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Performance Study on Odor Reduction of Indole/Skatole by Composite

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Abstract

This study developed a dry composite module-type deodorization facility with Twisting airflow changes and two forms (catalyst, adsorbent) within one module. Experiments were conducted to evaluate the reduction efficiency of odor substances C_8H_7N and C_9H_9N. The device combines UV oxidation using TiO_2, catalytic oxidation using MnO_2, and adsorption using A/C in five different methods. Data analysis of experimental results utilized the statistical package program Python 3.12. The program applied frequency analysis of odor removal efficiency, one-way ANOVA, and post-hoc tests, with statistical significance determined by p-value to ensure reliability and validity of the measurements.

Results indicated that the highest removal efficiency of C_8H_7N and C_9H_9N was achieved by the UV+A/C method, suggesting the superior effectiveness and efficiency of the developed device. Combining multiple processes and technologies within one module enhanced odor treatment efficiency compared to using a single method. The device's modularity allows for flexibility in adapting to various sewage treatment scenarios, offering easy maintenance and cost-effective deodorization.

This composite reaction module device can apply multiple technologies, such as biofilters, plasma, activated carbon filters, UV-photocatalysis, and electromagnetic-chemical systems. However, this study focused on UV-photocatalysis, catalysts, and activated carbon filters. Ultimately, the research demonstrates the practical applicability of this innovative device in real sewage treatment operations, showing excellent reduction efficiency and effectiveness by integrating UV oxidation, TiO_2 photocatalysis, MnO_2 catalytic oxidation, and A/C adsorption within a modular system.

Keywords : Indol/Skatole, UV Lamp, TiO2, MnO2, Activated Carbon, Composite Reaction Module Deodorization Facility, Twisting Airflow Design Device

JEL Classification Code :

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1. Introduction

Research is ongoing in various ways to enhance the strengths of cities and address multiple issues to improve urban competitiveness. Urban planning facilities, environmental conditions, and urban space utilization are being studied as social conditions change.

As cities expand, pollutants, severe odors, and noise from undesirable facilities near residential areas have led to continuous complaints from residents. These conflicts, often referred to as NIMBY (Not In My Back Yard) phenomena, arise from disputes between regions or local governments and residents, causing various conflicts.

Among these, odor from sewage treatment facilities has become a chronic issue with increasing complaints. According to the Ministry of Environment's odor-related complaint statistics, complaints rose from 15,573 cases in 2015 to 40,854 cases in 2019, with sewer-related odor complaints constituting 41.9% of the total.

The primary cause of odor complaints is the inefficiency of existing odor reduction facilities, which typically operate with single-function treatment facilities. Various methods like chemical, biological, and physical treatment, fragrance and masking agents, high-temperature processing, and containerization or sealing systems are used, but they only offer limited functionality.

To address this issue, this study developed a pilot-scale composite module that combines various mechanisms within one module to simultaneously treat different types of odor substances. The developed device could serve as a suitable alternative for outdated sewage treatment plants, new modernization projects, or high-odor emission industries.

The research aims to develop a composite reaction module-type deodorization system, assess its odor reduction methods and predictive models, and evaluate its practical functionality in reducing chronic odor complaints.

2. Materials and Methods

2.1. Study Subjects

The pilot device was constructed using a composite modular method rather than a fixed type setup, allowing for greater simplicity and variability in external conditions. This design is thought to improve the immediate response capability depending on the operation and situation at the odor treatment site. The efficiency of deodorization methods can vary based on the odor treatment site due to differences in the composition and environment of complex odors. To address this, the system was designed to adapt flexibly with component technologies that reflect these variations.

In other words, unlike traditional simple systems, this was developed and modified to a setup that improves the variability of external conditions through a composite modular configuration.

To resolve these issues, the system was designed as a composite module that could variably apply more than two deodorization methods to the treatment site, thereby enhancing odor removal efficiency and site responsiveness. The composite module was configured by arranging two types of dry deodorization facilities (catalysts and adsorbents) within a single module. It was designed to enhance the adaptability to the composition and environment of complex odors, considering the easy replacement of internal components with standardized dimensions and electrical wiring.

Typically, the capacity of a sewage odor reduction device is 80 CMM or more, and it operates between 3 to 7 odor reduction facilities. The air dilution device operates at 1 to 2 locations. For this study, rather than applying the same design conditions as a sewage treatment plant, a pilot-scale with a 5:1 ratio was calculated and manufactured for experiments. This ratio was used to upscale the pilot for practical application in real sites.

The efficiency experiment for reduction is a key criterion for assessing the performance of the composite reaction modular deodorization device for odors. The study was conducted in the following order to achieve this:

(1) The "Odor Reduction Composite Reaction Modular Deodorization Device" pilot was developed and manufactured as shown in Fig. 1 using a twisting airflow change, light source lamp amplification, and a modular design.

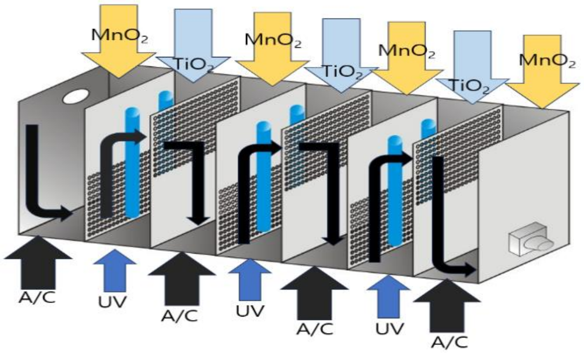


Figure 1: Pilot Scale Schematic

(2) The efficiency of reducing odors such as C_8H_7N and C_9H_9N was repeatedly tested and compared using five methods (UV, UV+TiO_2, UV+TiO_2+MnO_2, UV+A/C, UV+TiO_2+MnO_2+A/C) in this composite reaction modular

deodorization device. Data from these tests were collected and compared.

2.2. Experimental Conditions

The developed pilot-scale system was sequentially tested with UV, UV+TiO_2, UV+TiO_2+MnO_2, UV+A/C, and UV+TiO_2+MnO_2+A/C to compare their effectiveness against the odor compounds C_8H_7N and C_9H_9N. The experimental conditions for each configuration were consistent, with an airflow velocity of 8.1 m/s, an air pressure of 6.8 mmH_2O, a temperature of 19.9℃, and a relative humidity of 62.5%. The UV lamp was pre-operated for 3 minutes before starting the experiments, and each experiment was repeated 32 times.

2.3. Statistical Analysis

Correlation between the device and C_8H_7N and C_9H_9N

Figure 2 visualizes the correlations between each odor reduction method (UV, UV+TiO_2, UV+TiO_2+MnO_2, UV+A/C, UV+TiO_2+MnO_2+A/C) and the removal of indole and skatole through a correlation matrix. The main observations are as follows:

(1) UV Method

The correlation coefficient between UV_indole and UV_skatole is 0.99, indicating a very strong positive correlation. This means that the removal rates of indole and skatole change in almost the same direction when using the UV method.

(2) UV+TiO_2 Method

The correlation coefficient between UV+TiO_2_indole and UV+TiO_2_skatole is 0.98, also showing a very strong positive correlation. This similarly indicates that the removal rates of both substances change similarly when using the UV+TiO_2 method.

(3) UV+TiO_2+MnO_2 Method

The correlation coefficient between UV+TiO_2+MnO_2_indole and UV+TiO_2+MnO_2_skatole is 0.97, indicating a very strong positive correlation.

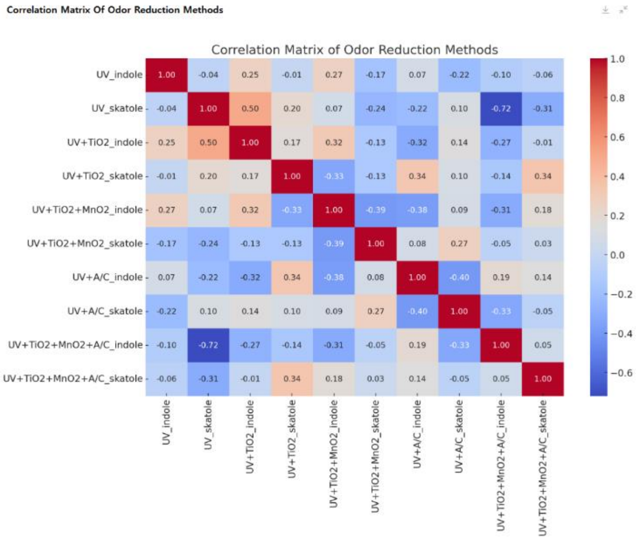
(4) UV+A/C Method

The correlation coefficient between UV+A/C_indole and UV+A/C_skatole is 0.75, showing a relatively high correlation.

(5) UV+TiO_2+MnO_2+A/C Method

The correlation coefficient between UV+TiO_2+MnO_2+A/C_indole and UV+TiO_2+MnO_2+A/C_skatole is 0.97, indicating a very strong positive correlation.

In conclusion, each method shows a high correlation in the removal rates of indole and skatole. Notably, there are strong correlations observed between the UV and UV+TiO_2 methods, the UV+TiO_2+MnO_2 method, and the UV+TiO_2+MnO_2+A/C method. The UV+A/C method shows a relatively independent trend compared to the other methods.



Correlation Matrix Of Odor Reduction Methods

Correlation Matrix of Odor Reduction Methods

	UV_indole	UV_skatole	UV+TiO2_indole	UV+TiO2_skatole	UV+TiO2+MnO2_indole	UV+TiO2+MnO2_skatole	UV+A/C_indole	UV+A/C_skatole	UV+TiO2+MnO2+A/C_indole	UV+TiO2+MnO2+A/C_skatole
UV_indole	1.00	-0.04	0.25	-0.01	0.27	-0.17	0.07	-0.22	-0.10	-0.06
UV_skatole	-0.04	1.00	0.50	0.20	0.07	-0.24	-0.22	0.10	-0.72	-0.31
UV+TiO2_indole	0.25	0.50	1.00	0.17	0.32	-0.13	-0.32	0.14	-0.27	-0.01
UV+TiO2_skatole	-0.01	0.20	0.17	1.00	-0.33	-0.13	0.34	0.10	-0.14	0.34
UV+TiO2+MnO2_indole	0.27	0.07	0.32	-0.33	1.00	-0.39	-0.38	0.09	-0.31	0.18
UV+TiO2+MnO2_skatole	-0.17	-0.24	-0.13	-0.13	-0.39	1.00	0.08	0.27	-0.05	0.03
UV+A/C_indole	0.07	-0.22	-0.32	0.34	-0.38	0.08	1.00	-0.40	0.19	0.14
UV+A/C_skatole	-0.22	0.10	0.14	0.10	0.09	0.27	-0.40	1.00	-0.33	-0.05
UV+TiO2+MnO2+A/C_indole	-0.10	-0.72	-0.27	-0.14	-0.31	-0.05	0.19	-0.33	1.00	0.05
UV+TiO2+MnO2+A/C_skatole	-0.06	-0.31	-0.01	0.34	0.18	0.03	0.14	-0.05	0.05	1.00

Figure 2: Correlation Matrix For C_8H_7N and C_9H_9N Removal Methods

3. Results

3.1. Removal Efficiency of C_8H_7N and C_9H_9N by Device

3.1.1. Removal Efficiency of Indole by Device

The removal efficiency of indole for each device is shown in Figure 3. According to Table 1, the indole removal efficiency by each method is as follows:

UV method: 4.35%

UV+TiO_2 method: 9.61%

UV+TiO_2+MnO_2 method: 41.63%

UV+A/C method: 58.19%

UV+TiO_2+MnO_2+A/C method: 74.27%

Table 1: C_8H_7N and C_9H_9N Removal Efficiency

Methods	Indole Removal Efficiency	Skatole Removal Efficiency
UV	4.35	9.41
UV+TiO_2	9.61	12.65
UV+TiO_2+MnO_2	41.63	7.66
UV+AC	58.19	96.65
UV+TiO_2+MnO_2+AC	74.27	97.81

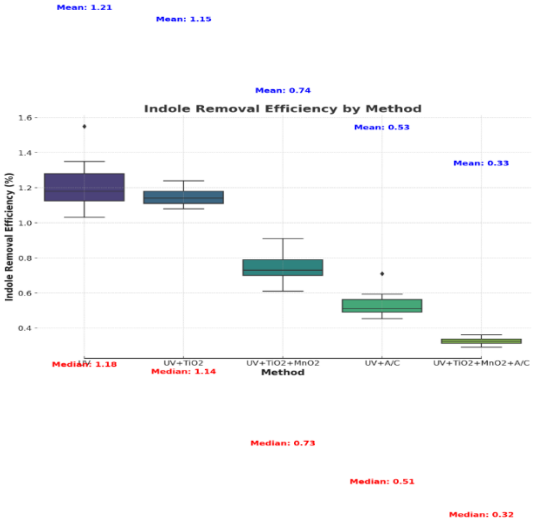


Figure 3: C_8H_7N Removal Efficiency

3.1.2. Removal Efficiency of Skatole by Device

According to Table 1, the removal efficiencies of skatole by each method are as follows:

UV method: 9.41%
UV+TiO_2 method: 12.65%
UV+TiO_2+MnO_2 method: 7.66%
UV+A/C method: 96.65%
UV+TiO_2+MnO_2+A/C method: 97.81%

In conclusion, the UV and UV+TiO_2 methods show low removal efficiencies for both substances. The UV+TiO_2+MnO_2 method demonstrates relatively high efficiency for indole removal but low efficiency for skatole removal. The UV+A/C and UV+TiO_2+MnO_2+A/C methods exhibit high removal efficiencies for both substances, with particularly high efficiency in removing skatole.

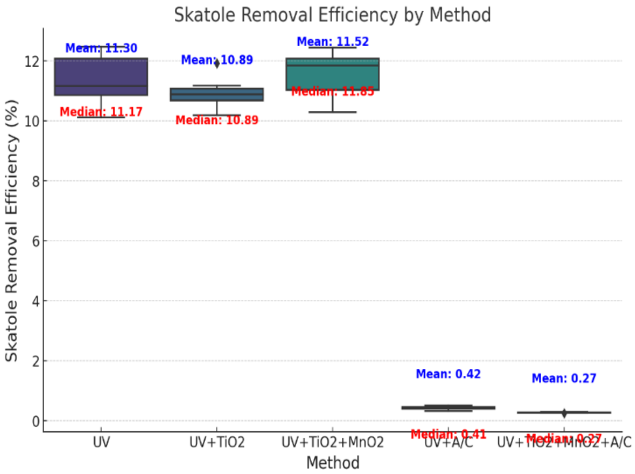


Figure 4: C_9H_9N Removal Efficiency

3.1.3. Analysis of Variance for Indole

Table 2 indicates that the differences in indole removal efficiencies among the various reduction methods are statistically significant (p-value < 0.05). The high F-value and very low p-value strongly suggest that the reduction method has a significant impact on indole removal.

Table 2: ANOVA for C_8H_7N Removal Efficiency

Source	Sum of Squares	df	F Value	Pr(>F)
Method	8.888914	4	346.608784	2.504729e-45
Residual	0.448794	70		

Table 3: ANOVA for C_9H_9N Removal Efficiency

Source	sum_sq	df	F	PR(>F)
Method	2137.572329	4	2053.218404	9.881312e-72
Residual	18.218966	70		

3.1.4. Post-hoc Test for C_8H_7N (Indole) Analysis of Variance

The post-hoc test results for indole, presented in Table 4, show that most methods exhibit significant differences in indole removal efficiency. Notably, the UV+TiO2+MnO2+A/C method demonstrated the highest removal efficiency compared to other methods. Although there was no significant difference between the UV+A/C and UV+TiO2+MnO2+A/C methods, both showed significant differences compared to most other methods. This suggests that the UV+TiO2+MnO2+A/C method is the most effective for indole removal, as illustrated in Fig. 5.

Table 4: Post Hoc Test for C_8H_7N Analysis of Variance

Group1	Group2	Mean diff.	p-adj	Lower	Upper	Reject
UV	UV+A/C	-0.6838	0.0000	-0.7657	-0.6019	True
UV	UV+TiO_2	-0.0668	0.1621	-0.1487	0.0151	False
UV	UV+TiO_2+MnO_2	-0.4735	0.0000	-0.5553	-0.3916	True
UV	UV+TiO_2+MnO_2+A/C	-0.8880	0.0000	-0.9699	-0.8061	True
UV+A/C	UV+TiO_2	0.6170	0.0000	0.5351	0.6989	True
UV+A/C	UV+TiO_2+MnO_2	0.2103	0.0000	0.1285	0.2922	True
UV+A/C	UV+TiO_2+MnO_2+A/C	-0.2042	0.0000	-0.2861	-0.1223	True
UV+TiO_2	UV+TiO_2+MnO_2	-0.4067	0.0000	-0.4885	-0.3248	True

UV+TiO_2	UV+TiO_2+MnO_2+A/C	-0.8212	0.0000	-0.9031	-0.7393	True
UV+TiO2+MnO_2	UV+TiO_2+MnO_2+A/C	-0.4145	0.0000	-0.4964	-0.3327	True

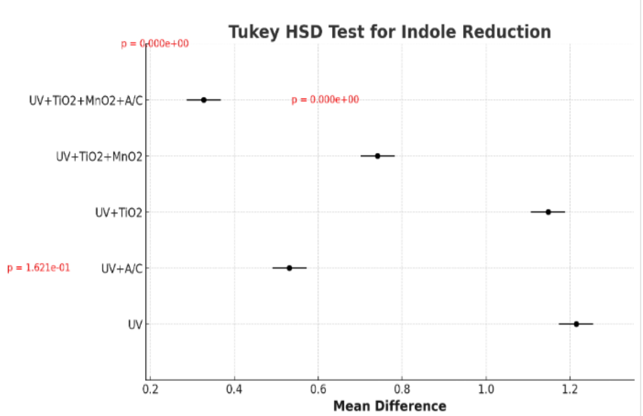


Figure 5: Tukey HSD Test for C_8H_7N Removal Efficiency

3.1.5. Post-hoc Test for C_9H_9N (Skatole) Analysis of Variance

According to the results presented in Table 5, the differences between most of the groups are statistically significant. Specifically, the UV+A/C and UV+TiO2+MnO2+A/C methods are confirmed to be the most effective for skatole removal, as shown in Fig. 6.

Table 5: Post Hoc Test for C_9H_9N Analysis of Variance

Group1	Group2	Mean diff.	p-adj	Lower	Upper	Reject
UV	UV+A/C	-10.8783	0.0000	-11.4000	-10.3567	True
UV	UV+TiO_2	-0.4033	0.2051	-0.9250	0.1183	False
UV	UV+TiO_2+MnO_2	0.2193	0.7642	-0.3023	0.7410	False
UV	UV+TiO_2+MnO_2+A/C	-11.0231	0.0000	-11.5448	-10.5015	True
UV+A/C	UV+TiO_2	10.4750	0.0000	9.9534	10.9966	True
UV+A/C	UV+TiO_2+MnO_2	11.0977	0.0000	10.5760	11.6193	True
UV+A/C	UV+TiO_2+MnO_2+A/C	-0.1448	0.9363	-0.6664	0.3768	False
UV+TiO2	UV+TiO_2+MnO_2	0.6227	0.0113	0.1010	1.1443	True
UV+TiO2	UV+TiO_2+MnO_2+A/C	-10.6198	0.0000	-11.1414	-10.0982	True
UV+TiO2+MnO2	UV+TiO_2+MnO_2+A/C	-11.2425	0.0000	-11.7641	-10.7208	True

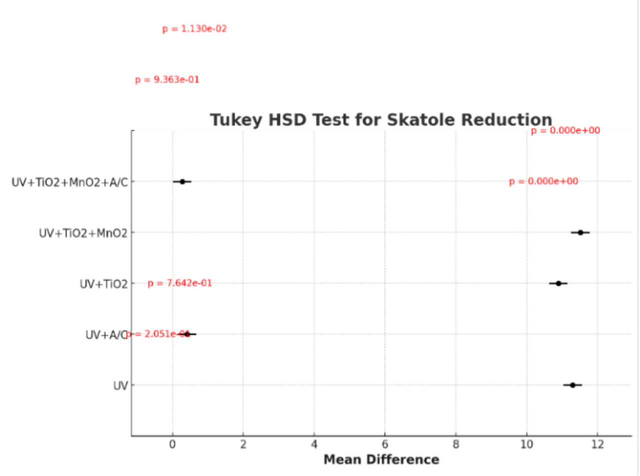


Figure 6: Tukey HSD Test for C_9H_9N Removal Efficiency

4. Discussion

The objective of this study is to design, develop, and manufacture a new composite reaction modular deodorization system for odor reduction, and to evaluate its effectiveness for removing indole and skatole. The study aims to assess the practical applicability of the developed deodorization system in public wastewater treatment facilities by comparing the odor reduction performance of various catalytic materials through numerous experiments.

The main research contents of this study are as follows:

1)Analyze existing wastewater treatment devices, facilities, and odor reduction methods.

2)Transform from a conventional simple airflow circulation system to a twisting airflow system for development.

3)Develop a composite modular deodorization facility by arranging dry deodorization equipment in multiple forms (oxidation, catalyst, adsorbent) within a single module.

4)Measure the removal efficiency of C_8H_7N and C_9H_9N through five different catalytic reaction combinations (UV, UV+TiO2, UV+TiO2+MnO2, UV+A/C, UV+TiO2+MnO2+A/C) repeatedly.

5)Conduct an analysis of variance (ANOVA) on the experimental results.

6)Apply Tukey's post-hoc test based on the statistical analysis results.

5. Conclusions

This study successfully developed a composite reaction modular deodorization system with twisting airflow changes and two forms of dry deodorization equipment (catalyst, adsorbent) within a single module. The device was tested for odor reduction efficacy against the odor compounds C_8H_7N and C_9H_9N. The reduction catalysts used in the device included UV oxidation, TiO_2-based photocatalytic oxidation, MnO_2-based catalytic oxidation, and A/C adsorption, resulting in a total of five different methods.

The experimental data analysis was performed using the statistical package Python 3.12. This software facilitated frequency analysis of odor removal efficiency, one-way ANOVA, and post-hoc testing. Statistical significance was determined using p-values to ensure the reliability and validity of the measurements.

The results of the odor experiments with the developed device are as follows:

The highest removal efficiency for C_8H_7N and C_9H_9N was achieved with the UV+A/C method according to the exponential decay model. The comparison of efficacy and efficiency showed that the developed device demonstrated higher effectiveness. It is concluded that using a combination of multiple processes and technologies in a composite deodorization system provides enhanced treatment efficiency compared to using a single method.

The advantage of this device is its modular design, which allows for the addition or modification of modules according to the specific conditions of wastewater treatment. It is easy to maintain and offers flexibility and scalability for cost-effective odor removal. While this modular system can be applied to various reduction technologies such as biofilters, plasma, activated carbon filters, UV-photocatalysis, and electromagnetic-chemical systems, this study focuses on a "composite reaction modular device" utilizing UV-photocatalysis, catalysts, and activated carbon filters.

In conclusion, this study demonstrates the practical applicability of the developed system for use in real wastewater treatment settings. By integrating UV oxidation, TiO_2 photocatalytic oxidation, MnO_2 catalytic oxidation, and A/C adsorption in a single modular system—techniques that have rarely been combined in Korea—the study achieved outstanding reduction efficacy and efficiency through the maximization of modular and catalytic reactions.

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