

# Bio-Filtration Technologies for Filtering Ammonia in Fish Tank Effluent for Reuse—A Review

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**Abstract:** Peri-urban fish farms with limited access to open natural water bodies draw fresh water from urban water supply and dug wells, which is unreliable and costly. Reuse of fish pond effluent is also limited by high ammonia concentration ( $> 0.3$  mg/L) that renders water toxic and is stressful to fish. Despite the existence of several fish effluent treatment methods, not all may be appropriate for a particular location. This review article therefore examines the various fish effluent treatment methods to aid selection of the most suitable one(s) for peri-urban areas. The key parameters considered in their comparison were: initial, operational and maintenance costs; ammonia removal efficiency; energy consumption and land requirement. The effluent treatment methods are both conventional and non-conventional. Despite a slight higher treatment efficiency and less space requirement by conventional methods, they mainly require reliable power supply for continuous running, highly skilled labor for operation and maintenance leading to high operational costs. In addition, their investment costs are higher than non-conventional methods, hence not widely applied in developing countries and majority have broken down. On the other hand, non-conventional methods such as constructed wetlands are widely in use for treating effluent mainly due to their cost effectiveness and no or little energy requirement. Constructed wetlands were found most suitable bio-filtration system for treating fish effluent because they are cost effective, require less skilled labor and still have better effluent treatment though space required is slightly more. Vegetables (lettuce, collards, etc.) have potential to grow in constructed wetlands thus form vegetable-based bio-filtration units which serve not only as bio-filters but also provide additional sources of nutrition and income. This review indicated limited information on the appropriate size and performance of vegetable-based bio-filtration unit utilizing indigenous vegetables and recommended further research to explore the idea.

**Key words:** Ammonia, peri-urban fish farming, bio-filtration, fish tank effluent.

## 1. Introduction

Globally, the scarcity of fresh water has contributed to increase in reuse of treated wastewater in agriculture over the last few decades [1, 2]. Wastewater is contaminated water having poor quality due to the presence of foreign matter (organic matter, ammonia, phosphorus, heavy metals, dissolved salts etc.) rendering it unsafe for reuse. Rapid global

expansion of fish farming due to high demand for fish has prompted the need for techniques for sustainable fish tank effluent management [3]. Fish effluent is poor quality water from fish farm mainly polluted with ammonia, phosphorus and solid matter which becomes unsafe (toxic) for fish. Ammonia is the major toxic pollutant in fish tank effluent [3]. Therefore, open disposal of such highly ammonia polluted fish effluent not only results into environmental pollution, but also restricts the availability and sustainable management of water for fish farming [4-6]. According to Omitoyin, et al. [6] sustainable water

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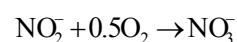
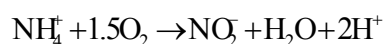
management in fish farming could be achieved using technologies coupled with bio-filtration systems (biological processes) for effective fish effluent treatment. Bio-filtration systems are natural or artificial systems that make use of several microorganisms: bacteria, fungi, algae and green plants to treat fish effluent [6, 7]. The treatment process involves degradation of organic wastes into less toxic and harmless oxidized products [8]. Bio-filtration technologies are less costly and ecofriendly as compared to non-biological methods [9]. A study done by Tanyi [10] revealed that sludge produced by chemical method ( $\text{FeCl}_3$  &  $\text{FeCl}_4^-$ ) is 25% more as compared to bio-filtration method in removing phosphorus resulting into saving in sludge disposal. According to Dehghanzadeh, et al. [11], increased costs for chemicals and harsh hazardous waste disposal have provided necessary incentives for bio-filtration system.

Access to fresh water in peri-urban fish farming from urban water supply and dug wells is unreliable and costly. Also the reuse of fish farm effluent is limited by high concentration of ammonia ( $> 0.3$  mg/L) that renders water toxic to fish, brings less appetite for feeds and later contributes to fish mortality [12]. The objective of this review was to examine various existing bio-filtration methods of treating fish effluent to aid selection of most suitable method for peri-urban areas. The methods were examined to create basis for taking decision for research and development in treating fish tank effluent. The examination was done with the view of evaluating strength and weaknesses of the methods, lessons learned and future directions for treating fish tank effluent using bio-filtration system.

## 2. The Concept of Bio-Filtration in Treating Aquaculture Effluent

Bio-filtration system incorporates nitrifying bacteria or both bacteria and green leafy plants for fish effluent treatment [13]. The process occurs in two

phases; ammonia is oxidized first to nitrite which is toxic, and then to nitrate, which is relatively non-toxic [14]. The green leafy plants then absorb nitrate for vegetative growth. Two groups of naturally occurring bacteria (*Nitrosomonas* and *Nitrobacter*) mediate this two-step process [14]. The system requires solid porous media (gravel) to provide surface area for bacterial loading. The overall equations for these two reactions are represented as follows:



## 3. Overview of Bio-Filtration Systems for Treating Fish Tank Effluent

Methods incorporating bio-filtration system for fish effluent treatment are categorized into two, conventional and non-conventional methods. Conventional methods (activated sludge, trickling filters, rotating biological contactors, nutrient film technique and drip system recovery) require continuous energy supply to drive effluent pump and aerator during treatment process [15]. The pump creates pressure difference to move effluent from one point to another in the treatment system while aerator increases dissolved oxygen level for effective nitrification in the effluent. According to Lee, et al. [16] non-conventional method constructed wetland where effluent flow is controlled by gravity, no or little external energy is required for supplementary aeration and hence less operational and maintenance costs.

### 3.1 Activated Sludge Bio-Filter

The constructional design of activated sludge (Fig. 1) comprises aeration and settling tanks with accessories such as return pipe, wastewater pumps, mixers, blowers for aeration and a flow measurement device. It uses the principle of intense effluent aeration to form flocks of bacteria called activated sludge [17]. The concentration of active bacteria in the tank is

maintained by recycling part of it. Primary effluent is mixed with returned activated sludge to form mixed liquor which is aerated for a specified length of time. Aeration enables activated sludge organisms to use the available organic matter as food, thereby producing stable solids and more organisms [17]. The organic matter is later on degraded and separated by sedimentation in the settling tank. The SS (Suspended Solid) is produced and the additional organisms become part of the activated sludge.

Although this system requires less space and has high effluent quality, it is much costly to operate because it requires skilled labor for operation and maintenance, energy is needed to run pumps and aerators [18]. Many of these facilities have been installed by large hotels [18, 19] for treatment of

industrial and domestic wastewater.

### 3.2 Trickling Filters

Trickling filter has a basic concept of providing surface area on which microbial films (aerobic, anaerobic, fungi, algae and protozoa), responsible for treatment, grow [20] (Fig. 2).

It is made up of a round tank filled with filter media (volcanic rock, gravel or synthetic material). Effluent is supplied from above and trickles through the media allowing organic material to be adsorbed by microbial film or slime layer (approximately 0.1 to 0.2 mm thick) attached to the medium. Degradation of organic material by the aerobic microbial occurs in the outer part of the slime layer [21]. As the layer thickens through microbial growth, oxygen cannot penetrate

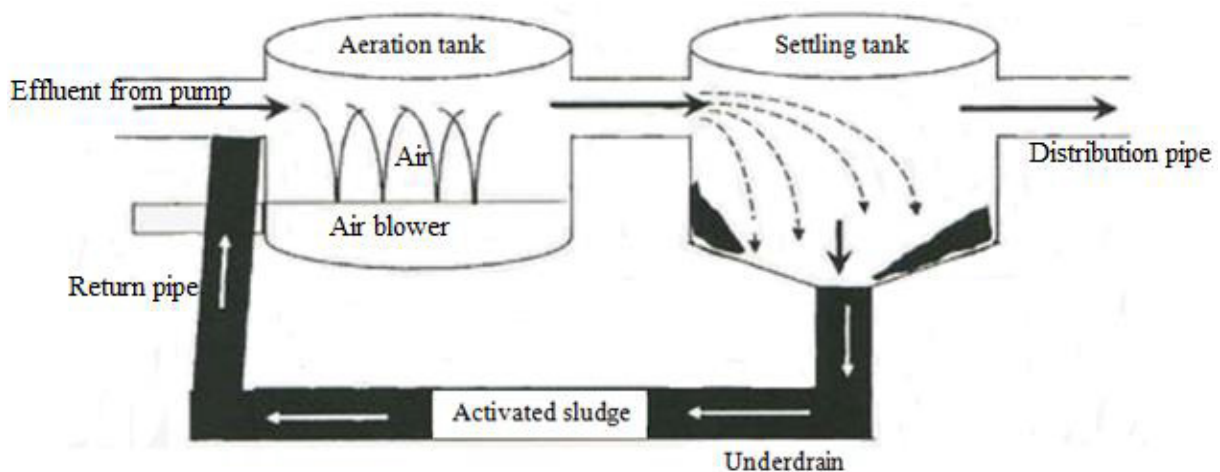


Fig. 1 Activated sludge system, source [46].

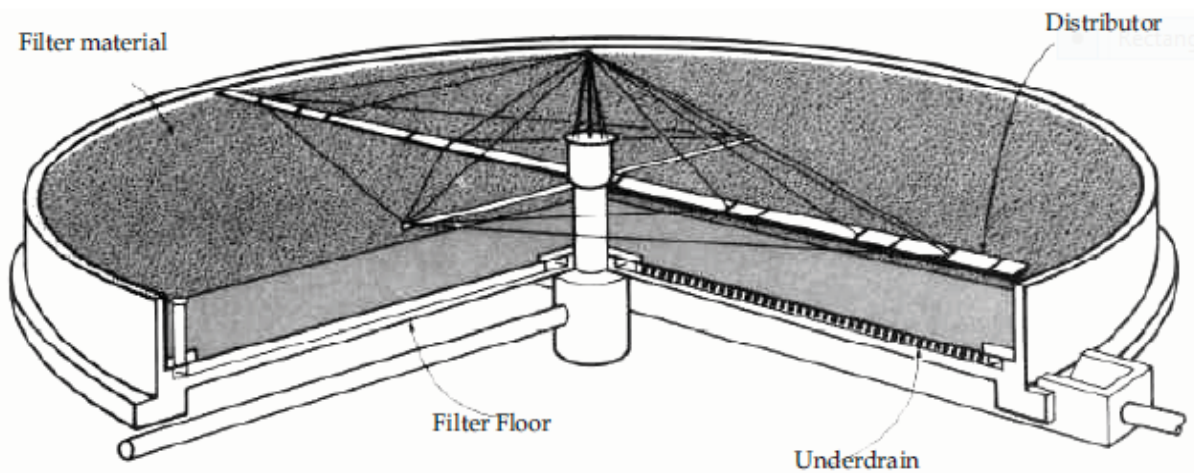


Fig. 2 Cross section of a trickling bio-filter, source [46].

the layer and anaerobic organisms develop. The microbial film continues to grow until microorganisms near the surface cannot cling to the medium and a portion of the slime layer falls off the filter. This process is known as sloughing. The sloughed solids are picked up by the under drain system and transported to a clarifier for removal from the wastewater. Trickling filters are efficient in effluent quality in terms of BOD (Biochemical Oxygen Demand), SS removal is high and has potential to impede odor and filter flies [20]. However, operation and maintenance costs are high due to continuous use of electrical energy for pumping effluent and skilled labor. This method has been widely used for treatment of industrial wastewater [15].

### 3.3 Rotating Biological Contactors

Rotating biological contactors (Fig. 3) consist of two vertically arranged plastic cylinders on a horizontal rotating shaft.

The biomass-coated media are alternately exposed to wastewater and atmospheric oxygen as the shaft slowly rotates [22]. This provides hydraulic shear for sloughing and to maintain turbulence to keep solid in suspension with about 40% of the media submerged [23]. High surface area allows a large stable biomass population to develop, with excess growth continuously and automatically shed and removed in a

downstream clarifier [24]. Although it offers better effluent quality, it requires energy for continuous pumping, moderately skilled labor for operation and maintenance, however, requires intensive capital for installation and is sensitive to temperature.

### 3.4 Nutrient Film Technique

Nutrient film technique (Fig. 4.) is a treatment system in which a thin film of fish effluent is continuously pumped and flows through plastic channels/tubes containing the plant roots. The bottom of the roots is exposed to the nutrient solution while the top parts are kept moist but not waterlogged [25]. The channels are continuously fed with effluent at a rate of about 1 L/min. The plants in the growing tubes are typically suspended above the effluent by placing seedlings in starter cubes (perforated plastic baskets). The starter tubes are then placed in small holes in the top of the tubes. The roots hang downwards to the bottom of the tube where they get nutrients from the shallow film of effluent flowing through [26]. At the lower end of each channel, the excess nutrient solution drains into another channel and conveys back to the reservoir where it is re-circulated in the system [27].

A separate bio-filter is required to provide sufficient surface area for bacterial loading. The system has better effluent quality since effluent is recirculated several times within the system to achieve high

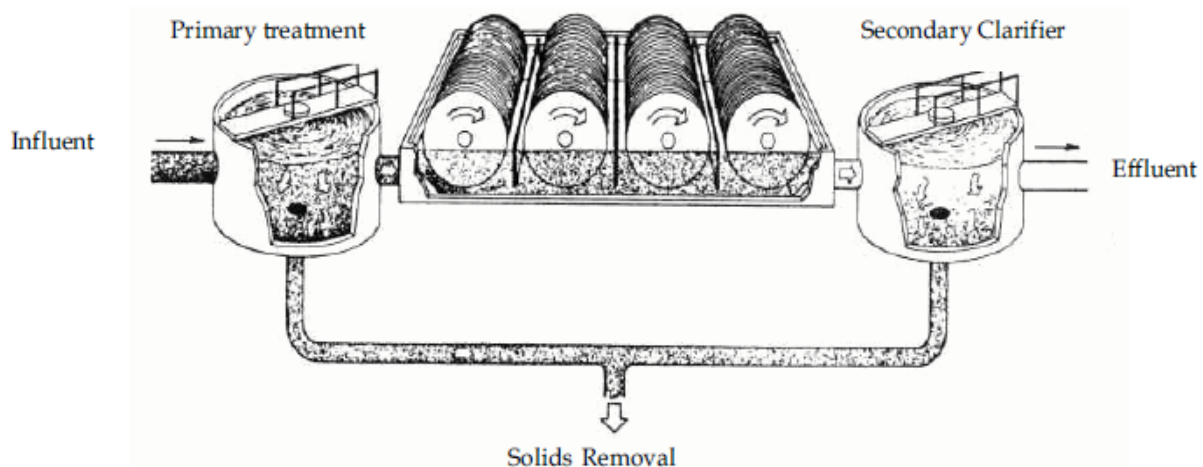


Fig. 3 Rotating biological contactors, source [46].

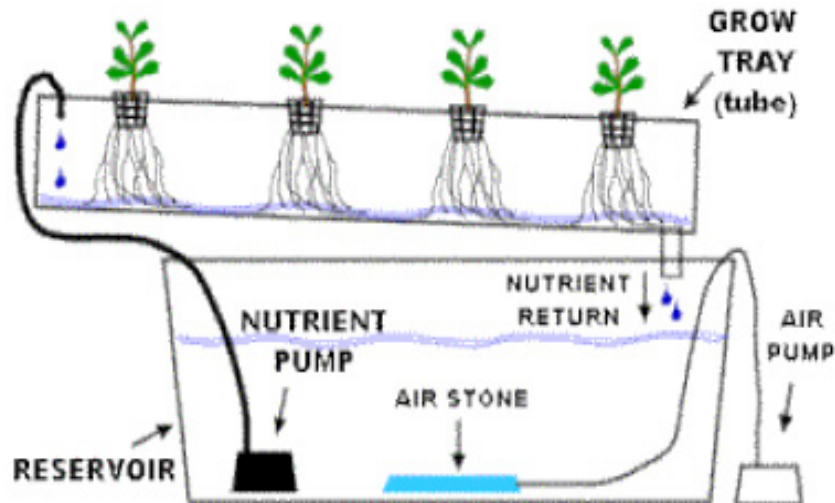


Fig. 4 Nutrient film technique. Source: <http://www.simplyhydro.com>.

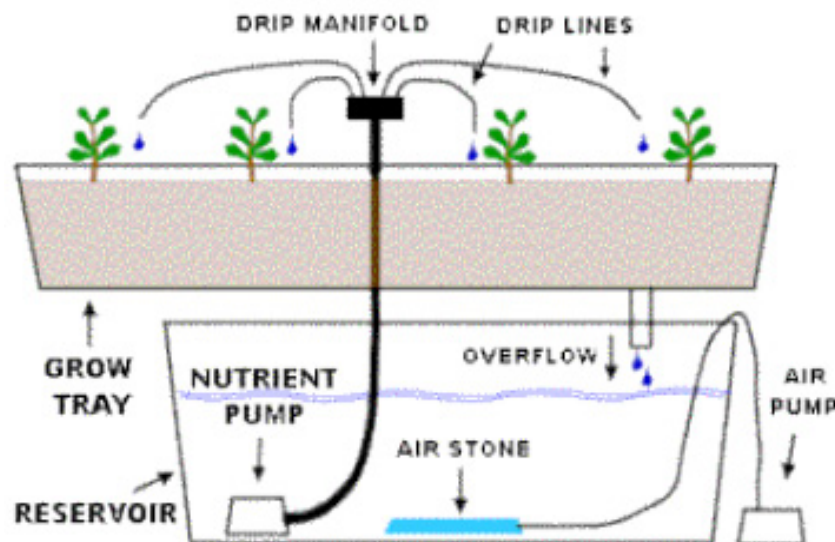


Fig. 5 Drip systems recovery. Source: <http://www.simplyhydro.com>.

treatment efficiency before it is conveyed for reuse [28]. Despite better effluent quality, it has relatively high construction, operation and maintenance costs, and requires skilled labor and constant energy supply for operation.

### 3.5 Drip Systems Recovery

Drip system recovery (Fig. 5) is one of the most widely used types of aquaponics system in the developed world. It consists of a timer that controls a submersed pump. The timer turns the pump on and effluent is dripped at the base of the plants through small drip lines [29]. The effluent that has passed

through the solid media is collected back in the reservoir for recirculation. The non-recovery system does not collect the effluent back in the reservoir, instead it is directed for reuse. A recovery system provides better effluent quality since the treatment process involves recirculating effluent several times before directed for reuse. However, it requires energy for continuous pumping, intensive capital for installation, skilled labor for operation and maintenance.

### 3.6 Constructed Wetlands

Constructed wetlands are wastewater treatment technology incorporating green wetland plants and

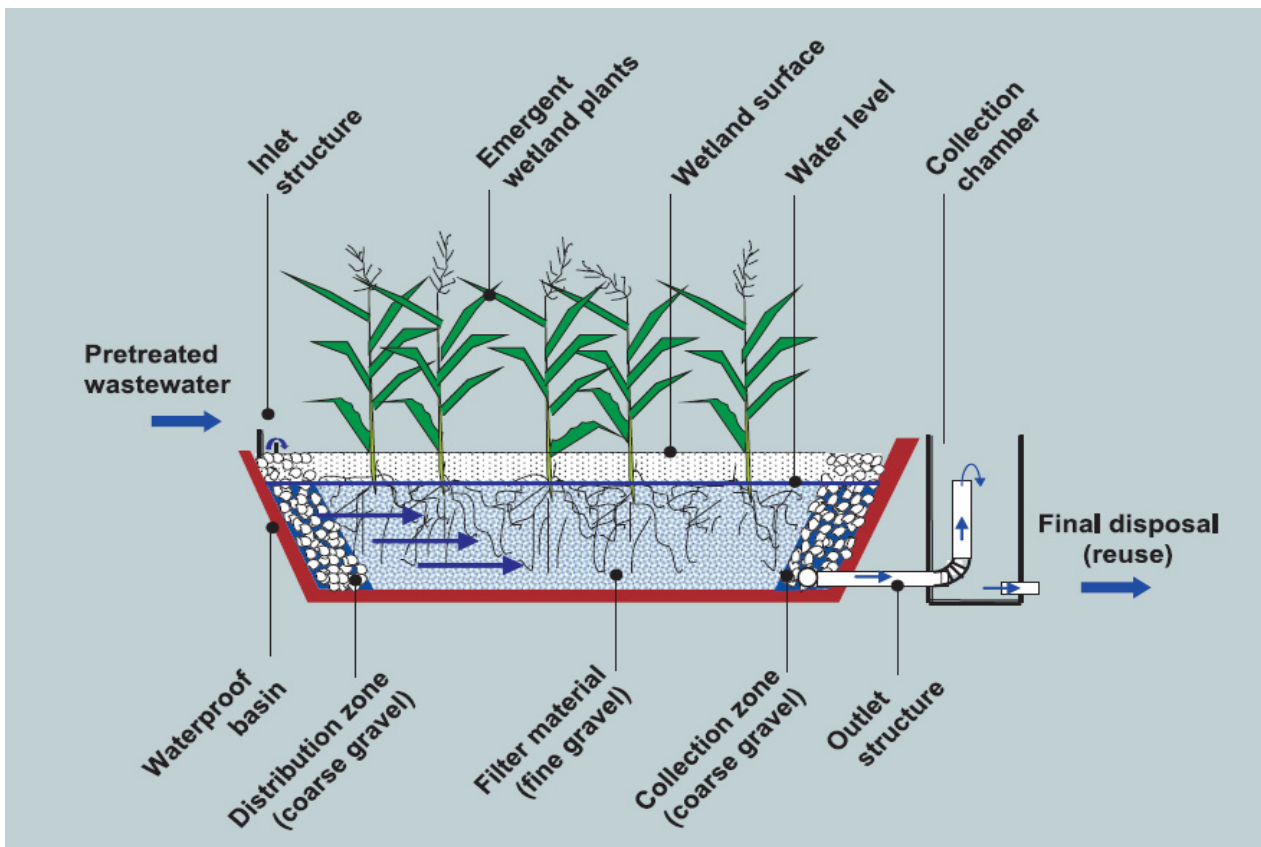


Fig. 6 Profile of sub-surface flow constructed wetland [35].

bacteria. They are made of excavated ponds lined with impermeable material and filled with solid porous media (gravel/sand) [30]. The media provides surface area for bacterial loading and supports plant roots [31]. Wetlands are known to offer a suitable combination of physical and biological factors for the removal of pathogenic organisms, organic matter, ammonia, SS etc. [32]. The wastewater flows through the porous media in which the plants are rooted. The flow of wastewater through the system is by gravity without using any external source of energy. The flow may be vertically or horizontally depending on the design [33]. They are eco-friendly and suitable for the removal of organic materials, SS, nutrients, pathogens, heavy metals and toxic pollutants [34]. Two categories of constructed wetlands exist depending on the hydraulic water flow characteristics in the system: free water surface and subsurface flow systems. In free water surface, wastewater flows above the media bed and is

suitable for treating secondary and tertiary effluents while providing habitat to aerobic microbial. While in subsurface flow systems, wastewater flows through the porous media without any contact with atmosphere (Fig. 6) [16]. It is anaerobic as oxygen supplied by the roots of plants is used up in biofilm growth.

Wetlands plants in constructed wetlands including cattails, bulrush, duckweed, water hyacinth, water lettuce, reed, have been widely used in the wetlands [36]. They are relatively cheaper to construct, operate and easy to maintain [35].

#### 4. Criteria for Selecting Most Suitable Bio-Filtration Method

The selection of the suitable method was based on comparing various bio-filtration methods against four main parameters: initial, operational and maintenance costs; waste removal efficiency; energy consumption and land requirement.

Constructed wetland has less initial and operational costs than conventional methods. Although constructed wetland requires slightly wider space, has higher removal efficiency for suspended solids. Another added advantage is that green plants in constructed wetland do remove heavy metals from the effluent [16, 37]. A study by [16] on comparison of costs and removal efficiency of constructed wetland with conventional wastewater treatment plant having the same treatment capacity is shown in Table 1.

Further more conventional methods (activated sludge, trickling filter and rotating biological contactors) exhibit higher total capital, operational and maintenance costs than non-conventional methods (constructed wetland and aerated lagoons) [38]. Although aerated lagoon is less costly than constructed wetland, it requires wider space for establishment [39]. In peri-urban areas, land is a scarce

resource and therefore aerated lagoons are not suitable. A study by [38] on capital, operational and maintenance costs of various effluent treatment methods for a population of 1,000 people in France in 1997 are shown in Table 2

Activated sludge requires maximum energy consumption while aerated lagoons require minimum energy requirement [38]. According to Phuntsho, et al. [40] energy consumption by conventional methods is higher than that for non-conventional. However, according to Gauss [35], effluent flow in constructed wetland is controlled by gravity, also the dissolved oxygen used for nitrification is supplied by macrophytes (wetland plants) [37], hence little energy is required for supplementary aeration. A study by [38] on typical electrical energy requirements for activated sludge, aerated lagoons and rotating biological contactors of same capacity (3,780 m<sup>3</sup> per day) are indicated in Table 3.

**Table 1 Comparison of costs and removal efficiency of constructed wetlands with conventional wastewater treatment plant.**

| Type of treatment system | Treatment capacity      | Economic considerations |                         |                               | Removal efficiency, % |       |                      |
|--------------------------|-------------------------|-------------------------|-------------------------|-------------------------------|-----------------------|-------|----------------------|
|                          |                         | Initial cost, \$        | Operation cost, \$/year | Facility size, m <sup>3</sup> | BOD                   | SS    | Remarks              |
| Constructed wetland      | 100 m <sup>3</sup> /day | 220,000                 | 300                     | 800                           | 80-90                 | 80-90 | Removes heavy metals |
| Conventional Plant       | 100 m <sup>3</sup> /day | 300,000                 | 2,000                   | 450                           | 80-99                 | 70-80 |                      |

Source: Ref. [16].

**Table 2 Capital, operational and maintenance costs of various effluent treatment methods for a population of 1,000 people in France in 1997.**

| Treatment methods              | Capital costs (ecu) per person | Operation & maintenance costs (ecu) per person per year | Total cost for 1,000 people (ecu) |
|--------------------------------|--------------------------------|---|-----------------------------------|
| Activated sludge               | 230                            | 11.50   | 241,500                           |
| Trickling filter               | 180                            | 7.00  | 187,000                           |
| Rotating biological contactors | 220                            | 7.00  | 227,000                           |
| Aerated lagoon                 | 130                            | 6.50  | 136,500                           |
| Constructed wetland            | 190                            | 5.50  | 195,500                           |

Average exchange rate in 1997: 1 ecu = £0.69 (www.oanda.com/convert/fxhistory).

Source: Ref. [38].

**Table 3 Typical electrical energy requirements of various effluent treatment methods of capacity 3,780 m<sup>3</sup> per day.**

| Treatment process              | Electrical energy usage (kWh/year) |
|--------------------------------|------------------------------------|
| Activated sludge               | 1,000,000                          |
| Aerated lagoons                | 800,000                            |
| Rotating biological contactors | 120,000                            |

Source: Ref. [38].

Constructed wetland is therefore selected as the most suitable bio-filtration method for treating fish effluent in peri-urban areas of developing countries based on the criteria described above.

## 5. Lesson Learned in Fish Effluent Treatment Using Bio-Filtration Systems

Though conventional treatment methods have higher treatment efficiency (effluent quality) than non-conventional, they are not widely used in developing countries. Most of them have broken down due to: unreliable power supply for continuous operation; high initial and maintenance costs; high skilled labor for operation and maintenance [41].

Due to low construction, operation and maintenance costs, constructed wetlands are more widely applied for treating various categories of wastewater than conventional treatment methods.

Treated effluents from activated sludge, trickling filters, rotating biological contactors and aerated lagoons are mainly reused for irrigation but less in fish farms due to presence of nitrate which is toxic to fish at relatively high concentration ( $> 200$  mg/L) [12, 29]. While effluent from constructed wetlands was treated, nutrient film technique and drip system recovery are mainly reused in fish farms.

Proper design and construction procedures coupled with proper operation and maintenance by skilled personnel give rise to the success of bio-filtration systems. Constructed wetlands are cost-effective alternatives for treating wastewater [42], they are low energy-consuming ecosystems that need only sunlight energy for effective operation

## 6. Future Direction in Bio-Filtration Systems for Fish Effluent Treatment

In developed countries, research has proved that green vegetables with fibrous root systems (lettuce, romaine, collards etc.) have potential to grow in constructed wetlands and are efficient in absorbing nutrient from fish effluent [43]. This is termed as

vegetable-based constructed wetland or vegetable-based bio-filtration system. Comparative studies by Shahmansoury, et al. [44] and Sakuma, et al. [45] reported that up to 99.9% and 100% ammonia removal efficiencies were achieved in bio-filtration systems. However, such systems have not been fully explored in developing countries using indigenous green leafy vegetables. This is due to limited information on appropriate size and performance of the system. Such systems could be a cheap option for reducing concentration of toxic ammonia in fish farm effluent. This is through oxidation of ammonia to nitrate by microbial film and absorption of nitrogen in nitrate form by green leafy vegetables. Fish effluent is rich in plant nutrients which are highly required by green leafy vegetables. Successful establishment of vegetable-based bio-filtration system for treating fish farm effluent would increase water availability and reduce environmental pollution by open disposal of fish farm effluent. The vegetables grown in the bio-filter would provide an additional source of food/income for the fish farmer. Currently there is no available information on the biomass of vegetables to remove a unit of ammonia in fish farm effluent except the ammonia removal efficiency.

## 7. Recommendations

Majority of conventional methods of effluent treatment in developing countries have broken down due to high operational and maintenance costs as well as continuous energy demand for effective operation. It is therefore recommended that methods such as constructed wetland with no or little energy demand and less operational and maintenance costs are appropriate option for effluent treatment in developing countries, most specifically in peri-urban areas where income levels are very low.

Further, research is needed to explore the use of constructed wetlands using indigenous green leafy vegetables in order to obtain available information on appropriate size and performance on vegetable-based



bio-filtration for peri-urban areas. However, the vegetables will need to be tested for the presence of common toxic metals before they are recommended to be safe for human consumption.

## Acknowledgement

The authors appreciate the financial support from Marketplace Agricultural Innovation Brazil which facilitated smooth implementation of the research Project ID 411.

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