Systems (RAS) used for farming aquatic organisms employ the principle of reusing the outlet water from the production tanks instead of discarding it and getting new water for the system (Rahman, Verdegem, & Wahab, 2008). As a result, the quantity of new water required is reduced, thus reducing pressure on water supply systems (Avnimelech, 2006).

RAS has been in existence as early as the 1950s, although their potential to grow fish on a commercial-scale has only been realized in the past few years (Badiola et al., 2010). Upon realization of the potential of RAS, water quality technology, testing and monitoring instrumentation widely used in wastewater treatment has been extended to RAS. According to Helfrich and Libey (1991), tank aquaculture systems can be referred to as closed aquaculture systems. It is possible to recycle all the water from the production tanks such that the replacement of water will only be done to cater for evaporative needs or consumptive needs of the fish (Lekang, 2013).

2.2 Limitations of RAS

Due to the high cost of treating and purifying the effluent from the production system, the possibility of 100% recycling is not usually possible (Badiola et al., 2010). The quality and quantity of water, leaving the production tanks to differ from one system to another, depending on the type of aquatic organisms being raised (Avnimelech, 2006; Kazmierczak & Caffey, 1996). These make standardization of RAS for different cultured species complex since some organisms can tolerate higher levels of contaminants as compared to others, for example, tilapia can survive levels of dissolved oxygen (DO) below 2.3 mg/L. At the same time, trout requires oxygen concentrations of at least 4.0 mg/L to survive (Ngugi et al., 2007). As a result, the levels of contaminant removal will be different for different species of aquatic organisms.

Moreover, RAS is not a completely closed system since some water replacement has to be done to compensate for evaporative losses and water lost to flushing settle-able solids. This water replacement is done because no biofilter material is 100% efficient.

2.3 Recirculating Aquaculture Systems

A Recirculating Aquaculture System (RAS) includes the production unit which houses the aquatic organisms, a pump to transport the water around the system and water treatment system to remove contaminants from the effluent water, a pipe network joining, the production tank, the pump and the treatment system and sometimes an aeration component to add oxygen to the water (Lekang, 2013). The pump for recirculating the water and the water filtration system for removing contaminants from the water are the items that make the RAS system distinct from traditional flow-through systems. Physical, chemical and biological processes are involved in the water treatment system to improve the water quality to levels which the farmed species can tolerate and remain productive (Van Rijn, 2013). According to Lekang (2013), due to the water-conserving nature of RAS, aquaculture can be practised in areas where water is a limiting factor. Moreover, production in established farms can be increased with the available amounts of water.

Aquaculture water reuse systems will be the most suitable in the current situation of diminishing freshwater resources and increasing competition for the same resources (Colt, 2006). With reuse systems, there are fewer energy requirements for heating where heating is required to keep the water at a desirable temperature for the organisms. RAS has proved to be effective and efficient in the usage of water and land. With RAS, production can be maximized in a small area of land with up to 80% reduction on the amount of water needed (Martins, et al., 2010; Helfrich & Libey, 1991).

RAS systems are also easier to clean and have fewer costs associated with water treatment and water delivery, especially if the water used in the production has to be cleaned or is pumped before use (Crab et al., 2007). However, RAS, despite their many pros, have several limitations (Pillay & Kutty, 2005). These include the initial costs of installation, the operation costs and costs of maintenance. Due to the high level of technology applied

in the RAS systems, the system requires close, frequent and knowledgeable monitoring for efficient functioning. The pump, filter, aeration, heating and biofilter systems used are all prone to failure, and a few minutes failure can lead to huge losses. The system design and installation requires good knowledge in engineering as well as in life organism biology and husbandry (Badiola et al., 2010). As a result, it is agreeable that the design of a water reuse system requires a good understanding of the interactions between biology, chemistry, physics engineering and economics. As at present, there are no identical systems in RAS, and therefore this makes it challenging to construct a useful RAS using a particular example. A right choice of an effective biofilter whose Purification efficiency is known may also prove to be very expensive to acquire.

2.4 A Brief Review of RAS in Kenya

Aquaculture, the fastest growing sector of food production, is increasing rapidly in Kenya (Tschikof, 2018). The dominant aquaculture systems in Kenya include earthen and lined ponds, dams, and tanks distributed across the country (Munguti et al., 2014). The adoption of modern, sustainable, aquaculture technologies and practices such as recirculating aquaculture systems (RAS) will aid in increasing food security and decreasing the current reliance on imported fish and stressed wild stocks (Clough et al., 2020). Recirculating aquaculture systems (RAS) are intensive cultivation technologies recently introduced to Africa that try to address environmental concerns, including high water consumption and nutrient pollution (Tschikof, 2018). The maintenance of optimal water quality for fish production is one of the significant challenges in aquaculture. Aquaponics systems can improve the quality of water for fish by removing the undesirable wastes and in turn, produce a second marketable crop (Gichana et al., 2019). Currently, there are no documented RAS practices in the country on a commercial scale. Most of the reported cases are on laboratory studies majorly on biofilter materials. According to Munguti et al. (2014), the dominant aquaculture systems in Kenya include earthen and lined ponds, dams, and tanks distributed across the country.

2.5 RAS Components and Water Quality

Figure 2.1 presents a typical layout of an intensive RAS with crucial system components (Brinkop & Piedtrahita, 1996). The Figure shows the various components which constitute a RAS system and through which the RAS water has to go through. However, not all the components will be found in most RAS systems.

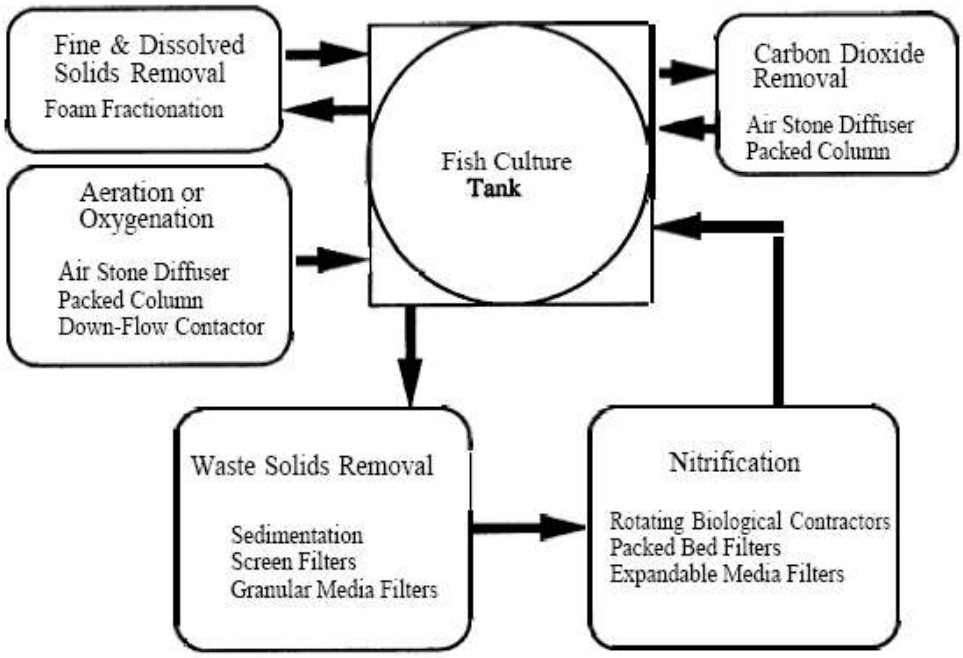

Figure 2.1: A Typical Layout of an Intensive RAS with all System Components

A standard RAS constitutes the fish production tank, the aeration system, a biofilter, a pump and a connection pipes for recirculating water and reliable energy supply. Some sophisticated systems can include a heating system, a filtration system, and a disinfection system among other systems (Lekang, 2013). The more the components, the more expensive the system and the more it requires experienced personnel to operate. Most RAS have relatively long payback periods of up to 8 years, mostly due to high initial costs (Badiola et al., 2010).

In typical RAS systems, fish is stocked in the tank at a low weight and grow over time to harvest weight with feed being supplied over time. When ready for harvest, the fish are at

their most massive weight while the feed rate is also at its highest. At this stage, fish excrete the most ammonia while bacteria in the biofilter consumes the most oxygen and releasing the most carbon dioxide. As a result, a RAS should be designed such that the water flow satisfies the fish environmental conditions throughout their growing period (Alt, 2015). Most of the biological or management problems experienced in RAS can be attributed to the poor initial design of the RAS modules (Badiola et al., 2010). The type and number of organisms to be raised is determined by the water requirements of the system in order to satisfy the oxygen requirements of the fish, dilute and remove waste products to acceptable levels and ensure self-cleaning of the tanks.

The water flow required to satisfy the oxygen requirements of the aquatic organisms, specific water flow per kilogram of fish-Q_{in}, depends on the oxygen concentration of the inlet water (C_i), the specific oxygen requirements of the fish (M_{sp}) and the concentration of oxygen in the outlet water (C_o). In mathematical form, this can be expressed, as shown in Equation 2.1 after Lekang (2013):

$$Q_{in} = \frac{M_{sp}}{C_{in-}C_o} \quad \text{..... (2.1)}$$

2.1)

To dilute and remove substances produced by the fish from the RAS water, i.e. CO2, TAN and suspended solids, the amount of water required is calculated based on mass balance. Equations for a single substance as presented in Equation 2.2 after Chen et al., (2006) and given as:

$M_{in} + M_{ro} + M_f = M_o$ ……. ……. (2.2)

Where:

M_{in} = mass of substances in the new incoming water (mg)

M_{ro} = mass of substances from water entering from the re-use circuit (mg)

M_f = mass of substances produced by the fish in the tank (mg)

M_o = mass of substance in the outlet from the tank (mg)

The concentration of a substance in the outlet from the tank (Co) can be calculated if Mo and the water flow out of the tank Qo are known as given in Equation 2.3:

$$Qo \geq \frac{M}{C_{o-acc}} \quad \text{(2.3)}$$

Where;

Co-acc is the acceptable concentration of the substance in the outlet to avoid a reduction in growth. According to Lekang (2013), in order to properly size the various RAS components, the connection between outlet concentrations, degree of re-use and effectiveness of the water treatment system must be established. The concentration of substances in a RAS increases gradually from a minimum until it stabilizes at a given level. If "C" is the concentration at the tank outlet of a re-use system, (M_f/Q_{out}) the concentration at the outlet of the flow-through tank, R is the degree of re-use, and re is the removal efficiency of the filter system in the circuit, then the concentration can be calculated according to Equation 2.4:

$$C = \frac{1}{(1-R+(Rre))} \frac{M_f}{Q_{out}} \quad \text{(2.4)}$$

By re-arranging the Equation 2.4, the desired efficiency of the biofilter system and the acceptable degree of re-use for a chosen biofilter system can be calculated.

The Purification efficiency is a factor of water flow into the fish tank and from the fish tank as well as the biofilter's efficiency, which in turn determines the hydraulic detention time of the effluent water for the removal of TAN. Given the biofilter capacity and the flow through the biofilter, the detention time can be determined using Equation 2.5:

$$\text{Detention time} = \frac{\text{Biofilter capacity (L)}}{\text{Prevailing water flow rate(L/min)}} \quad \text{(2.5)}$$

The system recirculation time, on the other hand, refers to the amount of time taken to move the water in the system through one cycle. It is obtained by dividing the capacity of the culture tank by the prevailing flow rate, as presented in Equation 2.6:

$$Recirculation\ rate = \frac{culture\ tank\ capacity\ (L)}{Prevailing\ flow\ rate\ (L/min)} \quad \text{(2.6)}$$

Most RAS systems are designed to provide at least one turnover per hour, which translates to 24 turnovers per day.

According to Badiola et al. (2010), trickling filter is the most expanded type of biological filtration used in RAS. As at present, proper design and management of commercial-scale RAS biofilter have been made difficult by the continued investigations in laboratory-scale biofilter modules which are entirely dissimilar to the large scale biofilter (Badiola et al., 2010). The trickling type of biofilter is more reliable and inexpensive as compared to other commercial biofilters, and increased research in this biofilter will provide for improvement in its cleaning efficiency.

2.5.1 Fish Tank

The size of a fish tank depends on several factors including stocking rates, fish species selected, quality of water and economic considerations (Pillay & Kutty, 2005). The design of the tank must correspond with the capacity of the other RAS components, especially the size of the biofilter. Aquaculture tanks can be made from a variety of materials such as concrete, fibreglass, marine plywood, metal or other hard substances (Azim & Little, 2008). However, only durable and smooth-surfaced materials that are free from toxic chemicals are used for the construction of aquaculture tanks. Fibreglass has recently become a popular material for tank construction due to its lightweight (Pillay & Kutty, 2005). However, fibreglass is relatively expensive as compared to metallic tanks. Metal tanks can readily be obtained in the market in many places and can be quickly erected or dismantled. Circular tanks are friendly to the cultured fish as the fish can swim all along without making sharp turns as is the case in rectangular tanks.

Moreover, the tanks are easy to install and clean as the water supply, and drainage in such tanks can be organized in such a way as to create a vortex that sweeps most of the detritus and other waste material out of the system (Avnimelech, 2006; Pillay & Kutty, 2005). The size of the fish tank is determined by the expected carrying capacity depending on the type of fish to be raised (Wik, Linden, & Wramner, 2009). However, regardless of the shape

of the tank, the water quality that can be maintained in RAS determine the most appropriate stocking density that can be used in a RAS.

2.5.2 Fish Stocking Densities

Stocking density in aquaculture refers to the number or mass of fish in a unit volume of water. It is commonly expressed in kilogram per cubic meter (kg/m^3). Stocking density is a critical aspect in aquaculture practice as it helps in computing system requirements such as feeding, aeration and biofilter requirements.

According to Ngugi et al. (2007), the average stocking rate in a pond system is 2-6 fingerlings per cubic meter which is approximately 2 – 3 kg/m^3 of fish a maturity. However, RAS being an intensive system, fish stocking rates of 2 kg/m^3 and above are used (Sri-uam, Donnuea, Powtongsook, & Pavasant, 2016; Gibtan, 2008; Ridha, 2006). Moreover, Liu et al. (2016) in a study on the influence of stocking density on growth performance and physiological response of juvenile turbot, Scophthalmus maximu, reared in land-based recirculating systems used 5.1 kg/m^3, 7.7 kg/m^3 and 10.8 kg/m^3 as low, medium and high stocking densities respectively. However, according to Ellis et al. (2002) in Liu et al. (2016); it is crucial to find a balance between the maximum gains and the minimum incidence of physiological disorders and growth inhibition for cost-effective production.

Stocking densities of up to 15 kg/m^3 have been used successfully in cage systems and RAS studies depending on the levels of water quality and environmental control (Gibtan, 2008; Ridha, 2006; Sriuam, 2016). On the other hand, stocking densities below 3 kg/m^3 have been used in pond systems successfully. From the preceding, stocking densities 2 kg/m^3 to 10 kg/m^3 are appropriate in RAS depending on the levels of biofiltration and environmental control.

2.5.3 The Biofilter

Biological filtration abbreviated as bio-filtration is the most commonly used method for ammonia removal (Schreier, Mirzoyan, & Saito, 2010). The biofilter is the heart of the RAS. A biofilter is composed of media such as; plastic granules, sheets or beads, gravel, volcanic rock or sand grains on which bacteria film grows. The bacteria so housed in the biofilter assist in waste treatment by removing pollutants. The primary water pollutants in a RAS that need to be removed are fish waste, which is primarily ammonia, and uneaten feed remains (Gutierrez-wing & Malone, 2006). Bio-filtration involves oxidation of ammonia to nitrite, and finally to the less toxic nitrate. The process involves two types of bacteria — Nitrosomonas (ammonia) and Nitrobacter (nitrite to nitrate), as shown by process Equations 2.7 to 2.9 given as:

$NH_{3(aq)} + H^{+}_{(aq)} \rightleftharpoons NH_4^{+}{}_{(aq)}$, mostly influenced by the water pH…….(2.7)

$NH_4^{+}{}_{(aq)} + 2O_{2\,(g)} \longrightarrow NO_2^{-}{}_{(aq)} + 2H_2O_{\,(l)}$, by the nitrosomonas bacteria.....(2.8)

$2NO_2^{-}{}_{(aq)} + O_{2(g)} \longrightarrow 2NO_3^{-}{}_{(aq)}$, by the nitrobacter bacteria ……...(2.9)

The Nitrosomonas bacteria convert ammonium to nitrites while the Nitrobacter bacteria convert the nitrites to nitrates. The two processes are aerobic can only occur in the presence of oxygen. For biofiltration to take place, a substrate that has a high specific surface area (SSA), i.e. a large surface area per unit volume is required to provide attachment sites for the bacteria. The amount of biofilter material used depends on the biofilter specific surface area on which nitrifying and denitrifying bacteria can grow and remove ammonia from the water, leaving the fish tank (Timmons & Joseph, 2010). The rate of feed consumption by the fish and the amount of ammonia excreted determines the size of the biofilter required. An ideal biofilter media is one with a high surface area, sufficient pore spaces for water movement, is clog resistance and easy to clean and maintain (Helfrich & Libey, 1991; Kroupova, Machova & Svobodova, 2005). The feed fed per day is estimated as 4% of the total body weight of the fish.

Moreover, the ammonia production by the fish is estimated to be 2.5% of the feed fed to the fish (Alt, 2015; Crab et al., 2007). It is not possible to get an ideal biofilter media that

can provide a 100% removal of wastes to produce in a RAS. However, most materials used in conventional wastewater treatment can provide reasonable purification rates of RAS water if operated with care and proper maintenance.

2.5.3.1 Inoculation of Biofilter

A newly constructed biofilter requires an establishment time. The establishment time is the time between its construction and the time it can effectively remove a significant proportion of the contaminant of interest. To accelerate this establishment process, an inoculant, water or substrate that contains the bacteria of interest, is introduced to the newly constructed biofilter (Yang Chou & Shieh, 2001). Inoculation helps to accelerate the bacteria multiplication and hence rapid colonization of the biofilter media. Raw water from a nearby fish pond can serve as an excellent inoculant to accelerate the growth of the nitrifying bacteria in a newly constructed RAS (Helfrich & Libey, 1991).

2.5.3.2 Ammonia Removal

Ammonia is the primary product of fish waste, and due to its toxicity at high concentrations, its levels must l to provide a conducive environment for the fish in the tank (Masser, Rakocy & Losordo, 1999). In water medium, there is equilibrium between the concentration of ammonia (NH_3) and ammonium (NH_4^+) ions at a given temperature and pH (Fontenot, Bonvillain, Kilgen, & Boopathy, 2007). The equilibrium, shown in Equation 2.8, depends on temperature and pH. The conversion of one of the equilibrium components compensates a decrease in the other component.

Total Ammonia Nitrogen (TAN) is the sum of the ammonia and ammonium ions in the water. For a long time, biological filters have been used for the removal of ammonia through its conversion to nitrites then to less toxic nitrates. Ammonia (NH_3), is highly toxic to fish and therefore, should be kept at levels below 0.05 mg/L (Shulin, 2014). On the other hand, Chen et al. (2006) argue that the acceptable levels of unionized ammonia should be 0.0125 mg/L. Chen et al. (2006) observed that there is the consumption of about

4.18 g of oxygen and 7.07 g of alkalinity (as $CaCO_3$), and production of 0.17 g of bacteria biomass for every 1.0 g of TAN converted to nitrate nitrogen.

The oxidation of ammonium to nitrate leads to the production of an intermediate component, nitrite. At high concentration, nitrite is a potential problem for freshwater fish. At high concentration, nitrite take-up across the gills in competition with other radicals and anions such as chloride (Cl^-) which is one of the most important factors influencing the toxicity of nitrite to fish (Kroupova et al., 2005). As a result, nitrite (NO_2^-) levels should be kept below 0.5 mg/L to avoid fish poisoning (Helfrich & Libey, 1991). Ammonia production estimates in the tank per day are around 25 mg of ammonia for every 100 g of fish in the tank. However, scaling down on the fish feed, adding freshwater or reducing the fish stocking density reduces the amount of ammonia produced.
Similarly, ammonia loading can be estimated based on the feed fed to the fish by taking the ammonia produced as 2.5% of the total feed fed (Webb, Hitzfelder, Faulk, & Holt, 2007). For the nitrification process to take place, a sufficient continuous flow of water from the culture tank must pass through the biofilter. Favourable water temperature and water quality, i.e. pH, oxygen and salinity must also be maintained to provide the bacteria with a conducive nitrification process (Sugita, Nakamura, & Shimada, 2005).

The effectiveness of the biofilter can be described by the nitrification rate, which is the amount of ammonium oxidized per unit biofilm surface area per unit time (mg $NH_4^+/(m^2$ day). However, according to Lekang (2013), the growth of bacteria culture is affected by the concentration of ammonia in the effluent water, the water temperature, oxygen concentration, the pH of the incoming water, organic substances and toxic substances. Moreover, the for maximum bacteria growth ammonia concentrations above 3 mg/L is recommended. Also, adequate oxygen must be available throughout the entire nitrification process. Nitrification, being an aerobic process, requires oxygen. For every 1.0 milligram of ammonia converted, about 5.0 milligrams of oxygen is consumed.

Moreover, another 5.0 milligrams of ammonia is required to satisfy the nitrifying bacteria oxygen demands (Helfrich & Libey, 1991). Experiments have shown a reduction in Nitrosomonas activity with oxygen levels below 4 mg/L while the corresponding value for the nitrobacteria is 2 mg/L. Similarly, the action of the two bacteria on ammonia and nitrites increases with temperature to optimize at around a temperature of 30º C (Chen et al., 2006). Nitrification is also optimal at a pH of 8.0 to 9.0. Experiments by Odegaar (1992) have shown that the nitrification process reduces by 90% when pH falls from 7.0 to 6.0.

2.5.3.3 Wastewater Treatment Methods and Systems

The most commonly used biofilter in RASs are the ones used in the municipal wastewater treatment for a long time. They include the rotating biological contactors (RBC), the trickling filters and the fluidized bed filters. The rotating biological contactors are based on the rotation of the filter media attached to the shaft partially submerged in water. The nitrifying bacteria coat the surfaces of the filter media. The filter spends 40% of the rotation time submerged and 60% of the time exposed in the air to provide for the oxidation process. The RBCs have a treatment capacity of 3.6 kilograms of feed/day/m^3, assuming that 2.5% of food becomes Total Ammonia Nitrogen (TAN) (Van Rijn, 2013).

In trickling filters, wastewater is introduced into the filter media and moves through the media upwards, horizontally or vertically downwards. The non-submerged nature of this type of biofilter allows for aeration and removal of carbon (IV) oxide from the effluent waters. Trickling filters have a relatively higher efficiency of 90 grams TAN/day m^3 of a

medium compared to RBC. Figure 2.2 shows a simple section of a trickling biofilter (Tomer & Wheaton, 1996).

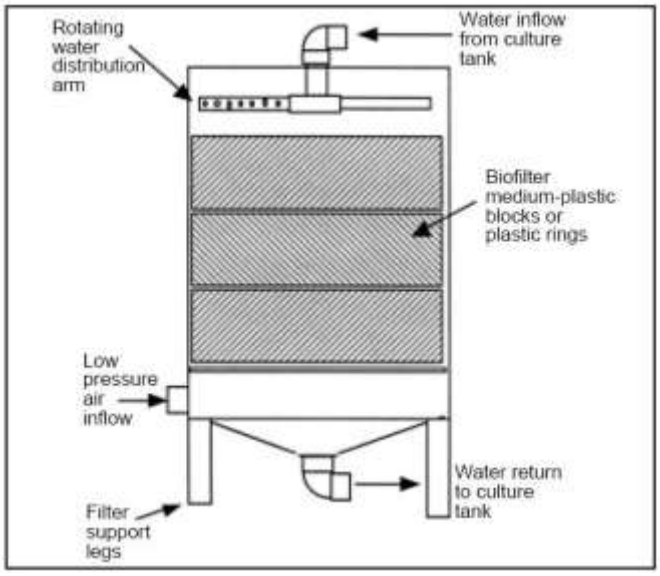

Figure 2.2: A simple Section of a Trickling Biofilter

The fluidized bed filters operate continuously on a backwashing mode so that the sand or plastic media becomes fluidized. These filters use finer-grained media and are usually tall columns, thereby minimizing space consumption. However, their efficiencies are relatively lower than those of trickling filters. Fluidized bed filters need additional aeration before and after passing the filter in order to prevent the reduction of ammonia removal efficiency (Turcios & Papenbrock, 2014). Both the RBC and trickling biofilter do not require additional oxygen to the water before the nitrification process. They indeed provide for the incorporation of oxygen in the water as the water passes through the media, thereby reducing aeration requirements of RAS system (Brinkop & Piedtrahita, 1996). For this reason, these two types of biofilter are most preferred to the fluidized Bed Reactor (FBR) in the treatment of RAS water (Helfrich & Libey, 1991).

Wetland systems can also be used in the treatment of aquaculture wastewater. Wetland systems consist of extensive areas of land on which vegetation materials with high

nitrogen and phosphorous absorption rates are grown. The systems harbour bacteria which convert ammonia and other phosphate compounds into forms that can be assimilated by the plants (Raude, Mutua, & Kamau, 2018). The plants then use the nutrients in the form of nitrates and phosphates and hence prevent eutrophication of surface water systems into which this water flows into (Turcios & Papenbrock, 2014). However, due to the extensive areas of land required by these wetlands, they are less desirable for use in treating RAS wastewater since RAS aims at utilizing a small space as possible. Figure 2.3 shows a general setup of a wetland treatment system for aquaculture wastewater (Turcios and Papenbrock, 2014).

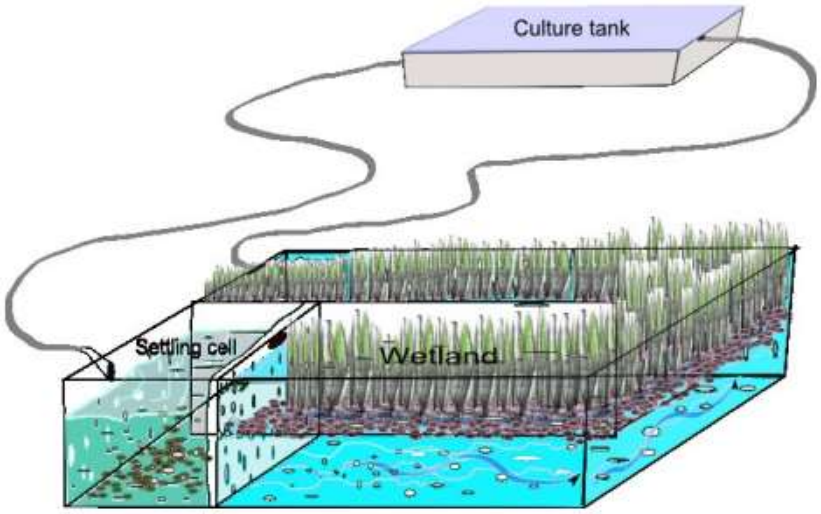

Figure 2.3: A General Outline of a Wetland Treatment System

2.5.4 Pumps and Aerators in a RAS

The RAS is a complex system whereby the speed, pressure and direction of water flow are critical to the efficient functioning of each of the RAS components (Pillay & Kutty, 2005). The flow of water may require to be pressurized to facilitate filtration where a fine mesh filter is used for mechanical filtration. On the other hand, the pump's flow rate must be regulated to provide the desired retention time in the biofilter (Gutierrez-Wing et al., 2006). Movement of water between RAS components is unavoidable and forms the most significant component of operational costs together with feeds. As a result, water reuse

systems have a high cost of operation associated with correspondingly high energy costs that are associated with the pumping of the purified water back to the production tank. Therefore, the appropriate type of pump that delivers a considerable head at a low energy rating becomes the most suitable for work in RAS (Badiola et al., 2010). Therefore for the sustainability of RAS, pump selection is a critical component that should guide the system is operating at optimum conditions.

There exists a wide range of pumps in the market with each type of pump suited for different use. Such pumps include reciprocating or piston pumps, rotary pumps with screws and gears, peristaltic pumps (accurate delivery, but at small volumes), centrifugal pumps (with impeller blades in a housing), and airlift pumps. Each of these varieties has or may have a specialized use.

The factors considered in the selection of a pump include the type and properties of liquid the pump is supposed to pump, compatibility with other construction materials, and the pump inlet size. Also considered are the net positive suction head (NPSH), the pump's adaptability to environmental conditions, energy source, energy rating of the pump, the flow rate, and pressure the pump can deliver (Larralde & Ocampo, 2010). Centrifugal pumps are by far the most commonly used pumps in RAS. They come in relatively small sizes and can work at a wide range of environmental condition (Larralde & Ocampo, 2010). Moreover, these pumps deliver considerable heads and have relatively lower energy consumptions as compared to other pumps. The size of the pump should be such that it can sufficiently pump back all the treated water back to the fish tank. As a result, the selected pump should be such that it can accommodate a range of flow rates designed for the biofilter. A pump's pumping rate Q_{pump} must be greater than or equal to the flow rate through the fish biofilter, $Q_{biofilter}$, as shown in Equation 2.10.

$$Q_{pump} > Q_{biofilte}. \quad (2.10)$$

On the other hand, an aerator is an air pump which pumps air into the purified water before it returns into the fish tank or directly into the fish tank. The aeration is meant to add oxygen to the culture water to meet the oxygen demands of the fish and the nitrification and denitrification processes. Typical concentrations of a healthy environment for most fish is a dissolved oxygen (O2) level of at least 6 mg/L and a carbon (IV) dioxide (CO2) concentration below 25 mg/L (Chen et al., 2006). A rule of thumb for the transfer rate of diffused aeration is around 0.45 kgO2/kW, and typical oxygen consumption rate of a well-designed RAS (one in which settleable solids are quickly and efficiently removed) can be estimated at 50% (or 0.5 kg O2/kg of feed fed) (Zafarzadeh et al., 2011). The purpose of the aerator is to maintain a given level of oxygen concentration in fish tank depending on the specific oxygen consumption of the fish. The aerator consists of an air suction on one side and air outlet(s) on the other side. The air outlets are then fitted with rubber tubing which delivers the air into the water via air stones, i.e. diffusers. These diffusers help break down the air stream into thinner streams which upon entering the water mass form small bubbles. These bubbles release air into the water as they move up through the water column to the water surface.

2.6 Simulation/ Prediction of RAS performance

Simulation is the imitation of a process or situation. According to Wik (2004), to fully explore the advantages of RASs to its maximum and make the systems commercially successful, the recirculation ratio should be as high as possible.

Modeling in aquaculture necessitates dynamic modeling that provides a more in-depth insight into the aquaculture performance (Wik et al., 2009). The development of the use of simulation models in aquaculture has been witnessed in the last few years (Wik, 2004). Most of the simulation models originate from ecological modeling and applies to through-flow systems (Kazmierczak & Caffey, 1996). On the other hand, studies on RASs which consider wastewater treatment, use basic steady-state models of the treatment processes, where the efficiency is set to either a fixed percentage removal or a fixed removal rate (Verdegem, Van Dam, Cabarcas-Nunez, & Opera, 2000). However, according to Wik

(2004), since the system is dynamic, the dynamics of biology in the treatment processes and a more diversified waste description have to be included for realistic simulations.

Due to their feedback and multivariable character, the complexity of RAS implies that nontrivial dynamic models of all critical system components - the fish, feed, bacteria, rearing basins, treatment units among others - are required (Alt, 2015). The steady-state simulator proposed and developed by Wik (2004) comprises models based on dynamic mass balances with the notations and units following the standards in wastewater treatment. The basic models in the simulator include the total produced waste of a compound "i" at a time "t," the fish growth model which is a function of the water temperature, a model of the total fish mass (kg) in the fish tank and model for the mass growth rate in each tank which is proportional to the digested feed (Wik, 2004). According to Wik (2004), oxygen may be introduced as a liquid added to the tank influent. The mass balance for a component "i" in a fish tank is given by Equation (2.11) as:

$$V \frac{d}{dt} Z_i = Q (Z_{i,in} - Z_i) + w_i + u_i \quad \text{..... (2.11)}$$

Where:

Z_i = either soluble concentration S_i or particulate concentration X_i, (mg/L)

$Z_{i,in}$ = in is the concentration in the tank influent, (mg/L)

w_i = the produced waste (mg)

u_i = the amount of externally added or removed matter (mg)

The model discussed by Wik (2004) is complex and requires a considerable number of parameters to be measured to facilitate model calibration and validation.

2.7 Modeling of the RAS

The primary goals of farmers, researchers, and system designers are to improve the efficiency and predictability of intensive aquaculture operations. These improvements are

subject to accurate quantification of the fish's metabolic rates and the relationships between water quality and fish growth. Moreover, improvements and refinement of water reuse technologies are inevitable towards the improvement of intensive aquaculture systems (Kazmierczak & Caffey, 1996). Computer models are useful tools for analyzing water treatment units and fish metabolic response effects on overall system performance. With such models, the performance of several water reuse processes and configurations can be predicted while at the same time simulating water quality, resource requirements, and production capabilities of the systems. The simulation predictions are useful in the design and installation of new systems, the evaluation and selection of system components, implementation of changes to existing systems, and the management of water quality and production schedules in existing farms (Brinkop & Piedtrahita, 1996).

2.7.1 Available Simulation/Prediction Models for RAS

Brinkop and Piedtrahita (1996) proposed an aquaculture model developed using a modeling software package (Extend) that allows for the creation of blocks, each of which simulates a separate unit operation. Once the blocks are created, they are stored in a library from where they can be accessed and connected on the screen to create a model for a particular system configuration. The proposed model can simulate water quality changes and fish biomass production in an aquaculture system over any desired duration and account for oxygen and feed consumption, based on assumptions in each block.

The desired simulation period and time-step are chosen, and the model is executed. Brinkop and Piedtrahita (1996) suggest that time steps used for model execution should be less than one day since most state variables fluctuate daily. The short time steps also prevent possible instability in the numerical integration calculations. The output from this model is then presented in graphs and tables.

The model is dynamic and hence can predict the system changes over time and deterministic in that it has no associated probability distribution since it makes predictions for state variables based on input conditions and model assumptions only. Moreover, all the components of the model are mechanistic, meaning they are based on physical laws.

The water quality variables used in the model include dissolved gases (oxygen, carbon dioxide), solids (suspended solids), dissolved nutrients (total ammonia, combined nitrite, and nitrate, total phosphorus), nutrients in suspended solids (nitrogen, phosphorus), organic matter (dissolved, in suspended solids), alkalinity, pH, salinity, and temperature. In addition to these variables are the other state variables used in the model, including fish size, total fish biomass, and oxygen consumption. The blocks in this model include water supply, flow mixers, and splitters, fish culture tank, generic biofilter, trickling biofilter, fine-screen solids removal, settling tank, granular media filter, in-line diffused oxygenation, pure oxygen, air stone, multi-stage low head oxygenation, packed column aerator, chemical addition and output blocks (Wik et al., 2009).

Brinkop and Piedtrahita (1996) give a detailed description of a model different from those described by Wik et al. (2009). In their model, the RAS is broken into blocks. In the trickling biofilter block, nitrification and BOD removal are calculated using theoretical and empirical formulas developed in earlier studies (Brinkop & Piedtrahita, 1996). Ammonia removal is calculated based on oxygen and ammonia concentrations, diffusion rates, nitrification kinetics, water temperature, media-specific surface area, void ratio, and hydraulic loading rate (Verdegem et al. et al., 2000).

Losordo and Hobbs (2000) created a spreadsheet driven program for sizing the water treatment based on expected nitrogen load. Wik (2004) proposed and developed a steady-state simulator which comprises of models based on dynamic mass balances with the notations and units following the standards in wastewater treatment. The basic models in the simulator include the total produced waste of a compound “i” at a time “t,” the fish growth model which is a function of the water temperature, a model of the total fish mass (kg) in the fish tank and model for the mass growth rate in each tank which is proportional to the digested feed. Oxygen may be introduced as a liquid added to the tank influent (Wik, 2004).

Other models developed to help to problem-solve in aquaculture includes FISHSIM, which was developed to analyses the financial feasibility and performance of aquaculture production facilities based on the output prices and quantities, variable input costs, survival rates, feed conservation rates and stocking densities (Wik et al., 2009). Pedersen et al. (2012) used the modeling tool AQUASIM (Reichert, 1994) to build a prediction model, majorly focused on TAN and its removal and calibrated it to measurements taken from replicated experimental systems. Pedersen (2018), developed LibRAS which is an improved version of FISHSIM developed by Wik et al. (2009). His model concentrated on several water treatment topologies, ranging from a fully open system to a closed RAS system with a Moving bed biofilm reactor.

2.7.2 Modelling Process

According to Tomer and Wheaton (1996), with the ever-growing knowledge of information technology and the galloping financial constraints in the aquaculture industry, models can be developed for various uses in RAS. Such models are developed using an algorithm. For instance, Figure 2.4 presents a Step by step development procedure of a model, including verification and validation stages (Tomer & Wheaton, 1996).

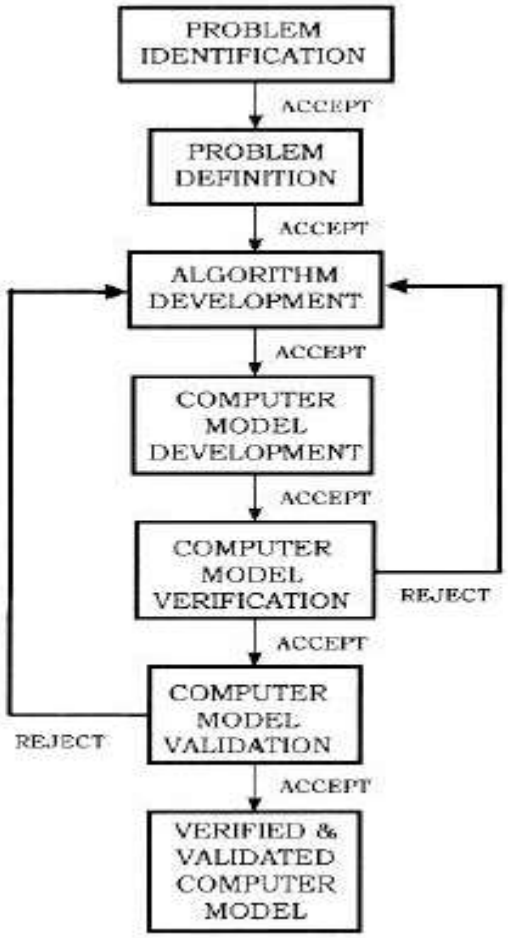

Figure 2.4: Step by Step Development Procedure of a Model Including Verification and Validation

The two most commonly used models for RAS systems are the empirical growth models and the physical growth models (Brinkop & Piedtrahita, 1996; Sokolowski & Banks, 2011). The main difference between the two models is that an empirical model is a model based on a statistical analysis of a specific data set. In contrast, a physical model, sometimes called an analytical model, is a model based on physical, chemical, or biological laws that describe how a system works (Wik et al., 2009). The physical growth models are suitable because the physical model is based on understanding physical and biological processes and their relationship to the environment. On the other hand, the empirical model is based on the phenomenon's site-specific data.

System functioning issues such as head losses, pump sizes, and tank circulation can be modeled, evaluated, and optimized. Therefore a model can be developed for every problem facing aquaculture today as long as the cause-effect relationship can be identified and expressed in a formula. However, the main challenges are identifying the most critical parameters to use in model development, verification, and validation (Kazmierczak & Caffey, 1996).

2.7.3 Model Calibration, Validation and Sensitivity Analysis

Sensitivity analysis determines the rate of change in model output for changes in model inputs (parameters). In a practical sense, this first step helps determine the active processes for the component of interest. Two types of sensitivity analysis are generally performed: local, by changing the parameter values one at a time, and global, by allowing all parameter values to change. The two analyses, however, may yield different results. On the other hand, calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty (Brinkop & Piedtrahita, 1996; Arnold et al., 2012).

Model calibration is performed by carefully selecting values for model input parameters, within their respective uncertainty ranges, by comparing model predictions and output for a given set of assumed conditions with observed data for the same conditions. Model validation demonstrates that a given site-specific model is capable of making sufficiently accurate simulations. Validation involves running a model using parameters determined during the calibration process and comparing the predictions to observed data not used in the calibration. Calibration and validation are typically performed by splitting the available observed data into two datasets: one for calibration, and another for validation (Arnold et al., 2012).

Some of the model evaluation statistics include the coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NSE). The coefficient of determination (R^2) describes the degree of collinearity between simulated and measured data. It ranges from 0 to 1, with

higher values indicating less error variance, and values greater than 0.5 are considered acceptable. Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance. NSE indicates how well the plot of the observed versus simulated data compares to the 1:1 line. NSE ranges between $-\infty$ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values < 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance (Moriasi et al., 2007).

2.8 The Study Conceptual Framework

Figure 1.1 shows the conceptual framework of the study.

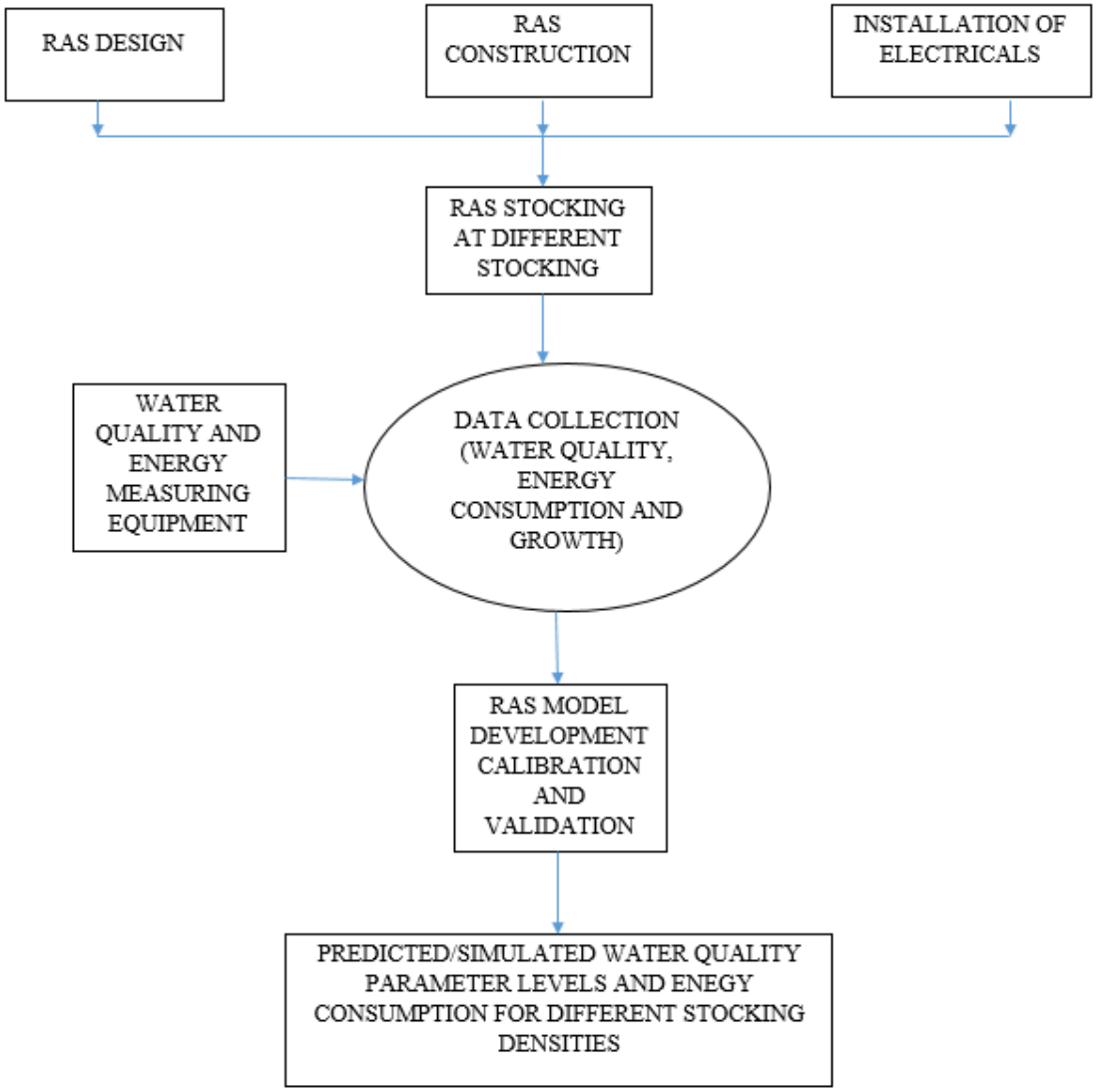

Figure 2.5: Conceptual Framework of the Study

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The Recirculating Aquaculture System (RAS) was set up at the Jomo Kenyatta University of Agriculture and Technology (JKUAT), the main campus situated in Juja, 36 km northeast of Nairobi along the Nairobi-Thika superhighway. Juja is characterized by warm weather most of the year, with an average temperature of 19.6 ˚C. The area also receives an average annual rainfall of 799 mm, from March to May and November to December. The terrain is relatively flat, with water ponding on the surface during heavy storms. The institution draws its water from the nearby Ndarugo River for all its uses, including irrigating its farms. In this study, the untreated water used in irrigating the farms was drawn from a nearby hydrant and used in the RAS.

3.2 The RAS Set-up

The laboratory set-up of the recirculating aquaculture system was as shown in Figures 3.1 and 3.2. The RAS system made of a connection of PPR pipes and plastic tanks for the production tank, biofilter tanks, and sump tanks is housed in an 8m by 15m greenhouse. The greenhouse structure helped in providing the appropriate ambient temperature and consequently, the water temperatures for the fish to thrive well. Evironmental

parametersand energy requirements were measured and recorded for different flow rates and stocking densities in this experimental set-up.

Figure 3.1: The RAS Systems in the Greenhouse

Figure 3.2: The RAS Production Tanks, Biofilter Tank and Sump Tank among other Components

3.2.1 Research Design

The study involved several activities from the construction of the RAS and the greenhouse, stocking the production tanks data collection and analysis, model

development, and testing, as shown in the workflow diagram presented in Figure 3.3. The activities presented in the workflow diagram were executed systematically one after the other until the completion of the study. The workflow diagram is a step by step summary of the activities involved across the entire study.

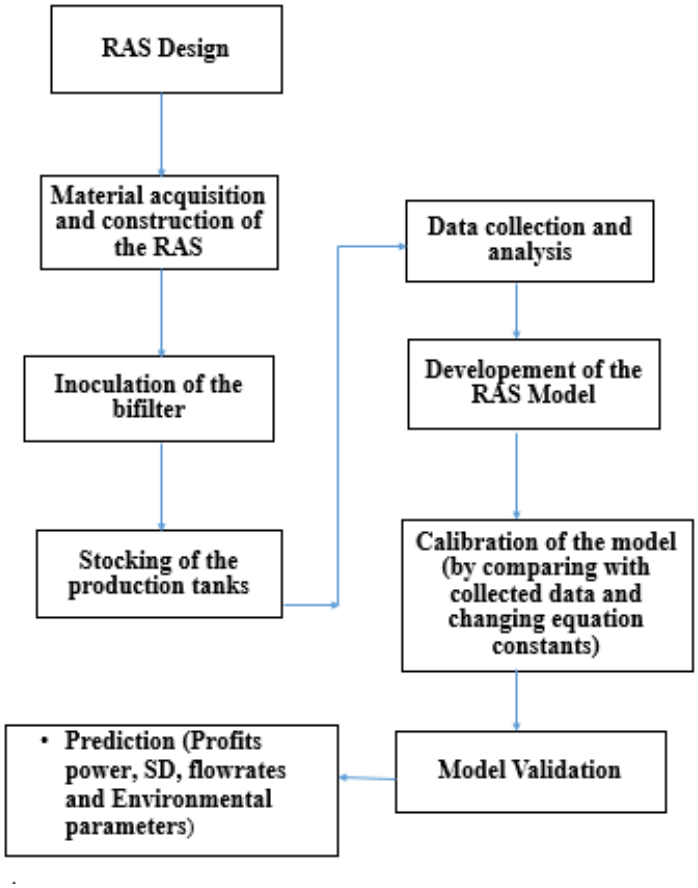

Figure 3.3: Workflow Diagram for the Study from RAS Design through Experimentation to RAS Model Development

3.2.2 Design Drawings and RAS Setup

The Design drawings for the RAS system are presented in Appendix D. The drawings show the plan and side views of the RAS setup and the dimensions of each component in

the system. The materials, tools, and equipment used for the study are presented in detail in Table 3.1:

Table 3.1: Materials and Equipment Used in the Study

S.No	Equipment/Materia	Parameters or dimensions
1.	Green house	8 x 15m tunnel greenhouse
2.	Nile Tilapia (Oreochromis niloticus)	tilapia fish weighing 200±20g
3.	Pipes (PPR) and fittings	1 Inch pipes with 1 inch fittings
4.	Tanks	Three 1000L nested tanks
		Two 1000L closed tanks
		One 1000L water storage tank
5.	Pump	One 0.5hp Pedrollo submersible pump
6.	Aerators	15 L/min rating aerators
7.	Multimeter	HQ40d HACH™ multimeter
8.	Probes	PHC101 pH probe
		ISENH3181 ammonia probe
		LDO101 dissolved oxygen probe
		CDC401 electrical conductivity probe
9.	Biofilter material	One 500L closed tank with pumice
10.	Electricals	Extension cables with plugs, electricity meters
11.	Shade nets	for covering the production tanks
12.	Power Supply	Mains Electricity
13.	Laptop	personal computer for write-ups and data analysis

3.2.3 The Biofilter Design

The biofilter is designed to remove ammonia from the RAS water to levels below the lethal point. Pumice was selected as the biofilter media. The values used in the biofilter design are presented in Table 3.2:

Table 3.2: The Values Used in the Biofilter Design Calculations

S.No	Parameter/ item	Value/ Range	Units	Description	source/Citation
1.	Mass density of pumice	200 - 250	kg/m^3	Mass of pumice in a unit volume of pumice	(Whitham, & Sparks, 1986)
2.	Specific surface area of pumice	500 - 2,340	m^2/kg	Total exposed area of pumice per unit mass of pumice	((Troell et al., 2009; Whitham, & Sparks, 1986)
3.	Highest stocking density	10	kg/m^3	Mass of fish in a unit volume of water	(Liu et al., 2016)
4.	Feed fed to fish per day	4	%	As a percentage of the fish body mass	(Crab et al., 2007)
5.	Assumed biofilter efficiency	55	%	Assumed to remove approximately half of the total wastes in the water (particularly ammonia	(Wheaton et al., 1994).
6.	The pumice biofilter ammonia removal rate	0.857	$mg/m^2/day$	This is attributed to its low specific surface area	(Wheaton et al., 1994).
7.	Pump	1	Number	Based on the prevailing Total Dynamic head	(Larralde & Ocampo, 2010)
8.	Pipe diameter	1	inch	based on pump inlet, outlet and the allowable flow rate and velocity	(Larralde & Ocampo, 2010)

Based on the expected ammonia production from the constructed RAS and the Biofilter nitrification rate estimated at $0.000857g/m^2/day$ (Dong & Reddy, 2012) and the biofilter volume required was determined. The nitrification rate was achieved by considering the highest stocking density to be used for this study. The biofilter material used was packed in a 1000L tank and operated as a trickling filter. Webb, Hart, Hollingsworth & Danylchuk

(2015) observed that an oversized biofilter provides additional space for aeration and to degas as the water goes through the biofilter media.

Porous lava rock (pumice) was the substrate of choice used as a biofilter material for this study. Pumice is light in weight, highly porous, and provides sufficient porosity for water movement compared to sand, gravel, and other alternative substrates. The high density of pores in pumice provides a high specific surface area for bacteria films' growth. The biofilter was also inoculated with raw water from a nearby fish pond to accelerate the growth of the nitrifying bacteria (Helfrich & Libey, 1991). The biofilter design was aimed at keeping the ammonia levels below 0.05 mg/L and nitrite levels below 0.5 mg/L (Badiola, 2010). To prevent the entry of organic solids such as the fish droppings and uneaten feed that could have sunk in the production tank, a receiving sump installed at the point of entry of water into the biofilter was used trap such solids. This sump was periodically removed, cleaned, and returned into place.

3.2.4 Pipe Size and Flowrate

The selection of pipe size was based on the anticipated maximum flow rate and velocity (Schobeiri, 2010) as the water is exchanged between the biofilter and the production tanks.
The maximum flow rate was estimated at 10 L/min = 0.167L/s = 0.000167m^3/s
And the maximum flow velocity at 19m/min = 0.32m/s
The diameter of the pipe was computed using the continuity Equation 3.1 as:

$Q = AV$ …….(3.1)

$$Q = \frac{\pi D^2}{4} \times V$$

Hence

$$D = \sqrt{\left(\frac{4 \times Q}{\pi \times V}\right)} \quad \ldots\ldots (3.2)$$

3.2.5 The Production Tanks and Stocking Density

Three 1,000L production tanks made of a good grade polyethylene were used. The RAS was operated with seven (7) stocking densities broken down into low (2.3, 3.5 and 4.0

kg/m^3), medium (5.0 and 7.0 kg/m^3), and high (9.0 and 10.0 kg/m^3). The stocking densities were run in triplicates. The system was run for one month before the stocking density was increased from one density to the next. At the end of the experiment at a given stocking density, the fish were weighed to determine their corresponding weight. The deficit weight to attain the next stocking density was then calculated, and the fish of that weight was introduced into the tanks. Each tank was aerated by one aerator with an aeration rate of 15 L/min air. The production tanks were fitted with flush out pipes at the side near the bottom to allow for the removal of any solids from fish waste and uneaten feeds. Once in a week, 50-100 L of the water in the production tanks was drained to flush out settleable solids in the production tanks and replaced with clean water (Badiola, 2010).

Upon completion of setting up the RAS components, the production tanks were stocked with Nile Tilapia of masses ranging between 180 g and 220 g.

3.2.6 Feeding

The fish were fed with a 3mm pelleted (25% protein, 7% fat, and 7% fiber) feed. The feeding was done twice a day at 9:00 AM and 4:00 PM by broadcasting the feed on the water surface. The fish were fed approximately 4% of their body weight. Any excess feed floating on the water surface was scooped with a net and removed to reduce the water's organic waste.

3.2.7 Pump, Aerator and Connection Pipes

A 0.5hp (0.37 kW) submersible pump was used to pump water from the sump after purification back into the production tanks. A gate valve fitted just after the pump was used to regulate the flow. Polypropylene (PPR) pipes of 25.4mm internal diameter were used to connect the various tanks to allow for water recirculation. The choice of pipe diameter selected follows the pump's designer's recommendation that the used pipe diameter corresponds to the pumps' intake and discharge diameters to avoid reducing the pumps working efficiency (Larralde & Ocampo, 2010). Aerators with aeration rates of 15 L/min were used to pump air into the production tanks to boost oxygen availability. The

pump's air outlets were fitted with an atomizer (air stones) to produce microbubbles. The recirculated water was released from a height of about 0.5 m above the water level in the production tanks to splash the water in the production tanks, thus increasing the infusion of oxygen into the water.

3.2.8 Fabrication and Evaluation of the Full Scale Models in the Constructed Greenhouse

In this study, the components constructed or assembled included; a fish tank, a biofilter, connection of pipes and their fittings, installation of pumps and aerators as well as installation of a greenhouse in which the complete set-up was housed. Each component was fabricated and installed in place and equipped with the relevant accessories. Production tanks were then filled with water, and the system allowed to run before stocking to identify any leakages and correct any areas that were not functioning as expected. The production tanks were fitted with flush out pipes at the side near the bottom to allow for the removal of any solids from fish waste and uneaten feeds to be drained out. About 10% of the water was drained to remove these solids (Badiola et al., 2010). This water was then replaced by a nearby freshwater source to restore the system capacity. A bell siphon fabricated and installed in the biofilter tank helped to provide continuous emptying of the water from the biofilter upon a treatment, thereby preventing water from overfilling and spilling. The siphon also ensured sufficient contact time between the RAS wastewater and the biofilter material.

Once the whole set-up was functioning properly, the fish tanks were stocked with grown fish (200$\pm$ 20 g) each to enable the rapid generation of ammonia. The RAS was operated with low (2.3 kg/m^3 – 4.0 kg/m^3), medium (5.0 kg/m^3 – 7.0 kg/m^3) and high (9.0 kg/m^3 – 10.0 kg/m^3) stocking densities. The system was run for one month before the stocking density was increased to the next level. Figure 3.4 presents the Flow diagram of the various

RAS components.

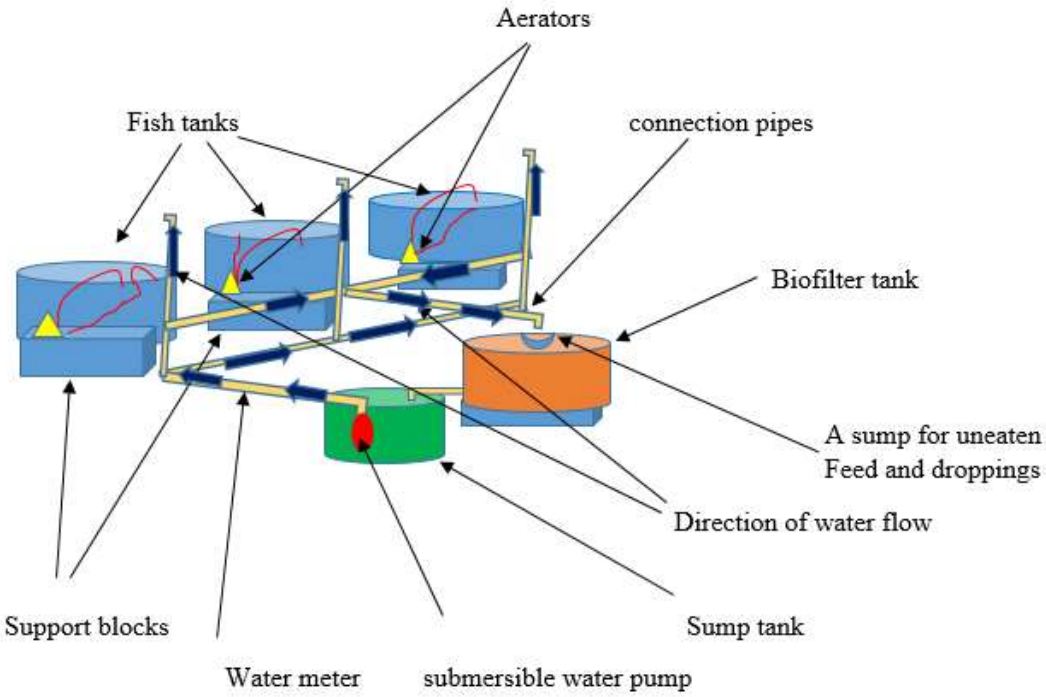

Figure 3.4: A Layout of the RAS Components

The size and shape of the production tanks were selected based on ease of cleaning, the ease of fish movement and the maximum mass of fish to be stocked per unit volume. 1000L (1.0 m^3) circular tanks were chosen because of their ease to clean and allow ease of swimming for the fish. Circular tanks also help to prevent the creation of dead zones where water aeration is low, and the accumulation of sediments is high (Troell et al., 2009).

3.3 Measurement of Flow rate, Energy and Water Environmental Parameters

Once the system was tested and found to be leakproof and stocked with fish, with traces of bacterial films in the biofilter and walls of the sump tank, the water quality parameters namely temperature, ammonia, DO, pH and EC were measured. Three (3) 250ml samples were collected into a sampling cups from the centre of the water surface in the production tanks and at the point of water exit from the biofilter tank daily (between 4:00-5:00 pm).

The parameters were measured within 15min after sample collection for the different stocking densities and water flow rates. A newly acquired HQ40d HACHTM multimeter, a PHC101 pH probe, ISENH3181 ammonia probe, an LDO101 dissolved oxygen probe and a CDC401 electrical conductivity probe were used to take the readings. The procedures of measurement are as described in the HACH manual for the multimeter used (HACH, 1992). The flow rate was varied from 2.0 L/min and increased at intervals of 1 L/min to a flow rate of 10 L/min. The water flow rate was varied by use of a gate valve positioned just before the biofilter. The desired flow rate was then determined using the stopwatch and bucket method.

The flow rate measurement was done repeatedly until the desired flow rate was achieved. Each flow rates was maintained for 24 hours and repeated three times. On the other hand, electricity consumption was measured by an installed electric meter. The pump would only start pumping when the float switch attached to the pump had been raised beyond a given level. The pumping then continued until the float switch drops to minimum levels after which the sump tank starts to fill again. The difference in power consumption at different flow rates emanated from the fact that high flow rates would lead to rapid fill of the sump tank and hence more frequent pumping as compared to low flow rates. All the collected data were recorded in excel sheets. Purification efficiencies (PE) of biofilter at different flow rates were then computed for each set of flow rate for the various stocking densities based on the amount of ammonia removed as presented in Equation 3.3 (Fletcher, Jones, Warren & Stentiford, 2014).

$$\text{PE} = \frac{(\text{Ammonia in the production tank} - \text{Ammonia after the biofilter})}{\text{Ammonia in the production tank}} \quad \ldots\ldots\ldots (3.3)$$

Line graphs, bar graphs and measures of central tendency were generated from the collected data. Analysis of variance (ANOVA) of the environmental parameters was also conducted for the stocking densities and the corresponding flow rates. The ANOVA was conducted based on the randomized complete block design (RCBD) with the two primary

factors being measured flow rate at corresponding stocking density. For every stocking density, all the flow rate levels were run, and each parameter tested.

3.4 Simulation using Predicting Model

A physical growth model developed using the procedure described by Tomer & Wheaton (1996) was used to simulate the RAS performance. Matrix Laboratory (MATLAB) programming language was used to accomplish the model development task. The data collected on installation costs, fish growth, energy consumption, running costs, biofilter efficiency and flow rates through the connection pipes were used to calibrate and validate the model.

3.4.1 RAS Computer Simulation Model Development

In this study, a prediction model touching on the cost of installation and operation and RAS water quality was developed and used to simulate RAS performance. Physical growth models, model based on physical, chemical, or biological laws and theories, were used to allow for the computer model's applicability within the country and beyond. Matrix laboratory (MATLAB) appdesigner was used to accomplish the model development task.

The developed model was used to predict profits, energy requirements and water quality and the different costs associated with a RAS.

3.4.1.1 Revenue/Profits Maximization

The objective function for the maximizing profits was as presented in Equation 3.4

Maximize profit (δ)

$$= (Pq \times Qf) \times P_{cy} - ((C_e + C_f + C_s + C_{om}) \times t) \times P_{cy} + C_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Where:

δ = is profit in (KES)

Pq = the price per kg of the harvested fish (KES)

Qf = the quantity of the harvested fish (Kg)

Ce = the cost of electricity (KES)

The unit cost of electricity = (KES/kWh)

Cf = the cost of feed (KES)

Cost of feed per kg (KES/kg)

Cs = the cost of fish during stocking (KES)

Ci = cost of installation of the RAS structures (production tanks, pumps aerators pipework, biofilter)

Com – operation and maintenance cost (assumed at 15% of the installation cost)

Pcy – Number of production cycles (Number) whereby the duration of the production cycle is taken like 6 months

t = the age of the fish (days)

Unit cost of fish, fingerlings, at introduction (KES/fish)

The profit maximization constraints are as presented in Equations 3.5 and 3.6

Equation 3.5 constraints profit to at least 10% of the total revenue (Engle, 2010; Smith & Nagle, 1994).

$$\frac{(Pq \text{ x } Qf) \text{ x } Pcy - ((Ce + Cf + Cs + Com) \text{x } t) \text{ x } Pcy + Ci)}{(Pq \text{ x } Qf) \text{ x } Pcy} \geq 0.1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

For profitability of the enterprise, the total revenues should be greater than the total costs for a given crop and can be computed using Equation 3.6.

$$(P_q \times Qf) \times P_{cy} \geq ((C_e + C_f + C_s + C_{om})\, x\, t) \times P_{cy} + C_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

The constraint variables, P_q, Q_f, C_e, Cf, C_s, C_i & C_{om} should be greater than 0.

The equations used for the development of the RAS prediction model were as follows:

3.4.1.2 Energy and Dissolved Oxygen Consumption of the RAS

The energy consumed by the pump (Pp) in one day was computed as presented in Equation 3.7

$$\text{Energy } (P_p) = \frac{W\rho g h Q}{60{,}000 \; x \; 1000} \times 24 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.7)$$

Where;

W = A modification factor (s/Nm). It is a constant bound to change based on the type and size of pump use. It partly captures variation in pump efficiency alongside other pump characteristics

P_p = the energy (kWh/day)

ρ = the density of the fluid (1000kg/m^3)

g = acceleration due to gravity (9.81N/kg)

h = the height to which the fluid is being raised (m)

Q = the discharge in (L/min)

The energy consumed by the pump for an entire production cycle was calculated as the product of Pp and the length of the production period in days. The systems oxygen demand was computed based on the systems prevailing stocking density, specific oxygen consumption and production water volume. Mathematically, this is presented in Equation 3.8.

$$OD = SD \times SOC \times \frac{V}{1000} \quad \text{.....(3.8)}$$

where:

OD = Oxygen demand (mg O^2/hr)

SD = Stocking density (kg/m^3)

SOC = Specific oxygen consumption (mg O^2/kg fish.hr)

V = is the volume of the production tanks (L)

From the computed oxygen demand, the amount of energy consumed by the aerators was calculated using Equation 3.9.

$$P_A = 0.001 \times OD \times AER \times \frac{SAE}{100} \times 24hr \quad \text{..... (3.9)}$$

where:

P_A= energy required for aeration (kWh)

OD = Oxygen demand (mg O^2/hr).

AER = Aerators energy rating (watts/mg O^2)

SAE = Specific aeration efficiency as a percentage (%)

0.001 converts energy from watts into kilowatts

The oxygen concentration (DO) of the production water is computed using Equation 3.10.

$$DO = F \times \frac{OD}{60 \times Q} \quad \text{.....(3.10)}$$

where:

DO = dissolved oxygen (mg/L)

OD = Oxygen Demand (mg O^2/hr)

F = constant of proportionality (hr/min)

Q = flow rate (L/min)

The total cost of energy for running the RAS system over a production cycle (P_{cy}) is as presented in Equation 3.11.

$C_e = (P_p + P_A) \times$Unit cost of Energy KES, per day $\times$ t .....(3.11)

where:

C_e = Cost of energy of running the RAS over a production cycle (KES)

t = number of days from stocking to the harvesting (days)

The amount of energy utilized by the RAS in a day ($C_{e\ day}$) was calculated by dividing the total amount of energy consumed by the system during a production cycle (C_e) by the number of days from stocking to the harvesting (t).

3.4.1.3 Stocking, Feeding and Fish Growth

The number of fish to be stocked was calculated as using Equation 3.12.

$$NoF = \left(\frac{SD}{Unit\ weight\ of\ fish} \times \frac{V}{1000}\right) \quad \text{.....(3.12)}$$

where:

NoF = Number of fish to be stocked (Number)

SD = the stocking density in (kg/m^3)

V = the volume of the production tank (Litres)

Unit weight of fish (kg)

The cost of stocking (C_s) was computed as presented in Equation 3.13

$C_s = NoF \times$ price per fish .....(3.13)

The cost of stocking per day ($C_{s\ day}$) is obtained by dividing the cost of stocking (C_s) by the number of days from stocking to harvesting (t)

The weight gain of the fish is a function of the water temperature, 22˚C - 31˚C, initial fish weight and the stocking density, which is influenced by the ammonia and oxygen concentration and the fish appetite and amount of feed fed, (Kazmierczak & Caffey, 1996).

The quantity of the harvested fish was calculated from Equation 3.14;

$Qf = 0.9 \times NoF \times A \times SD_{gc} \times e^{kt}$ ……(3.14)

where:

NoF = Number of fish to be stocked (Number)

0.9 = a survival rate (Variable)

t = the age of the fish from stocking (days)

A = is the initial body weight of the fish (kg)

$SD_{gc} = 0.261$

SD_{gc} is the stocking density growth coefficient that will be obtained through calibration using experimental data. An approximate value to this coefficient is 0.261 after Huang & Chiu (1997).

"k" is the temperature-dependent growth coefficient which ranges from 0.0259 at 22˚C through 0.0416 at 28˚C to 0.0374 at 30˚C (Santos, Mareco & Dal Pai Silva, 2013; Iwama & Tautz, 1981).

The amount of feed fed to the fish (F) over an entire production period (t) and amount of feed fed per day was calculated at 4% of the fish body weight(F day) (Alt, 2015; Crab et al., 2007) as presented in Equations 3.15 and 3.16 respectively.

$F = 0.04 \times Qf$ ……(3.15)

$Fday = \frac{F}{t}$…….....(3.16)

where:

Q_f = Quantity of harvested fish (kg)

F_{day} = Feed fed to the fish per day (kg)

F = Feed fed to the fish from stocking to harvesting (kg)

t = number of days from stocking to the harvesting (days)

The cost of feed was computed as a product of the feed fed and the unit cost of feed as presented in Equations 3.17 and 3.18

$C_f = F \times$ unit price per kg …….....(3.17)

$C_{f\,day} = F_{day} \times$ unit price per kg ……..….....(3.18)

Where:

$C_{f\,day}$ = cost of feed per day (KES)

C_f = cost of feed from stocking to harvesting age (KES)

3.4.1.4 Ammonia and Biofilter Purification Efficiency

The ammonia generated was computed as 2.5% (Alt, 2015; Crab et al., 2007) of the feed fed to the fish from as in Equition 3.19.

AMMprd = 0.025 x Fday …….... (3.19)

The ammonia concentration was then estimated using Equation 3.20

$AMMconc = AMMprd \times \frac{10^6}{V}$……...(3.20)

Ammonia produced > 0

where:

AMMprd = Ammonia produced by the fish (kg)

AMMconc = Ammonia concentration in water (mg/L)

0.05mg/L< AMMconc

Purification efficiency (PE) was expressed as presented in Equation 3.21. This was based on the postulation that PE varies with flow rate, stocking density and dissolved oxygen.

$PE = y\frac{DO}{10{,}000\ x\ Q\ x\ SD}$..... (3.21)

And, $0<PE \leq 100$

Where:

y = a proportionality constant ($m^3.min/L^2$)

PE = Purification efficiency (%)

DO = the dissolved oxygen (mg/L)

Q = the system flow rate (L/min)

SD = the system stocking density (kg/m^3)

Since the main contaminant to be removed is ammonia, the amount of ammonia removed was expressed as in Equation 3.22;

$$AMMRe = \frac{PE}{100} \times AMMconc \quad \text{.....(3.22)}$$

where:

AMMRe = Removed ammonia (mg/L)

PER = Purification efficiency (%)

AMMconc = Ammonia concentration (mg/L)

The residual ammonia was was computed as in Equation 3.23

$$AMMLL = AMMconc - AMMRe \quad \text{..... (3.23)}$$

where:

AMMLL = Residual ammonia

AMMLL ≤0.05mg/L

3.4.1.5 pH and Electrical Conductivity (EC)

pH of the production water was presented as in Equation 3.24

$$c = \frac{AMMconc(mg/L)}{1000\ x\ MM}$$

where:

c = concentration of ammonia (mol/L)

MM = molar mass of ammonia (17.031g/mol) and,

$[OH^-] = \sqrt{(Kb \times c)}$

$[H^+] = \frac{10^{-14}}{[OH^-]}$

Where;

$[H^+]$ = Concentration of hydrogen ions (mol/L)

$[OH^-]$ = Concentration of hydroxyl ions (mol/L)

Kb = ionization constant of ammonia (1.8×10^{-5})

Hence;

$pH = S \times (-\log [H+])$ ……..……..……(3.24)

Where;

S = constant of proportionality (Unitless)

and $6<pH<9.5$

The Electrical conductivity (EC) of the system was expressed as presented in Equation 3.25

$EC = N \times AMM$ ……..…….(3.25)

where:

N = constant of proportionality (Unitless)

AMM = ammonia concentration in the production water (mg/L)

Figure 3.5 shows a simplified flow of processes, decisions and actions in the developed RAS computer model.

3.5 A Flow Chart Diagram of the Computer Model

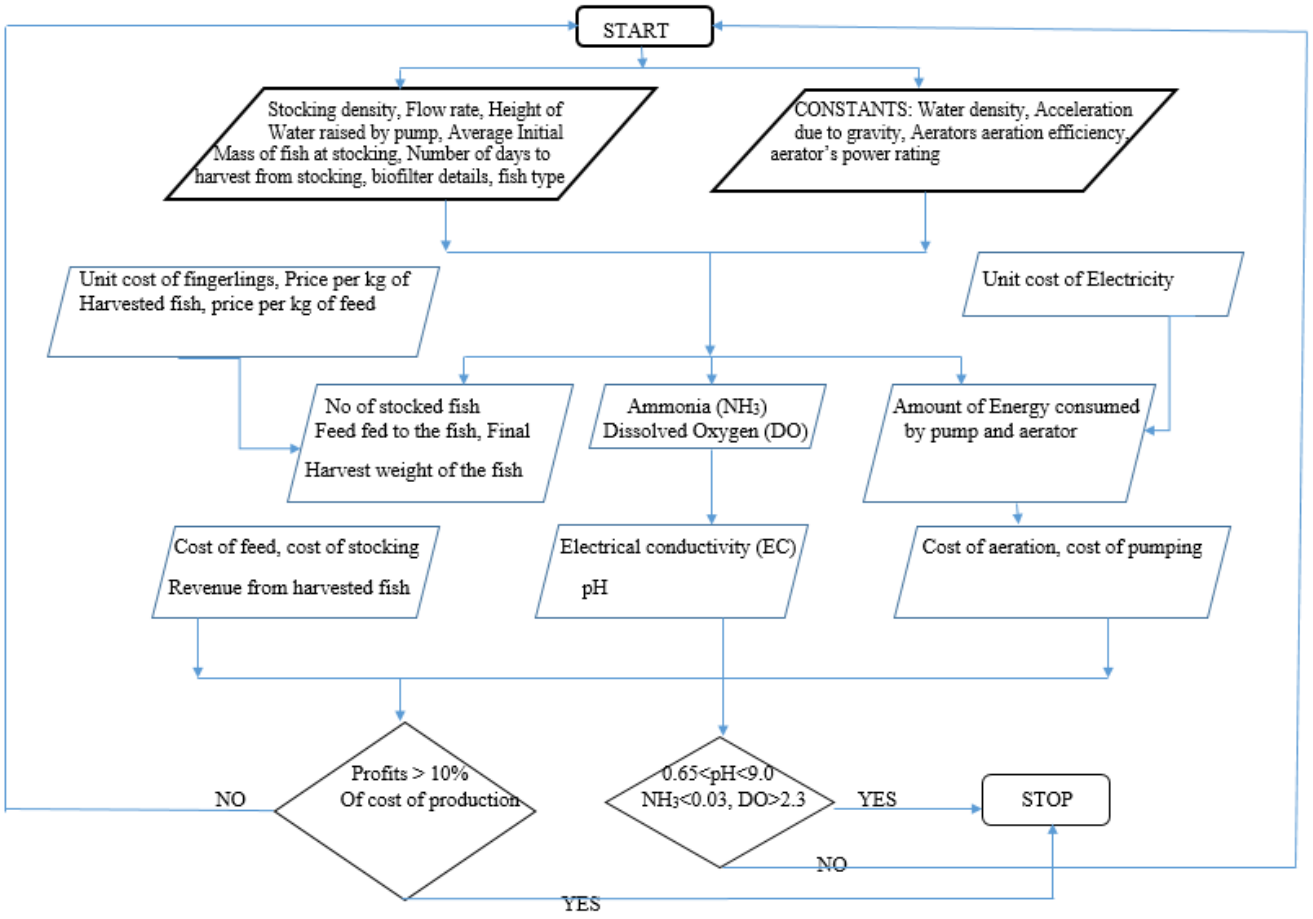

Figure 3.5: A Flow Chart Diagram of the Computer Model

3.6 RAS Prediction Model Development

The RAS computer model was developed using MATLAB (Matrix Laboratory) programing language. The model development involved the coding of the equations presented in section 3.4.1 using MATLAB's Appdesigner. The development of the model involved lambing of equation touching on a particular parameter or aspect such as Energy, Costs, stocking et cetera into individual panels. The codes for each aspect or parameter equation was then written in the code view paying attention to the names given to the various parameter. The MATLAB code for the Computer simulation model is presented in Appendix E. The RAS prediction model has currently three tabs: the input, the output and the data tab.

3.6.1 Input Tab

The input tab appears as presented in Figure D1 in Appendix D. The Input tab is divided into three minor panels: fish, energy consumption and a panel that consists of the most critical parameters of the model – stocking density & flow rate. The user enters the input, and according to these values the output can be determined through formulas that are defined in the code.

3.6.2 Output Tab

The output tab is as presented in Figure D2 in Appendix D. In the output tab; the user finds output values generated from the input values provided in the input tab.

3.6.3 Data Tab

The Data tab is as presented in Figure D3 in Appendix D. In the Data tab, if ever the Ammonia button is clicked, the graph plots the data achieved from experiments and the data obtained from a theoretical view of point.

3.7 Model Calibration and Validation

A sensitivity analysis of the model parameters was conducted to determine the most significant components for every aspect of the RAS. The sensitivity analysis was done in order to identify the most significant parameters to use in the calibration and validation

process. The most sensitive parameters of the study were then selected and used to calibrate and after that, validate the model (Verdgem et al., 2000). The local type of sensitivity analysis was used for this process. It involved changing one parameter at a time and running the model to see changes in the outputs. It involves fewer runs as compared to global sensitivity analysis which involves changing two or more parameters of the model in one go.

The calibration and validation process involved comparing observations on the actual system with the predictions of the simulation model. The available data of the identified parameters were then divided into two equal similar halves. There being no other available data from other studies to calibrate and validate the model, data from this study at different stocking densities were used to calibrate and validate the developed model. Stocking density 4 kg/m^3 for calibration then 10 kg/m^3 for validation. The Nash-Sutcliffe efficiency (NSE), Root mean square error (RMSE) were used in evaluating the performance of the RAS model after the calibration and validation processes. NSE is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance while Root Mean Square Error (RMSE) measures how much error there is between two data sets (Kazmierczak & Caffey, 1996).

The smaller an RMSE value, the closer predicted and observed values are. RMSE carries the units of the variables under evaluation. On the other hand, the NSE is a normalized statistic that determines the relative magnitude of residual variance. Nash–Sutcliffe efficiency can range from $-\infty$ to 1. An efficiency of 1 (NSE = 1) corresponds to a perfect match of modelled discharge to the observed data. An efficiency of 0 (NSE = 0) indicates that the model predictions are as accurate as of the mean of the observed data, whereas an efficiency Less than zero (NSE < 0) occurs when the observed mean a better predictor than the model. Essentially, the closer the model NSE is to 1, the more accurate the model is. Threshold values to indicate a model of sufficient quality have been suggested between $0.5 < NSE < 0.65$. The R^2 value compares the predicted and the observed data plot to the

1:1 line. It varies from 0 to 1. The closer the R^2 value is to 1, the better the model predictions.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Raw Water Quality

The raw water parameter levels were as presented in Table 4.1. The water pH was around the neutral pH (7) while the dissolved oxygen was above 2.3 mg/L as opined by Ngugi et al. (2007). In another study, Silva et al. (2017) reported mean temperature (23.2±0.8ºC), dissolved oxygen (7.1±0.4 mg L-1) and pH (8.1±0.1). In yet another study, the temperature was (26±0.5 °C), DO of 6.5 mg/L and ammonia of 0.059 mg/L (Hegazi et al., 2010). Gichana et al. (2019) reported water temperature ranging from 22.4–24.2 ˚C, pH maintained between 7.68 and 8.17, electrical conductivity fluctuating between 839.68 and 929.92 mg/L, oxygen values ranging between 1.97 to 4.67 mg/L and the maximum observed ammonia was 3.7 mg/L. in a different study by Gullian-Klanian & Arámburu-Adame (2013), the simple RAS design was successful in maintaining water quality within acceptable levels; mean temperature (25.6 ± 1.9 ˚C), ammonia nitrogen (0.20 0.16 mg/L NH_3-N), 5.1 ± 0.6 mg/L dissolved oxygen and 7.79 ± 0.33 pH. According to Azim & Little (2008), the average water temperature (28 °C, range 26–30 °C), DO concentrations (6 mg/L, range 3.0–7.5 mg/L) and pH (6.7, range 5.0–8.5) were within the range for tropical fish culture except for low pH levels observed, and then corrected for, on several occasions. In comparison to findings from other studies, the raw water quality was therefore found to be within the recommended water quality levels for Nile tilapia culture.

Table 4.1: Raw water quality parameter levels and ideal values used for tilapia culture

	Range of parameter levels	
Parameter	**Ideal Values**	**Raw water**
DO	5 mg/L	4.0 - 6.0 mg/L
pH	6.9 -9.0	6.8-7.5
Temperature	20-35 ˚C	22-24 ˚C
Electrical Conductivity	50 -100 mg/L	46-60 mg/L
Ammonia	0.05 mg/L<	Below Detectable level

4.2 Environmental Parameters for Different Production Densities and Water Flow Rates

4.2.1 Ammonia of the RAS Water

Figures 4.1 and 4.2 show the concentrations of ammonia at different flow rates and stocking densities before and after the biofilter, respectively. On the other hand, Tables of variations of ammonia with flow rate, before and after passing the biofilter, at the different stocking densities are presented in Appendix A1-A2. In most of the cases, the ammonia concentration increased with an increase in flow rate. Rafiee and saad (2005) reported similar findings of positive accumulation of ammonia with time and stocking densities. The accumulation is a clear indication of reducing ammonia removal with increasing flow rate. However, injection of smaller volumes of water to replace the water lost to flushing and unclogging of pipes together with the variation of bacterial populations in the biofilter could have contributed to inconsistencies in ammonia variation with flowrate and stocking density as seen in stocking density 5 kg/m^3 and flow rates 2, 4 and 5 L/min in Table 4.2. Similar observations were reported by Azim & Little (2008) who noticed that dissolved inorganic nitrogen (TAN, NO_2–N and NO_3–N) concentrations had a high degree of fluctuations throughout the experimental period. Change of appetite by the fish and presence of leftovers after feeding might have contributed to a sudden rise in the ammonia generated in the RAS. Little is known about the most suitable levels of ions for optimum growth in fish, although their concentration tends to increase with the accumulation of waste and uneaten feed (López-Luna et al., 2013). At low flow rates, the hydraulic retention time is longer as compared to that at higher flow rates leading to better removal of ammonia.

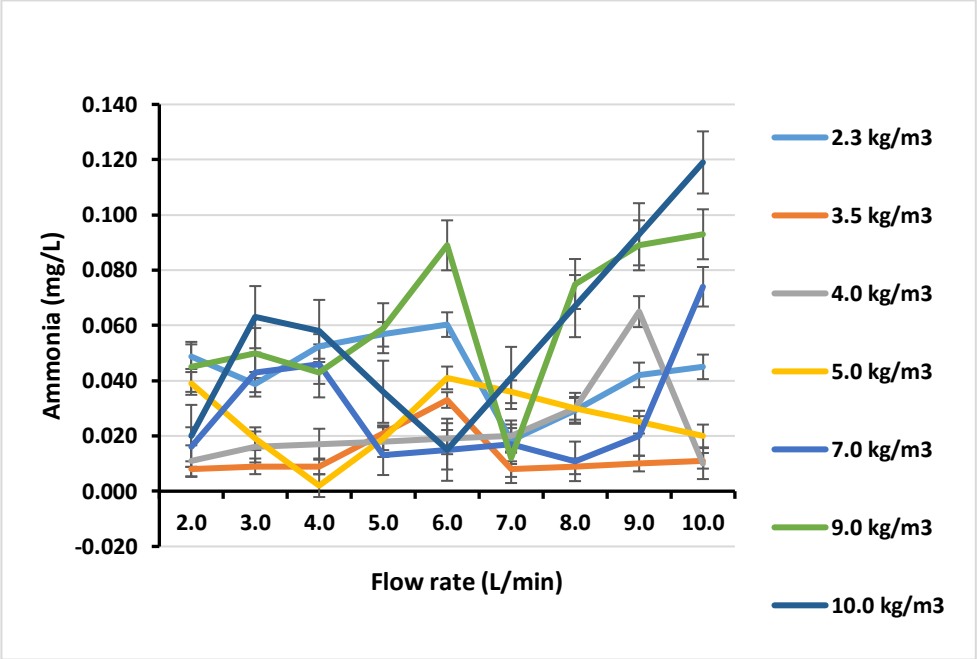

Figure 4.1: Plots of Ammonia versus flow rate for different stocking densities in the production tank

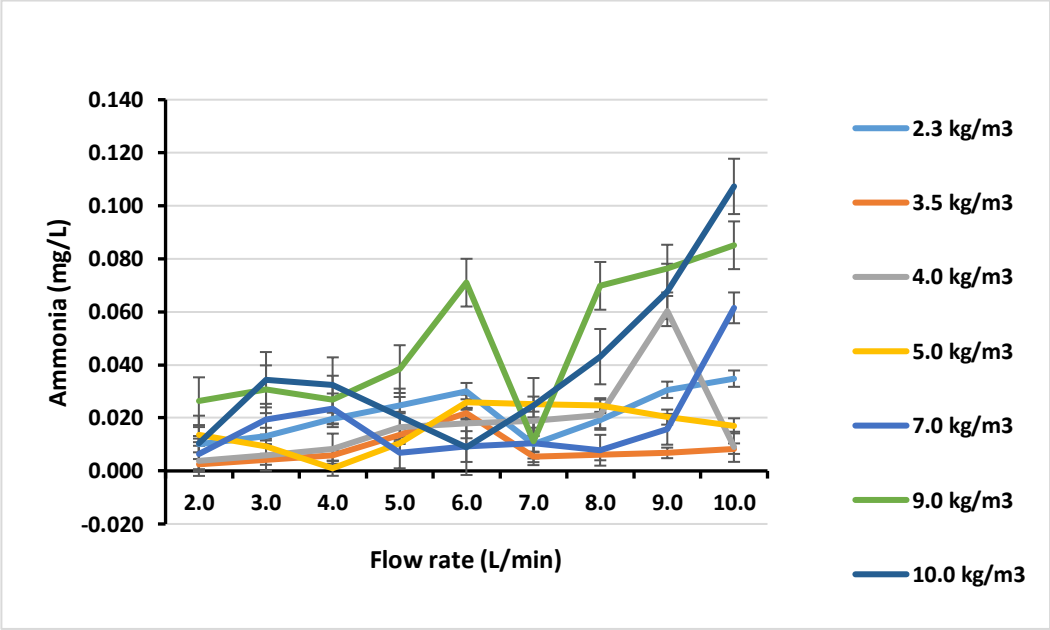

Figure 4.2: Plots of Ammonia versus flow rate for different stocking densities after the biofilter

Figures 4.1 and 4.2 also show a tendency to increase in ammonia concentration with an increase in stocking density. The increase is because high stocking densities lead to higher ammonia generation as compared to low stocking densities. Ammonia concentration was high at the start of the experiment but decreased with time and ranged between 0.27 ± 0.15–1.37 ± 0.12 mg/L (Gichana et al., 2019).

Ammonia becomes lethal to the fish at concentrations above 0.05 mg/L (Ngugi et al., 2007; Sri-uam et al., 2016). The ammonia concentration levels recorded were substantially below the lethal levels (ammonia < 0.05 mg/L) for most flow rates in both the production tanks and the biofilter, from the analysis of variance ($P < 0.05$), the variation of stocking density had a significant effect on the ammonia concentration before and after biofilter as shown in Tables 4.2 and 4.3. However, variation in Flow rate had a significant influence on the RAS ammonia concentration before the biofilter ($P < 0.05$) but not after the biofilter ($P > 0.05$).

Table 4.2: ANOVA of ammonia after biofilter

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Flow rate	0.005569	8	0.000696	1.797427	**0.100871**	2.138229
Stocking Density	0.018121	6	0.00302	7.797738	**6.95E-06**	2.294601
Error	0.018591	48	0.000387			
Total	0.042281	62				

Table 4.3: ANOVA of ammonia after biofilter

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Flow Rate	0.00804	8	0.001005	4.041485	**0.000981**	2.138229
Stocking Density	0.010811	6	0.001802	7.245697	**1.52E-05**	2.294601
Error	0.011936	48	0.000249			
Total	0.030787	62				

Sun, Wang & Liu (2016) also found out that, ammonia nitrogen was significantly affected by flow rate. Another study, Rahman et al. (2008) found out that additional stocking of

Nile Tilapia led to increased concentration of Nitrogen and phosphorous nutrients in RAS water. In a study to test the efficiency of two biofilter media (polypropylene plastic chips and polyethene blocks) media, Ridha & Cruz (2001) observed that the two filters were efficient in removing toxic ammonia and in maintaining the quality parameters within the acceptable and safe limits for the growth and survival of Nile Tilapia.

4.2.2 Dissolved Oxygen of the RAS Water

Figures 4.3 and 4.4 present dissolved oxygen concentration at different flow rates and stocking densities before and after the biofilter, respectively. Tables of dissolved oxygen versus flow rate at the different stocking densities are presented in Appendix A3-A4. Dissolved oxygen increased gradually with increasing flow rate at most of the stocking densities as shown. The tendency of the dissolved oxygen to increase with flow rate was attributed to the mixing of the waters in the production tank as the water plunges back into the production tanks with increasing force and velocities. Findings by Scully (2016) echo this. According to Scully, there was a much more rapid increase in the rate of oxygen dissolution with an increasing rate of stirring or wind velocity.

However, a change of appetite by the fish and presence of leftovers after feeding might have contributed to the sudden drop in the oxygen in the RAS due to oxygen utilization by the sunken decaying feeds at the tank bottom. These sediments are supported by findings by Gullian-Klanian & Arámburu-Adame (2013), who noted that the accumulation of organic matter increased the oxygen-consumer heterotrophic bacteria population. Moreover, injection of smaller volumes of water to replace the water lost to flushing and unclogging of pipes together with the variation of bacterial populations in the biofilter could have contributed to inconsistencies in dissolved oxygen variation with flowrate and stocking density as seen in stocking density 3.5 kg/m^3 and 5.0 kg/m^3 as well as 4 L/min and 5 L/min flow rates in Figure 4.4. Moreover, even with oxygen consumption by the nitrifying bacteria in the biofilter, there is a tendency of higher dissolved oxygen after the biofilter compared to before the biofilter. This is evident in the stocking density of 7.0 kg/m^3 and flow rates 2 and 3 L/min and stocking density of 9.0 kg/m^3 and flow rate

2 L/min. This scenario was attributed to the aerating nature of the biofilter at these low flow rates as much of the biofilter exhibited air pockets which contributed to increased oxygen dissolution as the water went through it. Dissolved oxygen levels at a flow rate of 10 L/min for a stocking rate of 4.0 and 5.0 L/min were found to be the same. This could be attributed to rapid oxygen dissolution at this high flow rate and approximately the same level of oxygen demand by the fish given the closeness of the two stocking densities. Both before the biofilter and after the biofilter, dissolved oxygen decreased with increasing stocking density a sign of increased oxygen demand with increasing biomass. Similar findings were reported by García-trejo et al. (2016) where oxygen consumption of 460, 600 and 650 was recorded for fish biomass of 0.14, 0.28, and 0.42 kg/m^3 although these stocking densities are less than the densities used in this study.

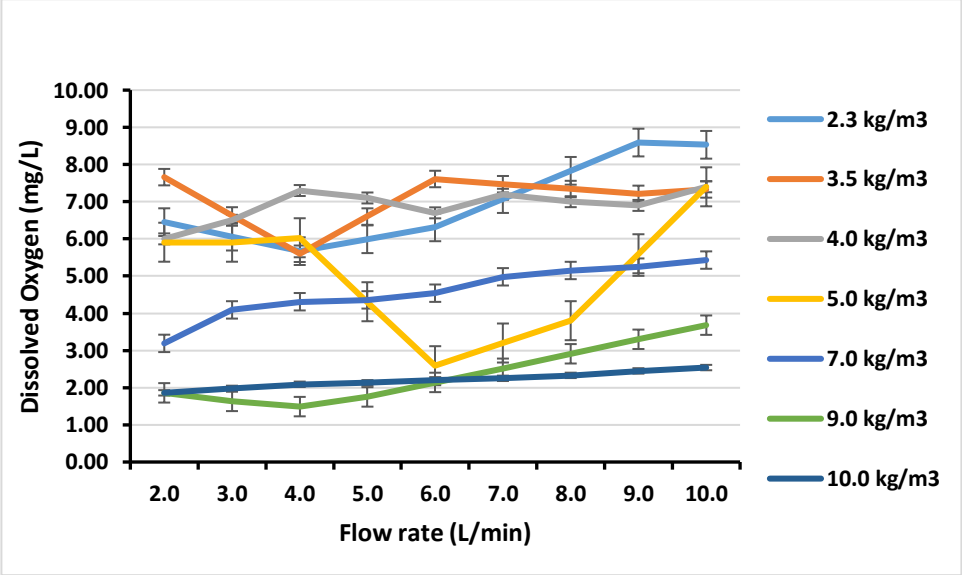

Figure 4.3: Plots of dissolved oxygen versus flow rate for different stocking densities in the production tank

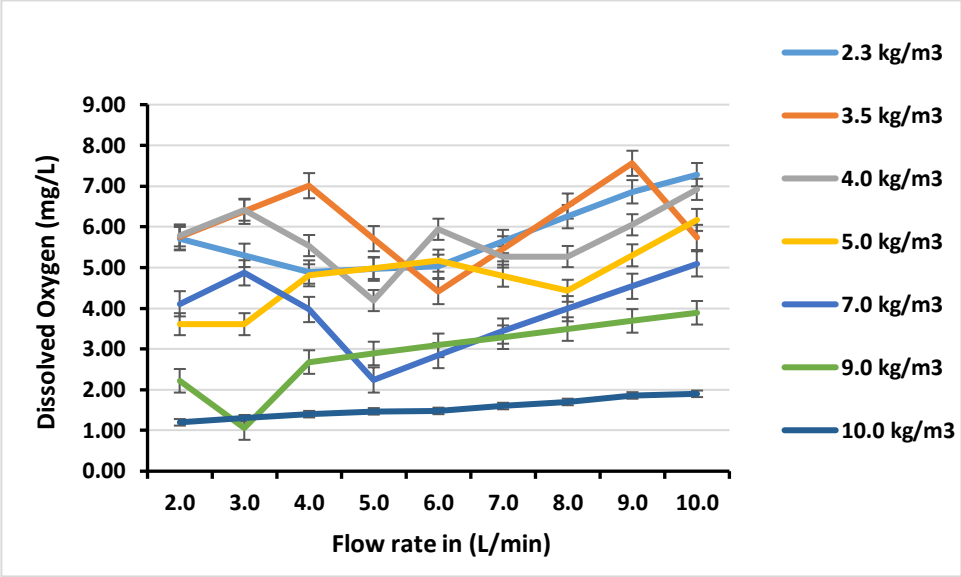

Figure 4.4: Plots of dissolved oxygen versus flow rate for different stocking densities after biofilter

The reduced detention time with increasing flow rate leads to reduced oxygen uptake by the nitrifying bacteria; a phenomenon which would also lead to an increase in oxygen concentration with increasing flow rate. The aerator which operated at a pumping rate of 15 L/min maintained the dissolved oxygen levels above 2.3 mg/L for most stoking densities. However, there was an observed decrease in oxygen concentration with increasing stocking density, as shown in Figures 4.3 and 4.4. According to Ngugi et al. (2008) and Sri-um et al. (2016), the Nile Tilapia is a bit hardy and can survive low oxygen concentrations to levels below 3mg/L. This makes the oxygen levels achieved in this study reasonably appropriate for the survival of Nile Tilapia at most stocking densities except at 9.0 kg/m^3 and 10kg/m^3 where the oxygen levels went below 2.3 mg/L, and the fish seemed to gasp for oxygen especially at midday when the temperatures were highest. Gullian-Klanian & Arámburu-Adame (2013) noticed that, even when the mean of DO was not different between treatments, the data suggests that the DO concentration supplied in their RAS was not enough for the high stocking densities.

Moreover, the oxygen concentration in the production tanks was relatively higher than that in the sump tank after the water flows through the biofilter a phenomenon observed by Zhang et al. (2011). This is illustrated in the plots of dissolved oxygen versus flow rate at the different stocking densities as presented in Figures 4.3 and 4.4. This behaviour can be explained by the fact that the nitrification process is an aerobic process in which oxygen is consumed to allow for the conversion of ammonium (NH_4^+) into nitrite and then into nitrates. The rate of dissolution with flow rate showed an approximately linear increase (Scully, 2016). Variations in stocking density had a significant effect on the oxygen concentrations of the RAS water before and after the biofilter ($P < 0.05$) as observed from analysis of variance as presented in Tables 4.4 and 4.5. Variation in Flow rate had a significant influence on the RAS dissolved oxygen before the biofilter ($P < 0.05$) but not after the biofilter ($P > 0.05$).

Table 4.4: ANOVA of dissolved oxygen in production tank

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
Flow rate	17.37245	8	2.171556	2.368551	**0.030901**	2.138229
Stocking Density	322.65	6	53.77499	58.65326	**2.03E-20**	2.294601
Error	44.00778	48	0.916829			
Total	384.0302	62				

Table 4.5: ANOVA of dissolved oxygen after biofilter

Source of Variation	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
Flow rate	37.24242	8	4.655303	1.94871	**0.07403**	2.138229
Stocking Density	285.3218	6	47.55364	19.90596	**1.62E-11**	2.294601
Error	114.6679	48	2.388915			
Total	437.2322	62				

A significant difference ($P < 0.05$) in oxygen consumption by Nile tilapia at different stocking densities in recirculating aquaculture was also observed by García-trejo et al. (2016).

4.2.3 Electrical Conductivity (EC) of the RAS Water

Figures 4.5 and 4.6 shows electrical conductivity in the production tanks and after the biofilter, respectively. Tables of variations of electrical conductivity with flow rate at the different stocking densities are presented in Appendix A5-A6. The levels of electrical conductivity increased with an increase in flow rate and stocking density. This was attributed to the decreasing conversion of ammonia into nitrites and nitrates with increasing flow rates (Van Rijn, 1996). According to López-Luna et al. (2013), water quality is affected by stocking density in RAS. Electrical conductivity is thus affected by stocking density since it is not an exception when it comes to water quality.

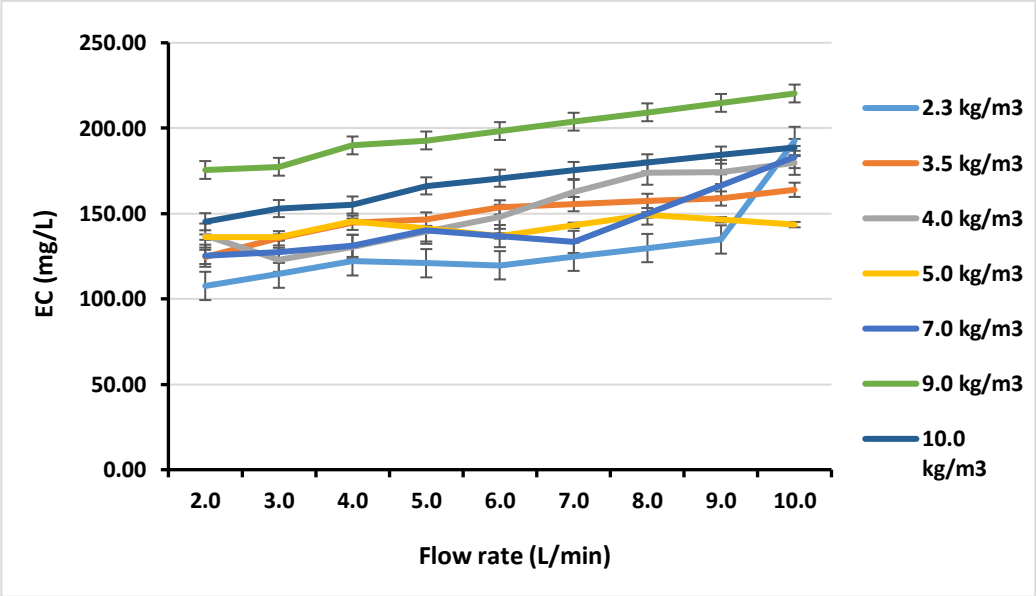

Figure 4.5: Plots of electrical conductivity versus flow rate for different stocking densities in the production tank

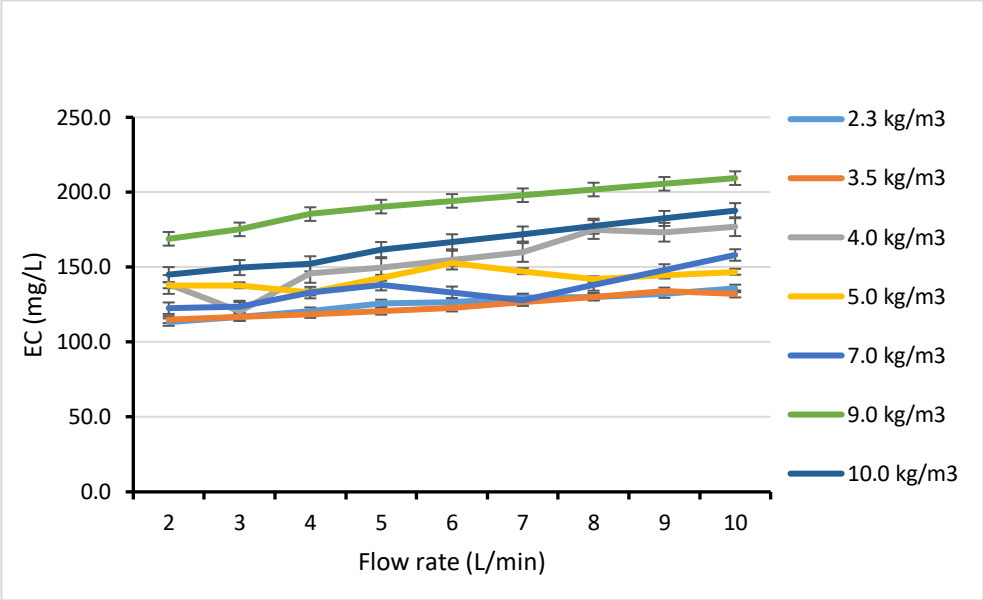

Figure 4.6: Figure A8: Plots of electrical conductivity versus flow rate for different stocking densities after the biofilter

The difference in the levels of EC before and after the biofilter at each flow rate was quite small for most stocking densities as presented. However, a slight increase in EC in the water after passing the biofilter was visible at lower flow rates as compared to higher flow rates supporting findings by Zhang et al. (2011). Martins et al. (2009) also noticed that the high-accumulation water had significantly higher conductivity. From the analysis of variance, as shown in Tables 4.6 and 4.7, both stocking density and flow rates showed a significant influence ($P < 0.05$) of the RAS water electrical conductivity.

Table 4.6: ANOVA of Electrical conductivity in the production tank

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Flow rate	7963.324	8	995.4155	5.430912	**6.87E-05**	2.138229
Stocking Density	27177.43	6	4529.572	24.713	**3.98E-13**	2.294601
Error	8797.775	48	183.287			
Total	43938.53	62				

Table 4.7: ANOVA of Electrical conductivity after biofilter

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Flow rate	5945.142	8	743.1427	15.51994	**4.37E-10**	2.18017
Stocking Density	26455.78	5	5291.156	110.5015	**2.58E-22**	2.449466
Error	1915.324	40	47.8831			
Total	34316.24	53				

Kabir Chowdhury, Yi, Lin & El-Haroun (2006) observed a significant effect of EC on biomass growth. This was an indication of reducing carrying capacity in Nile tilapia with increasing salinity.

4.2.4 pH of RAS Water

pH in the production tanks and after the biofilter is presented in Figures 4.7 and 4.8 respectively. Tables of variations of pH with flow rate at the different stocking densities are presented in Appendix A7-A8. pH increased gradually with an increase in flow rate both before and after biofilter. At most stocking densities, the pH was higher in the production tank and lowered in the sump tank after the biofilter (Zhang et al., 2011). This is an indication of ammonia removal by the biofilter. During the conversion of ammonia to nitrite and nitrates, hydrogen ions are produced, which then combine with the hydroxyl

radicals leading to the lowering of pH. Ammonia varies proportionately with pH and temperature Wurts (2003).

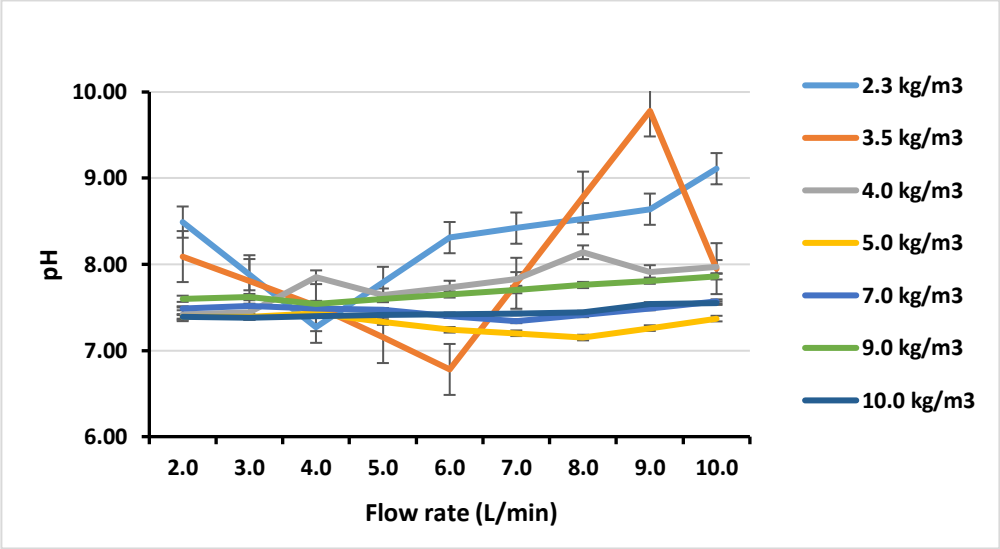

Figure 4.7: Plots of pH versus flow rate for different stocking densities in the production tank

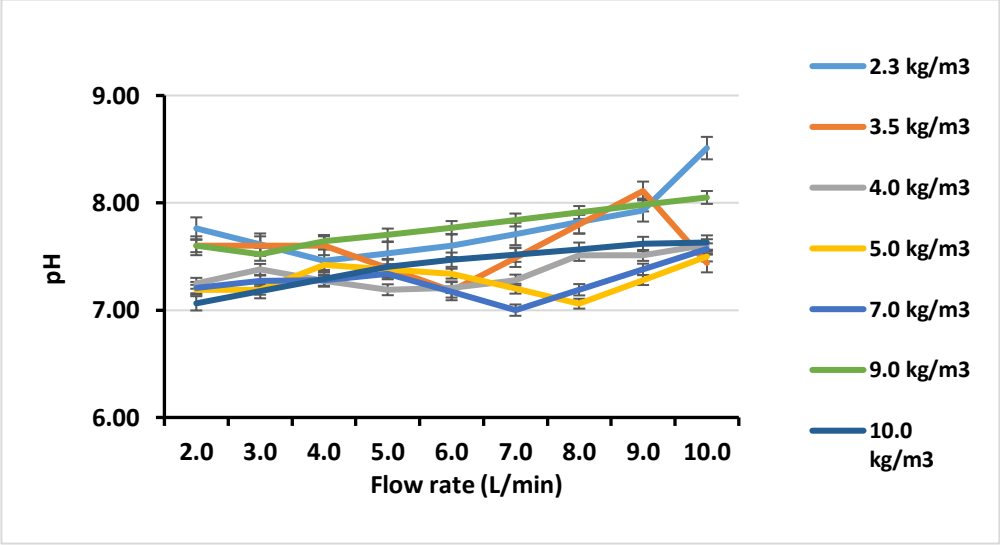

Figure 4.8: Plots of pH versus flow rate for different stocking densities after the biofilter

At lower pH levels, the ammonia is lower, and at higher pH levels, the ammonia is also higher. As more ammonia is produced, more hydrogen (H+) ions are taken up leaving hydroxyl radical (OH-) to dominate and hence a rise in pH. On the other hand, as ammonia gets removed in the water, ammonium breaks down to create an equilibrium (Miron et al., 2008). This breakdown process releases hydrogen ions, thereby leading to a decrease in pH, as presented in Equation 2.7 (Masser, Rakocy & Losordo, 1999).

It was observed that the pH levels in the production tank and after the biofilter were within the acceptable range 7.7 ± 0.49 and 7.49 ± 0.28 respectively for the fish and the nitrifying bacteria to thrive. Water pH was around 7 in almost all the phases of the trials, indicating that the bacteria in the bio-filters were working correctly (López-Luna et al., 2013). The author further noted that water pH seemed to follow a completely different evolution for the highest density since it had a lower initial concentration and lower accumulation rate. From the analysis of variance, as shown in Tables 4.8 and 4.9, stocking density had a significant influence ($P < 0.05$) on pH while the flow rate did not show significant influence

($P > 0.05$) on the RAS water pH.

Table 4.8: ANOVA of pH in production tank

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Flow rate	2.181723	8	0.272715	1.821071	**0.096137**	2.138229
Stocking Density	6.110534	6	1.018422	6.80057	**2.92E-05**	2.294601
Error	7.188262	48	0.149755			
Total	15.48052	62				

Table 4.9: ANOVA of pH after biofilter

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Flow rate	0.513603	8	0.0642	1.584835	**0.154412**	2.138229
Stocking Density	2.563349	6	0.427225	10.54637	**1.92E-07**	2.294601
Error	1.944441	48	0.040509			
Total	5.021394	62				

4.2.5 Temperature of the RAS Water

Tables 4.10 and 4.11 show temperature values in the production tanks and after the biofilter, respectively. The greenhouse cover in place helped to keep the temperatures within an acceptable range for the Nile tilapia to survive. The most favourable water temperatures for Nile tilapia survival are within a range of 25-33˚C as opined by Ngugi et al. (2007).

Table 4.10: Temperature (˚C) in the production tanks at different flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	24.86	24.76	23.10	23.60	24.63	28.10	25.56
3.0	29.20	26.61	23.86	25.13	22.46	30.63	28.80
4.0	29.53	28.46	23.50	26.66	26.06	30.03	29.26
5.0	26.10	23.76	23.30	27.96	28.60	29.63	28.70
6.0	28.66	22.06	24.06	29.26	29.56	29.13	27.76
7.0	28.53	23.33	23.23	27.83	28.53	28.63	26.83
8.0	28.40	27.60	22.60	26.40	27.93	28.13	25.90
9.0	28.26	28.86	23.36	24.96	25.33	27.63	24.96
10.0	28.88	27.01	24.56	23.53	22.73	27.13	24.03

Each value is an average of three (3) readings

The average temperature of the water in this study was 26.48 ˚C before the biofilter and 26.20 ˚C after the biofilter, which made it suitable for both the fish and the nitrifying bacteria. These temperatures were slightly higher than those reported by Gichana (2019), where the water temperature ranged from 22.4–24.2˚C.In most scenarios, the water temperature after the biofilter was slightly higher by 2 ± 0.7 ˚C compared to before the biofilter. The ambient temperature in the greenhouse ranged between 39.5 ˚C and 49.0 ˚C at mid-day. The high ambient temperatures in the greenhouse help maintain the water temperature within the appropriate levels for the Nile tilapia to thrive. There was minimal variation in water temperature during the experimental period. This is because the greenhouse covering helped in stabilizing the temperature in the greenhouse According to

García-Trejo et al. (2016) the water temperature inside the tanks did not show a wide variation as the environmental temperature did, showing an average of 18.50 ± 11.92°C, while the temperature in treatments tanks had an average of 24.68 ± 3.0° C. This is similar to the findings in this study. Slight heating of the water by the warm column of air in the biofilter pack could have contributed to the slight increase in the temperature of the water. This was in agreement with findings by Zhang et al. (2011). This temperature is relatively higher than the average water temperature outside the greenhouse (temperature of the raw water before being brought into the greenhouse), which was 22.8 ˚C.

Table 4.11: Temperature (˚C) after biofilter tanks at different flow rates and stocking densities

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	26.50	25.70	23.00	23.80	24.70	30.10	26.40
3.0	27.60	23.20	23.90	25.40	22.60	26.40	29.20
4.0	29.70	20.70	23.90	27.00	26.10	29.50	30.00
5.0	28.70	23.50	22.90	29.50	25.50	29.80	28.30
6.0	26.70	26.30	21.20	30.00	28.90	29.30	27.80
7.0	27.70	24.10	24.50	29.80	29.30	28.80	27.30
8.0	28.70	21.90	23.20	27.60	28.10	28.30	26.80
9.0	29.70	19.70	21.80	25.40	23.90	27.80	26.30
10.0	29.40	28.10	22.40	23.20	19.70	27.30	25.80

Each value is an average of three (3) readings

According to Santos, Mareco & Dal Pai Silva (2013) growth of different strains of Nile Tilapia was undifferentiated at a temperature of 22 ˚C. However, as the temperature was raised to 30 ˚C, some strains presented a higher growth rate.

4.2.6 Biofilter Purification Efficiency (PE)

Figure 4.9 shows the Purification efficiency values (%) of the pumice biofilter. Table of variations of Purification efficiency with flow rate at the different stocking densities is presented in Appendix A9.

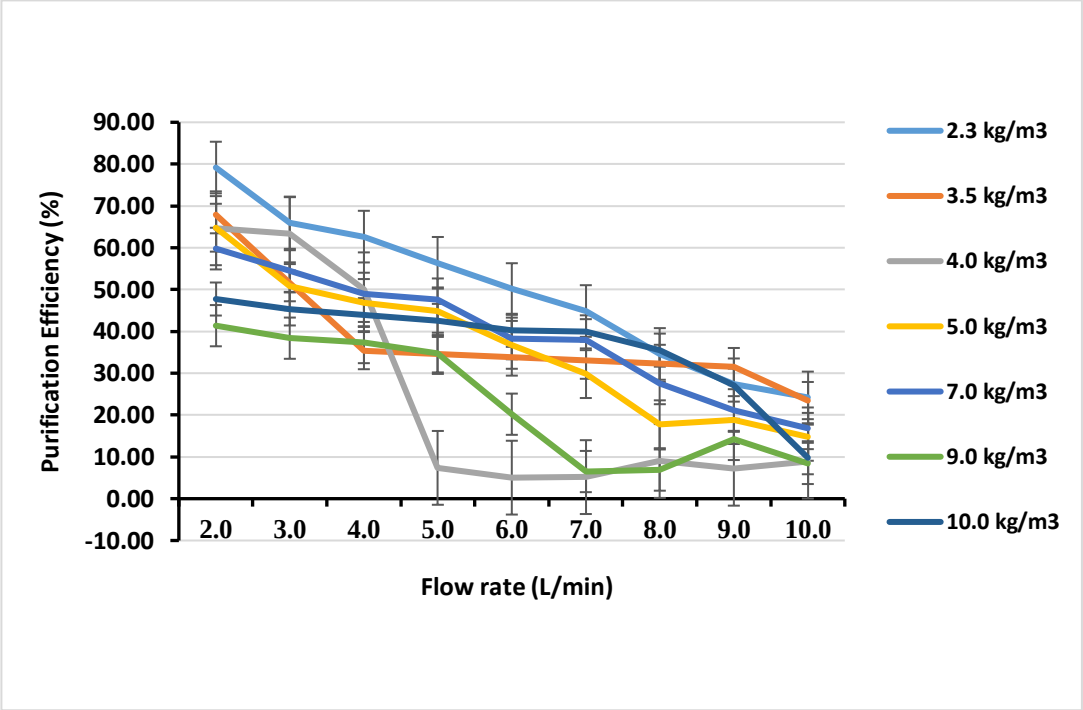

Figure 4.9: Plots of purification efficiency versus flow rate for different stocking densities

It was observed that purification efficiencies decreased with increasing stocking density at a given flow rate

This was attributed to the increased ammonia production with increasing stocking density and reducing nitrification due to reducing detention time as the flow rates increased as well as increased oxygen demand as opined by Jechalke et al. (2011). Gullian-Klanian & Arámburu-Adame (2013), reported an ammonia removal rate of 57±7% at 1.22 kg/m^3 stocking density and 10 L/hr water flow rate. Ebeling, Rishel & Sibrell (2005) reported TSS removal efficiencies as high as 99% using polymers as flocculation aids in RASs. Similarly, Ebeling, Sibrell, Ogden, & Summerfelt (2003) reported TSS and phosphorous removal efficiencies of 89% and 93% while using alum and ferric chloride coagulants in a RAS system, respectively. In a study using immobilized Ba-alginate and Ca-alginate beads to remove ammonia, 94% and 87% of loaded ammonia were removed within 3.4 h of hydraulic retention time (Kim et al., 2000). ANOVA for Purification efficiency, as

presented in Table 4.12 showed that both variations in flow rate and stocking density had a significant influence ($P < 0.05$) on the Purification efficiency.

Table 4.12: ANOVA of Purification efficiency

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Flow rate	13342.09	8	1667.761	18.05452	**4.33E-12**	2.138229
Stocking Density	4151.701	6	691.9501	7.490776	**1.07E-05**	2.294601
Error	4433.934	48	92.37362			
Total	21927.72	62				

4.3 Energy Requirements for Environmental Control

Figure 4.10 shows the energy consumed by the pump and the aerators at different flow rates and stocking densities per day. The study aimed at the cumulative energy consumption for aeration and pumping hence the summation and presentation of the two as one value. Table of variations of energy (kWh) with flow rate at the different stocking densities is presented in Appendix A10. The amount of energy consumed by the pump and the aerators increased progressively with flow rate as presented in Figure 4.10.

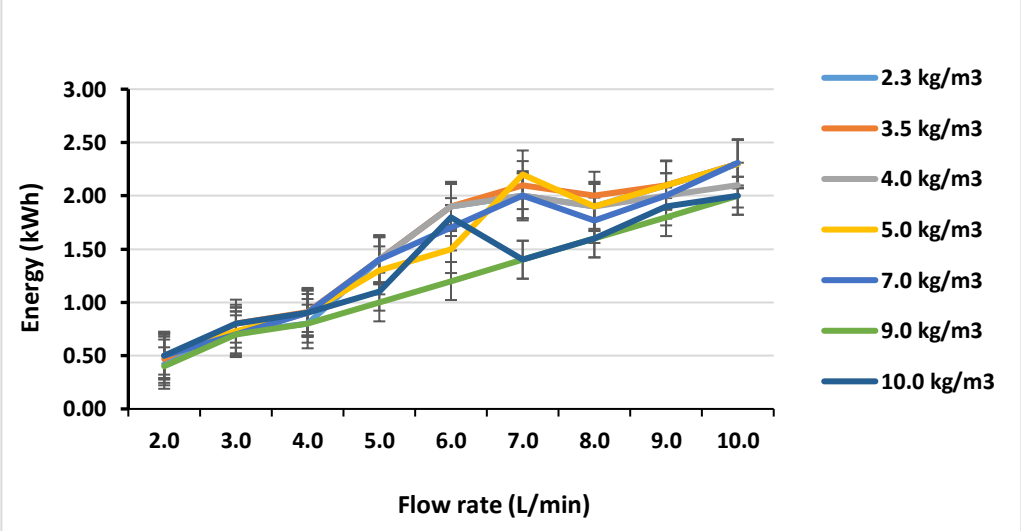

Figure 4.10: Plots of Energy consumed per day versus flow rate for different stocking densities in the production tank

From the observations, the right combinations of stocking densities and flow rate leads to lower cost of energy and favourable environment for the Nile tilapia to thrive. Lower stocking densities require low flow rates and minimum aeration, while higher stocking densities require higher flow rates and aeration to maintain a favourable environment for the fish to thrive and minimize production costs. Park, Kim, Kim & Jo (2008) in a study to determine the energy consumption and changes in water quality in a pilot-scale RAS monitored for 155 days reported total power consumption of 3925 kW. This power consumption included power for heating aeration and pumping. Approximately 11.22 kWh and 22.44 kWh of energy were consumed to produce 1 kg of fish using RAS tanks and Biofloc technology (BFT) tanks, respectively (Luo et al., 2014). According to Song et al. (2019) in order to systematically assess the environmental performance of RAS farming, it is crucial to take the whole life cycle into account to avoid ad hoc and suboptimal environmental measures. The study by song et al. showed that 1-tonne live-weight salmon production required 7,509 kWh farm-level electricity.

4.4 Fish Growth

The fish weight was measured during stocking and after the experimental period for each stocking density. The fish growth data presented here was vital for model development concerning feed fed, ammonia production and revenue computation. The mass increase was for one month for each density. The average weight gain and feed conversion ratio (FCR) was also computed from the weight data. The weight data is as presented in Table 4.13.

Table 4.13: Weight data of fish at different stocking densities over a period of a month for each density

Stocking Density (kg/m^3)	Number of fish per replicate	Average Initial Body Mass (g)	Initial Total Mass (g)	Average Final Body Mass (g)	Total Mass increase (g)	Average weight gain (%)	Feed Fed (g)	FCR
2.3	13.00	186.80	2,300.60	191.86	62.38	2.71	92.00	1.48
3.5	18.00	194.50	3,501.00	199.70	93.60	2.67	140.00	1.50
4.0	21.00	190.50	4,000.50	195.57	106.40	2.66	160.00	1.53
5.0	26.00	192.40	5,002.40	197.10	122.20	2.44	200.00	1.64
7.0	36.00	198.17	7,000.67	203.07	173.10	2.47	280.00	1.62
9.0	46.00	198.57	9,000.73	203.43	220.63	2.45	360.00	1.64
10.0	51.00	198.83	10,001.90	203.53	236.33	2.36	400.00	1.69

The percentage of weight gain was slightly higher at low stocking densities than at high stocking densities (García-Trejo et al., 2016; Gibtan et al., 2008). Conversely, FCR increased with increasing stocking density. The lower weight gain at high stocking densities was attributed to stress and more reduced water quality at higher stocking densities (Verster, 2017). The RAS maintained optimal water temperatures (26 ˚C) for the Nile tilapia to survive (Santos et al., 2013).

4.5 Model Calibration and Validation

4.5.1 Model Calibration Results

The model calibration results after multiple iterations and parameter modification at 4.0 kg/m^3 gave the results presented in Table 4.14, which showed a reasonably good prediction of the observed data.

Table 4.14: Calibration results at 4 kg/m^3

	Observed data						Predicted data				
	Stocking density kg/m^3	**Ammonia (mg/L) in P.Tank**	**Dissolved Oxygen (mg/L) P.Tank**	**pH in P.Tank**	**Ec P.Tank**	**Energy (kwhr)**	**Ammonia (mg/L) in P.Tank**	**Dissolved Oxygen (mg/L) in P.Tank**	**pH in P.Tank**	**Ec P.Tank**	**Energy (kwhr)**
	2.0	0.011	6.0	7.42	137.1	0.5	0.010	4.8	7.05	119.3	0.4
	3.0	0.016	6.5	7.44	122.9	0.7	0.015	5.2	7.07	106.9	0.6
	4.0	0.017	7.3	7.85	130.5	0.9	0.016	5.8	7.46	113.5	0.8
	5.0	0.018	7.1	7.64	139.3	1.4	0.017	5.7	7.26	121.2	1.2
	6.0	0.019	6.7	7.73	148.1	1.9	0.018	5.4	7.34	128.8	1.6
	7.0	0.020	7.2	7.83	162.7	2.0	0.019	5.8	7.44	141.5	1.7
	8.0	0.030	7.0	8.14	173.9	1.9	0.029	5.6	7.73	151.3	1.6
NB:	9.0	0.065	6.9	7.91	174.3	2.0	0.062	5.5	7.51	151.6	1.7
	10.0	0.010	7.4	7.97	179.7	2.1	0.010	5.9	7.57	156.3	1.8

P.Tank in table 4.4 stands for production tank.

4.5.2 Validation/Prediction Results at 10 kg/m^3

After calibration, the model was rerun with data at 10 kg/m^3 to how well it could make predictions from a different set of data. Table A11 in Appendix A shows the observed data and the predicted data during the validation process. Figure 4.11 shows the differences between the observed values and the model predicted values. Just like after calibration, the model gave a reasonably good prediction of the observed data at 10 kg/m^3.

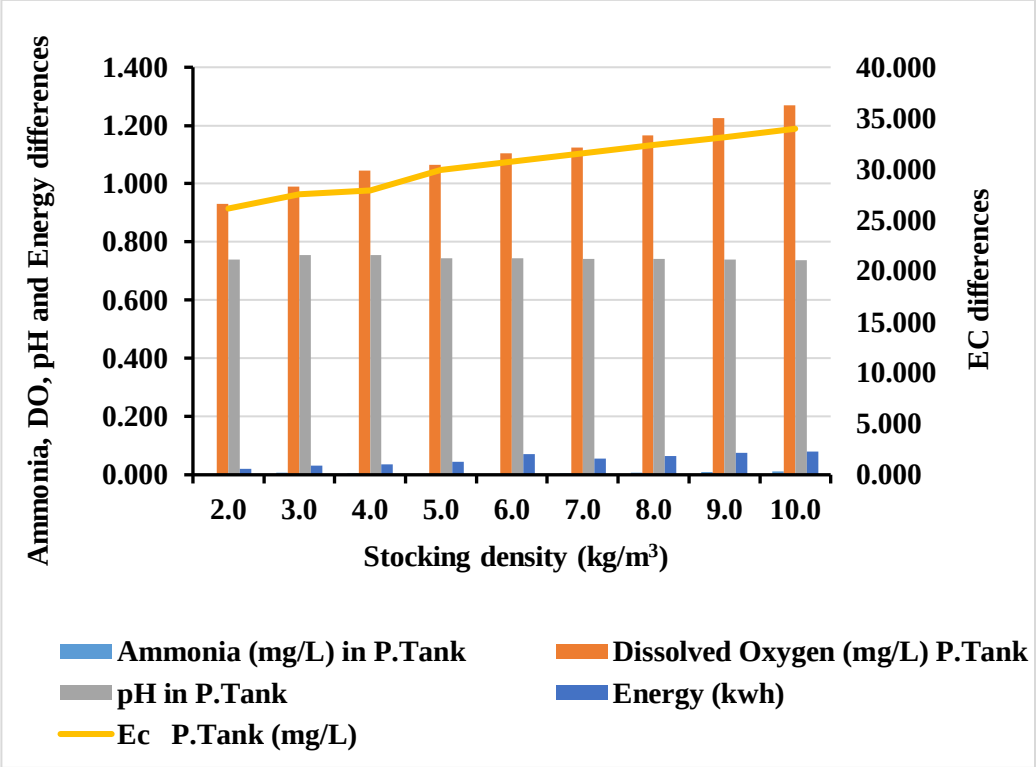

Figure 4.11: Differences between observed data and predicted data at different stocking densities

4.5.3 Model Evaluation

Most of the RAS water quality and energy consumption during validation after calibration concurred with the model water quality and energy predictions to a reasonable degree of precision. The Nash Sutcliff efficiency (NSE), Root Mean Square Error (RMSE) and

coefficient of determination R^2 values for the different parameters before the biofilter are as presented in Table 4.15. RMSE quantifies how different a set of values are.

The values were computed by comparing the observed values, and the model predicted values in Table A11. Tanveer, (2020) in a study to develop a model for goldfish aquaculture reported R^2 values of 0.99 and 0.98 for Ammonia and dissolved oxygen, respectively. The only parameter whose validation results did not show a remarkable degree of correspondence with the model predicted values based on the R^2 statistic was dissolved oxygen. The reduced prediction level in oxygen was attributed to high variations in oxygen concentration in the raw water and varied incorporation of oxygen in the water as it recirculates at different flow rates.

Table 4.15: Nash Sutcliff efficiency (NSE), RMSE and R^2 values for the different parameters before the Biofilters

Parameter	RMSE (with parameter units)	NSE (Unit-less)	R^2
Ammonia (mg/L)	0.03	-4.26	0.95
pH	1.33	0.97	0.89
DO (mg/L)	2.39	0.77	0.23
EC (mg/L)	240.86	0.59	0.87
Energy (kWh)	0.29	0.94	0.85

From the NSE and RMSE analysis, the model gave a reasonably good prediction of pH, DO and energy. The ammonia and EC model predictions did not reasonably correspond to the observed values. The ammonia and EC model values were relatively higher than the observed values. This was attributed to the accumulation of ammonia and EC with time as there were only minimal water exchanges.

4.5.4 Costs and Revenue Projections for Different Production Densities

Table A12 in Appendix A shows the projected costs, revenues profits/losses for the different production densities for two production cycles. Profit and revenue projections were included in the model in this study because as long as an aquaculture undertaking aims at attaining conducive environment fro the cultured species, the economics of the

entire investment can not be ignored. From the costs/revenues, it is evident that low stocking densities take long before break-even as compared to high stocking densities. Figure 4.12 shows a plot of projected profits for different stocking densities.

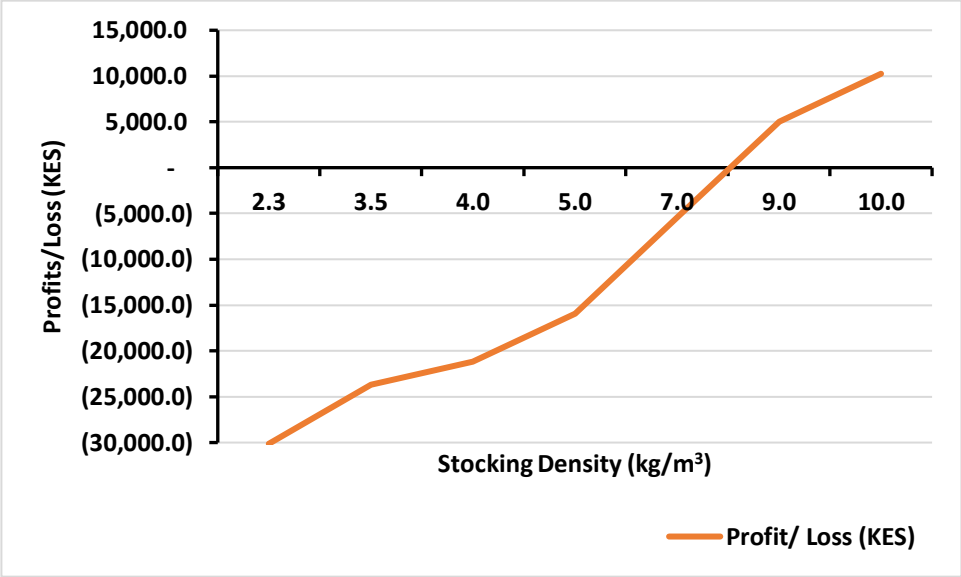

Figure 4.12: A plot projected profits for different stocking densities

Most appropriate profit scenarios did not coincide with the best water quality conditions for most of the stocking densities. Conversely, the conducive water quality levels did coincide or lead to profitable scenarios (Pedersen, 2018).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

1. From the study, it was concluded that environmental parameters of a RAS are greatly affected by variations in stocking densities and flow rates ($P<0.05$). For each stocking density, flow rates above 7 L/min led to poor environmental conditions than at lower flow rates (flow rates below 5 L/min). The pumice rock showed a functional capacity to remove ammonia from RAS water with an efficiency as high as 70%.
2. Energy consumption increased from a low of 0.4 kWh at 2.0 L/min to a high of 2.3 kWh at 10.0 L/min for each stocking density.
3. The developed RAS model demonstrated sufficient capability to predict environmental requirements for different stocking densities. The R^2 values for ammonia, pH, dissolved oxygen, electrical conductivity and energy as 0.95, 0.89, 0.23, 0.87 and 0.85 respectively.

5.2 Recommendation

From this research and its findings, the following recommendations are given:

1. In order to maintain good RAS water quality and increased production and profits among farmers using RAS in Kenya, the right combination of stocking density, energy and water flowrate should be utilized.
2. Similar studies on RAS should be carried out for other fish species such as African catfish as well as with other biofilter media other than pumice in order to develop suitable biofilter materials for use in RAS for increased fish production.

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Appendix A: Data Tables

Table A1: Average ammonia concentration (mg/L) in the production tanks at different flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	0.049	0.008	0.011	0.039	0.016	0.045	0.020
3.0	0.039	0.009	0.016	0.019	0.043	0.050	0.063
4.0	0.052	0.009	0.017	0.002	0.046	0.043	0.058
5.0	0.057	0.021	0.018	0.019	0.013	0.059	0.036
6.0	0.060	0.033	0.019	0.041	0.015	0.089	0.015
7.0	0.018	0.008	0.020	0.036	0.017	0.012	0.041
8.0	0.029	0.009	0.030	0.030	0.011	0.075	0.067
9.0	0.042	0.010	0.065	0.025	0.020	0.089	0.093
10.0	0.045	0.011	0.010	0.020	0.074	0.093	0.119

Each value is an average of three (3) readings

Table A2: Ammonia concentration (mg/L) after biofilter tank at different flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	0.010	0.003	0.004	0.014	0.006	0.026	0.010
3.0	0.013	0.004	0.006	0.009	0.020	0.031	0.034
4.0	0.020	0.006	0.008	0.001	0.023	0.027	0.032
5.0	0.025	0.014	0.017	0.010	0.007	0.038	0.021
6.0	0.030	0.022	0.018	0.026	0.009	0.071	0.009
7.0	0.010	0.005	0.019	0.025	0.011	0.011	0.025
8.0	0.019	0.006	0.021	0.025	0.008	0.070	0.043
9.0	0.031	0.007	0.060	0.020	0.016	0.076	0.068
10.0	0.035	0.008	0.009	0.017	0.062	0.085	0.107

Each value is an average of three (3) readings

Table A3: Dissolved oxygen concentration (mg/L) in the production tanks at different flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	6.45	7.66	6.00	5.91	3.19	1.86	1.86
3.0	6.06	6.63	6.50	5.91	4.09	1.63	1.98
4.0	5.67	5.60	7.30	6.03	4.31	1.49	2.09
5.0	5.99	6.60	7.10	4.31	4.36	1.75	2.13
6.0	6.31	7.61	6.70	2.59	4.54	2.14	2.21
7.0	7.07	7.47	7.20	3.20	4.98	2.52	2.25
8.0	7.83	7.34	7.00	3.80	5.15	2.91	2.33
9.0	8.59	7.21	6.90	5.60	5.24	3.30	2.45
10.0	8.53	7.33	7.40	7.40	5.43	3.68	2.54

Each value is an average of three (3) readings

Table A4: Dissolved oxygen concentration (mg/L) after biofilter tanks at different flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	5.71	5.75	5.78	3.61	4.11	2.22	1.20
3.0	5.30	6.38	6.41	3.61	4.87	1.06	1.30
4.0	4.89	7.01	5.54	4.81	3.97	2.68	1.40
5.0	4.96	5.71	4.19	4.99	2.24	2.89	1.47
6.0	5.03	4.41	5.94	5.17	2.84	3.09	1.48
7.0	5.64	5.46	5.26	4.80	3.44	3.29	1.60
8.0	6.25	6.51	5.27	4.43	3.99	3.49	1.70
9.0	6.86	7.56	6.05	5.30	4.54	3.69	1.86
10.0	7.28	5.74	6.92	6.17	5.09	3.89	1.90

Each value is an average of three (3) readings

Table A5: Electrical conductivity (mg/L) in the production tanks at different flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	107.60	124.60	137.10	136.20	125.30	175.50	145.20
3.0	114.80	135.50	122.90	136.20	127.60	177.40	152.90
4.0	122.00	144.60	130.50	145.50	131.10	189.90	155.00
5.0	120.90	146.50	139.30	141.20	140.10	192.80	166.20
6.0	119.70	153.60	148.10	136.90	136.80	198.30	170.70
7.0	124.70	155.50	162.70	143.10	133.40	203.80	175.20
8.0	129.80	157.40	173.90	149.20	150.00	209.30	179.70
9.0	134.80	158.80	174.30	146.40	166.50	214.80	184.20
10.0	192.50	163.90	179.70	143.50	183.10	220.30	188.70

Each value is an average of three (3) readings

Table A6: Electrical conductivity (mg/L) after biofilter tanks at different flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2	113.3	115.0	138.4	137.9	122.6	168.9	145.0
3	116.7	116.7	120.5	137.9	123.7	175.2	149.7
4	120.6	118.5	145.8	133.1	133.0	185.4	152.2
5	125.8	120.6	149.7	142.9	138.3	190.4	161.7
6	126.5	122.8	154.7	152.7	133.2	194.2	166.9
7	129.8	126.5	159.8	147.3	128.1	198.0	172.1
8	130.3	130.3	175.1	141.9	138.1	201.8	177.3
9	132.0	134.0	173.3	144.4	148.1	205.6	182.5
10	135.8	132.1	177.0	146.9	158.1	209.4	187.7

Each value is an average of three (3) readings

Table A7: pH in the production tanks at different water flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	8.49	8.09	7.42	7.39	7.49	7.60	7.39
3.0	7.88	7.81	7.44	7.39	7.52	7.62	7.38
4.0	7.27	7.52	7.85	7.43	7.49	7.54	7.40
5.0	7.79	7.15	7.64	7.33	7.47	7.60	7.41
6.0	8.31	6.78	7.73	7.24	7.40	7.65	7.42
7.0	8.42	7.78	7.83	7.20	7.34	7.70	7.43
8.0	8.53	8.78	8.14	7.15	7.41	7.76	7.44
9.0	8.64	9.78	7.91	7.26	7.49	7.81	7.54
10.0	9.11	7.95	7.97	7.37	7.57	7.86	7.55

Each value is an average of three (3) readings

Table A8: pH after biofilter tanks at different water flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	7.76	7.60	7.25	7.19	7.21	7.60	7.06
3.0	7.61	7.60	7.38	7.19	7.27	7.52	7.18
4.0	7.46	7.60	7.27	7.42	7.28	7.64	7.29
5.0	7.53	7.39	7.19	7.38	7.34	7.70	7.40
6.0	7.60	7.18	7.21	7.34	7.17	7.77	7.47
7.0	7.71	7.49	7.28	7.20	7.00	7.84	7.52
8.0	7.82	7.80	7.51	7.06	7.19	7.91	7.56
9.0	7.93	8.11	7.51	7.28	7.38	7.98	7.62
10.0	8.51	7.44	7.61	7.50	7.57	8.05	7.63

Each value is an average of three (3) readings

Table A9: Purification efficiency (%) of the pumice biofilter

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	79.18	67.90	64.66	64.79	59.80	41.37	47.74
3.0	65.92	51.65	63.40	50.79	54.43	38.38	45.37
4.0	62.66	35.40	50.06	46.79	49.05	37.33	44.00
5.0	56.40	34.64	7.37	44.79	47.68	34.76	42.63
6.0	50.13	33.87	5.03	36.79	38.31	20.20	40.26
7.0	44.87	33.11	5.16	29.79	37.94	6.49	39.89
8.0	34.61	32.35	29.01	17.79	27.57	6.84	35.52
9.0	27.35	31.59	7.16	18.79	21.20	14.17	27.16
10.0	24.21	23.46	8.87	14.79	16.83	8.43	9.79

Each value is an average of three (3) readings

Table A10: Energy (kWh) consumed by the pump and the aerator in one day at different flow rates and stocking densities.

Flow rate (L/min)	Stocking density (kg/m^3)						
	2.3	3.5	4.0	5.0	7.0	9.0	10.0
2.0	0.42	0.47	0.50	0.50	0.50	0.40	0.50
3.0	0.72	0.80	0.71	0.73	0.70	0.70	0.80
4.0	0.80	0.91	0.90	0.90	0.90	0.80	0.90
5.0	1.40	1.40	1.40	1.30	1.40	1.00	1.10
6.0	1.90	1.90	1.90	1.50	1.70	1.20	1.80
7.0	2.00	2.10	2.00	2.20	2.00	1.40	1.40
8.0	1.90	2.00	1.90	1.90	1.77	1.60	1.60
9.0	2.10	2.10	2.00	2.10	2.00	1.80	1.90
10.0	2.30	2.30	2.10	2.30	2.31	2.00	2.00

Each value is an average of three (3) readings

Table A11:

Observed data						Predicted data				
Stocking density kg/m^3	**Ammonia (mg/L) in P.Tank**	**Dissolved Oxygen (mg/L) P.Tank**	**pH in P.Tank**	**Ec P.Tank**	**Energy (kwhr)**	**Ammonia (mg/L) in P.Tank**	**Dissolved Oxygen (mg/L) in P.Tank**	**pH in P.Tank**	**Ec P.Tank**	**Energy (kwhr)**
2.0	0.020	1.9	7.39	145.2	0.5	0.018	0.9	6.65	119.1	0.5
3.0	0.063	2.0	7.55	152.9	0.8	0.057	1.0	6.80	125.4	0.8
4.0	0.058	2.1	7.54	155.0	0.9	0.052	1.0	6.79	127.1	0.9
5.0	0.036	2.1	7.44	166.2	1.1	0.032	1.1	6.70	136.3	1.1
6.0	0.015	2.2	7.43	170.7	1.8	0.014	1.1	6.69	140.0	1.7
7.0	0.041	2.3	7.42	175.2	1.4	0.037	1.1	6.68	143.7	1.3
8.0	0.067	2.3	7.41	179.7	1.6	0.060	1.2	6.67	147.4	1.5
9.0	0.093	2.5	7.40	184.2	1.9	0.084	1.2	6.66	151.0	1.8
10.0	0.119	2.5	7.38	188.7	2.0	0.107	1.3	6.64	154.7	1.9

Observed and predicted data at 10 kg/m^3

Table A12: Projected costs for the RAS system over two production cycles (12 months) for each stocking density

Projected costs for the RAS system over two production cycles (12 month10) for each stocking density							
Stocking density(kg/m^3)	2.30	3.50	4.00	5.00	7.00	9.00	10.00
Stocking Cost (KES)	1,820.00	2,520.00	2,940.00	3,640.00	5,040.00	6,440.00	7,140.00
Feeds Cost (KES)	3,312.00	5,040.00	5,760.00	7,200.00	10,080.00	12,960.00	14,400.00
Energy Cost (KES)	5.20	6.50	7.41	9.10	12.09	16.25	32.50
Construction Cost (KES)	36,500.00	36,500.00	36,500.00	36,500.00	36,500.00	36,500.00	36,500.00
O & M Cost (KES)	5,475.00	5,475.00	5,475.00	5,475.00	5,475.00	5,475.00	5,475.00
TOTAL cost per Stocking density (KES)	47,112.20	49,541.50	50,682.41	52,824.10	57,107.09	61,391.25	63,547.50
Expected Revenues (KES)	16,974.00	25,830.00	29,520.00	36,900.00	51,660.00	66,420.00	73,800.00
Profit/Loss (KES)	(30,138.20)	(23,711.50)	(21,162.41)	(15,924.10)	(5,447.09)	5,028.75	10,252.50

Appendix B: RAS Setup Calculations

The ammonia generated by the fish at the highest anticipated stocking density was calculated using the followings guide

(i) The amount of feed fed to 30kg of fish (stocked in three 1000L tanks) was calculated as:

= 0.04 x 30kg

= 1.2kg

(ii) The ammonia to be generated by the fish was estimated as:

= 0.025 x 1.2kg

= 0.03kg

(iii) The amount of surface area required for the removal of this amount of ammonia was calculated as:

(Ammonia to be removed)/ (ammonia removal rate)

= 30/0.000857

=35,000m^2

(iv) Taking the lowest specific surface area of pumice as 0.5 m^2/g (Troell et al., 2009), the amount of pumice (in Kg) required for the removal of this amount of ammonia will be;

= (Required Surface Area)/ (SSA of pumice)

= 35,000/0.5

=70Kg

(v) The volume of pumice required was calculated as:

= Mass/Density = 70kg/ (200kg/m^3)

= 0.35m^3

(vi) An average efficiency of 55% of the biofilter was assumed, giving a compensation volume that was added.

(Calculated volume)/ (Biofilter efficiency)

= 0.35/0.55

= 0.63m^3

Hence a 1000L circular tank was filled to about 60% of its volume with pumice rock and it served as a trickling biofilter for the developed RAS. The biofilter was inoculated (Helfrich & Libey, 1991) with water from a nearby fish pond in order to shorten its establishment time. This water from a fish pond contains the nitrifying bacteria community (nitrosomonas and the nitrobacter bacteria).

Pipe size calculation was based on Equation 3.2

$$A = Q/V$$

$$= 0.000521875m^2$$

But $A = (\pi D^2)/4$

$$= 0.000521875m^2$$

$$D = \sqrt{((0.000521875 \times 4)/3.142)}$$

$$= 2.57cm$$

This is approximately 1inch (0.0254 m = 25.4 mm) internal pipe diameter, since 1 inch = 25.4mm. Therefore 1″ PPR pipes and fittings were used for plumbing of the entire recirculation system.

Appendix C: Design Drawings

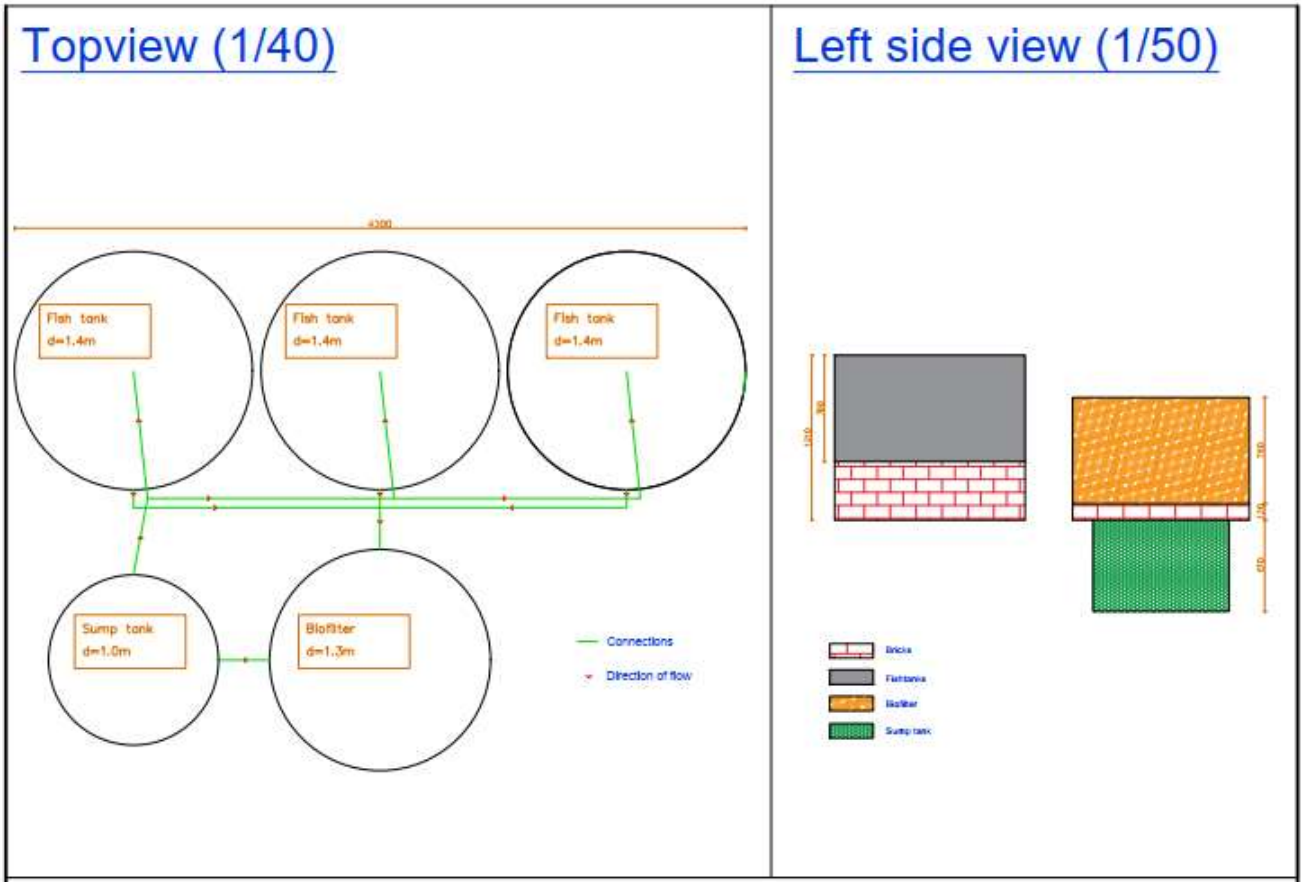

Figure C1: Top and side view of the RAS setup

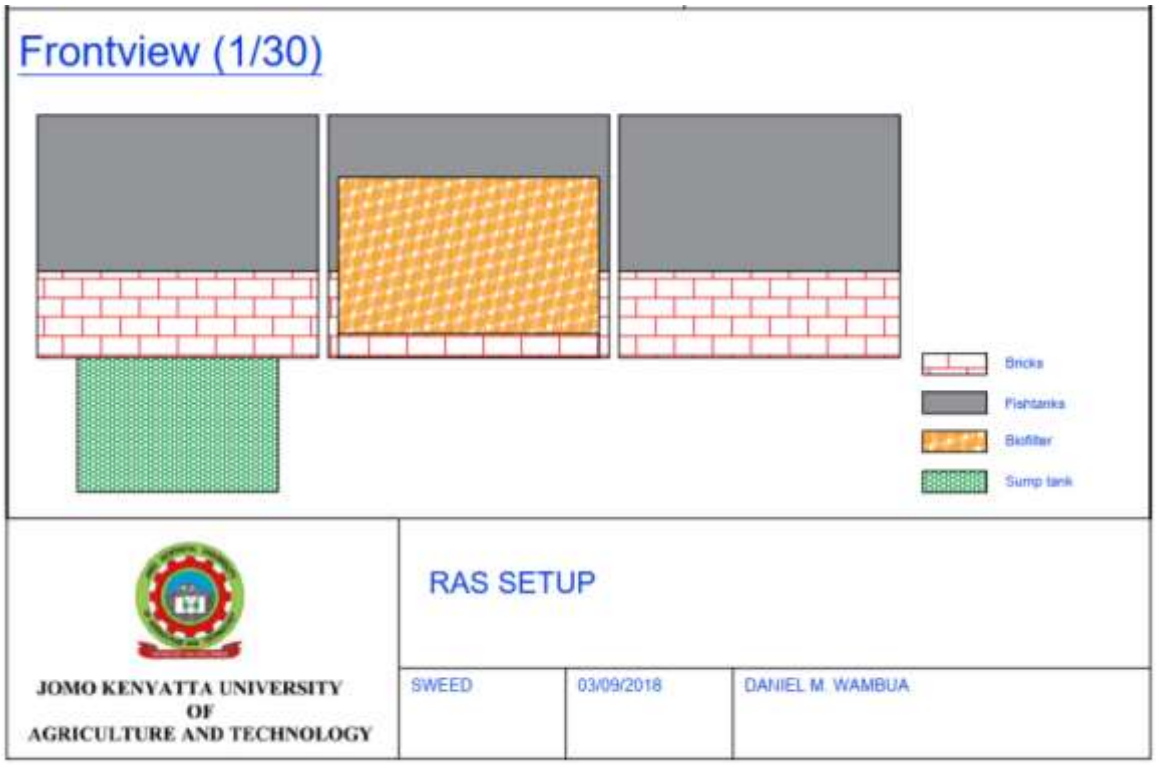

Figure C2: Front view of the RAS setup

Appendix D: Screenshots of the Developed RAS Simulation/Prediction Model

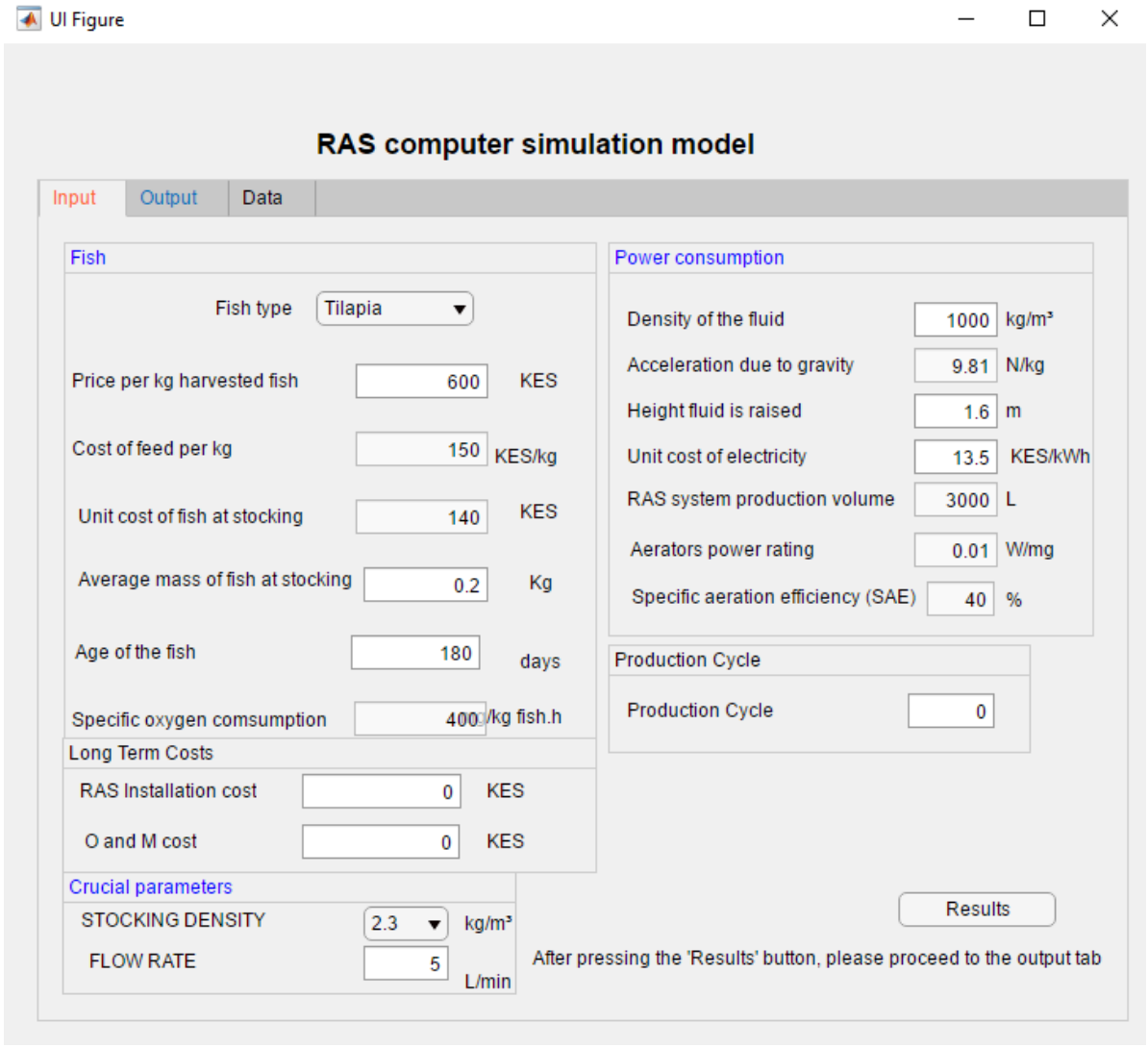

Figure D1: The Input Panel of the RAS Computer Model

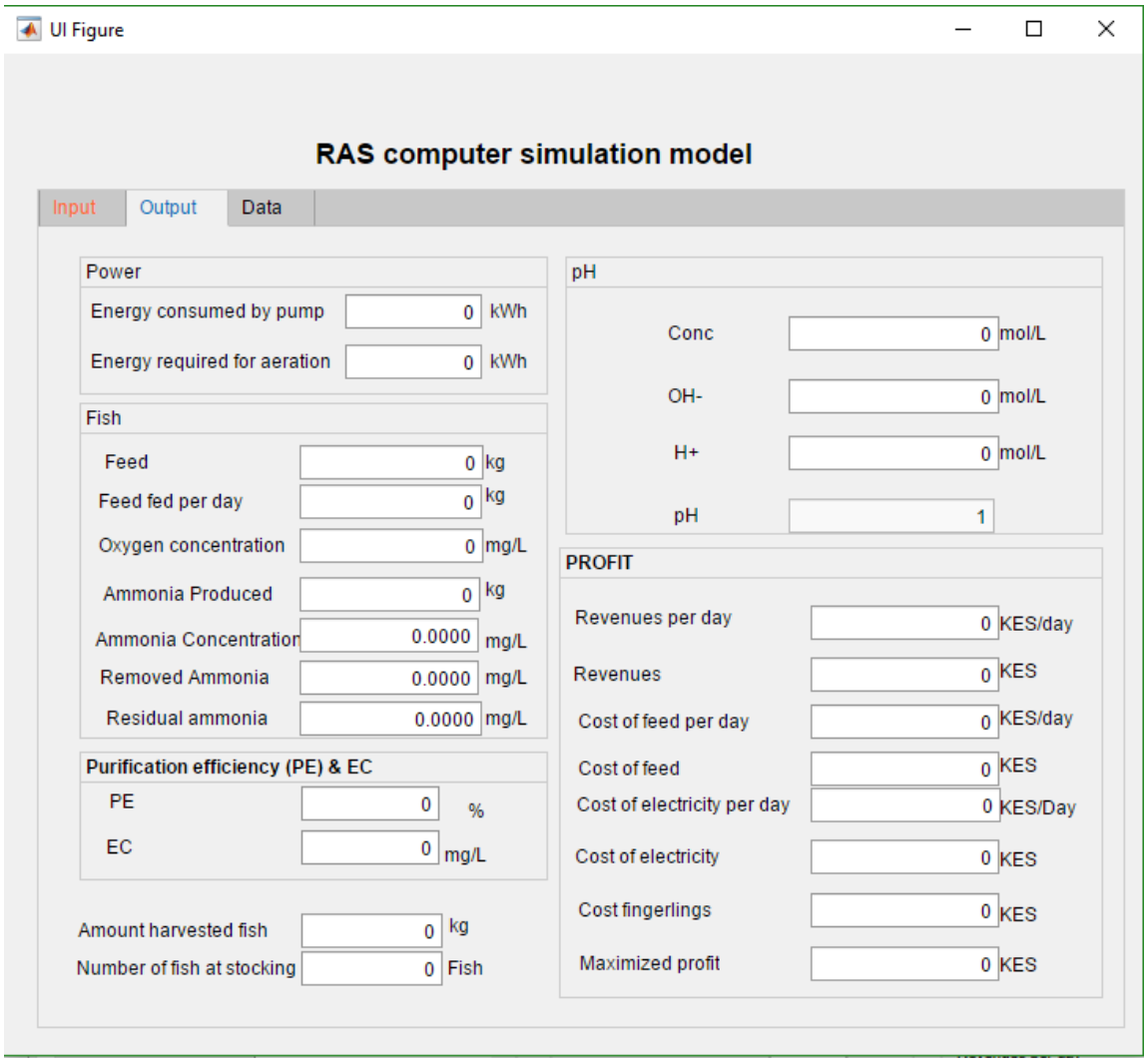

Figure D2: The Output Panel of the RAS Computer Model

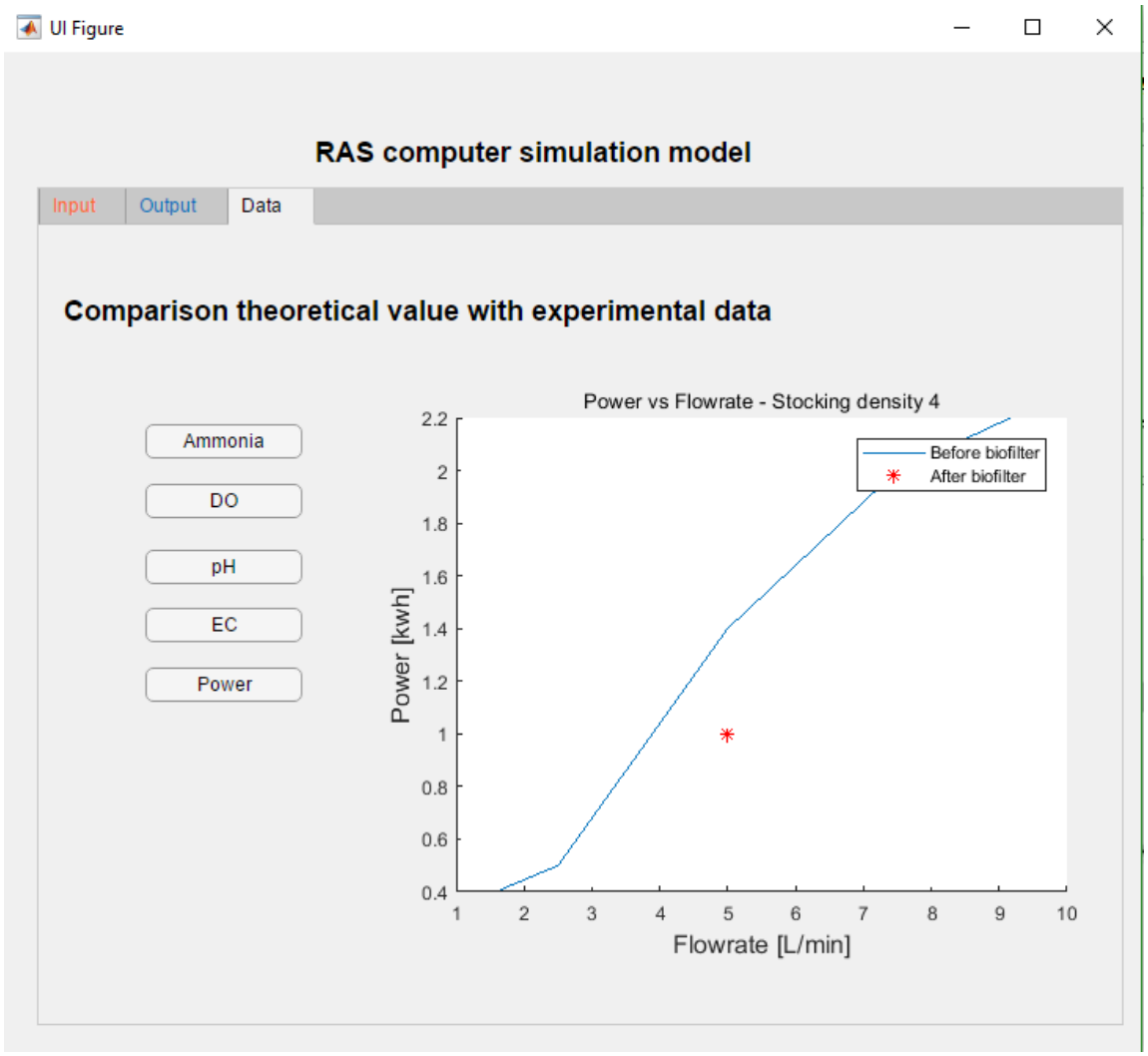

Figure D3: The Data Tab of the RAS Computer Model

Appendix E: RAS Simulation Model Code

```
classdef RASPredMod2019111 < matlab.apps.AppBase

    % Properties that correspond to app components
    properties (Access = public)
        UIFigure                        matlab.ui.Figure
        RAScomputersimulationmodelLabel  matlab.ui.control.Label
        TabGroup                        matlab.ui.container.TabGroup
        InputTab                        matlab.ui.container.Tab
        ResultsButton                   matlab.ui.control.Button
        PowerconsumptionPanel           matlab.ui.container.Panel
        kgmLabel                        matlab.ui.control.Label
        DensityofthefluidEditFieldLabel  matlab.ui.control.Label
        DensityofthefluidEditField      matlab.ui.control.NumericEditField
        AccelerationduetogravityEditFieldLabel  matlab.ui.control.Label
        AccelerationduetogravityEditField  matlab.ui.control.NumericEditField
        HeightfluidisraisedEditFieldLabel  matlab.ui.control.Label
        HeightfluidisraisedEditField    matlab.ui.control.NumericEditField
        NkgLabel                        matlab.ui.control.Label
        mLabel                          matlab.ui.control.Label
        KESkWhLabel                     matlab.ui.control.Label
        UnitcostofelectricityEditFieldLabel  matlab.ui.control.Label
        UnitcostofelectricityEditField  matlab.ui.control.NumericEditField
        LLabel                          matlab.ui.control.Label
        RASsystemproductionvolumeEditFieldLabel  matlab.ui.control.Label
        RASsystemproductionvolumeEditField  matlab.ui.control.NumericEditField
        AeratorspowerratingEditFieldLabel  matlab.ui.control.Label
        AeratorspowerratingEditField    matlab.ui.control.NumericEditField
        WmgLabel                        matlab.ui.control.Label
        Label_16                        matlab.ui.control.Label
```

SpecificaerationefficiencySAEEditFieldLabel matlab.ui.control.Label

SpecificaerationefficiencySAEEditField matlab.ui.control.NumericEditField

FishPanel_2 matlab.ui.container.Panel

KESLabel matlab.ui.control.Label

KESkgLabel matlab.ui.control.Label

KESLabel_2 matlab.ui.control.Label

FishtypeDropDownLabel matlab.ui.control.Label

FishtypeDropDown matlab.ui.control.DropDown

KgLabel matlab.ui.control.Label

daysLabel matlab.ui.control.Label

mgkgfishhLabel matlab.ui.control.Label

PriceperkgharvestedfishEditFieldLabel matlab.ui.control.Label

PriceperkgharvestedfishEditField matlab.ui.control.NumericEditField

CostoffeedperkgEditFieldLabel matlab.ui.control.Label

CostoffeedperkgEditField matlab.ui.control.NumericEditField

UnitcostoffishatstockingEditFieldLabel matlab.ui.control.Label

UnitcostoffishatstockingEditField matlab.ui.control.NumericEditField

AveragemassoffishatstockingEditFieldLabel matlab.ui.control.Label

AveragemassoffishatstockingEditField matlab.ui.control.NumericEditField

AgeofthefishEditFieldLabel matlab.ui.control.Label

AgeofthefishEditField matlab.ui.control.NumericEditField

SpecificoxygencomsumptionEditFieldLabel matlab.ui.control.Label

SpecificoxygencomsumptionEditField matlab.ui.control.NumericEditField

CrucialparametersPanel matlab.ui.container.Panel

kgmLabel_2 matlab.ui.control.Label

LminLabel matlab.ui.control.Label

FLOWRATEEditFieldLabel matlab.ui.control.Label

FLOWRATEEditField matlab.ui.control.NumericEditField

STOCKINGDENSITYDropDownLabel matlab.ui.control.Label

STOCKINGDENSITYDropDown matlab.ui.control.DropDown

AfterpressingtheResultsbuttonpleaseproceedtotheoutputtabLabel matlab.ui.control.Label

LongTermCostsPanel matlab.ui.container.Panel

KESLabel_3 matlab.ui.control.Label

KESLabel_4 matlab.ui.control.Label

RASInstallationcostEditFieldLabel matlab.ui.control.Label

RASInstallationcostEditField matlab.ui.control.NumericEditField

OandMcostEditFieldLabel matlab.ui.control.Label

OandMcostEditField matlab.ui.control.NumericEditField

ProductionCyclePanel matlab.ui.container.Panel

ProductionCycleEditFieldLabel matlab.ui.control.Label

ProductionCycleEditField matlab.ui.control.NumericEditField

OutputTab matlab.ui.container.Tab

PROFITPanel matlab.ui.container.Panel

RevenuesperdayEditFieldLabel matlab.ui.control.Label

RevenuesperdayEditField matlab.ui.control.NumericEditField

KESDayLabel matlab.ui.control.Label

KESdayLabel matlab.ui.control.Label

MaximizedprofitEditFieldLabel matlab.ui.control.Label

MaximizedprofitEditField matlab.ui.control.NumericEditField

KESLabel_9 matlab.ui.control.Label

KESdayLabel_2 matlab.ui.control.Label

CostfingerlingsEditFieldLabel matlab.ui.control.Label

CostfingerlingsEditField matlab.ui.control.NumericEditField

KESLabel_8 matlab.ui.control.Label

CostofelectricityperdayEditFieldLabel matlab.ui.control.Label

CostofelectricityperdayEditField matlab.ui.control.NumericEditField

RevenuesEditFieldLabel matlab.ui.control.Label

RevenuesEditField matlab.ui.control.NumericEditField

CostoffeedEditFieldLabel matlab.ui.control.Label

CostoffeedEditField matlab.ui.control.NumericEditField

CostofelectricityEditFieldLabel matlab.ui.control.Label

CostofelectricityEditField matlab.ui.control.NumericEditField

KESLabel_5 matlab.ui.control.Label

CostoffeedperdayEditFieldLabel matlab.ui.control.Label

CostoffeedperdayEditField matlab.ui.control.NumericEditField

KESLabel_6 matlab.ui.control.Label

KESLabel_7 matlab.ui.control.Label

PowerPanel matlab.ui.container.Panel

kWhLabel_2 matlab.ui.control.Label

kWhLabel matlab.ui.control.Label

EnergyconsumedbypumpEditFieldLabel matlab.ui.control.Label

EnergyconsumedbypumpEditField matlab.ui.control.NumericEditField

EnergyrequiredforaerationEditFieldLabel matlab.ui.control.Label

EnergyrequiredforaerationEditField matlab.ui.control.NumericEditField

PurificationefficiencyPEECPanel matlab.ui.container.Panel

Label matlab.ui.control.Label

EditField matlab.ui.control.NumericEditField

ECEditFieldLabel matlab.ui.control.Label

ECEditfield matlab.ui.control.NumericEditField

PELabel matlab.ui.control.Label

mgLLabel_7 matlab.ui.control.Label

FishPanel matlab.ui.container.Panel

kgLabel_3 matlab.ui.control.Label

FeedfedperdayEditFieldLabel matlab.ui.control.Label

FeedfedperdayEditField matlab.ui.control.NumericEditField

mgLLabel_6 matlab.ui.control.Label

OxygenconcentrationEditFieldLabel matlab.ui.control.Label

OxygenconcentrationEditField matlab.ui.control.NumericEditField

mgLLabel_3 matlab.ui.control.Label

mgLLabel_4 matlab.ui.control.Label

mgLLabel_5 matlab.ui.control.Label

AmmoniaConcentrationEditFieldLabel matlab.ui.control.Label

AmmoniaConcentrationEditField matlab.ui.control.NumericEditField

RemovedAmmoniaEditFieldLabel matlab.ui.control.Label

RemovedAmmoniaEditField matlab.ui.control.NumericEditField

ResidualammoniaEditFieldLabel matlab.ui.control.Label

ResidualammoniaEditField matlab.ui.control.NumericEditField

FeedEditFieldLabel matlab.ui.control.Label

FeedEditField matlab.ui.control.NumericEditField

kgLabel_2 matlab.ui.control.Label

AmmoniaProducedEditFieldLabel matlab.ui.control.Label

AmmoniaProducedEditField matlab.ui.control.NumericEditField

kgLabel_4 matlab.ui.control.Label

pHPanel matlab.ui.container.Panel

pHEditFieldLabel matlab.ui.control.Label

pHEditField matlab.ui.control.NumericEditField

molLLabel matlab.ui.control.Label

molLLabel_2 matlab.ui.control.Label

molLLabel_3 matlab.ui.control.Label

ConcEditFieldLabel matlab.ui.control.Label

ConcEditField matlab.ui.control.NumericEditField

OHEditFieldLabel matlab.ui.control.Label

OHEditField matlab.ui.control.NumericEditField

HEditFieldLabel matlab.ui.control.Label

HEditField matlab.ui.control.NumericEditField

```
    AmountharvestedfishEditFieldLabel  matlab.ui.control.Label
    AmountharvestedfishEditField    matlab.ui.control.NumericEditField
    kgLabel                         matlab.ui.control.Label
    NumberoffishatstockingEditFieldLabel  matlab.ui.control.Label
    NumberoffishatstockingEditField  matlab.ui.control.NumericEditField
    FishLabel                       matlab.ui.control.Label
    DataTab                         matlab.ui.container.Tab
    AmmoniaButton                   matlab.ui.control.Button
    ComparisontheoreticalvaluewithexperimentaldataLabel  matlab.ui.control.Label
    DOButton                        matlab.ui.control.Button
    pHButton                        matlab.ui.control.Button
    UIAxes                          matlab.ui.control.UIAxes
    ECButton                        matlab.ui.control.Button
    PowerButton                     matlab.ui.control.Button
end



properties (Access = private)
    data4
    data5
    data7
    mydata
    Flowrate
    DO
    DObef
    DOaft
    AMM
    Ammoniabef
```

```
    Ammoniaaft
    Q
    ax
    sd
    pH
    pHbef
    pHaft
    GraphAmmonia
    fish
    EC
    ECbef
    ECaft
    power
    Conc
    OH
    H
end



% Callbacks that handle component events
methods (Access = private)

    % Code that executes after component creation
    function startupFcn(app)
```

```
        app.data4 =load  ('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project
proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App
design work\RAS UI\Data\stockingdensity4.mat');
        app.data5 =load  ('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project
proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App
design work\RAS UI\Data\stockingdensity5.mat');
        app.data7 =load  ('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project
proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App
design work\RAS UI\Data\stockingdensity7.mat');
    end


    % Button pushed function: ResultsButton
    function ResultsButtonPushed(app, event)

        %Revenues
        Pq=app.PriceperkgharvestedfishEditField.Value;
        Qf=app.AmountharvestedfishEditField.Value; %Harvested fish
        Pcy=app.ProductionCycleEditField.Value;
        app.RevenuesEditField.Value=(Pq*Qf)*Pcy;

app.RevenuesperdayEditField.Value=(Pq*Qf)/(app.AgeofthefishEditField.Value);

        %energy consumed by the pump Pp
        Omega=1; %out of data
        Density=app.DensityofthefluidEditField.Value;
        g=app.AccelerationduetogravityEditField.Value;
        h=app.HeightfluidisraisedEditField.Value;
        V=app.RASsystemproductionvolumeEditField.Value;
        app.Q=app.FLOWRATEEditField.Value;
```

```
Pp=((0.001*Omega*Density*g*h*app.Q)/(60000))*24;
app.EnergyconsumedbypumpEditField.Value=Pp;

%Energy required for aeration Pa
app.sd= str2double(app.STOCKINGDENSITYDropDown.Value);
specOxyCons=app.SpecificoxygencomsumptionEditField.Value;

Oxydemand=app.sd*specOxyCons*V/1000;
APR=app.AeratorspowerratingEditField.Value;
SAE=app.SpecificaerationefficiencySAEEditField.Value;

Pa=0.001*Oxydemand*APR*(SAE/100)*24;
app.EnergyrequiredforaerationEditField.Value=Pa;

app.DO = (0.38*Oxydemand)/(60*app.Q);
app.OxygenconcentrationEditField.Value = app.DO;

%COST OF ENERGY Ce
Ceday=(Pp+Pa)*app.UnitcostofelectricityEditField.Value;
app.CostofelectricityperdayEditField.Value=Ceday;
Ce=Ceday*app.AgeofthefishEditField.Value;
app.CostofelectricityEditField.Value=Ce;
%COST OF FISH AT STOCKING Cs

app.NumberoffishatstockingEditField.Value=(app.sd*0.001*app.RASsystemproduction
volumeEditField.Value)/app.AveragemassoffishatstockingEditField.Value;
PriceFingerling=app.UnitcostoffishatstockingEditField.Value;
Cs=app.NumberoffishatstockingEditField.Value*PriceFingerling;
```

```
app.CostfingerlingsEditField.Value=Cs;

%Fish weight M
x=app.AgeofthefishEditField.Value;
A=0.2;
Dstc=0.00500; %Experimental
e=2.7182;
k=0.0416; %0.0259 at 22°C, 0.0416 at 28°C, 0.0374 at 30°C.
Qf=0.9*app.NumberoffishatstockingEditField.Value*A*Dstc*e^(k*x)*Pcy;
app.AmountharvestedfishEditField.Value=Qf;

%Feed fed to fish per day F
Fday=0.04*app.sd*V/1000;
app.FeedfedperdayEditField.Value=Fday;
Feed=Fday*app.AgeofthefishEditField.Value;
app.FeedEditField.Value=Feed;
%COST OF FEED Cf
Cfperkg=app.CostoffeedperkgEditField.Value;
Cf=Feed*Cfperkg;
app.CostoffeedEditField.Value=Cf;
Cfday=Fday*Cfperkg;
app.CostoffeedperdayEditField.Value=Cfday

%Ammonia produced by the fish AMM
app.AmmoniaProducedEditField.Value=0.025*Fday;

app.AMM=0.025*Fday*1000/app.RASsystemproductionvolumeEditField.Value;
app.AmmoniaConcentrationEditField.Value=app.AMM;
```

```
%Purification efficiency PE
y=500000; %uncertain

PE=((y*app.DO)/(app.Q*app.sd*10000));
app.EditField.Value=PE;

%Removed ammonia AMMre
AMMre=0.01*PE*app.AmmoniaProducedEditField.Value;
app.RemovedAmmoniaEditField.Value=AMMre;

%Residual ammonia AMMll
AMMll=(1-0.01*PE)*app.AMM;
app.ResidualammoniaEditField.Value=AMMll;

%Conc
MM=17.031;
app.Conc=(app.AMM)/(1000*MM);
app.ConcEditField.Value=app.Conc;

%OH-
Kb=1.8*10^(-5);
app.OH=sqrt(Kb*app.ConcEditField.Value);
app.OHEditField.Value=app.OH;

%H+
app.H=(10^(-14))/app.OH;
app.HEditField.Value=app.H;

%pH
```

```
S=1;
m=0
app.pH=(S*-log10(app.H))+m;
app.pHEditField.Value=app.pH;

%EC
L=9600; % to be adjusted
app.EC=L*app.AMM;
app.ECEditfield.Value=app.EC;

%MAXIMIZED PROFIT δ if optimization constraints are fulfilled.
Ci=app.RASInstallationcostEditField.Value;
Com=0.15*Ci;
app.OandMcostEditField.Value=Com
Constraint1=((Pq*Qf)-
((Ce*Pcy)+(Cf*Pcy)+(Cs*Pcy)+(Com*Pcy)+Ci))/((Ce*Pcy)+(Cf*Pcy)+(Cs*Pcy)+(Co
m*Pcy)+Ci);
Constraint2=((Pq*Qf)-((Ce*Pcy)+(Cf*Pcy)+(Cs*Pcy)+(Com*Pcy)+Ci));

if ((Constraint1>0.1)&&(Constraint2>0))
app.MaximizedprofitEditField.Value=((Pq*Qf)*Pcy-
((Ce*Pcy)+(Cf*Pcy)+(Cs*Pcy)+(Com*Pcy)+Ci));
MaxProfit=app.MaximizedprofitEditField.Value;
end



app.ax=app.UIAxes;
cla(app.ax,'reset')
```

```
    end

    % Button pushed function: AmmoniaButton
    function AmmoniaButtonPushed(app, event)

        cla(app.ax,'reset')

        if (app.sd==4)

        %Loading data
        app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity4.mat')

        %Variables
        stockingdensity4=app.mydata.stockingdensity4;
        app.Flowrate=stockingdensity4(:,1);
        app.Ammoniabef=stockingdensity4(:,2);
        app.Ammoniaaft=stockingdensity4(:,8);


        plot(app.ax,app.Flowrate,app.Ammoniabef);
        title(app.ax,'Ammonia vs Flowrate - Stocking density 4','FontWeight','normal');
        xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
```

```
        ylabel(app.ax,'Ammonia [mg/L]','FontSize',12)
        hold(app.ax,'on')
        plot(app.ax,app.Flowrate,app.Ammoniaaft);
        plot(app.ax,app.Q,app.AMM,'r*');

        legend(app.ax, 'Before biofilter','After biofilter','theoretical value')

        end

        if (app.sd==5)

        %Loading data
        app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project
proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App
design work\RAS UI\Data\stockingdensity5.mat')

        %Variables
        stockingdensity5=app.mydata.stockingdensity5;
        app.Flowrate=stockingdensity5(:,1);
        app.Ammoniabef=stockingdensity5(:,2);
        app.Ammoniaaft=stockingdensity5(:,7);

        % Update plot

        plot(app.ax,app.Flowrate,app.Ammoniabef);
        title(app.ax,'Ammonia vs Flowrate - Stocking density 5','FontWeight','normal');
        xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
        ylabel(app.ax,'Ammonia [mg/L]','FontSize',12)
        hold(app.ax,'on')
```

```
plot(app.ax,app.Flowrate,app.Ammoniaaft);
plot(app.ax,app.Q,app.AMM,'r*');

legend(app.ax, 'Before biofilter','After biofilter','theoretical value')

end

if (app.sd==7)

%Loading data
app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity7.mat')

%Variables
stockingdensity7=app.mydata.stockingdensity7;
app.Flowrate=stockingdensity7(:,1);
app.Ammoniabef=stockingdensity7(:,2);
app.Ammoniaaft=stockingdensity7(:,7);

% Update plot

plot(app.ax,app.Flowrate,app.Ammoniabef);
title(app.ax,'Ammonia vs Flowrate - Stocking density 7','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
ylabel(app.ax,'Ammonia [mg/L]','FontSize',12)
hold(app.ax,'on')
plot(app.ax,app.Flowrate,app.Ammoniaaft);
plot(app.ax,app.Q,app.AMM,'r*');
```

```
        legend(app.ax, 'Before biofilter','After biofilter','theoretical value')

        end
    end

    % Button pushed function: DOButton
    function DOButtonPushed(app, event)

        cla(app.ax,'reset')

        if (app.sd==4)

        %Loading data
        app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity4.mat');

        %Variables
        stockingdensity4=app.mydata.stockingdensity4;
        app.Flowrate=stockingdensity4(:,1);
        app.DObef=stockingdensity4(:,3);
        app.DOaft=stockingdensity4(:,9);

        % Update plot

        plot(app.ax,app.Flowrate,app.DObef);
        title(app.ax,'DO vs Flowrate - Stocking density 4','FontWeight','normal');
        xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
```

```
ylabel(app.ax,'DO [mg/L]','FontSize',12)
hold(app.ax,'on')
plot(app.ax,app.Flowrate,app.DOaft);
plot(app.ax,app.Q,app.DO,'r*');

legend(app.ax, 'Before biofilter','After biofilter','theoretical value')



end

if (app.sd==5)

%Loading data
app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity5.mat')

%Variables
stockingdensity5=app.mydata.stockingdensity5;
app.Flowrate=stockingdensity5(:,1);
app.DObef=stockingdensity5(:,3);
app.DOaft=stockingdensity5(:,8);

% Update plot

plot(app.ax,app.Flowrate,app.DObef);
title(app.ax,'DO vs Flowrate - Stocking density 5','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
ylabel(app.ax,'DO [mg/L]','FontSize',12)
```

```
hold(app.ax,'on')
plot(app.ax,app.Flowrate,app.DOaft);
plot(app.ax,app.Q,app.DO,'r*');

legend(app.ax, 'Before biofilter','After biofilter','theoretical value')

end

if (app.sd==7)

%Loading data
app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity7.mat')

%Variables
stockingdensity7=app.mydata.stockingdensity7;
app.Flowrate=stockingdensity7(:,1);
app.DObef=stockingdensity7(:,3);
app.DOaft=stockingdensity7(:,8);

% Update plot

plot(app.ax,app.Flowrate,app.DObef);
title(app.ax,'DO vs Flowrate - Stocking density 7','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
ylabel(app.ax,'DO [mg/L]','FontSize',12)
hold(app.ax,'on')
plot(app.ax,app.Flowrate,app.DOaft);
```

```
        plot(app.ax,app.Q,app.DO,'r*');

        legend(app.ax, 'Before biofilter','After biofilter','theoretical value')

        end
    end

    % Button pushed function: pHButton
    function pHButtonPushed(app, event)
        cla(app.ax,'reset')

        if (app.sd==4)

        %Loading data
        app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity4.mat')

        %Variables
        stockingdensity4=app.mydata.stockingdensity4;
        app.Flowrate=stockingdensity4(:,1);
        app.pHbef=stockingdensity4(:,4);
        app.pHaft=stockingdensity4(:,10);

        % Update plot

        plot(app.ax,app.Flowrate,app.pHbef);
        title(app.ax,'pH vs Flowrate - Stocking density 4','FontWeight','normal');
        xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
```

```
ylabel(app.ax,'pH','FontSize',12)
hold(app.ax,'on')
plot(app.ax,app.Flowrate,app.pHaft);
plot(app.ax,app.Q,app.pH,'r*');

legend(app.ax, 'Before biofilter','After biofilter','theoretical value')

end

if (app.sd==5)

%Loading data
app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity5.mat')

 %Variables
stockingdensity5=app.mydata.stockingdensity5;
app.Flowrate=stockingdensity5(:,1);
app.pHbef=stockingdensity5(:,4);
app.pHaft=stockingdensity5(:,9);

% Update plot

plot(app.ax,app.Flowrate,app.pHbef);
title(app.ax,'pH vs Flowrate - Stocking density 5','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
ylabel(app.ax,'pH','FontSize',12)
hold(app.ax,'on')
```

```
plot(app.ax,app.Flowrate,app.pHaft);
plot(app.ax,app.Q,app.pH,'r*');

legend(app.ax, 'Before biofilter','After biofilter','theoretical value')

end

if (app.sd==7)

%Loading data
app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity7.mat');

%Variables
stockingdensity7=app.mydata.stockingdensity7;
app.Flowrate=stockingdensity7(:,1);
app.DObef=stockingdensity7(:,4);
app.DOaft=stockingdensity7(:,9);

% Update plot

plot(app.ax,app.Flowrate,app.pHbef);
title(app.ax,'pH vs Flowrate - Stocking density 7','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
ylabel(app.ax,'pH','FontSize',12)
hold(app.ax,'on')
plot(app.ax,app.Flowrate,app.pHaft);
plot(app.ax,app.Q,app.pH,'r*');
```

```
        legend(app.ax, 'Before biofilter','After biofilter','theoretical value')


        end
    end

    % Button pushed function: ECButton
    function ECButtonButtonPushed(app, event)
         cla(app.ax,'reset')

        if (app.sd==4)

        %Loading data
        app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity4.mat')

        %Variables
        stockingdensity4=app.mydata.stockingdensity4;
        app.Flowrate=stockingdensity4(:,1);
        app.ECbef=stockingdensity4(:,6);
        app.ECaft=stockingdensity4(:,12);

        % Update plot

        plot(app.ax,app.Flowrate,app.ECbef);
        title(app.ax,'ECButton vs Flowrate - Stocking density 4','FontWeight','normal');
        xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
```

```
ylabel(app.ax,'EC [mg/l]','FontSize',12)
hold(app.ax,'on')
plot(app.ax,app.Flowrate,app.ECaft);
plot(app.ax,app.Q,app.EC,'r*');

legend(app.ax, 'Before biofilter','After biofilter','theoretical value')

end

if (app.sd==5)

%Loading data
app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity5.mat')

 %Variables
stockingdensity5=app.mydata.stockingdensity5;
app.Flowrate=stockingdensity5(:,1);
app.ECbef=stockingdensity5(:,6);
app.ECaft=stockingdensity5(:,11);

% Update plot

plot(app.ax,app.Flowrate,app.ECbef);
title(app.ax,'ECButton vs Flowrate - Stocking density 5','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
ylabel(app.ax,'EC [mg/L]','FontSize',12)
hold(app.ax,'on')
```

```
plot(app.ax,app.Flowrate,app.ECaft);
plot(app.ax,app.Q,app.EC,'r*');

legend(app.ax, 'Before biofilter','After biofilter','theoretical value')



end

if (app.sd==7)

%Loading data
app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity7.mat');

%Variables
stockingdensity7=app.mydata.stockingdensity7;
app.Flowrate=stockingdensity7(:,1);
app.ECbef=stockingdensity7(:,6);
app.ECaft=stockingdensity7(:,11);

% Update plot
plot(app.ax,app.Flowrate,app.ECbef);
title(app.ax,'ECButton vs Flowrate - Stocking density 7','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
ylabel(app.ax,'EC [mg/L] ','FontSize',12)
hold(app.ax,'on')
plot(app.ax,app.Flowrate,app.ECaft);
plot(app.ax,app.Q,app.EC,'r*');
```

```
        legend(app.ax, 'Before biofilter','After biofilter','theoretical value')


        end
    end

    % Value changed function: ECEditfield
    function ECEditfieldValueChanged(app, event)




    end


    % Button pushed function: PowerButton
    function PowerButtonPushed(app, event)
      cla(app.ax,'reset')

        if (app.sd==4)

        %Loading data
        app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity4.mat')

        %Variables
        stockingdensity4=app.mydata.stockingdensity4;
        app.Flowrate=stockingdensity4(:,1);
```

```
app.power=stockingdensity4(:,7);

% Update plot

plot(app.ax,app.Flowrate,app.power);
title(app.ax,'Power vs Flowrate - Stocking density 4','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
ylabel(app.ax,'Power [kwh]','FontSize',12)
hold(app.ax,'on')
plot(app.ax,app.Q,app.EnergyconsumedbypumpEditField,'r*');

legend(app.ax, 'Before biofilter','After biofilter','theoretical value')

end

if (app.sd==5)

%Loading data
app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity5.mat')

 %Variables
stockingdensity5=app.mydata.stockingdensity5;
app.Flowrate=stockingdensity5(:,1);
app.power=stockingdensity5(:,7);

% Update plot
```

```
plot(app.ax,app.Flowrate,app.power);
title(app.ax,'Power vs Flowrate - Stocking density 4','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
ylabel(app.ax,'Power [kwh]','FontSize',12)
hold(app.ax,'on')
plot(app.ax,app.Q,app.EnergyconsumedbypumpEditField,'r*');

legend(app.ax, 'Before biofilter','After biofilter','theoretical value')



end

if (app.sd==7)

%Loading data
app.mydata = load('F:\JKUAT STDT\MSC\YEAR 2\Thesis Proposal\Project proposal\Proposal write up\Programming languages\Matlab\App design\Kevins App design work\RAS UI\Data\stockingdensity7.mat');

%Variables
stockingdensity7=app.mydata.stockingdensity7;
app.Flowrate=stockingdensity7(:,1);
app.power=stockingdensity7(:,7);


% Update plot

plot(app.ax,app.Flowrate,app.power);
title(app.ax,'Power vs Flowrate - Stocking density 4','FontWeight','normal');
xlabel(app.ax,'Flowrate [L/min]','FontSize',12)
```

```
        ylabel(app.ax,'Power [kwh]','FontSize',12)
        hold(app.ax,'on')
        plot(app.ax,app.Q,app.EnergyconsumedbypumpEditField,'r*');

        legend(app.ax, 'Before biofilter','After biofilter','theoretical value')


        end
    end
end


% Component initialization
methods (Access = private)

    % Create UIFigure and components
    function createComponents(app)


        % Create UIFigure and hide until all components are created
        app.UIFigure = uifigure('Visible', 'off');
        app.UIFigure.Position = [100 100 724 637];
        app.UIFigure.Name = 'UI Figure';


        % Create RAScomputersimulationmodelLabel
        app.RAScomputersimulationmodelLabel = uilabel(app.UIFigure);
        app.RAScomputersimulationmodelLabel.VerticalAlignment = 'top';
        app.RAScomputersimulationmodelLabel.FontName = 'Arial';
        app.RAScomputersimulationmodelLabel.FontSize = 18;
```

```
            app.RAScomputersimulationmodelLabel.FontWeight = 'bold';
            app.RAScomputersimulationmodelLabel.Position = [199 563 287 23];
            app.RAScomputersimulationmodelLabel.Text = 'RAS computer simulation
model';

            % Create TabGroup
            app.TabGroup = uitabgroup(app.UIFigure);
            app.TabGroup.Position = [22 18 692 534];

            % Create InputTab
            app.InputTab = uitab(app.TabGroup);
            app.InputTab.Title = 'Input';
            app.InputTab.ForegroundColor = [1 0.4118 0.1608];

            % Create ResultsButton
            app.ResultsButton = uibutton(app.InputTab, 'push');
            app.ResultsButton.ButtonPushedFcn = createCallbackFcn(app,
@ResultsButtonPushed, true);
            app.ResultsButton.Position = [546 60 100 22];
            app.ResultsButton.Text = 'Results';

            % Create PowerconsumptionPanel
            app.PowerconsumptionPanel = uipanel(app.InputTab);
            app.PowerconsumptionPanel.ForegroundColor = [0 0 1];
            app.PowerconsumptionPanel.Title = 'Power consumption';
            app.PowerconsumptionPanel.Position = [362 244 308 250];
```

```
            % Create kgmLabel
            app.kgmLabel = uilabel(app.PowerconsumptionPanel);
            app.kgmLabel.VerticalAlignment = 'top';
            app.kgmLabel.Position = [252 194 35 15];
            app.kgmLabel.Text = 'kg/m³';

            % Create DensityofthefluidEditFieldLabel
            app.DensityofthefluidEditFieldLabel = uilabel(app.PowerconsumptionPanel);
            app.DensityofthefluidEditFieldLabel.HorizontalAlignment = 'right';
            app.DensityofthefluidEditFieldLabel.VerticalAlignment = 'top';
            app.DensityofthefluidEditFieldLabel.Position = [7 194 105 15];
            app.DensityofthefluidEditFieldLabel.Text = 'Density of the fluid';

            % Create DensityofthefluidEditField
            app.DensityofthefluidEditField = uieditfield(app.PowerconsumptionPanel,
'numeric');
            app.DensityofthefluidEditField.Position = [194 190 53 22];
            app.DensityofthefluidEditField.Value = 1000;

            % Create AccelerationduetogravityEditFieldLabel
            app.AccelerationduetogravityEditFieldLabel =
uilabel(app.PowerconsumptionPanel);
            app.AccelerationduetogravityEditFieldLabel.HorizontalAlignment = 'right';
            app.AccelerationduetogravityEditFieldLabel.VerticalAlignment = 'top';
            app.AccelerationduetogravityEditFieldLabel.Position = [7 165 149 15];
            app.AccelerationduetogravityEditFieldLabel.Text = 'Acceleration due to gravity';
```

```
        % Create AccelerationduetogravityEditField
        app.AccelerationduetogravityEditField =
uieditfield(app.PowerconsumptionPanel, 'numeric');
        app.AccelerationduetogravityEditField.Editable = 'off';
        app.AccelerationduetogravityEditField.Position = [194 161 53 22];
        app.AccelerationduetogravityEditField.Value = 9.81;

        % Create HeightfluidisraisedEditFieldLabel
        app.HeightfluidisraisedEditFieldLabel = uilabel(app.PowerconsumptionPanel);
        app.HeightfluidisraisedEditFieldLabel.HorizontalAlignment = 'right';
        app.HeightfluidisraisedEditFieldLabel.VerticalAlignment = 'top';
        app.HeightfluidisraisedEditFieldLabel.Position = [7 136 116 15];
        app.HeightfluidisraisedEditFieldLabel.Text = 'Height fluid is raised';

        % Create HeightfluidisraisedEditField
        app.HeightfluidisraisedEditField = uieditfield(app.PowerconsumptionPanel,
'numeric');
        app.HeightfluidisraisedEditField.HandleVisibility = 'off';
        app.HeightfluidisraisedEditField.Position = [194 132 53 22];
        app.HeightfluidisraisedEditField.Value = 1.6;

        % Create NkgLabel
        app.NkgLabel = uilabel(app.PowerconsumptionPanel);
        app.NkgLabel.VerticalAlignment = 'top';
        app.NkgLabel.Position = [252 165 30 15];
        app.NkgLabel.Text = 'N/kg';
```

```
            % Create mLabel
            app.mLabel = uilabel(app.PowerconsumptionPanel);
            app.mLabel.VerticalAlignment = 'top';
            app.mLabel.Position = [252 136 25 15];
            app.mLabel.Text = 'm';

            % Create KESkWhLabel
            app.KESkWhLabel = uilabel(app.PowerconsumptionPanel);
            app.KESkWhLabel.VerticalAlignment = 'top';
            app.KESkWhLabel.Position = [255 100 58 22];
            app.KESkWhLabel.Text = 'KES/kWh';

            % Create UnitcostofelectricityEditFieldLabel
            app.UnitcostofelectricityEditFieldLabel = uilabel(app.PowerconsumptionPanel);
            app.UnitcostofelectricityEditFieldLabel.HorizontalAlignment = 'right';
            app.UnitcostofelectricityEditFieldLabel.VerticalAlignment = 'top';
            app.UnitcostofelectricityEditFieldLabel.Position = [7 107 119 15];
            app.UnitcostofelectricityEditFieldLabel.Text = 'Unit cost of electricity';

            % Create UnitcostofelectricityEditField
            app.UnitcostofelectricityEditField = uieditfield(app.PowerconsumptionPanel,
'numeric');
            app.UnitcostofelectricityEditField.Position = [194 103 53 22];
            app.UnitcostofelectricityEditField.Value = 13.5;

            % Create LLabel
            app.LLabel = uilabel(app.PowerconsumptionPanel);
```

```
            app.LLabel.VerticalAlignment = 'top';
            app.LLabel.Position = [252 80 25 15];
            app.LLabel.Text = 'L';

            % Create RASsystemproductionvolumeEditFieldLabel
            app.RASsystemproductionvolumeEditFieldLabel =
uilabel(app.PowerconsumptionPanel);
            app.RASsystemproductionvolumeEditFieldLabel.HorizontalAlignment = 'right';
            app.RASsystemproductionvolumeEditFieldLabel.VerticalAlignment = 'top';
            app.RASsystemproductionvolumeEditFieldLabel.Position = [7 80 175 15];
            app.RASsystemproductionvolumeEditFieldLabel.Text = 'RAS system production
volume';

            % Create RASsystemproductionvolumeEditField
            app.RASsystemproductionvolumeEditField =
uieditfield(app.PowerconsumptionPanel, 'numeric');
            app.RASsystemproductionvolumeEditField.Editable = 'off';
            app.RASsystemproductionvolumeEditField.Position = [194 76 53 22];
            app.RASsystemproductionvolumeEditField.Value = 3000;

            % Create AeratorspowerratingEditFieldLabel
            app.AeratorspowerratingEditFieldLabel = uilabel(app.PowerconsumptionPanel);
            app.AeratorspowerratingEditFieldLabel.HorizontalAlignment = 'right';
            app.AeratorspowerratingEditFieldLabel.VerticalAlignment = 'top';
            app.AeratorspowerratingEditFieldLabel.Position = [9 48 122 15];
            app.AeratorspowerratingEditFieldLabel.Text = 'Aerators power rating';
```

```
        % Create AeratorspowerratingEditField
        app.AeratorspowerratingEditField = uieditfield(app.PowerconsumptionPanel,
'numeric');
        app.AeratorspowerratingEditField.Editable = 'off';
        app.AeratorspowerratingEditField.Position = [194 44 53 22];
        app.AeratorspowerratingEditField.Value = 0.01;

        % Create WmgLabel
        app.WmgLabel = uilabel(app.PowerconsumptionPanel);
        app.WmgLabel.VerticalAlignment = 'top';
        app.WmgLabel.Position = [252 48 36 15];
        app.WmgLabel.Text = 'W/mg';

        % Create Label_16
        app.Label_16 = uilabel(app.PowerconsumptionPanel);
        app.Label_16.VerticalAlignment = 'top';
        app.Label_16.Position = [252 16 25 15];
        app.Label_16.Text = '%';

        % Create SpecificaerationefficiencySAEEditFieldLabel
        app.SpecificaerationefficiencySAEEditFieldLabel =
uilabel(app.PowerconsumptionPanel);
        app.SpecificaerationefficiencySAEEditFieldLabel.HorizontalAlignment = 'right';
        app.SpecificaerationefficiencySAEEditFieldLabel.VerticalAlignment = 'top';
        app.SpecificaerationefficiencySAEEditFieldLabel.Position = [9 18 186 15];
        app.SpecificaerationefficiencySAEEditFieldLabel.Text = 'Specific aeration
efficiency (SAE)';
```

```
        % Create SpecificaerationefficiencySAEEditField
        app.SpecificaerationefficiencySAEEditField =
uieditfield(app.PowerconsumptionPanel, 'numeric');
        app.SpecificaerationefficiencySAEEditField.Editable = 'off';
        app.SpecificaerationefficiencySAEEditField.Position = [202 13 43 22];
        app.SpecificaerationefficiencySAEEditField.Value = 40;

        % Create FishPanel_2
        app.FishPanel_2 = uipanel(app.InputTab);
        app.FishPanel_2.ForegroundColor = [0 0 1];
        app.FishPanel_2.Title = 'Fish';
        app.FishPanel_2.Position = [17 179 338 315];

        % Create KESLabel
        app.KESLabel = uilabel(app.FishPanel_2);
        app.KESLabel.VerticalAlignment = 'top';
        app.KESLabel.Position = [262 220 31 22];
        app.KESLabel.Text = 'KES';

        % Create KESkgLabel
        app.KESkgLabel = uilabel(app.FishPanel_2);
        app.KESkgLabel.VerticalAlignment = 'top';
        app.KESkgLabel.Position = [262 172 47 22];
        app.KESkgLabel.Text = 'KES/kg';
```

```
% Create KESLabel_2
app.KESLabel_2 = uilabel(app.FishPanel_2);
app.KESLabel_2.VerticalAlignment = 'top';
app.KESLabel_2.Position = [262 137 31 22];
app.KESLabel_2.Text = 'KES';

% Create FishtypeDropDownLabel
app.FishtypeDropDownLabel = uilabel(app.FishPanel_2);
app.FishtypeDropDownLabel.HorizontalAlignment = 'right';
app.FishtypeDropDownLabel.VerticalAlignment = 'top';
app.FishtypeDropDownLabel.Position = [91 266 54 15];
app.FishtypeDropDownLabel.Text = 'Fish type';

% Create FishtypeDropDown
app.FishtypeDropDown = uidropdown(app.FishPanel_2);
app.FishtypeDropDown.Items = {'Tilapia', 'Catfish'};
app.FishtypeDropDown.Position = [160 262 100 22];
app.FishtypeDropDown.Value = 'Tilapia';

% Create KgLabel
app.KgLabel = uilabel(app.FishPanel_2);
app.KgLabel.VerticalAlignment = 'top';
app.KgLabel.Position = [262 92 25 22];
app.KgLabel.Text = 'Kg';

% Create daysLabel
app.daysLabel = uilabel(app.FishPanel_2);
```

```
app.daysLabel.VerticalAlignment = 'top';
app.daysLabel.Position = [262 61 31 15];
app.daysLabel.Text = 'days';

% Create mgkgfishhLabel
app.mgkgfishhLabel = uilabel(app.FishPanel_2);
app.mgkgfishhLabel.VerticalAlignment = 'top';
app.mgkgfishhLabel.Position = [262 14 70 15];
app.mgkgfishhLabel.Text = 'mg/kg fish.h';

% Create PriceperkgharvestedfishEditFieldLabel
app.PriceperkgharvestedfishEditFieldLabel = uilabel(app.FishPanel_2);
app.PriceperkgharvestedfishEditFieldLabel.HorizontalAlignment = 'right';
app.PriceperkgharvestedfishEditFieldLabel.VerticalAlignment = 'top';
app.PriceperkgharvestedfishEditFieldLabel.Position = [6 219 149 15];
app.PriceperkgharvestedfishEditFieldLabel.Text = 'Price per kg harvested fish';

% Create PriceperkgharvestedfishEditField
app.PriceperkgharvestedfishEditField = uieditfield(app.FishPanel_2, 'numeric');
app.PriceperkgharvestedfishEditField.Limits = [0.1 Inf];
app.PriceperkgharvestedfishEditField.Position = [203 215 52 22];
app.PriceperkgharvestedfishEditField.Value = 600;

% Create CostoffeedperkgEditFieldLabel
app.CostoffeedperkgEditFieldLabel = uilabel(app.FishPanel_2);
app.CostoffeedperkgEditFieldLabel.HorizontalAlignment = 'right';
app.CostoffeedperkgEditFieldLabel.VerticalAlignment = 'top';
```

```
app.CostoffeedperkgEditFieldLabel.Position = [6 176 107 15];
app.CostoffeedperkgEditFieldLabel.Text = 'Cost of feed per kg';

% Create CostoffeedperkgEditField
app.CostoffeedperkgEditField = uieditfield(app.FishPanel_2, 'numeric');
app.CostoffeedperkgEditField.Editable = 'off';
app.CostoffeedperkgEditField.Position = [203 172 51 22];
app.CostoffeedperkgEditField.Value = 150;

% Create UnitcostoffishatstockingEditFieldLabel
app.UnitcostoffishatstockingEditFieldLabel = uilabel(app.FishPanel_2);
app.UnitcostoffishatstockingEditFieldLabel.HorizontalAlignment = 'right';
app.UnitcostoffishatstockingEditFieldLabel.VerticalAlignment = 'top';
app.UnitcostoffishatstockingEditFieldLabel.Position = [6 135 148 22];
app.UnitcostoffishatstockingEditFieldLabel.Text = 'Unit cost of fish at stocking';

% Create UnitcostoffishatstockingEditField
app.UnitcostoffishatstockingEditField = uieditfield(app.FishPanel_2, 'numeric');
app.UnitcostoffishatstockingEditField.Editable = 'off';
app.UnitcostoffishatstockingEditField.Position = [203 138 48 22];
app.UnitcostoffishatstockingEditField.Value = 140;

% Create AveragemassoffishatstockingEditFieldLabel
app.AveragemassoffishatstockingEditFieldLabel = uilabel(app.FishPanel_2);
app.AveragemassoffishatstockingEditFieldLabel.HorizontalAlignment = 'right';
app.AveragemassoffishatstockingEditFieldLabel.VerticalAlignment = 'top';
app.AveragemassoffishatstockingEditFieldLabel.Position = [6 92 179 22];
```

```
        app.AveragemassoffishatstockingEditFieldLabel.Text = 'Average mass of fish at
stocking';

        % Create AveragemassoffishatstockingEditField
        app.AveragemassoffishatstockingEditField = uieditfield(app.FishPanel_2,
'numeric');
        app.AveragemassoffishatstockingEditField.Position = [203 92 48 22];
        app.AveragemassoffishatstockingEditField.Value = 0.2;

        % Create AgeofthefishEditFieldLabel
        app.AgeofthefishEditFieldLabel = uilabel(app.FishPanel_2);
        app.AgeofthefishEditFieldLabel.HorizontalAlignment = 'right';
        app.AgeofthefishEditFieldLabel.VerticalAlignment = 'top';
        app.AgeofthefishEditFieldLabel.Position = [6 61 82 15];
        app.AgeofthefishEditFieldLabel.Text = 'Age of the fish';

        % Create AgeofthefishEditField
        app.AgeofthefishEditField = uieditfield(app.FishPanel_2, 'numeric');
        app.AgeofthefishEditField.Position = [203 57 45 22];
        app.AgeofthefishEditField.Value = 180;

        % Create SpecificoxygencomsumptionEditFieldLabel
        app.SpecificoxygencomsumptionEditFieldLabel = uilabel(app.FishPanel_2);
        app.SpecificoxygencomsumptionEditFieldLabel.HorizontalAlignment = 'right';
        app.SpecificoxygencomsumptionEditFieldLabel.VerticalAlignment = 'top';
        app.SpecificoxygencomsumptionEditFieldLabel.Position = [6 17 167 15];
```

```
        app.SpecificoxygencomsumptionEditFieldLabel.Text = 'Specific oxygen
comsumption';

        % Create SpecificoxygencomsumptionEditField
        app.SpecificoxygencomsumptionEditField = uieditfield(app.FishPanel_2,
'numeric');
        app.SpecificoxygencomsumptionEditField.Editable = 'off';
        app.SpecificoxygencomsumptionEditField.Position = [203 14 45 22];
        app.SpecificoxygencomsumptionEditField.Value = 400;

        % Create CrucialparametersPanel
        app.CrucialparametersPanel = uipanel(app.InputTab);
        app.CrucialparametersPanel.ForegroundColor = [0 0 1];
        app.CrucialparametersPanel.Title = 'Crucial parameters';
        app.CrucialparametersPanel.Position = [16 17 288 78];

        % Create kgmLabel_2
        app.kgmLabel_2 = uilabel(app.CrucialparametersPanel);
        app.kgmLabel_2.VerticalAlignment = 'top';
        app.kgmLabel_2.Position = [255 38 35 15];
        app.kgmLabel_2.Text = 'kg/m³';

        % Create LminLabel
        app.LminLabel = uilabel(app.CrucialparametersPanel);
        app.LminLabel.VerticalAlignment = 'top';
        app.LminLabel.Position = [255 1 35 15];
        app.LminLabel.Text = 'L/min';
```

```
            % Create FLOWRATEEditFieldLabel
            app.FLOWRATEEditFieldLabel = uilabel(app.CrucialparametersPanel);
            app.FLOWRATEEditFieldLabel.HorizontalAlignment = 'right';
            app.FLOWRATEEditFieldLabel.VerticalAlignment = 'top';
            app.FLOWRATEEditFieldLabel.Position = [8 14 77 15];
            app.FLOWRATEEditFieldLabel.Text = 'FLOW RATE';

            % Create FLOWRATEEditField
            app.FLOWRATEEditField = uieditfield(app.CrucialparametersPanel, 'numeric');
            app.FLOWRATEEditField.Position = [191 9 54 22];
            app.FLOWRATEEditField.Value = 2;

            % Create STOCKINGDENSITYDropDownLabel
            app.STOCKINGDENSITYDropDownLabel =
uilabel(app.CrucialparametersPanel);
            app.STOCKINGDENSITYDropDownLabel.HorizontalAlignment = 'right';
            app.STOCKINGDENSITYDropDownLabel.VerticalAlignment = 'top';
            app.STOCKINGDENSITYDropDownLabel.Position = [7 40 122 15];
            app.STOCKINGDENSITYDropDownLabel.Text = 'STOCKING DENSITY';

            % Create STOCKINGDENSITYDropDown
            app.STOCKINGDENSITYDropDown =
uidropdown(app.CrucialparametersPanel);
            app.STOCKINGDENSITYDropDown.Items = {'1', '2', '2.3', '3.5', '4', '5', '6', '7',
'8', '9', '10', '11', '12', '13', '14', '15', '16', '17', '18', '19', '20'};
            app.STOCKINGDENSITYDropDown.Position = [191 34 54 22];
```

```
            app.STOCKINGDENSITYDropDown.Value = '1';

            % Create AfterpressingtheResultsbuttonpleaseproceedtotheoutputtabLabel
            app.AfterpressingtheResultsbuttonpleaseproceedtotheoutputtabLabel =
uilabel(app.InputTab);

app.AfterpressingtheResultsbuttonpleaseproceedtotheoutputtabLabel.VerticalAlignment
= 'top';
            app.AfterpressingtheResultsbuttonpleaseproceedtotheoutputtabLabel.Position =
[314 33 372 15];
            app.AfterpressingtheResultsbuttonpleaseproceedtotheoutputtabLabel.Text =
'After pressing the "Results" button, please proceed to the output tab';

            % Create LongTermCostsPanel
            app.LongTermCostsPanel = uipanel(app.InputTab);
            app.LongTermCostsPanel.Title = 'Long Term Costs';
            app.LongTermCostsPanel.Position = [16 94 339 86];

            % Create KESLabel_3
            app.KESLabel_3 = uilabel(app.LongTermCostsPanel);
            app.KESLabel_3.Position = [269 41 30 22];
            app.KESLabel_3.Text = 'KES';

            % Create KESLabel_4
            app.KESLabel_4 = uilabel(app.LongTermCostsPanel);
            app.KESLabel_4.Position = [269 9 30 22];
            app.KESLabel_4.Text = 'KES';
```

```
            % Create RASInstallationcostEditFieldLabel
            app.RASInstallationcostEditFieldLabel = uilabel(app.LongTermCostsPanel);
            app.RASInstallationcostEditFieldLabel.HorizontalAlignment = 'right';
            app.RASInstallationcostEditFieldLabel.Position = [7 41 116 22];
            app.RASInstallationcostEditFieldLabel.Text = 'RAS Installation cost';

            % Create RASInstallationcostEditField
            app.RASInstallationcostEditField = uieditfield(app.LongTermCostsPanel,
'numeric');
            app.RASInstallationcostEditField.Position = [152 41 101 22];

            % Create OandMcostEditFieldLabel
            app.OandMcostEditFieldLabel = uilabel(app.LongTermCostsPanel);
            app.OandMcostEditFieldLabel.HorizontalAlignment = 'right';
            app.OandMcostEditFieldLabel.Position = [8 9 77 22];
            app.OandMcostEditFieldLabel.Text = 'O and M cost';

            % Create OandMcostEditField
            app.OandMcostEditField = uieditfield(app.LongTermCostsPanel, 'numeric');
            app.OandMcostEditField.Position = [152 9 100 22];

            % Create ProductionCyclePanel
            app.ProductionCyclePanel = uipanel(app.InputTab);
            app.ProductionCyclePanel.Title = 'Production Cycle';
            app.ProductionCyclePanel.Position = [362 170 268 69];
```

```
            % Create ProductionCycleEditFieldLabel
            app.ProductionCycleEditFieldLabel = uilabel(app.ProductionCyclePanel);
            app.ProductionCycleEditFieldLabel.HorizontalAlignment = 'right';
            app.ProductionCycleEditFieldLabel.Position = [9 16 96 22];
            app.ProductionCycleEditFieldLabel.Text = 'Production Cycle';

            % Create ProductionCycleEditField
            app.ProductionCycleEditField = uieditfield(app.ProductionCyclePanel,
'numeric');
            app.ProductionCycleEditField.Position = [190 16 55 22];

            % Create OutputTab
            app.OutputTab = uitab(app.TabGroup);
            app.OutputTab.Title = 'Output';
            app.OutputTab.ForegroundColor = [0 0.451 0.7412];

            % Create PROFITPanel
            app.PROFITPanel = uipanel(app.OutputTab);
            app.PROFITPanel.Title = 'PROFIT';
            app.PROFITPanel.FontWeight = 'bold';
            app.PROFITPanel.Position = [332 19 346 287];

            % Create RevenuesperdayEditFieldLabel
            app.RevenuesperdayEditFieldLabel = uilabel(app.PROFITPanel);
            app.RevenuesperdayEditFieldLabel.HorizontalAlignment = 'right';
```

```
app.RevenuesperdayEditFieldLabel.VerticalAlignment = 'top';
app.RevenuesperdayEditFieldLabel.Position = [7 228 103 22];
app.RevenuesperdayEditFieldLabel.Text = 'Revenues per day';

% Create RevenuesperdayEditField
app.RevenuesperdayEditField = uieditfield(app.PROFITPanel, 'numeric');
app.RevenuesperdayEditField.Position = [160 228 109 22];

% Create KESDayLabel
app.KESDayLabel = uilabel(app.PROFITPanel);
app.KESDayLabel.VerticalAlignment = 'top';
app.KESDayLabel.Position = [280 107 55 22];
app.KESDayLabel.Text = 'KES/Day';

% Create KESdayLabel
app.KESdayLabel = uilabel(app.PROFITPanel);
app.KESdayLabel.VerticalAlignment = 'top';
app.KESdayLabel.Position = [280 224 53 22];
app.KESdayLabel.Text = 'KES/day';

% Create MaximizedprofitEditFieldLabel
app.MaximizedprofitEditFieldLabel = uilabel(app.PROFITPanel);
app.MaximizedprofitEditFieldLabel.HorizontalAlignment = 'right';
app.MaximizedprofitEditFieldLabel.VerticalAlignment = 'top';
app.MaximizedprofitEditFieldLabel.Position = [9 8 93 22];
app.MaximizedprofitEditFieldLabel.Text = 'Maximized profit';
```

```
% Create MaximizedprofitEditField
app.MaximizedprofitEditField = uieditfield(app.PROFITPanel, 'numeric');
app.MaximizedprofitEditField.Position = [160 11 109 22];

% Create KESLabel_9
app.KESLabel_9 = uilabel(app.PROFITPanel);
app.KESLabel_9.VerticalAlignment = 'top';
app.KESLabel_9.Position = [280 7 31 22];
app.KESLabel_9.Text = 'KES';

% Create KESdayLabel_2
app.KESdayLabel_2 = uilabel(app.PROFITPanel);
app.KESdayLabel_2.VerticalAlignment = 'top';
app.KESdayLabel_2.Position = [280 164 54 22];
app.KESdayLabel_2.Text = 'KES/day';

% Create CostfingerlingsEditFieldLabel
app.CostfingerlingsEditFieldLabel = uilabel(app.PROFITPanel);
app.CostfingerlingsEditFieldLabel.HorizontalAlignment = 'right';
app.CostfingerlingsEditFieldLabel.VerticalAlignment = 'top';
app.CostfingerlingsEditFieldLabel.Position = [7 49 90 15];
app.CostfingerlingsEditFieldLabel.Text = 'Cost fingerlings';

% Create CostfingerlingsEditField
app.CostfingerlingsEditField = uieditfield(app.PROFITPanel, 'numeric');
app.CostfingerlingsEditField.Position = [160 45 109 22];
```

```
% Create KESLabel_8
app.KESLabel_8 = uilabel(app.PROFITPanel);
app.KESLabel_8.VerticalAlignment = 'top';
app.KESLabel_8.Position = [280 39 31 22];
app.KESLabel_8.Text = 'KES';

% Create CostofelectricityperdayEditFieldLabel
app.CostofelectricityperdayEditFieldLabel = uilabel(app.PROFITPanel);
app.CostofelectricityperdayEditFieldLabel.HorizontalAlignment = 'right';
app.CostofelectricityperdayEditFieldLabel.VerticalAlignment = 'top';
app.CostofelectricityperdayEditFieldLabel.Position = [7 109 140 22];
app.CostofelectricityperdayEditFieldLabel.Text = 'Cost of electricity per day';

% Create CostofelectricityperdayEditField
app.CostofelectricityperdayEditField = uieditfield(app.PROFITPanel, 'numeric');
app.CostofelectricityperdayEditField.Position = [160 112 110 22];

% Create RevenuesEditFieldLabel
app.RevenuesEditFieldLabel = uilabel(app.PROFITPanel);
app.RevenuesEditFieldLabel.HorizontalAlignment = 'right';
app.RevenuesEditFieldLabel.Position = [5 195 60 22];
app.RevenuesEditFieldLabel.Text = 'Revenues';

% Create RevenuesEditField
app.RevenuesEditField = uieditfield(app.PROFITPanel, 'numeric');
app.RevenuesEditField.Position = [160 195 109 22];
```

```
% Create CostoffeedEditFieldLabel
app.CostoffeedEditFieldLabel = uilabel(app.PROFITPanel);
app.CostoffeedEditFieldLabel.HorizontalAlignment = 'right';
app.CostoffeedEditFieldLabel.Position = [7 135 70 22];
app.CostoffeedEditFieldLabel.Text = 'Cost of feed';

% Create CostoffeedEditField
app.CostoffeedEditField = uieditfield(app.PROFITPanel, 'numeric');
app.CostoffeedEditField.Position = [160 135 109 22];

% Create CostofelectricityEditFieldLabel
app.CostofelectricityEditFieldLabel = uilabel(app.PROFITPanel);
app.CostofelectricityEditFieldLabel.HorizontalAlignment = 'right';
app.CostofelectricityEditFieldLabel.Position = [5 79 97 22];
app.CostofelectricityEditFieldLabel.Text = 'Cost of electricity';

% Create CostofelectricityEditField
app.CostofelectricityEditField = uieditfield(app.PROFITPanel, 'numeric');
app.CostofelectricityEditField.Position = [160 79 109 22];

% Create KESLabel_5
app.KESLabel_5 = uilabel(app.PROFITPanel);
app.KESLabel_5.VerticalAlignment = 'top';
app.KESLabel_5.Position = [280 194 31 22];
app.KESLabel_5.Text = 'KES';
```

```
% Create CostoffeedperdayEditFieldLabel
app.CostoffeedperdayEditFieldLabel = uilabel(app.PROFITPanel);
app.CostoffeedperdayEditFieldLabel.HorizontalAlignment = 'right';
app.CostoffeedperdayEditFieldLabel.Position = [7 165 114 22];
app.CostoffeedperdayEditFieldLabel.Text = 'Cost of feed per day';

% Create CostoffeedperdayEditField
app.CostoffeedperdayEditField = uieditfield(app.PROFITPanel, 'numeric');
app.CostoffeedperdayEditField.Position = [160 165 109 22];

% Create KESLabel_6
app.KESLabel_6 = uilabel(app.PROFITPanel);
app.KESLabel_6.VerticalAlignment = 'top';
app.KESLabel_6.Position = [280 134 31 22];
app.KESLabel_6.Text = 'KES';

% Create KESLabel_7
app.KESLabel_7 = uilabel(app.PROFITPanel);
app.KESLabel_7.VerticalAlignment = 'top';
app.KESLabel_7.Position = [280 74 31 22];
app.KESLabel_7.Text = 'KES';

% Create PowerPanel
app.PowerPanel = uipanel(app.OutputTab);
app.PowerPanel.Title = 'Power';
app.PowerPanel.Position = [27 403 298 88];
```

```
            % Create kWhLabel_2
            app.kWhLabel_2 = uilabel(app.PowerPanel);
            app.kWhLabel_2.VerticalAlignment = 'top';
            app.kWhLabel_2.Position = [261 7 29 22];
            app.kWhLabel_2.Text = 'kWh';

            % Create kWhLabel
            app.kWhLabel = uilabel(app.PowerPanel);
            app.kWhLabel.VerticalAlignment = 'top';
            app.kWhLabel.Position = [261 39 29 22];
            app.kWhLabel.Text = 'kWh';

            % Create EnergyconsumedbypumpEditFieldLabel
            app.EnergyconsumedbypumpEditFieldLabel = uilabel(app.PowerPanel);
            app.EnergyconsumedbypumpEditFieldLabel.HorizontalAlignment = 'right';
            app.EnergyconsumedbypumpEditFieldLabel.VerticalAlignment = 'top';
            app.EnergyconsumedbypumpEditFieldLabel.Position = [4 39 152 22];
            app.EnergyconsumedbypumpEditFieldLabel.Text = 'Energy consumed by
pump';

            % Create EnergyconsumedbypumpEditField
            app.EnergyconsumedbypumpEditField = uieditfield(app.PowerPanel, 'numeric');
            app.EnergyconsumedbypumpEditField.Position = [169 42 87 22];

            % Create EnergyrequiredforaerationEditFieldLabel
            app.EnergyrequiredforaerationEditFieldLabel = uilabel(app.PowerPanel);
            app.EnergyrequiredforaerationEditFieldLabel.HorizontalAlignment = 'right';
```

```
        app.EnergyrequiredforaerationEditFieldLabel.VerticalAlignment = 'top';
        app.EnergyrequiredforaerationEditFieldLabel.Position = [5 7 155 22];
        app.EnergyrequiredforaerationEditFieldLabel.Text = 'Energy required for
aeration';

        % Create EnergyrequiredforaerationEditField
        app.EnergyrequiredforaerationEditField = uieditfield(app.PowerPanel,
'numeric');
        app.EnergyrequiredforaerationEditField.Position = [169 10 87 22];

        % Create PurificationefficiencyPEECPanel
        app.PurificationefficiencyPEECPanel = uipanel(app.OutputTab);
        app.PurificationefficiencyPEECPanel.Title = 'Purification efficiency (PE) & EC';
        app.PurificationefficiencyPEECPanel.FontWeight = 'bold';
        app.PurificationefficiencyPEECPanel.Position = [27 94 298 82];

        % Create Label
        app.Label = uilabel(app.PurificationefficiencyPEECPanel);
        app.Label.HorizontalAlignment = 'right';
        app.Label.VerticalAlignment = 'top';
        app.Label.Position = [232 37 26 15];
        app.Label.Text = '%';

        % Create EditField
        app.EditField = uieditfield(app.PurificationefficiencyPEECPanel, 'numeric');
        app.EditField.Position = [141 38 88 22];
```

```
        % Create ECEditFieldLabel
        app.ECEditFieldLabel = uilabel(app.PurificationefficiencyPEECPanel);
        app.ECEditFieldLabel.HorizontalAlignment = 'right';
        app.ECEditFieldLabel.Position = [9 10 25 22];
        app.ECEditFieldLabel.Text = 'EC';

        % Create ECEditfield
        app.ECEditfield = uieditfield(app.PurificationefficiencyPEECPanel, 'numeric');
        app.ECEditfield.ValueChangedFcn = createCallbackFcn(app,
@ECEditfieldValueChanged, true);
        app.ECEditfield.Position = [141 10 88 22];

        % Create PELabel
        app.PELabel = uilabel(app.PurificationefficiencyPEECPanel);
        app.PELabel.Position = [19 39 78 22];
        app.PELabel.Text = 'PE';

        % Create mgLLabel_7
        app.mgLLabel_7 = uilabel(app.PurificationefficiencyPEECPanel);
        app.mgLLabel_7.Position = [232 5 33 22];
        app.mgLLabel_7.Text = 'mg/L';

        % Create FishPanel
        app.FishPanel = uipanel(app.OutputTab);
        app.FishPanel.Title = 'Fish';
        app.FishPanel.Position = [27 184 298 214];
```

```
% Create kgLabel_3
app.kgLabel_3 = uilabel(app.FishPanel);
app.kgLabel_3.VerticalAlignment = 'top';
app.kgLabel_3.Position = [258 141 25 22];
app.kgLabel_3.Text = 'kg';

% Create FeedfedperdayEditFieldLabel
app.FeedfedperdayEditFieldLabel = uilabel(app.FishPanel);
app.FeedfedperdayEditFieldLabel.HorizontalAlignment = 'right';
app.FeedfedperdayEditFieldLabel.VerticalAlignment = 'top';
app.FeedfedperdayEditFieldLabel.Position = [7 144 97 15];
app.FeedfedperdayEditFieldLabel.Text = 'Feed fed per day';

% Create FeedfedperdayEditField
app.FeedfedperdayEditField = uieditfield(app.FishPanel, 'numeric');
app.FeedfedperdayEditField.Position = [140 140 116 22];

% Create mgLLabel_6
app.mgLLabel_6 = uilabel(app.FishPanel);
app.mgLLabel_6.VerticalAlignment = 'top';
app.mgLLabel_6.Position = [258 116 32 15];
app.mgLLabel_6.Text = 'mg/L';

% Create OxygenconcentrationEditFieldLabel
app.OxygenconcentrationEditFieldLabel = uilabel(app.FishPanel);
app.OxygenconcentrationEditFieldLabel.HorizontalAlignment = 'right';
app.OxygenconcentrationEditFieldLabel.VerticalAlignment = 'top';
```

```
app.OxygenconcentrationEditFieldLabel.Position = [7 116 124 15];
app.OxygenconcentrationEditFieldLabel.Text = 'Oxygen concentration';

% Create OxygenconcentrationEditField
app.OxygenconcentrationEditField = uieditfield(app.FishPanel, 'numeric');
app.OxygenconcentrationEditField.Position = [140 112 117 22];

% Create mgLLabel_3
app.mgLLabel_3 = uilabel(app.FishPanel);
app.mgLLabel_3.VerticalAlignment = 'top';
app.mgLLabel_3.Position = [258 55 32 15];
app.mgLLabel_3.Text = 'mg/L';

% Create mgLLabel_4
app.mgLLabel_4 = uilabel(app.FishPanel);
app.mgLLabel_4.VerticalAlignment = 'top';
app.mgLLabel_4.Position = [258 32 32 15];
app.mgLLabel_4.Text = 'mg/L';

% Create mgLLabel_5
app.mgLLabel_5 = uilabel(app.FishPanel);
app.mgLLabel_5.VerticalAlignment = 'top';
app.mgLLabel_5.Position = [258 6 32 15];
app.mgLLabel_5.Text = 'mg/L';

% Create AmmoniaConcentrationEditFieldLabel
```

```
app.AmmoniaConcentrationEditFieldLabel = uilabel(app.FishPanel);
app.AmmoniaConcentrationEditFieldLabel.HorizontalAlignment = 'right';
app.AmmoniaConcentrationEditFieldLabel.VerticalAlignment = 'top';
app.AmmoniaConcentrationEditFieldLabel.Position = [2 49 140 22];
app.AmmoniaConcentrationEditFieldLabel.Text = 'Ammonia Concentration';

% Create AmmoniaConcentrationEditField
app.AmmoniaConcentrationEditField = uieditfield(app.FishPanel, 'numeric');
app.AmmoniaConcentrationEditField.ValueDisplayFormat = '%.4f';
app.AmmoniaConcentrationEditField.Position = [140 55 114 22];

% Create RemovedAmmoniaEditFieldLabel
app.RemovedAmmoniaEditFieldLabel = uilabel(app.FishPanel);
app.RemovedAmmoniaEditFieldLabel.HorizontalAlignment = 'right';
app.RemovedAmmoniaEditFieldLabel.VerticalAlignment = 'top';
app.RemovedAmmoniaEditFieldLabel.Position = [8 32 113 15];
app.RemovedAmmoniaEditFieldLabel.Text = 'Removed Ammonia';

% Create RemovedAmmoniaEditField
app.RemovedAmmoniaEditField = uieditfield(app.FishPanel, 'numeric');
app.RemovedAmmoniaEditField.ValueDisplayFormat = '%.4f';
app.RemovedAmmoniaEditField.Position = [140 28 114 22];

% Create ResidualammoniaEditFieldLabel
app.ResidualammoniaEditFieldLabel = uilabel(app.FishPanel);
app.ResidualammoniaEditFieldLabel.HorizontalAlignment = 'right';
app.ResidualammoniaEditFieldLabel.VerticalAlignment = 'top';
```

```
app.ResidualammoniaEditFieldLabel.Position = [12 6 108 15];
app.ResidualammoniaEditFieldLabel.Text = 'Residual ammonia';

% Create ResidualammoniaEditField
app.ResidualammoniaEditField = uieditfield(app.FishPanel, 'numeric');
app.ResidualammoniaEditField.ValueDisplayFormat = '%.4f';
app.ResidualammoniaEditField.Position = [140 2 116 22];

% Create FeedEditFieldLabel
app.FeedEditFieldLabel = uilabel(app.FishPanel);
app.FeedEditFieldLabel.HorizontalAlignment = 'right';
app.FeedEditFieldLabel.Position = [11 165 33 22];
app.FeedEditFieldLabel.Text = 'Feed';

% Create FeedEditField
app.FeedEditField = uieditfield(app.FishPanel, 'numeric');
app.FeedEditField.Position = [140 165 117 22];

% Create kgLabel_2
app.kgLabel_2 = uilabel(app.FishPanel);
app.kgLabel_2.VerticalAlignment = 'top';
app.kgLabel_2.Position = [258 162 25 22];
app.kgLabel_2.Text = 'kg';

% Create AmmoniaProducedEditFieldLabel
app.AmmoniaProducedEditFieldLabel = uilabel(app.FishPanel);
```

```
app.AmmoniaProducedEditFieldLabel.HorizontalAlignment = 'right';
app.AmmoniaProducedEditFieldLabel.Position = [12 81 111 22];
app.AmmoniaProducedEditFieldLabel.Text = 'Ammonia Produced';

% Create AmmoniaProducedEditField
app.AmmoniaProducedEditField = uieditfield(app.FishPanel, 'numeric');
app.AmmoniaProducedEditField.Position = [140 81 115 22];

% Create kgLabel_4
app.kgLabel_4 = uilabel(app.FishPanel);
app.kgLabel_4.VerticalAlignment = 'top';
app.kgLabel_4.Position = [258 81 32 22];
app.kgLabel_4.Text = 'kg';

% Create pHPanel
app.pHPanel = uipanel(app.OutputTab);
app.pHPanel.Title = 'pH';
app.pHPanel.Position = [336 314 342 177];

% Create pHEditFieldLabel
app.pHEditFieldLabel = uilabel(app.pHPanel);
app.pHEditFieldLabel.HorizontalAlignment = 'right';
app.pHEditFieldLabel.VerticalAlignment = 'top';
app.pHEditFieldLabel.Position = [60 5 25 15];
app.pHEditFieldLabel.Text = 'pH';
```

```
% Create pHEditField
app.pHEditField = uieditfield(app.pHPanel, 'numeric');
app.pHEditField.HandleVisibility = 'off';
app.pHEditField.Editable = 'off';
app.pHEditField.Position = [142 1 131 22];
app.pHEditField.Value = 1;

% Create molLLabel
app.molLLabel = uilabel(app.pHPanel);
app.molLLabel.Position = [276 117 35 22];
app.molLLabel.Text = 'mol/L';

% Create molLLabel_2
app.molLLabel_2 = uilabel(app.pHPanel);
app.molLLabel_2.Position = [276 77 35 22];
app.molLLabel_2.Text = 'mol/L';

% Create molLLabel_3
app.molLLabel_3 = uilabel(app.pHPanel);
app.molLLabel_3.Position = [276 41 35 22];
app.molLLabel_3.Text = 'mol/L';

% Create ConcEditFieldLabel
app.ConcEditFieldLabel = uilabel(app.pHPanel);
app.ConcEditFieldLabel.HorizontalAlignment = 'right';
app.ConcEditFieldLabel.Position = [60 117 34 22];
app.ConcEditFieldLabel.Text = 'Conc';
```

```
% Create ConcEditField
app.ConcEditField = uieditfield(app.pHPanel, 'numeric');
app.ConcEditField.Position = [142 117 134 22];

% Create OHEditFieldLabel
app.OHEditFieldLabel = uilabel(app.pHPanel);
app.OHEditFieldLabel.HorizontalAlignment = 'right';
app.OHEditFieldLabel.Position = [60 77 27 22];
app.OHEditFieldLabel.Text = 'OH-';

% Create OHEditField
app.OHEditField = uieditfield(app.pHPanel, 'numeric');
app.OHEditField.Position = [142 77 134 22];

% Create HEditFieldLabel
app.HEditFieldLabel = uilabel(app.pHPanel);
app.HEditFieldLabel.HorizontalAlignment = 'right';
app.HEditFieldLabel.Position = [60 41 25 22];
app.HEditFieldLabel.Text = 'H+';

% Create HEditField
app.HEditField = uieditfield(app.pHPanel, 'numeric');
app.HEditField.Position = [142 41 134 22];

% Create AmountharvestedfishEditFieldLabel
```

```
app.AmountharvestedfishEditFieldLabel = uilabel(app.OutputTab);
app.AmountharvestedfishEditFieldLabel.HorizontalAlignment = 'right';
app.AmountharvestedfishEditFieldLabel.VerticalAlignment = 'top';
app.AmountharvestedfishEditFieldLabel.Position = [21 55 126 15];
app.AmountharvestedfishEditFieldLabel.Text = 'Amount harvested fish';

% Create AmountharvestedfishEditField
app.AmountharvestedfishEditField = uieditfield(app.OutputTab, 'numeric');
app.AmountharvestedfishEditField.Position = [168 51 90 22];

% Create kgLabel
app.kgLabel = uilabel(app.OutputTab);
app.kgLabel.VerticalAlignment = 'top';
app.kgLabel.Position = [262 51 28 22];
app.kgLabel.Text = 'kg';

% Create NumberoffishatstockingEditFieldLabel
app.NumberoffishatstockingEditFieldLabel = uilabel(app.OutputTab);
app.NumberoffishatstockingEditFieldLabel.HorizontalAlignment = 'right';
app.NumberoffishatstockingEditFieldLabel.VerticalAlignment = 'top';
app.NumberoffishatstockingEditFieldLabel.Position = [21 24 144 22];
app.NumberoffishatstockingEditFieldLabel.Text = 'Number of fish at stocking';

% Create NumberoffishatstockingEditField
app.NumberoffishatstockingEditField = uieditfield(app.OutputTab, 'numeric');
app.NumberoffishatstockingEditField.Position = [168 27 90 22];
```

```
            % Create FishLabel
            app.FishLabel = uilabel(app.OutputTab);
            app.FishLabel.VerticalAlignment = 'top';
            app.FishLabel.Position = [261 31 28 15];
            app.FishLabel.Text = 'Fish';


            % Create DataTab
            app.DataTab = uitab(app.TabGroup);
            app.DataTab.Title = 'Data';


            % Create AmmoniaButton
            app.AmmoniaButton = uibutton(app.DataTab, 'push');
            app.AmmoniaButton.ButtonPushedFcn = createCallbackFcn(app,
@AmmoniaButtonPushed, true);
            app.AmmoniaButton.Position = [69 361 100 22];
            app.AmmoniaButton.Text = 'Ammonia';


            % Create ComparisontheoreticalvaluewithexperimentaldataLabel
            app.ComparisontheoreticalvaluewithexperimentaldataLabel =
uilabel(app.DataTab);
            app.ComparisontheoreticalvaluewithexperimentaldataLabel.VerticalAlignment =
'top';
            app.ComparisontheoreticalvaluewithexperimentaldataLabel.FontSize = 18;
            app.ComparisontheoreticalvaluewithexperimentaldataLabel.FontWeight = 'bold';
            app.ComparisontheoreticalvaluewithexperimentaldataLabel.Position = [17 444
471 23];
```

```
        app.ComparisontheoreticalvaluewithexperimentaldataLabel.Text = 'Comparison
theoretical value with experimental data ';


        % Create DOButton
        app.DOButton = uibutton(app.DataTab, 'push');
        app.DOButton.ButtonPushedFcn = createCallbackFcn(app, @DOButtonPushed,
true);
        app.DOButton.Position = [69 323 100 22];
        app.DOButton.Text = 'DO';


        % Create pHButton
        app.pHButton = uibutton(app.DataTab, 'push');
        app.pHButton.ButtonPushedFcn = createCallbackFcn(app, @pHButtonPushed,
true);
        app.pHButton.Position = [69 281 100 22];
        app.pHButton.Text = 'pH';


        % Create UIAxes
        app.UIAxes = uiaxes(app.DataTab);
        title(app.UIAxes, 'AMM,DO,pH,EC,T vs Flowrate')
        xlabel(app.UIAxes, 'Flowrate [L/min]')
        ylabel(app.UIAxes, 'AMM,DO,pH,EC,T')
        app.UIAxes.Position = [220 42 443 366];


        % Create ECButton
        app.ECButton = uibutton(app.DataTab, 'push');
```

```
            app.ECButton.ButtonPushedFcn = createCallbackFcn(app,
@ECButtonButtonPushed, true);
            app.ECButton.Position = [69 244 100 22];
            app.ECButton.Text = 'EC';


            % Create PowerButton
            app.PowerButton = uibutton(app.DataTab, 'push');
            app.PowerButton.ButtonPushedFcn = createCallbackFcn(app,
@PowerButtonPushed, true);
            app.PowerButton.Position = [69 206 100 22];
            app.PowerButton.Text = 'Power';


            % Show the figure after all components are created
            app.UIFigure.Visible = 'on';
        end
    end


    % App creation and deletion
    methods (Access = public)


        % Construct app
        function app = RASPredMod2019111


            % Create UIFigure and components
            createComponents(app)
```

```
            % Register the app with App Designer
            registerApp(app, app.UIFigure)

            % Execute the startup function
            runStartupFcn(app, @startupFcn)

            if nargout == 0
                clear app
            end
        end

        % Code that executes before app deletion
        function delete(app)

            % Delete UIFigure when app is deleted
            delete(app.UIFigure)
        end
    end
end
```

Appendix F: Project Photos

Plate F1: HQ40d multimeter used for data collection

Plate F2: RAS water samples, the multimeter and two probes connected to it during data collection

Plate F3: A data collection session in the greenhouse

Plate F4: The RAS setup showing the production tanks, connection pipes, biofilter and sump tank

Plate F5: Some of the fish during a sampling process seven months after stocking

Plate F6: One of the tilapia weighing 730g