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The Effect of Variation in Cone Position Heigth on Raw Water Turbidity Removal in Sedimentation Unit Continuous Discharge Flow (CDF) Method as a New Method

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ABSTRAK
Unit sedimentasi metode *continuous discharges flow* (CDF) adalah metode baru dalam menyisihkan kekeruhan yang menggunakan prinsip tangki bocor secara kontinu dan terkendali. Perubahan ketinggian posisi *cone* dari dasar zona pengendapan ke bagian atas, dapat memperkecil jarak antara sumber aliran buang akibat bocor yang berasal dari *cone* sebagai sumber gaya baru yang bekerja terhadap flok, dan pada akhirnya meningkatkan efisiensi penyisihan kekeruhan. Penelitian ini bertujuan untuk menganalisis efisiensi penyisihan kekeruhan air baku pada 3 variasi ketinggian posisi *cone* di zona pengendapan. Penelitian menggunakan reaktor skala laboratorium kapasitas 240 L/jam yang terdiri dari unit koagulasi terjunan, flokulasi *baffle channel* dan sedimentasi metode CDF. Unit sedimentasi metode CDF yang digunakan adalah CDF 6% dengan variasi ketinggian posisi *cone* 0 m, 0,33 m dan 0,66 m dari dasar zona pengendapan. Air baku yang digunakan adalah Sungai Batang Kuranji Kota Padang dengan kekeruhan 25,876 – 26,012 NTU dan tawas sebagai koagulan dalam proses koagulasi. Hasil penelitian menunjukkan efisiensi penyisihan kekeruhan pada ketinggian posisi *cone* 0 m, 0,33 m dan 0,66 m secara berurutan adalah sebesar 82,88%, 83,86% dan 84,60%. Ketinggian posisi *cone* 0,66 m dari dasar zona pengendapan adalah posisi optimum dengan efisiensi penyisihan kekeruhan 1,72% lebih besar dari posisi *cone* di dasar zona pengendapan, yaitu 0 m. Analisis pengaruh ketinggian posisi *cone* terhadap penyisihan kekeruhan menggunakan korelasi Rank Spearman, menunjukkan pengaruh yang sangat kuat, semakin tinggi posisi *cone* semakin besar efisiensi penyisihan. Bilangan Reynolds (NRe)dan bilangan Froude (NFr) pada aliran buang ini secara berurutan adalah 23,83 dan $9{,}33 \times 10^{-4}$.

***Keywords*:** efisiensi penyisihan, kekeruhan, ketinggian posisi cone, sedimentasi, metode CDF

ABSTRACT
The continuous discharges flow (CDF) sedimentation unit is a new method for removing turbidity using the principle of a continuous and controlled leaking tank. Changes in the height of the cone position from the bottom of the settling zone to the top, can reduce the distance between the exhaust flow sources due to leakage from the cone as a new force source acting on the floc, and ultimately increase the efficiency of turbidity removal. This study aims to analyze the efficiency of raw water turbidity removal at 3 variations in the height of the cone position in the settling zone. The study used a laboratory-scale reactor with a capacity of 240 L/hour consisting of a plunge coagulation unit, baffle channel flocculation, and CDF sedimentation method. The sedimentation unit for the CDF method used is 6% CDF with variations in the height of the cone position 0 m, 0.33 m, and 0.66 m from the bottom of the settling zone. The raw water used is Sungai Batang Kuranji, Padang City with a turbidity of 25.875 – 26.012 NTU and alum as a coagulant in the coagulation process. The results showed that the efficiency of removal of turbidity at the height of the cone 0 m, 0.33 m, and 0.66 m respectively was 82.88%, 83.86%, and 84.60%. The height of the cone position 0.66 m from the bottom of the settling zone is the optimum position with a turbidity removal efficiency of 1.72% greater than the cone position at the bottom of the settling zone, which is 0 m. Analysis of the effect of the height of the cone position on the removal of turbidity using Spearman's Rank correlation showed a very strong influence, the higher the cone position the greater the removal efficiency. Reynolds number (NRe) and Froude number (NFr) in this exhaust stream are 23.83 and 9.33×10^{-4}, respectively.

***Keywords*:** removal efficiency, turbidity, cone position height, sedimentation, CDF method

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1. Introduction

The sedimentation unit using the continuous discharges flow method, abbreviated as CDF by Ridwan et al. (2021) is a sedimentation unit with a new method for removing turbidity in a drinking water treatment plant. This CDF method of sedimentation unit uses the

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principle of a leaky tank to create a continuous and controlled exhaust flow with a very small leak discharge at the bottom of the settling zone (Ridwan et al. 2021).

According to Reynolds and Richards (1996), the settling of particles in the settling zone is influenced by the interaction of forces around the particle, namely friction, and thrust. The thrust is the resultant force produced by the particle's gravity and the buoyant force, while the frictional force is the force due to fluid friction against the particles. These forces will affect the process of particle settling in the settling zone of the sedimentation unit. The flow conditions in the settling zone are also very influential, so the Froude number (NFr) and Reynolds number (NRe) which describe the flow conditions must meet the design criteria. According to Huisman (1977), NFr that is too small causes the flow to be at rest, so that the removal efficiency decreases, while NFr that is too large is not recommended, because it can cause high water fluctuations, thus breaking up the formed floc. Likewise, if the NRe is too large, it causes the flow to become turbulent so that the previously formed floc will break and it is difficult to settle in the settling zone. Therefore, to improve the efficiency of turbidity removal, the sedimentation rate engineering must pay attention to the NRe and NFr numbers of the flow in the settling zone.

The presence of exhaust flow caused by a leaking tank at the bottom of the sedimentation zone becomes the source of the net force acting on the particles in the settling zone. With the addition of the leaking force referred to by Ridwan et al. (2021) as the CDF force, the value of the resultant force acting on the particles increases so that the efficiency of removing turbidity in the sedimentation unit also increases (Ridwan and Afrianita. 2021). The idea of a leaky tank sedimentation unit was introduced as a sedimentation unit using the CDF method by Ridwan et al. (2021), due to operational constraints of the sedimentation unit with the settlers method commonly used in the field, namely the breakdown of the settlers arrangement (Saputri, 2011) and the formation of moss (Putri, 2013) after several years of operation, while in the sedimentation tank the solids contact method and the sludge blankets method require a mechanical mud stirrer unit in the flocculation process and a larger sludge management unit (Crittenden, JC et al. 2012).

The efficiency of the removal of turbidity from the sedimentation unit using the CDF method is based on the ratio of the discharge flow rate to the production flow rate (in percent) which is referred to as the CDF value by Ridwan and Afrianita. (2021), is quite high, when compared to the sedimentation settlers method by Bhorkar et al. (2018) is 82-97%. Turbidity removal efficiency at 0% CDF value (no exhaust flow) is 74.64% and removal efficiency increases at 2%, 4%, and 6% CDF values with removal efficiency values respectively 78.14%, 80.25%, and 82.38% with the position of the cone are at the bottom of the settling zone (Ridwan and Afrianita. 2021).

The effect of exhaust flow due to a leaking tank in the form of a point is converted into a plane effect called a cone by Ridwan et al., (2021) which is in the form of a cone. The ratio of the cone area to the surface area of the sedimentation unit (surface area) is 30%, giving the effect of increasing velocity on particles due to exhaust flow of 0.00057 m/s at a production discharge of 240 L/hour with a CDF value of 6% and an area of 4 cone units of 0.071 m^2 or 0.01766 m^2 area of each cone. In the sedimentation unit, not all of the floc particles in the sedimentation zone will settle, or some are still suspended and some even tend to float and are carried away by the outflow of the sedimentation unit which as a whole reflects the value of removal efficiency.

The effect of increasing velocity on the floc particles in the settling zone due to this CDF exhaust stream is expected to be more effectively aimed at floc particles that are still suspended and tend to float by adjusting the height of the cone position concerning the floc particles. Changes in the height of the cone position from the bottom of the settling zone to the top will reduce the distance from the influence of the CDF exhaust flow to suspended and floating floc particles as the main target to increase the efficiency of turbidity removal of the sedimentation unit using this CDF method. The purpose of this study was to analyze the effect of variations in the height of the cone position in the settling zone, namely: 0 m, 33 cm, and 66 cm from the bottom of the settling zone on the efficiency of turbidity removal, and to determine the optimum height of the cone position in sedimentation using the CDF method in the removal of raw water turbidity.

2. Material and Method

This research was conducted on a laboratory scale reactor with a production capacity of 240 L/hour consisting of a plunge coagulation unit, flocculation baffle channel, and a sedimentation unit using the CDF method as can be seen in Figure 1 and Figure 2. The research reactor was designed based on the specifications and planning procedures for a drinking water treatment plant by BSN 6773-6774, (2008) with a recapitulation of the results of the research reactor design can be seen in Table 1. The raw water used in this study is Sungai Batang Kuranji Water, Padang City with the raw water sampling method referring to the technical standard BSN 6989.57, (2008), while the coagulant used is alum with the acquisition of the optimum dose using jar test (BSN 19.6449, 2000).

The experiment in the research reactor was intended to observe the effect of variations in the height of the cone position on the sedimentation unit using the CDF method with a CDF value of 6% on the removal of turbidity. This 6% CDF value is the percentage of the comparison value of the discharge flow which is the leakage flow from the bottom of the settling zone to the production capacity of this research reactor, which is 240 L/hour (Ridwan and Afrianita. 2021). The height of the sedimentation cone position of the CDF method in this study was varied into 3 heights, namely 0 m, 0.33 m and 0.66 m from the bottom of the settling zone and as the initial height was 0 m.

The treatment process in this research reactor begins with flowing raw water with a capacity of 240 L/hour from the raw water storage container to the coagulation, flocculation, and sedimentation units respectively. The research experiment was carried out by repeating 2 times (Duplo) for each variation in the height of the cone position with the amount of data retrieval 10 times per 5 minutes at each repetition of the experiment to obtain data close to real-time conditions as the need for process monitoring.

The turbidity removal efficiency is calculated based on the decrease in the final turbidity value at the outlet to the initial turbidity value at the inlet, while the turbidity value measurement is carried out using a UV-vis spectrophotometer which refers to the standard provisions of BSN 06-6989.25, (2005). The turbidity removal efficiency for each variation in the height of the cone position is calculated using the formula below (Hudson, 1981).

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

while the flow condition caused by exhaust flow due to leakage made from the bottom of the settling zone of 6% CDF value through the cone is described by the Reynolds number (NRe) and Froude (NFr) using the following equation (Qasim, et al., 2000) :

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

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

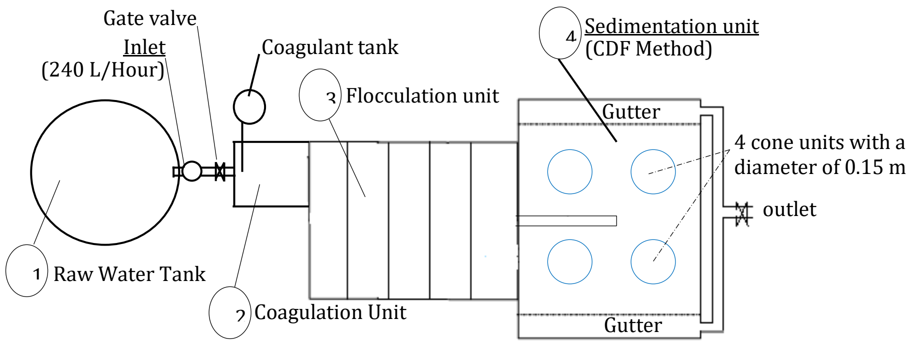

Figure 1. Top View Section of Components of the Research Reactor Sedimentation Unit CDF Method (unscaled)

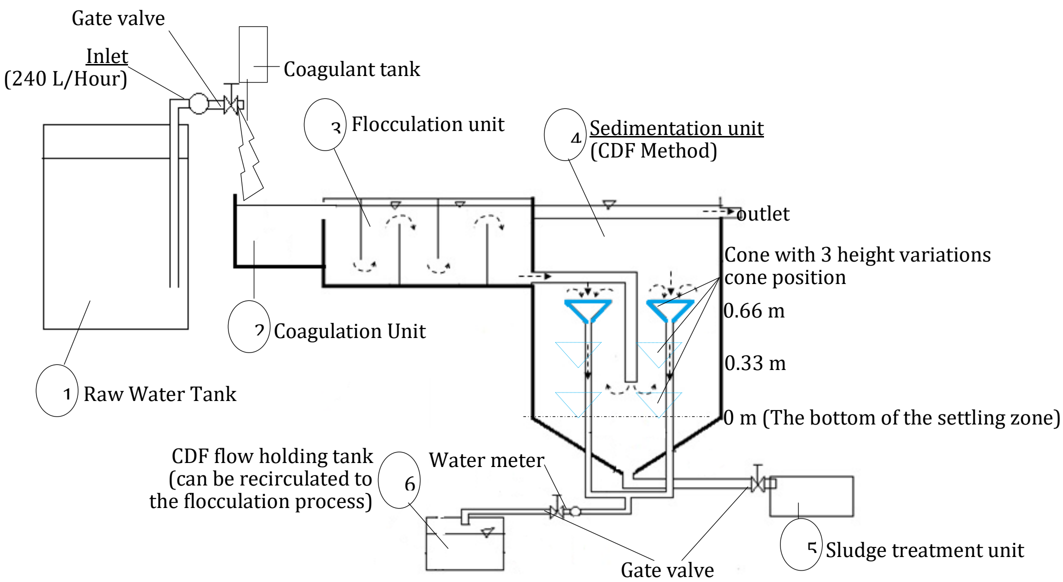

Figure 2. View Section of Reactor Components Sedimentation unit research CDF method (unscaled)

Table 1. Reactor design

The design	Calculation Value	Value of Design Criteria
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	-
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
Detention time (hour)	1	1-3.5
Flow velocity (m/s)	0.00278	≤ 9
The amount of gutter	2	-
The amount of V-notch	22	-
Number of CDF cones	4	-
CDF cone diameter (m)	0.15	-
CDF pipe diameter(m)	0.01	-
CDF Exhaust NRe Value	23.83	< 2000
CDF Exhaust NFr Value	9.33×10^{-4}	$> 10^{-5}$
Variation in height of cone position from the bottom of settling zone (m)	0	-
	0.33	-
	0.66	-

Table 2. Interpretation of 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

Variations in the height of the cone position of the sedimentation unit using the CDF method to the efficiency of turbidity removal were analyzed statistically by looking at the Spearman Rank correlation coefficient and the significance value using the Statistical Package for the Social Sciences (SPSS) application (Sujarweni, 2014). The Rank Spearman correlation coefficient value shows the direction and strength of the relationship between variations in the height of the cone position and the value of the removal of turbidity, while the significance value indicates whether there is a significant relationship between variations in the height of the cone position and the efficiency of removal of turbidity.

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 2. The Spearman Rank correlation coefficient value is declared significant if the significance value obtained is equal to or less than 0.05 (Sujarweni, 2014) 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.

3. Result and Discussion

3.1. Optimum Coagulant Dosage

Jar test results are the basis for determining the optimum dose of coagulant used in the study. The optimum dose of alum coagulant using Jartest begins with variations in coagulant doses of 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, 50 mg/L, and 60 mg/L, then the interval is reduced until the optimum dose is obtained based on the size of the floc formed, the time of floc settling and the turbidity of the water measured after the jar test (Pratiwi and Annisa, 2017). The results of the jar test showed that the optimum coagulant dose for the raw water used was 18 mg/L with the final turbidity value at the jar test result of 2.468 NTU.

The efficiency of removing turbidity in the jar test is 90.46%, much higher than the efficiency of the research reactor, which is 84.60%. This is caused by imperfect processes in the coagulation and flocculation units, namely fast stirring in the jar test using an impeller and stirrer blade at a speed of 120 rpm for 1 minute and slow stirring using an impeller and a stir bar at a speed of 60 rpm for 20 minutes, while the coagulation process in the research reactor using a plunge with a height of 0.29 m and stirring time for 5 seconds. In the flocculation process using a baffle channel system with a stirring time of 30 minutes which meets the design criteria, (BSN 6773-6774, 2008).

3.2. Turbidity Removal Efficiency

From the experiment, it was found that the value of raw water turbidity at the outlet of the sedimentation unit using the CDF method decreased after going through the process of coagulation, flocculation, and sedimentation as can be seen in Table 3 below. The turbidity removal efficiency value expressed as a percentage indicates the turbidity value that can be removed by this research reactor from the initial turbidity value.

Based on Table 3, the highest turbidity decrease occurred at an altitude of 0.66 m. The efficiency of decreasing raw water turbidity at a height of 0.66 m is 84.60% and there is a decrease in turbidity from

26,012 NTU to 4,006 NTU. In Budiono's research (2018), the efficiency of raw water turbidity removal by the addition of baffle-shaped vertical bulkheads in the sedimentation unit reached 65.55%, while in Ermayendri's (2019) study, the efficiency of turbidity removal in the sedimentation unit with the addition of granite tile as a settling area was able to remove turbidity. by 54.62%.

Based on the 2 comparative studies mentioned above, the efficiency of removal of turbidity is 84.60% in this study using 6% CDF sedimentation method with a cone position height of 0.66 m from the bottom of the settling zone is relatively high and the efficiency of removal of turbidity in this study is in the value interval. removal of turbidity in the sedimentation unit with the settlers method, which is 82-97% (Bhorkar et al. 2018). The efficiency of turbidity removal of the sedimentation unit using the CDF method is 6% at the height of the cone position at the bottom of the settling zone (0 m) of 82.38% (Ridwan and Afrianita, 2021), indicating that the efficiency of the removal of turbidity sedimentation by the CDF method is relatively constant in this study, which is 82.88%. Increasing the height of the cone position from the bottom of the settling zone, which is 0.33 m and 0.66 m, can increase the efficiency by 0.98% and 1.72%.

Table 2 explains that the higher the cone position from the bottom of the settling zone, the higher the efficiency of removing turbidity, this is because the closer the suspended floc particles are to the new force source generated by the CDF exhaust stream (leaking tank) coming from the cone so that the particles The floc is carried by the CDF exhaust stream to the exhaust flow collection tank which in principle can be recirculated back to the flocculation process to maintain production discharge and increase the efficiency of turbidity removal as well as the principle of solid contact sedimentation method (Kawamura, 1991). This study also explains that the height of the cone position at 0.66 m from the settling zone is the optimum height of the cone position that can improve the performance of the sedimentation unit using the CDF method.

The value of 6% CDF in the sedimentation unit using the CDF method in this study is the value of the discharge flow as a continuous and controlled leak flow of 6% of the production capacity, which is 14.4 L/hour. This 6% CDF value creates an increase in the settling velocity of floc particles in the sedimentation unit sedimentation zone of the CDF method of 5.66×10^{-4} m/s and affects the flow conditions which can be seen from the Reynolds number (NRe) and Froude number (NFr). It is hoped that the CDF exhaust flow created by the continuous and controlled leakage of the tank will not cause turbulence so that the formed floc does not break, but on the contrary, it can increase the removal efficiency. Based on formulas (1) and (2), the NRe and NFr values in this CDF exhaust stream are 23.83 and 9.33×10^{-4}, respectively, as can be seen in Table 4. The type of flow created by the 6% CDF exhaust flow is the laminar flow which is smaller than 2000 and the NFr value is greater than 10^{-5}.

According to the Indonesian Ministry of Health, (2010), the standard value of drinking water turbidity is 5 NTU and in this study, the turbidity value produced has met the standard, which is below 5 NTU, but if it refers to the WHO standard, 2008, then the performance of the allowance must be continuously increased until it reaches a turbidity value of 0.1 NTU.

3.3. Variation of Cone Position Height on Turbidity Removal Efficiency

From the research data produced, the Spearman Rank correlation value and the significance between the variable height value of the cone position from the bottom of the settling zone to the efficiency of turbidity removal in the sedimentation unit using the 6% CDF method using the SPSS application can be seen in Table 5.

Table 3. Turbidity removal efficiency

Variation in height of cone position (m)	**Data to-** (minutes)	**Initial Turbidity** (NTU)	**Final Turbidity** (NTU)	**Turbidity Removal Efficiency** (%)
0	5	25.876	4.407	82.97%
	10	25.876	4.411	82.96%
	15	25.876	4.441	82.84%
	20	25.876	4.518	82.54%
	25	25.876	4.435	82.86%
	30	25.876	4.343	83.22%
	35	25.876	4.490	82.65%
	40	25.876	4.463	82.75%
	45	25.876	4.495	82.63%
	50	25.876	4.299	83.39%
	Average value		4.430	82.88%
0.33	5	25.876	4.256	83.55%
	10	25.876	4.293	83.41%
	15	25.876	4.196	83.78%
	20	25.876	4.120	84.08%
	25	25.876	4.176	83.86%
	30	25.876	4.198	83.78%
	35	25.876	4.117	84.09%
	40	25.876	4.199	83.77%
	45	25.876	4.117	84.09%
	50	25.876	4.086	84.21%
	Average value		4.176	83.86%
0.66	5	26.012	4.181	83.93%
	10	26.012	4.162	84.00%
	15	26.012	4.101	84.23%
	20	26.012	4.138	84.09%
	25	26.012	4.112	84.19%
	30	26.012	3.992	84.65%
	35	26.012	3.913	84.96%
	40	26.012	3.856	85.18%
	45	26.012	3.776	85.49%
	50	26.012	3.830	85.28%
	Average value		4.006	84.60%

Table 4. Calculation of NRe and NFr on Exhaust Flow in Cone

No.	Parameter	Unit	Value	Information
1	Reactor capacity **(Q)**	L/hour	240	
		m^3/hour	0.24	
		m^3/s	0.00067	
2	Exhaust discharge 6% of reactor discharge (Q_{CDF})	L/hour	14.4	Number of cones 4 units
		m^3/hour	0.0144	
		m^3/s	0.00004	
3	Discharge exhaust flow per cone (Q_{CDF})	m^3/s	0.00001	
4	Cone			
	Cone diameter (Ø)	m	0,15	
	Area of cone circle (A)	m^2	0.01766	$A = 0.25.\pi.\emptyset^2$
	Exhaust flow velocity in Cone (Vo)	m/s	0.000566	$Vo = \frac{Q_{CDF}}{A}$
	Circumference of the cone circle (C)	m	0.471	$C = \pi.\emptyset$
	Cone Circle hydraulic radius (R)	m	0.0375	$R = {}^{A}/_{C}$
5	The viscosity of water (ϑ)	N.s/m^2	$0.891\text{x}10^{-6}$	
6	Acceleration of gravity (g)	m/s^2	9.81	
7	Reynolds numbers (NRe)	-	23.83	$NRe = \frac{Vo.R}{\vartheta}$
8	Froude numbers (NFr)	-	$9.33\text{x}10^{-4}$	$NFr = \frac{Vo}{\sqrt{g.R}}$

Tabel 5. Correlation Value and Significance of Cone Position Altitude Variation on Turbidity Removal Efficiency

			Cone position height	Turbidity Removal Efficiency
Spearman's rho	Cone position height	Correlation Coefficient	1.000	0.856**
		Sig. (2-tailed)	.	.000
		N	60	60
	Turbidity Removal Efficiency	Correlation Coefficient	0.856**	1.000
		Sig. (2-tailed)	.000	.
		N	60	60

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

Based on Table 5, it is known that the correlation value between the two variables shows a value of 0.856 when compared with Table 2, this value shows a very strong and unidirectional correlation between the height of the cone position of the sedimentation unit using the CDF method and the efficiency of removing raw water turbidity. A positive value in the correlation coefficient indicates a unidirectional effect between the two variables, which means that the higher the cone position, the greater the efficiency of removal of turbidity and vice versa. The significance value obtained is 0.000 and the value is 0.05, which means that the relationship between the two variables is significant or very significant.

4. Conclusion

Variations in the height of the cone position from the bottom of the settling zone of the 6% CDF sedimentation unit, ie 0 m, 0.33 m and 0.66 m can increase the efficiency of turbidity removal 82.88%, 83.86%, and 84.60%, respectively.

Variations in the height of the cone position from the settling zone have a very strong influence on the efficiency of removal of turbidity, the higher the position of the cone from the bottom of the settling zone, the value of the efficiency of removal of turbidity increases.

The height of the cone position from the bottom of the sedimentation zone of the sedimentation unit using the 6% CDF method, which is optimum in removing the turbidity of raw water, is 0.66 m high.

Nomenclature

E	turbidity removal efficiency	%
Co	Initial turbidity	NTU
Ci	Final turbidity	NTU
NRe	Reynolds numbers	-
NFr	Froude numbers	-
Vo	Exhaust flow velocity in Cone	m/s
R	Hydraulic radius	m
g	Acceleration of gravity	m/s^2
ϑ	Viscosity of water	N.s/m^2

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