REMOVAL OF PHOSPHORUS AND SUSPENDED SOLIDS IN AQUACULTURE WASTEWATER BY USING FERROUS SULPHATE IN COAGULATION PROCESS VIA ZETA POTENTIAL AND PARTICLE SIZE MEASUREMENTS

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By

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ABSTRAK

Satu kajian telah dilakukan untuk mengenalpasti tahap kualiti air yang dari sistem akuakultur Arowana yang terletak di Simpang Empat, Semanggol, Perak berdekatan dengan Lebuhraya PLUS di Bukit Merah (5°01'00.3"U, 100°38'15.4"B). Parameter kualiti air yang dipilih untuk kajian ini adalah BOD, COD, TSS, P dan *E.coli* telah di kaji kandungannya dalam aliran masuk dan pelepasan sistem akuakuntur Arowana. Ferrous sulfat hidrat ($FeSO_4.7H_2O$) telah dipilih sebagai bahan penggumpal untuk merawat air sisa akuakultur melalui proses penggumpalan bagi mengurangkan jumlah pencemaran dari kolam akuakultur. Pencemaran seperti pepejal terampai dan fosforus telah dinyatakan sebagai salah satu isu industri akuakultur oleh Jabatan Perikanan, Malaysia yang boleh menjejaskan populasi spesis akuatik dan penggunaan kos sektor akuakultur. Objektif utama kajian ini adalah untuk menerapkan kaedah pengukuran zeta dan saiz zarah dalam menentukan julat optimum pH dan kepekatan bahan penggumpal untuk merawat air sisa akuakultur. Keputusan kajian pencirian air sisa menunjukkan nilai TSS dan P untuk pelepasan adalah masing-masing 107 mg/L dan 0.36 mg/L. Bagi menuntukan pH optimum, kaedah pengukuran potensi zeta dan saiz zarah telah dilakukan secara berasingan bagi sampel air sisa dan $FeSO_4.7H_2O$ dalam lingkungan julat pH 2 sehingga pH 12. Daripada hasil yang diperoleh, nilai-nilai pH yang sesuai untuk digunakan dalam proses penggumpalan adalah pH 5 dan pH 9. Seterusnya, ciri-ciri penggumpalan dan pengasiangan terhadap air sisa dan kepekatan bahan penggumpal telah dianalisis. Daripada kaedah ini, kepekatan $FeSO_4.7H_2O$ yang sesuai untuk proses penggumpalan didapati 600 mg/L bagi pH 5 dan 800 mg/L bagi pH 9. Fasa terakhir kajian adalah kaedah ujian jar yang dilakukan dengan menggunakan 600 mg/L kepekatan $FeSO_4.7H_2O$ pada pH 5 dan pH 9 dengan kepekatan 800 mg/L. Hasil yang diperolehi mendapati P untuk pH 5 dan pH 9 adalah masing-maisng 0.05 mg/L dan

0.005 mg L dengan penyingkiran peratusan sebanyak 86.1% dan 98.6%. Sementara itu, hasil TSS yang diperoleh adalah sama untuk kedua-dua pH 5 dan pH 9 iaitu 2 mg / L dengan penyingkiran peratus sebanyak 98.1%. Oleh itu, penyingkiran terbaik untuk P dan TSS dalam kajian ini adalah pada pH 9 dengan kepekatan 800 mg/L $FeSO_4.7H_2O$.

ABSTRACT

A study was conducted to analyse the level of water quality that is discharge from a local Arowana aquaculture farming pond system located at Simpang Empat, Semanggol, Perak along the PLUS Highway at Bukit Merah (5°01’00.3”N, 100°38’15.4”E). At the aquaculture farm, the selected water quality parameter which were BOD, COD, TSS, P and *E.coli* of inflows and discharges were measured. Ferrous sulphate hydrate ($FeSO_4.7H_2O$) was selected as a coagulant to treat the aquaculture wastewater in the coagulation process in order to reduce the amount of pollution from the aquaculture ponds. Pollution such as suspended solids and phosphorus had been stated as one of the aquaculture industry issues by the Department of Fisheries, Malaysia which can affect the growing population of aquatic species and cost consumption of aquaculture sector. The main objective of this study was to apply the zeta potential and particle size measurements in determining the optimum pH and coagulant range to treat the aquaculture wastewater. The wastewater characteristics study result showed the value of TSS and P for discharges are 107 mg/L and 0.36 mg/L, respectively. This was subsequently followed by a pH study to determine the optimum pH by using the zeta potential and corresponding particles size with pH 2 to pH 12 for both wastewater sample and $FeSO_4.7H_2O$ which were determined separately. From the result obtained, the suitable pH values to be used in coagulation process are pH 5 and pH 9. Next, the aggregation and disaggregation behaviour of the wastewater suspension was analysed as a function of a coagulant concentration. From this method, the suitable concentration of $FeSO_4.7H_2O$ to be used in coagulation process was found to be 600 mg/L for pH 5 and 800 mg/L at pH 9. The last phase of the study was the jar test experiment which was carried out by using pH 5 with 600 mg/L of $FeSO_4.7H_2O$ concentration and pH 9 with 800 mg/L. From the result obtained, P for pH 5 and pH 9 were 0.05 mg/L and 0.005

mg/L with percentage removal of 86.1% and 98.6%, respectively. Meanwhile, the result for TSS obtained was same for both pH 5 and pH 9 which is 2 mg/L with percentage removal of 98.1%. Hence, the best removal for P and TSS in this study was at pH 9 with 800 mg/L concentration of $FeSO_4.7H_2O$.

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LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOF	Department of Fisheries
FAO	Food and Agriculture Organization
$FeSO_2.7H_2O$	Ferrous Sulphate
NH_3	Ammonia
NH_4^+	Ammonium
P	Phosphorus
RAS	Recirculating Aquaculture System
TAN	Total Ammonium Nitrogen
TSS	Total Suspended Solids

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

In Malaysia, Arowana is well known to breed successfully at Bukit Merah. The source of inflow water is from the Bukit Merah reservoir. It provides irrigation water for double cropping to 24,000 Ha of paddy land under the Kerian-Sungai Manik Project. Other than that, it also provides some 5.6 m^3/s of water to meet the domestic and industrial demand for the Kerian District (Ahmad Awalluddin *et al.*, 2012).

Arowana is one of the most valuable species in the Asian ornamental trade (Natalia *et al.*, 2004). There are three varieties of the colour of this species which are Golden Arowana, Red Arowana and Green Arowana. Among these three varieties, the best quality is the Malaysia Golden Arowana which can only breed successfully at Bukit Merah Lake in the state of Perak, Malaysia. The breeding seasons for Arowana normally occur from August to October every year (Suleiman, 2003).

The main purpose of this study is to observe the water quality for both inflows and discharges from Arowana aquaculture farm. Several parameters from both water samples were determined including BOD, COD, P, TSS and *E.coli*. TSS and P for discharges from Arowana aquaculture farm were removed by using ferrous sulphate coagulant through coagulation process. The optimum pH and concentration of ferrous sulphate were determined separately by observing the aggregation and disaggregation behaviour of the discharge suspension as a function of coagulant concentration.

1.2 PROBLEM STATEMENT

Arowana aquaculture industry has been identified as one of the main sectors of agriculture in coming years, as part of a global solution to the rapid depletion of the world's natural fish stock. According to Food and Aquaculture Organization (FAO), brackish water aquaculture dominates the aquaculture industry in Malaysia, with the total production of 144 189 tonnes per year, covering an area 17 357 ha. Pollution such as suspended solids and phosphorus had been stated as one of the aquaculture industry issues by the Department of Fisheries, Malaysia which can affect the growing population of aquatic species and cost consumption of aquaculture sector.

From intensive aquaculture systems, it tends to produce wastes which consider as the pollution. The principal wastes are solid waste, chemicals, and therapeutics. Other than that, the release of bacteria, pathogens and farmed species escapees should also be included as waste components (Phillips and Tanabe, 1989). Solid waste which also known as particulate organic matter consists of faeces or uneaten food. A build-up of particulate organic matter can cause oxygen depletion and an increase in ammonia toxicity when it decomposes (Sarà *et al.*, 2004). The urine and faeces from the aquatic animals can cause the high content of phosphorus and an increase of BOD as well (Schwitzguébel and Wang, 2007).

In aquaculture wastewater treatment, alum and ferric sulphate are very famous coagulants among the researchers (Ozbay, 2005)(Steinman *et al*, 2004)(J. Ebeling *et al.*, 2004). However, Mc *et al.*, (2017) had been carried out the comparative assessment of the performance of alum and ferrous sulphate as coagulants in water treatment. From the study, they suggested that ferrous sulphate is more efficient in suspended solids and phosphorus removal compared to alum.

In this study, the characteristics including BOD, COD, P, TSS and *E.coli* of the wastewater discharge from Arowana aquaculture farm were determined. Coagulation process by using ferrous sulphate was carried out to the discharge water sample from Arowana aquaculture farm to remove the TSS and P. However, the characteristics for BOD, COD and *E.coli* after coagulation process also had been determined as additional parameters to monitor the removal efficiencies of the ferrous sulphate in wastewater treatment. The suitable pH and concentration were determined by evaluating the aggregation and disaggregation behaviour of the wastewater suspension as a function of coagulant concentration.

1.3 RESEARCH OBJECTIVES

The overall aim of the study was to treat the polluted wastewater discharge from aquaculture industry by using the ferrous sulphate in order to recover and reuse back the water discharge from the aquaculture pond as an influent to the ponds or in human daily basis such as washing and watering.

The study was carried out to fulfil several objectives as below;

1. To characterize the major type of pollutant that constitutes in aquaculture wastewater;
2. To determine the optimum pH range by measuring the average zeta potential and corresponding particle size of both the wastewater sample and selected coagulant type;
3. To systematically evaluate the aggregation and disaggregation behaviour of the wastewater suspension as a function of coagulant concentration;

4. To calculate the percentage removal of suspended solids and phosphorus based on the predetermined optimum pH and coagulant dosage range.

1.4 SCOPE OF STUDY

The scope of this study is to identify the suitable concentration range in optimum pH to maximize the removal of suspended solids and phosphorus. This study was carried out experimentally which is aquaculture discharge as the wastewater sample. Basically, TSS and P from the water discharge were removed by using ferrous sulphate as the coagulant. This study aims to improve the understanding of the use of ferrous sulphate as the coagulant in wastewater treatment from aquaculture discharge.

The characteristics of the water sample including Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Phosphorus (P), Total Suspended Solids (TSS) and *E.coli* were determined in order to observe the water quality of the wastewater sample before coagulation process. After that, the zeta potential and the particle size of the wastewater samples also had been identified. The particles size which are cannot be observed by naked eyes can be analysed by using the dynamic light scattering technique.

The suitable pH and concentration were determined by evaluating the aggregation and disaggregation behaviour of the wastewater suspension as a function of coagulant concentration. The treatment had been carried out by conducting the jar test with ferrous sulphate as the coagulant by using the suitable pH and the concentration. The jar test was carried out to verify the removal efficiencies for TSS and P from wastewater sample. Other than that, additional removal efficiencies for BOD, COD and *E.coli* also had been determined.

1.5 SIGNIFICANCE OF STUDY

The outcome of the study is improving the existing water treatment from aquaculture discharge. Other than that, at the end of the study, the result will contribute in a better understanding of ferrous sulphate as the coagulant in the wastewater treatment from aquaculture discharge. Last but not least, the treatment that carried out will result in the minimum dosage of coagulant with the maximum of removal efficiency.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND ON AQUACULTURE INDUSTRY

Aquaculture farming is known as fish or shellfish farming. This type of farming refers to the breeding, rearing and harvesting of plants and animals in all types of water environments including ponds, rivers, lakes and the ocean (NOAA Fisheries). Other than that, aquaculture farming is also known as the controlled cultivation and harvest of aquatic animals and plants (Sapkota *et al.*, 2008).

In the past few decades, aquaculture industry sector in Malaysia has shown and interesting trend in production outputs and values. The aquaculture industry sector in Malaysia is primarily associated with its economic gains as benefits of supplying domestic and foreign demands for the producer (Witus *et al.*, 2016). Figure 2.1 shows the total production of aquaculture farming in Malaysia (Fish and Agriculture, 2017).

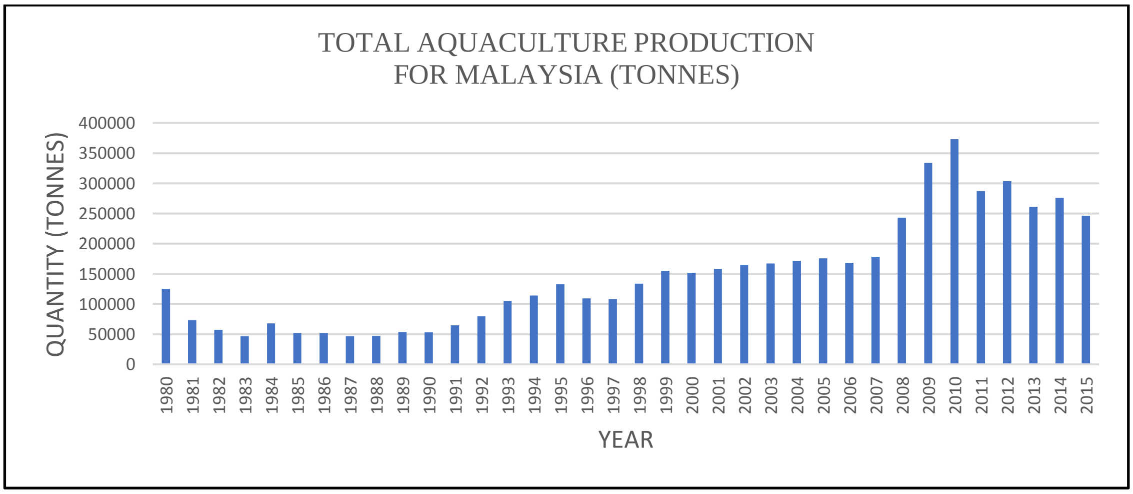

Figure 2.1: Total aquaculture production for Malaysia (tonnes)

There are three type of aquaculture ponds that commonly practice in Malaysia including the marine aquaculture, brackish aquaculture and freshwater aquaculture. These types of the aquaculture is depending on the water salinity (Evans and Frick, 2001). Basically, the salinity of the marine water is more than 35 ppt, followed by brackish water which is in range 0.5 ppt to 35 ppt. The salinity of the freshwater is below than 0.5 ppt (Haimowitz, 2013). Figure 2.2 shows the total production of aquaculture by type in Malaysia. (Fish and Agriculture, 2017).

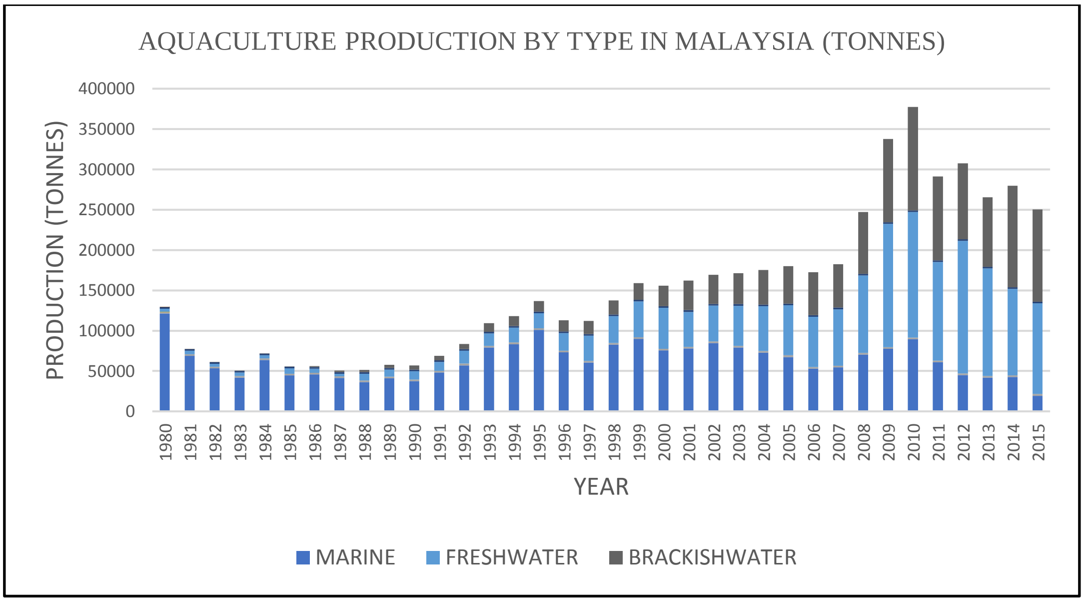

Figure 2.2.: Graph of aquaculture production by type in Malaysia (tonnes)

The aquaculture farming is introduced in 1980 by marine aquaculture. During year 1995, the freshwater and brackish water aquaculture are getting increase in production. While marine aquaculture production is decreasing in production start 2010 until recently. Among all, the freshwater aquaculture is getting the highest production due to the growing of the aquaculture sector in Malaysia.

2.2 POLLUTANT FROM AQUACULTURE INDUSTRY

Water pollution is a common problem that frequently occurs in the aquaculture industry. Pollutants such as phosphorus, nitrogen and suspended solids are both either directly or indirectly discharged into aquaculture ponds. It is essential to implement proper adequate treatment to remove harmful compounds as this could lead to inheritable environment degradation if left untreated.

2.2.1 TYPES OF POLLUTION IN AQUACULTURE FARM

The common problem occurs in aquaculture farm is water pollution (Phillips and Tanabe, 1989). Without adequate treatment to remove the harmful compounds, this environmental degradation can occur when pollutants are directly or indirectly discharged into aquaculture ponds.

2.2.1.1 Phosphorus, Nitrogen, Ammonium

Phosphorus is required for optimum growth, feed efficiency, bone development and maintenance of acid-base regulation in fish (Kibria *et al.*, 2014). However, high concentration of phosphates may pollute the water bodies as it may accelerate plant growth (Beveridge, 1984) and the aquatic ecosystem may be disrupted (Buschmann *et al*, 1996).

Feed is the main source of phosphorus loadings in aquaculture farm to the environment. Moreover, Hamilton *et al.*, (2016) also had reported that one-third of imports of phosphorus go to fish feed. Basically, phosphorus can be lost during aquaculture farm operation in many ways such as feed fines, uneaten food, faeces, dead fish and excretion (Kibria *et al.*, 2014). Figure 2.3 shows the typical phosphorus cycle in the aquaculture ponds. Dissolved inorganic phosphorus is released through excretion, particulate organic phosphorus is lost through defecation and uneaten feed, and dissolved organic phosphorus occurs through the dissolution of particulate phosphorus (Schwitzguébel and Wang, 2007). However, Mann (1993) reported that the main loading of phosphorus to the environment is via faecal pellets.

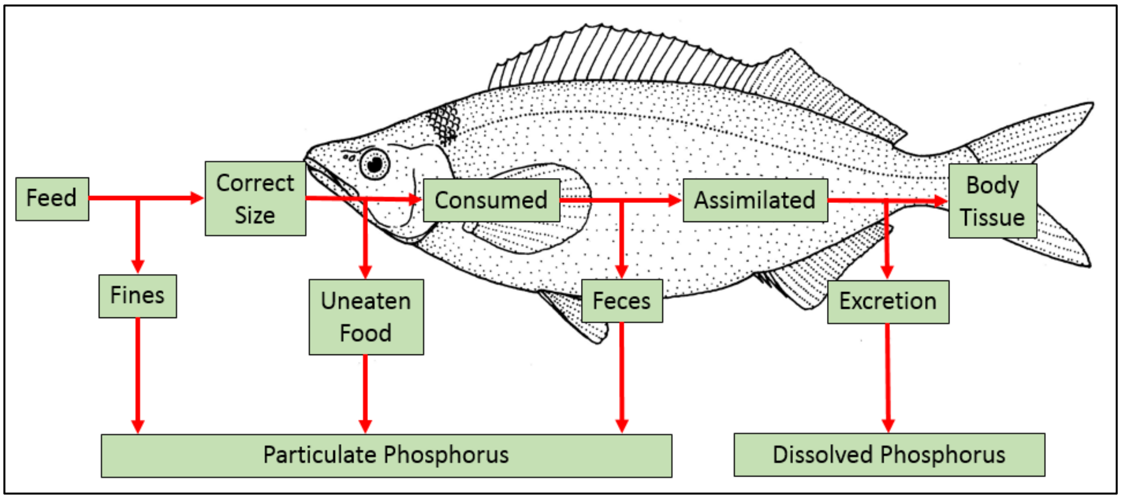

Figure 2.3: Flowchart of origin of phosphorus in aquaculture from feeding

Other than phosphorus, nitrogen and ammonium also had been discharged from the aquaculture systems into the aquatic environment. Around 75% of the feed nitrogen and phosphorus are unutilized and remain as waste in the water bodies (Piedrahita, 2003). While, ammonia is one of the end products of protein metabolism (Walsh and Wright, 1995). In water, ammonia (NH_3) and ammonium (NH_4^+) are in equilibrium depending on the pH and the temperature (Timmons *et al.*, 2002). The sum of the two forms is called total ammonium nitrogen (TAN).

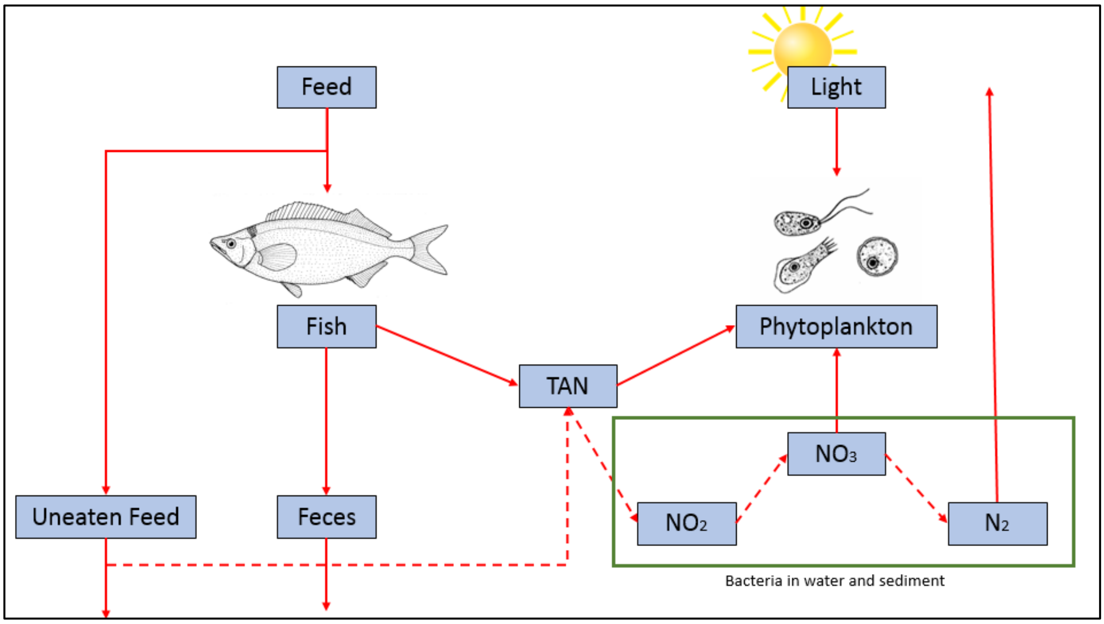

Figure 2.4: Nitrogen Cycle in Aquaculture Ponds

In Figure 2.4, the typical nitrogen cycle in aquaculture ponds is shown with a long hydraulic residence time (Crab *et al.*, 2007). The nitrogen input considered is formulated feed. A part of the remains unconsumed in the system (Franco-Nava *et al.*, 2004). The consumed feed will be converted into fish biomass and excreted as ammonium or egested as faeces. The uneaten feed and faeces will be suspended in the aquaculture pond which contribute to the organic matter load. According to Jiménez-Montealegre *et al.*, (2002), the microbial decomposition of organic matter in the system will contribute in increasing the levels of TAN and nitrate which both of them will be harmful to the fish even in low concentrations.

TAN present in the aquaculture system may be transformed into nitrite, nitrate and nitrogen gas (Crab *et al.*, 2007). Based on previous studies by Turker *et al.*, (2003), the bacteria present in the water and sediment will carry out the nitrogen transformations by nitrification and denitrification. Then, both TAN and nitrate will be assimilated by phytoplankton which are present in the water system as well.

NH_3 and NH_4^+ may be toxic to fish, however, unionized ammonia is more toxic that it is uncharged and lipid soluble and traverses biological membranes which is more readily compare to the charged and hydrated NH_4^+ ions (Körner *et al.*, 2001). According to Neori *et al.*, (2004), the acceptable level of unionized ammonia in aquaculture system is only 0.025 mg N/l. Concentration higher than 0.025 mg N/l will be very harmful to aquaculture ponds creatures.

2.2.1.2 Mud

Muddy habitats are usually composed of silty reduced sediments with high organic loadings (Hyland *et al.*, 2005). The most widely effect of fish farming is the organic enrichment of the sediment in the vicinity of the net cages (Holby and Hall, 1994). Basically, the organic matter from the muddy may change the physical and chemical composition of the sediments and finally affect the composition and function of benthic communities (Boström *et al.*, 2006).

Muddy water is not only unattractive, but also harmful to aquatic life. The mud, basically, contains high levels of suspended sediments (Thrush *et al.*, 2004). These sediments may affect the ecosystem of the aquaculture such as, limit light penetration and oxygen production by aquatic plants and increase the water temperature. Besides, high levels of suspended sediment may smother fish eggs, retard the growth of sportfish and reduce the holding capacity of ponds as well (Helfrich *et al.*, 1999).

According to Rowe *et al.*, (2001), there are causes which may lead to this situation. First, large populations of common carp, goldfish and bullheads can cause the muddy due to their spawning and feeding activities in the aquaculture system. Additionally, waterflow during raining weather often eat bank vegetation which can increase the erosion as. Furthermore, Helfrich *et al.*, (1999) also had mention that muddy ponds water are normally the result of soil erosion as well. Heavy rains and strong winds transport eroded soil particles into ponds from overgrazed pastures, unprotected croplands ad unvegetated shorelines.

2.2.1.3 Suspended Solids

Suspended solids is one of the crucial factors that may cause the pollution in water bodies. Mostly, the suspended solids in aquaculture ponds comes from the mud which result of soil erosion (Helfrich *et al.*, 1999). Basically, it comes with the heavy rains and strong winds which transport the soil particle into the ponds. In some other ways, the human activities such as logging, grazing, agriculture, mining, road building, urbanization and commercial construction have often resulted in periodic pulses or chronic levels of suspended sediment in streams.

Suspended solids can directly affect fish production. Chen *et al.*, (1993) had concluded that there were at least five ways in which an excessive concentration of fine suspended solids in water bodies might be harmful to fisheries. These include killing fish, reducing their growth rate, increasing their susceptibility to diseases and many others. Other than that, high concentration of suspended solids basically can lower water quality by absorbing light. When water become warmer, then it will lessen the ability to hold oxygen which necessary for aquatic life.

Moreover, it also can affect life in other ways. Small particles of suspended solids can clog the fish gills. Plus, the suspended solids may be unfavourable factor to growth rates as well as resistance to disease. Basically, this contaminated stream will flow to the aquaculture ponds as well as contributes in pollution from aquaculture system.

2.2.1.4 Acid and Alkaline

The pH of aquaculture system is a chemical measurement indicating how acidic or alkaline the water is on a standard scale ranging from 0 to 14. Sportfish favour waters within a range of 6.5 to 9.0. Values above and below this range may kill fish or lower production (Helfrich *et al.*, 1999). Extremely acid waters, below pH 4 or alkaline waters, above pH 11 are lethal to most sportfish.

The main pollutants responsible for acid decomposition (or acid rain) are Sulphur Dioxide (SO_2) and Nitrogen Oxide (NO_x) (Lenntech, 2017). Power stations and industrial plants, like the mining and smelting of high-sulphur ores and the combustion of fossils fuels. These compounds will mix with water vapor at unusual proportion to cause acid deposition with a pH of 4.2 to 4.7. The effects of acid deposition are much greater on water bodies with little buffering capacity. Much of the damage to aquatic life in sensitive areas with this little buffering capacity is a result of 'acid shock'. This is caused by the sudden runoff of large amounts of highly acidic water.

If water from aquaculture are consistently too acidic, liming materials can be broadcast over the bottoms of empty ponds or over the surface waters. Common liming materials are agricultural limestone [$CacO_3$ or $CaMg(CO_3)_2$], hydrated or slaked lime [$Ca(OH)_2$], and unslaked or quicklime [CaO] (Helfrich *et al.*, 1999). This acidic liming material may elevate the pH too high and cause fish kills.

In conclusion, aquaculture system with a low pH is highly acidic and can burn a fish's skin. Same goes to if the water from aquaculture is highly basic or alkaline and can chap or chemically burn a fish's skin as well. While young fish are more sensitive to higher acidic water than adult fish will be damaged even more. Fish water that has a pH of 5 is too acidic and will kill off fish eggs, they will not hatch (Rohlin, 2017).

2.2.1.5 Pesticides and Herbicides

Herbicides has been used in treatment of weed-infested waters by most of the farmers. The use of this chemical must be with caution and only after careful consideration of alternative control methods and the potential uses of the treated water for drinking, livestock, watering, swimming, fish production, irrigation or other uses. This chemicals that kill nuisance waterweeds may also kill beneficial water weeds and fish, disrupt aquatic food chains or have other undesirable side effect to aquaculture ecosystem (Helfrich *et al.*, 1999).

While, pesticides are beneficial chemical that can protect against forest and farm crop losses and can aid in more efficient food production. However, the benefits of pesticides are not derived without consequences. According to Michelle, (2009), when pesticides enter aquatic systems, the environmental costs can be high. Fish and other aquatic creatures have been victims of pesticides poisoning. Thus, pesticides use is one of many factors contributing to the decline of fish and other aquatic species.

2.3 IMPACT TO THE ENVIRONMENT AND HUMAN HEALTH

Aquaculture is the farming of aquatic organisms, including finfish and shellfish, by individuals, groups or corporations using interventions such as feed, medications, controlled breeding and containment that enhance production (Sapkota *et al.*, 2008). Industrial aquaculture is a rapidly growing industry in many development and developing countries. Cabello, (2006) had predicted that this growth will increase at an even faster rate in the future, stimulated by the depletion of fisheries and the market forces that globalize the sources of food supply.

The industry covers a wide range of species and methods, from simple traditional systems, in which fish or other aquatic animals are reared in small ponds for domestic consumption, to intensive industrial scale production systems. However, there are challenges in this industry to maintain the production which is to make the fishes stay healthy.

Generally, aquatic bacteria are not different from other bacteria in their responses to exposure to antimicrobial agents, and they are capable of transferring antimicrobial resistance genes to other bacteria (Akinbowale *et al.*, 2007). Thus, according to Heuer *et al.*, (2009), this overlap between various ecological environments including aquaculture and the human environment, means that bacteria and the drug-resistance genes that they contain may exchange between environment and implying a risk that this drug resistance genes may be transferred to human from the reservoir in the aquatic bacteria. This constitutes a potential human health hazard that has received relatively attention, because the human health hazard consequences of use of antimicrobial agents in animals have been regarded mainly in relation to terrestrial farm animals (Heuer *et al.*, 2009).

Other than that, micro sizes of materials as well may cause hazard to health if it exposes to human environment. Micro particles have the same dimensions as biological molecules such as proteins. Basically, the micro particles from aquaculture will flow to other water surface together with the pollutants as well. When the polluted water surface is used in human daily routines, then they tend to expose to hazard from this pollution.

2.4 TYPE OF AQUACULTURE WASTEWATER TREATMENT

A number of physical, chemical and biological methods used in conventional wastewater treatment have been applied in aquaculture systems. The objective of the water treatment from aquaculture system, basically, either to reuse the water effluent back to the culture tank by recirculating the water systems or reuse the water in human daily basis such as watering plants, washing clothes and others. In order to reuse the water back, the water quality from the effluents have to improve. The typical wastewater treatment used are bead filters, wetlands, biofilters (Sharrer *et al.*, 2009) and geotextile filter (Guerdat *et al.*, 2013).

Bead filters or expandable granular biofilters (EGBs) that display a bioclarification behaviour similar to sand filters (Malone and Beecher, 2000), can operate as both mechanical and biological filters (Turcios and Papenbrock, 2014). Besides act as a physical filtration device, bead filters can encourage the growth of bacteria that remove wastes from the water through biofiltration processes (Malone and Beecher, 2000). According to Sastry *et al.*, (1999), during normal filtration, bacteria tends to grow in the pore spaces and attached to the beads, extracting dissolved organics, ammonia and nitrate from the effluent to the media. The bacterial biomass and solids will accumulate and increase the headloss while decrease the hydraulic conductivity of the bed that impedes the transfer of nutrients and dissolved oxygen to the bacteria.

Another method that is typically used to treat water from effluent aquaculture are wetlands. Wetlands are a half-way world between terrestrial and aquatic ecosystems and exhibit some of the characteristics of each (Scholz and Lee, 2005). In other words, the wetlands are the interface between water and land. Turcios and Papenbrock, (2014) reported that wetlands are able to regulate pollutant removals through various biotic and abiotic processes. The variety of the removal mechanisms including sedimentation, filtration, precipitation, volatilization, adsorption and plant uptake are well documented in Faulwetter *et al.*, (2009). The typical plants for constructed wetland treatment systems are Schoenoplectus Validus, Phragmites Australis, Glyceria Maxima, Baumea Articulata, Bolboschoenus Fluviatilis, Cyperus Involucratus, Juncus Effusus and Zizania Latifolia (Tanner, 1996).

From Turcios and Papenbrock (2014), the biofilter is also one of the method to treat the water effluent from the aquaculture. Biofiltration systems or biofilters, are soil-plant based filtration systems which can be easily scaled and incorporated into urban landscapes. A typical biofiltration consists of a filter medium which generally has a high sand content and is underlain by a sand transition layer and a gravel drainage layer (Deletic *et al.*, 2014). Figure 2.5 below show a typical biofilter system. According to Deletic *et al.*, (2014), this system can provide treatment through a combination of physical (sedimentation, mechanical of straining), chemical (sorption, precipitation, redox reactions) and biological (plant and microbial uptake, microbial respiration) process as the water flows through dense vegetation and temporarily ponds on the surface before filtering through media.

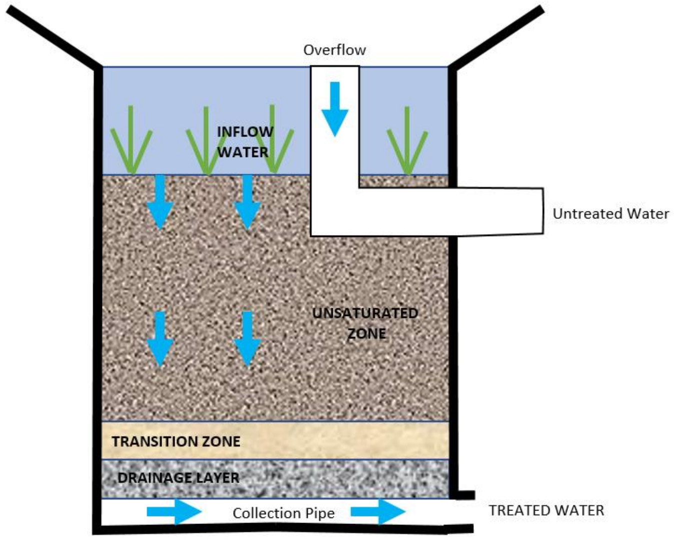

Figure 2.5: Biofilter system

Guerdat *et al.* (2013) also had reported that geotextile bag system is an efficient method to capture solid waste from the recirculating aquaculture system. The system constructed to treat solid aquaculture waste from fish species and it was designed to eliminate discharges to the environment and the need for solid waste disposal (Boxman *et al.*, 2015). Pederson and Adams (2005) mentioned that geotextile bags are filled with dredge material that offer the advantage of ease of placement and constructability, cost effectiveness, minimal impact on the environment and confident in containment. In addition to filling with sandy materials, the geotextile bags also filled with fined-grained maintenance dredge material. From their study, they concluded that the geotextile bags are capable of filtering the contaminants so that the effluent water passing through the fabrics will meet the desirable water quality.

2.4.1 PHYSICAL TREATMENT

Physical water treatment typically consists of filtration techniques that involve the use of screens, sand filtration or cross flow filtration membranes. Solids are usually removed using physical process, including sand and mechanical filters (Lin *et al.*, 2005). Solids characteristics of aquaculture effluent do vary substantially depending on culture techniques adopted and also over the culture period (Steicke *et al.*, 2007). Total Suspended Solids (TSS) generation in a Recirculating Aquaculture System (RSA) generally depends on the many physical and biological factors involved. This includes temperature, fish species and size and filtration components and efficiencies.

Baird *et al.*, (1996) indicated that solid loads in an aquaculture system generally range from 5 to 50 ppm. However, this range may be considered relatively low to compared to other industries such as municipal waste water treatment (Droste, 1997). According to Bergheim and Cripps, (1998), the treatment efficiency of aquaculture waste increased with higher TSS concentration, illustrating the fact that aquaculture waste is more difficult to treat compared to other industries due to often relatively low concentration of solids (Cripps, 2000).

It has been acknowledged that 90% of the total weight of solids in a RAS are below than 35μm (Chen *et al.*, 1993). Therefore, the use of sedimentation and screening filters to remove small particles size can be impractical. Due to the ability to remove solid particles >20μm, sand filters are classified as excellent filters. However, these filters are not employed in RAS unless in exceptional situations where TSS concentrations are expected to be very low (Timmons *et al*, 2002).

According to Malone and Beecher, (2000), the use of floating granular media as a filter medium has gained substantial interest as an alternative that can overcome the downfalls of sand as the media while producing a similar filtration efficiency. Research has been focusing on the potential of dual processing within floating medium filters whereby physical removal of solids and the conversion of total ammonia nitrogen can be achieved (Golz *et al.*, 1999). However, these filters require extensive maintenance and management regimes to maintain a balanced process throughout the culture duration (Malone and Beecher, 2000).

2.4.2 CHEMICAL TREATMENT

Basically, the chemical treatment is carried out to remove the heavy metal from the waste water. According to Wang and Ping, (2016), with the rapid development of industry in this recent years, the heavy metal in all walks of life is widely used. So, this matter will contribute in pollution especially in water pollution which is near the coast and river. The concentration of mercury, lead, chromium, cadmium, zinc, iron, nickel, germanium, manganese and other ion metal ions. These heavy metal have relatively strong activity of the Earth which is they will migrate among water, sediment and suspended solids and accumulate in the food chain (Wang and Ping, 2016).

The typical method used to remove these heavy metal is lime treatment plant (Dean *et al.*, 1972). The basic mechanism of removing heavy metals in waste water is by using coagulation and flocculation techniques (Georgiou *et al.*, 2003). In previous study by Georgiou *et al.*, (2003), they suggested of using lime and ferrous sulphate to remove the heavy metal from textile waste water. While in aquaculture waste water treatment, two commonly used coagulation-flocculation aids which are alum and ferric chloride was conducted by Ebeling *et al.*, (2003) for the supernatant overflow from settling cones. It was used to treat the effluent from micro screen filters in an intensive recirculating aquaculture system.

In other study by Ebeling *et al.*, (2004), they used the alum and ferric chloride again to determine the optimum conditions for treating the backwash effluent from micro screen filters in an intensive recirculating aquaculture system. In their study did mentioned that the orthophosphate removal efficiency was achieved greater than 90% by using alum and ferric chloride as coagulant at a dosage of 60 mg/L. The optimum turbidity suspended solid removals also achieved with the same value of dosage for both coagulants.

However, recently, the used of alum and ferric chloride as the coagulants in water treatment has been replaced by the high molecular weight long-chain polymers for flocculation of suspended solids. According to Ebeling *et al.,* (2005), apart from lower dosage requirements in treating the waste water and could reduce sludge production, polymers are also easier to storage and mixing with no pH adjustment required. Other than that, both the molecular weight and charge densities can be optimized creating ‘designer flocculant aids’ which is it can directly improve the floc resistance to shear forces.

Polymers or polyelectrolytes consists of simple monomers that are polymerized into high molecular weight substances (Tchobanoglous *et al.*, 2003). Polymers can vary in molecular weight, structure (linear versus branched), amount of charge, charge type and composition. The intensity of the charge depends upon degree of ionization of the functional groups, the degree of copolymerization and/or the amount of substituted groups in the polymer structure (Tarleton and Wakeman, 1998). The effectiveness of high molecular weight long-chain polymer treatment of aquaculture wastewater depends on the efficiency of each stage of the process such as coagulation, flocculation and solids separation. According to Ebeling *et al.,* (2005), the process efficiency can depend on polymer concentration, polymer charge (anionic, cationic and non-ionic), polymer molecular weight and charge density and discharge water treatment levels that required. Apart from that, the efficiency also depends on the raw waste water characteristics such as particle size, concentration, temperature, hardness and pH and physical parameters of the process, for instance the dosage, mixing energy, flocculation energy and duration.

In previous study by Ebeling *et al.*, (2003), coagulation and flocculation have been used to increase the effectiveness of removing phosphorus from the culture tanks. A classical coagulation and flocculation unit process consist of three steps (Figure 2.6) which are rapid mixing, slow mixing and sedimentation.

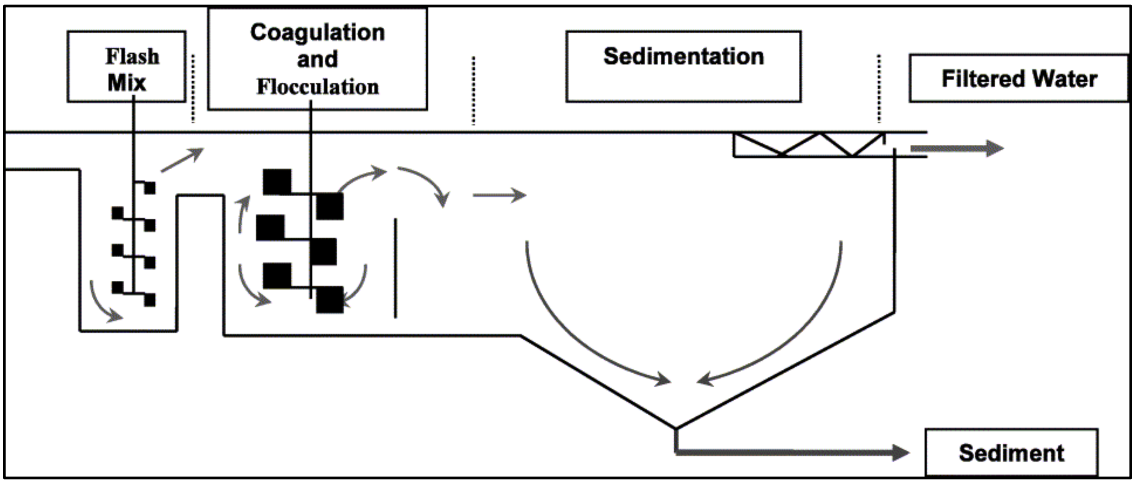

Figure 2.6 : The coagulation/flocculation unit process

In rapid or flash mixing process, the suitable chemical such as alum and ferric chloride are added to the wastewater stream, which is stirred and intensively mixed at high speed. Next, the slow mixing is including the coagulation and flocculation process. The wastewater is only moderately stirred in order to form large flocs which are easily settled out. Lastly, the flocs will move to the sedimentation tanks together with the stream. The flocs formed is allowed to settle out and is separated from the effluent stream and pump back to the culture tanks. However, Mc *et al.*, (2017) had been carried out the comparative assessment of the performance of alum and ferrous sulphate as coagulants in water treatment. According to the study, it was recorded that ferrous sulphate at dosage of 10 g successively removed as high as 91.11% of P and 98% of TSS while, alum was removed 80% of P and 85% of TSS at the same dosage. Therefore, they suggested that ferrous sulphate is more efficient in suspended solids and phosphorus removal compared to alum.

2.4.3 BIOLOGICAL TREATMENT

Biological treatment is the secondary treatment of water using a variety of microorganisms, primarily bacteria. There are three methods typically used by the farmers in aquaculture industries including by using filter feeder, by using water plants and by using both filter feeder and water plants (Devi and Gowri, 2007).

The use of the filter feeding silver carp, *Hypopthalmichthys molitrix* (Val.), as a biomanipulation tool to reduce phytoplankton biomass in a aquaculture pond remains controversial (Collins and Wahl, 2017). Filter-feeding bivalves such as oyster and mussles, have strong water-filtration ability. They are able to filter a large number of fine particulate matters including phytoplaktons, zooplanktons, and microorganism such as bacteria (Stabili *et al.*, 2005). All of the economically important bivalve mollusks derive most of their nutritional needs from filtering particles from the water. These filtered particles include suspended silt and clay particles, phytoplankton and detritus particles. This bivalves can actively sort particles according to nutritional value and they ingest the food particles and release the rejected particles as mucous-coated masses called pseudofeces that are deposited to the seabed (Radke and Kahl, 2002).

Van Rijn (1996) also had mentioned on the most common water purification treatments in intensive recirculation system. Three types of treatments can be distinguished: water treatment by earthen ponds or reservoirs, nitrification and solids removal and macrophytes, nitrification and solids removal. However, there are some constraints of these treatments. Treatment by earthen ponds is simple with low operating costs, treatment by nitrification and solids removal is relatively stable, while treatment by plants or macroalgae and solids removal results in an extra crop in addition to the fish. However, compared with earthen pond treatment system, the nitrification and solids removal and macrophytes treatments system only achieve partial purification (Van Rijn, 1996).

2.5 WASTEWATER RECOVERY AND REUSE FROM AQUACULTURE FARM

According to the Food and Agriculture Organization of the United Nations, over 70% of the world seafood species are fully exploited or depleted. Traditional aquaculture practices use pond and flow-through systems which are often responsible for discharging pollutants into the environment (Kuhn, 2008). Furthermore, aquaculture feeds often contains high levels of fish protein, so the demand on wild fisheries is not completely eased. Even though this activity has these drawbacks, there is a significant practice towards sustainability. For instance, implementation of recirculating aquaculture system (RAS). This practices can maximizes the reuse of water from aquaculture which is in the same time could decrease the water demand, hence, minimizes the levels of pollutants being discharged to the environment (Kuhn, 2008).

2.5.1 RECIRCULATING AQUACULTURE SYSTEM (RAS)

Aquaculture activity is rapidly expanding and growing around the world. The majority of aquaculture operations employ flow through systems whereby residual feed and metabolic products are discharged together to a nearby water body such as rivers