Prepublished copy

Nature Environment & Pollution Technology

This is a peer-reviewed prepublished version of the paper

# Performance of Venturi Aerator Combined with Zeolite Filter for Removing Iron and Manganese

**Euis Nurul Hidayah*,Okik Hendriyanto Cahyonugroho*,R Mohammad Alghaf Dienullah†*, Brillyan Kusuma Pradani***

*Environmental Engineering Study Program,Universitas Pembangunan Nasional Veteran Jawa Timur,Rungkut, Surabaya, 60924, Indonesia

†Corresponding author: alghaf.ft@upnjatim.ac.id

## ABSTRACT

Groundwater is the primary source of drinking water, but this source frequently contaminated by heavy metals such as iron (Fe) and manganese (Mn) due to contact with metallic minerals in the soil. This contamination not only causes discoloration and the formation of scale that damages pipes but also poses serious health risks, including neurological disorders and even cancer if consumed over a long period. Some water treatments, such as aeration and filtration, are capable to removal Fe and Mn concentration in groundwater. This study aims to solve this problem by testing the effectiveness of a combination of venturi aeration and zeolite filtration in reducing each Fe and Mn concentration in groundwater. Variations were made to the venturi aerator's air hole size with diameters of 12 mm, 10 mm, and 8 mm. During the aeration and filtration process, sampling was conducted at 0 minute; 15 minutes; 30 minutes; and 60 minutes. The highest removal Fe and Mn concentration occurred at the 8 mm diameter variation, with an Fe removal efficiency 97% and Mn removal efficiency54% during the aeration process. After that, Mn reduction is up to 99% during the filtration process.



| | |
|---|---|
| Key Words | Groundwater; Aeration; Filtration; Iron; Manganese |
| DOI | https://doi.org/10.46488/NEPT.2025.v24i03.D1717 (DOI will be active only after the final publication of the paper) |
| Citation of the Paper | Euis Nurul Hidayah,Okik Hendriyanto Cahyonugroho, R Mohammad Alghaf Dienullah, Brillyan Kusuma Pradani, 2025. Performance of Venturi Aerator Combined with Zeolite Filter for Removing Iron and Manganese. *Nature Environment and Pollution Technology*, 24(3), D1717. https://doi.org/10.46488/NEPT.2025.v24i03.D1717 |



## INTRODUCTION

Most developing countries use groundwater as a large source of drinking water because it is considered a lesser pollutant (Islam & Mostafa, 2024). In many parts of Asia such as Indonesia, groundwater is mostly freshwater, but anthropogenic and natural activities degrade and transform groundwater into contaminated water (Irfeey et al., 2023). Almost the groundwater in Indonesia contains a relatively high concentration of Iron (Fe) and manganese (Mn) (Sudiarto et al, 2021). Groundwater has the potential to be contaminated by heavy metals contained within the soil. The presence of heavy metals such as Fe and Mn in the soil can contaminate groundwater in a dissolution form (Arrizal et al., 2021). Fe is the element that commonly found in almost every place on all geological layers and all bodies of water. In water, it can be dissolved as $Fe^{2+}$ (ferrous) or $Fe^{3+}$ (ferric); and suspended as colloidal grains (<1 µm in diameter). Besides that, Mn in nature is generally found in the form of compounds with various valences. High Mn content can cause turbidity, discoloration, and taste in water (Febrina & Ayuna, 2019).

The concentrations of Fe and Mn in soil vary depending on soil conditions and the surrounding environment. (Said, 2018). Refers to the World Health Organization (2017), a critical concentration value of Mn in water must not excess of 0.05 mg/L with the range value for its intake being 11 mg/day for humans. Whereas for Fe, a critical concentration value of Fe in water must not excess 0,1 mg/L with the range concentration value for humans up to 50 mg/day.

Several cases with the excess of Fe and Mn in water cause a yellow coating to build up inside pipes, which can block them if not cleaned (Annisah & Subhan, 2020). Drinking groundwater with heavy metals can be dangerous to health. It can cause problems with nerves, harm unborn babies, and even lead to cancer (Fuad et al, 2018). The excess Fe concentrations can irritate the eyes, skin, and intestinal disorders, while excess Mn concentrations cause the element to be neurotoxic (Febrina & Ayuna, 2019). Water with high Fe and Mn concentrations requires treatment before it can able to consumption. Various technologies can be used to reduce Fe and Mn concentrations in water. Aeration and filtration are commonly used technologies for the degradation of Fe and Mn. According to Kalyani et al (2021), a module water treatment plant containing an aeration unit and a filtration unit is effective for removing manganese and iron in raw water.

Several aeration methods have been developed recently, such as venturi aeration (Said, 2018). The Venturi Aerator has several parts consisting of a diverging section, a nozzle, and a suction chamber (Mahmud et al, 2024).According to Yadav et al. (2021), the venturi aerator process works by oxidizing Fe and Mn ions into insoluble hydroxide compounds. Venturi aeration can increase dissolved oxygen levels up to 6.3 mg/L within 19 minutes. Dissolved oxygen concentration in water influences the reduction of Fe and Mn concentrations (Taufan, 2010). Venturi aerators operate using the Bernoulli principle, where air from a pipeline is naturally surface flowed in the throat of the pipe, so when compared to other aeration methods such as conventional air transport, stirred tanks, and bubble columns, venturi aerators require less energy (Mahmud et al, 2024). Subsequently, water treatment is conducted using filtration with an adsorbent media such as zeolite. Zeolite has been shown to be effective in degrading Fe and Mn parameters with efficiencies of up to 97.45% and 95.81%, respectively (Annisah & Subhan, 2020). Based on previous research, this study will evaluate the efficiency of Fe and Mn concentrations in groundwater using a combination of venturi aeration and zeolite filtration.

## MATERIALS AND METHODS

This research is an experimental study aimed at degrading Fe and Mn parameters commonly found in groundwater. The water samples were collected from Sengon Village, Jombang District, East Java, Indonesia. The water was treated using aeration and filtration processes.

Aeration was conducted using a venturi aerator with 8 – 12 mm air diameter. The venturi aerator diameters used in this study were 12 mm, 10 mm, and 8 mm. The venturi aerator's throat diameter and neck length are kept constant. A constant flow rate of 0.3 L/s was used in this study. In the filtration reactor, the zeolite media was used a size 8 x 16 mesh, and a filter media height was used 30 cm.

The initial Fe and Mn concentrations of the samples were analyzed. The initial analysis revealed a Fe concentration was 0.743 mg/L and a Mn concentration was 1.84 mg/L. The water treatment process was conducted continuously and it was collected periodically. Sampling was conducted at each reactor outlet. The sample was collected prior to analysis at the time; 0 minute; 15 minutes; 30 minutes; and 60 minutes. The parameters were used such as Dissolved Oxygen (DO), pH, Fe, and Mn. DO concentration was tested and analyzed with using the SNI 06-6989 14-2004 standard method. pH was tested by using standard method of SNI 6989-11 2019. The collected samples were analyzed for residual Fe concentration refers to Standards Methods 3500-Fe Band for Mn concentrations refers to Standard Methods 3500-Mn B. Performance of the process was measured by using an initial concentration of raw water to treated raw water. The performance of the venturi aerator and zeolite filtration units was determined based on their removal efficiency against the Fe and Mn concentration parameters.

## RESULTS AND DISCUSSION

The groundwater samples appeared clear upon visual inspection but had a metallic odor. Based on experiment results, the ability of venturi aerators and zeolite filters to removal Fe concentration in water are shown in Figure 1.

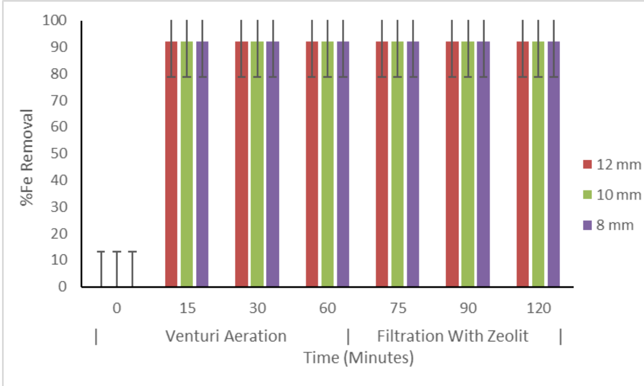


Figure 1. Fe Removal Efficiency Based on Diameter Aerator Hole Variation

As shown in Figure 1, the percent removal of Fe concentration in each variant of aerator hole diameter and each sampling time shows 99% or based on the analysis results, the Fe concentration was 0.0567 mg/L. According to Wang & Wang (2022), aeration is one of the best methods to reduce the concentration of Fe because using air as an oxidant for aeration is a simple process to convert the soluble Fe (II) to the form particle Fe (III). Despite in groundwater Fe produces compounds with valence 2 such as FeCO3and Fe(HCO3)2 which have high solubility (Febrina & Ayuna, 2019), Fe has the property of being easily oxidized by oxygen (Miarti, 2023). According to Said (2018), the Fe compound can oxidize continuously, an ionic reaction will occur in which Fe will separate into $Fe^{2+}$ molecules. These compounds will react with oxygen and water to form valence 3 compounds such as Fe $(OH)_3$ which tend to be insoluble in water. The equation of oxygen reaction in degrading dissolved Fe parameters are:

$$4\,Fe^{2+} + \,O_2 + 10\,H_2O\,-\,4\,Fe(OH)_3 + 8\,H^+$$

Based on the equation, it can refer that to oxidize 1 mg/liter Fe concentration will required 0.14 mg/L $O_2$.

According to Mahmud et al (2024), the high Fe removal efficiency is also supported by the venturi aerator, this is reinforced by the ability of the venturi aerator to produce bubbles with an average diameter below 100 µm, thus providing a high interface area for mass transfer. Consequently, during operation, the venturi aerator generates higher kinetic energy from the liquid and gas streams creating intense mixing and turbulence leading to high diffusion of air which includes oxygen.

Unlike the parameter Fe, parameter Mn in water is more difficult to oxidize by oxygen. This is because Mn has owing to the higher redox potential (Cheng et al., 2020). The Mn oxidation rate is lower than iron at a pH below 9.5 (APPLEBAUM, 1947). The result of experiment showed that the observed water pH was at a value 7.1 to 7.8, which resulted in a decrease Mn concentration during the aeration process that did not efficient. The ability of venturi aerators and zeolite filters to removal Mn concentration in water are shown in Figure 2.

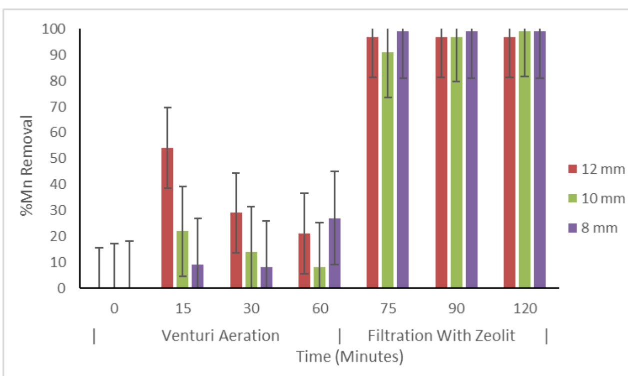


Figure 2. Mn Removal Efficiency Based on Diameter Aerator Hole Variation

As shown in Figure 2, the percent removal of Mn concentration in each variant of aerator hole diameter and each sampling time are varying. After the aeration process, the highest Mn removal efficiency is 54% (from Mn concentration 1.84 mg/L to 0.85 mg/L) when using a venturi aerator with a hole diameter of 12 mm and is at 15 minutes sampling time, while the lowest Mn removal efficiency is 8% (from Mn concentration 1.84 mg/L to 1.69 mg/L) when using a venturi aerator with a hole diameter of 8 mm (30 minutes sampling time) and 10 mm (60 minutes sampling time).

During the filtration process with zeolite, Figure 2 showed that the percent Mn removal increased dramatically. the percent removal of Mn concentration in each variant of aerator hole diameter and each sampling time shows varied. After the filtration process, the highest Mn removal efficiency is 99% (from Mn concentration 1.84 mg/L to 0.014 mg/L) when using a venturi aerator with a hole diameter of 12 mm and 8 mm, it is at 15 minutes; 30 minutes; and 60 minutes sampling time, while the lowest Mn removal efficiency is 91% (from Mn concentration 1.84 mg/L to 0.16 mg/L) when using a venturi aerator with a hole diameter of 8 mm (15 minutes sampling time).

The results of the efficient aeration for removing Fe concentration need attention on the view of the filtration process with zeolite. The zeolite filtration mechanism relies on ion exchange and adsorption to heavy metals such as Mn and Fe (Annisah & Subhan, 2020). The filtration results showed that Mn removal efficiency is up to 99% because of zeolite's ability that adsorb Mn at neutral pH levels (Febrina & Ayuna, 2019). The aeration stage can make higher DO concentration because of oxidation of Mn and then Mn forming Mn (IV) oxides that are easily removed from filtration (Cheng et al., 2020). Several factors can affect the filtration performance such as zeolite grain size; contact time; and pH (Fuad et al., 2018). The aeration stage is significant for increasing DO concentration and provides conditions for Mn oxidation, it can make the efficiency of aeration and filtration the same, despite their operational principles.

Based on figure 2, it shows that the efficiency of reducing Mn levels using aeration tends to be less effective, where the optimal reduction in Mn content in aeration with an aeration hole diameter of 12 mm in the first 15 minutes is 54%, but there is a decrease in the following minutes. At the 8 mm diameter variation, the most efficient aeration was obtained at the 60 minutes with an efficiency of 27% and the remaining Mn content of 1.35 mg/L. The efficiency achieved by this 8 mm diameter variation tends to be stable where the decrease in Mn levels increases over time. The air vents in the aerator venturi have an important role in the aeration process (Yadav et al, 2019), The larger size of the hole allows more air to enter the reactor. However, on the other hand, larger air holes can lead to the formation of large bubbles, resulting in less surface area of air in contact with water than smaller bubbles (Wijayanti, 2008).

The decrease in Mn levels of the aeration process affects the filtration performance. In the combination of a venturi aerator with 8 mm air holes with zeolite has a removal efficiency of 99%. This occurs because the process of decreasing Mn levels that occurs during the aeration process increases over time. At 60 minutes of aeration, the 8 mm diameter variation has a higher effectiveness than other variations. In the 12 mm and 10 mm variations, the process of decreasing Mn levels tends to decrease over time, which can lead to higher zeolite adsorption loads.

The venturi aerator and zeolite filtration can be combined to offer a sustainable water treatment. Compared to conventional air diffusers, the venturi aerator required low energy input same as with the filtration medium. It is widely available and cost-effective (Mahmud et al., 2024). The study found that Venturi aeration requires lower energy input compared to conventional air diffusers, while zeolite, as a filtration medium, is cost-effective and widely available (Mahmud et al., 2024). This study's research can contribute to water management policies for regions with groundwater contamination by providing knowledge about energy-efficient, practical, and other measurable treatment solutions (Kalvani et al., 2021). Adoption technologies can increase access to drinking water otherwise reducing operational costs for facilities of water treatment.

This study is made up of a unique combination of zeolite filtration and venturi aeration, which can utilize the performance of both oxygenation and adsorption mechanisms to reduce heavy metal concentration. The ability of the venturi aerator to generate small bubbles will increase the surface area for the interaction of liquid-gas, and it can make more efficient oxygen transfer (Yadav et al., 2019). Compared to conventional methods, this research showed using unit venturi aeration before unit filtration will improve zeolite's adsorption efficiency by up to 99% Mn removal. The aerator hole diameters are a novelty. It showed that air inlet size affects dissolved oxygen levels and filtration outcomes. Future research could investigate cost optimization strategies for large-scale that including hybrid treatment systems and automated aeration controls or automated aeration controls (Sudiarto et al., 2021). Testing the method under varying groundwater conditions potential to do, such as different metal concentrations or pH ranges. It is for evaluating the scalability and reliability of groundwater conditions.

## CONCLUSIONS

Based on the results of research on the combination of venturi system aeration and adsorption in degrading Fe and Mn parameters, it is concluded that the larger the air hole, the efficiency of dissolved oxygen concentration increases. The most effective Mn concentration reduction also occurred in the largest air hole diameter variation (12 mm) with the largest percentage reduction of 54% in 15 minutes of aeration time. While the concentration of Fe can be removed up to 99% since the beginning of processing because Fe is easy to oxidize.

## REFERENCES


Annisah, A. and Subhan, M. (2020) ‘Efektifitas regenerasi bentonit dan zeolit bekas untuk menyerap logam mangan dan besi dalam limbah cair laboratorium’, *Jurnal Teknik Kimia*, 26(1), pp. 12–21. Available at: https://doi.org/10.36706/jtk.v26i1.442.

APPLEBAUM, S.B. (1947) ‘Iron and manganese removal.’, *Water & sewage works*, 94(12), pp. 439–444.

Arrizal, S. *et al.* (2021) ‘Analisis Kadar Logam Besi (Fe) Pada Air Sumur Bor Di Kecamatan Praya Tengah Menggunakan Spektrofotometri Serapan Atom’, *Jurnal Sanitasi dan Lingkungan*, 2(2), p. 2.

Cheng, L.H. *et al.* (2020) ‘Aeration-manganese sand filter-ultrafiltration to remove iron and manganese from water: Oxidation effect and fouling behavior of manganese sand coated film’, *Journal of Water Process Engineering*, 38(September), p. 101621. Available at: https://doi.org/10.1016/j.jwpe.2020.101621.

Febrina, L. and Ayuna, A. (2019) ‘Studi Penurunan Kadar Besi (Fe) dan Mangan (Mn) dalam Air Tanah Menggunakan Saringan Keramik’, *Jurnal Teknologi*, 7(1), pp. 36–44. Available at: https://jurnal.umj.ac.id/index.php/jurtek/article/download/369/341.

Fuad, H., Mukaromah, A.H. and Wardoyo, F.A. (2018) ‘PENURUNAN KADAR ION MANGAN (II) DALAM AIR DENGAN PENAMBAHAN SERBUK ZEOLIT ZSM-5 BERDASARKAN VARIASI pH LARUTAN’, *Repository Universitas Muhamadiyan Semarang*, 1(Ii), p. 61.

Irfeey, A.M.M. *et al.* (2023) ‘Groundwater Pollution Impact on Food Security’, *Sustainability (Switzerland)*, 15(5), pp. 1–20. Available at: https://doi.org/10.3390/su15054202.

Islam, M.Z. and Mostafa, M.G. (2024) ‘Iron, manganese, and lead contamination in groundwater of Bangladesh: a review’, *Water Practice and Technology*, 19(3), pp. 745–760. Available at: https://doi.org/10.2166/wpt.2024.030.

Kalvani, N. *et al.* (2021) ‘Evaluation of iron and manganese removal effectiveness by treatment plant modules based on water pollution index; a comprehensive approach’, *Journal of Environmental Health Science and Engineering*, 19, pp. 1005–1013. Available at: https://doi.org/10.1007/s40201-021-00665-2.

Mahmud, R., Carpenter, J. and MacPhee, D.W. (2024) ‘Performance Assessment of Venturi-Assisted Confined Tube Aerators with Varying Diameter’, *Energies*, 17(7), pp. 1–19. Available at: https://doi.org/10.3390/en17071733.

Miarti, A. (2023) ‘PENURUNAN KADAR BESI (Fe) DENGAN SISTEM AERASI DAN FILTRASI PADA AIR SUMUR GALI’, *Journal of Innovation Research and Knowledge*, 2(10), pp. 4161–4170. Available at: https://doi.org/10.53625/jirk.v2i10.5382.

Said, N.I. (2018) ‘Metoda Penghilangan Zat Besi Dan Mangan Di Dalam Penyediaan Air Minum Domestik’, *Jurnal Air Indonesia*, 1(3), pp. 239–250. Available at: https://doi.org/10.29122/jai.v1i3.2352.

Sudiarto, D., Nurhayati, N. and Fajriansyah, F. (2021) ‘Effectiveness of aerator ventures, deposition with magnets, filtering, and ion exchange in one unit against reduction of iron, total dissolved solid, and marine well water’, *Open Access Macedonian Journal of Medical Sciences*, 9, pp. 1486–1490. Available at: https://doi.org/10.3889/oamjms.2021.6986.

Taufan, A. (2010) ‘Model Alat Pengolahan Fe dan Mn Menggunakan Sistem Venturi Aerator dengan Variabel Kecepatan Aliran Dan Jumlah Pipa Venturi’, *Teknik Lingkungan* [Preprint].

Wang, L.K. and Wang, M.-H.S. (2022) ‘State-of-the-Art Technologies and Terminologies for Iron and Manganese Control’, 2022(December 2022), pp. 1–80.

Wijayanti, Y. (2008) ‘Pengaruh Debit Terhadap Dinamika Gelembung Udara dalam Kolom Aerator (Penelitian Awal Pembuatan Model Matematika Proses Aerasi)’, *Jurnal Teknik Sipil*, 8(2), pp. 133–147.

World Health Organization, W.H.O. (2017) *Guidelines for Drinking-water Quality (Fourth Edition)*. Available at: https://doi.org/10.5005/jp/books/11431_8.

Yadav, A., Kumar, A. and Sarkar, S. (2019) ‘Design characteristics of venturi aeration system’, *International Journal of Innovative Technology and Exploring Engineering*, 8(11), pp. 63–70. Available at: https://doi.org/10.35940/ijitee.J9929.0981119.