Improvement of the raw drinking water quality from shallow well by ozone treatment

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Abstract. The interests of ozonation has increased significantly in recent years and today the ozonation is used in other steps in the drinking water treatment process. Ozonation has been used in the refill drinking water depot in the region of Indonesia for several years as disinfection at the end of the drinking water treatment process. Except for the disinfection, ozone has other benefits such as oxidation of iron and manganese, micro flocculation, reduction of taste and odour and it is also effective to reduce the water colour. The micro flocculation leads to the fact that less or no coagulants need to be used in the process. This study started with a lab scale experiments on ozonation and filtration of raw drinking water taken from shallow well followed by examination in the pilot plant. Research result showed the removal efficiency for organics, iron, manganese, and turbidity is up to 75%; 98%; 85%; and 98% respectively. All the parameter is comply with the drinking water standard regulated by Indonesia Ministry of Health No. 492/Menkes/PER/IV/2010. Disinfection capability of ozone against microorganisms will be reported in the full paper.

1. Introduction

Groundwater is a potential resource to fulfil water demands for the community; however groundwater sometimes has a high concentration of suspended solid, organics (caused by unappropriate sanitation behavior), iron (Fe) and manganese (Mn), especially for groundwater on a certain depth, which has a long contact with the rocks. In Bandung, the high concentration of iron and manganese in groundwater is because of Bandung was a lacustrine plains, so that the soil become anoxic (soil that is inundated by water or poor drainage) [1]. Characteristics of ground water which contain Fe and Mn is depend on the depth and the duration of contact between groundwater itself with the rock. The high concentration of Fe and Mn in water can lead water become smelly, yellowish, and cause stains & corrosive. Based on the Ministry of Health Regulation 492/Menkes/PER/IV/2010 regarding drinking water quality requirements, the iron content in water should not exceed 0.3 mg/l whereas the manganese content should not exceed 0.4 mg/l [2].

Aeration and chemical oxidation are commonly used technique in removing those water contaminant. Oxygen will oxidized some organics and iron from raw water, while chlorine was
add to oxidized iron, manganese, organics and kill microorganisms. Several known oxidant and their oxidizing potential was summarized in Table 1.

Ozone has greater disinfection effectiveness against bacteria and viruses compared to chlorination. Except for the disinfection, ozone has other benefits such as oxidation of iron and manganese, micro-flocculation, reduction of taste and odour and it is also effective to reduce the water colour. The micro-flocculation leads to the fact that less or no coagulants need to be used in the process. Ozone oxidizes the iron, manganese, and sulphur in the water to form insoluble metal oxides or elemental sulphur. These insoluble particles are then easily removed by post-filtration unit. Ozone is unstable, and it will degrade over a time frame ranging from a few seconds to 30 minutes. The rate of degradation is a function of water chemistry, pH and water temperature.

Ozone is an unstable gas comprising of three oxygen atoms, the gas will readily degrade back to oxygen, and during this transition a free oxygen atom, or free radical form. The free oxygen radical is highly reactive and short lived; under normal conditions it will only survive for milliseconds. Ozone is known as a powerful oxidant agent for water and wastewater. Once dissolved in water, ozone reacts with a great number of organic compounds in two different ways: by direct oxidation as molecular ozone or by indirect reaction through formation of secondary oxidants like OH• radicals [3, 4, 5].

| Oxidant          | Electrochemical oxidation potential (EOP), V | EOP relative to chlorine |
|------------------|--------------------------------------------|--------------------------|
| Fluorine         | 3.06                                       | 2.25                     |
| Hydroxyl radical | 2.80                                       | 2.05                     |
| Oxygen (atomic)  | 2.42                                       | 1.78                     |
| Ozone            | 2.08                                       | 1.52                     |
| Hydrogen peroxide| 1.78                                       | 1.30                     |
| Hypochlorite     | 1.49                                       | 1.10                     |
| Chlorine         | 1.36                                       | 1.00                     |
| Chlorine dioxide | 1.27                                       | 0.93                     |
| Oxygen (molecular)| 1.23                                      | 0.90                     |

As depicted in Table 1, ozone is a powerful oxidant, second only to the hydroxyl free radical, among chemicals typically used in water treatment. Therefore, it is capable of oxidizing many organic and inorganic compounds in water. Ozone have oxidizing potential of 1.5 fold higher relative to chlorine (most used oxidant in water treatment plant).

In the presence of many compounds commonly encountered in water treatment, ozone decomposition forms hydroxyl free radicals. According to the USEPA [6], ozone demands are associated with the following:

- Reactions with natural organic matter (NOM) in the water. The oxidation of NOM leads to the formation of aldehydes, organic acids, and aldo- and ketoacids.
- Organic oxidation by-products. Organic oxidation by-products are generally more amenable to biological degradation.
- Synthetic organic compounds (SOCs). Some SOCs can be oxidized and mineralized under favorable conditions. To achieve total mineralization, hydroxyl radical oxidation should usually be the dominant pathway, such as achieved in advanced oxidation processes.
- Oxidation of bromide ion. Oxidation of bromide ion leads to the formation of hypobromous acid, hypobromite ion, bromate ion, brominated organics, and bromamines.
• Bicarbonate or carbonate ions, commonly measured as alkalinity, will scavenge the hydroxyl radicals and form carbonate radicals.

The purpose of this experiment is testing the performance of the innovative modular, small scale, low-technology water treatment plant in removing iron, manganese, organics and turbidity. Water treatment installation is supposed to have optimum condition based on the quantity and the quality of the water effluent. Factors that affected the optimum condition are iron and manganese stripper unit and water flow rate in the filtration unit operation.

2. Methods
Small scale water treatment system used in this study was a small-scale, low-technology aeration and filtration system.

2.1. Water Treatment Installation
Initially, there are 5 levels multiple tray aerators made of perforated plastic bowl with stone media inside. The distance between one tray to another was 22cm, the stone’s height in each tray was 6cm and a mean diameter of the stone was 3.1 cm. The contact time between water with air approximately to 9 seconds [7]. Improvement was made by substituting the multiple tray aerators with electric aerator (Resun, 30 watts) was applied as the aeration system to oxidize the iron and manganese by contacting raw water with induced air. For the filtration system, there are two rapid sand filtration units arranged in series. This filtration unit is made of PVC material with a tubular shape; the height is 140cm and the diameter is 30cm. The first filter, used sand as its media while the second filter used activated carbon. Further improvement was made by substituting the electric aerator with an ozone injection system. Generic ozone generator (Resun, RSO-25) with ozone discharge capacity of up to 300 mg/hour was mixed with raw water via venturi injector which is mounted after the water pump outlet pipe. The water treatment installation that used in this study is shown in Figure 1.

![Figure 1. Schematic of small-scale water treatment installation: 1) ozone dissolution tank, 2) settling tank, 3) sand filter, 4) activated carbon filter, 5) reservoir, 6) well pump, 7) ozone generator.](image)

2.2. Water Treatment Operation
The water treatment unit performance test started by pumping the raw water into the storage tank until reaching its capacity. The raw water was circulated to the multiple tray aeration units with circulating pump. After certain time, the water flowed into the filtration unit. This installation was equipped by valve and flow meter to control the water flow rate during the experiment. The capacity of the circulating pump to the tray aerator unit is 9 LPM. The water will flow by gravity
forces into the filtration unit and the treated water will be collected at storage tank. Sampling was drawn using 600 ml bottles and stored for further analysis.

Improvement operation by substituting the multiple tray aerators and replaced with electric aerator. Water treatment plant is operated in normal operation by pumping the raw water into the storage tank until reaching its capacity. The electric aerator is turned on and off each 2 hour time interval. Sampling was drawn using 600 ml bottles and stored for further analysis.

3. Result and Discussion

Further improvement operation was made by substituting the electric aerator and replaced with ozone injection system. Water treatment plant is operated in normal operation by pumping the raw water into the storage tank until reaching its capacity. The ozone injection system is turned on and off everytime the raw water pump is operated. Sampling was drawn using 600 ml bottles and stored for further analysis.

The current study is a continuation of previous research with improvements in the operation of the addition of ozone injection system. Ozone injection system is replacing both multiple tray aerators and electric aerators in order to improve the performance of water treatment plant. As mentioned previously, the raw water comes from shallow groundwater by wells drilled to a depth of 24 m.

| Parameters            | Unit | Previous* | Current | Standard** |
|-----------------------|------|-----------|---------|------------|
| TDS                   | mg/l | 602.8     | 447     | 500        |
| Turbidity             | NTU  | 302.6     | 175     | 5          |
| Color                 | Pt.Co| >30       | 18      | 15         |
| Odor                  | -    | Odor      | Odor    | Odorless   |
| Taste                 | -    | Taste     | Taste   | Tasteless  |
| Organics (KMnO₄)      | mg/l | 14.4      | 22.6    | 10         |
| Fe                    | mg/l | 14.31     | 10.22   | 0.3        |
| Mn                    | mg/l | 1.76      | 1.35    | 0.4        |
| pH                    | -    | 7.05      | 7.58    | 6.5-8.5    |

*Adapted from [7]

**Indonesian Ministry of Health Regulation No. 492/2010

Based on Hamandi et al. [8], the area of this study (Cicadas district, City of Bandung) geologically belong to the kosambi formation formerly known as lake sediment consisting of tuffaceous clay, silt and sandstone. This condition led to many transformations of materials in groundwater which causes a decrease in the quality of groundwater. The characteristics of the raw water is described in Table 2. The raw water characteristics indicating all parameters were exceeds the standard excluding pH. High turbidity due to clay content and metallic odor due to iron and manganese content, also high organics content making the raw water is not suitable for consumption without treatment. According to Notodarmojo [1], a high iron content is due to Bandung being a lacustrine (lake sediment) plains, which led to so anoxic soil conditions (soil that is inundated by water or poor drainage). It is also supported because of the topography, the potential for groundwater basin in Great Bandung is mostly located in the aquifer layer which is not depressed [9], therefor in anoxic conditions, the iron ions will dissolved in the soil [10].
The Multiple Tray Aerators Performance

The installed water treatment operates with effective filtration flowrate of 3 LPM. Initially, raw water is pumped to the first storage tank until reaching its capacity (0.5 cubic meter). The raw water was circulated to the multiple tray aeration (MTA) unit with circulating pump. Optimum aeration time was found to be 45 minute (MTA optimization data not shown). After going through the process of aeration in the MTA, raw water flow to the second storage tank to allow oxidized iron and manganese to settled. Clarified water then go to the first filtration unit (sand filter) to remove TSS and passed to the second filtration unit (activated carbon/AC filter) to remove remaining iron, manganese, turbidity, and organics. The performance of water treatment installation was shown in Table 3.

Table 3. MTA performance

| Sampling, min | Fe, mg/l | Mn, mg/l |
|---------------|----------|----------|
|               | RW       | MTA      | RW   | MTA   |
| 30            | 12.25    | 5.14     | 1.54 | 1.29  |
| 90            | 13.62    | 5.63     | 1.59 | 1.31  |
| 150           | 13.67    | 5.85     | 1.59 | 1.32  |
| 210           | 16.19    | 6.14     | 1.63 | 1.36  |
| Average       | 13.93    | 5.69     | 1.59 | 1.32  |
| Eff. %        | 59.16    | 16.85    |      |       |

| Sampling, min | Turbidity, NTU | Organics, mg/l |
|---------------|----------------|----------------|
|               | RW             | MTA            | RW   | MTA   |
| 30            | 227            | 38.7           | 12.49| 9.87  |
| 90            | 229            | 47.6           | 13.04| 10.13 |
| 150           | 238            | 53.5           | 13.1 | 10.52 |
| 210           | 240            | 55.1           | 13.18| 10.67 |
| Average       | 233.50         | 48.73          | 12.95| 10.30 |
| Eff. %        | 79.13          | 20.50          |      |       |

RW: raw water; MTA: multiple tray aerator
ACF: activated carbon filter.
Figure 3. Installation of small scale, low-technology water treatment plant, inset: multiple tray aerator

MTA operation shows a good performance in reducing the turbidity (79%) and iron (59%), while poor performance in reducing organics (20%) and Mn (16%). It was known that oxygen (O$_2$) oxidization potential was the lowest among other oxidant (Table 1). Effort to improve the water treatment performance is by replacing the MTA with the electric aerator. However, the performance of the electric aerator in reducing Fe, Mn, Turbidity, and Organics are not significantly different with the previous installed MTA (electric aerator performance data not shown).

3.2. Ozone Injection System

Further improvement in treating raw water quality is installed an ozone injection system. Initially, the raw water is pumped and then passed through a venturi throat which creates a vacuum and pulls the ozone gas into the water or the air is then bubbled up through the water being treated. Adjustment to the ozone injection system was made by re-installing the ozone generator and injected/bubbled directly into the ozone mixing tank. This adjustment was aimed to make longer contact between ozone and raw water. Ozone generator was turned on for 30 minute operation and off with 2 hour interval period. Since the ozone will react with metals to create insoluble metal oxides, post filtration unit is required. Ozone injection system performance in reducing contaminant from raw water is shown in Table 4.

Ozone is reacting fast in water, the reaction time is only about 20 to 30 minutes in distilled water at 20°C and much shorter if contaminants are present. Ozone is produced by oxygen radicals and the process is energy demanding. When ozone is destroyed or self destructed the ozone molecules revert back to oxygen. Ozone reacts with organic and inorganic compounds in natural waters in two different ways. First is direct reaction with molecular ozone, and second is indirect reaction with the radical species that are formed when ozone decomposes in water.

| Parameters     | RW    | OMT  | SF   | ACF  | Eff. % |
|----------------|-------|------|------|------|--------|
| Fe, mg/l       | 10.22 | 0.48 | 0.25 | 0.05 | 99.51  |
| Mn, mg/l       | 1.36  | 0.54 | 0.21 | 0.11 | 91.91  |
| Turbidity, mg/l| 175   | 35.4 | 2.29 | <1   | 99.43  |
| Organics, mg/l | 22.6  | 14.4 | 6.66 | 2.25 | 90.04  |
| Microbe, CFU/100ml | 210 | 0    | 0    | 1    | 99.52  |

RW: raw water; OMT: ozone mixing tank; SF: sand filter; ACF: activated carbon filter.
The main reason to use ozone instead of chlorine as disinfection in drinking water treatment is that chlorine causes unwanted by-products such as halogenated organic products (chloroform and trichloroacetonitrile). Also, chlorine is a weaker disinfectant and therefore ozone can be used with less contact time and at lower concentrations. Taste and odour-causing compounds are very resistant to oxidation but strong oxidation with ozone cause a significant decrease in both taste and odour. Ozone oxidises iron and manganese, ferrous (II) iron into the ferric (III) state and manganese (II) to the (IIII) state. The oxidized forms will precipitate as ferric hydroxide and manganese hydroxide [11].

4. Conclusion
Research results indicated that ozone have superior oxidation potential and shows a superior removal efficiencies agains major raw water contaminant (Fe, Mn, Organics, and Turbidity).

• Ozone is effect over a wide pH range and rapidly reacts with bacteria, viruses, and protozoans and has stronger germicidal properties then chlorination. Has a very strong oxidizing power with a short reaction time.
• 2.The treatment process does not add chemicals to the water.
• Ozone can eliminate a wide variety of inorganic, organic and microbiological problems and taste and odor problems.
• Natural organics matter and other oxidation by-product is not analyzed in this work.

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