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Effectiveness of Nanobubble Technology with Gas Variations in Improving the Quality of Vetiver Wastewater and River Water

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ABSTRACT

Improving the quality of wastewater and river water is a critical priority for environmental conservation. Vetiver root wastewater and water from the Citepus River in the Cikamiri sub-watershed, Garut Regency, have the potential to cause pollution that affects water quality and local ecosystems. This study evaluated different gases (air, oxygen, and ozone) during the application of nanobubble technology to improve the quality of vetiver root wastewater and Citepus River water in the Cikamiri sub-watershed. Parameters measured were DO, pH, and TDS before and during 15-minute nanobubble treatment. Results showed that oxygen and ozone gases significantly increased DO content of the wastewater and river water. In addition, ozone gas improved pH in river water, and decreased TDS most effectively with ozone. It was concluded that nanobubble technology has potential for enhancing wastewater treatment and river conservation.

1. INTRODUCTION

The Citepus River is located in the Mount Papandayan area, which is administratively in Samarang District and Pasirwangi District, Garut Regency, West Java (Romli, 2020). This area is known as a natural tourist attraction in Darajat, and is also the center of the vetiver (locally called "Akar Wangi") processing industry which produces essential oils which is located in Sukakarya Village. Vetiver plants can be used as raw materials for perfume, medicine and crafts. Even though it is economically beneficial, the liquid waste from vetiver distillation has the potential to cause pollution and affect the water quality of the Citepus River.

Water quality is an important indicator in environmental management, especially in wastewater treatment and water resources protection. Refining industrial wastewater, such as vetiver waste, often contains high concentrations of total dissolved solids (TDS) and organic matter, which can cause a decrease in dissolved oxygen (DO) levels and undesirable changes in pH. Meanwhile, pollution of river water by vetiver industrial waste can also cause problems, and affect the ecosystem and overall water quality.

Nanobubble technology is one innovative solution to overcome this challenge. Nanobubbles, with very small particle sizes (<200 nano meters), provide significant advantages in increasing DO, stabilizing pH, and reducing TDS in various water treatment applications (Huang *et al*., 2018). Apart from that, nanobubbles can also increase the transfer of oxygen into water more effectively compared to ordinary air bubbles because of the larger contact surface area (Takahashi, 2018).

Previous research shows that using nanobubbles with various types of gas, such as oxygen and ozone, can improve water treatment efficiency (Chen *et al*., 2019). Oxygen, for example, is known to significantly increase DO levels, while ozone has the ability to oxidize solutes and organic contaminants (Wang *et al*., 2020). Changes in pH can also occur as a result of chemical reactions caused by nanobubbles, thereby helping to stabilize acidic or alkaline water environments. Nanobubbles can be applied in mineral separation using foam flotation (Calgaroto *et al*, 2016).

The application of nanobubbles in water treatment is due to the ability of nanobubbles to produce highly reactive free radicals (Yamasaki *et al*, 2010). The effects of free radicals and shock waves produced during nanobubble explosions can deactivate microorganisms (Ito & Sugai, 2021). Thus, the nanobubbles approach is appropriate for use in aquatic ecosystem cleaning applications because nanobubble dispersions present a significant surface area of high interfacial tension that can attract contaminants, thereby preventing deposition to the surface (Alheshibri *et al*., 2016).

Although nanobubble technology has been widely studied, research that directly compares the effectiveness of three types of gas (air, oxygen, ozone) on two types of water (sewage and rivers) in a local context is still rare. Therefore, this study is important to evaluate the practical application of nanobubbles in the context of vetiver industry and river conservation.

This study aims to evaluate the effectiveness of applying nanobubble technology using three types of gas (air, oxygen, and ozone) in increasing dissolved oxygen (DO) levels, stabilizing pH, and reducing total dissolved solids (TDS) in two types of water that represent different characteristics, namely vetiver wastewater from distilleries and Citepus River water in the Cikamiri sub-watershed as the final disposal site for vetiver wastewater. A comparison between wastewater and river water was carried out to assess the potential of nanobubble technology not only as a solution for processing industrial waste, but also as a method for restoring the quality of polluted river water. By exploiting the advantages of each type of gas, this research is aimed at recommending optimal gas selection strategies and application duration, so that nanobubble technology can be applied both to improve the quality of waste water before it is discharged into the environment and for sustainable rehabilitation of river ecosystems.

2. MATERIALS AND METHODS

The research was carried out in March-July 2023 at the Akar Wangi Factory, Sukakarya Village, Samarang District, Garut Regency (Figure 1) and in the workshop of Agricultural Equipment and Machinery Laboratory, Faculty of Agricultural Industrial Technology, Padjadjaran University.

The materials used in this research were vetiver wastewater and Citepus river water samples (10 L of each). This research used the following tools: nanobubble generator, oxygen concentrator, ozone generator, DO meter, DO sensor, pH sensor, and TDS meter.

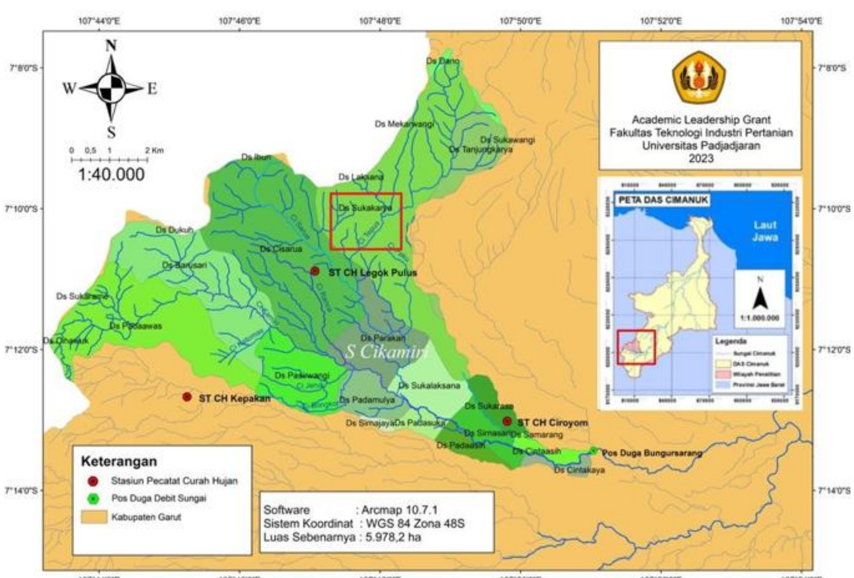

Figure 1. Research location in Sukakarya Village in the Cikamiri Sub-watershed

2.1. Research Methods

This research was carried out by testing the effects of nanobubble technology using three types of gas (air, oxygen and ozone) on vetiver wastewater and Citepus River water in the Cikamiri Sub-watershed. The vetiver wastewater is collected in tiered tanks, which after filling each tank to full capacity and settling, the wastewater eventually flows into the Citepus River. Water samples were taken from the vetiver distillation plant and the Citepus River, then divided into three treatment groups. Nanobubble was applied via a generator with a circulation system for 15 min under three different gases, namely air, oxygen and ozone. During the nanobublle generation treatment, dissolved oxygen (DO), pH, and total dissolved solid (TDS) levels were measured using a DO meter, pH meter, and TDS meter. Data was taken every minute for 15 min for further statistical analysis.

3. RESULTS AND DISCUSSION

3.1. Dissolved Oxygen (DO) Content

The results of testing dissolved oxygen (DO) levels during 15 min of nanobubble treatment using three types of gas (air, oxygen and ozone) are presented in two separate graphs based on the type of water tested, namely vetiver waste water and Citepus River water (Figure 2). This graph illustrates the dynamics of DO increase over time for each gas, as well as showing the differences in response between the two types of water to treatment. This comparison aims to evaluate the relative effectiveness of each gas type in increasing DO as one of the key parameters in water quality.

The graph in Figure 2 shows that the use of nanobubbles with oxygen and ozone gas significantly increases DO levels in both vetiver wastewater and Citepus River water. Oxygen and ozone show a sharper and more stable increasing trend in DO compared to air. This increase occurred due to the higher solubility and reactivity of oxygen and ozone gas, as stated by Ebina *et al*. (2013), who stated that nanobubbles from these gases were able to accelerate oxygen transfer and facilitate oxidation reactions. Meanwhile, air containing only 21% oxygen provides a slower and more stable increase in DO, as explained by Agarwal *et al*. (2011). On the other hand, the relatively more stable natural conditions of river water are also a factor in why DO does not increase drastically when only normal air is used, in accordance with explanation of Diersing (2009) on the dynamics of river ecosystems.

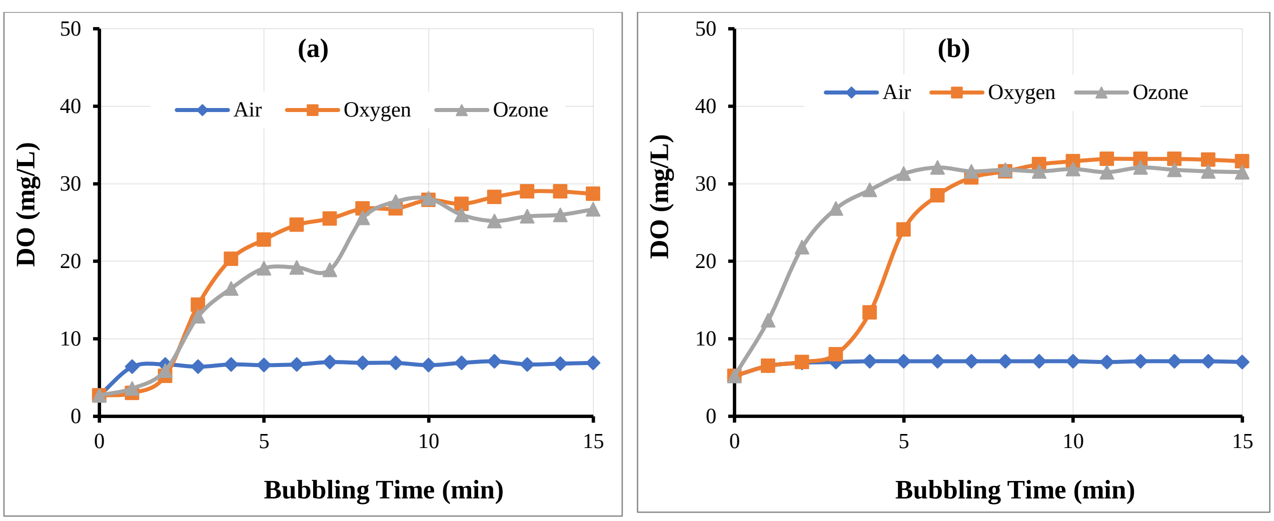

Figure 2. Effect of gas type during nanobubble treatment on the DO content of: (a) Vetiver wastewater, and (b) Citepus River water

The effectiveness of ozone in increasing DO appears to be the most significant compared to oxygen or air. In both types of water, ozone showed the most striking speed and height of DO increase. This is supported by Li *et al*. (2009), who stated that nanobubbles increase the contact area between gas and water, allowing the solubility of gases such as ozone to be higher. Ozone, as a very strong oxidizing agent, not only dissolves quickly but also reacts actively with contaminants in water. According to Tsuge (2014), ozone is able to remain in nanoform for a longer time, prolonging contact with water and allowing oxidation reactions to occur more efficiently. This makes ozone very suitable for use in treating wastewater and polluted rivers using nanobubble technology.

Furthermore, the effectiveness of ozone in increasing DO is also strengthened by its ability to produce hydroxyl radicals (OH) during the decomposition process in water. According to Khuntia *et al*. (2015), this radical has very high oxidative potential and can break down complex organic compounds into simple compounds that are more easily broken down biologically. This process not only reduces the pollutant load that normally consumes dissolved oxygen, but also releases free oxygen as a by-product, thereby directly increasing DO in the water. Thus, the combination of small size of nanobubbles, high solubility, and the reactive chemical properties of ozone make ozone-based nanobubble technology the most effective method for improving water quality, both for vetiver waste and Citepus river water.

3.2. Effect of Treatment on pH

Results of measuring pH values in two types of water, namely vetiver waste water (left) and Citepus River water (right), each of which was treated using nanobubble technology with three types of gas: air, oxygen and ozone (Figure 3). This graph shows changes in pH values during 15 minutes of treatment, with the aim of evaluating the impact of each type of gas on stability and changes in pH in different water characteristics. Vetiver wastewater generally has a lower initial pH due to the high organic content, while river water has a pH that tends to be more neutral. By observing this graph, it can be analyzed how each gas affects chemical reactions in water, including the potential for increasing or decreasing pH which can contribute to overall water quality. This graph also provides important insight in determining the suitability of a particular gas for water treatment applications considering pH stability.

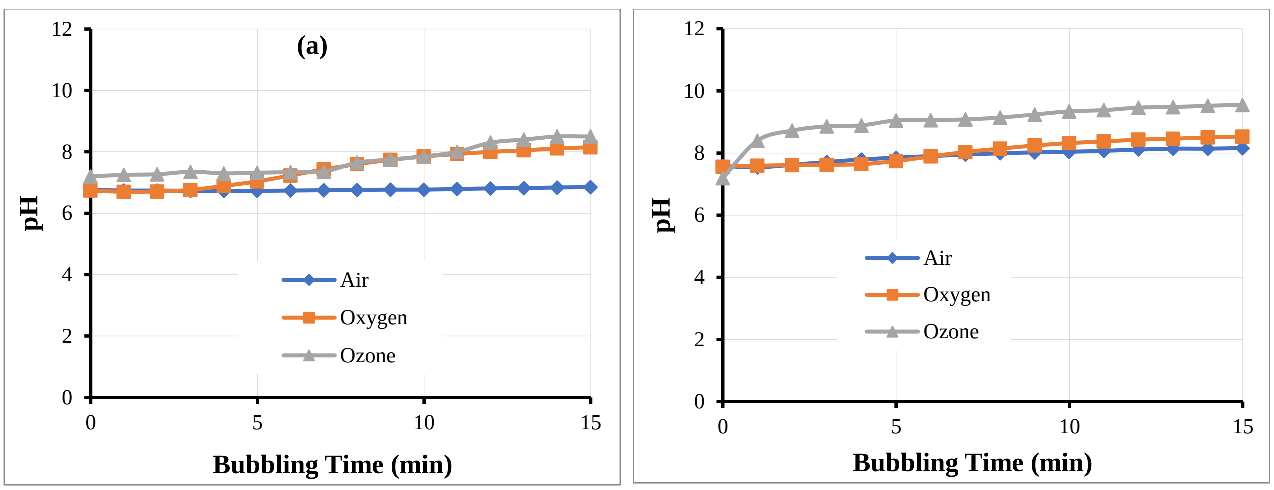

Figure 3. Effect of gas type during nanobubble treatment on the pH of: (a) Vetiver wastewater, and (b) Citepus River water

The graph in Figure 3 shows the effect of three types of gas (air, oxygen, and ozone) used in nanobubble technology on changes in pH values in two types of water, namely: vetiver waste water and Citepus River water. It can be seen that the use of ozone has the most significant effect on increasing pH, especially in Citepus River water. Ozone is known as a strong oxidizing agent, and in nanobubble form, its ability to react with dissolved compounds is higher, causing an increase in the concentration of hydroxyl ions (OH^-) which results in an increase in pH. According to Ebina *et al*. (2013), the oxidative reaction of ozone in the form of nanobubbles is effective in increasing pH, especially in water environments with low organic matter such as river water. Meanwhile, the use of air and oxygen does not provide significant changes, because there is no significant chemical reaction to the components in the water (Agarwal *et al*., 2011).

The initial pH value for both types of water is in the neutral to slightly acidic range (around 6.4–6.8). After treatment, the pH in Citepus River water treated with ozone increased to around 8 in 10 minutes, indicating a reactive response to inorganic compounds or dissolved metals that are more easily oxidized. This shows that water characteristics, such as clarity and contaminant content, greatly influence the effectiveness of nanobubble technology. Guo *et al*. (2022) stated that ozone in nanobubbles reacts quickly with reductive compounds and produces basic compounds such as OH^-, which increases the pH of the water. The different responses in these two types of water show that ozone is more effective in media with low levels of organic matter.

In contrast, in vetiver wastewater, the increase in pH due to ozone appears to be slower and not as high as in river water. This is thought to be because complex organic compounds contained in wastewater, such as essential oils and lignin, undergo oxidation reactions by ozone and produce acidic compounds such as carboxylic acid, which neutralize or even inhibit the increase in pH (Takahashi *et al*., 2007). The effectiveness of ozone nanobubble treatment in wastewater is also influenced by the buffering ability of the organic compound. Research by Agarwal *et al*. (2011) confirmed that the chemical content in water influences the results of the nanobubble reaction, where more complex environments such as wastewater cause the ozone reaction to produce compounds that do not always increase the pH. Therefore, changes in pH as an indicator of gas reactivity in nanobubbles are very dependent on the characteristics of each type of water.

3.3. Total Dissolved Solids (TDS) Measurement Results

Total Dissolved Solids (TDS) measurements were carried out to assess the amount of dissolved substances in vetiver wastewater and Citepus River water during the nanobubble treatment process using three types of gas, namely air, oxygen and ozone. The two graphs show a comparison of the dynamics of TDS values during the 15 minute aeration process with nanobubble technology. The graph on the left shows the trend of changes in TDS in vetiver wastewater, while the graph on the right shows the results of TDS measurements in Citepus River water (Figure 4). Differences in the initial characteristics of the two types of water, including the level of pollution and the content of organic/inorganic substances, are important factors influencing the TDS response to different gas treatments.

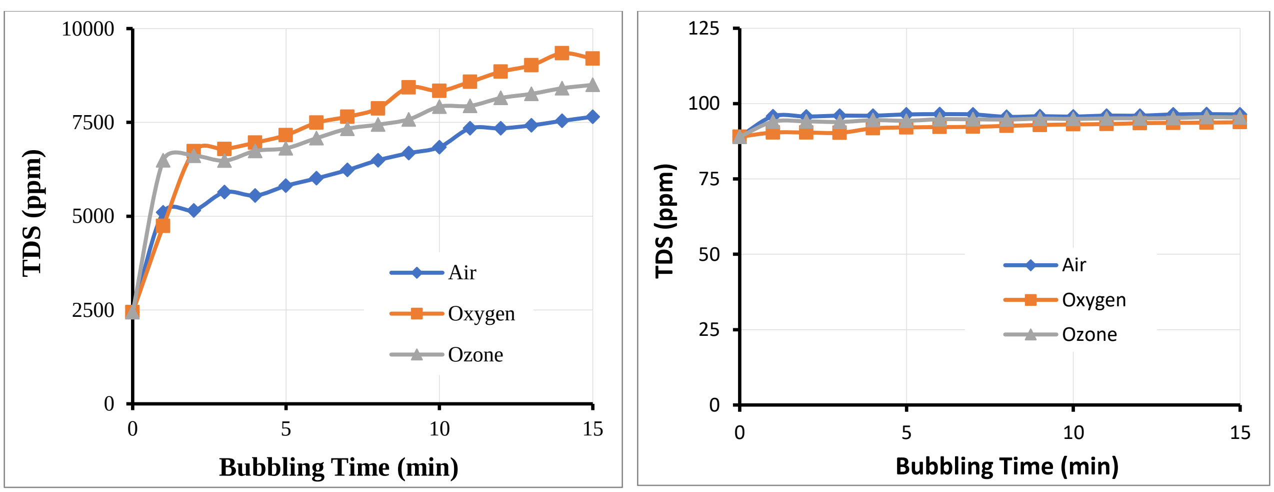

Figure 4. Effect of gas type during nanobubble treatment on the TDS of: (a) Vetiver wastewater, and (b) Citepus River water

Based on the graph in Figure 4, it can be seen that vetiver wastewater experienced an increase in TDS over time after nanobubble treatment, while Citepus River water showed TDS values that tended to be stable or even decreased slightly. This phenomenon shows that the initial chemical properties of each type of water greatly influence the response to nanobubble treatment. Vetiver wastewater which is rich in organic and inorganic compounds tends to experience increased particle dissolution due to microbubbles which expand the contact surface and accelerate the dissolution reaction (Zhang & Li, 2018; Agarwal *et al*., 2011). In contrast, river water which has a more balanced and natural dissolved composition does not show large dissolution reactions, in line with the opinion of Diersing (2009) which states that the stability of natural ecosystems is able to maintain the composition of dissolved substances.

Significant differences in the increase in TDS were also seen in the variation of gases used in the nanobubble system, namely air, oxygen and ozone. The graph shows that the use of ozone gas produces the greatest TDS in vetiver wastewater. This can be explained by the ability of ozone which has a very high oxidation potential, so it is able to break down complex organic compounds into smaller molecules that are easily precipitated (Jekel, 2000). Ahmed *et al*. (2018) also emphasized that nanobubbles with ozone were able to increase the coagulation of microparticles that were previously dissolved in water. This process causes the dissolved compounds to turn into floc and be removed from the solution, contributing to a significant increase in TDS.

Overall, the effectiveness of nanobubbles in changing TDS levels is influenced by the complex interaction between the size of the microbubbles, the type of gas used, and the initial properties of the water being processed. In wastewater, the dissolution process increases sharply due to the high amount of organic substances, and the role of nanobubbles as activators of chemical reactions further accelerates the conversion of compounds into soluble forms (Metcalf & Eddy, 2014). Ebina *et al*. (2013) also explained that the increase in dissolved oxygen due to nanobubbles can strengthen the oxidation and degradation processes of complex compounds.

4. CONCLUSION

The research results show that nanobubble technology with variations of air gas, oxygen and ozone is effective in improving the quality of vetiver wastewater and Citepus River water. The most significant increase in dissolved oxygen (DO) levels was achieved with oxygen gas and ozone, while the improvement in pH mainly occurred in river water with ozone treatment. TDS parameters have increased in wastewater due to the intensive dissolution process by nanobubbles. Overall, ozone gas has proven to be the most effective in improving these three water quality parameters, especially in wastewater that has a high contaminant content. The practical implication of these findings is that the ozone-based nanobubble system can be adopted as an efficient and environmentally friendly alternative technology in the treatment of organic material-based industrial wastewater, including the vetiver refining sector. Therefore, it is recommended that the nanobubble ozone system be implemented sustainably on a pilot and industrial scale, accompanied by economic studies and regular monitoring, to ensure its long-term effectiveness and contribution to sustainable water resources management.

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