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RESEARCH ARTICLE

Study of Nitrification Process in a Media Raised Bed Based Aquaponic System

Haniif Prasetiawan[1]*, Aulia Mukadis[1], Afrissa Viola Motti[1], Nurhayati[1], Budi Setiawan[1]

[1)]Chemical Engineering Department, Universitas Negeri Semarang, Gd E1 lt. 2 UNNES Sekaran Campus, 50229 Gunungpati, Semarang, Indonesia

(**[*]Corresponding author's e-mail:** haniif.prasetiawan@mail.unnes.ac.id)

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Abstract

Aquaponics is an integrated and sustainable farming method that combines aquaculture and hydroponics in a recirculating water system. This system utilizes fish waste as a nutrient source for plants, and the plants act as biofilters to clean the water before it returns to the fish tank. A critical process in this system is nitrification, where ammonia is converted into nitrite and nitrate by beneficial bacteria, reducing toxicity to fish and providing nutrients for plants. This study investigates the efficiency of the nitrification process using four different biofilter media—rockwool, pumice stone, gravel, and zeolite—in a media-raised bed aquaponic system. Results showed that pumice stone provided the highest nitrate concentration (131.62 mg/L), indicating superior nitrification performance. The findings offer valuable insights for optimizing biofilter media selection in aquaponic systems, which is crucial not only for maintaining water quality but also for enhancing crop productivity. The study contributes to the development of more efficient and sustainable aquaponic designs, particularly in regions facing water scarcity and the need for integrated food production solutions.

Keywords: aquaponic; rockwool; ammonia; nitrification

Introduction

Aquaculture production is steadily increasing each year due to the rising demand for aquaculture products driven by population growth[1]. To meet the need for protein, aquaculture, particularly in the fisheries sector, is rapidly expanding globally. Indonesia has also experienced a year-over-year rise in production. However, this continuous growth in aquaculture activities has adversely affected the environment, notably through the accumulation of aquaculture waste. This waste, which stems from the residual metabolism of fish and uneaten feed that dissolves in the water, can be harmful to fish survival[2]. Aquaculture operations produce significant amounts of organic matter and nutrients, including nitrogen, phosphorus, and other elements, which necessitate proper treatment or disposal[3]. To minimize waste in aquaculture and uphold water quality, a sufficient water supply is crucial. Unfortunately, the availability of clean water is declining[4]. Consequently, there is a pressing requirement for cost-effective and efficient technologies that can improve fish survival and growth. One solution is the aquaponic system, which primarily employs a recirculating framework.

Aquaponic is an integrated farming system between hydroponic and fish aquaculture system[5]. This system utilizes fish excretion as a nutrient for plants in hydroponic system, hydroponic component is served as a bio-filter which converts the dirty water into clean water and can be recirculated in the fish tank. Fish feed contains nitrogen which is mostly needed by plants for growing up. Most fish only need 20 – 30% of Nitrogen for their feed[6]. It means that at least 70% of Nitrogen in fish food becomes a waste. There are three types of aquaponic system, namely Media Raising Bed System (MRB), Nutrient Flow Technique (NFT) and Floating Raft System (FR)[5], [7], [8].

A biological filter (biofilter) is a crucial component of the recirculating aquaculture system, primarily focusing on removing nitrogen waste (total ammonia nitrogen/TAN, NO_2-N, and NO_3-N) and carbon dioxide (CO_2)[9]. The biofilter also serves as a planting medium where plant roots can attach. Temperature and pH influence the balance of TAN, with an increase in pH and temperature causing NH3 to become more dominant. The toxicity of NH_3 is indicated by symptoms such as hyperactivity and loss of balance. NH_3 also slows fish growth due to poor feed digestion and reduced disease resistance[10]. Several studies have successfully implemented aquaponic systems, including using tilapia[11], eggplant[12], tomatoes[11], and cucumbers[13]; using white shrimp and tomatoes[14]; using tilapia and water spinach[15]; and using tilapia and lettuce[16].

In this study, MRB system is used due to its residence time which theoretically should have a better ammonia nitrogen conversion efficiency. The plants used are Pak Choi (Brassica rapa L), while the fish used are tilapia (*Oreochromis niloticus*), which have high economic value. The aquaponic system was equipped with the solar cell to supply the energy as a support in the clean technology for environmentally friendly system. Four different bio-filter as a hydroponic medium are used in this research namely pumice stone (PS), rockwool (RW), gravel (GR) and Zeolite (ZL). Nitrate production in each bio-filter media is evaluated.

Materials and methods

MRB Aquaponic System

The Aquaponic system used in this research which contains a growing bed and fish tank is shown in Figure 1.

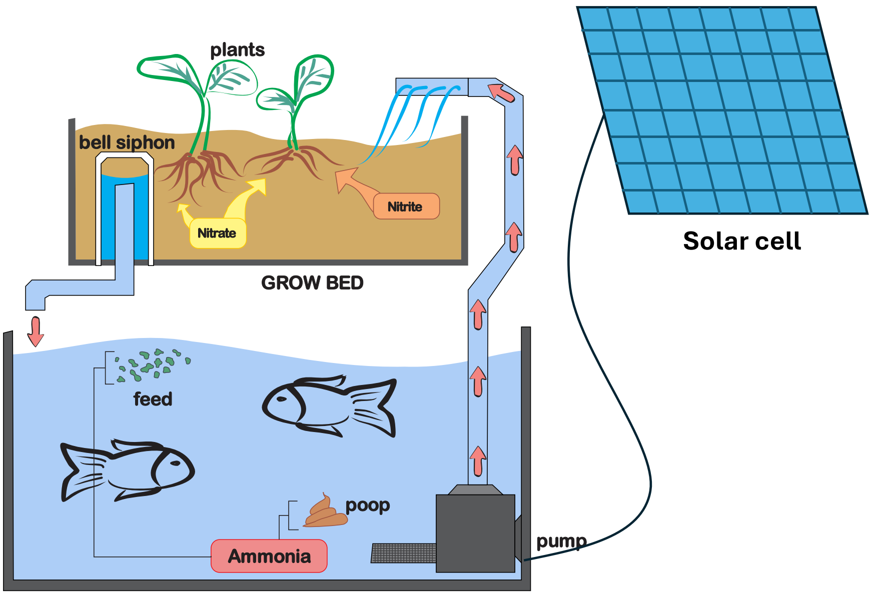

Figure 1. Schematic Representation of Aquaponic System

The media in a grow bed as shown in Figure 1 is varied using PS, RW, GR and ZL. There is also a separate fish tank which is used to observe every parameter without bio-filter as a control variable. In this study, we use *Oreochromis niloticus* for the fish in aquaculture, meanwhile we used *Brassica rapa* for the plant in the growth bed media.

Chemical Analysis

Standard methods were used to measure the temperature, pH, TDS, ammonia-nitrogen, nitrate-nitrogen and nitrite-nitrogen.

Results and discussion

The pH measurement for each bio-filter is shown in Figure 2. The pH average value of the aquaculture effluents was 8.05, 8.04, 7.96, 8.22 and 7.90 for RW, PS, GR, ZL and control variable respectively.

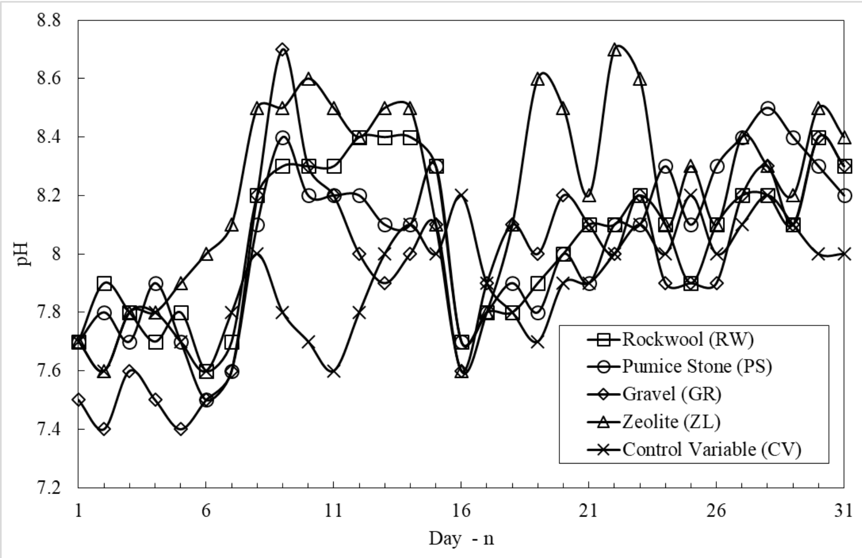

Figure 2. Variation in pH for RW, PS, GR, ZL and control variable.

Nitrification bacteria work very well at pH condition of ±7.0 if the condition drop to lower than 7 it might reduce the efficiency of nitrifying process due to the death of bacteria. It can be seen from Figure 2 that all tanks are in base condition. An aquaponic system equipped with a biofilter can convert ammonia into nitrate compounds. Ammonia is basic in nature, so the higher the ammonia concentration, the higher the pH level.

The Temperature profile of each aquaponic system is shown in Figure 3. Temperature in aquaponic system is important for the aquaculture ecosystem. From the figure, there is a temperature fluctuation in the fish tank. It is known that the temperature ranges between 21.5 – 25.5°C. This range is still inside the acceptable category for tilapia growth media, because tilapia can live optimally in the temperature range of 25-32°C [17]. Many factors affect temperature fluctuations in fish tanks, including ambient temperature and dissolved particles[18]. Quite high dissolved particles affect the absorption of sunlight. The lower the dissolved particles, the lower the water temperature. In addition, the nitrification process that runs requires a lot of energy, resulting in an increase in temperature.

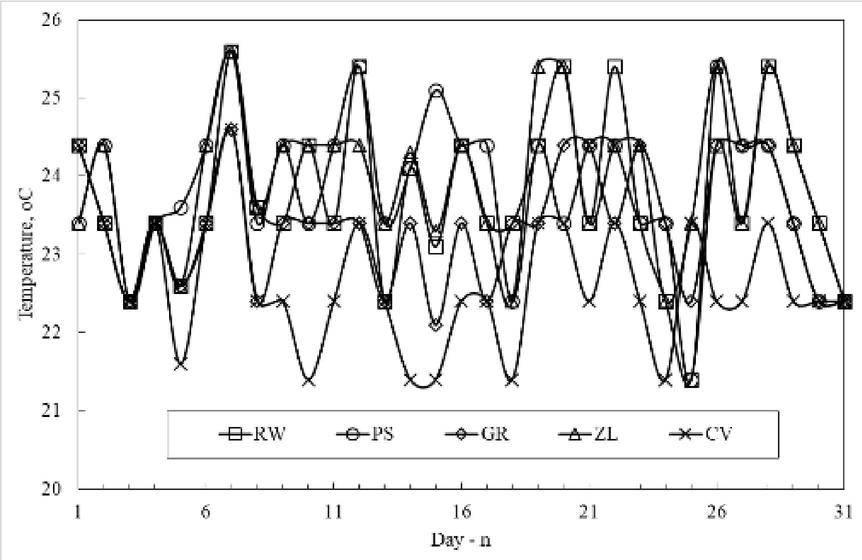

Figure 3. Variation of Temperature for RW, PS, GR, ZL and control variable.

Growth data of the plant in this research were collected every three days for 1 month. From Figure 4. The plant growth rate for bio-filter RW, PS, GR and ZL are 0.353, 0.3, 0.313 and 0.307 cm/day respectively. The plants exponentially grow for the first two week, after that the growth seems to become slower. Aquaponic plants obtain nutrients from fish feces. Fish feces contain ammonia, which is then converted by the biofilter, also acting as a bioreactor, into nitrate[19]. This nitrate is used by the plants as nutrients to support their growth. With the same treatment, hydroponic plant receives fewer natural nutrients for growth, resulting in less optimal growth. The plant growth shows a significant increase in height during the first two weeks as it is still in the germination phase. During the germination phase, height changes are more pronounced compared to plants that already have permanent organs[20].

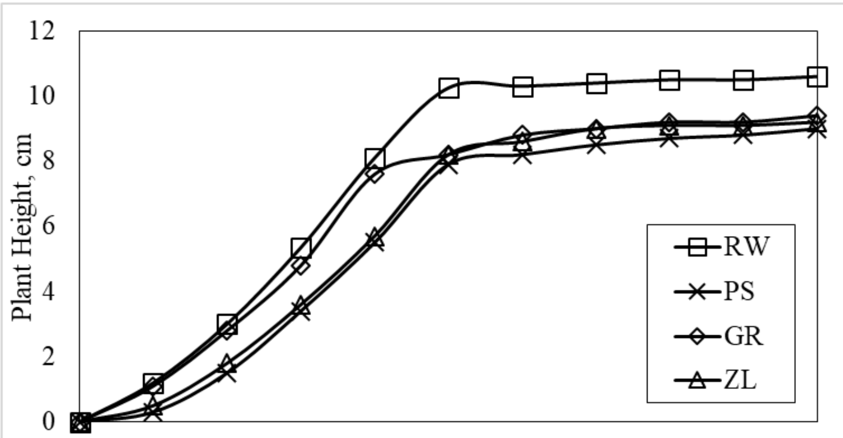

Figure 4. Plant growth in aquaponic system at different biofilter

Chemical analysis result for aquaponic system with different bio-filter is shown in Table 1. Essentially, the presence of ammonia in fishponds can be toxic and inhibit the growth of the fish themselves; the lower the ammonia level, the better for the fish's survival. The water quality standard for ammonia in fisheries is < 0.99 mg/L[21]. From the table, the ammonia level was reduced more than twice of its level. This is because the aquaponics system has a bioreactor in the form of zeolite stones that can convert ammonia into nitrate compounds. The ammonia amount in aquaponic with gravel bed is higher compared to other media. Its nitrification process into nitrite and nitrate is valuable for the plant for growing up.

Table 1: Water quality during the experiment for aquaponic system with different bio-filter.

Bio-Filter	Influent (mg/L)	Effluent (mg/L)
RW	0.65	0.389
PS	0.63	0.276
GR	0.63	0.247
ZL	0.64	0.24

Nitrite amount as a result of ammonia conversion can be seen in Figure 5. The Aquaponic system with RW as a biofilter has the lowest nitrite amount, it indicates that most of the nitrites converted from ammonia were consumed by the plants as a nutrient.

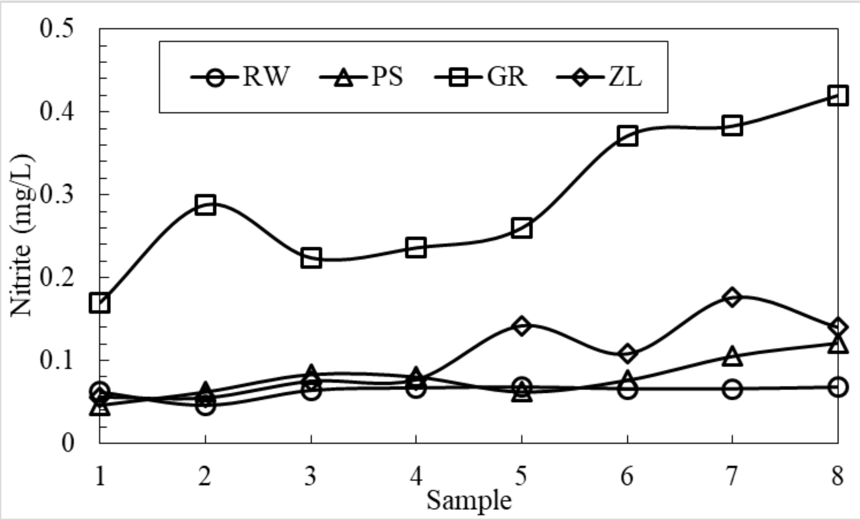

Figure 5. Nitrite Profile at different bio-filter

The aquaculture pond water samples have low nitrite levels due to the presence of a bioreactor that converts pollutants like ammonia into nitrite. The aquaponics system contains a bioreactor that houses Nitrosomonas microorganisms capable of converting ammonia into nitrite[7]. Nitrite levels in the water are influenced by several factors, including the availability of ammonia as a raw material, the number of Nitrosomonas bacteria that produce nitrite, and the number of Nitrobacter bacteria that convert nitrite into nitrate.

Conclusions

This study demonstrates that biofilter media significantly influence the efficiency of the nitrification process in media-raised bed aquaponic systems. Among the four tested media, pumice stone exhibited the highest conversion of ammonia to nitrate, which correlates with improved nutrient availability for plant growth and safer water quality for aquaculture. These results highlight the importance of media selection in optimizing the performance of integrated aquaponic systems. More broadly, the findings support the use of aquaponics as a clean and circular food production method, especially relevant for urban or water-limited regions seeking sustainable agricultural solutions. The approach not only addresses the environmental concerns of aquaculture waste but also provides a pathway to enhance food security by enabling efficient, low-waste nutrient cycling. Future studies should investigate the long-term performance of these media under varied environmental conditions and crop-fish pairings to better understand their applicability across different geographic and socioeconomic contexts.

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