Design of Submerged Fixed Bed Filter for High Density Shrimp Culture in Recirculating Aquaculture System

L. Thesiana*, K. Adiyana
Research Center for Fisheries-Ministry of Marine Affairs and Fisheries (KKP)
* Corresponding author: lolita.thesiana@kkp.go.id

Abstract. Shrimp is Indonesia’s the leading export commodities from Indonesia, but in recent years the shrimp industry has been threatened by disease outbreaks due to environmental quality decline. To overcome these challenges, there is a need for a cultivation technology which provides opportunities for intensive shrimp culture in a narrow area, resulting high productivity and having less environmental impact. Recirculating aquaculture systems (RAS) was the best option to provide high density shrimp culture without leading to environmental damage due the system equipped with water treatment unit. This study aimed to design a submerged filter which can be used in commercially recirculating systems for high density shrimp culture. Submerged filter as water treatment unit for ammonia conversion, it was designed based on organic load mass balance derived from feeding regimes. A RAS with 8 m³ volume capacity use for rearing 400 shrimps m⁻³, has dissolved oxygen levels range between 6-7 mg L⁻¹, nitrification rate 0.45 g TAN m⁻²day⁻¹ and TAN levels <1.8 mg L⁻¹, based on spreadsheet calculation will require submerged filter media with 0.07 m³ in volume, media depth 0.3 m, and filter media specific surface area 1200 m² m⁻³. Submerged filter design for high density shrimp culture in a narrow place must have a compact design. It can be achieved by selecting filter media type with large specific surface area values. Filter media with a large specific surface area makes biofilter design has smaller dimensions. Submerged filter as water treatment unit in recirculating system for high density shrimp culture will reduce TAN level in water. Waste water in this system is reuse for shrimp culture, no waste water disposal to the environment which leading to sustainable aquaculture practice.

1. Introduction
Recirculating aquaculture system (RAS) is using reused water during fish farming operations. This method is more environment friendly because it uses water treatment units and consume less raw water than fish farming with a flow through system. Application of water treatment unit such as biological and physical filter become the core of RAS technology, each filter can be adjusted to meet water quality requirements for aquaculture commodities [1]. RAS technology uses recycled water during the production process, leading to non waste water discharged into rivers or sea.

Waste water resulting from intensive shrimp farming usually contain high level of organic content, which derived from accumulation of organic residues from uneaten feed, ammonia excretion, feces, and feed particles [2]. Untreatment waste water from intensive shrimp farming which streamed directly into the sea will cause an environmental impact [3]. Application of RAS technology provide opportunities for intensive shrimp farming to produce a large quantity of shrimp with less severe environmental damage and more sustainable.
RAS technology was not commonly used for intensive vaname grow out. Farmers prefer to use RAS technology for shrimp nursery because this system is able to manage more stable water quality. The aims of this study is to design submerged fixed bed filter as one device used in RAS water treatment unit, which can be used in commercially viable recirculating systems for high density shrimp culture until reach harvest size. Submerged fixed bed filter design formulation in this study applied from [4, 5] research, we compiled them in computer spreadsheet to calculate filter dimension.

2. Method
2.1. Filter Design
Design of recirculating system filter based on the highest waste result during farming operation which achieved at harvest time [5]. In this study we will design submerged fixed bed filter for recirculation system with total volume 8 m$^3$, it can be used for shrimp farming with density 400 shrimp m$^{-3}$ and total harvest 46 kg of shrimp. Filter capacity is designed to be 1.5 times greater than total harvest weight to prevent water overflow. Water quality requirements for shrimp farming are: dissolved oxygen range between 6-7 mg L$^{-1}$, TAN $<$1.8 mg L$^{-1}$. Assumptions used in this study are: Feeding rate 3% of body weight, feed protein content 30%, filter efficiency for TAN removal 50%, nitrification rate 0.45 g TAN m$^{-2}$ day$^{-1}$, specific media surface area 1200 m$^2$m$^{-3}$. Equation (1) until equation (7) used to calculate the biofilter dimensions, all equations adopted from [4, 5].

\[ P_{TAN \ load}(\text{kg day}) = F_{feeding \ rate}(\text{kg day}) \times PC_{feed's \ protein \ concentration} \times 0.065 \]  

\[ W_{\text{feed weight}}(\text{kg}) = \text{total harvest weight (kg)} \times \text{Feeding rate ()} \]  

\[ Oxygen \ demand (kg) = 0.25 \times W_{\text{feed weight}}(kg) \]  

\[ A_{biofilter}(m^2) = \frac{P_{TAN \ load}(g \ day)}{r_{TAN} \ (m^2 \ day)} \]  

\[ V_{biofilter}(m^3) = \frac{A_{biofilter}(m^2)}{a(m^2 \ biofilter \ media)} \]  

\[ S_{cross \ sectional \ area}(m^2) = \frac{Q_{biofilter}(m^3 \ day)}{HLR, \ hydraulic \ loading \ rate(m^3 \ m^2 \ day)} \]  

\[ H_{biofilter \ height} (m) = \frac{V_{biofilter}(m^3)}{S_{cross \ sectional \ area} \ (m^2)} \]  

2.2. Experimental Design
Recirculating aquaculture system (RAS) used in this study has eight culture tanks, each culture tank has 1000 L in volume, 1 unit fixed bed submerged filter with dimension presented in (Table 2) filled with sponge media and one 1766 L aeration tank presented in figure 1. Shrimp with average weight 0.74 ± 0.02 gr, reared in each culture tank with density of 400 shrimp/m$^3$ for 60 days. Shrimp were fed five times a day with CJ shrimp feed (protein content ± 32-35) with feeding rate 3% of total shrimp weight. RAS is operated for 24 hours with zero sea water replacement, however we add fresh water periodically to keep water salinity beyond 23-25 ppt.

2.3. Water sampling
Total ammonia nitrogen (TAN), ammonia, nitrite and nitrate from all rearing tank were recorded every 10 days by composite sampling method. Water salinity, dissolved oxygen, temperature, pH in each rearing tank and filter effluent pipe, were recorded daily for 60 days with YSI 556 multi parameter tester.

3. Result and discussion
3.1. Submerged fixed bed filter design
Submerged fixed bed filter used for this study was built with some assumptions and criteria presented in Table 1. The calculation result of formulation (1) until formulation (7) to define filter dimension was presented in Table 2.

| Table 1. Assumptions used for the design of filter |
|-----------------------------------------------|
| **TAN Mass balance calculation**               |
| Feed protein content                          | 30% |
| Total ammonia nitrogen (TAN) production rate   | 0.04212 kg/day |
| % TAN from feed                               | 1.95 % |
| Desired TAN Concentration in system            | 1.8 mg/L |
| Passive nitrification                          | 10% |
| TAN available after passive nitrification      | 0.0379 kg/day |
| Passive denitrification                        | 0% |
| Maximum nitrate concentration desired          | 150 mg/L |
| TAN available to filter after effluent removal | 0.037 kg/day |
| Filter efficiency for TAN removal              | 50% |
| Flow rate to remove TAN desired concentration  | 41614.56 L/day |

Table 2 showed that fixed bed filter dimension used in this study has 0.3 m media depth, 0.543 m bottom area diameter and 1200 m²/m³ filter media surface area. Filter media play important role to determine filter dimension and influence filter ability in reducing ammonia concentration. High surface area filter media will result in smaller filter dimension. [6] compared ceramsite, zeolite and sponge filter media performance for municipal wastewater treatment, he stated that sponge filter media has better ability as biofilm carrier than other filter media and resulting higher capability in TAN removal. Based on his research, in this filter design we used sponge with 1200 m²/m³ surface area as filter media. Aside from media filter selection, feeding frequency also affecting waste production...
variation in recirculation system. Feeding mechanisms difference will impact flow rate design, fluctuation of water quality and alteration on water treatment unit dimension required for recirculation system [7].

Figure 1. Recirculating aquaculture design used in this study

3.2. Water quality parameter
The result of RAS water quality values during the study was compared with the water quality standard requirement for the grow out culture of white shrimp (Table 3). Figure 2 shows the water nutrient concentration in the rearing tank during the 60 day culture of white shrimp.

Figure 2. Total ammonia nitrogen (TAN), nitrite and nitrate concentration during culture period

TAN concentration gradually increased from day 0 to day 50, it reach the highest value (1.898 mg/L) at 50th day and slowly decreased at 60th day. TAN concentration increased due to addition of organic matter input from feeding during shrimp farming. Although there was an increase in TAN concentration in the system, TAN concentration still compatible with standard criteria for shrimp farming. Nitrite concentration value fluctuate range from 0.521 – 0.756 mg/L during the study. However nitrate concentration slightly fluctuates in 2.002 – 2.089 mg/L. Fluctuation of nitrite and nitrate concentrations in RAS tends to be stable because nitrification process by nitrification bacteria
has worked, they able to regulate concentration of dissolved nitrogen to comply with water quality standard for shrimp culture.

Table 3. Water parameters

| Parameter           | Values       | References |
|---------------------|--------------|------------|
| Ammonia (mg/L)      | 0.001 – 0.019| < 0.1 [8]  |
| TAN (mg/L)          | 0.058 - 1.898| N.A.       |
| Nitrite (mg/L)      | 0.521 – 0.756| < 1 [8]    |
| Nitrate (mg/L)      | 2.002 – 2.089| <200 [9]   |
| Temperature (ºC)    | 29.15–30.3    | 29-32 [8]  |
| Salinity (ppt)      | 23 – 25       | 26-32 [8]  |
| pH                  | 7.45-7.68     | 7.5-8.5 [8]|
| Dissolved Oxygen (mg/L) | 5.5 – 7.1   | >4 [8]     |

Water quality parameters have a great impact on crustacean immune system [10]. Moreover water quality degradation can lead to shrimp growth disruption which resulting lower survival rate [11]. Application of fixed bed submerged filter in this recirculating system is essential to water replenishment and comply with water quality requirement for optimum shrimp growth. Table 3 showed that fixed bed submerged filter has good performance in keeping nitrogen value below standard level. Furthermore, all water parameter in the recirculating system meet water quality standard for vaname growout. [12] also conducted research on shrimp growout in recirculation systems, their system reach maximum ammonium concentration 1.8 ppm, nitrite 3.7 ppm and nitrate 170 ppm, compared with their system, water quality result from this study has better performance.

4. Conclusion

Submerged fixed bed filter design dimension strongly influenced by the highest amount of waste generated in the system as well as the desired water quality criteria. Moreover, if the high density shrimp culture located in narrow place, the filter design must has a compact design. Smaller and compact filter dimension can be achieved by selecting filter media type which has large specific surface area values (example sponge media). Submerged fixed bed filter as water treatment unit in recirculating system for high density shrimp culture will reduce TAN level according to desired criteria. Waste water in this system is recycle and reuse during shrimp farming, zero waste water disposal to the environment which leading to sustainable shrimp farming method.

Acknowledgements

This work was supported and funded by Ministry of Fisheries and Marine Affairs Republic of Indonesia.

References

[1] Bregnballe, Jacob. 2015. A Guide to Recirculation Aquaculture An Introduction to the new environmentally friendly and highly productive closes fish farming system.FAO and EUROFISH International Organisation.

[2] Lorenzo, M.A., Schweitzerb, R., Santo, C.M.D., Candiaa, E.W.S., Mouriñoa,J.L.P., Legardaa, E.C., Seifferta, W.Q., Vieiraa, F.D.N. 2015. Intensive Hatchery Performance Of The Pacific White Shrimp In Biofloc System. Aquacultural Engineering 67 53-58.

[3] Samocha, T. M. 2019. Sustainable biofloc systems for marine shrimp. 125 London Wall: Academic Press
[4] Lodorso, M., Hobbs, A.O., DeLong, D.P. 2000. The design and operational characteristic of the CP & L/EPRI fish barn: a demonstration of recirculation aquaculture technology. *Aquacultural Engineering* 22 3-16.

[5] Eding, E.H., Kamstra, A., Verreth, J. A. J., Huisman, E. A., & Klapwijk, A. 2006. Design and operation of nitrifying trickling filters in recirculating aquaculture: a review. *Aquacultural Engineering*, 34, 234-260.

[6] Zhang X, Li J, Yu Y, Xu R and Wu Z 2016 Biofilm characteristics in natural ventilation trickling filter (NVTFs) for municipal wastewater treatment: Comparison of three kinds of biofilm carriers. *Biochemical Engineering Journal* 106 87-96.

[7] Heinsbroek L.T.N, Kamstra, A.1990. Design and performance of water recirculating system for eel culture. *Aquaculture Engineering* 9 87-207.

[8] Ministry of Marines Affairs and Fisheries (MMAF). 2016. Regulation of the Minister of Marines Affairs and Fisheries of the Republic of Indonesia number 75. General guidelines for tiger shrimp (*Penaeus monodon*) and vannamei shrimp (*Litopenaeus vannamei*) growout farming.

[9] Suantika, G., Adiwati, P., Indriani, D.A., Khotimah, Z.A.2013. The use of Indigenous Probiotic *Halomonas aquamarina* and shewanella algae for white shrimp (*Litopenaeus vannamei boone*) hatchery productivity ub zero water discharge system. *Journal of Aquaculture Research & Development* 4(5) 1-8.

[10] Vergehese, B., Radhakrihnan, E.V., Padhi, A. 2007. Effect of environmental parameter on immune response of the Indian spiny lobster, *Panulirus homarus* (Linnaeus, 1758). *Fish and Shellfish Immunology* 23 928-936.

[11] Suantika, G., Situmorang, M.L., Nurfathurahmi, A., Taufik, I., Aditiawati, P., Yusuf, N., Aulia, R. 2018. Application of Indoor Recirculation Aquaculture System for white shrimp (*Litopenaeus vannamei*) growout Super-Intensive Culture at Low Salinity Condition. *Journal of Aquaculture Research & Development* 9 1-6.a

[12] Suantika, G., Situmorang, M.L., Kurniawan, J.B., Pratiwi, S.A., Aditiawati, P., Astuti, D.I., Azizah, F.F.N., Djohan, Y.A., Zuhri, U., Simatupang, T.M. 2018. Development of a Zero Water Discharge (ZWD) – Recirculating Aquaculture System (RAS) Hybrid System for Super Intensive White Shrimp (*Litopenaeus vannamei*) Culture under Low Salinity Conditions and Its Industrial Trial in Commercial Shrimp Urban Farming in Gresik, East Java, Indonesia. *Aquacultural Engineering*. [https://doi.org/10.1016/j.aquaeng.2018.04.002](https://doi.org/10.1016/j.aquaeng.2018.04.002)