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Analysis of Headloss in Controlled Recirculating Aquaculture System for Fish Heatcheries

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Abstract

Conventional fish hatchery faces many challenges, such as extensive land use, excessive water use, environmental pollution, and a controlled maintenance system, making the fish hatchery process inefficient. The development of a Controlled Water Recirculation System (SRAT) can be a solution to overcome this problem. This study aims to obtain a water balance model and determine the amount of pressure loss that occurs in the SRAT piping network to improve the performance of SRAT by maintaining the uniformity of water discharge in each water tank in the SRAT. First, the average discharge was 2,134 L/min, with a uniformity of only 79%. After the intervention of the model, the uniformity value increased to 99% with an average of 1,269 L/min. It can be concluded that the built model can maintain the uniformity of water discharge in each tub contained in the SRAT.

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1. Introduction

Aquaculture is globally defined by the *Federation of Agriculure Organization* (FAO) as the controlled cultivation of aquatic organisms and aquatic plants that aims to increase production, ownership, and operation by individuals or business entities. In Indonesian regulations, aquaculture is defined as an activity that maintains, raises, or breeds fish and harvests results in a controlled environment. (Fisheries Law No. 45/2009)

Fish hatcheries are the basis for building sustainable aquaculture that produces high-quality fish seeds, both in terms of yield and health, continuously and in large quantities (Kadarusman et al., 2019). Conventional fish hatcheries face many challenges, such as extensive land use, excessive water usage, environmental pollution, and unsustainable maintenance systems, which make the fish hatchery process inefficient. From the aspect of technology development, the application of controlled water recirculation system (SRAT) is one of the ways to replace conventional hatchery systems.

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SRAT is an aquaculture production system that combines fish farming with wastewater treatment using recirculation technology. Wastewater produced by fish is then treated biologically and mechanically, so that it can be reused as clean water for fish needs (Fauzia & Suseno, 2020). Water recirculation is one of the best options for minimizing the volume of clean water required, especially for ornamental fish farming. Various types of ornamental fish require the best water quality as hatchery and growth medium, with the support of operational variables and external environmental conditions (Kristina et al., 2023). In general, SRAT components consist of aquaculture tanks, pumps and pipes, aerators, mechanical filtration, and biological filtration. (Potnis et al., 2022). SRAT uses advanced technology to maintain optimal water quality for fish growth and health. SRAT allows the production of fish in larger quantities and is more efficient than conventional aquaculture systems (Nugraha et al., 2023). In addition, this system reduces the negative impacts on the environment and water conservation owing to more efficient water use. Fish farming using SRAT creates a controlled environment and maintains the stability of water quality, so that it can be relied upon for fish rearing (Prawilta et al., 2022). The utilization of SRAT can create an optimal environment for fish growth, thus increasing productivity in a relatively short cultivation time with a low mortality rate (Saputra & Setiawan, 2011).

SRAT can be considered as a form of engineering application, especially in hydraulic engineering. Ineffective design causes fish hatcheries to fail to determine the pump, which is a crucial factor in the success of SRAT. This was because the pump drove the controlled water recirculation system. Pipes are SRAT components that play a role in fluid distribution. Pipes are the media used to carry, distribute, and control fluids (Mahardhika et al. 2023). The interaction between the water fluid and pipe walls results in pressure loss (Headloss) due to friction between the water and pipe walls (ASME, 2013). This research aims to compile and develop a water equilibrium model in SRAT, determine the amount of pressure loss (headloss) that occurs in the SRAT pipe network, and improve SRAT performance by determining the uniformity of water discharge in SRAT. The benefits of this research are expected to provide information on the pressure loss that occurs in SRAT pipe networks. The results of this calculation can be applied to the design of an appropriate piping system for the SRAT management model.

2. Research Methods

This research was conducted from September 2023 to July 2024 at the Integrated Laboratory of the Department of Civil and Environmental Engineering and Wisma Wageningen, IPB University, Babakan, Dramaga District, Bogor Regency, West Java. The tools and materials used in this study were a set of controlled water recirculation systems (SRAT). The SRAT tool (Figure 1) consists of a 1. Supply tank, 2. Maintenance tank; 3. Filtration tank; 4. Storage tank. Water flow discharge in SRAT was measured with a stopwatch, 1000 ml measuring cup, stopwatch, stationery, and calculating aids, and computers with Microsoft Excel and AutoCAD programs.

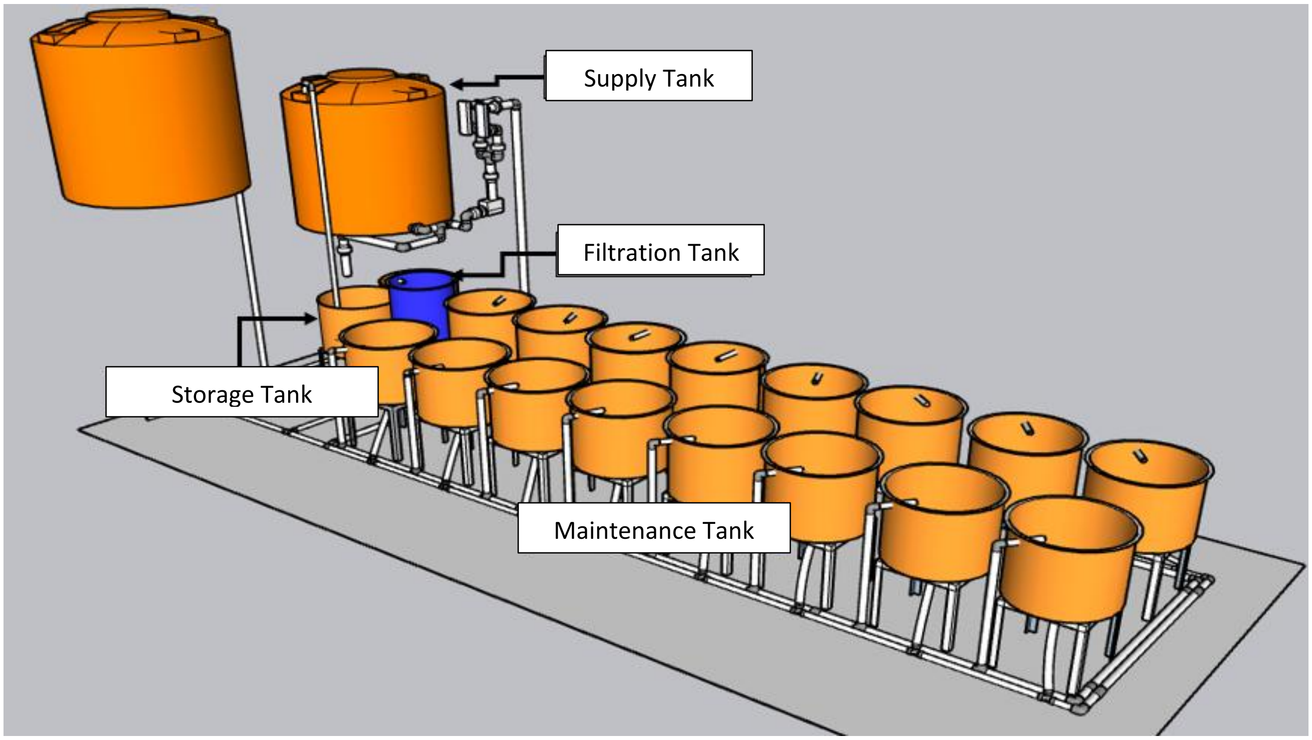

Figure 1. Controlled Water Recirculation System in the Study.

2.1 Controlled Water Recirculation System (SRAT) Model

A Controlled Water Recirculation System can be defined as a system that treats and reuses water with less than 10% water replacement every day (Rudiyanto et al., 2006). SRAT usually requires a small area, less water than conventional aquaculture systems, and an environment that tends to be constant and predictably optimal for the species being cultivated (Ardiyansyah et al., 2004). Treated water is required to accommodate high feed inputs to support high growth rates and stocking densities (Hutchinson et al., 2004). Stocking density refers to the number of animals maintained in a given area or volume. Aquaculture refers to the number of fishes per unit volume of water.

The SRAT model in this study was arranged lengthwise with pipes based on patent No IDP000024637 of Recirculation System and Water Warming System for Fish Hatcheries (Setiawan et al., 2009). The specifications of the SRAT model are listed in Table 1.

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Table1. Tool specifications for SRAT.

No	Subsystem	Specifications		
1	Water Supply Tank	Number of tanks	:	1
		Diameter	:	1,44 m
		Height	:	1,5 m
		Capacity	:	2000 liter
2	Maintenance Tank	Number of tanks	:	16
		Diameter	:	0,8 m
		Height	:	0,6 m
3	Filtration Tank	Number of tanks	:	2
		Diameter	:	0,58 m &0,8m
		Height	:	0,9 m &0,6m
4	Storage Tank	Number of tanks	:	1
		Diameter	:	0,8 m
		Height	:	0,6 m
5	Water pump	Number of Pumps		2
		Dimensions (PxLxT)		165x165x300 mm
		Max Capacity		70 Lpm
		Head		6 m

The SRAT was arranged lengthwise with the pipe connections. Floating flow meters were installed in the supply tanks to measure the discharge flow into the maintenance tanks.

2.2 Data Retrieval

Broadly speaking, this research method was divided into two stages: data collection and analysis. The research began with a literature review and data collection. Primary and secondary data were also collected. The primary data were obtained in the form of the hydraulic parameter data, discharge data, and pipe specifications. Secondary data used in past SRAT research. The data were then calculated and analyzed for water balance and head loss in the SRAT. The values obtained in the previous analysis were used to calculate and analyze discharge uniformity (CU). In this study, the reference CU value was 80%. If the CU value was below 80%, intervention was performed by setting the valve on the SRAT. Valve settings were determined by paying attention to the calculations to achieve the desired CU value. After the intervention, measurements were again taken to obtain the latest data. Flowchart of the research can be seen in Figure 2.

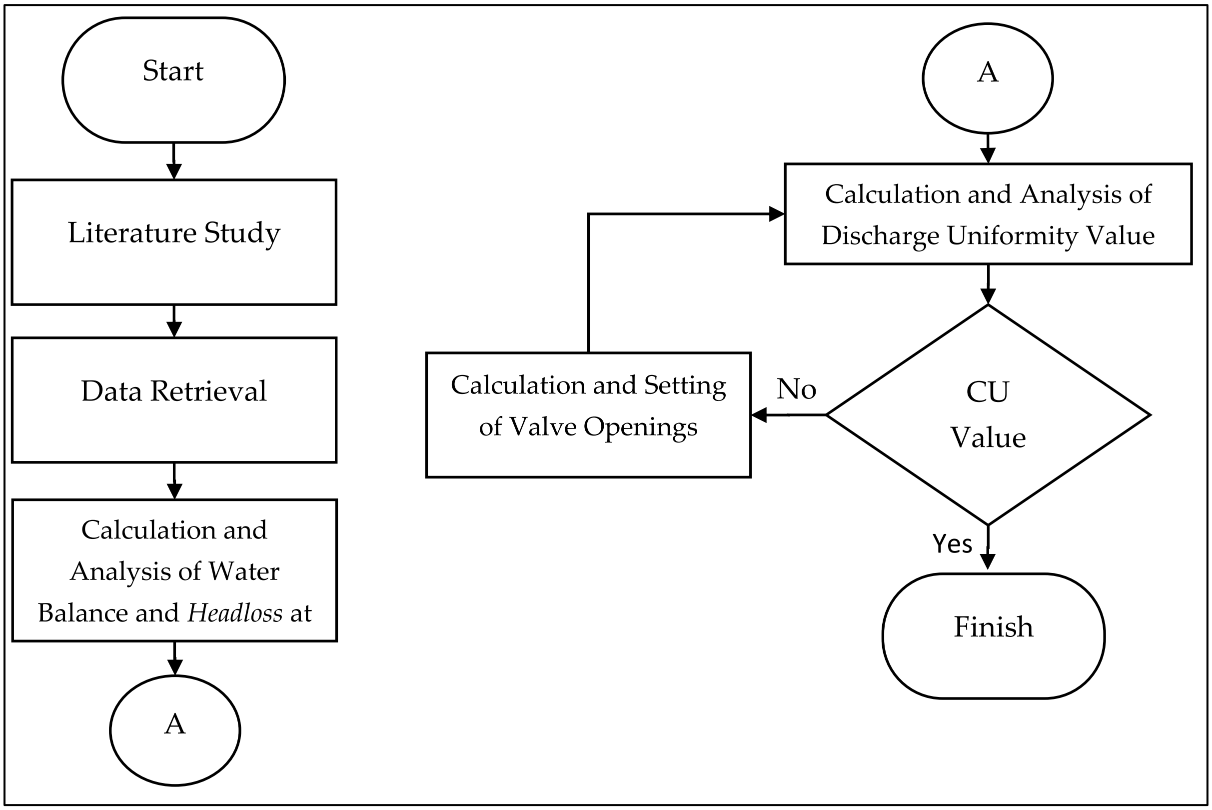

Figure 2. Flowchart of Research Stages.

The discharge data (Q) was used in this study. Discharge is one of the parameters used to calculate pressure loss. Discharge uniformity in SRAT shows that the water recirculation system design is ideal (Saputra & Setiawan, 2011). The more uniform the discharge in the cultivation tank, the better the design that has been made. The discharge data were measured at each maintenance tank output to determine the amount of discharge that came out of each tank. Water discharge was measured 10 times in each maintenance tank, and the results were recorded from the average results. Water discharge can be calculated using the following equation:

$$Q = \frac{V}{t} \quad (1)$$

$$Q = A\,x\,V \quad (2)$$

Where Q is the flow discharge (liter/second) (m^3/s), V is the volume (liter), t is the time, A is the channel cross-sectional area (m^2), and v is the flow velocity (m/s). The obtained discharge value was then analyzed for its uniformity value.

The data obtained from the measurements were analyzed. An analysis was performed to determine the uniformity value. The uniformity of the water distribution is expressed by a parameter

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called the uniformity coefficient (CU). The uniformity coefficient can be calculated using the following equation (I Dewa Gede Jaya Negara et al. 2021):

$$CU = 100\%\ x\ \left(1 - \frac{D}{\bar{Y}}\right) \tag{3}$$

$$D = \sqrt{\frac{\sum(yi-\bar{Y})^2}{n-1}} \tag{4}$$

Where CU is the coefficient of uniformity, D: Standard deviation, $\bar{Y}$: Average price of observations, Yi: value of each observation, n: number of observation points. The CU value obtained is the uniformity value for the SRAT system. The table shows the criteria for uniformity.

Table 2. Criteria for Degree of Uniformity.

Criteria	*Statistical Uniformity* (SU)	*Coefficient of Uniformity* (CU)
Very good	95% - 100%	94% - 100%
Good	85% - 90%	81% - 87%
Good enough	75% - 80%	68% - 75%
Not good	65% - 70%	56% - 62%
Not Feasible	< 60%	< 50%

To obtain the best system design, the discharge uniformity coefficient should be 100%, such that each maintenance tank receives the same volume of water. However, in reality, it is difficult to obtain a perfect uniformity coefficient because of many factors that influence it. In this study, the expected uniformity was greater than 80%.

To set the uniformity value above 80%, it is necessary to analyze the water balance model in the SRAT. The analysis of the water equilibrium model in the system was based on the presence of pressure loss in the system. Pressure loss is defined as the reduction in energy per unit weight of fluid in the flow of liquid in a piping system(Triatmodjo et al, 2008). *Headloss* consists of *major headloss* (hf), *minor headloss* (hm), and *total headloss* (htot) (Putra et al., 2017). A *headloss* is a loss in a piping system that cannot be eliminated.

The loss of energy due to friction is also known as the major head loss. This occurs because of the liquid viscosity and turbulence due to pipe roughness and causes friction, which causes loss of energy along a pipe with a constant diameter in uniform flow(Fathurrohman et al., 2012). The calculation of major headloss uses the Darcy-Weisbach equation, the Darcy-Weisbach equation states "Pressure loss is proportional to the velocity squared of the water flow, the length of the pipe and inversely proportional to the diameter"(Çengel & Cimbala, 2014). The Darcy-Weisbach equation is calculated using the following formula:

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$$h_f = f.(\frac{L}{d}\frac{v_1^2}{2g}) \quad (5)$$

$$v = \sqrt{\frac{2g.d}{L.f}} \quad (6)$$

where hf is *the headloss*, f is the Friction Factor, K is *the minor headloss* coefficient, L is the pipe length, d is the pipe diameter, v is the flow velocity (m/s), and g is the acceleration due to gravity (m/sec^2).

The friction factor for laminar flow is related to the Reynolds number; for laminar flow, the Reynolds number is less than 2000. The Reynolds number and friction factor can be calculated using the following equation:

$$Re = \frac{V.d}{\nu} \quad (7)$$

where Re is the Reynolds number, v is the flow velocity (m/s), d is the pipe diameter (m), and v is kinematic viscosity.

Table 3. Properties of water at Atmospheric pressure.

Temperature (C^o)	Kinematic Viscosity x 10^{-6} (m^2/s)
0	1.792
5	1.519
10	1.308
20	1.007
30	0.804
40	0.661
50	0.556
60	0.477
70	0.415
80	0.367
90	0.327
100	0.266

Source : (Triatmodjo, 2008)

In turbulent flow, the calculations cannot be analytical and are determined empirically using graphs, tables, and empirical equations. Then, the factor f is empirically determined. Several equations have been used to determine f based on the Reynolds number.

The coefficient of friction (f) of the pipe was obtained using the following equation:

1. If the flow in the pipe is laminar (Re < 2000), then the friction coefficient can be calculated using the following equation:

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$$f = \frac{64}{Re} \tag{8}$$

2. Blasius (1913) proposed an empirical equation for the expression of turbulent flow coefficients in smooth pipes (Hager et al., 2003). Therefore, if the flow in the pipe is turbulent (Re>4000), then the friction coefficient can be calculated using the following equation:

$$f = \frac{0.316}{Re^{0,25}} \tag{9}$$

3. If the flow in the pipe is turbulent (Re>4000), then the friction coefficient can be calculated using the following equation:

$$\frac{1}{\sqrt{f}} = 1,74 - 2\log\left(\frac{2\varepsilon}{d}\right) \tag{10}$$

4. The coefficient of friction can also be used as a table, based on the Colebrook equation. The friction factor can also be estimated from a moody graph based on the Reynold's number value, ordinat factor friction and relative roughness parameters

$$f = \frac{\varepsilon}{D} \tag{11}$$

$$r = \frac{\varepsilon}{D}, 10^4 > r > \ 10^6 \tag{12}$$

Intervention actions were taken when the discharge uniformity (CU) was less than 80%. These actions were performed in the form of calculations and technical engineering. Calculations are based on water balance analysis and Bernaoulli's law by considering the pressure loss. Technical engineering is performed by adjusting the discharge output valve.

3 Results and Discussion

3.1 Performance of Controlled Water Recirculation System

During the observation period, the performance test of the controlled water recirculation system was observed as a whole. Initial observations and measurements were made to gauge the performance of the SRAT as well as its discharge uniformity. The measured data are presented in Table 4. In the Tank A row, the average discharge was 2.086 L/min, with a discharge uniformity of 74%. Furthermore, in tank line B, an average discharge of 2.183 L was obtained with a discharge uniformity of 83%. Overall, the average discharge from the SRAT was 2.134 L/min with a total discharge uniformity of 79%.

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Table 4. SRAT initial measurement data.

Tank	Diameter of pipe (mm)	Pipe length (m)	flow velocity (m/s)	Headloss (m)	Debit (L/menit)
Line Tank A					
1	9.57	2.4	0.608	1.621	2.621
2	9.57	4.655	0.591	2.998	2.551
3	9.57	6.82	0.536	3.697	2.312
4	9.57	8.905	0.549	5.033	2.367
5	9.57	11.05	0.547	6.209	2.359
6	9.57	13.29	0.448	5.268	1.934
7	9.57	15.478	0.337	3.734	1.456
8	9.57	20.137	0.251	2.903	1.085
Avarage Tank B Discharge					2.086
Standard Deviation					0.552
Discharge Uniformity (%)					74%
Line Tank B					
1	9.57	2.257	0.591	1.453	2.551
2	9.57	4.461	0.540	2.449	2.328
3	9.57	6.674	0.593	4.320	2.559
4	9.57	8.919	0.427	3.248	1.842
5	9.57	11.066	0.427	4.028	1.841
6	9.57	13.208	0.537	7.193	2.318
7	9.57	15.464	0.370	4.386	1.596
8	9.57	20.074	0.563	11.853	2.427
Average Tank B Discharge					2.183
Standard Deviation					0.369
Discharge Uniformity (%)					83%

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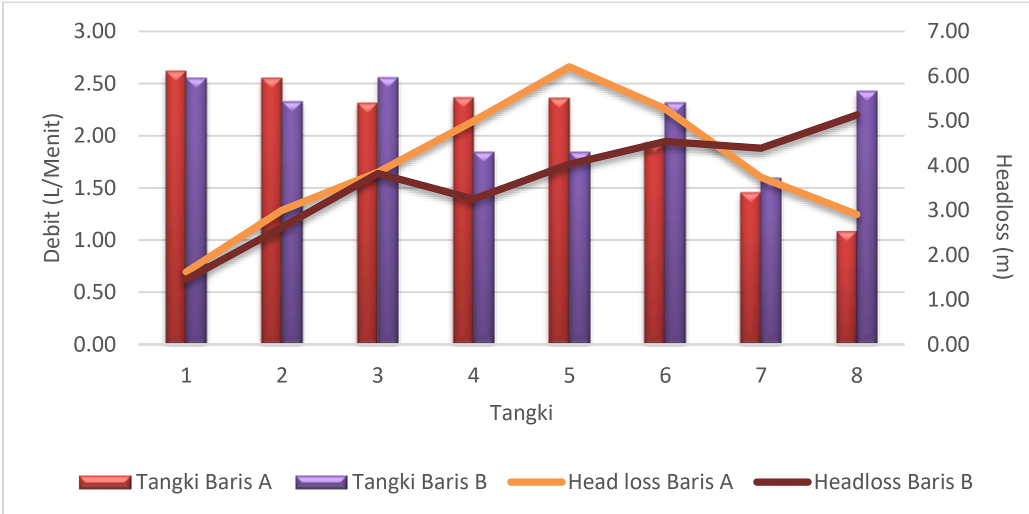

Figure 3. Initial Measurement of Discharge and Headloss.

Figure 3 shows the conditions of discharge and head loss. The farther away the tank, the smaller the discharge, and the calculated head loss follows the amount of discharge. This is in accordance with the fact that head loss can cause a decrease in the fluid pressure in the piping system. This affected the uniformity of discharge in the SRAT. To achieve the desired discharge uniformity, it is necessary to make arrangements (interventions) such that the discharge uniformity can be achieved.

Furthermore, a water equilibrium model analysis of SRAT was performed. The analysis of the water equilibrium model in the system was based on the presence of pressure loss in the system.

Table 5. Analysis of water balance model.

Tank	Reynold Number	Friction Coefficient *f*	Headloss (m)	calculation speed (m/s)	Calculated Debit (L/menit)
			Line Tank A		
1	7233	2.914	1.621	0.608	2.621
2	7038	2.894	2.998	0.591	2.551
3	6379	2.824	3.697	0.536	2.311
4	6532	2.841	5.033	0.549	2.367
5	6510	2.838	6.209	0.547	2.359
6	5335	2.701	5.268	0.448	1.933
7	4017	2.516	3.734	0.337	1.455
8	2993	2.337	2.903	0.251	1.084

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Tank	Reynold Number	Friction Coefficient *f*	Headloss (m)	calculation speed (m/s)	Calculated Debit (L/menit)
Line Tank B					
1	7040	2.894	1.453	0.591	2.550
2	6424	2.829	2.449	0.540	2.328
3	7060	2.897	4.320	0.593	2.558
4	5083	2.668	3.248	0.427	1.842
5	5081	2.668	4.028	0.427	1.841
6	6396	2.826	7.193	0.537	2.318
7	4404	2.574	4.386	0.370	1.596
8	6698	2.859	11.853	0.563	2.427

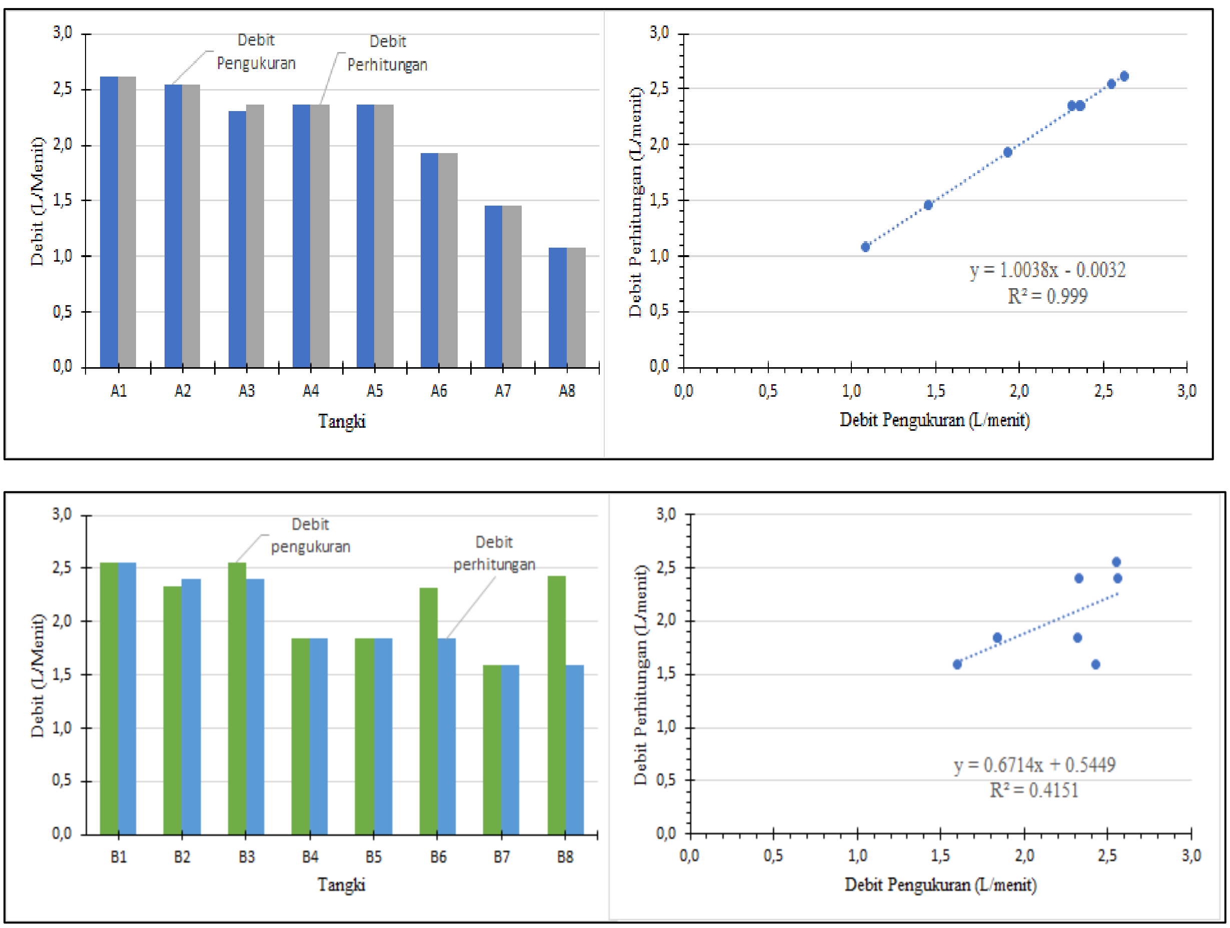

Figure 4. Water balance model analysis and simulation.

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The analysis of the water equilibrium model showed that the coefficient of determination of the equation was 1. This indicates that the results of the water equilibrium model can be used with high accuracy.

3.2 Discharge Uniformity Intervention

Intervention is the action taken to achieve the desired discharge uniformity of <80%. Table 6 shows the calculation results for the design of the discharge uniformity intervention. The valve opening of each tank was planned to achieve the desired discharge uniformity.

Table 6. Piping Design.

Tank	pipe length (m)	Valve Diameter (mm)	Value F	Headloss Hf	Design Debit (L/menit)
Line Tank A					
1	2.4	6.600	3.198	1.621	1.084
2	4.655	6.676	3.167	2.998	1.084
3	6.82	6.959	3.058	3.697	1.084
4	8.905	6.889	3.084	5.033	1.084
5	11.05	6.899	3.080	6.209	1.084
6	13.29	7.503	2.870	5.268	1.084
7	15.478	8.455	2.595	3.734	1.084
8	20.137	9.570	2.337	2.903	1.084
Line Tank B					
1	2.257	6.676	3.167	1.453	1.084
2	4.461	6.937	3.066	2.449	1.084
3	6.674	6.668	3.170	4.320	1.084
4	8.919	7.657	2.821	3.248	1.084
5	11.066	7.658	2.821	4.028	1.084
6	13.208	6.951	3.061	7.193	1.084
7	15.464	8.132	2.681	4.386	1.084
8	20.074	6.817	3.112	11.853	1.084

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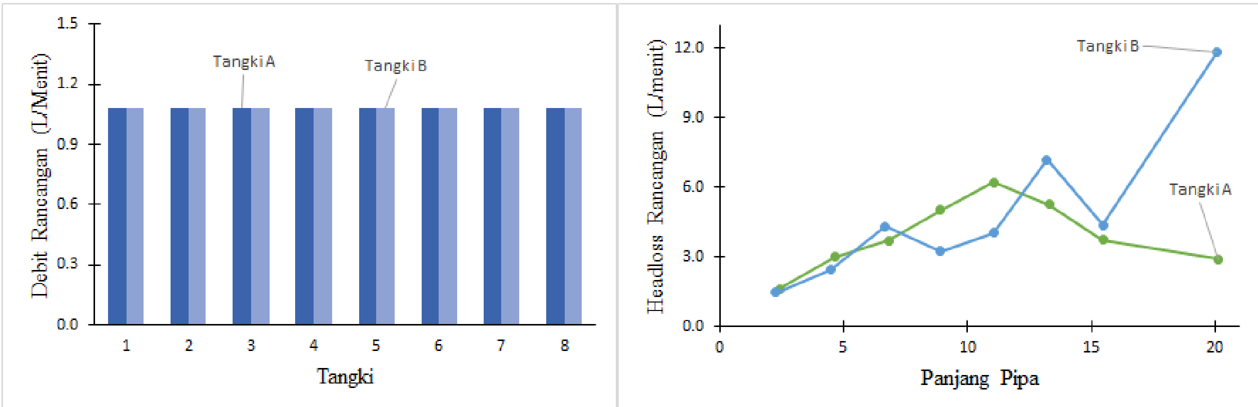

Figure 5. Plan Discharge and Pressure Loss.

Figure 5 shows the results of the planning for discharge uniformity with *valve* settings at each tank output. The planned discharge at the tank output was 1.084 L / minute and the discharge uniformity was 100%.

Head loss in fluid flow in pipes is not linear with changes in valve diameter and pipe length due to changes in flow velocity. The flow velocity in the pipe depends on the discharge and cross-sectional area. If the diameter changes, the flow velocity and head loss also change.

3.3 Water content Performance of Controlled Water Recirculation System After Intervention

Re-measurements were performed to obtain the latest data after engineering. The results of the intervention can be seen in the following table

Table 7. Measurement Data After Intervention.

Tank	Diameter of pipe (mm)	Pipe length (m)	flow velocity m/s)	Debit (L/Min)
		Line Tank A		
1	6.600	2.4	0.529	1.274
2	6.676	4.655	0.517	1.259
3	6.959	6.82	0.475	1.262
4	6.889	8.905	0.485	1.282
5	6.899	11.05	0.484	1.286
6	7.503	13.29	0.409	1.265
7	8.455	15.478	0.322	1.273
8	9.570	20.137	0.251	1.276
Average Tank Discharge Line A				1.272
Standard Deviation				0.010
Discharge Uniformity (%)				99%

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Tank	Diameter of pipe (mm)	Pipe length (m)	flow velocity m/s)	Debit (L/Min)
		Line Tank B		
1	6.676	2.257	0.517	1.238
2	6.937	4.461	0.478	1.273
3	6.668	6.674	0.518	1.291
4	7.657	8.919	0.393	1.239
5	7.658	11.066	0.393	1.247
6	6.951	13.208	0.477	1.280
7	8.132	15.464	0.348	1.294
8	6.817	20.074	0.495	1.264
Average Tank Discharge Line B				1.266
Standard Deviation				0.023
Discharge Uniformity (%)				98%

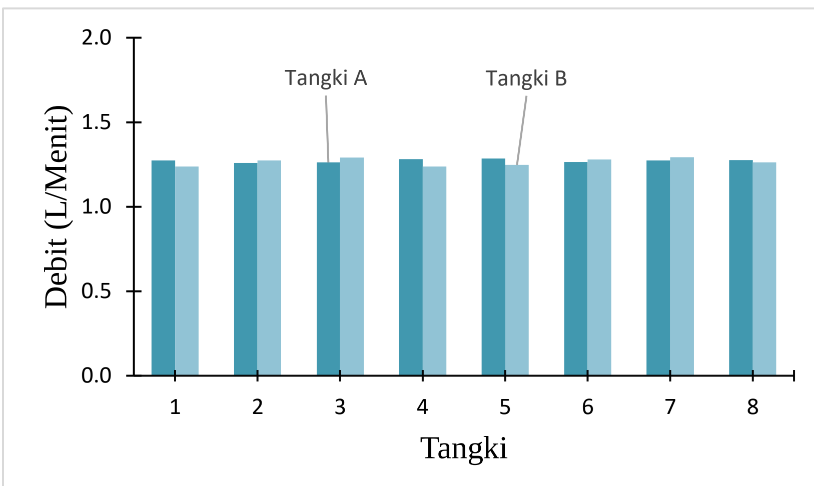

Figure 6. Discharge after Intervention.

In line Tank A, an average discharge of 1,272 L/min with a uniformity of discharge of 99% was observed. Furthermore, in tank line B, an average discharge of 1,266 L/min was obtained with a discharge uniformity of 98%. Overall, the average discharge from the SRAT was 1,269 L/min with a total discharge uniformity of 99%.

The discharge rates after the intervention and the plan were different. This was caused by the valve opening setting. The size of the valve used is so small that it affects the valve opening angle, and

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a slight lack of precision can cause the planned discharge to differ. The magnitude of the valve opening angle determines the amount of discharge flowing through the valve (Wahyu, 2015).

4. Conclusion

The initial performance of the controlled water recirculation system in the initial measurement showed an average discharge of 2.134 L/min with a discharge uniformity of 79%. This value is categorized as good, but still below the expected uniformity. Subsequently, a water equilibrium model was obtained. The created model showed that the coefficient of determination of the equation was close to 1. This indicates that the results of the water balance model can be used with high accuracy. The total head loss in the controlled water recirculation system was 60.8 m. The pressure loss in the SRAT shows that the farther away the tank is, the smaller the discharge will be, and the calculated head loss follows the discharge amount. The SRAT performance increased with increasing discharge uniformity. At the beginning of the measurements, the discharge uniformity is 79%. After intervention, the discharge uniformity reached 99%.

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