

A new method to improve raw water turbidity removal efficiency in sedimentation units with continuous discharges and flow recirculation

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Abstract

The CDF method sedimentation tank is a new method that makes a continuous and controlled exhaust flow a new force acting on the particles to be removed, increasing the efficiency of turbidity removal. The exhaust flow, due to continuous and controlled leaks, causes the production capacity of the sedimentation tank to decrease. To maintain the production capacity of the sedimentation tank and to increase the efficiency of the turbidity removal, the effluent due to leakage is recirculated to the inlet of the flocculation tank. The research reactor consisted of a coagulation tank in the form of a waterfall, a flocculation tank in the form of a baffle channel, and a sedimentation tank using the CDF method. The research reactor was designed with a production capacity of 240 L/hour. To test the capability of increasing the production capacity of the sedimentation tank using the CDF method without increasing the number of sedimentation tank units which is referred to as the uprating process, an experiment was carried out in this study by increasing the production capacity to 360 L/hour or 1.5 times the capacity of the original reactor design. The variations in the recirculation of the effluent due to leaking at the bottom of the settling zone to the inlet of the flocculation bath were 0% (no recirculation), 25%, 50%, 75%, and 100% (all effluent recirculated). The results showed that the higher the CDF flow recirculation value, the higher the turbidity removal efficiency. The highest turbidity removal efficiency was achieved at a 100% CDF flow recirculation value which was 87.21% with a treated water turbidity of 3.267 NTU at a design discharge of 240 L/hour, while at a discharge of 360 L/hour, it was 82.50% with a treated water turbidity of 4.528 NTU.

Keywords: Improved efficiency, Turbidity removal, Raw water, CDF method sedimentation, CDF flow recirculation

1. Introduction

One of the main problems in developing countries is waterborne diseases. Nearly a million people use contaminated water [1]. The removal of contaminants in the water can use coagulation, flocculation, sedimentation, filtration, and disinfection units. The sedimentation unit is one of the units in water treatment plants used to separate solid liquid using gravity settling [2]. The operational constraints of the sedimentation unit with settlers after being used for several years relate to the damage to the arrangement of the settlers [3] and the settlers easily become mossy [4]. In the sedimentation unit using the solid contact method and sludge blanket method, the problem is that a mechanical sludge stirrer is needed in the flocculation process and the need for a sludge management unit becomes larger [2]. Ridwan et al. [5] modified the sedimentation unit by adding a directional flow to the sedimentation zone by utilizing the principle of a continuous and controlled leaking tank at the bottom of the settling zone. This leakage flow causes a continuous and controlled discharge flow at the bottom of the settling which is referred to as the continuous discharge flow (CDF). This leakage flow becomes a new downward force known as CDF force, abbreviated as F_{CDF} , and acts on particles or flocs in the settling zone [6].

The CDF method of sedimentation tanks can achieve a turbidity removal efficiency of 82.38% with an initial raw water turbidity value of 23,613 NTU. The efficiency of 82.38% is achieved at the value of the wastewater flow which is introduced as a CDF value of 6% of the production capacity that enters the inlet of the sedimentation tank [6]. Continuous control of the amount of leakage flow is carried out by adjusting the CDF valve opening in the settling zone which is called the CDF value [5]. The value of the efficiency for removing turbidity from sedimentation by the CDF method can be categorized as relatively high when compared to conventional sedimentation tanks at 65-70% [7]. This continuous and controlled flow of leak discharge reduces the production flow of the system. The greater the CDF value, the greater the volume of the leak discharge flow. This is one of the weaknesses of the sedimentation unit studied by Ridwan et al. [8] which uses a CDF value of 6% of the inflow rate. To maintain the production capacity of the CDF sedimentation tank, the CDF waste stream is recirculated to the inlet of the flocculation unit. The recirculation of this waste stream can also increase the efficiency of the turbidity removal because in the CDF waste stream, there are solids that have been bound with coagulants called flocs [9].

The recirculation of CDF flow to the flocculation unit causes the contact of water flow to go from the outlet of the coagulation unit to the floc contained in the recirculation flow, thereby increasing the size of the floc formed. This is referred to as the settling process

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of the solid contact method [2]. The purpose of this study was to analyze the effect of variations in flow rate and the recirculation of CDF flow on the efficiency of raw water turbidity removal. This was to analyze the effect of variations in the value of CDF flow recirculation of 0%, 25%, 50%, 75%, and 100% to the flocculation unit on the efficiency of removal of turbidity. To get the optimum value of the variation of CDF flow recirculation related to the efficiency of removal of turbidity in the sedimentation unit, the CDF method was used.

2. Materials and methods

The study used a sedimentation reactor using the CDF method with a flow rate variation of 240 L/hour and 360 L/hour equipped with a water-fall coagulation unit and a flocculation unit in the form of a baffle channel. The CDF flow recirculation was added with variations of 0%, 25%, 50%, 75% and 100% of the CDF flow. The sedimentation unit reactor of the CDF method with CDF Flow Recirculation is presented in Figures 1 and 2 [10, 11]. The experiment began with preparing raw water from the Sungai Batang Kuranji, Kota Padang [12], and using alum as a coagulant. Raw water was pumped from the holding tank to the coagulation unit at a flow rate of 240 L/hour and 360 L/hour alternately. The optimum dose of coagulant was added to the coagulation unit along with the water drop. Then the water flowed to the flocculation unit and continued to flow to the sedimentation unit. The CDF effluent was circulated to the flocculation unit with 5 variations, namely 0% as the first variation which meant there was no recirculation, followed by 25% for the second variation, 50% for the third variation, 75% for the fourth variation, and 100% for the fifth variation which means that everything is recirculated. The magnitude of the discharge flow rate at a CDF value of 6% with a discharge of 240 L/hour and 360 L/hour for each recirculation variation is presented in Table 1, Table 2, and Table 3. The recapitulation of the reactor design calculations in this study is presented in Table 4.

Table 1 CDF Flow 6% of Production Discharge

Production Discharge Variation (L/hour)	CDF Value (%)	CDF Flow Discharge	
		(L/hour)	(L/s)
240	6	14.4	0.004
360	6	21.6	0.006

Table 2 CDF Flow Recirculation Discharge at 240 L/hour Production Discharge

CDF Flow Recirculation Variation (%)	CDF Flow Recirculation Discharge	
	(L/hour)	(L/s)
0	0	0
25	3.6	0.001
50	7.2	0.002
75	10.8	0.003
100	14.4	0.004

Table 3 CDF Flow Recirculation Discharge at 360 L/hour Production Discharge

CDF Flow Recirculation Variation (%)	CDF Flow Recirculation Discharge	
	(L/hour)	(L/s)
0	0	0
25	5,4	0,0015
50	10,8	0,0030
75	16,2	0,0045
100	21,6	0,0060

To measure the turbidity of water before entering the reactor and after entering the reactor, this study used a spectrophotometer. The spectrophotometer used was the Cole-Parmer Visible brand with the measurement process referring to the standard provisions of BSN [13]. The data was collected 8 times for each variation of the CDF flow recirculation in real-time, while the reactor was run twice (Duplo) for each discharge of 240 L/hour and 360 L/hour.

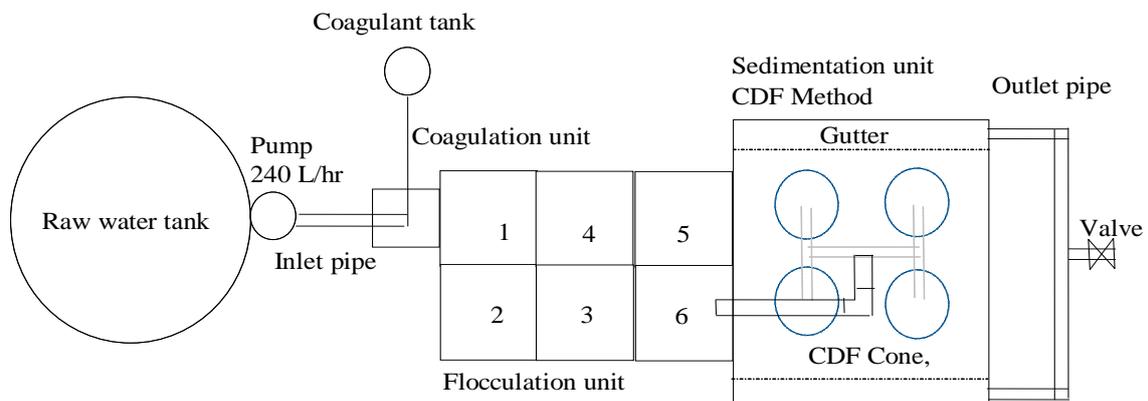


Figure 1 The layout of the sedimentation unit reactor CDF method

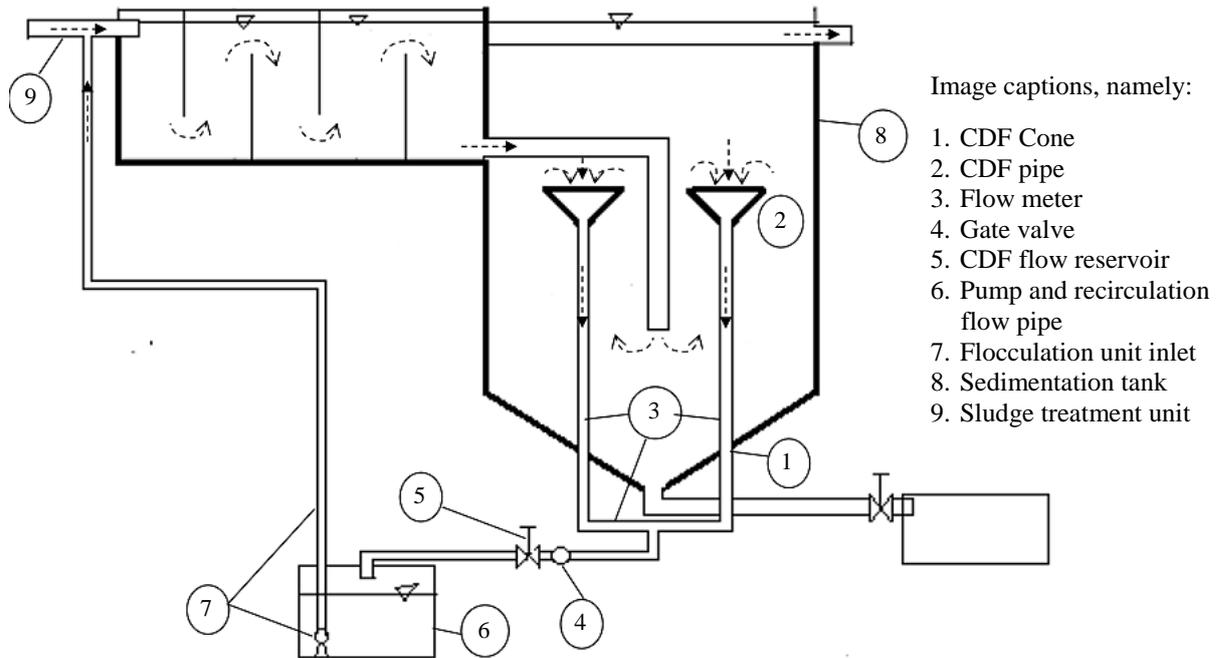


Figure 2 Part of sedimentation unit reactor CDF method with CDF Flow Recirculation

Table 4 Reactor design capacity 240 L/Hr

Design Parameters	Design Results	Design Criteria [11]
Flocculation Unit		
Detention time (minutes)	30	30-45
Velocity gradient (/s)	60-10	60-5
Velocity (m/s)	0.0013	≤ 9
Number of stages	6	6-10
Dimensions of each stage		
Length (m)	0.22	-
Width(m)	0.22	-
Water depth (m)	0.4	-
Sedimentation Unit		
Overflowrate (m ³ /m/hour)	0.22	< 11
Surface load (m ³ /m/hour)	1	0.8-2.5
Length (m)	0.54	-
Width(m)	0.44	-
Water depth (m)	1	1-5
Renolds number	78.81	< 2000
Froude's number	2.35 x 10 ⁻⁴	> 10 ⁻⁵
Detention time (hour)	1	1-3.5
Flow velocity (m/s)	0.00278	≤ 9
Number of collecting channels	2	-
Number of V-notch	22	-
Number of CDF cones	4	-
CDF cone diameter (m)	0.15	-
Variation of CDF flow recirculation to Flocculation Unit	0%	-
	25%	-
	50%	-
	75%	-
	100%	-

The turbidity removal efficiency in the research reactor is presented as a percentage (%) of the removal efficiency. The removal efficiency is formulated in equation (1) below [14].

$$E = \frac{C_o - C_i}{C_o} \times 100\% \tag{1}$$

The nomenclature equation can be explained, namely where E is turbidity removal efficiency (%), Co is initial turbidity (NTU), and Ci is final turbidity (NTU). The relationship between variations in CDF flow recirculation flow and the efficiency of turbidity removal at reactor production discharges of 240 L/hour and 360 L/hour was statistically analyzed using correlation coefficients and significance using the Spearman Rank Analysis [15]. The Spearman Rank correlation coefficient describes the direction and magnitude of the relationship between the variations in CDF flow recirculation discharge and turbidity removal efficiency. The significance value describes the presence or absence of a significant relationship in each variation of the CDF flow recirculation discharge related to the efficiency of removal of turbidity. The correlation coefficient and significant figures are classified into 5 groups, specifically very weak, weak, moderate, strong, and very strong as shown in Table 5. The Spearman rank correlation coefficient is significant if the significance value obtained is equal to or less than 0.05 [15]. The Spearman Rank correlation value is always between 1 and minus 1. If the value obtained is 0, there is no relationship between the independent and dependent variables. In contrast, at a positive value of 1, it can be concluded that there is a positive relationship between the independent variable and the dependent variable, and vice versa.

Table 5 Interpretation of the Correlation Values

Value	Interpretation
0.00 – 0.19	Very weak
0.20 – 0.39	Weak
0.40 – 0.59	Moderate
0.60 – 0.79	Strong
0.80 – 1.00	Very strong

3. Results and discussion

The Jar test results obtained the optimum coagulant dose of 16 mg/L. The final turbidity value obtained from the jar test results was 1.698 NTU with a turbidity removal efficiency of 93.35%. The turbidity of the raw water after passing through the research reactor has decreased as detailed in Table 6. The raw water turbidity allowance is expressed as a percentage where this value indicates the amount of turbidity that can be removed by the treatment unit due to the CDF flow recirculation process in this experiment.

The highest turbidity decrease level occurred when the CDF flow recirculation variation was 100%. The efficiency of decreasing the average turbidity in raw water with 100% CDF flow recirculation is 87.21% for a discharge of 240 L/hour. At the 40th minute or the 8th data point in the experiment, the turbidity removal efficiency reached 87.87% with the highest decrease in raw water turbidity from 25.536 NTU to 3.267 NTU. The greater the recirculated CDF flow, the higher the turbidity removal rate [9]. The variation of 0% CDF recirculation flow represents no recirculation treatment in reference to the CDF flow. In other words, the CDF flow generated from a 6% CDF value is immediately discarded and not reused. The average turbidity removal efficiency without this CDF flow recirculation treatment reached 82.41%. Variations in CDF flow recirculation by 25% can increase the efficiency of turbidity removal to 83.59%, at a 50% CDF flow recirculation to 84.78%, at a 75% CDF flow recirculation to 85.98%, and at a 100% CDF flow recirculation to 87.21%.

Table 6 describes the same trend between the production capacity of 240 L/hour as the reactor design discharge and the production discharge of 360 L/hour as the uprating discharge for the research reactor, namely an increase in the turbidity removal efficiency for each increase in the CDF flow recirculation value. The highest turbidity reduction efficiency increase occurs when the CDF flow recirculation variation is 100%. Variations of the recirculation flow of 100% CDF at a discharge of 360 L/hour can reduce the turbidity up to 4.528 NTU from the initial turbidity of 25.875 NTU with a removal efficiency of 82.50%. When the efficiency between variations in the discharge of 240 L/hour with a discharge of 360 L/hour is compared, the highest turbidity removal efficiency is obtained at a discharge of 240 L/hour. This is due to the fact that the 240 L/hour discharge is the design discharge of the research reactor, meaning that the detention time of each processing unit is in accordance with the design criteria [11] and the processing can function properly. At a discharge of 360 L/hour, there was an increase in production capacity to 1.5 times the initial capacity of the research reactor design which was 240 L/hour. The detention time of the flocculation and sedimentation units is shorter and faster when compared to the design criteria. The detention time of the flocculation unit is 20 minutes and the sedimentation unit is 40 minutes, while the design criteria for the detention time of the flocculation unit is 30-45 minutes and the sedimentation unit is 1-6 hours, even though the value of the velocity gradient (G) of the flocculation unit is still in accordance with the design criteria. However, what is interesting about the increase in production capacity from 240 L/hour to 360 L/hour in this study is that the treated water from the research reactor is still able to meet the quality standard for processed water, which is 4.528 NTU.

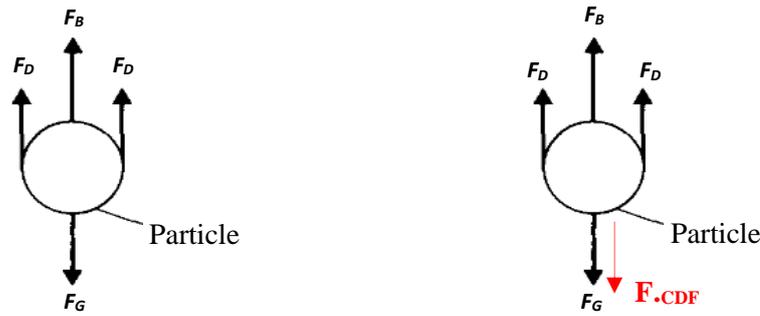
The results of this study provide information on the uprating capacity of the sedimentation tanks using the CDF method as seen from the increase in production capacity that has been carried out to achieve the quality standard of treated water. This is very reasonable if analyzed based on the Stokes equation. According to Stokes, a particle moving in a fluid will be affected by buoyant force (Fb), frictional force (Fd) and gravitational force (Fg).

$$F = F_g - F_b - F_d \quad (2)$$

This total force is equal to the force acting on the particle that accelerates the particle, so the above equation becomes:

$$m \cdot (dv/dt) = F_g - F_b - F_d \quad (3)$$

The description of the formula is (m) mass (g), (dv/dt) acceleration of the particle (m/s^2), (Fg) effective gravitational force (N), (Fb) buoyant force (N), (Fd) frictional force between wall and particle (N), and (F) the total force in the particle (N). The addition of the F_{CDF} force acting on the particles due to the CDF waste stream will increase the value of the settling velocity of the particles, as illustrated in Figure 3.



(a) There is no leak in the Sedimentation Tank

(b) There is a leak in the Sedimentation Tank

Figure 3 Forces Acting on Particles [2]

Detention time that is below the design criteria in the sedimentation unit can affect the process of separating particles in the water which requires sufficient time [16]. Therefore, this experiment, with a variation in the discharge of 360 L/hour, has not yet obtained the maximum turbidity removal efficiency. However, it is still relatively high compared to conventional sedimentation at 82.50% [17] and able to meet the quality standard of processed water.

Table 6 Analysis of the Effect of CDF Recirculation Flow Variations on the Efficiency of Turbidity Removal at 240 L/hour and 360 L/hour Production Discharges.

Time to (t) (minute)	Recirculation Variation (%)	Flow Discharge 240 L/hour			Flow Discharge 360 L/hour			Average Turbidity Removal Efficiency (%)
		Initial Turbidity (NTU)	Final Turbidity (NTU)	Turbidity Removal Efficiency (%)	Initial Turbidity (NTU)	Final Turbidity (NTU)	Turbidity Removal Efficiency (%)	
5	0	25.536	4.602	81.98	25.876	6.170	76.16	
10	0	25.536	4.570	82.11	25.876	6.102	76.42	
15	0	25.536	4.552	82.17	25.876	6.005	76.79	
20	0	25.536	4.527	82.27	25.876	5.965	76.95	
25	0	25.536	4.493	82.41	25.876	5.886	77.25	
30	0	25.536	4.427	82.66	25.876	5.808	77.56	
35	0	25.536	4.408	82.74	25.876	5.743	77.81	
40	0	25.536	4.350	82.97	25.876	5.731	77.85	77.10
5	25	25.536	4.297	83.17	25.876	5.684	78.04	
10	25	25.536	4.281	83.24	25.876	5.675	78.07	
15	25	25.536	4.242	83.39	25.876	5.662	78.12	
20	25	25.536	4.222	83.47	25.876	5.579	78.44	
25	25	25.536	4.177	83.64	25.876	5.527	78.64	
30	25	25.536	4.143	83.78	25.876	5.519	78.67	
35	25	25.536	4.134	83.81	25.876	5.480	78.82	
40	25	25.536	4.036	84.20	25.876	5.451	78.93	78.47
5	50	25.536	3.982	84.41	25.876	5.382	79.20	
10	50	25.536	3.966	84.47	25.876	5.374	79.23	
15	50	25.536	3.943	84.56	25.876	5.317	79.45	
20	50	25.536	3.930	84.61	25.876	5.257	79.68	
25	50	25.536	3.857	84.90	25.876	5.208	79.87	
30	50	25.536	3.846	84.94	25.876	5.184	79.97	
35	50	25.536	3.799	85.12	25.876	5.066	80.42	
40	50	25.536	3.767	85.25	25.876	5.032	80.55	79.80
5	75	25.536	3.691	85.55	25.876	4.991	80.71	
10	75	25.536	3.665	85.65	25.876	4.977	80.77	
15	75	25.536	3.626	85.80	25.876	4.964	80.82	
20	75	25.536	3.588	85.95	25.876	4.892	81.09	
25	75	25.536	3.551	86.09	25.876	4.854	81.24	
30	75	25.536	3.538	86.15	25.876	4.834	81.32	
35	75	25.536	3.507	86.27	25.876	4.770	81.57	
40	75	25.536	3.467	86.42	25.876	4.716	81.77	81.16
5	100	25.536	3.395	86.71	25.876	4.696	81.85	
10	100	25.536	3.357	86.85	25.876	4.638	82.08	
15	100	25.536	3.325	86.98	25.876	4.607	82.20	
20	100	25.536	3.299	87.08	25.876	4.601	82.22	
25	100	25.536	3.253	87.26	25.876	4.507	82.58	
30	100	25.536	3.215	87.41	25.876	4.467	82.74	
35	100	25.536	3.192	87.50	25.876	4.390	83.03	
40	100	25.536	3.099	87.87	25.876	4.323	83.29	82.50

The greater the amount of recirculated CDF stream is directly proportional to the increase in turbidity removal efficiency. This is because the presence of floc particles (colloid-coagulant) in the recirculated CDF flow will bind back to the floc particles in the flocculation unit to form larger flocs that are easy to settle [18]. This increase in the efficiency of the removal of turbidity is also due to the influence of the CDF effluent flow in the settling zone which increases the amount of floc removal from the treated water through the effluent so then the treated water has a lower turbidity value.

Based on the experiments carried out, there is a difference in the turbidity removal efficiency at 240 L/hour and 360 L/hour for a 100% CDF flow recirculation value of 4.71%. The turbidity removal efficiency at 240 L/hour discharge is higher than 360 L/hour. However, at 75% and 100% CDF flow recirculation with a discharge of 360 L/hour, the resulting turbidity value meets the quality standard which is below 5 NTU as referred to in Regulation [19].

The level of correlation and significance between the variations in CDF flow recirculation on the efficiency of raw water turbidity removal, which was statistically analyzed using the SPSS application using the Spearman Rank method, is presented in Tables 7 and 8. The variation of CDF flow recirculation and the efficiency of the removal of turbidity shows a strong correlation with a value of 0.980. It also indicates a unidirectional correlation between the recirculation variations and turbidity removal efficiency in raw water treatment. Thus, the greater the amount of recirculated CDF flow, the greater the efficiency of raw water turbidity removal, and vice versa. The significance value obtained is $0.000 \leq 0.05$ which means that the relationship between the two variables is significant.

Based on Tables 7 and 8, it can be seen that the level of correlation between the two variables, namely the variation of CDF flow recirculation and the efficiency of the removal of turbidity, shows a value of 0.980. This value shows a very strong and unidirectional correlation between the recirculation variations and the efficiency of removal of turbidity in the raw water treatment. A positive value in the correlation coefficient indicates a unidirectional effect between the two variables which means that the greater the amount of recirculated CDF flow, the greater the efficiency of raw water turbidity removal and vice versa. The significance value obtained is $0.000 \leq 0.05$ which means that the relationship between the two variables is significant.

Table 7 Correlation and Significance of the Variation of CDF Recirculation Flow on Efficiency of Raw Water Turbidity Removal at 240 L/hour Production Discharge

			Recirculation Variation	Turbidity Removal Efficiency
Spearman's rho	Recirculation Variation	Correlation Coefficient	1.000	.980**
		Sig. (2-tailed)	.	.000
		N	80	80
	Turbidity Removal Efficiency	Correlation Coefficient	.980**	1.000
		Sig. (2-tailed)	.000	.
		N	80	80

** . Correlation is significant at the 0.01 level (2-tailed).

Table 8 Correlation and Significance of the Variation of CDF Recirculation Flow on the Efficiency of Raw Water Turbidity Removal at 360 L/hour Production Discharge

			Recirculation Variation	Turbidity Removal Efficiency
Spearman's rho	Recirculation Variation	Correlation Coefficient	1.000	.980**
		Sig. (2-tailed)	.	.000
		N	80	80
	Turbidity Removal Efficiency	Correlation Coefficient	.980**	1.000
		Sig. (2-tailed)	.000	.
		N	80	80

** . Correlation is significant at the 0.01 level (2-tailed).

4. Conclusions

The greater the amount of recirculated CDF flow, the greater the efficiency of the raw water turbidity removal and vice versa. The highest average turbidity removal efficiency occurs at a 100% recirculating discharge from the CDF flow which is 87.21% for a production discharge of 240 L/hour and 82.50% for a production discharge of 360 L/hour. The turbidity value of treated water with CDF flow recirculation variations of 0%, 25%, 50%, 75%, and 100% ranged from 3.267-4.491 NTU at a production discharge of 240 L/hour to a flow rate of 360 L/hour which ranged from 4.528-5.926 NTU. The increase in production discharge from the sedimentation reactor using the CDF method from 240 L/hour to 360 L/hour reduced the efficiency of turbidity removal for each variation of 0%, 25%, 50%, 75%, and 100% recirculation of CDF flow. Increasing the production discharge from the sedimentation reactor using the CDF method from 240 L/hour to 360 L/hour can reduce the turbidity removal efficiency but is still able to reach the quality standard of CDF recirculation values at 75% and 100%. The sedimentation reactor and CDF method therefore has an uprating capability.

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