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The Effect of Coagulants Variations in the Coagulation Unit on the Efficiency of Raw Water Turbidity Removal Sedimentation Unit Continuous Discharges Flow (CDF) as a New Method

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Abstract –Variations in the type of coagulant resulted in different floc characteristics. The sedimentation unit with continuous discharges flow or (CDF) method is a sedimentation unit that applies the leaking tank phenomenon, so it is possible that it will affect the condition of the floc that has been formed and in the end can affect the efficiency of turbidity removal. This study was to determine the effect of the type of coagulant in the coagulation unit on the removal of raw water turbidity in the sedimentation unit using the CDF method with a 6% discharge ratio to the product discharge. The raw water used is Sungai Batang Kuranji water with a turbidity of 27.63 NTU. The experimental reactor consisted of a coagulation-flocculation unit and a sedimentation unit with various coagulants being Poly Aluminum Chloride (PAC), Ferric Chloride, and Alum. The results showed that the efficiency of removing turbidity from the Sungai Batang Kuranji by PAC coagulant was 90.12%, Ferric Chloride 86.99%, and Alum 81.72%. The Spearman correlation value of the coagulant variable on the efficiency of the removal of turbidity is 0.948, indicating a unidirectional effect between the two variables. The addition of 6% CDF flow in the settling zone did not break the floc because the flow formed was still laminar.

Keywords: Variation of Coagulant,Coagulation Unit, Efficiency, Turbidity, The Sedimentation CDF Method

1. Introduction

The sedimentation unit using the continuous discharges flow method, abbreviated as CDF, is a new mechanism for removing raw water turbidity in a drinking water treatment plant [1]. The CDF method of Sedimentation Unit applies the principle of a leaky tank by creating a continuous and controlled flow of discharge in a very small amount from the bottom of the sedimentation zone [1]. The exhaust flow due to leaking becomes a new force (the direction of the downward force) which acts on the floc particles apart from the buoyant force (the direction of the upward force), the frictional force (the direction of the force opposite to the direction of the floc movement) and gravity (the downward force direction). [2], so that the resultant force acting on the floc can increase the efficiency of turbidity removal from the sedimentation unit [3]. This idea arose because there were operational constraints of the sedimentation unit with the settlers method commonly used in the field, namely the breakdown of the settlers arrangement [4] and the formation of moss [5] after several years of use. In the sedimentation unit, the solids contact method and the sludge blanket method require a mechanical mud stirrer unit for the flocculation process and a larger sludge management unit [1,3]. The efficiency of turbidity removal of the sedimentation unit using the CDF method with a ratio of 6% to the production discharge, which is known as the CDF value of 5% [1], is relatively high, which is 91.09% compared to conventional sedimentation which has a removal efficiency of 75-89%. and 82-97% in the sedimentation unit of the settlers method [6].

Turbidity removal aims to remove some microbes, organic material, and other colloidal particles, to increase the effectiveness of the subsequent processing. The World Health Organization (WHO) recommends that drinking water turbidity should be less than 1 Nephelometric Turbidity Unit (NTU) and for water entering the disinfection unit it should be less than 4 NTU [7] and the United States

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Environmental Protection Agency (USEPA) sets the level of turbidity for most water treatment plants must be less than 0.3 NTU and 95% are at a maximum of 1 NTU [8].

To increase the efficiency of removal at water treatment plants, it is necessary to study the potential problems that may arise at each stage of the water treatment process, including the condition of raw water and the coagulation unit, flocculation, and sedimentation [9]. In water treatment plants, to achieve the optimum coagulation-flocculation process, it is necessary to regulate all conditions that are interrelated and affect the process, including the use of coagulants [10]. Coagulation-flocculation is a means for separating suspended solids (SS) and colloidal particles, such as clay, silt, etc., or their derivatives from organic materials such as decomposition products of plants or animals. SS colloids are smaller with a diameter of less than 1 mm and SS colloids are the cause of color and turbidity in water and cannot precipitate naturally. The coagulation process is a process of destabilizing colloidal particles and suspended particles, including bacteria and viruses, by neutralizing their electrical charge to reduce the repulsion between particles, and the material used for neutralization is called a coagulant [11]. Flocculation is defined as the process of combining unstable particles after the coagulation process through a slow mixing (stirring) process to form lumps or swarms that can be stored or filtered for further processing [12].

The coagulant can be a metal salt that reacts with alkaline water to produce an insoluble and easily precipitated floc of metal hydroxide. Goodsettling is the formation of flocs that produce solids that can settle by gravity in the sedimentation process [13]. Conventional coagulants commonly used in large-scale water treatment are mostly metal salts such as Aluminum Sulfate, Ferric Sulfate, and Ferric Chloride, which depend on the pH of the water and the correct dosage to produce consistently high coagulation efficiencies [14]. Various types of conventional coagulants are easily obtained at low prices in the market [15] such as Aluminum Chloride Polymer (PAC), Alum or Aluminum Sulfate, and Ferric Chloride. It is important to test the effectiveness of turbidity removal efficiency in the sedimentation unit using the CDF method using several types of coagulants, considering that the discharge flow caused by leakage in the sedimentation method will affect the strength of the floc bonds that have been formed in the previous flocculation coagulation process.

2. Material and Method

The research was conducted on a laboratory scale with a production flowrate of 240 L/hour using a sedimentation reactor using the CDF method which is equipped with a coagulation process in the form of a plunge and flocculation of baffle channels [1] as presented in Figures 1 and 2. The design of this reactor is guided by the specifications and procedures for planning a water treatment plant. [16,17] as presented in Table 2. The value of CDF as the ratio of discharge flow to production discharge is 6%. The raw water used in this study is the Sungai Batang Kuranji, Kota Padang at coordinates 0°54'46.02" S 100°27'9.72" E with a river flow velocity condition of 0.3 m/s, width the river is 47 m and the depth of the river is in the range of 40cm-60cm. The raw water of the Sungai Batang Kuranji is alternative raw water that has the potential to be used as a source of raw water for the urban drinking water supply system of Kota Padang in terms of quality, quantity, and continuity. A sampling of Batang Kuranji raw water refers to SNI 6989.57-2008 [18] which is presented in Table 1.

Table 1. Data Quality of Sungai Batang Kuranji Water Samples

No.	Parameter	Sungai Batang Kuranji Water Sample			
		First Day Sampling		***Sampling Day Two***	
		Test results	**Unit**	**Test results**	**Unit**
1	Turbidity	27.635	NTU	26.796	NTU
2	pH	7.2	-	7.1	-
3	Temperature	26.9	ºC	25.9	ºC
4	TDS	144	mg/L	142	mg/L

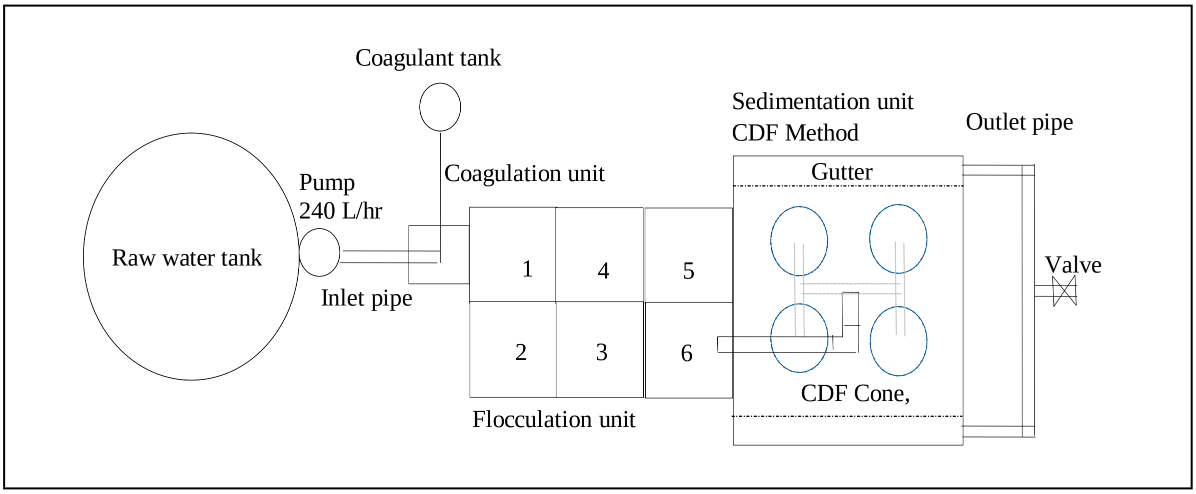

Figure 1. The layout of the sedimentation unit reactor CDF method [1]

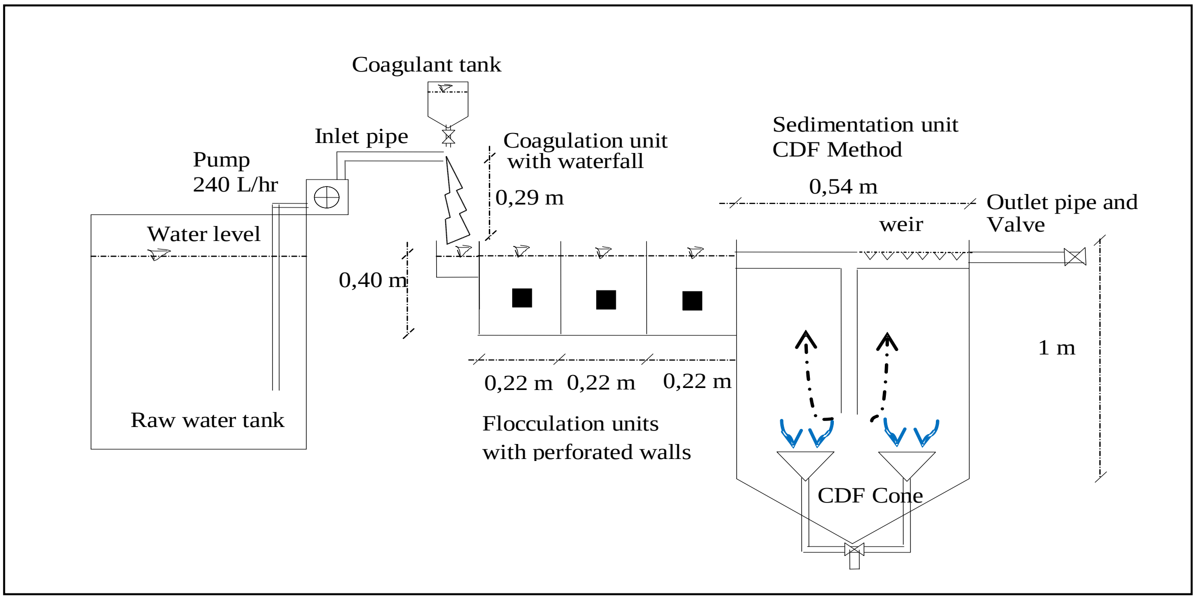

Figure 2. Part of sedimentation unit reactor CDF method [1].

The initial process of the research is that the raw water in the storage tank is flows to the coagulation unit which is equipped with a water plunge system as a coagulant hydraulic stirrer with raw water at a detention time of 5 seconds [16,17]. The coagulants used in this study were PAC, Alum, and Ferric Chloride, while the dose of coagulant added to raw water was the optimum dose obtained from the results of Jartest [19]. Then the water from the coagulation unit flows into the flocculation unit with a vertical baffle channel system with a detention time of 30 minutes, after that the formed floc is set aside in the sedimentation unit using the CDF method with a detention time of 1 hour. The research experiment on the reactor was carried out in 2 repetitions or duplicate for each variation of the coagulant used with the value of the research results being the average value of the data for each repetition. The data generated from this study are in the form of the optimum dose of each coagulant used, data on turbidity, acidity (pH), and temperature (°C) of raw water before processing and after processing as presented in Table 3. The research data were analyzed to obtain the turbidity removal rate of each coagulant in the sedimentation reactor using the CDF method. The correlation value and data significance of each type of coagulant on the efficiency of the removal of turbidity in the sedimentation unit using the CDF method, as presented in Table 3, were tested statistically using the Spearman Rank method through the statistical application package for the social sciences (SPSS) version 20 [20].

Table2. Reactor design [1]

The design	Calculation Value	Value of Design Criteria [16]
Coagulation Unit		
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
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	< 2000
NFr	1.96×10^{-4}	$> 10^{-5}$
Detention time (hour)	1	1-3,5
Flow velocity (m/s)	0.00278	≤ 9
Numbers of coneCDF	4	-
CDF cone diameter(m)	0.15	-
CDF pipe diameter(m)	0.01	-
The amount of gutter	2	-
The amount of V-notch	22	-

Table 3. Experimental Data Schematic

Coagulants	Initial Condition	The final result
PAC	Initial turbidity Initial pH Initial temperature The Optimum dose of coagulant	Final turbidity Final pH Final temperature
Alum	Initial turbidity Initial pH Initial temperature The Optimum dose of coagulant	Final turbidity Final pH Final temperature
Ferric Chloride	Initial turbidity Initial pH Initial temperature The Optimum dose of coagulant	Final turbidity Final pH Final temperature

The coagulants used were PAC, Alum, and Ferric Chloride. The optimum dose of coagulant was determined using jartest with variations in coagulant doses, namely 0.8 mL, 1.0 mL, 1.2 mL, 1.4 mL, 1.6 mL, and 1.8 mL. The selection of the optimum dose was determined based on the size of the floc formed, the time of settling of the floc, and the turbidity of the water measured after the jartest. The procedure for determining the optimum dose of coagulant using Jartest is SNI 19-6449:2000 [19]. The reactor in this study consisted of coagulation, flocculation, and sedimentation unit using the CDF method made of acrylic material with a thickness of 5 mm and acrylic pipe with a diameter of 10 mm. The reactor is equipped with a 240 L/hour submersible pump, QR30E Brushless DC Pump model to pump raw water from the holding tank to the reactor. Determination of the optimum coagulant dose using the Flocculator Jar Test model Velp JLT6 and UV-vis spectrophotometer used to measure the turbidity value of raw water [20].

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3. Result and Discussion

The efficiency of removing turbidity in the sedimentation unit using the CDF method for each coagulant variation from the results of the study was calculated using the formula below [21].

$$E = \frac{C_o - C_i}{C_o} x100\% \quad (1)$$

The flow conditions created by the CDF discharge stream at a ratio of 6% of the production discharge in the settling zone, are described by the Reynolds number (NRe) and Froude (NFr) using the following equation [22].

$$N\,\mathrm{Re} = \frac{v_0 x R}{\upsilon} \quad (2)$$

(2)

$$NFr = \frac{v_0}{\sqrt{gxR}} \quad (3)$$

(3) (2)

(2)

(3)

The data on the type of coagulant used on the efficiency of the removal of turbidity were statistically analyzed in the form of the Rank Spearman correlation coefficient value which indicates the direction and strength of the relationship between the type of coagulant used and the value of the removal of turbidity, and a significance value which indicates whether or not there is a significant relationship in each variation of the coagulant used. used for the efficiency of removal of turbidity [23]. The correlation coefficient value and significance value are interpreted in 5 classifications, namely very weak, weak, moderate, strong, and very strong as presented in Table 4. Spearman Rank correlation coefficient value is declared significant if the significance value obtained is equal to or less than 0.05 or 0.01 [23] and the Spearman Rank correlation value is between minus 1 to 1. If the value obtained is equal to 0, it means that there is no correlation or there is no relationship between the independent and dependent variables. A positive value of 1 means that there is a positive relationship between the independent variable and the dependent variable, while a negative value of 1 means that there is a negative relationship between the independent variable and the dependent variable.

Table4. Interpretation of CorrelationValues

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

3.1 Optimum Coagulant Dosage

Polymer Aluminum Chloride (PAC)

The optimum dose of coagulant was obtained from the jar test with dosage variations of 0.8 ml, 1.0 ml, 1.2 ml, 1.4 ml, 1.6 ml and 1.8 ml by considering the level of turbidity of the raw water because the coagulation process can be hampered if the raw water turbidity level is too low or too high [24]. At the standard water turbidity level of 27.635 NTU, the optimum dose for PAC coagulant is 1.4 ml [19]. The selection of the optimum dose was measured from the final turbidity produced after the jar test and the size of the floc formed and the time of settling of the floc [19]. The experimental results can be seen in Table 5 and Figure 3 below.

Table 5. Optimum Dose of PAC Coagulants

Initial turbidity(NTU)	Dose (mL)	pH beginning	Floc Size	Temperature (^{O}C)	Settling time	Water Turbidity After Jar test (NTU)	Optimum Dose (mL)
27.635	0.8	7.1	+++	7.1	13.55	5.678	1.4
	1.0		+	7.1	13.14	4.836	
	1.2		+++	7.0	04.21	3.325	
	1.4		+++	7.1	09.11	1.115	
	1.6		++	7.0	11.27	2.968	
	1.8		+++	7.2	12.10	3.370	

Information : + Small and few flocks
++ Large and few flocks
+++ Large and many flocks

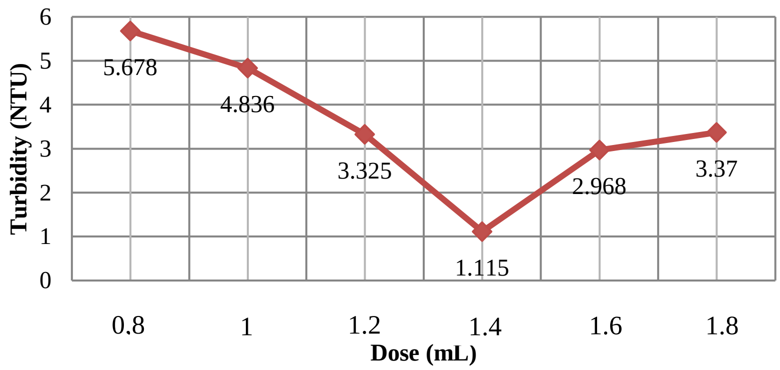

Figure 3. PAC Coagulants Turbidity Concentration

Alum Coagulant

With the same treatment and observation on Jar test of PAC coagulant, the optimum dose of Alum coagulant obtained was 1.6 mL with the lowest turbidity of 3.051 NTU. This dose can reduce the turbidity level of raw water to a level that meets the drinking water quality requirements based on the Regulation of the Minister of Health of the Republic of Indonesia, 2010 [25], which is less than 5 NTU. In addition, at this dose, the size of the floc produced was larger and more numerous as presented in Table 6 and Figure 4.

Table 6. Optimum Dose of Coagulant Alum

Initial turbidity (NTU)	Dose (mL)	pH beginning	Floc Size	Temperature (^{O}C)	Settling time	Water Turbidity After Jar test (NTU)	Optimum Dose (mL)
27.635	0.8	7.2	+	7.1	06.15	6.613	1.6
	1.0		++	7.1	09.12	5.751	
	1.2		++	7.0	09.21	4.517	
	1.4		+++	7.1	08.43	3.723	
	1.6		+++	7.0	08.93	3.051	
	1.8		++	7.2	08.16	3.203	

Information : + Small and few flocks
++ Large and few flocks
+++ Large and many flocks

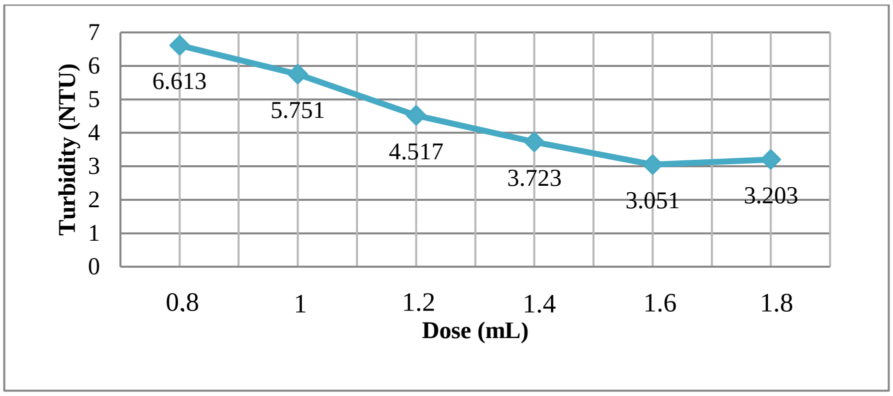

Figure 4. Alum Coagulants Turbidity Concentration

Ferric Chloride Coagulant

The optimum dose of Ferric Chloride coagulant using Jart test with dosage variations of 0.8 ml 1.0 ml, 1.2 ml, 1.4 ml, 1.6 ml, and 1.8 ml is 1.0 mL with the lowest turbidity is 1.268 NTU Experimental results can be seen in Table 7 and Figure 5

Table 7. Optimum Dosage of Ferric Chloride

Initial turbidity (NTU)	Dose (mL)	pH beginning	Floc Size	Temperature (°C)	Settling time	Water Turbidity After Jar test (NTU)	Optimum Dose (mL)
26.769	0.8	7.1	+++	7.2	12.53	3.259	1.0
	1.0		++	7.0	13.09	1.268	
	1.2		+++	6.9	12.09	2.673	
	1.4		+++	7.0	11.16	2.947	
	1.6		++	7,0	10.04	3.811	
	1.8		+++	7.0	10.32	1.732	

Information : + Small and few flocks
++ Large and few flocks
+++ Large and many flocks

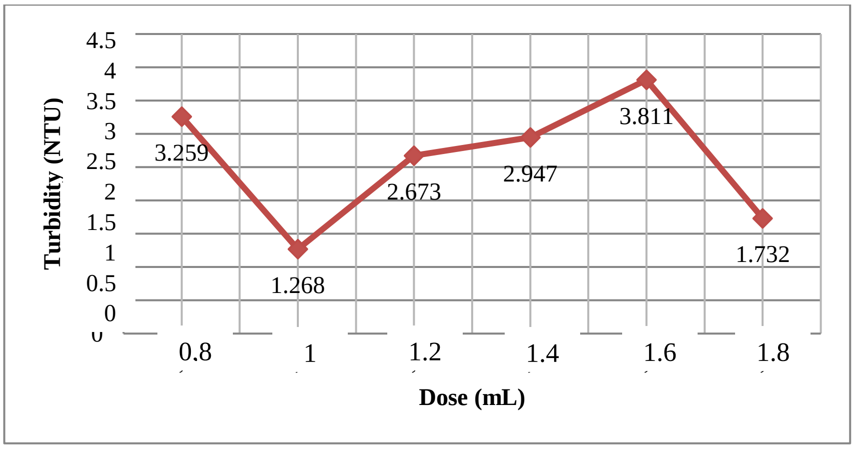

Figure 5 Ferric Chloride Coagulants Turbidity Concentration

3.2 Variation of Coagulant on Efficiency of Raw Water Turbidity Removal

In Table 8 and Figure 6 below, the highest efficiency of turbidity removal in the sedimentation unit using the CDF method is obtained using Poly Aluminum chloride (PAC) coagulant with an average efficiency of 90.12% decrease in turbidity, while with Ferric Chloride and Alum coagulants, respectively 86.99% and 81.72% respectively. The experimental results show that the type of coagulant used affects the effectiveness of the coagulation and flocculation processes. The coagulant becomes the core of the formed floc and increases the floc density, thereby accelerating the sedimentation process. Excessive doses of coagulant can also result in stabilization so that the level of turbidity can increase [26].

PAC is a polymer compound that has the dominant form of Aluminum species with the formula $Al_{13}O_4(OH)_{24}(H_2O)_{12}^{7+}$ abbreviated as Al_{13}^{7+}, while Alum is a monomer species dominated by Alum species $Al(H_2O)_{63}^{+}$, $Al(OH)_2^{+}$ and $Al(OH)_4^{-}$ [27]. According to Geng, the molecular weight of polymers is larger than that of monomers, on the other hand, the size of polymer species is smaller than that of monomer species and the density of polymer species is greater than that of monomer species. Therefore, PAC compounds react more easily with particles contained in water and the coagulation-flocculation process with PAC does not require large doses. At high raw water turbidity values, PAC coagulant is more effective than Aluminum Sulfate based on the optimum dose used. Coagulation studies on turbidity variations of 10-1000 NTU have been carried out using Alum and PAC, the highest removal performance obtained by PAC is 93% compared to 82% Alum [28]. The review proves that the addition of continuous and controlled discharge flow in the sedimentation zone of the CDF method does not break up the floc that has already been formed because the flow produced by this 6% CDF discharge does not cause flow turbulence or in other words, it is still laminar with Reynolds number. (NRe) is 78.81 (smaller than 2000) and the Froude Number (NFr) is 2.35 x10^{-4} (larger than 10^{-5}) [2,3].

Table 8. Variations in Coagulants Types on the Efficiency of Turbidity Removal

Repeat Trial	**Type of Coagulant**	**Initial Turbidity (NTU)**	**Data 1**		**Data 2**		**Average Allowance Efficiency (%)**
			Final Turbidity (NTU)	**Provision Efficiency (%)**	**Final Turbidity (NTU)**	**Provision Efficiency (%)**	
1	PAC	27.635	3.067	88.90	3.055	88.95	88.93
	Alum		5.215	81.13	4.953	82.08	81.61
	Ferric Chloride		3.553	87.14	3.370	87.81	87.48
2	PAC	26.769	2.145	91.99	2.510	90.62	91.31
	Alum		4.802	82.06	4.921	81.62	81.84
	Ferric Chloride		3.481	87.00	3.747	86.00	86.50
Average value	PAC						90.12
	Alum						81.72
	Ferric Chloride						86.99

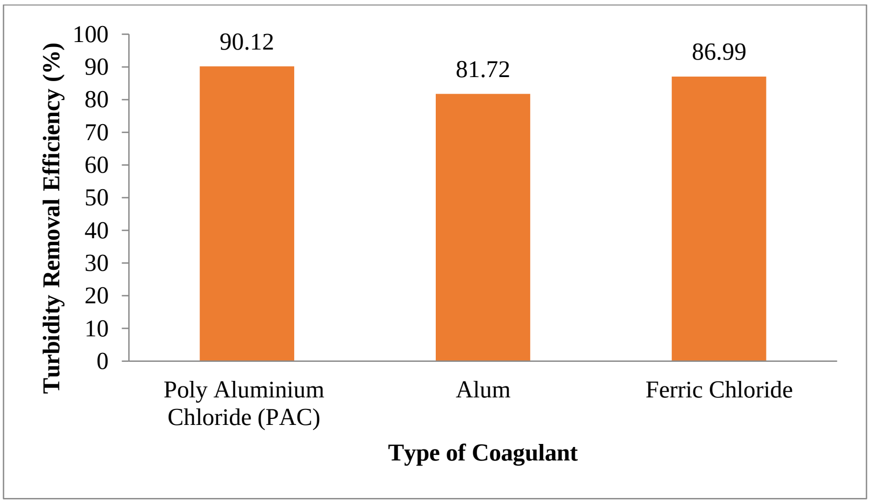

Figure 6. Removal of Raw Water Turbidity

The salt content in the coagulant also increases the efficiency of reducing turbidity in raw water, because the salt in the coagulant functions to bind the solids contained in the water. PAC and Alum coagulants contain Alumina salt (Al_2O_3) with different concentrations, namely 18% for Alum coagulant and 64% for PAC coagulant while Ferric Chloride coagulants contain 40% $Fero^{3+}$. Research shows that the greater the salt concentration in a coagulant, the higher the level of turbidity removal in raw water is also [11,13]. This is because the coagulant can bind colloidal particles [12]. The flocs that have been formed in the coagulation and flocculation units become more easily deposited to the bottom of the sedimentation tank and the controlled CDF discharge flow force acting on the floc can increase the floc removal itself [1]. Based on the research of Widyaningsih and Syafei [29], the optimum dose obtained by using Aluminum sulfate $Al_2(SO_4)_3$ as coagulant was 40 mg/L by performing floc recirculation by 50%, able to increase the efficiency of turbidity removal from 85.03% to 93.42 %. The optimum dose obtained using Polyaluminum chloride (PAC) coagulant was 35 mg/L. Polyaluminum chloride (PAC) coagulant by doing 20% floc recirculation can increase the efficiency of removal for turbidity from 95.13% to 97.66% Ferric Chloride (FeCl3) coagulant by doing floc recirculation by 10% can increase the removal efficiency for turbidity from 87.53% to 93.41%.

The Spearman Rank correlation value between various types of coagulants and the efficiency of removal of turbidity in the sedimentation unit using the CDF method using SPSS application, resulted in a positive number of 0.948. A positive value in the correlation coefficient indicates a unidirectional effect between the two variables, which means that the higher the binding salt content of the coagulant, the higher the efficiency of removing turbidity from raw water and vice versa. While the significance value obtained is 0.000, that is, the value is small or equal to 0.05, which means that the relationship between the two variables is significant or very meaningful [23]. The complete correlation and significance values are presented in Table 9 below.

Table 9. Correlation and Significance Values of Variations in Coagulants Types on Efficiency of Raw Water Turbidity Removal

Correlations				
			Coagulant	Turbidity
Spearman's rho	Coagulants	Correlation Coefficient	1.000	.948**
		Sig. (2-tailed)	.	.000
		N	12	12
	Turbidity	Correlation Coefficient	.948**	1.000
		Sig. (2-tailed)	.000	.
		N	12	12
**. Correlation is significant at the 0.01 level (2-tailed).				

4. Conclusion

The results of this study showed that the optimum dose for 3 types of coagulants, namely PAC was 1.4 mL, Alum 1.6 mL, and Ferric Chloride 1.0 mL. The type of PAC coagulant was able to achieve the highest level of turbidity removal in the sedimentation unit using the CDF method of 90.12%, followed by Ferric Chloride and Alum coagulants which were 86.99% and 81.72%, respectively. The addition of continuous and controlled discharge flow to the settling zone of the sedimentation unit using the CDF method as a new method does not break up the floc that has already been formed, because the nature of the resulting flow does not cause flow turbulence or is still laminar with a Reynolds number (NRe) 78.81 (smaller than 2000) and the Froude number (NFr) is 2.35×10^{-4} (larger than 10^{-5}) [2,3]. Optimizing the performance of the sedimentation unit using the CDF method can use PAC coagulants.

Nomenclature

E	turbidity removal efficiency	%
Co	Initial turbidity	NTU
Ci	Final turbidity	NTU
NRe	Reynolds numbers	
NFr	Froude numbers	

vo	Surface load	m3/m2/hour
R	hydraulic radius	m
g	acceleration of gravity	m/s2
ν	viscosity of water	$N.s/m^2$

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