

## Modification of the Sedimentation Unit with Continuous Discharges Flow (CDF) as a New Method to Increase Turbidity Removal in Raw Water

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**Abstract**—This study applies a new method to remove the turbidity of raw water in the sedimentation unit called CDF sedimentation using the working principle of a leaky tank at the bottom of the tank. The test was carried out on a laboratory scale reactor of 240 L/hour for 6 hours consisting of a waterfall coagulation unit for 5 seconds and alum as a coagulant. perforated wall flocculation unit with 30 minutes detention time and 1 hour CDF sedimentation unit. The study was conducted with 4 variations of CDF, namely 0%, 1%, 3%, and 5% with turbidity of 75.25 NTU. The results showed the greater the CDF value, the greater the decrease in turbidity that occurred. The highest level of turbidity removal occurred at 5% CDF value with an efficiency of 91,09%, a correlation value -0,927, and a significance value of 0,00 < 0,05. CDF value gives an influence on Reynolds numbers and Froude numbers in sedimentation units where Reynolds numbers are in the range 65,71-76,75 and Froude numbers  $1,96 \times 10^{-4}$ - $2,29 \times 10^{-4}$ . This shows the Reynolds number and the Froude number will get bigger as the value of the CDF and still matches the design criteria of the laminar.

*Keywords: The CDF sedimentation, Efficiency, and Turbidity.*

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### 1. Introduction

The sedimentation unit serves to remove air turbidity [1]. In the rainy season, soil erosion will increase the total suspended solids and colloids in river water until the turbidity value exceeds 1,000 NTU and this needs to be set aside one of them with a sedimentation unit [2]. Sedimentation units can be rectangular, square, and circular [3]. The sedimentation unit consists of 4 zones, namely the entry zone, settling zone, sludge zone, and outlet zone [1,3]. The addition of coagulants to the coagulation process will produce sludge between 0.5 to more than 1% of the sedimentation tank capacity with sludge concentrations ranging from 1-15% and highly dependent on the type of coagulant used, and the efficiency of the sedimentation tank itself [3]. Conventional sedimentation units can usually remove 65% - 70% suspended solids [4]. Modification of the sedimentation unit with a plate settler on a laboratory scale resulted in a turbidity removal efficiency of 71% and 56% without using a plate settler, whereas with variations in the flow rate of the sedimentation unit using a plate settler, namely 1 mm / s, 2 mm / s and 3 mm / s, the efficiency of turbidity removal was 85%, 82%, and 71%, respectively [5]. The detention time of conventional sedimentation units is 2-4 hours and when compared to tube settlers, the detention time is much shorter, namely 10-20 minutes with a turbidity removal efficiency of 70-80% [6]. Modification of tube settler with a circle diameter of 5.65 cm, a square with a side of 5 cm, a hexagonal with a side of 3.10 cm, and a chevron with a side of 4.20 cm, increased the percentage of removal between 82-97% compared to a conventional tube settler of 75-89% [6]. The operational constraints of sedimentation with settlers are disruption or damage to the settler arrangement so that it is irregular [7] and the formation of moss [8].

In addition to the settler method, improving the performance of the sedimentation unit can be done by using the solid contact method and the sludge blanket which is designed to be integrated into the sedimentation unit called the clarifier unit, with the radial flow, up-flow [1,3]. In the clarifier unit,

the solids contact method and the sludge blanket require a sludge stirrer unit mechanically in the flocculation process and that becomes an obstacle in its operation to manage the resulting sludge [1,3]. Another modification is the use of bulkheads in rectangular sedimentation units which can reduce the volume of the circulating flow area, and can improve flow uniformity, and can achieve maximum efficiency of suspended solids removal [9]. The precipitation in the sedimentation unit is influenced by the interaction of forces around the particles, namely the friction force caused by fluid friction against the particles and the impelling force which is the resultant force generated by gravity and the buoyancy of the particles [1,3]. Froude number (NFr) and Reynolds number (NRe) describe the flow conditions in the deposition zone which must meet design standards [1,3]. Too small NFr will cause the flow to stagnate so that the removal effectiveness will decrease, while NFr that is too large is also not recommended because it causes water turmoil so that it can break the floc formed [10]. NRe that is too large will cause the flow to become turbulent so that the floc will break and become difficult to settle [10]. Increasing the efficiency of turbidity removal with flow rate techniques should take into account the number of Reynolds and Froude in the deposition zone [5,10].

Due to the problem of plate settlers that are not neatly arranged and mossy during operation, as well as the need for mechanical flocculation and sludge management units on the clarifier unit, namely the solid contact method and sludge blankets [1,3,7,8]. in research This new modification was carried out to improve the efficiency of turbidity removal by using flow techniques in the deposition zone, namely increasing the downstream flow rate by applying the principle of a leaky reactor flow at the bottom of the continuous sedimentation tank in a very small amount. The effect of the discharge flow by the leakage hole in the form of a point is converted into a conical plane to expand and flatten the area of influence symmetrically. The continuous flow of discharge due to this leak is expected to increase the resultant downward force of the particles, or increase the value of the settling velocity of the particles in the deposition zone, thereby increasing the removal of turbidity [1,3].

In this study, the continuous discharge flow rate utilizes the leakage reactor principle and is referred to as continuous discharges flow or abbreviated as CDF. This study aims to design a water treatment reactor with a laboratory-scale CDF sedimentation unit, to analyze the effect of CDF variation on Froude number and Reynolds number, to analyze the effect of CDF variation on the efficiency of removing turbidity in raw water, and to determine the optimal number of CDF values in removing turbidity. This modification is expected to be implemented and become a new alternative to improve the performance of the sedimentation tank in removing turbidity.

## **2. Material and Method**

The CDF method of sedimentation unit research begins with the design and manufacture of a laboratory-scale reactor with a capacity of 240 L/hour with a test time of 6 hours. Reactor design refers to the specification and package unit planning procedures for water treatment plants [11,12]. The variation in the CDF value in the sedimentation unit is regulated by the rotation of the drainage valve at the bottom of the sedimentation tank. Valve rotation that causes CDF flow is expressed as the CDF value which is the percentage of the total continuous flow to the inlet discharge of the sedimentation unit, which is 240 L/hour. The coagulant used by alum with raw water from the Sungai Batang Arau, Kota Padang. Raw water sampling refers to the Indonesian National Standard [13]. The reactor was tested and operationalized to obtain research data that connected the CDF value with turbidity removal efficiency. Experimental data were analyzed statistically using the Rank Spearman method through the SPSS application to obtain the correlation value and the significance of the effect of the CDF value on the efficiency of turbidity removal [14].

the tools and materials needed in the manufacture of this reactor are 1). 5 mm thick acrylic, as the main construction material for the coagulation, flocculation, and sedimentation unit, 2). 10 mm acrylic pipe, for the manufacture of CDF pipes, inlet, and outlet sedimentation units, 3). Submersible pump 240 L/hour, model QR30E Brushless DC Pump, for pumping water from the raw water reservoir to the reactor, 4). Velp JLT6 Flocculator Jar Test Tool model, to determine the optimum coagulant

dose, 5). Spectrophotometer, to measure turbidity in raw water, 6). Stopwatch, to measure time in research, 7). Water storage containers, to store water before processing in the coagulation, flocculation, and sedimentation unit and the reservoir volume is 250 liters, 8). The coagulant container and hose function to regulate the release of alum entering the processing unit, and 9). 1000 mL beaker, for water sampling at the outlet of the sedimentation unit to be measured

The materials used in this research are 1). Alum coagulant with the optimum dosage procedure by using jar test [15], 2). The water sample used in this study was Batang Arau River water with coordinates 0°57'44"LS and 100°23'52" East Longitude with a height of 17 meters above sea level. Sampling for testing the turbidity value of water in the laboratory is carried out based on the Indonesian National Standard [16]. The Batang Arau River has sufficient potential to be used as a source of raw water for the City of Padang because it is quite adequate in the downstream area with a discharge ranging from 1.12 m<sup>3</sup>/s-144 m<sup>3</sup>/s [17].

**Table 1.** Characteristics of Sungai Batang Arau

No.	Parameter	Values
1	Turbidity (NTU)	75,25
2	pH	7,2
3	Temperature (C)	29,1

### 3. Result and Discussion

The steps of the analysis and discussion on the research, that are the removal efficiency are calculated using the equation.

$$E = \frac{C_o - C_i}{C_o} \times 100\% \quad (1)$$

and checking hydraulic numbers, NRe and NFr using equations.

$$NRe = \frac{v_0 \times R}{\nu} \quad (2)$$

$$NFr = \frac{v_0}{\sqrt{g \times R}} \quad (3)$$

The results of the analysis are correlation coefficients which show the direction and strength of the relationship between the CDF value and the turbidity removal value, and the significance value indicating whether there is a significant relationship or not in each variation of the CDF value [14]. Correlation coefficient values and significance values are interpreted into five groups in Table 2. The Spearman rank correlation coefficient is significant if the significance value obtained is equal to or smaller than 0,05 or 0,01 [14]. Spearman rank correlation value is between -1 to 1. If the value = 0, it means that there is no correlation or no relationship between the independent and dependent variables. Value = +1 means there is a positive relationship between the independent and dependent variables. Value = -1 means there is a negative relationship between the independent and dependent variables. The level of significance of the Spearman Rank correlation can be seen in the coefficient of significance (Zs). The Spearman Rank correlation coefficient will be significant if  $Zs \geq 1.96 \leq Zs$  at the significance level ( $\alpha$ ) is equal to 0,05 (or 0,01).

**Table 2.** Interpretation of Correlation Values

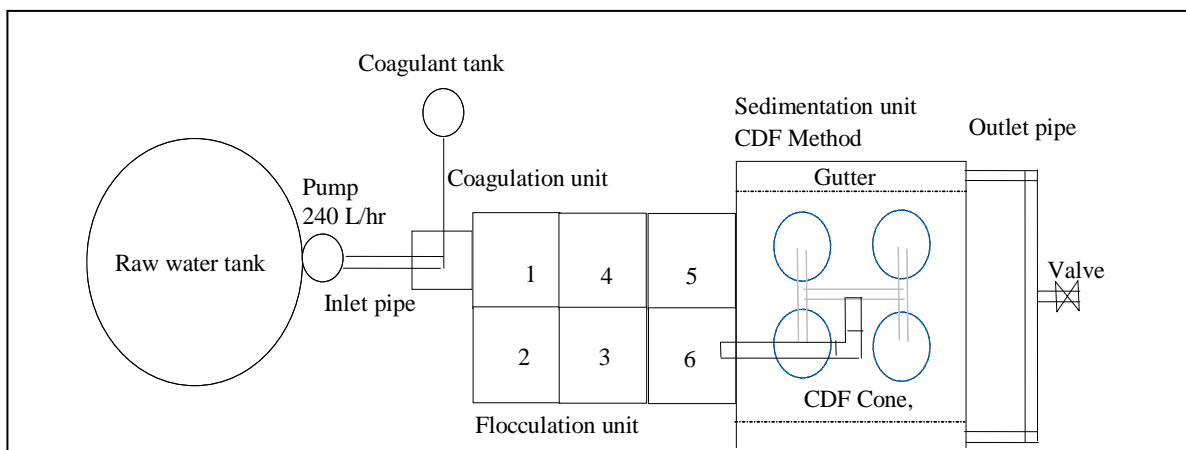
Value	Interpretation
0,00 – 0,19	Very weak
0,20 – 0,39	Weak
0,40 – 0,59	Moderate
0,60 – 0,79	Strong
0,80 – 1,00	Very strong

### 3.1 Reactor Design

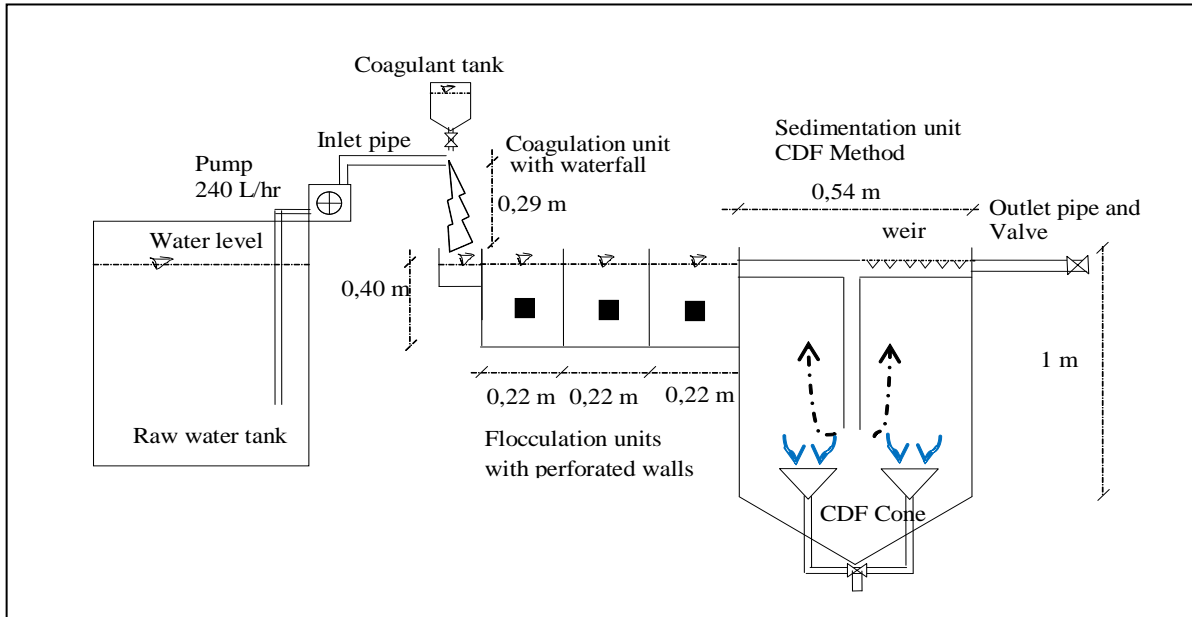
The recapitulation results of the reactor dimensions calculation and layout are presented in Table 3, Figures 1, and 2. Reactors that have been completed are tested first to avoid any leakage. The trial also determines the amount of valve rotation to produce CDF values of 0%, 1%, 3%, and 5%. Determination of the amount of valve rotation is done by measuring the flowrate on the CDF valve using a beaker glass to determine the volume and stopwatch to determine the time. The volume of water that enters the beaker glass compared to the time needed to obtain the appropriate flow rate at each variation of the CDF value.

**Table 3.** Reactor design

The design	Calculation Value	Value of Design Criteria [11]
<b>Coagulation Unit</b>		
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
<b>Flocculation Unit</b>		
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
<b>Sedimentation Unit</b>		
Surface load (m <sup>3</sup> /m <sup>2</sup> /hour)	1	0,8-2,5
Overflowrate (m <sup>3</sup> /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 x 10 <sup>-4</sup>	> 10 <sup>-5</sup>
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	-



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



**Figure 2.** Part of sedimentation unit reactor CDF method.

### 3.2 Effect of CDF on Reynolds and Froude Numbers

The influence of CDF values on Reynolds Numbers and Froude Numbers on the sedimentation unit is presented as shown in Table 4.

**Table 4.** CDF Value (%) and Flow Velocity (m/s)

CDF value (%)	Flow (Q) <sub>Inlet</sub> (L/hr)	Flow (Q) <sub>.CDF</sub> (L/hr)	Cone Area (m <sup>2</sup> )	Flow velocity (m/s)
0		0		0,28x10 <sup>-3</sup>
1	240	2,4	0,071	0,29x10 <sup>-3</sup>
3		7,2		0,31x10 <sup>-3</sup>
5		12		0,33x10 <sup>-3</sup>

The increase in downward flow velocity in the sedimentation unit also affects the flow conditions in the form of Reynolds numbers (NRe) and Froude numbers (NFr) [1,3,10]. The downward flow that is created is expected not to cause turbulence so that the formed floc does not break and can settle completely [1,3,10]. Based on calculations that have been done, the value of NRe and NFr for each CDF value can be seen in Table 5.

**Table 5.** Reynolds Numbers (NRe) and Froude Numbers (NFr) values for each CDF value

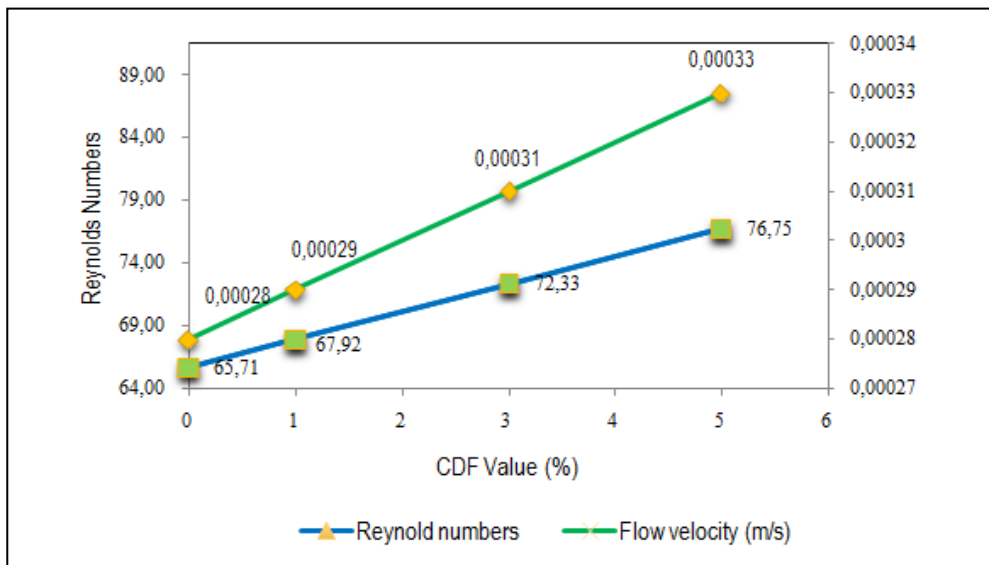
CDF Value (%)	NRe	Value of Design Criteria [11]	NFr	Value of Design Criteria [11]
0	65,71		1,96 x 10 <sup>-4</sup>	
1	67,92	< 2.000	2,00 x 10 <sup>-4</sup>	>10 <sup>-5</sup>
3	72,33		2,16 x 10 <sup>-4</sup>	
5	76,75		2,29 x 10 <sup>-4</sup>	

The relationship between CDF values, flow velocity, NFr and NRe can be seen in Figures 3 and 4, which is directly proportional. Flow velocity, NFr, and NRe values increase with additional CDF values. This is appropriate with research [18], the NRe value in a fluid increases proportionally with

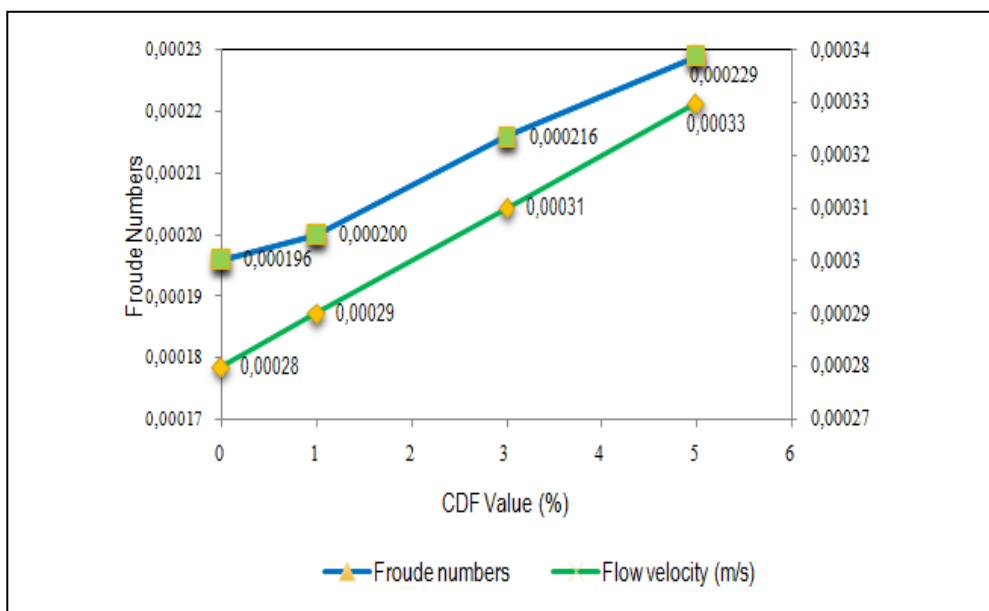
increasing flow velocity, and according to [19], the variation of discharge and flow velocity on a channel cross-section shows the value of NFr which is directly proportional to the flow velocity.

### 3.3 Effect of CDF on Turbidity Removal Efficiency

In Table 6, the highest level of turbidity removal occurred when the CDF value was 5% with an efficiency removal in raw water turbidity of 91,09%. The results of this research when compared with the research [20], the turbidity removal efficiency of raw water by the treatment of adding vertical baffles in the sedimentation unit reached 65,55% and research [21], the efficiency of turbidity removal in sedimentation units by adding granite tiles as a sedimentation field can removal turbidity by 54,62%, then turbidity removal efficiency of 91,09% in this research shows the performance of the CDF method sedimentation unit is very good, it can even reach the sedimentation removal range by modifying the tube settlers method, which is 82-97% [6]. The percentage of removal for raw water turbidity after treatment can be plotted into the graph in Figure 5. In Figure 5, the greater the CDF value, the higher the turbidity removal rate. The results of this research indicate the removal of turbidity at an optimum value of 91,09% is quite high [6].



**Figure 3.** Flow velocity and NRe Values for Each CDF Value.

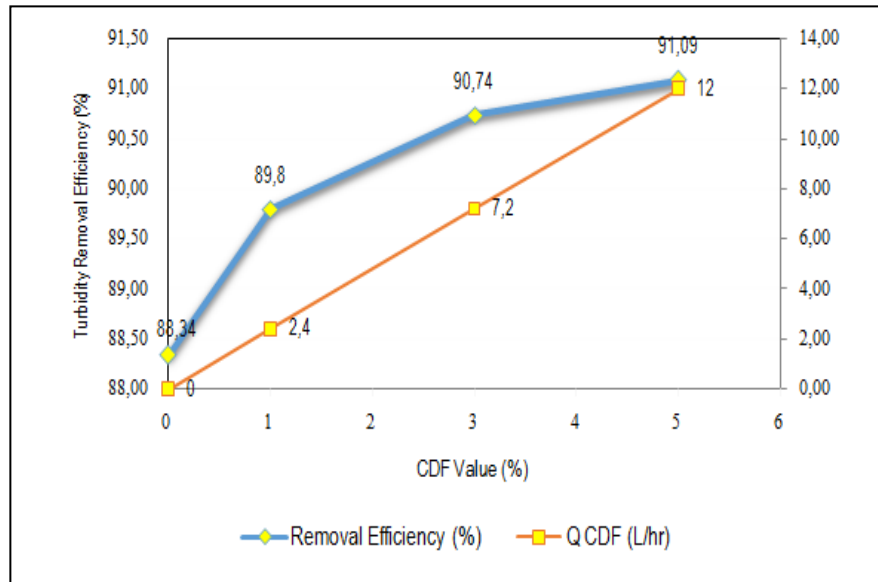


**Figure 4.** Flow velocity and NFr Values for Each CDF Value.

**Table 6.** Removal for Raw Water Turbidity

CDF value (%)	Initial turbidity (NTU)	Final turbidity (NTU)			Removal efficiency (%)
		1st test	2nd test	Average	
0		8,79	8,77	8,78	88,34
1	75,25	8,23	7,67	7,95	89,80
3		7,81	6,97	7,39	90,74
5		6,80	6,71	6,75	91,09

The research shows an increase in the removal efficiency of raw water turbidity along with the increasing value of the CDF. This is due to the influence of downward water flow caused by the CDF in the sedimentation unit which makes it easier for particles to settle to the bottom of the sedimentation tank [1,3]. The greater the value of the CDF, the resultant downward force on the particles will be greater so that the particles are more easily settling and the turbidity value of water at the outlet will be smaller [1,3]. The level of correlation and significance between the CDF values and the efficiency of the removal of raw water turbidity measured statistically using the SPSS application with Spearman Rank analysis are presented in Table 7.



**Figure 5** Removal of Raw Water Turbidity.

**Table 7.** Correlation and Significance of CDF value with Efficiency of Raw Water Turbidity Removal

Spearman's rho		Turbidity removal efficiency
Value	Correlation coefficient	-0,927
	Sig. (2-tailed)	0,001
	N	8

The correlation level between the two variables in Table 7 has a value of -0,927 which shows a very strong and unidirectional correlation between the CDF value and the turbidity removal efficiency

in the raw water treatment [14]. Positive values on the correlation coefficient indicate the direct effect between the two variables which means that the greater the CDF value, the greater the efficiency of removal of turbidity of raw water [14]. The significance value obtained is  $0,001 \leq 0,05$  which means that the relationship between the two variables is significant or very significant [14].

#### 4. Conclusion

The research reactor with a capacity of 240 L/hr which is designed following with SNI design criteria, consists of a coagulation unit in the form of a waterfall with dimensions  $0,92 \times 0,046 \times 0,08 \text{ m}^3$  and high of the waterfall is 0,29 m and a detention time of 5 seconds. 6-stage perforated wall-type hydraulic flocculation units with dimensions  $0,22 \times 0,22 \times 0,4 \text{ m}^3$  per stage and total detention time of 30 minutes and sedimentation units of CDF method with dimensions  $0,54 \times 0,44 \times 1 \text{ m}^3$  and detention time of 1 hour.

CDF value affects the Reynolds number (NRe) and the Froude number (NFr) in the sedimentation unit, the greater the CDF value, the greater the value of the number. NRe value increased from 65,71 to 76,75 at 5%. The NFr number has increased from  $1,96 \times 10^{-4}$  to  $2,29 \times 10^{-4}$  at a value of 5%, and NRe and NFr still meet the design standards. The highest turbidity removal at 5% CDF with an efficiency of 91,09%.

Statistical analysis showed a very strong relationship between variations in CDF values with turbidity removal efficiency, which are the correlation value of -0,927 and the significance value of  $0,001 < 0,05$ . Increasing the number of CDF values increases the depositional speed of particles and increases the NRe and NFr values. At CDF 5% the flow in the settling zone is a laminar with NRe value of  $76,75 < 2.000$  and NFr is  $2,29 \times 10^{-4} > 10^{-5}$ .

#### Nomenclature

E	turbidity removal efficiency	%
Co	Initial turbidity	NTU
Ci	Final turbidity	NTU
NRe	Reynolds numbers	
NFr	Froude numbers	
vo	Surface load	$\text{m}^3/\text{m}^2/\text{hour}$
R	hydraulic radius	m
g	acceleration of gravity	$\text{m}/\text{s}^2$
v	viscosity of water	$\text{N}\cdot\text{s}/\text{m}^2$

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