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Pipe Flow Simulation Model on Shrimp Hatching Infrastructure (Hatchery) Through Recirculating Aquaculture System (RAS) Approach

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Abstract: *The shrimp nursery infrastructure consists of nursery tanks, mechanical filters, biological filters, and ultraviolet (UV) filters. This study aimed to simulate the water level elevation (head) of shrimp nursery infrastructure, especially nursery tanks. The placement of the nursery greatly affects the elevation of the water table owing to the loss of energy (headloss) that occurs in the flow. The nursery tub used in this study was round and consisted of four tubs made of fiber resin measuring 250 cm in diameter and 120 cm in height. The bottom of the tub was placed at an elevation of +40 cm above the ground. The simulation was conducted for 24 h. The results of the EPANET 2.2 simulation showed head fluctuations in each nursery with the highest elevation (1.38m and the lowest (1.20m, from the data. The head fluctuated constantly after 6 h of the flow. The optimal pipe diameters were 3" (80 mm) PVC and 4" (110 mm) PVC.*

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INTRODUCTION

The vannamei *Shrimp* (*Litopenaeus vannamei*) is a marine biological resource that is widely distributed in Indonesia. Indonesia's shrimp production in 2016 was 698,138 tons and experienced a significant decrease of 20% in 2017 to 555,138 tons [1]. The high mortality rate of shrimp fry is a problem faced by farmers and the Vannamei Shrimp hatchery ([2], [3]). Increased production must be balanced with the supply of high-quality and sustainable seeds. However, to date, the need for shrimp seeds has not been met. This is due to the high mortality rate of shrimp fry in hatchery centers. High mortality is caused by various factors, one of which is the decline in the water quality of shrimp seed rearing media ([4], [5], [6], [7]).

Innovation of water quality control systems in shrimp hatchery media needs to be conducted. The water quality of shrimp larval rearing media can be controlled in various ways. The most common method that is mostly done is to replace the new media with water, circulate the media, and add certain ingredients to the media, such as probiotics and antibiotics ([8], [9]). The application of a water filtration system, ozonation treatment, and ultraviolet irradiation can help prevent disease outbreaks in hatcheries. Through proper water quality management, the need for medicines and antibiotics can be reduced ([10], [11], [12]). However, these efforts did not able to significantly reduce mortality. The decline in water quality is one of the problems that trigger the death of shrimp fry, and until now, shrimp hatchery groups have not found an optimal solution. The limited ability of the shrimp hatchery group to solve this problem causes the low production of Vannamei Shrimp from hatchery activities ([13], [14]). In this study, water management was carried out using various filtration systems to meet various industrial needs and drinking water consumption. Apart from being aimed at meeting community needs, industry is also a party that requires water in the production process. For example, the microelectronics industry requires high-quality water very high or known as ultrapure water. The pharmaceutical and medical industries often use membrane processes for water treatment. Water used for the pharmaceutical/medical industry it is generally water with very high purity ([15]; [16], [17]). Water is used in medicinal formulas, lotions, cleaning fluids, and cream. In addition, water is also the main component of fluids and is used to replace natural body fluids in patients with certain diseases. The presence of contaminants in these formulations can cause undesirable side effects, interfere with the chemical characteristics of the medication, and even harm the patient. In the shrimp cultivation industry, the quality of pond water greatly influences the cultivation of shrimp. Good water quality (according to cultivation standards) supported optimal growth. However, poor water quality can reduce shrimp appetite, resulting in stunted shrimp growth. The degradation of water quality causes stress to shrimp and can even cause death and reduce the survival rate, which in turn can reduce the biomass of shrimp [18]. Therefore, more innovative efforts are needed to reduce shrimp fry mortality. One objective of this research was the application of an ultrafiltration system in the Vannamei Shrimp seed production process. In this filtration system, water filters are carried out in stages so that it is hoped that the water quality will be cleaner from various pathogens.

One of the technologies currently being developed worldwide for aquaculture is recirculating aquaculture systems. This system has been widely applied in several developed countries, such as the United States, Israel, Singapore, and Germany. A Recirculating Aquaculture System was first introduced in the United States in the early 1960s [19]. At that time, it was found that river pollution originated from organic pollution sourced from fish and shrimp breeding sites. To avoid this pollution, several rules have been established by the local government, one of which is a Recirculating Aquaculture System [20]. According to [21], an aquaculture recirculation system module consists of a treatment unit, cultivation unit, supply canal, and clean water canal/sub-inlet. Water was added to the system through a relatively small number of quarantine units, which only replaced the volume of water lost due to evaporation, seepage, and cleaning of the pond bottom (siphon). In addition, the Recirculation Aquaculture System is provided with additional components, such as pumps and aerators. [22] stated that in the design of a recirculation system, the main thing to consider is the provision of conditions that allow for the disposal of solid waste, ammonia waste, and aerator.

The most important mechanical structural component of an RAS system is the piping network. A good circulation system is determined by a standard piping network, which plays a very important role in determining the quality of the water flowing through the shrimp hatchery. To analyze the water distribution pipeline network, an analysis tool is needed to facilitate the analysis, such as EPANET 2.0, WaterCad 8.0, and Pipe Flow Expert 2010. However, EPANET 2.0 software is used, which is easy to obtain and does not require high computer specifications ([23], [24], [25], [26]). Many studies have analyzed clean water distribution piping networks have been carried out in Indonesia. However, various studies have been carried out only calculated and analyzed clean water pipe networks. The fulfillment of water needs and clean water piping networks in the Maros Regency by comparing the simulation results of water distribution using EPANET 2.0 [27], with the results of field measurements through water meter readings. Sudarsono and Nugraha (2013) researched the use of thematic maps to analyze the location of the leakage of the distribution pipeline network belonging to the PDAM Demak by overlaying the map of the City of Demak with the distribution pipe network of clean water. There are still very few studies related to the analysis of water circulation in shrimp cultures, especially the analysis of piping networks in the RAS system in shrimp hatcheries. Thus, it is important to conduct more in-depth research related to the analysis of piping network systems in shrimp hatchery processes. This study aimed to simulate the water level elevation (head) of shrimp nursery infrastructure, especially hatcheries.

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METHODS

Study Area

The study was conducted at a shrimp hatchery at the UPTD SPAPAL, Manggar, Balikpapan City, East Kalimantan. This study was conducted from January to March 2023.

Data Collection

The research data were obtained by directly measuring the volume of the tank in the hatchery tank, the volume of the biofilter, the volume of the Mechanical Drum Filter (MDF), the volume of the reservoir, and the planned capacity of the water requirement of 20 m3/hour. The expected result is to obtain the most optimal pipe dimension value and also the electricity requirement that will be used in the Recirculating Aquaculture System (RAS) technology.

The research stages are illustrated in Figure 1.

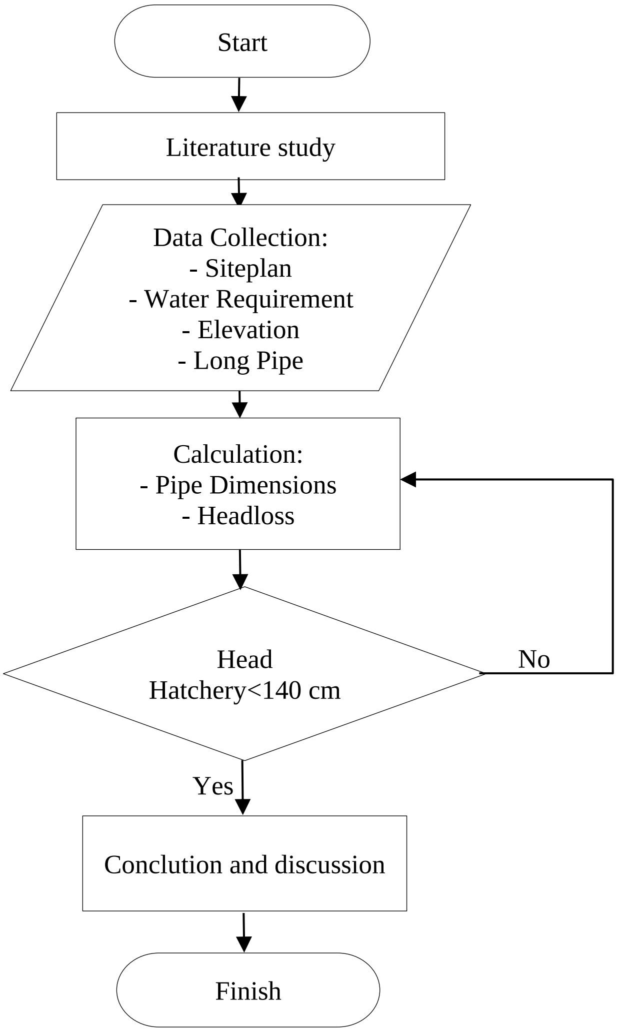


Figure 1. Research Stages

The scheme for the placement of the RAS infrastructure is shown in Figure 2. The flow of water from the nursery tank to the Mechanical Drum Filter (MDF) is driven by gravity. A pump was placed in the MDF to raise the water to the biological filter. The flow then moves by gravity to the resulting water and returns to the hatchery. The head fluctuated constantly after the flow lasted for 6 h.

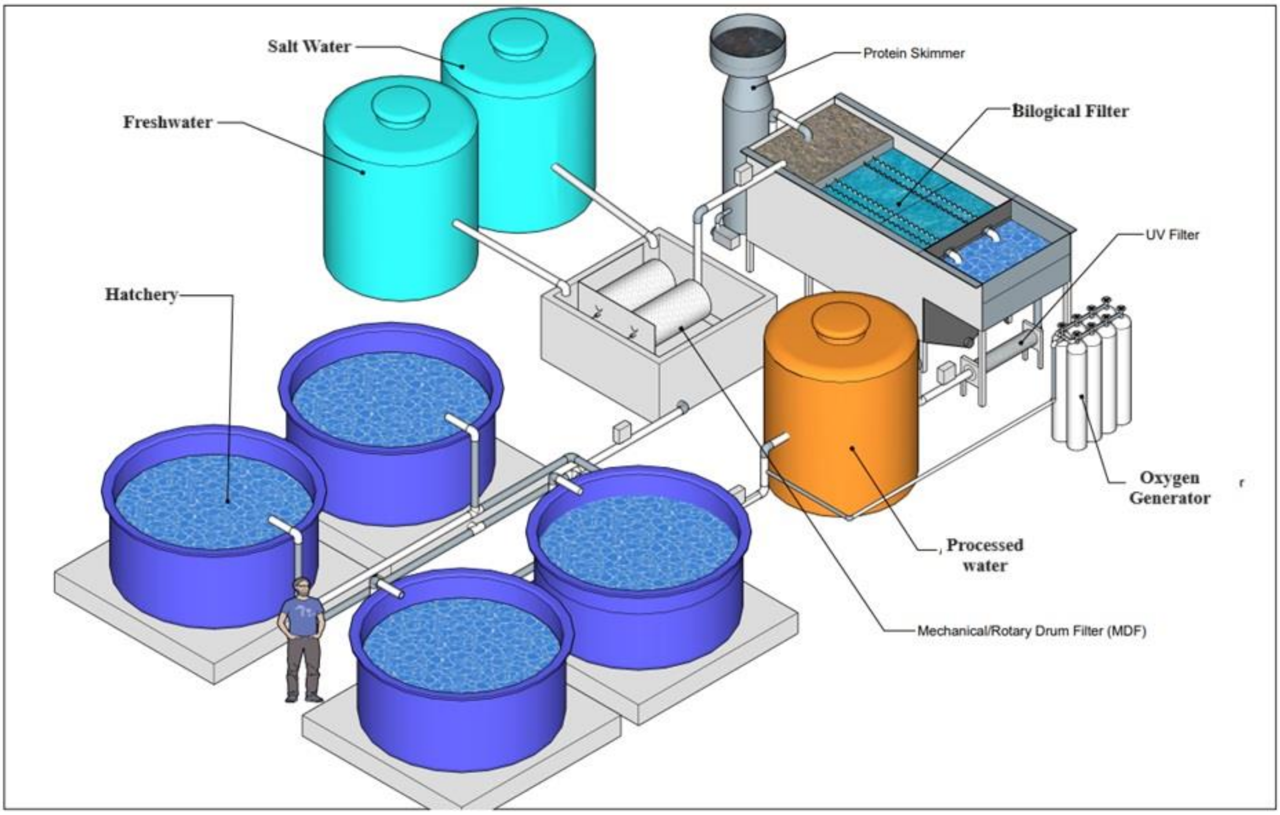


Figure 2. Recirculating Aquaculture System Shrimp Breeding Infrastructure Placement Scheme

Data Analysis

The method used in conducting the analysis consists of several stages, namely: (a) the preparation stage, in which a literature study is carried out to determine research references and collect primary and secondary data; (b) the research phase, which consists of making a map of the distribution network of pipelines with the help of ArcMap 10.3.1, calculating water needs (base demand), and modeling the pipeline network using EPANET 2.0; and (c) the analysis stage, where the parameters of water pressure and water velocity are analyzed in the piping network model made using EPANET 2.0, by calculating the water level elevation factor, owing to the loss of energy (headloss) that occurs in the flow.

EPANET is a computer program used for modeling pipelines and is a public domain. EPANET was developed by the US Environmental Protection Agency (USEPA). EPANET can simulate the hydraulic behavior and water quality in pipelines by describing hydraulic simulations and trends in the quantity of water flowing in pipelines.

The classic problem of flow in pipelines states that the flow rate and point pressure energy in pipelines are parameters that must be known. Two equations are required to solve this problem. The first equation requires the discharge conversion (continuity) to be fulfilled at every node (junction). The second equation is a nonlinear relationship between the discharge and energy loss in each pipe, such as the Darcy-Weisbach and Hazen-Williams's equations with the following formula:

Darcy Weisbach Equation:

$$Hf = f \cdot \frac{l}{d} \cdot \frac{v^2}{2 \cdot g} \tag{1}$$

Where:

Hf = energy loss (headloss) in meters

f = Coefficient Darcy (dimensionless coefficient)

L = long pipe (m)
d = pipe diameter (m)
v = water flow speed (m^2)
where g is the gravitational acceleration.

Hazen Williams Equation:

$$Hf = \frac{10{,}666 \times Q^{1,85}}{C^{1,85} \times d^{4,85}} \tag{2}$$

where:
Q = flow debit (m^3/second);
C = coefficient of Hazen–Williams

The data required in EPANET 2.0 is very important for the analysis, evaluation, and simulation of EPANET-based clean water networks. The required input data are as follows:

a) Network map
b) *Node/junction*/ point of distribution component
c) Elevation.
d) Length of the distribution pipe.
e) Pipe inside diameter.
f) Type of pipe used.
g) Pipe life.
h) Type of water source
i) Pump Specification.
j) Reservoir shape and size.
k) Load each node.
l) Fluctuation Factors in Water Usage.

The outputs produced include the hydraulic head of each point, pressure, velocity and headloss unit

RESULT AND DISCUSSION

The input data were obtained based on the field measurements, as shown in Table 1.

Table 1. Field data input

```
----------------------------------------------------------------------
Link           Start          End                 Length  Diameter
ID             Node           Node                     m        mm
----------------------------------------------------------------------
1              Tank1          5                     1.25       110
2              Tank2          6                     1.25       110
3              Tank3          7                     1.25       110
4              Tank4          8                     1.25       110
5              5              6                        3       110
7              7              8                        3       110
9              9              10                       6       110
10             10             FMEK                   1.5       110
12             FBIO           FHTank                   6       110
14             FHTank         9                        6       110
16             Source         10                       3        80
17             FMEK           Source                   3        80
18             9              Tank4                    6        80
19             9              Tank3                   18        80
20             9              Tank2                    6        80
21             9              Tank1                   18        80
6              6              1                        6       110
8              1              10                       6       110
11             8              1                        6       110
Pump           FMEK           FBIO                  #N/A      #N/A Pump
```

In this RAS system, there are four hatchery tanks with a diameter of 250 cm and height of 140 cm, with a water storage capacity of 20,000 m3, consisting of outflow and inflow components. The outflow component is located at the top of the tank wall which is connected between one tank and another via a pipe with a diameter of 110 mm and a height of 1.25 m. The length of the pipe between tanks was 3 m. The water flow from the four tubs meets at one point where the stop valve taps meet. The water flow then enters the mechanical drum filter (MDF) tub through a pipe 6 meters long. The MDF tank was also connected to the raw water tank, namely fresh water and salt water, through a pipe with a diameter of 80 mm and a pipe length of 3 m. After passing through the mechanical filtering process, the water in the MDF tub flowed to the protein skimmer and biological filter with the help of a pump. Next, the water flow continued to the final product tank, which was processed through a pipe with a diameter of 80 mm and a length of 3 m. In the final process of the RAS system series, water from the final tank flowed back into the hatchery tank through a pipe with a diameter of 80 mm and entered through the inflow component at the bottom of the hatchery tank. The water rotation cycle lasted for 6 h.

A network map was drawn based on the RAS system nursery infrastructure placement scheme, as shown in Figure 3.

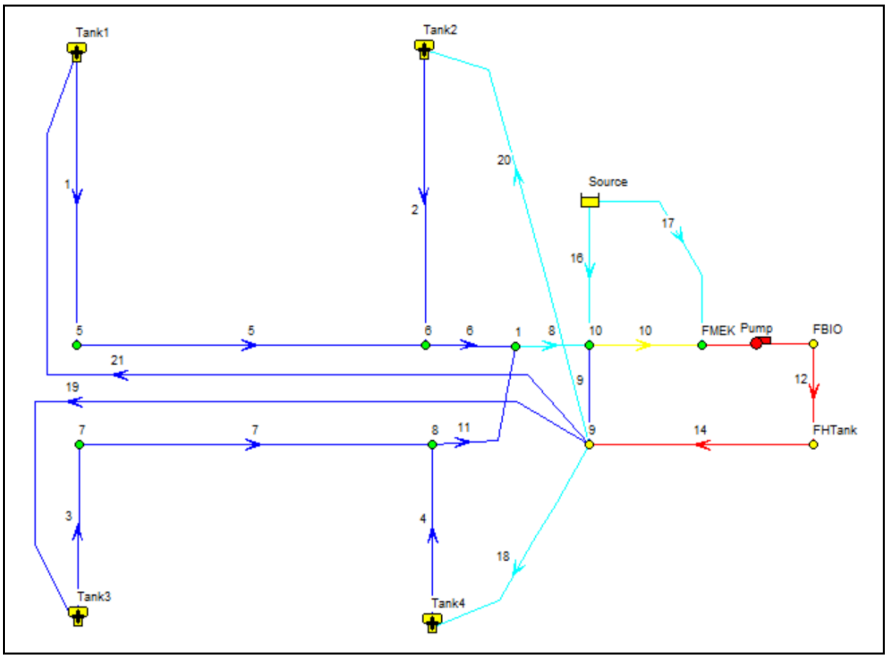
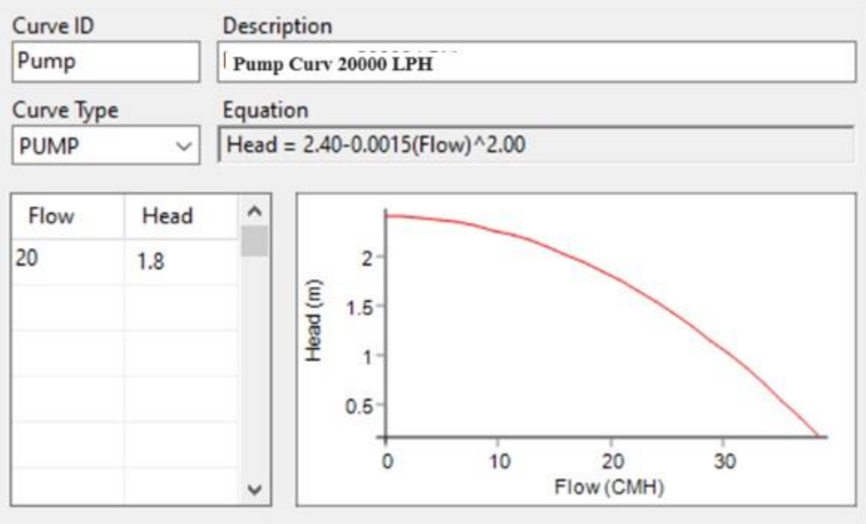


Figure 3. Network Map of RAS System Shrimp Breeding Infrastructure

The planned flow was 20 m^3/hour so a pump curve with a total head of 180 cm was obtained, as shown in Figure 4. The pump was placed between the Mechanical Drum Filter (MDF) and the biological filter.


Curve ID: Pump

Description: Pump Curv 20000 LPH

Curve Type: PUMP

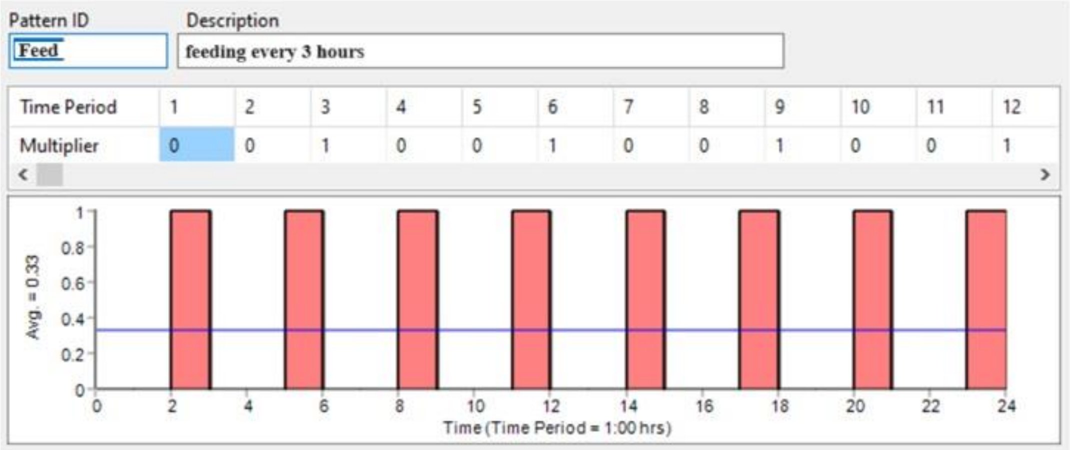
Equation: Head = 2.40-0.0015(Flow)^2.00

Flow	Head
20	1.8

Figure 4. RAS System Shrimp Breeding Infrastructure Pump Curve

The pump capacity used was in accordance with the piping working system analysis. Fluctuations in changes in the head (water level) that occur in the nursery tank indicate good piping performance, where there is no overflow in the nursery tank or in the MDF tank, and there is no excessive drop in head. Therefore, the water supply to the hatchery tank remained stable. It took 6 h to obtain a stable head.

The feeding pattern in each nursery was conducted every 3 h, as shown in Figure 5.



Pattern ID: Feed

Description: feeding every 3 hours

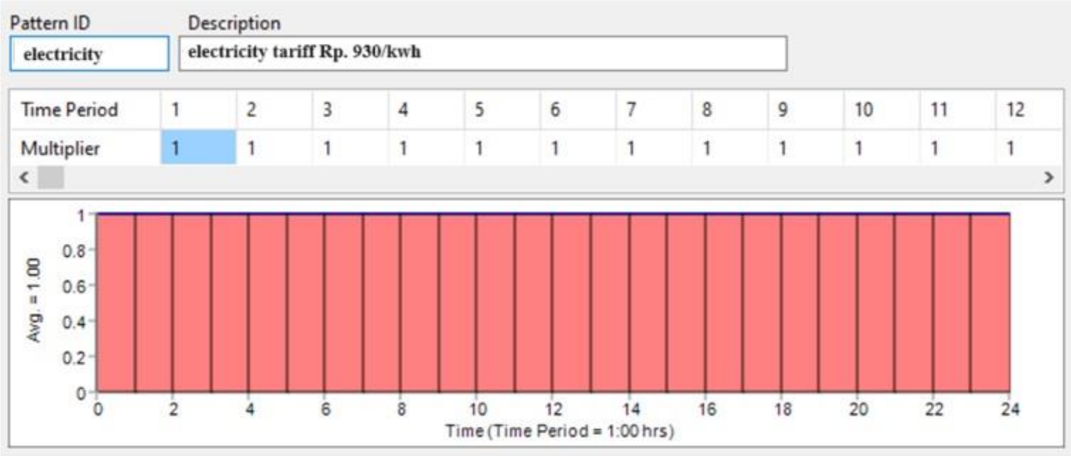
Time Period	1	2	3	4	5	6	7	8	9	10	11	12
Multiplier	0	0	1	0	0	1	0	0	1	0	0	1

Figure 5. Shrimp Feeding Pattern

Ammonia growth will continue because of the feeding of shrimp in each tank. Ammonia is toxic to shrimp farmed in marine waters and can reduce the solubility of oxygen in blood shrimp. High levels of ammonia come from excretion and feed residues that settle in the water, resulting in a high ammonia concentration. Safe ammonia concentrations for shrimp organisms are <0.1 mg/l. Ammonia levels of > 0.1 mg/l can disrupt the survival of vaname shrimp [28]. An ammonia content of 0.45 mg/l can cause disturbance and inhibit shrimp growth rate by up to 50% ([29],[30], [31]). Therefore, the quantity of shrimp feed must be adjusted according to the capacity of the Hatchery Tank. Based on the results of the analysis, it was determined that feeding shrimp in hatchery tanks with a diameter of 2.5 m and a height of 120 cm, and a water capacity of 5000 m^3 must be performed every 3 h. This feeding arrangement also affects the working system of the MDF and protein skimmer in filtering mechanical elements and reducing ammonia content.

Protein skimmers play an important role in reducing the ammonia content in shrimp cultivation water, especially in their role as aerators. The aeration system in protein skimmers is an alternative for increasing the supply of dissolved oxygen in cultivation ponds. Dissolved oxygen is necessary for bacteria during nitrification. The dissolved oxygen concentration must be maintained above 60% or 5 mg/l for the oxidation of ammonia into other forms [32].

The installation of the RAS system was run continuously for 24 h, and the pattern of the electricity consumption is shown in Figure 6. The electricity tariff used in this study refers to the standard PLN electricity tariff Rp. 930/kWh.



Pattern ID: electricity

Description: electricity tariff Rp. 930/kwh

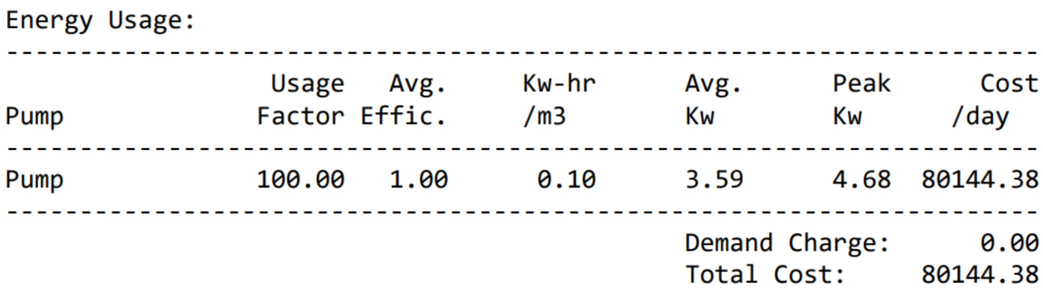
Time Period	1	2	3	4	5	6	7	8	9	10	11	12
Multiplier	1	1	1	1	1	1	1	1	1	1	1	1

Figure 6. Electricity Usage Pattern

Energy Used

The simulation results for 24 h using one pump, as shown in Table 2, obtained an average electricity use of 3.59Kw, with an electricity consumption cost of Rp.80.144.38/day. The use of electrical energy in this RAS system is very efficient because it only uses one booster pump that is placed between the mechanical drum filter and the Protein Skimmer and has been calculated to be able to stabilize the water circulation in the system for 6 h per rotation cycle. The design of this RAS system also considers savings in energy use by maximizing the gravity system as a driving force for water circulation. By standard, the use of electrical energy in a RAS system with a capacity of 20,000 m^3 requires energy of 83.33 Kw/day [33].

Table 2. Electricity Consumption



```
Energy Usage:
----------------------------------------------------------------------
                 Usage   Avg.     Kw-hr      Avg.      Peak      Cost
Pump             Factor Effic.    /m3        Kw        Kw        /day
----------------------------------------------------------------------
Pump             100.00   1.00     0.10      3.59      4.68  80144.38
----------------------------------------------------------------------
                                           Demand Charge:        0.00
                                           Total Cost:       80144.38
```

Ammonia Level

Figure 7 shows the average amount of ammonia loss. The term “bulk” refers to the reaction that occurs in the bulk fluid while “wall” refers to the reaction with the pipe material in the pipe wall. The last reaction was zero because the wall reaction coefficient was not determined in this study. The pipe used PVC, so it was assumed that it did not react with ammonia.

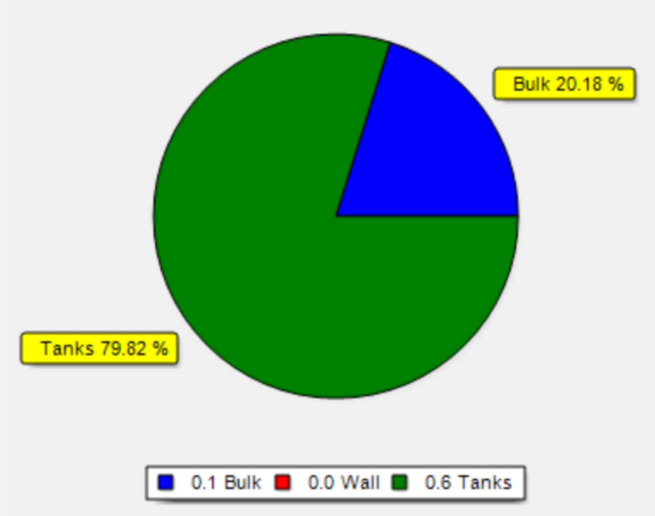


Figure 7. Ammonia Reduction Rate (Inflow Rate = 5 kg/day)

The reaction rate of increasing ammonia in the tank was 79.82%, the bulk (flow) was 20.18%, and the reaction on the wall (pipe wall) was 0%. The magnitude of the reaction rate in the tank may be due to the impact of feed accumulation. This is in line with the results obtained that ammonia comes from feed residues and also fish metabolism in the form of solid waste dissolved in water [34]. Ammonia is the main end-product of protein metabolism in fish and has a negative impact on living organisms [35]. Therefore, it is necessary to regulate feeding using a control-system approach.

The growth of ammonia in each nursery is shown in Figure 8.

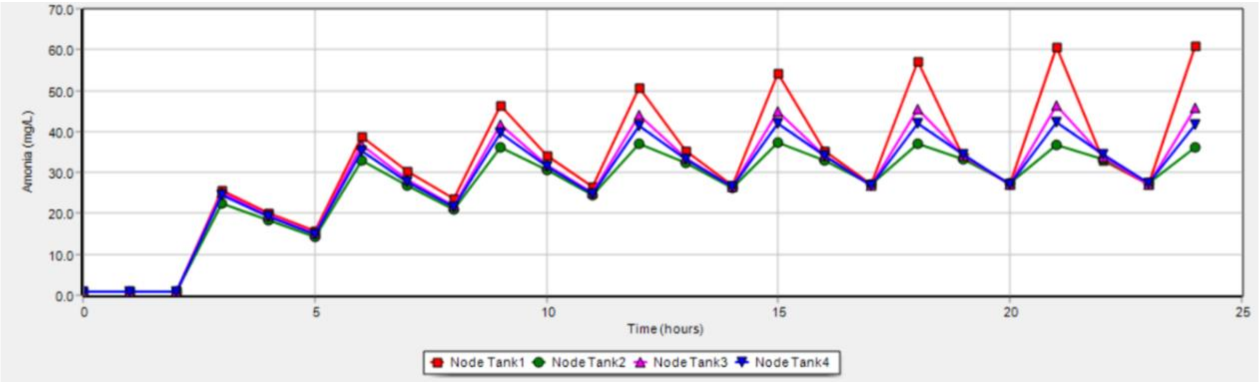


Figure 8. Ammonia Growth in each Nursery Tub

Based on Figure 8, an increase in the level of ammonia reaction began to occur at the 3rd hour after the system was running normally until the 2nd hour, after which it began to decrease until the 5th hour, after which it increased again. The pattern of increasing ammonia reaction occurred because it followed the feeding pattern every 3 h, resulting in bacterial growth, and the shrimp was eaten. Currently, feeding is given as much as 5 kg/day, which greatly affects the level of ammonia reaction in the tank by 79.20%. During 24 h of operation of the system (1 d the system is running), the ammonia level has reached 62 mg/l, and it is feared that feeding too densely will affect the rate of increase in the ammonia reaction; thus, if the feeding process is not controlled, then it is possible that levels will occur after 24 h of the system running. The ammonia reaction exceeds the quality standard threshold for ammonia levels set based on the Indonesian National Standard (SNI) in the shrimp seed production process, which is 100 mg/l [36].

Head that occurs in the Nursery Tub

The 24-hour simulation results show fluctuations in head changes (water level) that occur in each nursery, as shown in Figure 9.

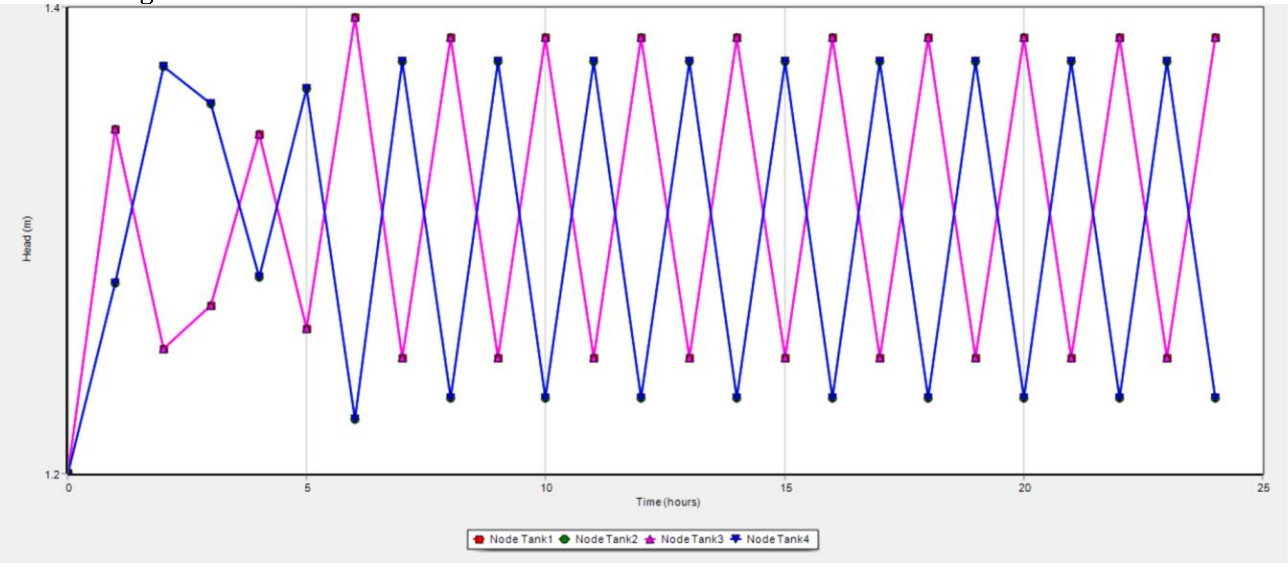


Figure 9. Head on each Nursery Tub

Based on Figure 9, fluctuations in head (water level) in the nursery tank range from 1.20 – 1.38 m. Thus, the minimum height of the tank used in RAS technology is a minimum of 1.4 m to prevent water spills in the hatchery tank. The dimensions applied to the RAS system are in accordance with the SNI standard reference for hatchery tank specifications, namely a minimum diameter of 2 m and a minimum height of 1 m [36].

CONCLUSION

Fluctuations in head changes (water level) that occur in the nursery tub indicate good piping performance, where there is no overflow in the nursery tub, and there is also no reduction in head that is too high. A reduction of the head can disrupt shrimp development due to a lack of water supply. It took 6 h to obtain a stable head. Ammonia growth continues because of shrimp feeding in each tank. Ammonia reduction can be achieved by increasing the capacity of the mechanical filters, biological filters, and moderate feeding.

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