Combination of Zeolite, Charcoal and Water Spinach as Integrated Filters to Reduce Ammonia Level in Aquaponic System

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Abstract

Aquaponic is a combination of aquaculture and hydroponic plants in the recirculation system. The aquaponic system has a constraint in the form of ammonia which is produced by fish metabolism. In order to increase the productivity of fish and plants in aquaponics, an approach by integrating filters and biofilter could be used to reduce ammonia waste. The aim of this research was to study the use of zeolite, charcoal, and water spinach as components of integrated filters to reduce ammonia concentration in an aquaponic system. This research was conducted for four weeks with three repetitions of water sampling sourced from pond, filters, and output. The results of this study indicated that the use of combination of zeolite, charcoal and water spinach as componentof integrated filters can reduce ammonia throughout the research period.

Keywords: aquaponic, ammonia reduction, integrated filters

Introduction

As global population continues to grow, the demand for vegetable and meat as food components will also be increased. These phenomenon requires solution for an effective and efficient cultivation system that produce more than one farming product from one effort. A system that is able to answer those challenges is aquaponic. An aquaponic is defined as combination of aquaculture and hydroponic plant cultivation in a recirculation system (Nugroho *et al.*, 2012). In this system, metabolic waste and feed residue from aquaculture are used as nutrients for plant growth (Graber and Junge, 2009; Wahyuningsih *et al.*, 2015).

Fish, as a constituent of aquaculture, produces nitrogen waste from their metabolism which contain 80-90% of ammonia and 10% of urea (Norjanna *et al.*, 2015). Ammonia content in water itself consists of ammonia (NH_3) and ionized ammonia or ammonium (NH^{4+}). These two types of ammonia are called Total Ammonia Nitrogen (TAN) (Wahyuningsih *et al.*, 2015). Plants can absorb ammonium (NH^{4+}) and nitrate (NO^{3-}) from fish metabolism as a source of nutrition with the help of nitrifying bacteria (Graber and Junge, 2009; Lund, 2014; Norjanna, *et al.*, 2015). Despite of its useful value, ammonia content can also have a negative impact on aquaponic systems. High levels of ammonia can cause death to farmed fish and cultivated plants. If released to ecosystem, ammonia can cause eutrophication and other environmental problems (Hastuti and Subandiyono, 2011; *Hu et al., 2015).* Refering to the potential problem that ammonia can bring, specific treatment to reduce ammonia level in an aquaponic system is needed.

The use of recirculation system without addition of plants is able to reduce 31-43 % of ammonia concentrations (Djokosetiyanto, *et al.*, 2006; Putra and Pamukas, 2011). Plants that are grown in aquaponic system could reduce 58% of Total Ammonia Nitrogen (TAN) (Setijaningsih, 2009), but this ability leads to plant growth decrease (Effendi, 2003). Accumulation of ammonia will further occured because the presence of plants as biofilter is not 100% effective. Therefore, it is necessary to add another component to reduce ammonia level.

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Zeolite and activated charcoal could be used as additional filters in an aquaponic system because of their ability to purify water and neutralize toxic ammonia compounds (Widayat, *et al.*, 2010). It is expected that the addition of a filter in the aquaponics system can reduce and maintain ammonia level below 0.8 ppm as standard threshold (Anonim, 2005). The aim of this research was to study the application integrated filters that consist of zeolite, charcoal and water spinach to reduce ammonia level in aquaponic systems. Zeolite and charcoal were used as representation of common water filters, while water spinach represented biofilter.

Materials and Methods

Location and Time of Research

The research was conducted in Kratonan, Serengan, Surakarta, from January to April 2020. Water sampling for analysis of water quality (temperature, TDS, pH and DO), fish and plant growth measurements were carried out in situ. Total ammonia content was analyzed in labolatories of Balai Besar Teknik Kesehatan Lingkungan dan Pencegahan Penyakit (BBTKLPP) Yogyakarta.

Materials

Main equipment used in this experiment is fish pond (Figure 1) that is constructed from several materials such as tarp, water pumps, aerator, PVC pipes, PVC pipe connectors, drum, rockwools, net pots, fresh water and inoculum of nitrifying bacteria. Catfish *(Clarias gariepinus)* was employed as fish component in this aquaponic. Each of 500 individual catfish has initial body length of 17-18 cm. Catfish were feeded with Hi-Pro-Vite 781-2. Plant component that was used in this system was water spinach (*Ipomoea aquatica* Forsk). Water spinach also served as biofilter in aquaponic system. Materials for filters in this system consist of zeolite and charcoal. For measuring plant and fish growth, some materials like stationery, balance, ruler, tray were needed. For measuring environmental parameters, several materials were used such as dark bottles, erlenmeyers, beker glass, thermometer, TDS meter, pH meter and DO kit.

Measurement of Water Quality

Water samples that were used for analysis of Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Dissolved Solid (TDS), temperature, pH, and ammonia were collected 4 times during 4 weeks of experiments with 3 replications from 3 sampling points namely fish pond (input), filter tank, and output.

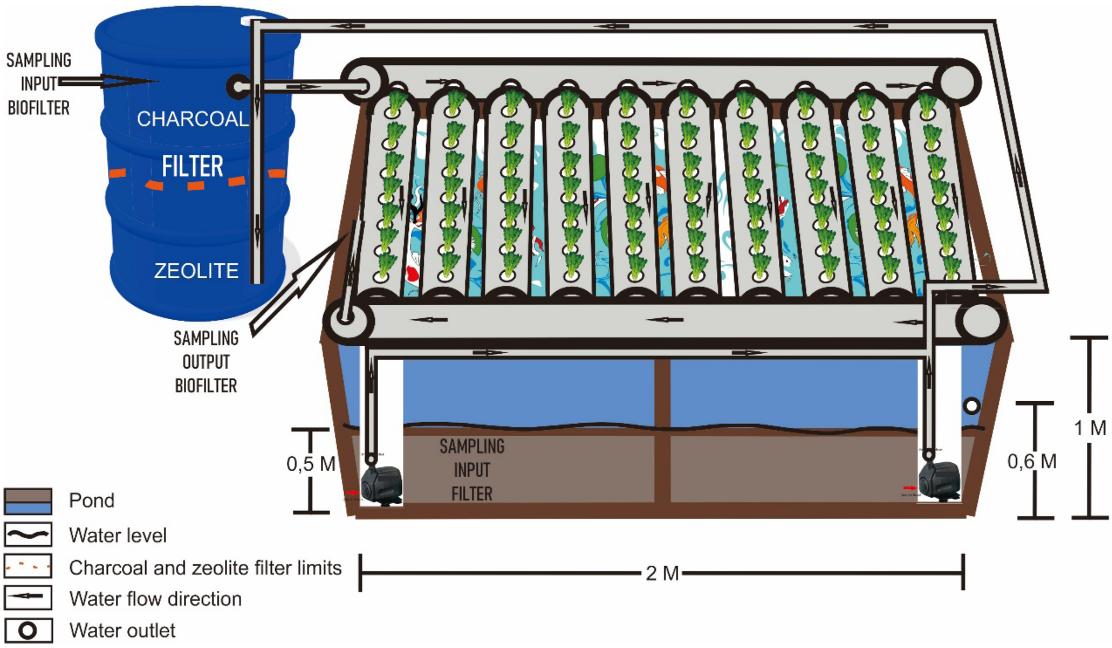

Figure 1. Fish pond design

Measurement of Fish and Plant Growth

a. Fish Growth

Parameters of fish growth consist of absolute weight growth, absolute length growth, feed conversion ratio (FCR), and survival rate. Each measurement was carried out at the beginning of each week. Random 100 individual fish were used as measured samples.

- Absolute weight growth

The calculation of absolute weight growth used the Weatherley formula (Dewantoro, 2001) as follows:

$$W = W_t - W_0$$

where,

W = Absolute weight growth (g)

W_t = Weight of fish at the end of fish farming (g)

W_0 = Weight of fish at the beginning of fish farming(g)

- Absolute Length Growth

Absolute length growth was calculated using the formula described by Effendi *et al.*, 2006 as follows:

$$L = L_2 - L_1$$

where,

L = Absolute length growth (cm)

L_2 = Length fish at the end of fish farming (cm)

L_1 = Length fish at the befinning of fish farming (cm)

- Feed Conversion Ratio (FCR)

The FCR was calculated using formula described by Yuwono *et al*. (2005) as follows:

$$FCR = F \,/\, (W_t + D + W_o)$$

where,

FCR = Feed Conversion Ratio (kg)

F = Feed consumption (g)

Wt = Weight of fish at the end of fish farming (g)

W_o = Weight of fish at the beginning of fish farming (g)

D = Weight of dead fish (g)

- Survival rate

The survival rate (SR) was calculated using the formula according to Effendi (1979), as follows:

$$SR = N_t \,/\, N_0 \; x \; 100\%$$

where,

SR = Survival of seeds (%)

N_t = Number of fish at the end of fish farming

N_0 = Number of fish at the beginning of fish farming

b. Plant Growth

Plant growth was measured on the comparison of plant weight, length, and number of leaves at the beginning and end of cultivation. Measurement of these parameters were conducted once per week.

Result

Water Quality

Observation of water quality was carried out for 4 consecutive weeks, each on the same day and hour. Measurement of DO, BOD, TDS, temperature, pH showed fluctuative values (Table 1). Temperature value and pH scale of pond water were observed still on normal range for aquaponics system. Measurement on DO concentration showed that only result from third week was considered within normal range. BOD values measured from pond water during experiment were considered within normal range (1-2 ppm). Fluctuation on TDS level were observed during experiment with a tendency of its increasing level at the end of experiments period.

Ammonia Level in Aquaponics Systems

Based on the observations made on ammonia levels in water from ponds, filters, and biofilters for 4 consecutive weeks, it was found that ammonia levels tended to be fluctuated each week (Table 2). The best ammonia level was measured at week 2 from all water samples from pond, filter and output. Amonnia level of water for aquaponic should be less than 0.8 ppm (Anonim, 2005).

Table 1.Water quality observations in the aquaponics system

	Week 1					Week 2				
	DO (ppm)	**TDS (ppm)**	**Temperature (°C)**	**pH**	**BOD**	**DO (ppm)**	**TDS (ppm)**	**Temperature (°C)**	**pH**	**BOD**
Pond	2.12	1170.00	28.60	7.07	1.12	1.12	765.00	27.30	7.07	1.05
Filter	1.80	1160.00	29.20	7.10	0.84	0.84	773.00	27.70	7.20	1.25
Output	2.67	1160.00	28.80	7.40	1.27	1.27	754.00	27.80	7.07	1.29
	Week 3					**Week 4**				
	DO (ppm)	**TDS (ppm)**	**Temperature (°C)**	**pH**	**BOD**	**DO (ppm)**	**TDS (ppm)**	**Temperature (°C)**	**pH**	**BOD**
Pond	3.20	1236.67	27.27	8.00	2.56	1.81	2410.00	29.90	7.47	0.47
Filter	2.64	1353.33	27.17	8.20	0.79	2.27	2210.00	30.10	7.10	1.43
Output	3.15	1353.33	27.60	7.90	1.81	1.11	2490.00	29.10	7.13	0.47

Table 2. Ammonia levels in the aquaponics system

	Week 1	Week 2	Week 3	Week 4
	Ammonia (ppm)	Ammonia (ppm)	Ammonia (ppm)	Ammonia (ppm)
Pond	0.52	0.47	3.45	4.95
Filter	0.57	0.65	5.71	1.35
Output	1.23	0.46	2.88	1.97

Growth of Catfish

Observations on the growth of catfish showed that the number of dead fish was increasing over time. Measurement of each growth parameter showed the best result was only observed on week 2, while the worst one occurred at week 3 (Table 3).

Growth of Water Spinach

Growth of water spinach was fluctuative during observation (Table 4). Plant length and number of leaves showed maximum results at week 3 and week 4, while the best result for plant weight was obtained on week 1 to week 2. The best conditions for water spinach morphology was observed on week 2 by appearance of bright green stems and leaves (Figure 2). However, plant morfologhy turned onto bad shape on week 4. It was showed by the breaking down of stem and color change of leaves from bright green onto pale green or yellowish green (Figure 3).

Figure 2. Condition of water spinach at week 2

Discussion

Water Quality

Water temperature did not directly affect metabolism of plants in the aquponics system because air temperature also has its influence on water temperature (Telaumbanua *et al.*, 2016). In this study, water temperature

Table 3. Growth of catfish (*Clarias gariepinus*) in the aquaponic system

	Week 1	Week 2	Week 3	Week 4
	23/02/2020	01/03/2020	08/03/2020	15/03/2020
Number of Dead Fish	5	6	12	18
Number of Survived Fish	495	489	482	472
Total Feed (kg)	46.2	51.8	57.4	63
Average Length (cm)	22.50	23.76	24.01	25.14
Average Weight (g)	90.41	103.88	107.15	120.54
Feed Convertion Rate (FCR)	1.022	1.007	1.095	1.096
Survival Rate (SR)	0.99	0.98	0.95	0.92

Table 4. Observations of the growth of water spinach (*Ipomoea aquatica Forsk.*)

	Week 1	Week 2	Week 3	Week 4
	23/02/2020	01/03/2020	08/03/2020	15/03/2020
Average Length (cm)	7.29	17.59	25.45	40.36
Average Number of Leaves	5.64	9.36	11.18	15.27
Average Weight (g)	7.82	10.09	11.91	12.18

Figure 3. Condition of water spinach at week 4

ranged from 27.17°C-30.10°C (Table 1). This range is categorized as safe or normal for the growth and survival of catfish (Nisrinah, 2013), and safe for bacteria motility and reproduction (Salle, 1961).

Exponent of hydrogen (pH) scale that was measured on this research showed a range between 7.07 to 8.20 (Table 1). Catfish can tolerate and live in wide range of water pH, from acidic (pH scale 6.4) to alkaline (pH scale 9) as mentioned by Boyd and Nill (1982) and Augusta (2016). Nitrification produces acidic condition that affects bacterial metabolism. When ammonia compounds are broken down into ammonium, it will provide source of nutrition for bacteria. TDS concentration does not describe water quality specifically and it is considered as one of many indicators to determine water quality (Atima, 2015). TDS concentration depend on the number of ions or compounds such as ammonia, nitrite and nitrate (Machdar, 2018). It is suggested that the decrease of TDS concentration that occurred on week 1 to week 2 (Table 1) was due to the oxidation and nitrification process of bacteria that worked optimally to convert ammonia produced by catfish. In addition, water spinach which are in a period of rapid growth have an important role in absorbing nitrate (Effendi *et al.*, 2016). The increase of TDS concentration that was occured in weeks 2 to 4 was caused by increase of fish metabolic waste. The overwhelming fish metabolic waste in the form of ammonia could not be handled by plants, filters, and bacteria for its reduction.

Dissolved Oxygen (DO) concentration that was observed in this research showed fluctuating results, where all DO values in pond water (Table 1) were below standard threshold value of 3 ppm (Augusta, 2016). This low DO concentration resulted in a higher level of ammonia that might lead to toxicity in the pond water, and causes shifting of equilibrium reaction and inhibits the oxidation process (Widyastuti, 2008; Wahyuningsih, *et al.*, 2015).

Ammonia Reduction in Aquaponics Systems

Reduction of ammonia level was observed on water that was used in this aquaponic system. Steps of ammonia reduction in this study began from the pond water as a source of ammonia to the filter (zeolite and charcoal), then passed through water spinach as biofilter which will then be flowed back to the pond. Ammonia produced by catfish in this system will be reduced by filtering process, nitrification by bacteria, and nitrate absorption by plants as biofilter.

Reduction of ammonia concentration or level that is shown in Figure 4 was created based on ammonium level data on Table 2. The reduction rate of ammonia was calculated from the substraction of ammonia level of output water (as the end step of circulation) to ammonium level of pond water as the source of ammonium due to its function as fish farming media.

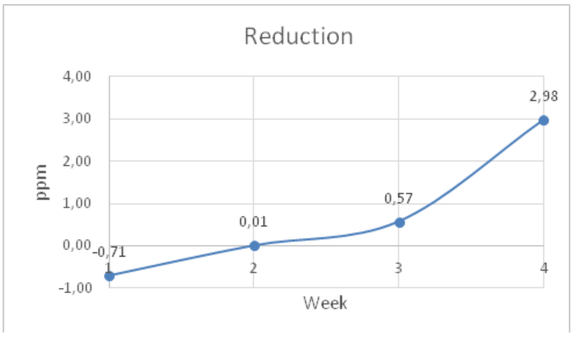

Figure 4. Reduction rate of ammonia level

Based on Figure 4, it can be seen that the highest reduction rate occurs on week 4, followed by week 3, week 2, and week week 1. Amonnium reduction on week 1 was not obviously observed because the circulation system was not optimally worked. The level of ammonia reduction on week 1 was -0.71 ppm. This value might be caused by the presence of cavities between zeolites and charcoal and led to the unfiltered metabolic waste flow in the output pipe and increased ammonia level on output water (Table 1). The value of ammonia reduction at week 2 was 0.01 ppm. This showed that the reduction of ammonia in the aquaponics system was starting to be well functioned. The reduction process occured in the third week was increased from the previous week because cavities between filters began to be filled and biofilters absorbed high amount of ammonia from fish metabolic waste. Ammonia reduction rate showed the highest rate on week 4. But despite of optimal function of integrated filters, this highest rate was due to the damage of aquaponic system. On week 4, ammonia that had previously accumulated in the system was flowed out and drained because of rain for 4 consecutive days.

Growth of Catfish

As a main component in aquaponic, growth of catfish is measured to gain information about fish farming effectivity. Main parameter to study on fish growth are its body weight and length, survival rate (SR) and feed conversion ratio (FCR). In general, Table 3 showed catfish were growing as shown by increasing value of body weight and length. Since research was conducted for 4 weeks and the measurement of growth parameters were done once per week, growth rate for catfish were obtained by comparing data from certain week to its previous week.

Catfish that were observed from week 1 to week 2 were very active, motile and has black skin colour. Comparison on body parameters between week 1 and week 2 showed data as follows : weight gain 13.47 g, length gain 1.26 cm, FCR was 1.007, and SR was 0.98. The highest growth rate of catfish was observed on week 1 to week 2, where FCR and SR values were close to 1 (Table 3). This result might be supported by environmental parameters of water, such as temperature, pH, and ammonia levels which are on the normal range as optimum fish farming condition.

From week 2 to week 3, catfish were physically observed having whitish skin color. Growth rate parameters data showed weight gain was 3.27 grams, length increase was 0.25 cm, FCR was 1.095, and SR was 0.95. The growth rate of catfish from week 2 to 3 were the lowest one. Increasing level of ammonia levels that surpassed threshold level of 0.8 ppm (Anonim, 2005) could play role as major inhibition factor for growth rate of catfish (Hastuti and Subandiyono, 2011). Increased FCR value observed on week 2 to week 3 (if compared to week 1 to week 2) may contribute to the rate of catfish growth.

On week 3 to week 4, catfish skin color were observed pale white and fish did not swim actively. Growth rate of catfish were shown as follows : weight gain was 13.39 g, length gain 1.13 cm, FCR was 1.096, and SR was 0.92. Catfish were assumed highly adaptive to environmental condition during week 3 to week 4. It was shown by weight and length gained eventhough FCR and SR levels are less than what was observed in the previous week (Table 3). Catfish are able to live in extreme environments , such as low dissolved oxygen (DO) concentrations. In order to adapt on poor oxygen environment, catfish have an additional breathing apparatus that has a function to take oxygen directly from the air (Supardi, 2003). The decreased of survival rate on week 4 was due to the decrease of DO concentration in water pond (Table 1). Level of dissolved oxygen could effect ammonia concentrations in aquaculture environment (Haslam, 1995). Low DO levels will increase ammonia toxicity to animals, including catfish which has ability to adapt to extreme environments condition (Dauhan *et al*, 2014; Rini *et al*., 2018).

Growth of Water Spinach

Similar to the measurement of catfish growth, measurement of water spinach as plant component in aquaponics is based on its body or habitus development. Growth of water spinach was measured from its weight, length and number of leaves. Growth rate of water spinach were measured once a week on certain day and hour. The value of plant growth rate were obtained by comparing data from certain week to its previous week

As shown in Figure 3, physical appearance of water spinach from week 1 to week 2 showed fresh bright green leaves and their stems were growing straight up. Growth rate of plants that measured in this period all showed increase in average length (10.3 cm), average weight (2.27 g) and average number of leaves (3.72) as based on Table 4. In this period, water spinach had a fast initial growth rate. During this initial period, plants were able to absorb nutrients for developing their organ size (Effendi *et al*., 2016). A fast initial growth rate as marked by increasing length of plant can also help reducing ammonia in aquaponics (Effendi *et al*., 2016). As shown in Table 2, ammonia levels on week 2 were lower than week 1.

On the period of week 2 to week 3, leaves of water spinach were yellowish and their stem began to bend. Growth rate in this periode consist of increase in average length (7.86 cm), increase in average weight (1.82 g) and increase in average number of leaves (1.82). On this period, the rate of plant growth was low due to the increased of water turbidity and ammonia concentration which prevented plants to absorb existing nutrients. The ability of plants to absorb nutrients will decrease as levels of turbidity and amonium concentration increase in the pond (Sugiharto, 1987 and Effendi, 2003).

Observation on week 3 to week 4 showed wilted and yelow color of water spinach leaves (Figure 3). All plant growth parameters were increasing, such as average length was 14.96 cm, average weight was 0.27 grams, and average number of leaves was leaves 4.09 (as based on Table 4). Plants growth rate that was observed in this period showed highest rate that might be caused by the etiolation effect. Water spinach plants that tend to grow under the biofilter pipe will be exposed to less sunlight and causing fast growth but poor physical condition.

It is important to mention that occurrence of rain for 4 consecutive days on the terminal period of research caused physical damage to water spinach that was marked by broken stems (Figure 3). Rain drops also interfered water condition of the aquaponic system and might reduced its chemical composition, such as dissolved oxygen value and lead to abnormality of water spinach growth (Sikawa and Yakupitiyage, 2010; Sugiharto, 1987).

Taken together, integration of zeolit and charcoal as filter and water spinach as biofilter helped reducing ammonia level in water of aquaponic system and supported the growth of catfish during period of research.

Conclusion

Combination of zeolit and charcoal as materias for filters and water spinach as material for biofilter in an integrated filter system is potential to reduce ammonia waste in an aquaponics system. Reduction of ammonia level in water of aquaponics system could support the growth of fish as main component to be farmed in aquaponic.

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