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Application of Continuous Discharge Flow (CDF) as a New Method in The Sedimentation Unit for Removal of Raw Water Turbidity

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Abstract

The research aims to determine the effect of continuous discharge flow (CDF) on the settling zone in the sedimentation unit as a new method for enhancing turbidity removal efficiency. The research using a laboratory-scale reactor with a capacity of 240 liters/hour for 6 hours. The reactor consists of a coagulation unit with a waterfall and detention time of 5 seconds and uses alum as a coagulant. Perforated walls flocculation unit with a detention time of 30 minutes, and a sedimentation unit of the CDF method with a detention time of 1 hour. The research conducted 4 variations of the CDF, which are 0%, 2%, 4%, and 6% with the initial turbidity of raw water in the Sungai Batang Kuranji Kota Padang being 23.61 NTU. Turbidity in sedimentation unit outlets ranged from 4.16 to 5.98 NTU with a maximum turbidity removal efficiency of 6% CDF was 82.38%. Statistical analysis showed a very strong relationship between variations in CDF values with turbidity removal efficiency, that is the correlation value of 0.988 and the significance value of 0.00 < 0.05. At 6% CDF, the flow in the settling zone was laminar with NRe values < 2,000 and NFr > 10^{-5}.

Keywords: Sedimentation continuous discharge flow method, Froude's number (NFr), Reynolds number (NRe), Efficiency, Turbidity

1 Introduction

The sedimentation unit is one of a series of processes in conventional water treatment plants, consisting of coagulation, flocculation, sedimentation, filtration, and disinfection units [1]. The sedimentation unit functions to remove the raw water turbidity parameters [1]. During the rainy season, soil erosion will increase the number of suspended solids and colloidal particles in the river water, so that the value of water turbidity can exceed 1.000 NTU and this needs to be removed with the sedimentation unit [2]. Sedimentation tanks can be rectangular, square, and circular [3]. Sedimentation tanks consist of 4 zones, that is inlet zones, settling zones, sludge zones, and outlet zones [1,3]. The addition of chemical coagulant 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 it is highly dependent on the type of coagulant used, as well as the removal efficiency of the sedimentation tank itself [3]. Conventional sedimentation units can remove suspended solids by 65-70% [4].

Enhancement of the turbidity removal efficiency in sedimentation units with higher overflow rates, which are 3 to 6 times that of conventional sedimentation overflow rates, can use tubes or plate settlers while maintaining laminar flow conditions in the settling zone [3]. Modification of the sedimentation unit by the plate settler method on a laboratory scale can produce turbidity removal efficiency of 71% and 56% without using a plate settler, while by varying the speed of flow rates on sedimentation units using plate settlers, that is 1 mm/s, 2 mm/s and 3 mm/s, the turbidity removal efficiency of 85%, 82%, and 71%, respectively [5]. Detention time in conventional sedimentation units is 2-4 hours and when compared to using tube settlers, the detention time required is much shorter, that is 10-20 minutes with an average turbidity removal efficiency of 70-80% [6].

Modifications to tube settlers with a circular diameter of 5.65 cm, square with 5 cm side, hexagonal with 3.10 cm side and chevron with 4.20 cm side, able to increase the removal percentage between 82-97% compared to conventional tube settlers, which is 75-89% [6]. At the time of operation, disturbance in the performance of sedimentation units can occur due to irregularly arranged plate settlers [7] and the formation of mosses [8]. Besides the tube or plate settlers method, the performance improvement of sedimentation units can be done with methods of solids contact and sludge blankets that are designed integrated with the sedimentation unit, which is called the clarifier unit, and by radial flow direction engineering [1,3]. In the clarifier unit the method of solids contact and sludge blankets requires a sludge stirring unit mechanically in the flocculation process and which becomes difficult in it is operating in the management of sludge produced [1,3]. Another

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modification is the use of baffles on rectangular sedimentation units that can reduce the volume of the circulation flow region, and can increase the uniformity of flow, and can achieve maximum removal efficiency of suspended solids [9].

Precipitation in sedimentation units is influenced by the interaction of forces around the particle, which are the frictional force caused by fluid friction against the particle and impelling which is the resultant force produced by the particle gravity and buoyancy [1,3]. Froude numbers (NFr) and Reynolds numbers (NRe) describe the flow conditions in the settling zone that must meet design standards [1,3]. NFr that is too small will cause flow in a state of stagnation so that the effectiveness of processing will decrease, while NFr is too large is also not recommended because it can be causing water turmoil, so it can break down the floc that has formed [10]. The same, NRe that is too large will cause the flow to become turbulent so that the previously formed floc will break and become difficult to settle in the sedimentation basin [10]. Improving the efficiency of turbidity removal by engineering flow rates must pay attention to the numbers of Re and Fr in the sedimentation basin [5,10].

Based on the problem of plate settlers that are not arranged orderly and mossy at the time of operation, and the need for mechanical flocculation units and sludge management in the clarifier unit of the method solid contact and sludge blankets [1,3,7,8], this study made new modifications to increase turbidity removal efficiency by flow engineering in the settling zone, that is an increase in the flow rate down by applying the phenomenon or principle of leakage reactor flow at the bottom of the sedimentation tank continuously in very small quantities. The effect of the discharge flow by the leaky hole in the form of a point is converted to a cone plane to expand and evenly spread the area of influence symmetrically. The continuous discharge flow due to this leak is expected to increase the resultant force down particles, or enlarge the settling velocity value of particles in the settling zone, thereby increasing the turbidity removal [1,3].

Continuous discharge flow rate by utilizing the phenomenon or principle of leaked reactors in this study is called and introduced as continuous discharges flow, abbreviated as CDF. The CDF flow can later be recirculated back to the sedimentation bath inlet using the solid contact method [1,3]. The research aims to design a water treatment reactor with a laboratory-scale CDF sedimentation unit, to analyze the effect of CDF variations on the efficiency of removal of raw water turbidity and to determine the optimum amount of CDF values in removing turbidity, and to analyze the effect of CDF variations on Froude numbers and Reynolds numbers. This modification is expected to be applied and become a new method to improve the performance of sedimentation tanks in removing turbidity.

2 Material and Methods

Continuous discharge flow rate by utilizing the phenomenon or principle of leaked reactors in this study is called and introduced as continuous discharges flow, abbreviated as CDF. The CDF flow can later be recirculated back to the sedimentation bath inlet using the solid contact method [1,3]. This modification is expected to be applied and become a new method to improve the performance of sedimentation tanks in removing turbidity.

2.1 Tools

The equipment and materials needed in making this reactor are 1). Acrylic 5 mm thickness, is the main construction material for the coagulation, flocculation, and sedimentation units, 2). Acrylic pipe diameter of 10 mm, for making CDF pipes, inlet and outlet sedimentation units, 3). Submersible pump 240 L/hr, model QR30E Brushless DC Pump, for pumping water from the raw water reservoir to the reactor, 4). Velp JLT6 Flocculator Jar Test Tool model, for determining the optimum dose of coagulant, 5). Shimadzu brand spectrophotometer, to measure turbidity in raw water, 6). Stopwatch, to measure time in research, 7). Water storage containers, to collect water before being treated in coagulation, flocculation, and sedimentation units and reservoir volume is 250 liters, 8). Coagulant container and hose function to regulate the discharge of alum that is put into the processing unit, and 9). Beaker glass 1,000 mL, for taking water samples at the sedimentation unit outlet to measure turbidity.

2.2 Materials

Materials used in the research are 1). Coagulant, the coagulant used is alum with the procedure of determining the optimum dosage with jar test which refers to the National Standard of Indonesia [15], 2). The raw water used in this study is Sungai Batang Kuranji Kota Padang in the upper part of the Batu Busuk Pauh area which is located at coordinates 0º54'46.02" S and 100º27'9.72" E with an altitude of 123 meters above sea level. Sampling for testing the value of water turbidity in the laboratory is carried out based on the National Standards of Indonesia [16]. Sungai Batang Kuranji has sufficient potential to be used as a raw water source for the Kota Padang due to adequate quality in the upstream area with a discharge ranging from 1.12 m^3/s - 833.58 m^3/s [17].

Table 1: Characteristics of Sungai Batang Kuranji

Parameter	Values
Turbidity (NTU)	23.61
pH	6.9
Temperature (°C)	26.7

3 Results and Discussion

3.1 Reactor design

The recapitulation results of the reactor dimensions calculation and layout are presented in Table 2, 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%, 2%, 4%, and 6%. 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.

3.2 Effect of CDF on Turbidity Removal Efficiency

In Table 3, the highest level of turbidity removal occurred when the CDF value was 6% with an efficiency removal in raw water turbidity of 82.38%. The results of this research when compared with the research of Budiono [21], the turbidity removal efficiency of raw water by the treatment of adding vertical baffles in the sedimentation unit reached 65.55% and Ermayendri's research [22], 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 82.38% 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]. In this research, for CDF values of 4% and 6%, the turbidity values obtained had met the standard, that is under 5 NTU [20]. The percentage of removal for raw water turbidity after treatment can be plotted into the graph in Figure 3. In Figure 3, 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 82.38% is quite high [6].

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 deposited 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 4.

The correlation level between the two variables in Table 4 has a value of 0.988 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 $0,000 \leq 0.05$ which means that the relationship between the two variables is significant or very significant [14].

3.3 Effect of CDF on Reynolds Number and Froude Number

Based on Table 5, increasing the size of the CDF value will increase the discharge of wasted water. This is also a limitation for the size of the CDF value to maintain the quantity of raw water so that in large-scale water treatment the quantity of treated water still meets existing needs.

Table 2: Reactor design

The design	Calculation value	Value of design criteria [11]
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	$1{,}96 \times 10^{-4}$	$> 10^{-5}$
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	-

Table 3: Removal of raw water turbidity

CDF value (%)	Initial turbidity (NTU)	Final turbidity (NTU)			Removal efficiency (%)	Quality standards (NTU) [20]
		1st test	2nd test	Average		
0	23,61	6,23	5,75	5,99	74,64	5
2		5,10	5,23	5,17	78,14	
4		4,50	4,83	4,67	80,25	
6		4,17	4,15	4,16	82,38	

Table 4: Correlation and significance of CDF value with the efficiency of raw water turbidity removal

Spearman's rho		Turbidity removal efficiency
Value	Correlation coefficient	0.988
	Sig. (2-*tailed*)	0.000
	N	8

Table 5: CDF value against CDF flow velocity

CDF value (%)	Flow $(Q)_{Inlet}$ (L/Hr)	Flow $(Q)_{CDF}$ (L/Hr)	Cone area (m^2)	Flow velocity (m/s)
0	240	0	0,072	$0,281x10^{-3}$
2		4,8		$0,300x10^{-3}$
4		9,6		$0,318x10^{-3}$
6		14,4		$0,337x10^{-3}$

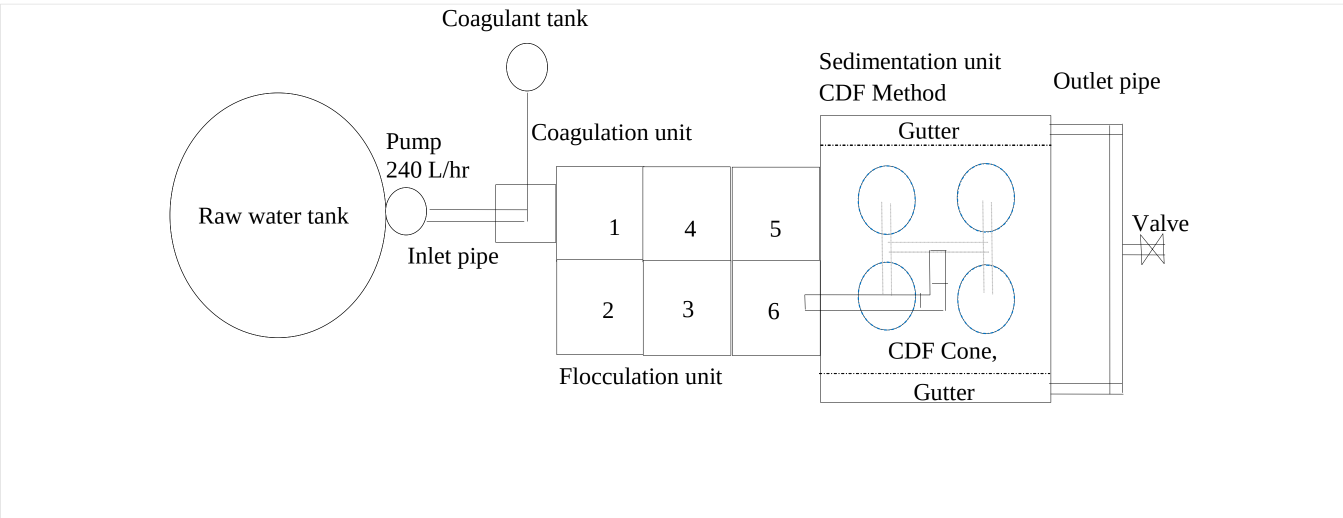

Figure 1: The layout of the sedimentation unit reactor CDF method

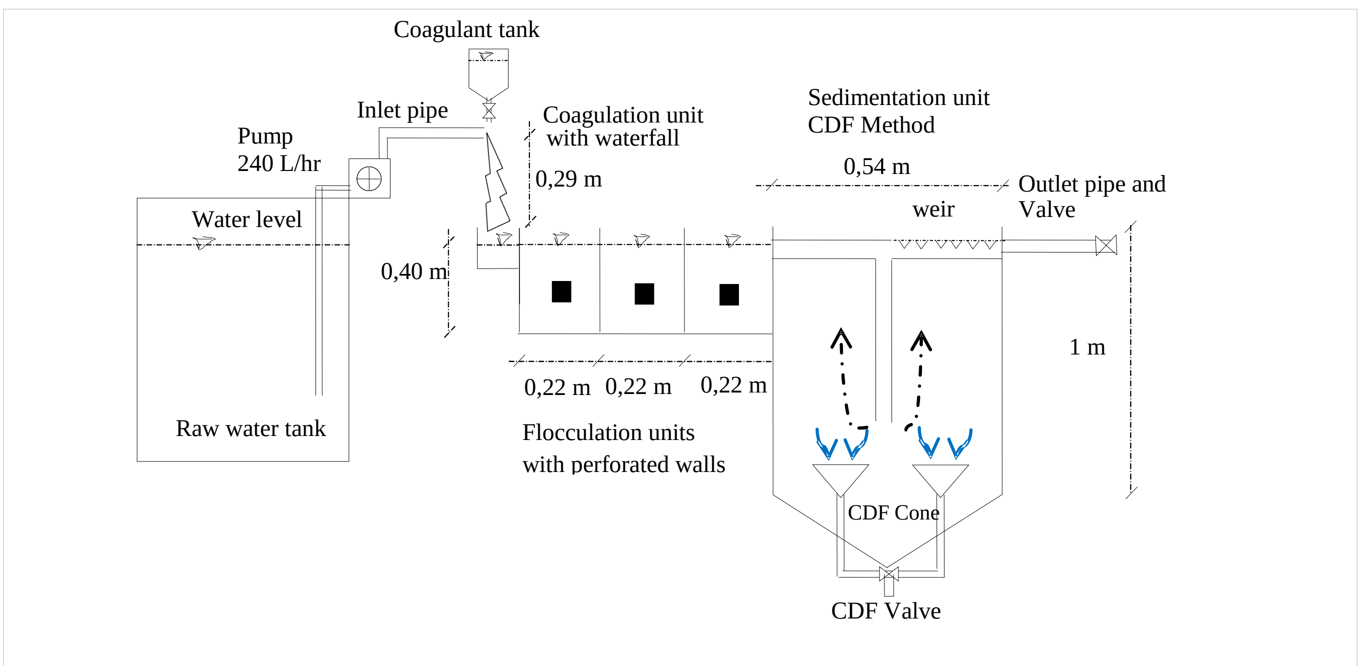

Figure 2: Part of sedimentation unit reactor CDF method

Besides, an increase in the downward flow rate of the sedimentation unit also affects the flow conditions in the form of Reynolds number (NRe) and Froude number (NFr). It is hoped that the resulting downward flow will not cause turbulence so that the floc formed does not break and can settle completely. Based on the calculations that have been done, the amount of NRe and NFr values at each opening can be seen in Table 6.

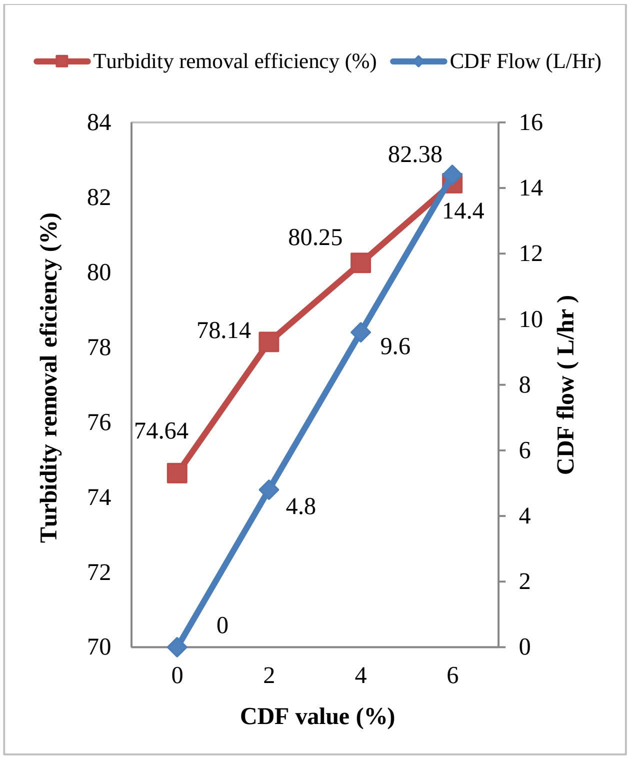

Figure 3 Removal of raw water turbidity

Table 6 NRe and NFr values at each CDF value

CDF value (%)	NRe	Value of design criteria [11]	NFr	Value of design criteria [11]
0	65,71	<2000	1,96 x 10^{-4}	>10^{-5}
2	70,06		2,09 x 10^{-4}	
4	74,36		2,22 x 10^{-4}	
6	78,81		2,35 x 10^{-4}	

The relationship between the size of the CDF opening, flow velocity, NFr and NRe can be seen in Figures 4 and 5. Based on Figures 4 and 5, it can be seen that the relationship between the CDF value, flow velocity, NRe, and NFr is directly proportional. This value increases as the size of the CDF value increases. According to Huisman [10], the NFr value must not reach the flow state in a stagnant or stationary state. The stagnant flow condition causes a dead area in the sedimentation building which will reduce the effective volume and cause a decrease in inefficiency. The flow will stagnate if the NFr value is below 10-5, therefore the NFr value must remain above 10-5. Also, according to Crittenden [1], too small an NFr can cause a back mixing mechanism. This causes the floc deposition path to change randomly and can be carried over to the outlet zone. Sedimentation using CDF on a large scale must pay attention to the amount of water discharge that is wasted and NRe and NFr must meet the criteria in determining the size of the CDF valve opening. This is done so that the quantity and quality of treated water can be maintained.

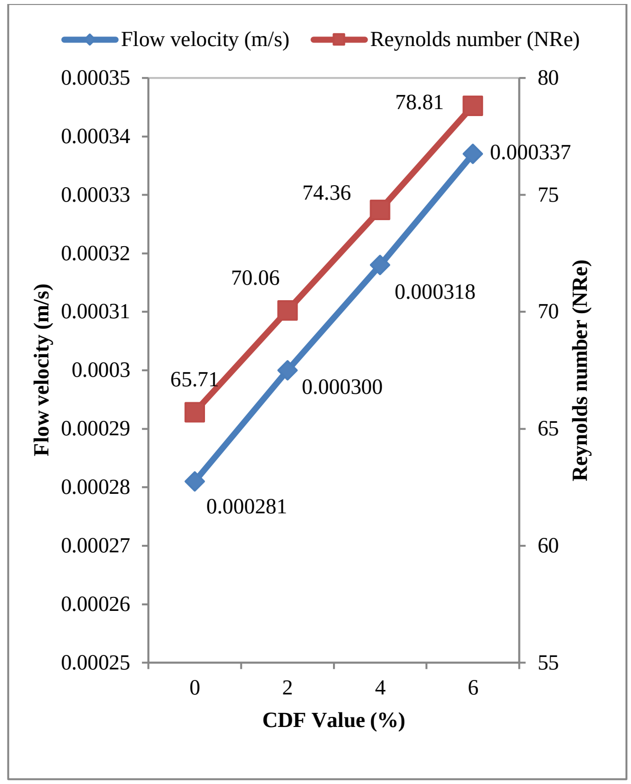

Figure 4 Value of Flow Velocity and Reynolds number (NRe) at each CDF value

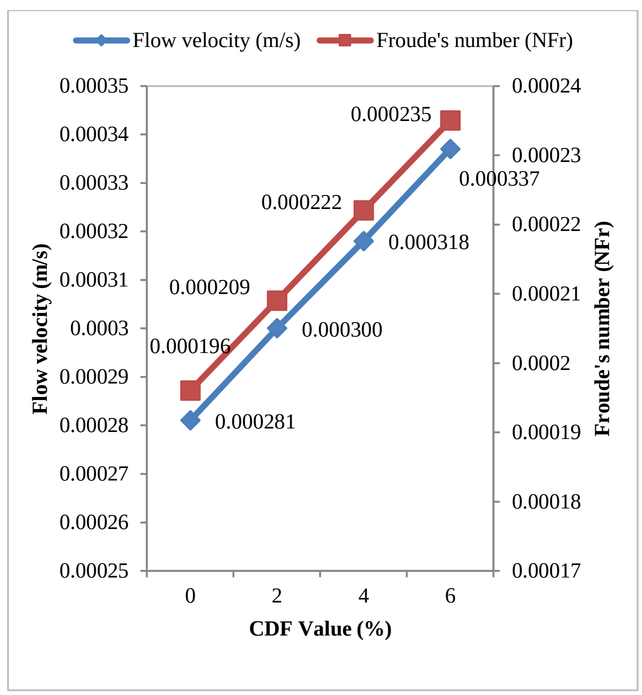

Figure 5 Value of flow rate and Froude's number (NFr) at each CDF value

4 Conclusions

The research reactor with a capacity of 240 L/Hr which is designed by the National Standard of Indonesia design criteria, consists of a coagulation unit in the form of a waterfall with dimensions (0.92 x 0.046 x 0.08) m^3 and high of the waterfall is 0.29 m and a detention time of 5 seconds [1,3,11,12]. 6-stage perforated wall-type hydraulic flocculation units with dimensions (0.22 x 0.22 x 0.4) m^3 per stage and total detention time of 30 minutes [1,3,11,12] and sedimentation units of CDF method with dimensions (0.54 x 0.44 x 1) m^3 and detention time of 1 hour [1,3,11,12]. 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 78.81 at 6%. The NFr number has increased from 1.96×10^{-4} to 12.35×10^{-4} at a value of 6%, and NRe and NFr still meet the design standards [11]. The highest turbidity removal at 6% CDF with an efficiency of 82.38%. Statistical analysis showed a very strong relationship between variations in CDF values with turbidity removal efficiency, that are the correlation value of 0.988 and the significance value of $0.00 < 0.05$. Increasing the number of CDF values increases the depositional speed of particles and increases the NRe and NFr values. At CDF 6% the flow in the settling zone is a laminar with NRe value of $78.81 < 2{,}000$ and NFr is $2.35 \times 10^{-4} > 10^{-5}$.

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Ethical issue

Authors are aware of and comply with, best practices in publication ethics specifically about authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that no conflict of interest would prejudice the impartiality of this scientific work.

Authors' contribution

Ridwan has developed the original idea of increasing the efficiency of turbidity removal in the sedimentation unit based on design standards, abstracting and analyzing data, writing a script. He has studied the concept and design of this work. He was involved in drafting the manuscript or critically revising its important intellectual content, and he is the guarantor

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