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Organic Removal in the Water Body as the Effect of Mineral Wool Installation

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ABSTRACT

In previous studies, the use of mineral wools as an onsite-supporting media in water bodies showed satisfactory results in removing organic pollutants. However, the analytical method chosen is still very conventional. This study aimed to model the removal of organic pollutants represented by the COD value to determine the mineral performance. The data used in this study included field scale data using two types of mineral wools, namely type I (density 80 kg/m^3 and water retention 95%) and type II (density 120 kg/m^3 and water retention 92%). There are form variations of mineral wool namely cubes and blocks on each type, which are placed in segments 2, 4, 8, and 9, respectively, on the Cikapayang River. The modeling results show that the most optimal type of mineral wool to remove COD is type II mineral wool-cube form at segment 4 using the first order kinetics equation. The reaction coefficient (k) obtained is 0.5378/s, standard deviation value is 14.532 mg/L COD, and the coefficient of determination is 0.1025. The kinetics value of the reaction removal and equations obtained were used to perform modeling in Matlab R2020b application to determine the dimensions of the mineral wool required to remove pollutants.

Keywords: additional treatment, COD, mineral wool, removal kinetic.

INTRODUCTION

One of the efforts to reduce and avoid the pollutant load in water bodies such as rivers is to carry out additional treatment. This kind of effort is one of the sanitation techniques with satisfactory results for people with inadequate sanitation facilities. The cost of constructing a sewerage system is usually more than four times more expensive than the alternative onsite treatment, making it impossible for developing countries to manage wastewater flows through centralized technology (Franceys et al., 1992; Prayogo et al., 2020). Adding supporting media to water bodies such as drainage and small rivers will help reduce the pollutant loads. One of the previous experiments that supported this research was a study conducted by Merola (2018) from India which used supporting media in the form of mineral wool as a medium for removing contaminants from wastewater in urban areas on a laboratory scale. The presence of biofilm in the mineral wool filter provides enough time for microorganisms to grow and develop; thus, it can help to remove COD, nitrogen, and ammonia concentrations effectively. On a laboratory scale, mineral wools could remove TSS, total nitrogen, total phosphate, and COD by 85%, 87%, 71% and 79%, respectively, in preliminary tests using a PFR reactor (Aphirta et al., 2020). In turn, on a field scale located in Cikapayang River, mineral wool could remove pollutants with COD removal percentage of 38–50%, TSS of 30–33%, total phosphate of 23–28%, and total nitrogen of 39–49% (Prayogo et al., 2023). COD removal modeling is carried out to determine the dimensions of the mineral wool that must be installed on the river body with a certain pollutant load level. The data used in this study involved field data from pilot experiment in the Cikapayang River, Bandung. The data used is the COD removal value from the mineral wool application that had been carried out in previous studies.

The study using mineral wool in environmental engineering field, especially for water or wastewater treatment, is still very limited. Thus, what has been done by previous people is still very shallow. A study by Prayogo et al. (2020) and Prayogo et al. (2023) is still limited to knowing their abilities to monitor results using general parameters, as has been done by Aphirta et al. (2020). The three most updated studies for mineral wool are because this is the latest research to try to remove pollutants from water streams. Hence, the method used is very conventional, which is only appropriate for monitoring to find differences in water quality before and after passing through the installed media. The weakness is that research costs are very expensive because so many samples must be analyzed; moreover, the parameters are comprehensive, covering physical, chemical, and biological ones. Another study using mineral wool has also been reported by Wanko et al. (2016) and Hao et al. (2019). However, they are only limited to studying the characteristics of the material. Hence, in this study, the ability of mineral wool to remove pollutants represented by organic parameter, i.e. COD, was examined using mathematical modelling. Moreover, 2 types of mineral wool which have different characteristics were used. To the best of authors' knowledge, there has been no research done.

METHODS

Mineral wool

Two types of mineral wool, from Drainblock B.V.-Netherlands, were used as filter media in this research in the Cikapayang River (Fig. 1). These two kinds are to improve the purity of the water. They were evaluated to discover the best product that could be used in both the Netherlands and Indonesia, given the differences in surface water conditions between the two countries. When applied, mineral wool is inserted into a steel support

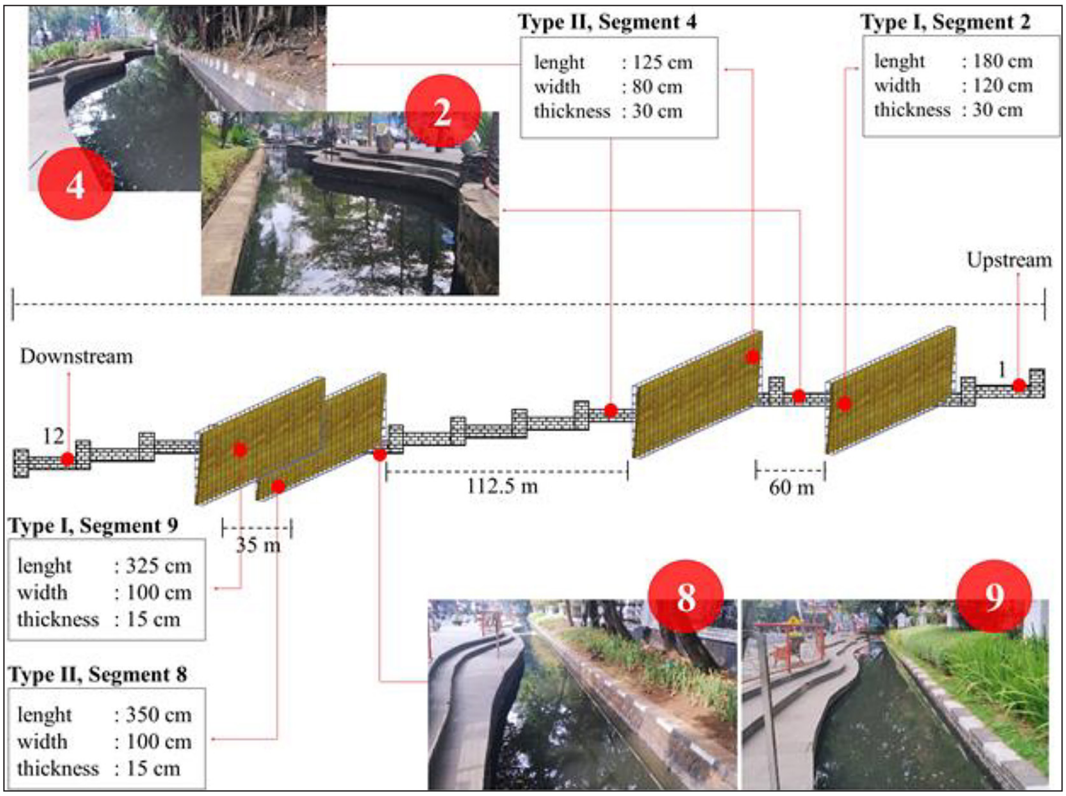

Figure 1. The Cikapayang River at Bandung City Hall: mineral wool type I-block shape at segment 2 (107º36′37.8″E 6º54′37.5″S), mineral wool type II- block shape at segment 9 (107º36′37.3″E 6º54′44″S), mineral wool type II-cube shape at segment 8 (6°54’41.3”S 107°36’37.5”E), mineral wool type I-cube at segment 9 (6°54’43.8”S 107°36’37.3”E)

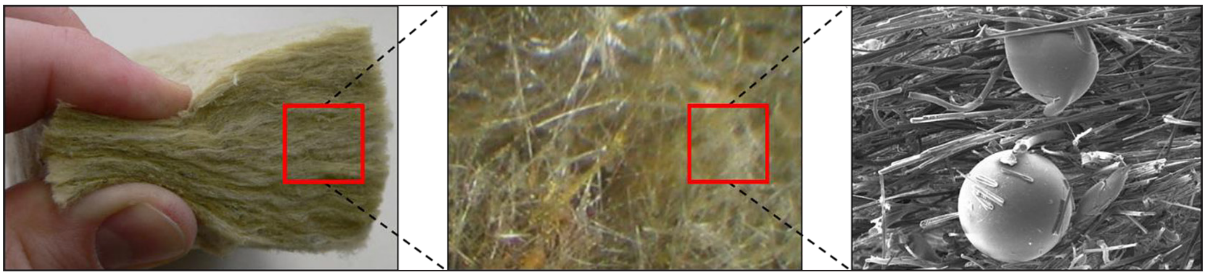

Figure 2. Mineral wool visualization

frame, with the length and depth of the material being adjusted for each section. In general, the physical visualization of mineral wool is shown in Figure 2. Because this study was conducted in the field, the dimensions of the media cannot be equated, because the segment where the media is placed also has different dimensions. Therefore, in this case, the media dimensions adjust for ease of installation in their respective segments.

Study site

The research location was carried out only on Segment 2 tributary of the Cikapayang River in the Bandung City Hall area. This segment is located between 6°54’37.5”S 107°36’37.8”E – 6°54›37.5»S 107°36›37.8» E and is considered to represent the original quality of the river, because it is located upstream, so it has not received natural treatment of river restoration design. The Cikapayang River is situated in a tropical climate with an average annual atmospheric temperature of 22.63 °C and 189.02 mm of rainfall from 1970 to 2020 (Yacub et al., 2022). As a result of the location of the river in urban areas, this area is densely populated by more than 2.5 million people, with a growth rate of 0.17% during 2018–2019. Tourism and education are the dominant sectors in Bandung, so domestic waste from residential and commercial areas is the main cause of pollution in the Cikapayang River. In contrast, domestic wastewater treatment facilities only serve 35% of the total need-dimensions of the river segment.

Water sampling

Water samples were taken from the middle of the river at a depth of 0.5 m below the water surface. Sampling was carried out in 2 time periods to determine the effect of seasonality on river quality, namely October 2018 – March 2019 (rainy season) and April – August 2019 (dry season). Sampling was carried out consecutively for seven days with a total lag between sampling cycles of 14 days. During the study, there were a total of 10 water sampling cycles. River water samples were taken using the grab sampling method every 9 a.m. considering the peak effect of a discharge from domestic activities-measurement of river discharge by determining the speed of water flow and multiplying it by the water level (Wulan et al., 2022). Water flow velocity measurements were carried out at 0.5 m canal intervals, and the values presented are the average of 5 repetitions of data recording. The samples for chemical parameter analysis were preserved by acidifying using 0.3 mL concentrated H_2SO_4. The preservation treatments were carried out after samples were taken from the river and placed in plastic bottles. The samples for the analysis of physical and chemical parameters were place in a box at 4 °C, then transported to the laboratory for further analysis. Both samples for the need for analysis of physical or chemical parameters use a 1 L polyethylene (PE) bottle. In situ parameters were measured using a portable measuring instrument, while others were measured according to Standard Methods for the Examination of Water and Wastewater (SMEWW).

Application model

The data used for modeling is field research data regarding COD removal using two types of mineral wools in the Cikapayang River, Bandung City. The data required include the dimensions of the mineral wool used, the form of mineral wool application, the width and depth of the river, the COD value before and after passing through the mineral wool, and the discharge of river water. In this research, there are four variations of mineral wool application, namely type I (density 80 kg/m^3 and water retention 95%) mineral wool-block form, type I mineral wool-cube form, type II (density 120 kg/m^3 and water retention 92%) mineral wool-cube form, and type II mineral wool-block form. Mineral wool type I is the drainage and water retention type and mineral wool type II is the water treatment type. Although all variations of the mineral wool application were placed in one river, each mineral wool application was considered as an independent reactor and did not influence each other. The position of each application in the Cikapayang river can be seen in Figure 1. The visualization of the mineral wool type that was used in this study and its application can be seen in Figure 1. The reaction kinetics is determined by entering the data into the zero order (Eq. 1), first order (Eq. 2), and second order (Eq. 3) reaction equations obtained from the derivation of the Plug Flow Reactor equation which is considered to represent the flow characteristics of a water body. The kinetics that occurs is the reaction kinetics of COD removal will be assumed as a complex reaction. To calculate the reaction coefficient, a regression plotting of data was carried out between residence time (τ) as the x- axis and the reaction order equation as the y-axis.

To determine the value of the reaction coefficient that will be used as well as to determine the application of the most optimal mineral wool application, several methods are used, namely by comparing the determination coefficient and the standard deviation of the difference between the actual data and the modeling results. The k value to be chosen is the k value with the smallest standard deviation from the difference between the actual and modeling results, which indicates the closeness between the actual data and the modeled data. The chosen k value will be used in the modeling equation to determine the dimensions of the supporting media. The removal model is an equation obtained from the kinetics and k values selected in the previous stage. The equation is then applied to MatLab to determine the dimensions of the supporting media that need to be added to the water body with a certain value of COD concentration. Several points that need to be considered in this research is the mineral wool application is considered as an ideal reactor under steady state conditions with constant density, modeling can be used for the influent range of 25 mg/L to 250 mg/L COD, and the measured COD concentration is the total COD concentration, both dissolved and suspended COD.

RESULTS AND DISCUSSION

Water quality and characterization

Measurement of the water quality of the Cikapayang River was carried out over a period starting from October 2018 to July 2019. There was a fluctuation in the concentration for each parameter. In the dry season, there is an increase of concentration in almost all parameters, both physical and chemical, accompanied by a decrease in DO concentration when compared to river quality during the rainy season. The water quality of the Cikapayang River can be seen in Table 1. The concentration of parameters affecting aquatic

Table 1. Water quality characteristics of the Cikapayang river on rainy season, dry season, and annual

Parameters	Unit	Standard	Rainy season		Dry season		Dev. (%)	Annual
			Range	Average	Range	Average		
Water discharge	m^3/s	-	0.04–1.56	0.33	0.09–0.67	0.28	15	0.32
Temperature	°C	Devi. 3	21–26	23	22–25	24	4	24
TSS	mg/L	50	7–121	23	10–118	29	21	22
Turbidity	mg/L	-	7–112	28	11–94	24	14	27
TDS	mg/L	1000	84–3070	357	99–205	130	64	185
EC	um/ms	-	160–2510	391	189–362	248	37	252
pH	-	6–9	5.5–9.8	7.3	6.9–8.0	7.8	6	7.5
DO	mg/L	4	0.5–5.3	2.6	0.1–5.0	1.2	54	2.7
COD	mg/L	25	19–208	45	10–179	77	42	42
TP	mg/L	0.2	0.045–1.02	0.44	0.07–1.61	0.50	13	0.48
TN	mg/L	-	2.4–64.8	24.9	5.3–80.3	36.6	32	31.8
NH_4	mg/L	-	0.00–0.32	0.09	0.00–0.40	0.18	48	0.12
NO_2	mg/L	0.06	0.02–4.31	1.10	0.02–3.36	0.81	27	0.92
NO_3	mg/L	10	0.03–3.09	0.70	0.02–1.77	0.56	21	0.64

conditions could be determined using Q, T, DO, and turbidity data. A total of 19 samples from 10 different sampling times had the COD concentrations that were higher than the acceptable limit of 42 mg/L. Eighty-nine percent of them came from the readings taken during the dry season. The Cikapayang River distribution of COD grew by 42% this season. Changes in basic parameters and the surrounding during the dry season affect the measured concentrations.

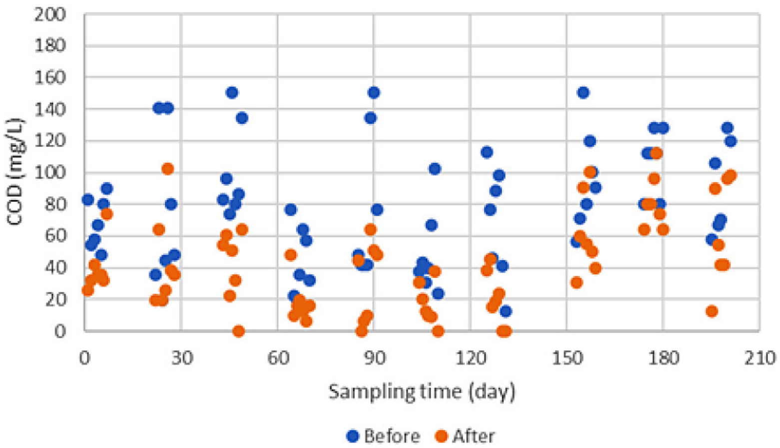

Figure 3. COD concentration before and after type I drainblock-block form application during sampling period in Segment 2

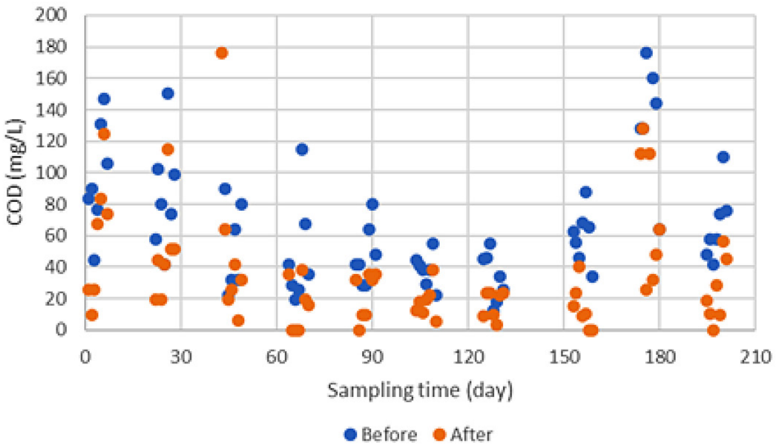

Figure 4. COD concentration before and after type I drainblock-cube form application during sampling period in Segment 4

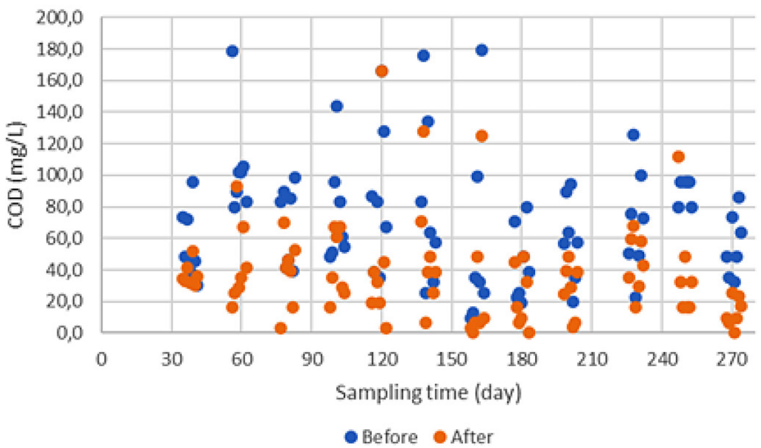

Figure 5. COD concentration before and after type II drainblock-cube form application during sampling period in Segment 8

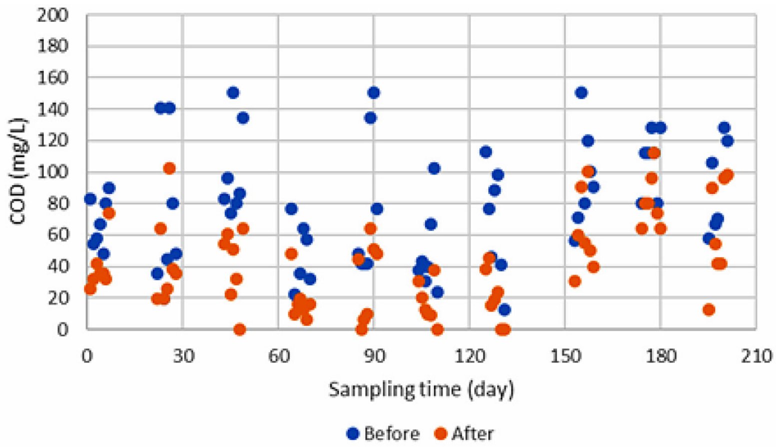

Figure 6. COD concentration before and after type II drainblock-block form application during sampling period in Segment 9

According to sampling time in the sampling period, the fluctuation of water quality is high. There is no exact value of water quality, thus the modeling will have low certainty. In this modelling, the number from both seasons will be used as overall data. COD removal by each type of mineral wool application is used as primary data to model the removal efficiency of mineral wool. The fluctuation of COD concentration before and after mineral wool application during sampling period can be seen in Figures 3–6, respectively. In general, the results of COD removal using mineral wool in the case of the Cikapayang River showed quite good results where the optimum results are even close to perfect removal, but the average value is at 54% for all segments (Prayogo et al., 2020).

Selection of removal kinetics model

In field studies, the factors that affect the concentration of organic substances such as temperature and pH cannot be adjusted as in laboratory studies. This causes the reactions that occur in the supporting media not to focus on just one process, but several processes, each of which has a role in removing organic compounds. The reaction coefficient value is calculated to express the overall pollutant removal reaction in the water body. To calculate the reaction coefficient, a regression plotting is performed between residence time (τ) as the x-axis and the reaction order equation as the y-axis. For a 0-order reaction the equation C_t-C_0 is plotted; for first-order reactions, the equation ln (C_t/C_0) is plotted; and for the second order equation the equation $(1/C_t)$-$(1/C_0)$ is plotted. C_0 is the initial concentration before water enters the supporting media (mineral wool) and Ct is the concentration after water passes through the supporting media. The results of the reaction kinetics calculation can be seen in Table 3. To determine the removal kinetics model, coefficient of determination alone and the calculation of the standard deviation between the difference of the actual data and the modeling results are used. The calculation of standard deviation can be seen in Table 2 and 3. The type of mineral wool application with the smallest standard deviation value and largest coefficient of determination is type II mineral wool with a cube shape, using the first order reaction equation as seen in Figure 6. The value of COD concentration that enters the supporting media always changes with time. At different sampling times, different concentration values will be obtained. This is caused by environmental factors such as temperature, pH, influent condition, flow rate and water velocity, weather, and climate, as well as anthropogenic influences that can cause the increase or decrease of COD concentrations.

Effect of different supporting media

The two types of mineral wools used show significant differences in their function as treatment for water bodies. Comparisons were made between type I-cube and type II-cube which has the same application form. The k value in type II-cube is higher than the k value in type I-cube shows that removal of organic pollutants in water bodies using type II mineral wool is better. Judging from the type II mineral wool, which is the water treatment type, it will certainly show better performance than the type I mineral wool, which primarily functions as water retention. Mineral wool type II has a density of 120 kg/m^3 which is greater than the density of type I mineral wool of 70–80 kg/m^3 (Hao et al., 2019; Prayogo et al., 2023). Density shows the measurement of the mass per unit volume of the object. The denser the supporting media are, the greater the filtration process that occurs when pollutants pass through the supporting media. The pores of the supporting media will become smaller and increase the chances of trapping particulates.

Mineral wool type II has a hydraulic conductivity of 7 mm/s which is smaller than the type I mineral wool of 12 mm/s. Hydraulic conductivity is the ability of a material to flow water at a certain speed (Wanko et al., 2016). The lower hydraulic conductivity value in type II mineral wools can provide longer residence time so that the processing of pollutants when passing through the supporting media can be maximized compared to type I mineral wools. The longer residence time also gives time for microorganisms to adhere to the surface of the supporting media. Mineral wool type II has a high level of roughness and rigid surface, while type I mineral wool has a low level of roughness. The roughness greatly supports the microorganisms to easily attach to the surface of the supporting media. Roughness also plays an important role in reducing the possibility of erosion of the biofilm that has formed on the supporting media. On the surface of the supporting media with low roughness, the biofilm that has been formed tends to be released easily, especially if there is a discharge jump in the water body. The mineral wool has a hydraulic conductivity equivalent to coarse gravel (based on Azmi et al. (2018) data). This means that water can easily pass through mineral wools and minimize clogging, supported by high porosity (Van Jaarsveld, 2020), allowing for a more optimal pollutant removal process compared to other filter media (Azmi et al., 2018).

The COD concentration during the rainy season averages 45 mg/L with a minimum value of 19

Table 2. The value of the reaction coefficient and the coefficient of determination for each drainblock application

Reaction kinetics	Type I, block		Type I, cube		Type II, block		Type II, cube	
	k	R^2	*k*	R^2	*k*	R^2	*k*	R^2
Orde 0	-1.1404	0.0016	-10.067	0.0283	17.158	0.0604	22.756	0.0652
Orde 1	0.1019	0.0259	-0.2954	0.0736	0.5378	0.1025	0.4968	0.0529
Orde 2	0.0097	0.0669	-0.0134	0.0548	0.0406	0.0707	0.021	0.019

Table 3. The standard deviation value for each drainblock application

Reaction kinetics	Standard deviation			
	Type I, block	Type I, cube	Type II, block	Type II, cube
Orde 0	22.723	31.568	24.759	18.292
Orde 1	18.837	62.799	14.532	16.367
Orde 2	26.875	33.960	24.366	30.078

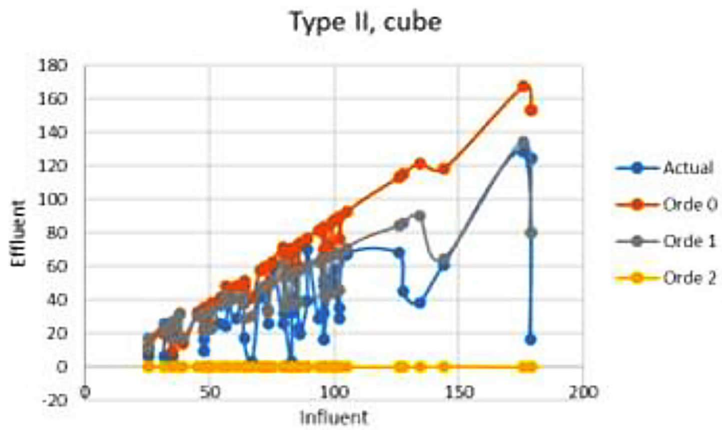

Figure 7. Plot comparison between actual data and modeling result data for type II-cubes application

mg/L and a maximum value of 208 mg/L. In the dry season the average is 77 mg/L with a minimum value of 10 mg/L and a maximum value of 179 mg/L. These differences are caused by the dilution from rainwater Prayogo et al. (2023). Therefore, the average measured COD value is smaller than in the dry season for each measured sample volume.

Effect of pollutant concentration

To determine the ability of mineral wool in removing various pollutant loads, modeling based on the range of pollutants that enter the supporting media has been done (Aphirta et al., 2020). The modeling results for each concentration range can be seen in Table 4.

Each range of COD concentration shows a different reaction coefficient (k) that shows the removal ability that can be done by the supporting media under these conditions. The greater the value of the reaction coefficient means the higher the removal, and vice versa. In general, the value of the reaction coefficient for type II-cube in each concentration range is around 0.5/s. The k value in type II-cube also tends to be stable and does not have high fluctuation. The greatest reaction coefficient values are in the influent concentration range of 50–100 mg/L which means that mineral wool can work optimally in that concentration range. The different k values in each concentration range can be caused by the influence of the season during sampling. In the rainy season there will be dilution and an increase in discharge which will speed up the residence time of water in the supporting media. In the dry season, although it has a smaller discharge compared to the rainy season, it has a higher concentration value.

Effect of residence time

From Table 5, the value of the removal percentage is higher as the residence time on the supporting media increases. Longer residence time will maximize the removal processes that occur in the supporting media.

Table 4. The k value based on the pollutant concentration for type ii-cubes application

Influent range (mg/L COD)	*k* (/s)	R^2
25-50	0.4802	0.1258
50-100	0.5722	0.0933
>100	0.5526	0.1365

Table 5. Removal percentage based on residence time for type ii-cubes application

T (s)	Removal percentage		
	Maximum	Mininum	Average
0.50	81.818	20	50.726
0.750	83.333	15.385	50.978
1.5	96.154	30	63.218

In the PFR reactor, the removal will be higher near the end of the reactor and shows the role of residence time. The longer residence time allows time for the contaminants to be absorbed by the pores of the supporting media. In addition to the adsorption process, the microorganisms in water bodies will also be easily attached because they are given a longer adhesion time. To determine the effect of residence time with pollutant removal results, a one-way ANOVA test was performed between the residence time value of 0.5 seconds; 0.75 seconds; and 1.5 seconds. The results show that there is no significant effect between residence time and the amount of COD removal, which means residence time is not the dominant factor in the removal process using mineral wool. There are many factors affecting the amount of COD removal in the field.

Validation of organic materials removal modelling

To determine the suitability of the model with actual data in the field, validation is necessary. Validation of a model can be done by calculating Root Mean Square Error (RMSE) and Mean Absolute Deviation (MAD). The results can be seen in Tables 6 and 7. The RMSE and MAD values, which are quite large, indicate that the modeling used is not good enough in approaching the real value or actual data. This is because there are many factors that need to be considered in modeling field data, especially environmental conditions that occur when sampling. This modeling just focused on the influent and effluent value of COD. Field data is very different from laboratory data because there is no adjustment under certain conditions.

Modeling simulation using MatLab software

The simulation in Figure 8 uses the equation obtained from the derivation of the equation of PFR reactor with reaction order I and the use of the average reaction coefficient value obtained from the modeling results. The reaction coefficient value used is 0.5378/s. An example of the

Table 6. Calculation in dry season

Reaction kinetics	Root mean square error (RMSE)			
	Type I, block	Type I, cube	Type II, block	Type II, cube
Orde 0	45.579	63.718	35.546	27.033
Orde 1	30.004	108.087	21.331	22.826
Orde 2	52.397	50.912	42.980	48.587

Table 7. Calculation in rainy season

Reactionkinetics	Mean absolute deviation (MAD)			
	Type I, block	Type I, cube	Type II, block	Type II, cube
Orde 0	39.619	55.509	25.684	20.045
Orde 1	23.481	88.371	15.717	16.050
Orde 2	45.114	38.200	35.531	38.354

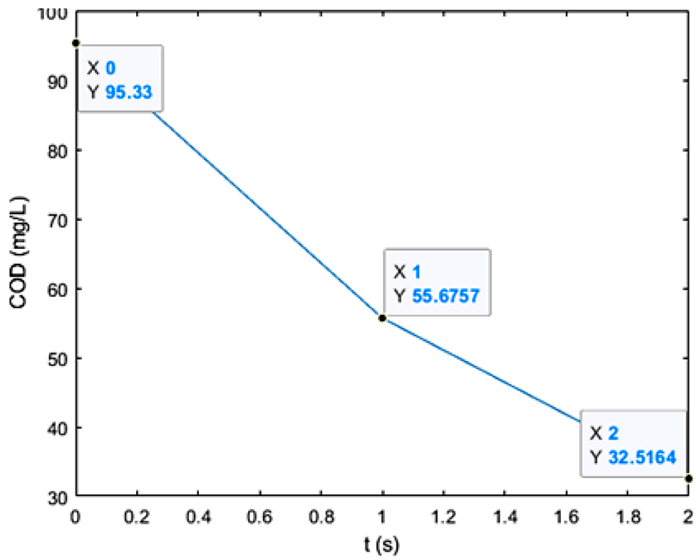

Figure 8. Graph of COD degradation using MatLab application

modeling simulation results can be seen in Figure 8. This figure is the result from modelling the data from polluted water body in Cikijing River canal, Ranaekek. The data include width 0.95 m, height 0.4 m, average discharge 0.023 m^3/s, average velocity 0.06 m/s, average COD concentration 95.33 mg/L. and removal target is 25 mg/L. From the modeling, the length of mineral wool to fulfill the target is 0.1506 m. The concentration value is decreasing which is directly proportional to the residence time of water in the supporting media. The residence time in water also indicates the length of the supporting media which needs to be applied (Dion et al., 2022).

Processes and reactions that possibly occur in COD removal by supporting media in water bodies

The trend that does not form a straight line caused by the fluctuating distribution of the data indicates that the reaction is a complex reaction. The reaction that occurs does not depend on one dominant reaction but the result of several reaction processes. The processes that may occur in organic materials removal when passing through the supporting media are filtration, adsorption, and biodegradation. In the filtration process, when water passes through the supporting media – acting as filter media – organic compounds will be retained, causing a decrease in COD concentration (Subroto et al., 2022). In the adsorption process, pollutants will enter the pores of the supporting media. The adsorption process that occurs in the supporting media is probably physical adsorption, namely adsorption caused by the Van der Waals forces that exist on the adsorbent surface. The biodegradation process occurs due to the formation of biofilms in the media. The biofilm was formed from the consortium of local microorganisms present in water passing through the supporting media (Cahyadi et al., 2014; Zhang et al., 2018). The presence of oxygen causes the aerobic oxidation process to take place, organic materials will be converted into relatively stable final products and the rest will be synthesized into new microbes (Subroto et al., 2022). According to Prayogo et al. (2020) and Prayogo et al. (2023), biofilms on a supporting media usually take 30–40 days to grow optimally.

CONCLUSIONS

The kinetics of the removal of organic materials obtained from the modeling the field data using supporting media in the form of mineral wools is 0.5378/s. Due to limitations in modeling and fluctuated field data, the accuracy of the model obtained in this study is not good. For future research, modeling using a specific process that can be seen using laboratory tests may be a solution. In addition, detailed environmental condition data sampling will be very helpful in field modeling. This aims to determine the dominant process that plays a role in eliminating pollutants in supporting media. In this study, the reaction kinetics coefficient value shows the whole process without specialization in a particular process. The processes that may occur in organic materials removal when passing through the supporting media are filtration, adsorption, and biodegradation.

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