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Analyze the Tray Spacing Effect in a Tray Aerator Reactor in Increasing Dissolved Oxygen and Its Application to Groundwater

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A B S T R A C T

This study aims to analyze the effect of tray spacing on increasing dissolved oxygen and to evaluate the performance of tray aerators in reducing dissolved Fe and dissolved Mn. The study was conducted in Rungkut District, Surabaya City using tray aerators as aeration reactors. This study is divided into 2 stages: optimization and application. The optimization stage analyzes the effect of tray spacing in increasing dissolved oxygen. This stage uses variations of 30 cm, 40 cm, and 60 cm spacing. The application stage employs the optimal tray spacing to reduce Fe and Mn in well water. The results showed that a tray spacing of 30 cm can increase dissolved oxygen up to 0.6 mg/L. Tray aerators used in the application stage can reduce Fe and Mn levels in well water by 39.77% and 20.19%, respectively. The results of tray aerator aeration have not met the quality standards of the Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023, namely 0.2 mg/L and 0.1 mg/L. This shows that aeration alone is not enough to reduce Fe and Mn in well water, so additional processes such as adsorption and filtration are required.

Contribution to Sustainable Development Goals (SDGs):
SDG 6: Clean Water and Sanitation
SDG 11: Sustainable Cities and Communities

1. INTRODUCTION

1.1. Research Background

Groundwater is vulnerable to contamination from various sources, such as industrial, agricultural, and domestic waste. In some cases, groundwater is susceptible to high iron and manganese content. A study in Lakardowo Village found that the iron and manganese content of residential groundwater reached 1.23 mg/l and 10.6 mg/l, respectively, exceeding quality standards [3]. This problem not only threatens individual health but also hinders efforts to achieve the Sustainable Development Goals (SDGs), particularly Goal 6, which targets the availability and management of clean water and sustainable sanitation for all. This situation demonstrates the need for appropriate management efforts to ensure groundwater remains safe for consumption and does not endanger public health.

Aeration increases contact between water and air, triggering iron oxidation and forming solid particles that are more easily removed [15]. This aeration can be performed using several methods such as diffusion, mechanical, spray, and gravity methods [14]. Gravity aeration methods have several advantages, such as not requiring additional costs for electricity because they only utilize the force of gravity. One gravity aeration method is the tray aerator.

A tray aerator is a treatment that can be implemented at lower cost because of its simple process and the fact that it does not require additional chemicals [7]. A tray aerator consists of several perforated trays arranged vertically, where water is flowed from the tray at the top and channelled to the next tray through small holes in the tray [7]. Water that passes through the holes and falls to the next tray will contact the air so that oxidation occurs. The tray spacing in a tray aerator can help reduce Fe and Mn levels in well water by 85.83% and 35.14%, respectively [9]. The distance between trays is related to the contact time of water with air. Contact time affects the tray aerator aeration process: the longer the aeration time, the greater the opportunity for water to come into contact with air. However, a contact time that is too long will make the water enter a phase saturated with oxygen so that it is no longer able to receive oxygen from the gas [10]. As the oxygen saturation phase approaches in the aeration process, the oxygen transfer coefficient decreases [2]. So, this study aims to analyze the effect of tray spacing on increasing dissolved oxygen and to evaluate the performance of tray aerators in reducing dissolved Fe and dissolved Mn.

1.2. Literature Review

1.2.1. Aeration

Aeration is the process of adding oxygen to water to increase its dissolved oxygen level. Simply put, aeration is the mixing of water with air or other substances, allowing oxygen-deficient water to come into direct contact with oxygen or air. The aeration process involves intensive contact between water and air to increase the oxygen content in the water [14]. This increase in oxygen levels helps remove volatile gases such as hydrogen sulfide and methane that can affect the taste and smell of water. Therefore, aeration is an effective method used in clean and drinking water treatment.

In water treatment, aeration can remove dissolved gases, oxidize iron, and reduce ammonia content through the nitrification process [14]. Water containing iron and manganese is usually brown in color and has a bitter taste, which is caused by biological reactions in anaerobic conditions [4]. The process of adding oxygen to water occurs in three stages. First, oxygen molecules move toward the water surface, which consists of water molecules, so that an equilibrium is established between the two boundary layers. Second, oxygen molecules diffuse through that boundary layer. Third, oxygen is mixed evenly throughout the entire volume of water. If this process occurs in laminar flow conditions, the rate of oxygen absorption depends on the diffusion rate of oxygen molecules through the water layer (the second stage). However, as water turbulence increases, a new layer (renewal) forms, allowing oxygen to be distributed more evenly throughout the liquid.

1.2.2. Tray Aerator

Tray aerators are aeration devices consisting of a vertical arrangement of perforated trays, where water flows from the top through each level and is collected at the bottom. This process aims to increase the dissolved oxygen levels in the water through air-water contact, ensuring an effective oxygen transfer from the gas phase to the liquid phase [6]. Tray aerators typically consist of 3 to 9 trays equipped with perforated, slatted, or wire-mesh bottoms. Water is distributed at the top, flows cascadingly through each tray, and is collected in a basin at the base. Tray aerators consist of a series of trays spaced 30-76 cm apart, with a surface area ranging from 50 to 160 m^2/m^3 [11].

1.2.3. Iron and Manganese in Groundwater

Iron is a metal element with the symbol (Fe) which is included in group VII. Iron has an atomic weight of 55.85; a specific gravity of 7.86; and a melting point of 2,450 °C. Iron in water is present as ferric and ferrous salts (valence 2). Ferric compounds found in water are $FePO_4$, Fe_3O_3, and $FeCl_3.Fe(OH)_3$. Meanwhile, the ferrous compounds found in water are FeO and $FeSO_4$. $7H_2O$, $FeCO_3$, $Fe(OH)_2$ and $FeCl_2$. The presence of iron in water can change the color to brownish yellow if there is brief contact with air [6]. Excess iron in the body can cause damage. Accumulation of iron in organs such as the liver, kidneys, and gastrointestinal tract can cause organ damage, including severe liver injury, acute kidney failure, and mucosal damage in the gastrointestinal tract. In acute cases, iron overdose can lead to multi-organ failure and death if not treated promptly [8].

Manganese (Mn) is a transition metal element with the symbol Mn and atomic number 25. It is hard, brittle, and silvery-gray in color. Chemically, manganese has several oxidation states, primarily +2, +3, and +4, commonly found in nature as oxides and carbonates. Manganese minerals are typically found in the form of pyrolusite, manganite, rhodochrosite, and psilomelan, often associated with volcanic rocks and limestone. Manganese is an essential element for human metabolism in trace amounts, playing a role in enzyme function and other biological processes. However, excessive exposure to manganese, especially through drinking water, can cause serious health problems, such as neurotoxicity similar to Parkinson's disease, cognitive impairment, and Attention-Deficit Hyperactivity Disorder (ADHD) in children [13].

1.3. Research Objective

This study aims to analyze the effect of tray spacing on increasing dissolved oxygen and to evaluate the performance of tray aerators in reducing dissolved Fe and dissolved Mn.

2. MATERIALS AND METHODS

2.1. Sample Preparation

This study used two water samples: demineralized water and groundwater. Demineralized water was used in the optimization phase, while groundwater was used in the application phase. The groundwater was taken from Rungkut District, Surabaya City. The groundwater used was previously tested for Fe and Mn levels using the SM APHA 24th edition, 3030B, 3111B, and 2023 methods. The quality standards used in this study refer to the Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023.

Table 1. Initial Groundwater Characteristic

Parameter	(mg/L)	Quality Standar (mg/L)
Fe^{2+}	0.513	0.2
Mn^{2+}	0.871	0.1

2.2. Tray Aerator Reactor and Aeration Process

This study used a tray aerator reactor with a total height of 2 meters. The tray spacing variations used were 30 cm (5 trays), 40

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cm (4 trays), and 60 cm (3 trays). 70 litres of water were pumped through a pipe by a submersible water pump to the discharge control tank until it was full, then returned to the initial reservoir tank through a recirculation pipe. Then the inlet pipe was opened according to a discharge of 0.137 l/s to flow to the tray aerator. After going through the aeration process in the tray aerator, the water was collected in the final reservoir tank.

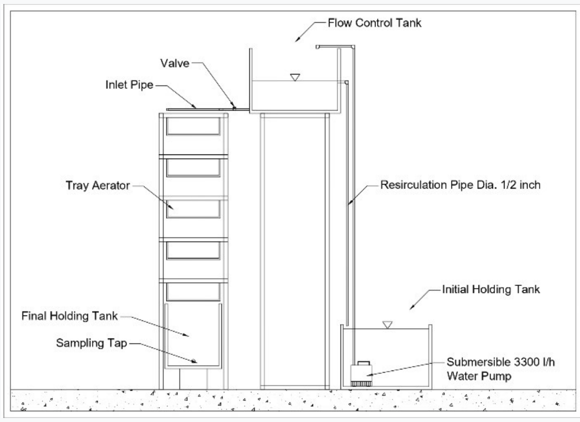

Fig 1. Tray Aerator Reactor Front View

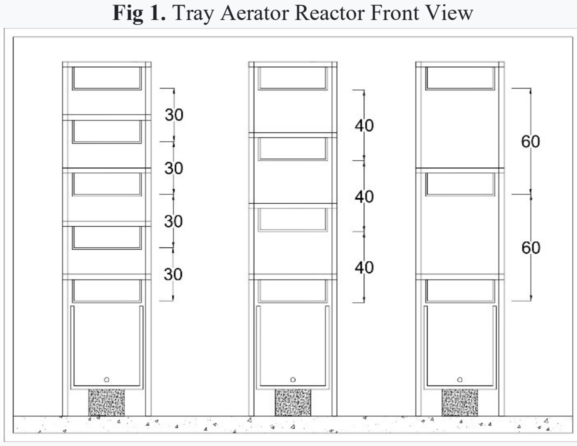

Fig 2. Tray Spacing Variations

2.3. *Experimental Procedure*

The research was carried out in December 2025 in Rungkut District, Surabaya City. This study used a tray aerator reactor with a tray height of 2 meters. The volume of sample water used was 70 liters. This study has two stages: optimization and application. The optimization stage is carried out by determining the best tray aerator distance in increasing dissolved oxygen levels using demineralized water. Variations in tray aerator distance are 30 cm, 40 cm, and 60 cm. The best tray aerator distance based on the optimization stage will be used in treating well water to reduce Fe and Mn levels.

3. RESULT AND DISCUSSION

3.1. *The Effect of Tray Spacing on Increasing Dissolved Oxygen*

In the optimization stage, the optimal tray spacing was determined to increase dissolved oxygen. Demineralized water was used in this stage. The research results in this stage are as follows.

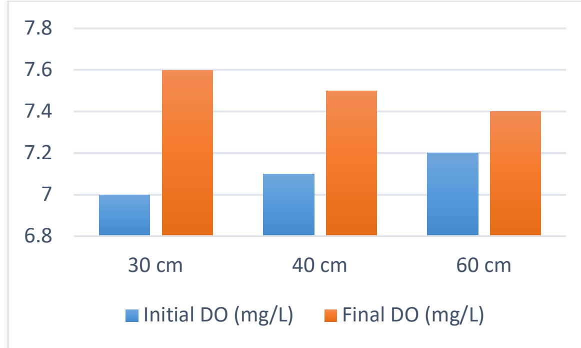

Fig 3. Tray Spacing on Increasing Dissolved Oxygen

The spacing between trays in a tray aerator plays a crucial role in determining the performance of the aeration process. The chart in Fig. 3.1 shows that a 30 cm tray spacing with 5 trays is optimal for increasing DO levels compared with 40 cm (4 trays) or 60 cm (3 trays), as it provides the longest total contact time between water and air. Although a 30 cm tray spacing results in slightly lower individual turbulence than a higher spacing, the greater number of trays (5) ensures a more consistent and continuous water droplet breakup process. This more frequent repetition of stages effectively maintains maximum surface area for contact between water and air during the aeration process [15].

Conversely, with a 40 cm tray spacing with 4 trays, water and air contact is shorter because the smaller number of trays reduces the interval between stages, allowing water to fall much faster than with the 30 cm and 40 cm tray spacing variations. Meanwhile, a 40 cm spacing with 4 trays can indeed provide stronger drop turbulence, but the number of repetitions (4 trays) is still fewer than the 5-tray configuration. Ultimately, the higher frequency of impacts and water breakups at a 30 cm spacing creates a more turbulent flow. The significantly longer total contact time between water and air at 30 cm spacing with 5 trays allows for more efficient oxygen transfer from the gas phase to the liquid phase [6].

In the ANOVA test, variations in tray spacing significantly affected the increase in dissolved oxygen (P-value < 0.05). Further Tukey Pairwise tests showed that the 30 cm tray spacing had a higher mean value than the other tray spacings.

3.2. *Tray Aerator Eficiency in Decreasing Fe^{2+} and Mn^{2+}*

After determining the optimal tray spacing on the tray aerator, it was applied to treat well water to reduce iron and manganese. The following are the results of the tray aerator research in treating well water.

Table 2. Tray Aerator Result In Well Water Treatment

Parameter	Initial (mg/L)	Final (mg/L)	Efficiency (%)	Quality Standar (mg/L)
Fe^{2+}	0.513	0.31	39.77%	0.2
Mn^{2+}	0.871	0.696	20.09%	0.1

The research results in Table 2 show that aeration with a tray aerator can reduce Fe and Mn levels in well water. After 20 minutes of aeration, the Fe concentration of 0.513 mg/L was reduced to 0.31 mg/L with a reduction efficiency percentage of 39.77. The results obtained still do not meet the quality standard of 0.20 mg/L. The reduction in Fe in the tray aerator aeration process occurs due to the oxidation of Fe by oxygen. Air contains oxygen, which is captured by water droplets produced by the tray aerator, thereby promoting gas diffusion. Gas diffusion increases the dissolved oxygen level in the water and acts as an oxidizing agent in oxidizing Fe and Mn. In Fe oxidation, oxygen converts the readily soluble ferrous ion, Fe2+, into the insoluble ferric ion, Fe3+. This oxidation reaction slowly binds iron to form a ferric hydroxide precipitate, or Fe(OH)3 [12].

The Mn concentration in this aeration process decreased from 0.871 mg/L to 0.696 mg/L with a reduction efficiency of 20.09%. The decrease in Mn occurred due to oxidation by oxygen as the main oxidant. The aeration process increases the diffusion of dissolved oxygen and stabilizes the oxidative conditions in the water, thus optimizing the rate of oxidation of Mn^{2+} to Mn^{4+}, which then forms MnO_2. The results obtained did not meet the quality standard of 0.1 mg/L. This occurs because the Mn oxidation rate is slower in conditions below pH 9 [5].

3.3. Comparisson from Previous Study

Several previous studies have shown that aeration using tray aerators can significantly increase DO. Abshar et al. (2023) used tray aerators with a tray spacing of 60 cm, showing an increase in DO of 0.7 mg/L after 60 minutes of aeration. Furthermore, a study by Puspitasari & Hidayah (2025) also showed that tray aerators with a 30 cm spacing can increase DO by 1.9 mg/L over 150 minutes. This is consistent with this study, which found that 20 minutes of aeration using tray aerators at a tray spacing of 30 cm can increase DO by 0.6 mg/L.

Furthermore, aeration using tray aerators can also reduce Fe and Mn levels in well water. A study by Namira and Hidayah (2025) showed that 150 minutes of aeration with tray aerators reduced Fe and Mn levels by 98.8% and 92%, respectively. The results of that study differ from this study, which showed that Fe and Mn levels in well water were reduced by only 39.77% and 20.19% respectively after 20 minutes of aeration. Prolonged aeration can affect the oxidation of Fe and Mn in well water. Furthermore, adding media to the tray can help accelerate the reduction of dissolved metal levels in well water. This suggests that further processes, such as filtration and adsorption, are needed to achieve optimal efficiency.

4. CONCLUSION

This study analyzed the effect of tray spacing on increasing dissolved oxygen and evaluated the performance of tray aerators in reducing Fe and Mn in groundwater in Rungkut District, Surabaya City. The results showed that tray spacing significantly affected the increase in DO. A tray spacing of 30 cm can increase dissolved oxygen by 0.6 mg/L. A 30 cm spacing was used with tray aerators to treat well water containing excess Fe and Mn. The results of tray aerator aeration with a tray spacing of 30 cm showed that the aerator reduced Fe from 0.513 mg/L to 0.31 mg/L (39.77% efficiency) and Mn from 0.871 mg/L to 0.696 mg/L (20.01% efficiency). These results indicate that aeration with a tray aerator can increase dissolved oxygen and reduce Fe and Mn levels in groundwater. However, the reduction in Fe and Mn levels in groundwater has not yet met the quality standards of the Regulation of the Minister of Health of the Republic of Indonesia No. 2023, where Fe is 0.2 mg/L, and Mn is 0.1 mg/L. This indicates that tray aerator aeration is a pre-treatment step and requires further processing, such as filtration and adsorption, to reduce Fe and Mn in groundwater.

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