
Study of Raw Water Turbidity Removal in Sedimentation Unit Continuous Discharges Flow (CDF) Method Using Plate Settlers

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Abstract— The sedimentation unit using the continuous discharges flow (CDF) method can remove raw water turbidity of 91.09% with initial turbidity of 75.248 NTU. The performance of the sedimentation unit using the CDF method needs to be tested at high turbidity, which is more than 100 NTU. Sedimentation using the CDF method with the addition of plate settlers is an alternative that can be done by increasing the turbidity value. This study aims to determine the performance of the sedimentation unit using the CDF method with the addition of plate settlers in the removal of high turbidity. The study used a laboratory-scale reactor of 240 L/hour, with units consisting of waterfall coagulation, baffle channel flocculation, and a 5% CDF method sedimentation unit with plate settlers. The study used artificial raw water with variations in turbidity of 110.355 NTU, 132.035 NTU, and 153.338 NTU. The research shows that the efficiency of removal of turbidity on average for the variation of turbidity is 92.32%, 91.25%, and 89.87%, respectively. The correlation value and significance of Rank Spearman from the variation of turbidity to reactor performance are -0.926 and 0.00, respectively. In other words, the more turbid the raw water, the lower the reactor performance.

Keywords: Turbidity, Sedimentation CDF method, Plate settlers

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1. Introduction

Drinking water treatment installation is a process of removing pollutant concentrations in water, so that water quality can meet drinking water quality requirements [1]. The drinking water treatment plant consists of intake, coagulation, flocculation, sedimentation, filtration, and reservoir units [2]. An intake is a building that catches water from raw water sources originating from surface water [2]. Coagulation is the process of adding and rapidly stirring coagulants to raw water which aims to destabilize colloidal and suspended solid particles [3]. Flocculation is slow stirring where small flocs collide resulting in clumps of colloidal particles that can be deposited [2], while sedimentation is a solid-liquid separation that utilizes gravity to remove suspended solids [3]. Filtration is a solid-liquid separation in which a liquid passes through a porous medium or other porous material to remove as much of the suspended solids as possible [3].

One source of raw water in drinking water treatment comes from surface water [4]. Surface water physically contains physical pollutants or sediments which include discrete materials such as gravel, sand, and total suspended solids that cause turbidity in water bodies [4]. There are 3 classifications of raw water turbidity levels, namely low turbidity (smaller than 50 NTU), moderate turbidity with an interval of 50-100 NTU, and high turbidity with a value of more than 100 NTU [5]. One of the drinking water treatment installation units that can eliminate the turbidity of raw water is a sedimentation tank [4]. The performance of the sedimentation tank in removing turbidity is influenced by hydraulic factors, such as uniformity of flow and suitable surface loads [6].

Surface load or often also called overflow rate is the ratio of incoming water discharge per unit surface area of the settling tank. In increasing the efficiency of turbidity removal in sedimentation units with overflow rates of 3 to 6 times that of conventional sedimentation, it is possible to add tube or plate settlers while maintaining laminar flow conditions in the settling zone [3]. Modification of the sedimentation unit with the plate settlers method can increase the efficiency of turbidity removal from 56% to 71%. The flow rate affects the efficiency of removal of turbidity where the smaller the flow rate, the efficiency of removal of turbidity becomes higher [7]. The detention time in the sedimentation unit using tube settlers is much shorter, from 2-4 hours to 10-20 minutes [8]. The performance of the sedimentation unit can also be improved by using the solids contact method which is designed to be integrated into the sedimentation unit called the clarifier unit by engineering the flow direction in a radial-flow manner [9]. To increase the efficiency of removal of turbidity, the conditions of the Reynolds number (NRe) and Froude number (NFr) must be considered in the deposition zone [7]. Based on [10], concerning Procedures for Planning Package Units for Water Treatment Plants, NRe must be less than 2.000 and NFr must be greater than 10^{-5} . NFr and NRe describe the state of flow in the depositional zone which must meet design standards [9]. NFr that is too small will cause the flow to be at rest so that the effectiveness of the treatment will decrease, while NFr that is too large will cause high water fluctuations so that it can break up the formed floc. NRe that is too large will cause the flow to become turbulent so that the floc formed will break and become difficult to settle in the sedimentation tank [11].

One of the latest method developments in the sedimentation unit is the continuous discharge flow (CDF) method. The CDF method is a continuous and controlled discharge flow at the bottom of the deposition zone which results in downflow [12]. According to [13], the removal of turbidity in raw water with a sedimentation unit using the CDF method is carried out by applying the principle of a leaky reactor or leaky flow. The results of research conducted by Kurniawan [13] using raw water with a turbidity of 75.248 NTU sedimentation unit CDF method with the value of the flue flow or what is called the CDF value is 5% of the production discharge, able to remove turbidity in raw water of 91.09%. Kurniawan's research [13] has not shown the performance of the CDF method of sedimentation units in treating raw water at high turbidity levels. It is considered necessary to test the performance of the sedimentation unit using the CDF method, especially during the rainy season, when turbidity tends to increase to 629 NTU, [14]. An increase in the turbidity of raw water can reduce the performance of the drinking water treatment plant unit [15]. Therefore, efforts to maintain a good removal performance from the CDF sedimentation unit in removing turbidity so that it can reach the maximum recommended turbidity level of 5 NTU are important [16]. The use of a great chamber unit and a pre-sedimentation unit is estimated to reduce the turbidity level of raw water in the range of 40-75% so that it can reduce the use of coagulants in the coagulation process [2].

The performance improvement of the sedimentation unit using the CDF method when the turbidity level is high can be done by expanding the depositional area by adding plate settlers in the settling zone. According to [17], plate settlers are parallel plate arrangements with predetermined distances, angles, and lengths that aim to widen the surface of the deposition area and shorten the deposition time. This study was intended to analyze the efficiency of the sedimentation performance of the CDF method with plate settlers in removing turbidity in raw water with a classification of high turbidity levels on a laboratory scale.

2. Method

The performance of the sedimentation unit reactor using the CDF method in removing turbidity with the addition of plate settlers using an artificial raw water sample with 3 variations of turbidity which is in the high-level turbidity classification, which is more than 100 NTU. The slope of the plate settlers is 60° . This study begins with a literature review, preparation of tools and materials, and the operation of tools to obtain data to be analyzed as a result of the research. The study used a miniature device in the form of a coagulation unit, flocculation, and sedimentation using the CDF method with the addition of plate settlers. The coagulation process uses hydraulic energy in the form of falling

water and the flocculation process uses hydraulic energy in the form of baffle channels, and the sedimentation process uses the CDF method with the addition of plate settlers. The design of the reactor refers to [10] with supporting equipment for reactor operations, namely, a submersible pump to pump raw water from the holding container to the sedimentation reactor with a flow rate of 240 L/hour, 1000 ml Beaker glass to accommodate the processed water as a water sample to be tested for parameters. turbidity, water reservoir and coagulant container, Jar test Velp JLT6 Flocculator to determine the optimum dose of coagulant, Shidmazu spectrophotometer to measure water turbidity before and after processing, Favorite brand Stirrer to stir the solution artificially so that it becomes homogeneous, Analytical Balance from Mettler Toledo brand to weigh PAC coagulant which is used in the manufacture of coagulants and kaolin clay which is used in the manufacture of artificial raw water.

The materials used in the study included: PAC coagulant with the optimum dose determined using a jar test based on the size of the floc formed, the time of deposition of the floc, and the turbidity of the water produced after the jar test [18]. The raw water used for this research is an artificial solution made in such a way with 3 variations in turbidity levels, namely 110±5 NTU, 130±5 NTU, and 150±5 NTU. Referring to the research of [19], an artificial solution was made by dissolving clay kaolin in water for 1 hour using a stirrer, then the clay kaolin solution was allowed to stand for 24 hours to ensure that the hydration process of the particles was going well so that the relative turbidity value stable as measured using a spectrophotometer. While Fiber is used as the basic material for making plate settlers with a length of 36 cm and a width of 44 cm as many as 6 pieces. Plate settlers made of fiber are installed in sedimentation tanks with an angle of 60° and glue is used to bond between the fibers and the walls of the sedimentation tank.

The design of the reactor consisting of a waterfall as a coagulation unit, insulated channels on the flocculation unit, and sedimentation of the CDF method with the addition of plate settlers refers to [16] as the results of the design can be seen in Table 1, Figure 1 and Figure 2. Operation of the reactor for data acquisition The research begins with checking the condition of the equipment to ensure it is in good condition. The raw water is pumped from the holding container to the coagulation bath with a flow rate of 240 L/hour and mixed with PAC coagulant at the optimum dose using a water plunger for rapid stirring. The water flows into the hydraulic flocculation and continues to flow to the sedimentation unit with a CDF value of 5%, which is a continuous and controlled flow of wastewater at 5% of the product discharge. The time interval for water sampling at the output of the sedimentation tank is adjusted to the steady flow time. Steady time is determined based on the flow of water entering and leaving the reactor the same. Reactor removal efficiency is determined based on the decrease in the level of turbidity and the amount of discharge wasted during the treatment process. The reactor running time was 90 minutes for one variation of turbidity in one experiment. Operational time begins when the running tool has been running for 90 minutes for the initial flow of the reactor and has reached a steady time. The operational time of the reactor for sampling lasted 50 minutes with the interval of time for taking water samples every 5 minutes so that during the operational time of the reactor, 10 samples of water were tested for turbidity values.

Table 1. Design of the CDF Sedimentation Reactor with the addition of Plate Settlers

The design	Calculation Value	Value of Design Criteria
<i>Coagulation Unit</i>		
High of the waterfall (m)	0.29	-
Long (m)	0.092	-
Wide (m)	0.046	-
Depth (m)	0.08	-
Detention time (s)	5	1-5
Velocity gradient (/s)	795.99	> 750

The design	Calculation Value	Value of Design Criteria
Flocculation Unit		
Stage	6	6-10
Length of each stage (m)	0.22	-
Width of each stage (m)	0.22	-
Depth of each stage (m)	0.4	-
Energy control	Perforated wall	Perforated wall
Detention time (minute)	30	30-45
Velocity gradient (/s)	60-10	60-5
Flow velocity (m/s)	0.0013	≤ 9
Sedimentation Unit		
Surface load (m ³ /m ² /hour)	1	0.8-2.5
Overflowrate (m ³ /m/hour)	0.22	< 11
Long (m)	0.54	-
Wide (m)	0.44	-
Depth (m)	1	1-5
NRe	65.72	< 2.000
NFr	1.96 x 10 ⁻⁴	> 10 ⁻⁵
Detention time (hour)	1	1-3.5
Flow velocity (m/s)	0.00278	≤ 9
Numbers of cone CDF	4	-
CDF cone diameter (m)	0.15	-
CDF pipe diameter(m)	0.01	-
The amount of gutter	2	-
The amount of V-notch	22	-
Plate Settlers		
Channel length (p)	m	0.54
Channel width (l)	m	0.44
Plate slope	o	60
Number of plates (n)	units	6
plate length (lp)	m	0.36
Distance between plates (w)	m	0.02
Detention time (t _d)	hour	0.07
Reynolds Number (Re < 2000)	-	13.748
Froude's Number (Fr > 10 ⁻⁵)	-	1.55 x 10 ⁻⁵

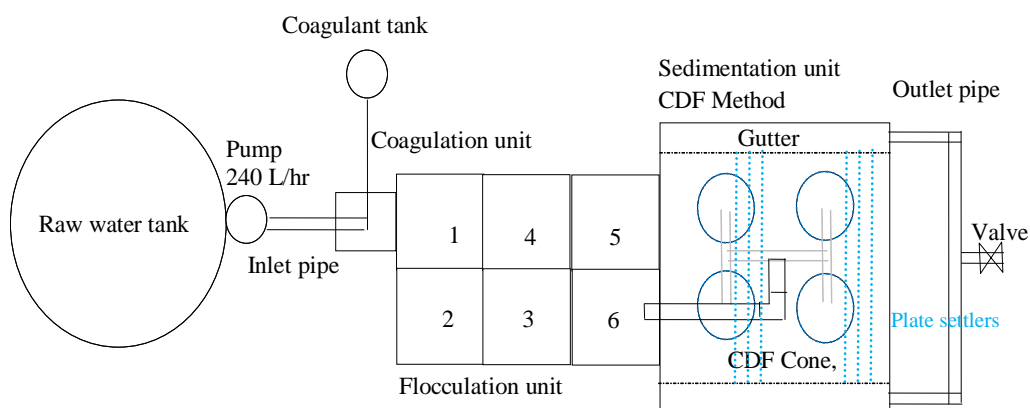


Figure 1. CDF method sedimentation unit layout with plate settlers

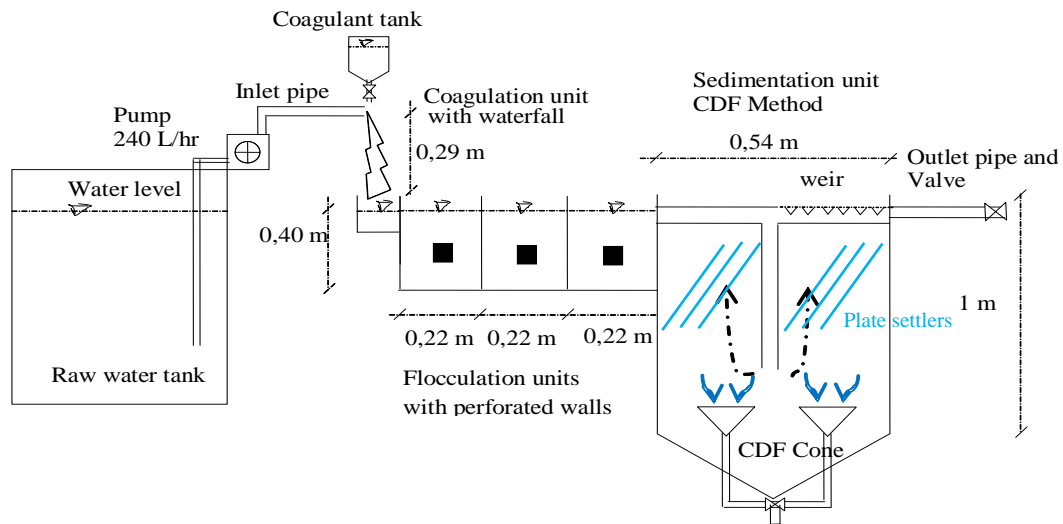


Figure 2. Parts of the CDF method sedimentation unit with plate settlers.

Water that comes out through the outlet of the sedimentation tank is accommodated using a 1000 mL beaker glass to measure its turbidity. The final turbidity measurement was carried out based on [20] in Nephelometric Turbidity Units (NTU). Data were collected twice (Duplo) for the 5% CDF value, equipped with a 0.15 m diameter cone and 60° slope plate settlers. The analysis and discussion were carried out after the experimental data were obtained. The data analysis carried out includes an analysis of the relationship between the performance of the sedimentation unit using the CDF method with plate settlers on variations in turbidity in artificial raw water with a high level of turbidity classification using a descriptive statistical approach using the Spearman Rank method.

3. Result and Discussion

3.1 Optimum Dose of Coagulant Poly Aluminum Chloride (PAC)

PAC is one of the main polymer coagulants used in drinking water treatment [21]. When there is a process of adding coagulant according to the optimum dose into the water, a Van der Waals force will occur, namely, the cation will neutralize the negative charge of the colloid so that floc will form [22]. In this study, the optimum dose of PAC coagulant for three variations of turbidity was 10 ppm. The results of the jar test measurement in determining the optimum coagulant dose can be seen in Table 2.

Table 2. Optimum Dose of PAC Coagulants in Raw Water

Dose	Initial Turbidity	Floc Size	Settling time	Final Turbidity
Raw Water Turbidity 110.355 NTU				
0.5 mL	110.355	++	09.50,2	20.766
1 mL		+++	09.05,7	8.377
1.5 mL		+++	09.33,5	12.426
2 mL		+	10.04,6	45.893
2.5 mL		+	10.15,2	46.773
3 mL		++	09.43,2	22.097
Raw Water Turbidity 132.035 NTU				
0.5 mL	132.035	++	08.38.26	19.108
1 mL		+++	07.26.27	11.231
1.5 mL		++	09.15.20	20.269
2 mL		++	08.43.44	19.209
2.5 mL		+	08.48.76	25.955

Dose	Initial Turbidity	Floc Size	Settling time	Final Turbidity
3 mL		++	09.30.08	28.797
Raw Water Turbidity 154.338 NTU				
0.5 mL	154.338	++	09.50.2	21.409
1 mL		+++	02.52.30	12.323
1.5 mL		++	03.30.30	15.776
2 mL		++	06.31.09	22.850
2.5 mL		+	06.33.08	11.309
3 mL		+	06.40.23	26.522

3.2 Effect of Turbidity on Sedimentation Performance of CDF Method with Plate Settlers

The data produced in this study as described in full in Table 3, shows a decrease in turbidity in the raw water after going through the processing at the coagulation, flocculation, and sedimentation units. Turbidity removal efficiency is expressed as a percentage, where this value indicates the amount of turbidity that can be removed by the raw water treatment reactor in this experiment.

Table 3. Removal of Raw Water Turbidity

Turbidity Variation (NTU)	Initial turbidity (NTU)	Trial 1		Trial 2		Average Final Turbidity (NTU)	Average Elimination Efficiency (%)
		Final Turbidity (NTU)	Removal Efficiency (%)	Final Turbidity (NTU)	Removal Efficiency (%)		
110	110.355	9.142	91.72	8.907	91.93	8.470	92.32
		9.054	91.80	8.891	91.94		
		8.881	91.95	8.768	92.06		
		8.411	92.38	8.682	92.13		
		8.313	92.47	8.632	92.18		
		8.212	92.56	8.385	92.40		
		8.204	92.57	8.295	92.48		
		8.182	92.59	8.175	92.59		
		8.105	92.66	8.066	92.69		
		8.088	92.67	8.012	92.74		
130	132.035	11.958	90.94	11.904	90.98	11.550	91.25
		11.916	90.98	11.866	91.01		
		11.772	91.08	11.855	91.02		
		11.755	91.10	11.692	91.14		
		11.645	91.18	11.616	91.20		
		11.553	91.25	11.524	91.27		
		11.263	91.47	11.518	91.28		
		11.219	91.50	11.371	91.39		
		11.191	91.52	11.211	91.51		
		11.045	91.63	11.136	91.56		
150	154.338	16.089	89.58	16.104	89.57	15.626	89.87
		15.906	89.69	15.855	89.73		
		15.837	89.74	15.727	89.81		
		15.693	89.83	15.704	89.82		
		15.659	89.85	15.643	89.86		
		15.553	89.92	15.573	89.91		
		15.432	90.00	15.527	89.94		
		15.337	90.06	15.504	89.95		
		15.315	90.08	15.402	90.02		
		15.285	90.10	15.384	90.03		

Based on Table 3, the average turbidity value of raw water treatment with initial turbidity of 110.355 NTU, 132.035 NTU, and 153.338 NTU, respectively, is 8.470 NTU, 11.550 NTU, and 15.626

NTU. Based on the Regulation of the Minister of Health of the Republic of Indonesia [16] concerning Drinking Water Quality Requirements, the standard value for water turbidity is 5 NTU. This shows that there is still a turbidity load left to be processed to meet the standard. However, the performance of the sedimentation unit using the CDF method with the addition of plate settlers is relatively high when compared to research conducted by Indrawan et al. [23] using coagulation tanks, flocculation tanks, and sedimentation tanks with plate settlers, the Ip/dp ratio of 15 using low turbidity raw water (5.36 NTU) with a standard water turbidity removal efficiency of 63.62%. Research by Husaeni, et al, [4], coagulation, flocculation, and sedimentation tanks with plate settlers using low turbidity standard water (3.56 NTU) with an efficiency of 68.45% turbidity removal from raw water. Meanwhile, Ermayendri & Riangdeko [24], the sedimentation unit with the application of a granite plate settler uses high turbidity raw water (238 NTU) with an efficiency of removing raw water turbidity of 61.82%.

The higher the turbidity value of raw water to be processed, the efficiency level of removal of raw water turbidity decreases. The percentage values of the average turbidity removal efficiency for raw water with initial turbidity of 110.355 NTU, 132.035 NTU, and 153.338 NTU were 92.32%, 91.25%, and 89.87%, respectively. In 2 experiments, the highest average turbidity removal percentage value occurred when the initial turbidity value of raw water was 110.355 NTU with a percentage of 92.32%. Based on Kurniawan's previous research [13] the efficiency of removing turbidity in sedimentation using the CDF method with a value of 5% only reached 91.09%. The CDF method sedimentation unit with plate settlers works quite well for raw water with high turbidity, this is evidenced by the high percentage of turbidity removal efficiency in this study. The statistical analysis used is Spearman Rank analysis. The value of the correlation and its significance can be seen in Table 4. below:

Table 4. Correlation and Significance of Artificial Turbidity Variation with Raw Water Turbidity Removal Efficiency

			Turbidity Variation	Removal Efficiency
<i>Spearman's rho</i>	Turbidity Variation	<i>Correlation Coefficient</i>	1.000	-0.926**
		<i>Sig. (2-tailed)</i>	.	0.000
		N	60	60
	Removal Efficiency	<i>Correlation Coefficient</i>	-0.926**	1.000
		<i>Sig. (2-tailed)</i>	0.000	.
		N	60	60

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

Based on Table 4. it can be seen that the level of correlation between the two variables is 0.926. This value indicates a very strong correlation. The negative correlation (-) indicates an inverse relationship between variations in turbidity and the efficiency of removing turbidity in the raw water treatment. This means that the greater the turbidity value of the raw water treated, the efficiency of the removal of turbidity of the raw water treated in the reactor decreases and vice versa. The significance value obtained is 0.000, which is smaller than 0.01 stating that there is a significant relationship between variables. Based on this relationship, it can be analyzed that by adding 6 plate settlers to the sedimentation unit, the efficiency of turbidity removal can be increased. However, as the turbidity load of the raw water to be treated increases, the work efficiency of plate settlers decreases. According to Kwak et al. [25] treatment of very cloudy raw water during the rainy season, the load of solids including larger particles can be reduced substantially by the application of pre-sedimentation in a water treatment plant during the rainy season, [26].

4. Conclusion

Modification of the sedimentation unit using the CDF method with a CDF value of 5% or with a wastewater discharge of 12 L/hour, by adding 6 plates of plate settlers with a distance between plates of 2 cm, plate length 36 cm, plate width of 44 cm and plate angle slope. 60°. The average turbidity removal efficiency of water is 92.32%, 91.25%, and 89.87% respectively, for the initial turbidity value of raw water is 110.355 NTU, 132.035 NTU, and 153.338 NTU.

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