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Preliminary study of infiltration gallery for water treatment towards Universal Access 2019 in Indonesia

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Abstract

Infiltration gallery is a method of water treatment through soil filtration. The mechanism is the filtering or absorption of contaminants in the river that flows through the soil. This method uses soil to remove contaminants. This method has three kinds of screening processes, ie physically, chemically and biologically. This process depends on moisture content, temperature, porosity, specific gravity, the saturated degree and hydraulic conductivity in the soil. Now a days, the cost of clean water production in the province of East Java, Indonesia requires a lot of cost, because the consumption of coagulant is very high; It is necessary to have a preliminary processing that helps the performance of water treatment in East Java, Indonesia. Natural water purification method using soil called infiltration gallery can be one solution in processing river water or as preliminary processing for water treatment in East Java. The purpose of this research is to know soil characteristics in soil samples in each region and its ability to removel TSS and Total Coliform. The second objective is to find good soil composition for removel TSS and total Coliform. The location of soil sampling is in Surabaya, Lumajang, Bangkalan, Mojokerto, Sidoarjo and Gresik, East Java province, Indonesia. The method of analysis used gravimetry, method 9223 B, the comparison between mass and specific gravity, constant head permeameter and wet grain. The results showed that the soil samples from each region were not able to remove the TSS and total coliform, so that the engineering of soil composition was required. Appropriate soil composition is sand and clay, 85% and 15%, with the percentage of TSS and total coliform removal of 63.50% and 99.67%.

Keywords: Infiltration gallery, soil purification, water treatment plant

Introduction

Rivers are usually, used for raw water treatment of drinking water. But the quality of the downstream river is not as good as the upstream area. Thus, it is necessary to process first to improve the quality of the river. Furthermore, the national government of Indonesia has targeted universal access to clean water and sanitation in the national medium-term plan (RPJMN 2015-2019). Therefore, to support the national target, further research on the infiltration gallery as one of the pre-treatment units in the river is required. Infiltration gallery is a natural water treatment mechanism using soil on the banks of the river. This method consists of perforated pipes under a gravel-covered river bank to collect water, from the river through soil filtration (Barbiero *et al*., 2008; Jurel *et al*., 2013; Bekele *et al*., 2013; Jones. 2008). The process mechanism in soil, consists of adsorption, filtration, degradation, called purification (Bekele *et al*., 1995). The infiltration gallery has the ability to remove TSS, nitrate and phosphate of (68; 28; 28.5)% (Assare and Hamilton. 2004). Filtration in soil depends on porosity, water velocity, pore size distribution, pore homogeneity, adsorption, filtration, sedimentation, and bacterial activity in the soil (Safadoust *et al*., 2012; Mosaddeghi *et al*., 2009).

Previous researchers have analyzed the characteristics of the soil, and each similar type of soil appears to have different physical characteristics. The porosity of sand for the infiltration gallery is 0.406; 0.367; 5.18 and the hydraulic conductivity is 0.434 x 10-7cm^2/day; 4.34 x 10-7 cm^2/day and 1.38 x 10-4 cm^2/day (Yoon and Mohtar. 2015). According to Valdes *et al. (*2001), clay has small pores that can filter TSS. Claystone has porosity 0.175, moisture content 7.6%, Specific gravity 2.7 g.cm, void ratio 0.216, and 95% degree of saturation (Wan *et al*., 1995). The ability of water to pass through the pore of sand is reduced by 50%, with the filtration rate of 13,000 mm / h and 10 M sand depth (Descroix *et al*., 2012). Composition (90, 1, 9)%, (86, 6, 8)%, and (85, 8, 7)% have a hydraulic conductivity of 6 x 10 $^{-3}$, 1.4 x 10^{-3} and 1.1 x 10-^{3} cm /s, respectively (Bughici and Wallach. 2016). It is proven that the filtration rate in clay will be lower than that of sand. Other researchers found the conductivity, hydraulic sand and clay between 2,544 cm / day - 2,617 cm / day and 2,275 cm / day - 2,374 cm / day (Wang *et al*., 2000).

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Table 1: Parameter and methods for TSS and total Coliform analyses

Parameter	Analysis method	Refereence	Year
TSS	gravimetri	-	-
E. Coli	METHOD 9223 B	US EPA	March 26. 2007
Soil porosity	Comparison between mass and specific gravity	ASTM D 2435 – 70 SNI 03-2812	1992
Permeability	*Constant head permeameter*	ASTM D 2434-68 SNI 03 - 6871	2002
Size grain	Wet grain	ASSHTO T-27-74 ASTM C-130-46	
Water content	Gravimetry	ASTM D 2216 -71 SNI 03-1965	1990

Table 2: Materials for miniature of the infiltration gallery

Sr. No.	Equipment	Quantity
1.	Holding tank 80 liter	1
2.	Acrylic pipe diametre 5.4 cm dan height 10 cm	4
3.	Knee 90^0 PVC 2”	4
4.	End Cap PVC 2 inch	4
5.	Outer Sock drat PVC 2”	4
6.	Inner Sock drat PVC 2”	4
7.	filter porous 0.001	4
8.	PVC pipe diametre 2 inch lenght 5 cm	10

Organic carbon and clay minerals can be found in agricultural areas (Nano *et al*., 1999). In the previous research found the type of clay engineering, heterostructure acusticus clay. Heterostructure acusticus clay is made by stirring 1 gram of clay and then put it into an oven with a temperature of 50 degrees Celsius and added by trimethyl ammonium bromide cetil. the results of the experiment appear as a type of activated carbon that was derived from clay that having a surface area of 752 m2 / gram having a porosity of 0.3 cm 3/g (Santos *et al*., 2010)**.**

Materials and methods

This research was conducted at soil mechanics laboratory in Civil Engineering ITS Surabaya, for characteristic soil analysis. The second research was conducted at the laboratory of water technology in Environmental Engineering in ITS Surabaya, for water quality analysis, such as TSS and total coliform. The soil characteristic parameters that were tested, moisture content, saturated degree, porosity, soil particle distribution, specific gravity, temperature and water quality parameters. Parameter and methods for analyses are shown in Table 1 and the material needed for this research can be seen in Table 2.

The reactor is made up of an acrylic tube with an internal diameter of 5.08 cm, an outer diameter of 5.48 cm and a height of 10 cm and is equipped a plastic container tub with a capacity of 80 liters as a water tank. The reactor can be seen in Figure 1. The acrylic tube was filled with soil that was taken from each region of Surabaya, Lumajang, Bangkalan, Mojokerto, Sidoarjo, and Gresik. The soil that was filled in the acrylic tube was undisturbed soil, and was not mixed at the time of sampling. Method of taking the soil used a tube Selbi. The process of this reactor was at the water from the container flowed into each acrylic tube and each acrylic tube was taken as the water sample, to be analyzed for TSS and total coliform parameters. The position of the acrylic reactor was placed vertically, which replicates the water performance in the soil during the infiltration process.

Figure 1. Soil reactor

The infiltration process in the reactor had a downward flow leading to the effluent point. The detention time at this reactor was 5 hours with water sampling every 1 hour. The time was short because the soil type in the sample contained a lot of clay so that in a short time the water could not flow out. There are 2 (two) flow namely infiltration and percolation. The soil consists of three components: air, water, and solids. When water passes through the soil, will replace the air within the pores, thus the air will be driven out of the soil. The water flow to the sand grains depends on gravity and water capillarity so that water spreads throughout the pores of the soil. This force occurs because of the attraction of water and soil. The reuse three filtration processes methods, at first physical screening, in which the solid particle was retained by the pores of the soil, provided that the larger diameter was greater than the soil pore. Second, the chemical process in which the process of oxidation and reduction occurred due to the incoming air to help bacteria in organic substances degradation. Thirdly, biological processes was the performance of biofilms that gradually broke down organic matter and total coliform which was lost due to physical filtration and the presence of competitors from other bacteria, temperature and radiation of sunlight.

Soil saturation is a condition when water could not penetrate between the pores in the soil. Figure 1 shows that water can pass through a grain of sand due to its grain texture. For example in the sand, water can penetrate pores easily than clay. The flow of water that flows through the pores, can replace the air trapped in the pores. If water carries organic pollutants or solid particles, it will be trapped in the soil pores. This condition causes water saturation and causes reduced flow at the outlet.

Results

Yield attributes

The soil in every state has different characteristic including the moisture content, saturated degree, porosity, soil particle distribution, specific gravity, temperature and water quality parameters. These characteristics will influence the water flow passed through the grain. The filtration ability depends on their characteristics such as water content, temperature, porosity, specific gravity, saturated degree, and permeability. Permeability is the ability of water to move through the porous media for example soil. Soil mechanism has two processes. they are physic and biology (Kedziorek and Bourg. 2009; Price *et al*., 2013 and Valdes *et al*., 2014).

The filtration process in porous media depends on porosity and permeability of the media. There are so many processes occurring when water moves through the media. One of the processes is absorption process. Absorption process occurred in porous media. However. water contains solid including dissolved solids and suspended solids (SS) and organic compounds. If the specific gravity of the SS is bigger than the water, then it will be accurately precipitate on the surface of soil and absorption inside of the pores of the soil. Therefore. gravel has the ability to remove organic compound about 44.2% - 72.6% (Kusuma *et al*., 2016). The ability of every single soil sample to remove TSS and total Coliform can be seen in Table 3.

Table 3: Percentage of Removal of TSS and Total Coliform

No.	Soil Sample	Sand (%)	Silt (%)	Clay (%)	Removal TSS (%)	Removal total coliform (%)
1	Lumajang	55,0	10,0	35,0	6.88	16.67
2	Mojokerto	60,0	5,0	30,0	26.16	92.78
3	Madura	16,2	30,5	53,3	15.62	28.89
4	Sidoarjo	70,0	15,0	15,0	21.10	92.78
5	Gresik	16,0	30,0	53,0	8.85	16.67
6	Surabaya	55,0	45,0	0,0	10.49	16.67

Table 3 shows that TSS and Total Coliform could be removed by the use of soil filtration but mostly not significant, so in the next research, there is a need of modifying soil composition to reach high percentage of Total Coliform and TSS removal. It can also be concluded from table 3 that the finer the soil pore diameter, the better removal of the contaminants and hydraulic conductivity becomes slower.

Water content is one of the parameters to know the amount of water contained in the soil. The result of the water content analysis determine the categories of soil; According to Tetegan *et al.* (2015) the sand and clay loam contains water content 0.06 cm^3/cm^3 and 0.136 cm^3/cm^3. Surabaya city, for example, has the highest water content than other cities in Jawa Timur Province. The range of temperature, each sample site is between 25-28 ^oC. Porosity is the value of pores of the media, pores use flowing water inside of the soil. The range value of porosity in the samples media is 0.55-0.59. Specific gravity (SG) is mass

per volume of soil, it's mean that for 1 gram soil have 1 cm^3 of volume. The range specific gravity each samples soil in each site are 2.478-2.647 gram.

Saturated degree shows soil saturation condition, due to water trapped inside. On the island of Madura especially in Bangkalan district a saturation value of 83.3%. This was reconcluded shows that Bangkalan district contains lots of clay. The distribution of soil grains also affects the saturation level of the soil (Nelsson and Rittenour. 2015). It also affects hydraulic conductivity other than porosity. This causes Bangkalan district have lower conductivity than other sample cities because there is a greater clay percentage.

Due to the amount of clay composition causes a lot of infiltration rate is reduced. In the previous study found that sand and clay have the hydraulic conductivity of 5 cm/hr and 0.05 cm/h (Dalai and Ramakarjha. 2014). The distribution of contaminants on soil depends on distance and hydraulic conductivity, biological processes, and soil physicochemical processes (Mustafa *et al*., 2016; Nham *et al*., 2015). Other researcher reported the conductivity of the soil in each different location or region (Shwetha and Varija. 2015). In the study, it can be proven that the same type of soil does not mean having the same characteristics in each place. The soil characteristics results of each study site are shown in Table 4.

Table 3 and Table 4; show that the ability of soil samples in each region has low contaminant filtration capability, requiring soil composition engineering, to improve screening performance. Soil composition engineering results are shown in Table 5.

Table 4: Soil Characteristics

No.	Soil sample	Water Content (%)	Temperature (^{0}C)	Porosity	Spesific Gravity (g/cm^3)	Saturated degree (%)	Hydroulic Conductivity (cm/s)
1	Lumajang	12.4	27.5	0.579	2.606	75.8	0.001767599
2	Mojokerto	14.3	27.8	0.598	2.478	81.4	0.000291684
3	Madura	10.9	28.0	0.599	2.506	83.3	0.000087
4	Sidoarjo	12.8	26.8	0.550	2.647	61.5	0.000165626
5	Gresik	14.4	26.3	0.596	2.573	83.9	0.000342206
6	Surabaya	15.3	25.5	0.573	2.501	67.9	0.000177234

Table 5: Performance of Soil composition engineering

No.	Clay (%)	Sand (%)	TSS (mg/L)	Total coliform (MPN/mL)	Percentage Removal TSS (%)	Percentage Removal Total coliform (%)	Hydroulic Conductivity (cm/s)
1	0	0	748	12 x 10^6	0	0	0
2	15	85	273	4 x 10^4	63.50	99.67	0,000217
3	20	80	344	11 x 10^3	54.01	99.91	0,000198
4	25	75	348	12 x 10^3	53.48	99.9	0.0000276
5	35	65	281	12 x 10^3	62.43	99.9	0,0000176
6	40	60	-	-	-	-	0.0000088
7	45	55	-	-	-	-	0.0000095

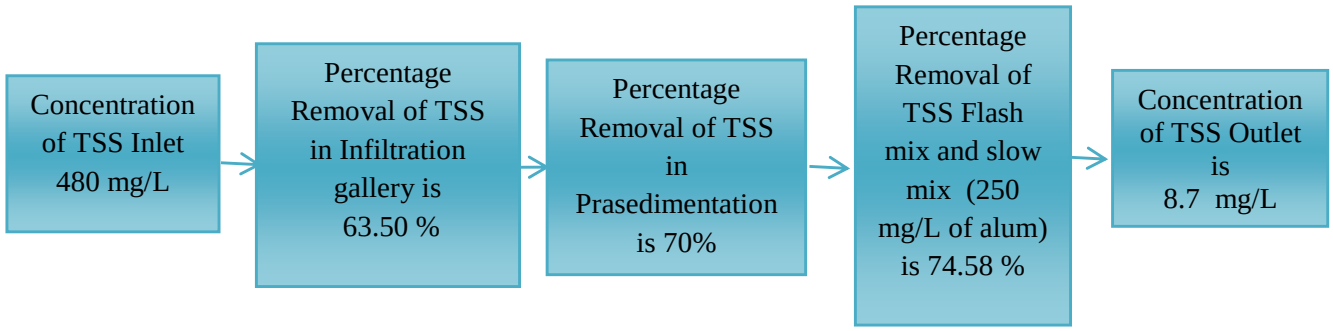

Figure 2: The flow of TSS concentration

Table 5, at number 6 and 7 did not show any decrease, because water could not get out because of the large amount of clay. Table 5 showed that the best composition of the sand to filter the contaminant was clay 15% and sand 85%. This composition was able to remove TSS and Total coliform by about 63.50% and 99.67%, respectively. The drinking water company in Indonesia which uses the river as its raw water usually adds alum to remove the physical contaminant. Based on the laboratory experiment results, the dose requirement of alum to remove 480 mg/L of TSS are 250 mg/L (74.58% removal), 500 mg/L (80.83% removal), and 750 mg/L (84.85% removal). Therefore, if the water treatment plant used the infiltration gallery for their pre-treatment, they can save the doses of alum to remove TSS and also total coliform. Here is one example of the concentration flow of TSS if using infiltration gallery as pre-treatment which is shown in Figure 2.

Figure 2 is the concentration flow of TSS concentration reduction when using infiltration gallery for water treatment in East Java, Indonesia. Water treatment in Indonesia is still using alum, so the consumption of alum should be saved to affordable water tariffs by the entire community. This saving aims to enable the entire community to access clean water in low price. In Figure 2, it is shown that the initial TSS concentration is 480 mg/L, which then decreased 63.5% by infiltration gallery. In sedimentation, TSS decreased again 70% and in the coagulation-flocculation process, with concentration of alum 250 mg/L, decreased 74.58%. At outlet or treated water obtained had TSS of 8.7 mg /L.

Conclusion

Infiltration gallery application is used as preliminary treatment at water treatment plant in East Java Province, Indonesia. The use of soil in the sample area resulted in poor quality of water, therefore it needs soil engineering to improve the soil's ability to reduce TSS and Total coliform. Soil engineering was done by changing the percentage of sand and clay. The results showed that the composition of sand and clay was 85% and 15%, able to decrease TSS and Total coliform about 63.50% and 99.67%, which resulted in savings of coagulant usage.

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