PROCEEDINGS

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A Stratified Activated Dry Sand Filter as an Alternative to Remove Iron and Manganese Concentrations in Ground Water Treatment Technology

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ABSTRACT

The occurrence of iron and manganese in ground water may pose problems to community. i.e. produces a bitter taste and odor, turns white clothes to yellowish ones, and stains laundry and plumbing fixtures. Activated Dry Sand Filter (ADSF) could remove high iron and manganese concentrations. This research aims to identify the effect of the variation of filter media and its depth towards the removal of iron and manganese concentrations in a stratified ADSF. Two sand diameters (0.84 mm and 1.19 mm) are used in two different positions, i.e. variation I, 50 cm depth of 0.84 mm sand is put above 50 cm depth of 1.19 mm sand: whereas in variation II it is oppositely placed. Iron concentration can be lowered as to meet the Water Quality Standard (WQS) issued by Indonesian Republic Ministry of Health (No. 907/MENKES/SK/VII year 2002) (i.e. 0.3 mg/L and 0.1 mg/L for tolerable iron and manganese concentrations in drinking water respectively). This is generally happened in 20 cm depth of filter with the efficiency of 93% to 100%. For manganese, it is only happened in 100 cm depth although the efficiency is 100%. The removal of these substances in variation I is better than that of variation II. The dissolved oxygen concentrations, pH and turbidity range from 6.1 mg/L to 8.0 mg/L, 7.0 to 7.4 and 0.2 to 0.5 NTU subsequently. This ADSF is economically viable due to the cost is only Rp. 460/m3 compared to the Perusahaan Daerah Air Minum Bandung (Bandung Water Supply Enterprise)'s water cost that is Rp. 880/m3 (for the first 10 m3).

Keywords: iron, manganese, sand diameter, sand or filter depth

1.0 INTRODUCTION

The availability of water in urban area is extremely important considering its dynamic community life. To fulfill the need of water, the community cannot only rely on the supply from the Bandung Water Enterprise (Perusahaan Derah Air Minum (PDAM) Bandung) due to its limited service. Ground water is therefore one of the alternatives to meet the need. Unfortunately, ground water is very limited in terms of its quality as well as its quantity. From the quality of view, it is far from the Water Quality Standard (WQS) set by Indonesian Republic Ministry of Health (No. 907/MENKES/SK/VII year 2002). Problems that are mostly found in ground water are those of the high turbidity and high concentrations of iron and manganese. It is therefore required to find alternatives of ground water treatment as to meet the WQS. Activated Dry Filter Sand (ADFS), that had once been successfully researched by Budianto, Dedi et al, 1988, could remove high iron and manganese concentrations until they meet the WKS. As that ADFS used uniform sand as its media, this research therefore aims to identify the effect of the variation of filter media and its depth towards the removal of iron and manganese concentrations in a stratified ADFS.

2.0 STEPS OF WORK

To meet the objective of this research, steps of work are arranged as can be seen in Fig. 2.1. These steps are described below.

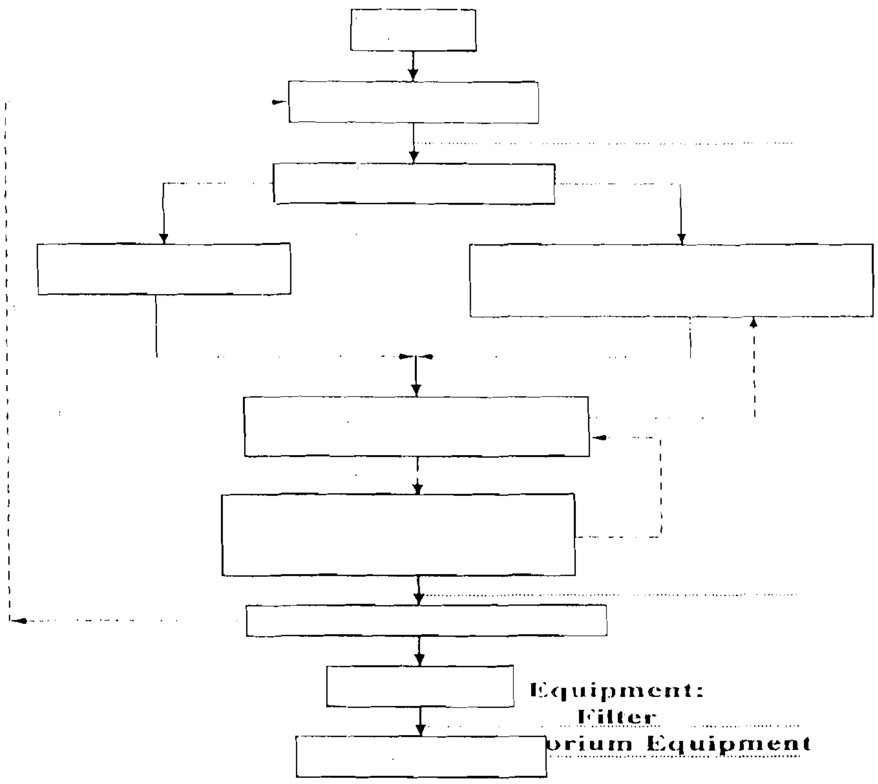


Figure 2.1. Steps of Work

2.1 Literature Review

Literature review should be done initially in order to find some references with regard to the research.

2.2 Media and Equipment Arrangement

2.2.1 ***Equipment Arrangement***

The filter used in this research is made of PVC pipe with 6 inches diameter and 150 cm height. There are 6 faucets as effluent channels (sampling valves) with 20 cm distance between each channel. Operationally, this filter is equipped with a water basin, a pump, a plastic hose, an influent tank, a valve as a discharge controller, as figured in Fig.2.2.

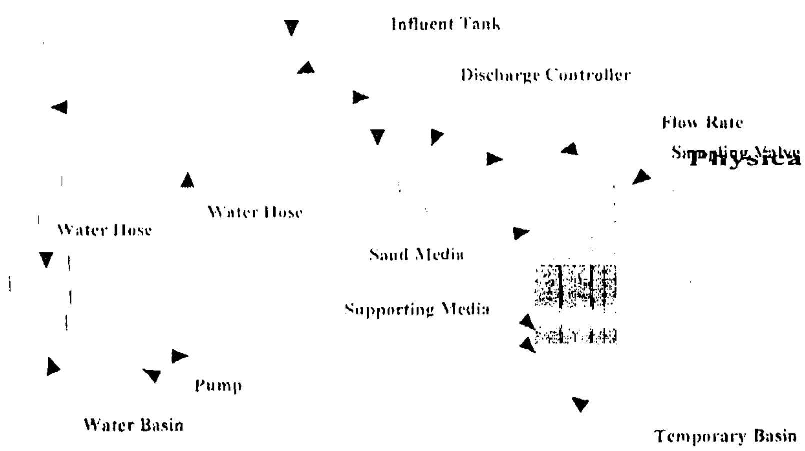


Figure 2.2. An Activated Dry Sand Filter

ADSF operation is as follows:
1. Artificial water is put in the water basin downly placed.
2. Water is pumped to the influent tank that is put in 60 cm height.
3. Discharged is controlled in accordance with the required operation.
4. All sampling valves are opened and let the water discharge for 5 minutes to first condition it
5. Effluent from each valve is storaged and measured for each parameter that is going to be analized.

2.2.2 Media Arrangement

Filter media that generally used in Indonesia is that of Bangka sand/kwarsa sand. From the previous research, it is known that the effective diametres to remove iron and manganese are those of 0.84 mm and 1.19 mm diametres [4]. These diametres are then used in this research. The next step is to produce active sand as follows:
1. 0.84 mm and 1.19 mm diametres sand is washed separately and dried after.
2. It is then soaked with $KMnO_4$ 0.01 N for about 24 hours. to make it active.
3. Next, it is dried at 105 °C in an oven for about 2 hours.
4. The sand is readily used then.
5. It is finally put in the PVC pipe with regards to its diametre in accordance with the variations below as shown in Fig 2.3:

a. Variation I, 50 cm depth of 0.84 mm sand diameter is put above 50 cm depth of 1.19 mm sand diameter
b. Variation II, the above position is oppositely placed

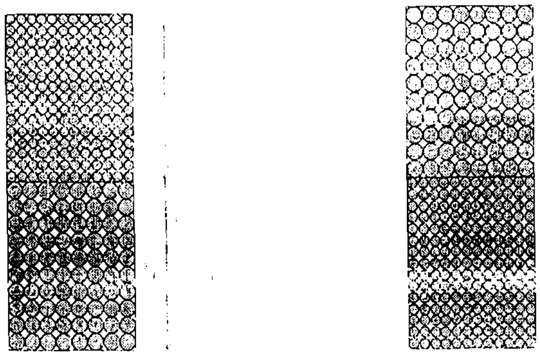


Figure 2.3. Variation of Media Composition

2.3 Laboratorium Analysis Methods

2.3.1 Physical Parameters

Physical parameters that are analyzed in the research along with their methods are as follows [1]:
- Turbidity : Turbidimetri Method
- pH : Elektroda Method

2.3.2 Chemical Parameters

Chemical parameters along with their methods used in this research are as follows [1]:
- Iron and manganese : Colorimetri Method
- Dissolved Oxygen (DO) : Titrimetri Method

2.4 Data Collection and Compilation

All data are collected and compiled to be easily analysed.

2.5 Data Analysis

Research results such as iron and manganese concentrations, DO concentration, turbidity and pH are then compared with the WQS.

2.6 Conclusion

Final results are then concluded. Analysis is needed both technically and economically to conclude the most effective filter variation.

3.0 RESEARCH RESULTS

This research is done with regards to some variations in terms of influent concentrations and filter compositions. Influent concentrations that are used are 3 mg/L, 7 mg/L and 10 mg/L respectively with the discharge of 0.389 L/dt. Sand diametres used are 0.84 mm and 1,19 mm. The result of this research are shown in Table 3.1-Table 3.6 as follows.

Table 3.1. Iron Removal Efficiency

Sand Depth (cm)	Iron Concentration, Discharge: 0.389 L/dt												Standard Fe**)
	Variation I						Variation II						
	3 mg/L	%	7 mg/L	%	10 mg/L	%	3 mg/L	%	7 mg/L	%	10 mg/L	%	
0	3.00	0	7.00	0	10.00	0	3.00	0	7.00	0	10.00	0	0.3
20	0.10*)	96.67	0.10*)	98.57	0.25*)	97.5	0.20*)	93.33	0.20*)	97.14	0.20*)	98	0.3
40	0.00*)	100	0.10*)	98.57	0.20*)	98	0.10*)	96.67	0.10*)	98.57	0.15*)	98.5	0.3
60	0.00*)	100	0.00*)	100	0.10*)	99	0.00*)	100	0.10*)	98.57	0.10*)	99	0.3
80	0.00*)	100	0.00*)	100	0.00*)	100	0.00*)	100	0.00*)	100	0.00*)	100	0.3
100	0.00*)	100	0.00*)	100	0.00*)	100	0.00*)	100	0.00*)	100	0.00*)	100	0.3

Note: *) Iron concentration complies with the WQS

**) Water Quality Standard (WQS) set by Indonesian Republic Ministry of Health (No 907/MENKES/SK/VII year 2002)

Source: Research result

Table 3.2. Manganese Removal Efficiency

Sand Depth (cm)	Manganese Concentration, Discharge: 0.389 L/dt												Standard Mn**)
	Variation I						Variation II						
	3 mg/L	%	7 mg/L	%	10 mg/L	%	3 mg/L	%	7 mg/L	%	10 mg/L	%	
0	3.00	0	7.00	0	10.00	0	3.00	0	7.00	0	10.00	0	0.1
20	0.99	67	2.97	57.57	3.96	60.4	1.98	34	2.97	57.57	3.96	60.4	0.1
40	0.00*)	100	1.98	71.71	2.97	70.3	0.99	67	1.98	71.71	2.97	70.3	0.1
60	0.00*)	100	0.99	85.86	1.98	80.2	0.99	67	0.99	85.86	1.98	80.2	0.1
80	0.00*)	100	0.00*)	100	0.99	90.1	0.00*)	100	0.00*)	100	0.99	90.1	0.1
100	0.00*)	100	0.00*)	100	0.00*)	100	0.00*)	100	0.00*)	100	0.00*)	100	0.1

Note: *) Manganese concentration complies with the WQ

**) Water Quality Standard (WQS) set by Indonesian Republic Ministry of Health (No. 907/MENKES/SK/VII year 2002)

Source: Research result

Table 3.3. Dissolved Oxygen (DO) Concentration

Sand Depth (cm)	Variation I								
	Discharge: 0,389 L/dt								
	3 mg/L			7 mg/L			10 mg/L		
cm	Fe	Mn	DO	Fe	Mn	DO	Fe	Mn	DO
0	3	3	6.78	7	7	6.7	10	10	6.1
20	0.10	0.99	6,77	0.10	2.97	6.6	0.25	3.96	6.1
40	0,00	0,00	7.59	0,10	1.98	7	0.20	2.97	7.3
60	0,00	0.00	7.64	0,00	0.99	7.5	0,10	1.98	7.3
80	0,00	0,00	7.72	0,00	0,00	7.5	0.00	0.99	7.4
100	0,00	0,00	7.99	0.00	0.00	7.6	0.00	0,00	7.5

Sand Depth (cm)	Variation II								
	Discharge: 0,389 L/dt								
	3 mg/L			7 mg/L			10 mg/L		
cm	Fe	Mn	DO	Fe	Mn	DO	Fe	Mn	DO
0	3	3	6.75	7	7	6,55	10	10	6,20
20	0,20	1,98	6,80	0,20	2.97	6,53	0,20	3,96	6,10
40	0.10	0,99	6.75	0,10	1.98	6,50	0,15	2,97	6,00
60	0,00	0,99	7,42	0,10	0.99	7,40	0,10	1,98	7,38
80	0,00	0,00	7,56	0,00	0.00	7,48	0,00	0,99	7,40
100	0,00	0,00	7,80	0,00	0,00	7,55	0,00	0,00	7,49

Source: Research result

Table 3.4. Turbidity

Sand Depth (cm)	Variation I								
	Discharge: 0,389 L/dt								
	3 mg/L			7 mg/L			10 mg/L		
cm	Fe	Mn	K	Fe	Mn	K	Fe	Mn	K
0	3	3	0,6*)	7	7	0,8*)	10	10	1,0*)
20	0,10	0,99	0,5*)	0,10	2,97	0,5*)	0,25	3,96	0,5*)
40	0,00	0,00	0,4*)	0,10	1,98	0,5*)	0,20	2,97	0,5*)
60	0,00	0,00	0,4*)	0,00	0,99	0,5*)	0,10	1,98	0,5*)
80	0,00	0,00	0,3*)	0,00	0,00	0,4*)	0,00	0,99	0,5*)
100	0,00	0,00	0,2*)	0,00	0,00	0,3*)	0,00	0,00	0,5*)
Sand Depth (cm)	Variation II								
	Discharge 0,389 L/dt								
	3 mg/L			7 mg/L			10 mg/L		
0	Fe	Mn	K	Fe	Mn	K	Fe	Mn	K
20	3	3	0,6*)	7	7	0,8*)	10	10	1,0*)
40	0,20	1,98	0,5*)	0,20	2,97	0,6*)	0,20	3,96	0,6*)
60	0,10	0,99	0,5*)	0,10	1,98	0,6*)	0,15	2,97	0,5*)
80	0,00	0,99	0,4*)	0,10	0,99	0,5*)	0,10	1,98	0,5*)
100	0,00	0,00	0,3*)	0,00	0,00	0,4*)	0,00	0,99	0,5*)
	0,00	0,00	0,2*)	0,00	0,00	0,3*)	0,00	0,00	0,5*)

Note: K = Turbidity (NTU), *) Mangan concentration comply with the WQS
Source: Research result

Table 3.5. pH

Sand Depth (cm)	Variation I								
	Discharge: 0,389 L/dt								
	3 mg/L			7 mg/L			10 mg/L		
cm	Fe	Mn	pH	Fe	Mn	pH	Fe	Mn	pH
0	3	3	7,05	7	7	7,1	10	10	7,1
20	0,10	0,99	7,31	0,10	2,97	7,3	0,25	3,96	7,4
40	0,00	0,00	7,28	0,10	1,98	7,4	0,20	2,97	7,4
60	0,00	0,00	7,28	0,00	0,99	7,4	0,10	1,98	7,4
80	0,00	0,00	7,29	0,00	0,00	7,4	0,00	0,99	7,4
100	0,00	0,00	7,29	0,00	0,00	7,4	0,00	0,00	7,4
Sand Depth (cm)	Variation II								
	Discharge: 0,389 L/dt								
	3 mg/L			7 mg/L			10 mg/L		
cm	Fe	Mn	pH	Fe	Mn	pH	Fe	Mn	pH
0	3	3	7,01	7	7	7,22	10	10	7,28
20	0,20	1,98	7,30	0,20	2,97	7,34	0,20	3,96	7,35
40	0,10	0,99	7,30	0,10	1,98	7,34	0,15	2,97	7,36
60	0,00	0,99	7,31	0,10	0,99	7,35	0,10	1,98	7,39
80	0,00	0,00	7,31	0,00	0,00	7,35	0,00	0,99	7,40
100	0,00	0,00	7,31	0,00	0,00	7,35	0,00	0,00	7,40

Source: Research result

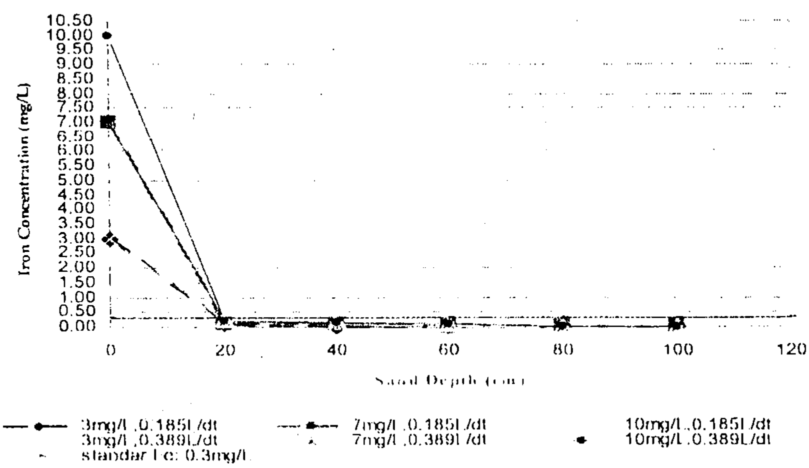
Table 3.6. Cost Estimation for Filter Production

No	Type of Cost	Unit	Qty	Unit Price	Total Price
I	Filter Equipment				
	1. 6 inch PVC Pipe	m	2	41250	82500
	2. ½ inch PVC Pipe	m	1	22000	22000
	3. Valve	unit	2	5000	10000
	4. Double niple ½ inch	unit	2	3000	6000
	5. Nozzle	unit	5	1500	7500
	6. 6 inch dop	unit	1	27500	27500
	7. 4 inch dop & screw	unit	1	30000	30000
	8. Pump	unit	1	350000	350000
	9. Glue	unit	2	5250	10500
	Sub Total I				546000
II	Production Cost				
	1. Labor cost	day	2	30000	60000
	Sub Total II				60000
	Total Price (A)				606000
III	**Filter Media**				
	1. 0,84 mm Bangka sand	kg	16	800	12800
	2. 1,19 mm Bangka sand	kg	16	800	12800
	3. $KMnO_4$	gr	6	150	948.24
	4. Aquadest	liter	20	700	14000
	Total Price(B)				40548.2

Source : Calculation result

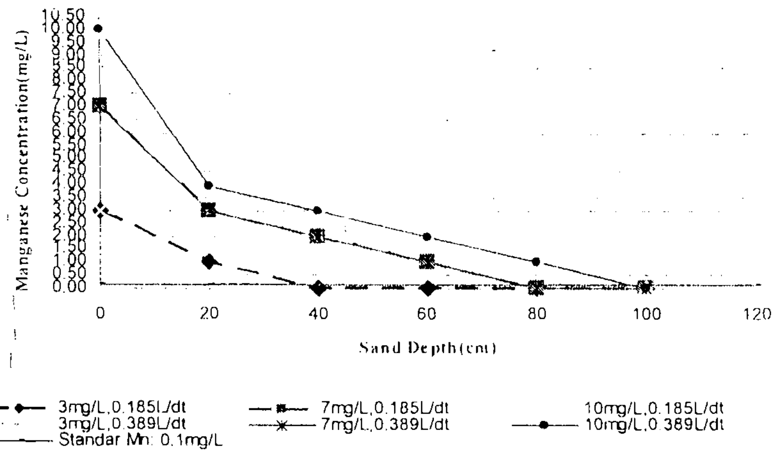
4.0 ANALYSIS

The removal of iron is best happened in 20 cm sand depth both for variation I and for variation II as it shown in Fig 4.1 and Table 3.1. It is seen that in that depth, iron could be reduced until below the prevailing WQS i.e 0.3 mg/L. Whereas, manganese could be removed generally in 100 cm sand depth as it shown in Table 3.2 and Fig 4.2.



Source : Research result

Figure 4.1. Sand Depth vs Iron Removal



Source : Research result

Figure 4.2. Sand Depth vs Manganese Removal

4.1 Iron and Manganese

Theoretically, iron is present in water along with manganese. Their concentrations can be removed by aeration and/or filtration.

In aeration, oxygen entered into the water that contains iron and manganese, would be used for oxidizing dissolved iron and manganese to become precipitate matters. Filtration is then required in order to remove these matters.

From the research, iron could be removed until it meets the WQS generally at 20 cm sand depth, with the efficiency of 93.33% to 100.00%. Manganese could be removed 100% at the depth of 100 cm. It is prevailed for all filter variations.

Influent concentrations are not affected the removal of iron; whereas for manganese, the higher concentration, the thicker filter is required.

Table 3.1 and Table 3.2 show that the removal of manganese is more difficult than that of iron. This describes that manganese oxidation is performed after iron oxidation is being run. This also proves that iron is much easier to be oxidized than that of manganese.

From the two variations of filter media used in this research, it can be found that variation I is better than that of variation II in removing iron and manganese. In variation I, the depth of filter to remove iron and manganese is shorter than that of variation II.

4.2 Supporting Parameters

Supporting parameters checked in the research are DO, turbidity and pH.

4.2.1 *Dissolved Oxygen*

Table 3.3 depicts that initial DOs for all influent concentrations range from 6.1 mg/L to 6.8 mg/L. It is also shown that the reduction of DO is performed at the depth of 20 cm and 40 cm, however, due to the continuous aeration process, the DO is getting higher at 400 cm depth to 100 cm depth.

4.2.2 Turbidity

Table 3.4 shows that by using ADSF, turbidity could be reduced to 0.2 - 0.5 NTU. It also shows that the higher iron and manganese concentration, the more turbid water.

4.2.3 pH

Table 3.5 describes that iron and manganese could be reduced to meet the WQS at 7.0-7.4 pH. This shows that iron and manganese could be best oxidized in that pH range.

4.3 Economic Analisys

Economic analysis is done by using Benefit Cost Ratio method. Validation period of filter is best defined first.

4.3.1 Filter Validation Period

Validation period of filter and pump is 8 years, whereas activated sand should be changed every 2 years [2]. It is assumed that this filter is used for 1 family with 5 persons. Daily water demand is therefore calculated as follows:

User numbers = 5 persons

- Water demand per capita per day = 120 lt [3]
- Water demand per day = 5 persons x 120lt/capita/day
  = 600 lt/day
  = 0.6 m^3/day

4.3.2 Equipment and Media Cost Production

4.3.2.1 Equipment Production

Cost for filter and pump production is as follows:

$$= \frac{Rp.606000}{8years \times 365days/year}$$

$$= Rp.207{,}53 \ldots\ldots (A_1)$$

4.3.2.2 Filter Media Cost Production

Cost for producing filter media is below:

$$= \frac{Rp.40.548{,}24}{2years \times 365days/year}$$

$$= Rp.55{,}55 \ldots\ldots (B_1)$$

4.4 Operational and Maintenance Cost

Sand filter has to be washed every 3 months and replaced every 2 years. 200 liter water is required to wash the filter [2]. Demand of water for washing in operational period is then:

$$= \frac{2years \times 12month/year}{3month} \times 200lt = 1600lt$$

- Pump capacity used is assumed as = 100 watt
- And can deliver water as about = 23 L/min = 1380 L/jam
- Electricity cost per kwh = Rp. 275 /kwh

It is assumed that washing water is taken from raw water so as it is free of charge. Electricity cost for delivering such water is therefore: $= \left(\frac{1600L}{1380L/hour}\right) \times 100Watt \left(\frac{1}{1000}Kwh\right) \times Rp\,275/Kwh = Rp.31.88 \ldots\ldots (C)$

4.5 Electicity Cost

Electricity cost for 2 years operational period can be calculated as follows:

- Time used for pumping the water: $= \frac{600L/day}{1380L/hour} = 0.43hours$
- Electricity power for a day operation = 100 watt X 0.43hours
  = 43 wh
  = 0.043 kwh
- Electricity cost for a day = 0.043kwh X Rp.275/kwh
  = Rp. 11.825
- Electricity cost for 2 years = Rp. 11.825 x 2 years x 365 days/year
  = Rp. 8.632.25 .... (D)
- Total electricity cost used in a day::

$$= \frac{C + D}{2years \times 365days/year}$$

$$= \frac{Rp.31.88 + Rp.8.632{,}25}{2years \times 365days/year}$$

$$= Rp.11.87 \ldots\ldots (E)$$

4.6 Water Cost for Using Filter

Total cost for a day is therefore:

= $A_1 + B_1 + E$
= Rp.207.53 + Rp.55.55 + Rp.11.87
= Rp. 274.95

Unit water cost is then:

$$= \frac{Rp.274.95}{0.6m^3}$$

$$= Rp.458.25 / m^3$$

Water cost for one family with 5 persons is therefore: Rp. $460/m^3$. This cost is lower than the water cost produced by PDAM Bandung (i.e. Rp. $880/m^3$).

5.0 RECAPITULATION ANALISYS

Recapitulation analysis for iron and manganese removal, and supporting parameters along with its cost is presented in Table 5.1.

Table 5.1 Recapitulation Analisys

Parameter	Variation I				Variation II			
Fe	Depth where WQS is met	%	0 mg/L	%	Depth where WQS is met	%	0 mg/L	%
3mg/L	20 cm	96.67%	40 cm	100%	20 cm	93.33%	60 cm	100%
7mg/L	20 cm	98.57%	60 cm	100%	20 cm	97.1[illegible]%	80 cm	100%
10mg/L	20 cm	97.50%	80 cm	100%	20 cm	98%	80 cm	100%
Mn	Depth where WQS is met	%	0 mg/L	%	Depth where WQS is met	%	0 mg/L	%
3mg/L	40 cm	100%	40 cm	100%	80 cm	100%	80 cm	100%
7mg/L	80 cm	100%	80 cm	100%	80 cm	100%	80 cm	100%
10mg/L	100 cm	100%	100 cm	100%	100 cm	100%	100 cm	100%
DO	Initial		Final		Initial		Final	
3mg/L	6.78 mg/L		7.99 mg/L		6.75 mg/L		7.8 mg/L	
7mg/L	6.7 mg/L		7.6 mg/L		6.55 mg/L		7.55 mg/L	
10mg/L	6.1 mg/L		7.5 mg/L		6.20 mg/L		7.49 mg/L	
Turbidity	Initial		Final		Initial		Final	
3mg/L	0.6 NTU		0.2 NTU		0.6 NTU		0.2 NTU	
7mg/L	0.8 NTU		0.3 NTU		0.8 NTU		0.3 NTU	
10mg/L	1.0 NTU		0.5 NTU		1.0 NTU		0.5 NTU	
pH	Initial		Final		Initial		Final	
3mg/L	7.05		7.29		7.01		7.31	
7mg/L	7.1		7.1		7.22		7.35	
10mg/L	7.1		7.1		7.28		7.4	
Cost	Rp. 458.25				Rp. 458.25			

Source : Research result

From Table 5.1, it is depicted that the removal of iron and manganese in variation I is faster than that of variation II. This can be seen from the differentiation of removal efficiency and depth of filter between those variations. Moreover, the DO in variation I is more than that of in variation II so that iron and manganese oxidation in variation I is performed faster than that of in variation II. However, from those variations in filter media composition, it is shown that there is no significant differentiation in terms of turbidity, pH and water cost.

6.0 CONCLUSIONS

1. Iron could be removed until below the WQS (0.3 mg/L) both for filter variation I and variation II. It is performed for all influent concentrations at the filter depth of 20 cm with the efficiency of about 93 % - 100 %.
2. Manganese (the WQS: 0.1 mg/L) could be removed 100% at the depth of 100 cm for all influent concentrations in variation I as well as in variation II.
3. Iron is oxidized faster than manganese.
4. The removal of iron and manganese in variation I is faster than that of in variation II.
5. Influent concentration is not significantly affected the iron removal. Whereas for manganese, the higher influent concentration, the thicker sand filter is required to remove it.
6. Iron and manganese could be removed until they met the WQS with the DO, turbidity, and pH of about 6.1 to 8.0 mg/L, 0.2 – 0.5 NTU, and 7.0 sampai 7.4 subsequently.
7. The ADSF is economically viable due to it costs only Rp.$460/m^3$ compared to the PDAM Bandung's unit water cost (i.e. Rp.880 $/m^3$).

References

1. Alaert G, & Sri Sartika. *"Water Research Method"*. Surabaya: National Effort. 1984.
2. Budianto. Dedi. et al. *"Activated Dry Sand Filter as an Alternative to Reduce Fe & Mn in Water Treatment"*. Environmental Engineering Department-Bandung Institute of Technology. 1988.
3. Chatib. Benny. *"Water Supply System"* Indonesian Water Enterprise Association (PERPAMSI) - Bandung Institute of Technology. 1997.
4. Indrayani. Santi. *"A Uniform Activated Dry Sand Filter as an Alternative to Reduce Fe & Mn in Ground Water Treatment"*. Environmental Engineering Department-National Institute of Technology. 2005.