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Some Aspects of Lake Water Treatment to Produce Clean Water Using Intergration Processes of Adsorption, Filtration and Ozonation

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Abstract: An integrated water and wastewater treatment methods for lakes and surface water resources are implemented in the University of Indonesia Campus (UIC) area to provide clean water. Basically, the water treatment system designed is a successive-combining process system involving filtration, micro-flocculation, adsorption and ozonation. As a preliminary study, each process of water and wastewater treatment is operated in batch system with 3 hours running time and 50 liter of water per batch. The experimental analysis for treated water quality has been demonstrated that there were improvements for some parameters with different values. As for instance, the concentration of iron and manganese can be reduced up to 97.7 and 99.0 %, respectively. Furthermore, by the same method, organic compound can be removed just for about 65.0 %, especially by analyzing of BOD and COD parameters. In general, the integrated process can improve the quality of lakes and surface water resources in the UIC area in terms of iron, manganese, TDS, pH and turbidity parameters.

Key words: Ozone · Water treatment · UI Lake · Iron removal · Manganese removal · Micro-flocculation

INTRODUCTION

Clean water accessibility is a crucial problem in urban and suburb areas, especially for clean water which comply with health requirement for daily uses. In addition, clean water shortage will be more stringent at dry season in Indonesia included Java island and its remote areas, where there are only a few rains and lead to many surface water resources including ground water suffers from dryness. Such phenomenon also occurs at campus area of the University of Indonesia, Depok. In dry season, water supply from ground water (collected in an only water tower at UI campus) suffers from shortage. Meanwhile, the need for clean water in campus area is increased through the years, represented by the more number of new students enrolled in the last decade. This phenomenon emerges anxiety of clean water deficiency from UI water sources.

The treatment of water from some lakes located in campus area can be one of promising alternatives. This treated water can be further used as water source for drinking water and or for fulfilling water daily needs in campus area. Regrettably, research about treatment of UI lake water has not been conducted either sectorally or integrally yet neither for local nor for national interests. Therefore, as a preliminary study, water treatment process proposed in this study is an integrated and combination processes of adsorption (including micro flocculation), filtration and ozonation.

Filtration process has been chosen due to its simplicity and ease in application and has relatively high separation range. The main problems in filtration treatment of UI lake water are as follows:

- UI lake water may contains various dangerous pollutants, in the form of physicals, organic and inorganic chemicals and microorganisms from macro to sub-micro molecules.
- Generally, pre-filtration process can only remove macro size particles (macro-filtration), while sub-micro size particles cannot be removed by conventional filtration process.

The ozonator being used in this research has been engineered prior during 1999 – 2004 research period and has been reported in London, Hong Kong and in national wide by Bismo *et al.*, [1-3]. The principle engineering design of the ozonator is oxygen conversion from

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compressed air in CD chamber (corona discharge chamber) exposed by high voltage cold plasma discharged in coaxial electrode configuration. An advanced study of the application of such ozonator and ozonation techniques for pesticides removal has also ever been published [4].

In the point of view water treatment process itself, an integration process of filtration and other process such as ozonation, micro-flocculation and adsorption is proposed to solve the above filtration problems. Thus, this process is expected to enhance filtration performance using ultra-filtration criteria, where the whole process system can remove macro to sub-micro pollutants.

As mentioned above, the aim of this study are to produce clean water from UI lakes water by an integration water treatment process, as well as to evaluate the effects of coagulation (by micro-flocculation), adsorption and ozonation techniques to the whole process. Several water quality standards such as total dissolved solid (TDS), turbidity, pH and concentrations of some oxidizable and heavy metals (such iron and manganese), will be evaluated to confirm the performance of water treatment process as proposed in this study. Furthermore, the study will also conduct preliminary analysis of several important parameters which can be used to propose the most favorable and suitable method for treating lake water around the UI campus area. The ultimate product of this process is clean water which meets the rugulation of Indonesian Ministry of Health for clean water **(PERMENKES No. 416/MENKES/PER/ IX/1990).**

UI lake was not as big as it is nowadays before Depok UI campus was built. By development of UI campus infrastructure, the lakes become water resorption marshes around campus complex. There are many lakes located around UI such as Agathis Lake, Mahoni Lake, Puspa Lake, Ulin Lake and Salam Lake, spread from South to North. Experiment in this study has been focused using feed water from Mahoni Lake.

The springs of UI lakes come from various sources in the region of campus area for more than 250 hectares, including streams and waterworks from Depok City and Northern Bogor, as well as domestic sewage from population around the campus. Therefore, various pollutants are unsurprisingly present in UI lake, ranging from physical, chemicals, to biological pollutants, especially pathogenic microorganism. The main goal of this study is to find suitable, simple and better applicative methods for treatment of UI lake water to serve clean water in campus area.

There are three water treatment methods proposed in this study, i.e. adsorption by natural zeolite clinoptilolite (produced of Southern Lampung – Southern Sumatra, Indonesia), UF filtration and ozonation. The clinoptilolite is expected to absorb the physical and chemical pollutants (fine particles and heavy metal ions) from feed water. In the other side, UF process may also improve effluent water quality by separation of pollutant particles based on their particle diameter size of 0.5 μm or higher. Furthermore, various pollutants that cannot be separated using filtration such as fine particles (metal ions, microorganism: bacteria and viruses) will be removed by ozonation.

Many researches have shown that gaseous ozone can alter and even better than chlorine derivatives as disinfectant [5-8]. Chlorine disinfection process have several advantages: satisfactorily to disinfect pathogenic bacteria and microorganisms in water, as well as separate dissolved compound and metal ions (iron, manganese and hydrogen sulfide) by oxidizing them to produce aggregate particulates which are more separable from water [9-10]. However, this process can not remove nitrate compounds in water and produce odor when excessive dosage is applied which affect the taste of the water permanently. Besides, chloride compound and its derivatives cause residual effect due to their recalcitrant in produced water.

Ozonation technique has been proposed as additional better process to remove fine pollutants under 5μm in size, in the form of particles, ions or microorganisms. This ozonation process may be operated either before or after filtration process, due to its high effectiveness for disinfecting and removing various pathogenic microorganisms and its potential role as coagulant aid for microfloc-culation, coagulation and sedimentation processes of colloid particulates in water as well [6, 9, 11]. Moreover, the microflocculation process may possibly produce larger size particles which are retained definitely by the regular filter [12-14].

Flocculation of colloid particles in water is an important step in clean water production process. The performance of this process determines the efficiency of a water treatment process installation. Failure of flock formation from colloid aggregates will lead to fouling of filtration system which can further decrease the subsequent filtration stages. Coagulation is utilized to separate suspended colloid compounds in water. Colloids in water may either be hydrophilic or hydrophobic. Colloidal compounds are particles with 1 to 100 μm in size, including dissolved sludge particles, bacteria and other particles which cause turbidity in water [8]. These particles are very difficult to precipitate and cannot be separated by conventional physical treatment processes.

Besides its role as of *coagulant aid*, ozone is highly effective to remove organic (such as phenolic compounds, pesticides, aromatics and unsaturated hydrocarbons and synthetic detergents) and inorganic pollutants (Fe^{2+} and Mn^{2+}) as well as bacteria and even viruses. As highly oxidizing agent, ozone may oxidize organic and inorganic compounds, kills bacteria and disinfect viruses [6-9,15]. This ozonation process can be conducted either as pre or post treatment of filtration process.

Other water quality parameters (BOD, COD, DO TDS) are defined as common or standard regulations presented in the form of statement or number showing the requirements that must be fulfilled so that the water is harmless healthfully, technically and esthetically.

EXPERIMENTAL

Water Treatment Process: The integrated water treatment process conducted in this study systematically consists of six different methods. The main difference of each method is the order or location of the filter and the flow pattern of the system. In each configuration, related to the treatment method, three identical levels of treatment used are: coagulation, filtration and ozonation or disinfection.

The main differences, as mentioned above, can be seen in Table 1 below. For example: in method 1, water or feed stream was introduced to PP (polypropylene cartridge) filter and directly sent to GAC filter by standard filtration flow pattern (dead-end filtration). While in method 4, by identical filter configuration with method 1, PP filter effluent having cross-flow configuration as a membrane filter, directly sent to GAC filter. Configuration criterion was selected based on considerations of efficiency and effectiveness of supporting operations (adsorption, filtration and ozonation).

Table 1: Six water treatment methods

Method	Filter Configuration	Flow type	Zeolite
1	PP before GAC	*dead-end*	no
2	PP before GAC	*dead-end*	yes
3	PP before GAC	*cross-flow*	yes
4	PP before GAC	*cross-flow*	no
5	Zeolit before PP	*cross-flow*	no
6	CTO before PP	*cross-flow*	yes

Notes (all methods use *cartridge filter*):
PP: polypropylene cartridge filter
GAC: granular active carbon cartridge filter
CTO: block-shaped active carbon filter

In this study, potash alum (technical grade, 70 %-wt) was still used as coagulant but in a relatively small dosage of 25 ppm compared to common dosages used by district/state water treatment plant (PDAM) in Indonesia (70 – 150 ppm). This dosage will be effectively used along with ozone as coagulant aid. The, ozonation (and disinfection) process has been conducted by injection of ozone to feed water stream using *Mazzei injector* before passing filtration stage.

Analysis of main water parameters, such as iron (Fe) and mangan (Mn) contents, turbidity, BOD, COD, pH and TDS, was cormirmed as well at BBIA (Agro Industry Research and Main Office) in Bogor, West Java.

Equipment Configurations: As mentioned above, the system was operated in batch or closed. In this design, water circulation was pumped using 105 watt *stainless-steel* centrifugal pump at 1.2 bars for 3 hours. The volume of treatment water reservoir is 50 L.

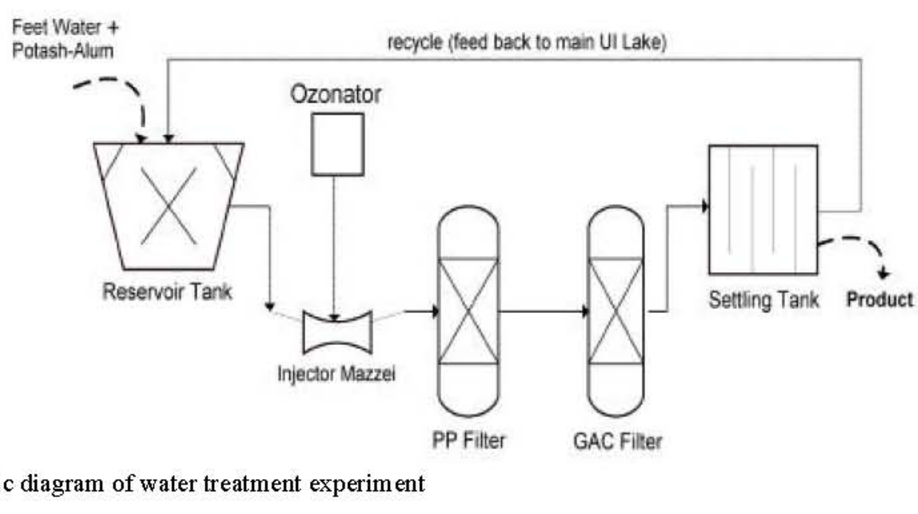

Fig. 1: Schematic diagram of water treatment experiment

Meanwhile, ozone gas (mixture with compressed air) is directly injected to the system using *Mazzei injector*, as open flow system, indicating that there is no gas circulation. With this kind of operating condition, the mechanism of adsorption, micro-flocculation and disinfection processes is expected to perform normally.

Schematic diagram of water treatment process experiment is shown in Figure 1. The main equipment used are ozonator (the 3rd generation, being designed and engineered in our laboratory, [1,2]), 105 Watt stainless steel centrifugal pump and *Mazzei injector*.

Feed water was taken from eastern side of Agathis Lake every morning at 9 – 10 am, in 5 containers of 20 L. Filter cartridge used were *WaterCure* (ex Taiwan) for GAC and *KDX* (ex Australia) for PP and CTO. All filters were replaced after 12 hours of operation.

RESULTS AND DISCUSSION

Fe^{2+} Removal Process: Fe removal was carried out by oxidation-filtration process and cation-cation exchange in water by zeolites. The oxidation-filtration of Fe was conducted by injecting ozone to feed water before passing filter. Hence, the mechanism of ferrous (Fe^{2+}) oxidation is [15]:

$$Fe^{2+} + O_3 + H_2O \rightarrow Fe^{3+} + O_2 + 2\,OH^-$$
$$Fe^{3+} + 3\,H_2O \rightarrow Fe(OH)_3\downarrow + 3H^+$$

The above reactions show that the stoichiometric ozone required is 0.43 mg O_3/mg Fe^{2+} [7,10]. Meanwhile, adsorption and ion exchange processes occurred in natural zeolites. Zeolites exchanged alkaline and alkaline earth cations in zeolites with dissolved iron ions in solution (most of them were in the form Fe^{2+}).

The result of iron removal from this study is presented systematically in the Table 2. It was noted that a high Fe^{2+} concentration (also Mn^{2+}) variations show the variety of pollutant sources from lake water. Table 2 shows that iron removal efficiency ranges between 80.2 to 97.7%. This revealed that the water treatment method is sufficiently effective to remove iron ion from lake water.

Besides, Table 2 shows that utilization of zeolites and crossflow pattern can improve the performance of the iron removal process. Application of zeolite as ion exchanger improves the percentage of iron removal by 2 – 7% (comparison of method 1 and method 2). Meanwhile, crossflow pattern application improves the iron removal percentage by more than 7% (comparison of method 1 and method 4 and method 2 and method 3).

Table 2: Result of Fe removal

Method	Position	Concentration (ppm)	Removal (ppm)	Removal (%)
1	feed	2.221	1.782	80.2
	product	0.439		
2	feed	1.220	1.001	82.0
	product	0.219		
3	feed	2.844	2.502	88.0
	product	0.342		
4	feed	1.281	1.083	84.5
	product	0.199		
5	feed	1.462	1.245	85.2
	product	0.217		
6	feed	4.622	4.515	97.7
	product	0.107		

Table 3: Result of Mn removal

Method	Position	Concentration (ppm)	Removal (ppm)	Removal (%)
1	feed	5.601	0.892	15.9
	product	4.709		
2	feed	11.021	9.839	89.3
	product	1.182		
3	feed	8.917	8.326	93.4
	product	0.591		
4	feed	10.083	7.965	79.0
	product	2.118		
5	feed	7.797	5.942	76.2
	product	1.854		
6	feed	14.630	14.490	99.0
	product	0.140		

The best result for iron removal is obtained by utilization of zeolite and crossflow application simultaneously. The iron removal in this method can achieve as high as 97.7%. This process can be so very effective due to slower liquid flow passing through zeolite bed in crossflow that better cation exchanger can be performed.

Mn^{2+} Removal Process: Based on the experiment, the effectiveness of Mn^{2+} removal cannot be presented by assessment of Mn^{2+}content in the effluent process due to the very wide range variation of Mn^{2+}content in feed water. Therefore, the removal effectiveness is examined entirely by the percentage of Mn^{2+} removal.

It is evident that oxidation of Mn is lower than iron oxidation, as it can be evaluated by the removal percentage of only 15.9% when using method 1. Similar tendencies has also demonstrated by some precedent investigators [10, 11, 15]. By using zeolite adsorbent, the removal performance can be improved to 93.4 %. Meanwhile crossflow pattern improved the removal performance to 79%. Although, Mn content in the effluent

Table 4: Turbidity of water from method 3 and 6

Method	Position	Turbidity (NTU)	Decrease (ppm)	Decrease (%)
3	feed	5.7	3.5	62.2
	product	2.2		
6	feed	7.8	4.3	55.1
	product	3.5		

Table 5: BOD Value in Water Treatment System

Method	Position	BOD (ppm)	Removal (ppm)	Removal (%)
3	feed	23.80	15.64	65.71
	product	8.16		
6	feed	10.40	3.97	38.17
	product	6.43		

Table 6: COD Value in Water Treatment System

Method	Position	BOD (ppm)	Removal (ppm)	Removal (%)
3	feed	52.70	34.40	65.28
	product	18.30		
6	feed	22.30	8.50	38.12
	product	13.80		

water is relatively low, the value is still higher than standard quality threshold of clean water. At overall, the best Mn removal process can be achieved by combination of zeolite utilization (as adsorbent) and crossflow pattern (in PP filter) simultaneously, giving 99.0 % removal.

Water Turbidity Test: Water turbidity test was conducted as an accomplishment parameter for the treatment process, i.e. the treatment process which had relatively short residence time compared to conventional processes in water treatment plant.

In order to give a clear and comprehensive description of systematic assessment, the values of turbidity are tabulated in Table 4. The table only gives turbidity value of method 3 and method 6 as both methods have the highest percentage of metal removal compared to others.

Table 4 shows that for water treatment method 3, the turbidity value of feed water decreased from 5.7 NTU to 2.2 NTU, meanwhile, for method 6 the turbidity value decreased from 7.8 NTU to 3.5, respectively. It should be noted that the turbidity value of all feed water are still higher than standard quality threshold of 5 NTU.

It can be seen from Table 4 that both method 3 and method 6 basically have a slight difference. The difference is due to the difference in cycle number of both methods. Method 3 has liquid flow rate of 6 L/min with approximately 22 cycles of ozonation and filtration, meanwhile method 6, which applied crossflow pattern, has flow rate of 1 L/min with only about 18 cycles of ozonation and filtration, respectively. However, the turbidity level of the products from both methods is below the standard quality threshold of clean water, whether for clean water or drinking water which is 5 NTU.

Organic Compound Content Test: Organic compound contents in feed and products were analyzed through BOD and COD values. BOD and COD values are summarized in Table 5 and Table 6, respectively.

The wide range of BOD and COD variation, which is similar to Fe and Mn contents, again showing the variety of pollutant sources in UI Lake water. Furthermore, based on the results in Table 5 and Table 6, both methods can reduce BOD and COD value of feed water. The BOD values of feed water are difference due to the difference time of sampling. The decrease in COD and BOD values indicates that the two methods are sufficiently effective to reduce organic compounds in water, such as pesticides, detergents, humic and phenol compounds.

The above results evidently demonstrate that the methods conducted in this study have been sufficiently effective for removing dissolved organic compounds in UI Lake. Moreover, method 3 can reduce more than half of organic compounds. The result of COD analysis gives value of 18.30 and 13.80 ppm for method 3 and 6, respectively, which are still higher than the clean water standard threshold of 10 ppm. These results revealed that advanced comprehensive research using ozonation technique should be conducted.

pH Analysis: The initial and effluent pH values generated from the process are in the range of standard quality requirement of clean water i.e. 6.5 - 8.5. All methods show a similar pH increasing tendencies. The changes of pH values are summarized below in Table 7.

The increasing of pH is probably appropriate to the removal of organic compounds by ozonation which produced acidic intermediates in water. However, the decrease of alkalinity to 0.25 mg/L due to alum addition should also be considered. Intermediate organic compounds such as acetic acid, lactic acid, etc. are generated during ozonation of organic compounds in water. However, if the ozonation proceeds for a sufficient length of time, these compounds will be further oxidized to produce CO_2 and H_2O [5]. The formation of acidic intermediate compounds as well as CO_2 gas will increase pH value of water.

Tabel 7: Result of pH Analysis

Method	Initial pH	Final pH
1	7.3	7.5
2	6.9	7.2
3	7.0	7.3
4	6.5	7.0
5	6.6	7.1
6	6.9	7.2

Tabel 8: Result of TDS Analysis

Method	Initial TDS (mg/L)	Final TDS (mg/L)
1	201	254
2	224	281
3	142	198
4	175	208
5	177	199
6	200	206

TDS Analysis: TDS (Total Dissolved Solid) value represents total amount of solid dissolved in water. The TDS value was measured using TDS meter. The result of TDS analysis in the liquid feed and effluent are presented in Table 8.

All of effluent TDS data confirmed an increasing value compared to TDS feed. This increasing value might be caused by addition of alum in the feed and dissolution of small particles from zeolites and active carbon. Relatively high feed flow rate (6 L/min) should also be considered as a causal factor of high TDS value.

At high flow rate, the contact time between water and solid of carbon active or zeolites is so small that the adsorption process cannot proceed effectively. Moreover, micro flocculation produced from alum coagulation can be re-dissolved at high flow rate. The existence of back flush (filtration cleaning method by applying backward (reverse) flow, method 5 and 6) affects TDS value by lowering the increase in TDS value. This is due to lower flow rate to filter as a result of back flushing, so that adsorption process by zeolites and or active carbon can be carried out more efficiently. However, the increase in TDS value is still below the clean water standard quality threshold of 1000 mg/L, so that the change of dissolved solid has no significant effect to effluent water produced.

CONCLUSIONS

The effluent water produced from water treatment process have obviously meet several parameters of clean water quality standard, such as iron content, turbidity, total dissolved solid and pH. All methods used in this study can improve water quality at a different level. Utilization of zeolites as adsorbent improved the performance of water treatment process, especially for metal ions and organic compound removal and lowering turbidity level. This fact is verified by the highest performance achieved by method 3 and 6, which use zeolites as adsorbent. The most favorable method for treating UI lake water is method 6, which use alum as coagulant, ozone as disinfectant and coagulant aid, CTO block cartridge filter, PP filter and zeolite adsorbent. *Crossflow* pattern can be used to improve iron and manganese removal. The best percentage of iron and manganese removal is 97.68 and 99.04%, respectively. Furthermore, the result of organic compound removal which was represented by COD and BOD parameters revealed that advanced comprehensive research with regard to ozonation technique must be conducted.

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