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Mount Merapi Volcanic Stones: Enhancing Odour Neutralization in Industrial Settings through Catalytic Ozonation

Rame Rame[1,2*], Purwanto Purwanto[1,3], Sudarno Sudarno[1,4]

[1] Doctorate Program in Environmental Science, School of Postgraduate Studies, Universitas Diponegoro, rameatmopawiro@gmail.com
[2] Center for Standardization and Industrial Pollution Prevention Services, Ministry of Industry of the Republic of Indonesia
[3] Department of Chemical Engineering, Faculty of Engineering, Universitas Diponegoro;
[4] Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro

Abstract

Utilizing the innate mineral properties of Mount Merapi's volcanic stones, this study aims to harness the potential of these stones, particularly magnetite (Fe_3O_4) and hematite (Fe_2O_3), in augmenting the catalytic ozonation process for odour neutralization in industrial contexts. The experiment source water was drawn from Semarang's reservoirs, a region known for its signifi-cant contamination concerns. The study established that standard ozonation and catalytic ozona-tion with Merapi stones have a marked impact on odour reduction. Notably introducing these catalysts speeds up the odour removal process, achieving in 20 minutes what standard ozonation does in 35. After distinguishing the volcanic stones based on their mineral content and magnetic properties, these were incorporated into a sequential ozonation process. Subsequent water quali-ty analyses involving Organoleptic assessments and Conductivity Testing revealed variations in water quality based on the method used. This research underscores the viability of such natural catalysts in addressing industrial odours while also reflecting on the broader environmental benefits associated with their use.

Correspondence Address:
Faculty of Engineering
Universitas Diponegoro
E-mail:
rameatmopawiro@gmail.com

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Introduction

Global industrialization has brought about technological advancements but also environmental challenges. A prominent concern among these is the emission of odorous compounds from various industries, negatively impacting air quality and public health. Industrial regions, especially in developing countries like Indonesia, grapple with ensuring clean air while maintaining economic growth. In the bustling city, frequent complaints arise regarding the unpleasant odour surrounding its industrial zones, with the underlying causes often being a complex mixture of Natural Organic Matter (NOM), microorganism activity, chemical compounds, environmental conditions, and contamination (Citra et al., 2020; E. Hayes et al., 2023; Fischer et al., 2008; Guo et al., 2021; Hu et al., 2020; Zheng et al., 2023).

Mount Merapi, one of the most active volcanoes in Indonesia, has indirectly offered a potential solution to this growing issue. Recent studies have shown that certain minerals, specifically magnetite (Fe_3O_4) and hematite (Fe_2O_3), found in volcanic rocks (Burgisser et al., 2020; Retnowati et al., 2015) can act as catalysts in ozonation processes. When utilized with ozonation (Wen et al., 2023), these minerals could provide a promising method to neutralize the odorous compounds prevalent in industrial settings.

Surface water quality in Semarang, influenced by natural occurrences and human activities, often bears the brunt of chemical contamination, leading to taste and odour issues. The application of Mount Merapi's volcanic stones, rich in magnetite and hematite, could pave the way for a sustainable and effective treatment process for such waters, converting them into potential sources of clean water or industrial applications.

This study aims to evaluate the efficacy of Mount Merapi's volcanic stones in enhancing odour neutralization through catalytic ozonation in industrial settings, mainly focusing on the surface water of Semarang. In addition to addressing the odour issue, this research aims to shed light on the implications of using natural materials in environmental remediation.

Methods

Chemicals and Materials

The water for the experiments was sourced from a reservoir in Semarang City known to contain contaminants at low to medium concentrations. The selected stones, Magnetite (Fe_3O_4) and Hematite (Fe_2O_3), were obtained from a unique region on Mount Merapi in Sengi village, Dukun District, Magelang Regency. This location is recognized for its rich iron ore content, favouring the formation of magnetite and hematite. The differentiation between the two stones was based on their magnetic attraction characteristics, lustre, and colour, as detailed below.

Selection of Magnetite and Hematite Stones

- ***Magnetic Attraction:***

Magnetite is ferromagnetic; magnetite displays a prominent characteristic of being attracted to magnets.

Hematite: Hematite generally lacks the ferromagnetic properties seen in magnetite. However, there are rare variations of hematite that are magnetic.

- ***Luster & Color***

Magnetite typically appears black or dark grey, radiating a metallic sheen.

Hematite: Its colour palette ranges from black or dark grey to even red or brown shades, often exhibiting a metallic or semi-metallic lustre.

Experimental Setup

Initial experiments involved the ozonation of surface water. The focus shifted to catalytic ozonation, incorporating Mount Merapi's Magnetite and Hematite rock catalysts to enhance the oxidation process. The experiment's flow and configuration mirror are shown in Figure S1.

Water Quality Analysis

The assessment of the efficiency of odour neutralization in the treated water was conducted using both Organoleptic Testing and Conductivity Testing.

- ***Organoleptic Testing***: Factors assessed included Earth/Musty Odor, Sulfur Smell, Chlorine Odor, Metal or Rusty Odor, Oil or Solvent Odor, and Sweet Odor.
- ***Conductivity Testing***: This method evaluated the presence of salts, minerals, organic contaminants, and inorganic contaminants that may affect water conductivity, emphasizing their relation to potential water odours. Testing conduct with conductivity meters (Hanna Instruments / Portable-type) on 1 l of water from a reservoir in Semarang.

Efficiency Analysis

In all scenarios, water samples were taken from the inlet and the outlet of the treatment process. The Conductivity Testing differences were then calculated to ascertain the efficiency of the ozonation process, mainly when catalyzed by Mount Merapi's volcanic stones. Figure 1. Flowchart representation of the Method section detailing the selection, differentiation, and experimental setup involving Magnetite and Hematite stones.

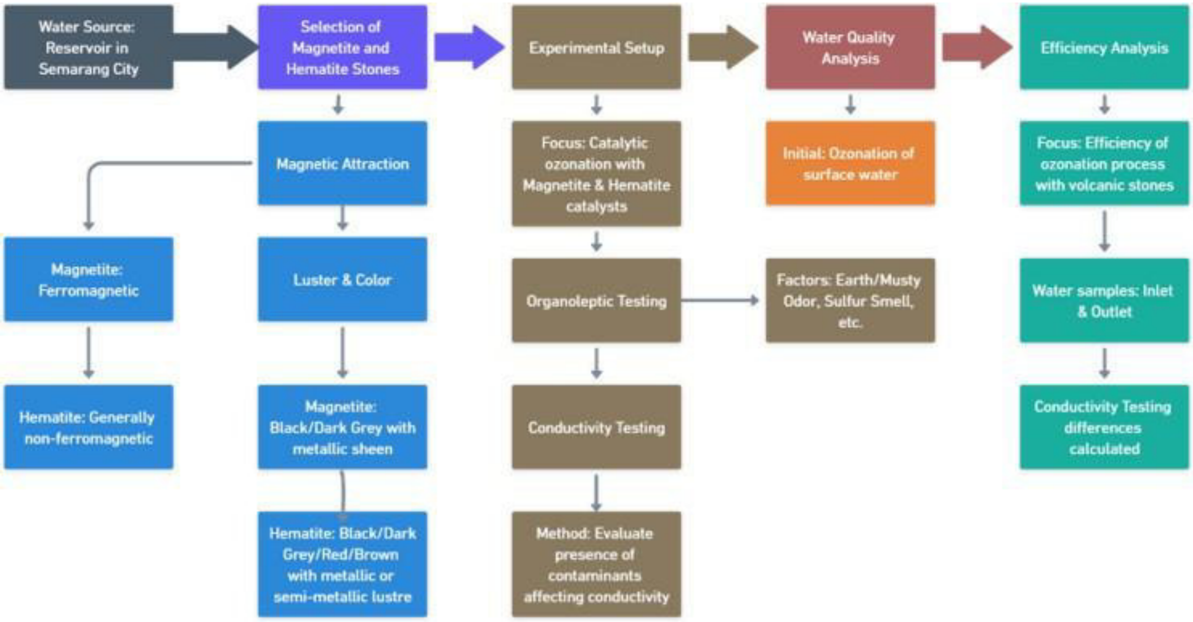

Figure 1. Methodology Overview

Results and Discussion

Odor Neutralization Potential in Semarang's Waters

Mount Merapi, an active stratovolcano in Indonesia, offers volcanic stones with potential catalytic properties beneficial for industrial settings. The utilization of these stones, especially in the framework of catalytic ozonation, necessitates a comprehensive understanding of the specific water conditions they will be used in, including the city of Semarang. During the exploration phase, specific attributes of Semarang's water, predominantly driven by geological and anthropogenic activities, were identified, bearing implications for odor-neutralization strategies. By examining these attributes, insights were gained into the effectiveness and potential synergistic actions of Mount Merapi volcanic stones in the catalytic ozonation process.

Among the identified causes of odour in Semarang's surface water, rob or seawater intrusion was a significant factor, resulting in the introduction of marine-based compounds with distinct odour profiles(Trinugroho et al., 2020). Industrial estates scattered across Semarang further contributed to this dilemma, as unchecked industrial waste seepage introduced many odorous compounds. Organic pollutants, a by-product of domestic activities and mishandled household waste, also played a role in the odour problem (Dhokhikah et al., 2015; Dsikowitzky et al., 2018, 2020; Supriyadi, Mustikaningrum, et al., 2018; Supriyadi, Septiana, et al., 2018; Widyaningsih et al., 2015). These pollutants often comprised compounds like phenols or sulphur compounds (Guo et al., 2021).

Intriguingly, geological conditions in certain Semarang regions presented a natural odorous challenge. These areas, characterized by specific soil and rock compositions, sometimes produced mineral-driven odours, such as those from high sulphur-content soils. Furthermore, microbial action, particularly by sulphate-reducing bacteria, could produce hydrogen sulphide (H2S), an agent responsible for the rotten egg-like odour, underscoring the significance of biological considerations in water treatment. Additional factors, such as aging infrastructure and proximity to waste disposal sites, compounded the odour issues.

However, a fascinating observation pertains to the ozonation treatment efficacy in response to these odours (Wen et al., 2023). Preliminary results suggest that catalytic ozonation using volcanic stones from Mount Merapi may be particularly effective against certain odorous compounds, especially those of organic origin. The reactive radicals produced during the catalytic ozonation process could target and break down these organic compounds, neutralizing their odours. Given the unique composition of these stones, further studies are warranted to fully understand their potential to enhance odour neutralization, especially within industrial settings in Semarang.

Addressing Specific Contaminants through Ozonation

Within the ozonation process, Mount Merapi volcanic stones have been increasingly considered as potential catalysts to enhance the rate of oxidization. As we understand the ozonation reaction at varied odour sources, it becomes imperative to understand its specific mechanisms and outcomes.

- *Rob or Seawater Intrusion*

The intrusion of seawater, characterized by specific ions and salts, presents challenges(Nilawati et al., 2023; Trinugroho et al., 2020). Ozone reacts with these salts and ions within the catalytic ozonation framework, transmuting them into non-odorous forms. The presence of catalysts, in this case, amplifies the reaction's efficiency by augmenting the generation of free radicals.

- *Industrial Pollution*

The pollutants from industrial settings, primarily industrial chemical compounds, undergo ozonization to disintegrate into benign compounds like carbon dioxide and water. Notably, the catalytic action propels the oxidization rate, ensuring a rapid breakdown of these compounds (Akihisa, 2008; Saoud et al., 2023).

- *Organic Pollution*

Once subjected to ozone and the generated free radicals, organic contaminants, including but not limited to phenols or sulphur compounds, undergo oxidization (Pirsaheb et al., 2018; Tanabe & Kunisue, 2007; Zheng et al., 2023). This reaction transforms them into stable, non-odorous compounds.

- *Geologic Conditions*

Certain geological regions, especially those around the Merapi volcanic range, contain specific minerals or chemical agents. The application of ozone can oxidize these agents, with the catalytic process further speeding up this transformation.

- *Microbial Proliferation*

Certain bacteria, such as sulphate-reducing variants, are notorious for producing malodorous compounds like hydrogen sulphide (H2S) (Sudarno et al., 2019). Ozone can effectively oxidize H2S into sulphur and water, with catalysts such as the Merapi volcanic stones optimizing the reaction's efficiency.

- *Infrastructure-Related Conditions*

Metal contaminants, particularly ions like iron from corroding infrastructures, can be oxidized into their oxide forms by ozone. This oxidization allows for their precipitation and subsequent removal, an expedited process that includes catalysts (She et al., 2023; Sudarno et al., 2019).

- *Waste Management*

Organic decomposition within waste management sites results in specific odorous compounds (Bagastyo et al., 2023; Fikri et al., 2015; Iswandari et al., 2021; Sasaki et al., 2014; Setiawan et al., 2019). These organic elements can be simplified through ozonation, and the catalytic addition amplifies the speed and efficacy of this transformation.

Proposed Catalytic Ozonation Reaction Using Mount Merapi Valcanoc Stones

Mount Merapi, an active volcano on Java Island, Indonesia, offers a unique array of volcanic rocks abundant in silicate minerals and elements such as iron, magnesium, and calcium. Notably, these rocks contain significant iron content in forms like magnetite (Fe_3O_4) or hematite (Fe_2O_3), making them potential catalysts in oxidation reactions.

Interaction with Organic Compounds (e.g., Benzene and Phenol)

Employing the Mount Merapi volcanic rocks as catalysts in ozonation may enhance the production of reactive oxygen species, primarily hydroxyl radicals (•OH). These radicals can oxidize organic compounds into CO_2 and H_2O. Using iron-rich catalysts can enhance the production of these radicals through reactions:

$Fe_3O_4/Fe_2O_3 + O_3 \rightarrow Fe{-}O\bullet + O_2$

$Fe{-}O\bullet \rightarrow \bullet OH$

Subsequently, the radicals interact with organic compounds:

Organic Compounds + $\bullet OH \rightarrow CO_2 + H_2O$

$C_6H_5OH + n\bullet OH \rightarrow CO_2 + H_2O$

Oxidation of Hydrogen Sulfide (H_2S)

Volcanic rock-catalyzed ozonation can convert H_2S to either sulphur dioxide (SO_2) or sulphates. The reactions facilitated by iron catalysts are:

$2H_2S + Fe{-}O\bullet \rightarrow 2SO_2 + H_2O$

$2H_2S + \bullet OH \rightarrow 2SO_2 + 2H_2O$

Continuous oxidation can convert SO_2 further:

$SO_2 + \bullet OH + ½\ O_2 \rightarrow SO_4^{2-}$

Oxidation of Iron Ions (Fe^{2+})

In the ozonation process, Fe^{2+} can be transformed to Fe^{3+}, which reacts with hydroxide ions in water to yield $Fe(OH)_3$ precipitates. The oxidation process, accelerated by iron-based catalysts, is:

$2Fe^{2+} + Fe{-}O\bullet \rightarrow 2Fe^{3+} + Fe_3O_4/Fe_2O_3$

$Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3$

The potential effectiveness of Mount Merapi's volcanic rocks as catalysts in ozonation hinges on their specific chemical compositions. Thus, extensive studies may be required to ascertain their suitability in various industrial contexts.

Deodorization Efficiency Using Volcanic Stone Catalysts

Utilizing volcanic stones from Mount Merapi, especially magnetite (Fe_3O_4) and hematite (Fe_2O_3), offers an innovative method for odour neutralization. This study explored how these iron-rich stones synergize with the catalytic ozonation process. Within industrial contexts, these volcanic rocks not only adsorb organic pollutants from water but also enhance the catalytic degradation of odour-causing compounds.

We assessed the efficiency of these volcanic stone catalysts by contrasting the results from pure ozonation to those from catalytic ozonation. This comparative analysis was crucial to ascertain the genuine potency of these catalysts in odour removal.

Table 1 shows the impact of varying ozonation durations at a concentration of 0.5 mg/L on water odour and conductivity levels, providing a clearer understanding of the ideal ozonation time for effective water treatment.

Table 1.
Effect of Ozonation Duration on Water Quality

No	Operational condition	Odor level (before treatment)		Odor level (after treatment)	
		Organoleptic testing	Conductivity (µS/cm)	Organoleptic testing	Conductivity (µS/cm)
1	Ozonation at 0.5 mg/L for 5 minutes	Moderate odour	500	Slight odour	510
2	Ozonation at 0.5 mg/L for 10 minutes	Moderate odour	500	Mild odour	515
3	Ozonation at 0.5 mg/L for 15 minutes	Moderate odour	500	Mild odour	518
4	Ozonation at 0.5 mg/L for 20 minutes	Moderate odour	500	Faint odour	520
5	Ozonation at 0.5 mg/L for 25 minutes	Moderate odour	500	Almost no odour	520
6	Ozonation at 0.5 mg/L for 30 minutes	Moderate odour	500	No detectable odor	522
7	Ozonation at 0.5 mg/L for 35 minutes	Moderate odour	500	No detectable odor	525

From the data in Table 1, it is evident that prolonged ozonation significantly reduces the odour level. Upon undergoing ozonation at 0.5 mg/L for 5 minutes, the water's moderate odour was reduced to a slight odour, with an increase in conductivity from 500 µS/cm to 510 µS/cm. When ozonated at 0.5 mg/L for 10 minutes, the water's odour shifted from moderate to mild, and the conductivity increased to 515 µS/cm. With 15 minutes of ozonation at 0.5 mg/L, the water retained a mild odour, and its conductivity rose to 518 µS/cm. After 20 minutes of ozonation at 0.5 mg/L, the water exhibited a faint odour and an increased conductivity of 520 µS/cm. A 25-minute ozonation treatment at 0.5 mg/L gave the water almost no odour, with conductivity remaining at 520 µS/cm. Post 30 minutes of ozonation at 0.5 mg/L; the water presented no detectable odour and a slightly elevated conductivity of 522 µS/cm. Lastly, after undergoing ozonation for 35 minutes at 0.5 mg/L, the water continued to have no detectable odour, with its conductivity registering at 525 µS/cm. After 35 minutes of treatment, the water reached an "almost no odour" level, ideal for consumption.

The results were even more promising when integrating Merapi stone catalysts, as shown in Table 2.

Table 2.
Effect of Catalytic Ozonation with Merapi Stone on Water Quality

No	Operational Condition (catalyst 50 g/l)	Odor Level (Before Treatment)		Odor Level (After Treatment)	
		Organoleptic Testing	Conductivity (µS/cm)	Organoleptic Testing	Conductivity (µS/cm)
1	Ozonation at 0.5 mg/L for 5 minutes	Moderate odour	500	Moderate odour	498
2	Ozonation at 0.5 mg/L for 10 minutes	Moderate odour	500	Slight odour	495
3	Ozonation at 0.5 mg/L for 15 minutes	Moderate odour	500	Almost no odour	493
4	Ozonation at 0.5 mg/L for 20 minutes	Moderate odour	500	No detectable odor	490
5	Ozonation at 0.5 mg/L for 25 minutes	Moderate odour	500	No detectable odor	488
6	Ozonation at 0.5 mg/L for 30 minutes	Moderate odour	500	No detectable odor	487
7	Ozonation at 0.5 mg/L for 35 minutes	Moderate odour	500	No detectable odor	485

After subjecting the water to ozonation at 0.5 mg/L for 5 minutes, the odour level remained moderate, with a slight reduction in conductivity from 500 µS/cm to 498 µS/cm. Upon ozonation at 0.5 mg/L for 10 minutes, the moderate odour was reduced to a slight odour, and the conductivity decreased to 495 µS/cm. With 15 minutes of ozonation at 0.5 mg/L, the water exhibited almost no odour and a further reduced 493 µS/cm conductivity. Extending the ozonation to 20 minutes at 0.5 mg/L eliminated detectable odours and lowered the conductivity to 490 µS/cm. A 25-minute ozonation at 0.5 mg/L ensured the water had no detectable odour and a 488 µS/cm conductivity. When ozonated for 30 minutes at 0.5 mg/L, the water maintained its state of having no detectable odour, with the conductivity further dropping to 487 µS/cm. Lastly, after 35 minutes of ozonation at 0.5 mg/L, the water's odour remained undetectable, and its conductivity registered at 485 µS/cm.

Both standard ozonation and catalytic ozonation using volcanic stones from Mount Merapi significantly impact odour reduction in water treatment. From the initial dataset, integrating Merapi stone catalysts notably enhances the effectiveness of the ozonation process. Within just 20 minutes, catalytic ozonation eradicates detectable odours, achieving results that standard ozonation can only reach in 35 minutes. Moreover, catalytic ozonation decreases water conductivity, suggesting potential mineral or contaminant removal. Conversely, ozonation slightly increases conductivity as the duration lengthens. In essence, introducing Merapi volcanic stones as catalysts expedites odour removal and influence the treated water's overall quality. This underscores the potential for these natural materials to revolutionize industrial odour-neutralization practices, making the process more sustainable and efficient.

Considering the results, especially when compared with standard ozonation, the potential of catalytic ozonation, augmented by Mount Merapi's natural catalysts, becomes evident. When harnessed appropriately, these volcanic stones could transform industrial odour mitigation strategies, paving the way for a sustainable and efficient method.

Odor Neutralization Mechanisms through Catalytic Ozonation

Throughout the exploration of the catalytic ozonation process, it was observed that the unique properties of volcanic stones, especially from Mount Merapi, significantly enhance the degradation of pollutants responsible for odours in various water sources. Drawing from nature, these stones have displayed intriguing characteristics when juxtaposed with catalytic agents in odour-neutralization endeavours.

The utilization of ozone in tandem with volcanic catalysts like Magnetite (Fe_3O_4) and hematite (Fe_2O_3) enables effective and rapid removal of odour-causing contaminants. As supported by the data, catalysts function as mediums and facilitate the formation of reactive species, which expedites these contaminants' degradation process.

A closer inspection of different odour sources reveals the versatile efficacy of this combined approach:

- Rob or Seawater Intrusion: Once daunting challenges, the prevalent salts and ions are now successfully addressed. The catalytic ozonation process oxidizes these salts into less harmful or even wholly odourless forms.
- Industrial Pollution: Industrial chemicals, often complex in structure, are broken down with the assistance of these catalysts. The accelerated production of free radicals catalyzes the oxidation of these compounds into more straightforward and less harmful entities.
- Organic Pollution: Organic constituents such as phenols undergo oxidation, yielding more stable and non-odorous compounds. This process's efficiency is amplified when ozone is coupled with the volcanic catalysts.
- Geologic Conditions: Once considered untreatable, minerals or compounds originating from the soil and rocks can now be oxidized into odourless substances with this process.
- Microbial Growth: Volatile compounds like H2S are effortlessly oxidized to sulphur and water, further denoting the robustness and versatility of this approach.
- Piping Conditions: Metal ions, like iron, undergo oxidation, forming precipitates, which can then be segregated from the water. The volcanic catalysts further expedite this oxidation process.
- Garbage Disposal: Decomposition products from garbage are treated efficiently, emphasizing the broad-spectrum capability of this approach (Setiawan et al., 2019).

Furthermore, justifying the underlying principles of catalytic ozonation, the combined effect of ozone and catalysts accentuates the pollutant removal process. The unique physicochemical nature of these volcanic stones acts as a catalyst, enhancing reaction rates, enabling pollutant adsorption, and forming reactive species for optimal odour neutralization. The practical implications suggest selecting appropriate volcanic stone catalysts and calibrating the ozone dose to achieve optimal results. This research serves as a beacon, directing toward sustainable and effective means of treating odours in varied water sources.

Conclusions

Through rigorous investigation, the volcanic stones from Mount Merapi, notably magnetite and hematite, have proven their worth in bolstering the catalytic ozonation process for industrial odour counteraction. Both standard ozonation and catalytic ozonation using these volcanic stones significantly impact odour reduction in water treatment. Integrating Merapi stone catalysts enhances the effectiveness of the ozonation process, eradicating detectable odours in just 20 minutes, a result that standard ozonation achieves only in 35 minutes. Furthermore, while catalytic ozonation tends to decrease water conductivity, suggesting potential mineral or contaminant removal, ozonation slightly increases conductivity. Applying these volcanic stones to the contaminated waters of Semarang presents a green and efficient treatment method. Embracing such naturally occurring materials resolves odour-related challenges and introduces broader environmental solutions within industrial spheres. As the results unfold, there is a pressing need to delve deeper into the multifaceted utilities of these volcanic stones to comprehensively determine their role in sustainable water treatments and other environmental applications.

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