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Study of Odor Nuisance and Mitigation Measures for Cup Lump Rubber Used in Rubber Manufacturing Plants

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Abstract

Odor nuisance in block rubber and compound rubber manufacturing plants poses an important environmental management challenge, particularly under actual industrial operating conditions. This study aims to systematically analyze the sources and root causes of odor generation associated with the use of cup lump rubber as a raw material and to develop effective mitigation measures appropriate for factory operations. Qualitative problem analysis tools, including the Fishbone Diagram (4M framework) and Why–Why Analysis, were applied to identify key factors contributing to odor emissions. The analysis identified four principal root causes related to raw material stockpiling practices, odor control equipment performance, deodorizing agent effectiveness, and the lack of systematic odor monitoring. Accordingly, targeted improvement measures were implemented, resulting in a 50% reduction in stockpile volume, enhanced spraying system performance, replacement of effective microorganisms (EM) with wood vinegar, and the introduction of odor intensity measurement at the plant boundary. After implementation, the measured odor intensity was 25, which is below the regulatory limit of 30, indicating compliance with the Ministry of Industry Regulation on Determining Odor Standards in the Air from Factories, B.E. 2568 (2025). The results demonstrate that systematic problem analysis combined with targeted operational improvements can effectively mitigate odor nuisance and support sustainable industrial operations in compliance with regulatory requirements.

Keywords
Cup lump rubber, Rubber manufacturing, Odor control agents, Root cause analysis, Sensory-based odor assessment

1. Introduction
The block rubber and compound rubber manufacturing industry is a fundamental sector within the natural rubber supply chain. Cup lump rubber, obtained from the coagulation of natural latex after tapping, is widely used as a primary raw material in these production processes. Owing to its high organic content and moisture, cup lump rubber is highly susceptible to microbial decomposition during storage, particularly when stockpiled in large quantities.

In industrial operations, cup lump rubber must be prepared and temporarily stockpiled in advance to ensure production continuity, as shown in Figure 1. This practice may involve various storage and handling conditions prior to feeding the material into the production line. Such conditions can facilitate the decomposition of organic substances under aerobic and semi-anaerobic environments, resulting in the generation and release of odorous gases and volatile compounds. Consequently, odors accumulated during storage and handling processes may be released and dispersed into the surrounding environment, potentially causing odor nuisance to nearby communities.

Although basic odor control measures have been implemented at the factory, as summarized in Table 1, operational observations indicate that these measures remain insufficient to effectively control odor emissions under actual operating conditions, particularly those associated with outdoor stockpiling of cup lump rubber. This situation highlights the need for a systematic analysis to identify the limitations of the existing odor control system and to develop improvement measures aligned with the root causes of the problem.

Accordingly, this paper presents a systematic analysis of odor nuisance associated with cup lump rubber handling and storage and proposes practical improvement measures based on real industrial operations. The objective is to enhance odor control efficiency, ensure compliance with regulatory requirements, and support sustainable industrial operations.

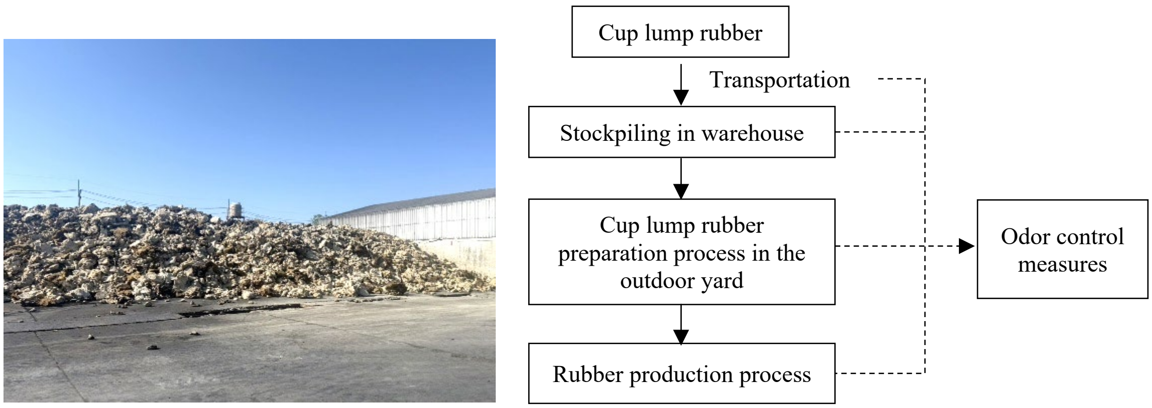

Figure 1**.** Process flow of cup lump rubber preparation prior to the production process.

Table 1. Existing Odor Control Measures for Cup Lump Rubber in Block Rubber and Compound Rubber Manufacturing Plants

No.	Odor Control Measures	Frequency
1	Conduct odor inspections and monitoring of odor impacts both inside and outside the factory. The inspection team observes wind direction using a windsock prior to each inspection and surveys odor conditions within a radius of 5–10 km.	Twice per week
2	Spray effective microorganisms (EM) solution in outdoor raw material stockpiles and raw material storage areas to prevent odor dispersion.	Twice daily (08:00–09:00 and 16:00–17:00)
3	Cover raw material stockpiles with plastic sheets during periods when EM spraying is not performed to reduce odor dispersion.	In addition to spraying periods
4	Clean drainage channels to prevent accumulation of odor-causing substances.	Once per week
5	Clean the area in front of the factory to remove rubber residues resulting from raw material transportation.	Once per week
6	Spray EM solution within the factory area at specified times to suppress odor dispersion in the air and reduce indoor odor problems.	Every 2 hours during daytime and nighttime
7	Clean exhaust hoods to prevent odor accumulation from the rubber drying process.	Entire system every 4 months; specific areas (drying chamber) monthly
8	Clean the odor treatment system and media in the wet scrubber to reduce odor emissions from exhaust stacks.	Once per week

1.1 Objective

This study aims to investigate the origin and causes of odor nuisance associated with the use of cup lump rubber as a raw material in block rubber and compound rubber manufacturing processes. A systematic analysis of odor sources is conducted using qualitative problem analysis tools, namely the Fishbone Diagram based on the 4M framework and Why–Why Analysis, to identify the underlying factors contributing to odor generation under actual operating conditions. Based on the analytical results, appropriate odor reduction and prevention measures are formulated and implemented suitable for factory use. The effectiveness of the improved odor control system is subsequently evaluated to ensure compliance with the Ministry of Industry Regulation on Determining Odor Standards in the Air from Factories, B.E. 2568 (2025).

2. Literature Review
Odor nuisance associated with natural rubber processing has been extensively reported, particularly in relation to cup lump rubber, which is commonly used as a primary raw material in block rubber and rubber compound manufacturing. Cup lump rubber typically contains high organic content and moisture, creating favorable conditions for microbial activity and anaerobic biodegradation processes. These processes result in the formation of malodorous compounds, including ammonia, hydrogen sulfide, mercaptans, and volatile organic acids, which are widely recognized as major contributors to odor nuisance in rubber processing facilities (Jawjit et al., 2010; Tassanakul and Somboonsuke, 2022; Tassanakul et al., 2023). Several studies have demonstrated that large-scale accumulation of cup lump rubber, particularly in outdoor or semi-open storage areas, significantly increases odor intensity and persistence due to continuous decomposition and unrestricted dispersion into surrounding communities (Khunrang et al., 2019; Dunuwila et al., 2018). Moreover, prolonged storage duration and excessive stockpile volume have been identified as critical operational factors that aggravate odor emissions and frequently exceed the effective capacity of conventional odor control systems in natural rubber processing plants (Nunes et al., 2025; Kaewchutima et al., 2026).

Regarding odor assessment, dynamic olfactometry is internationally recognized as a standard method for quantifying odor concentration in terms of odor units (ou/m^3) and is widely applied for regulatory and compliance purposes. However, previous research has consistently indicated that odor concentration alone is insufficient to fully represent odor nuisance as perceived by affected communities, particularly for diffuse and area sources such as raw material stockpiles (Nicell, 2009; Capelli et al., 2013). Consequently, integrated odor assessment approaches that incorporate sensory-based evaluation methods, including field inspections conducted by trained assessors and community-based surveys, have been increasingly recommended. These approaches explicitly consider nuisance-related factors such as frequency, intensity, duration, offensiveness, and location (FIDOL), thereby providing a more realistic representation of odor impact (Sironi et al., 2010; Brancher et al., 2016; Zarra et al., 2021). Sensory-based assessments have been shown to be particularly suitable for evaluating odor nuisance in complex industrial environments and for validating the effectiveness of mitigation measures under real operating conditions.

With respect to odor mitigation strategies, the literature emphasizes that effective odor control in natural rubber processing requires an integrated and source-oriented approach rather than reliance on a single control technique. Biological treatments, including the application of microorganisms in wastewater and raw material management systems, have been reported to reduce odor and organic loading; however, their performance may be limited under conditions of high pollutant concentration and rapid odor generation typically associated with cup lump rubber storage (Suriyon et al., 2019). In contrast, wood vinegar (pyroligneous acid) has received increasing attention due to its antimicrobial and deodorizing properties, with studies demonstrating its applicability in natural rubber processing, particularly in relation to coagulation, microbial control, and odor-related issues (Baimark and Niamsa, 2009; Chungsiriporn et al., 2020). Recent studies further indicate that sustainable odor reduction can be achieved through the combined implementation of suitable deodorizing agents, appropriate application practices, optimized stockpile management, and continuous odor monitoring (Dunuwila et al., 2018; Kaewchutima et al., 2026). These findings underscore the importance of systematic problem analysis and field-based odor evaluation, forming the foundation for the integrated analytical framework and mitigation measures adopted in the present study.

3. Methods
This study employed a systematic, problem-oriented methodology to analyze odor nuisance associated with cup lump rubber handling and storage in a rubber block and rubber compound manufacturing plant. The methodological framework was designed to support structured problem identification, root cause analysis, development of appropriate mitigation measures, and performance evaluation under actual operating conditions. The methods applied in this study consisted of four main stages: (1) problem analysis using qualitative analytical tools, (2) identification of root causes, (3) implementation of odor mitigation measures, and (4) odor assessment and performance evaluation.

3.1 Problem Analysis Using Fishbone Diagram (4M)
To systematically identify potential causes of odor nuisance associated with cup lump rubber, a Fishbone Diagram based on the 4M framework (Man, Machine, Material, and Method) was employed as a structured qualitative analysis tool. This

approach enabled the systematic classification and visualization of factors associated with personnel-related practices, equipment performance, raw material characteristics, and existing operational methods under actual operating conditions.

As illustrated in Figure 2, the application of the Fishbone Diagram provided an integrated view of the odor nuisance problem, indicating that odor occurrence was not attributable to a single dominant cause but rather to the interaction of multiple factors across different operational dimensions. Factors related to raw material characteristics and operational methods highlighted conditions that could promote odor generation, while factors related to machines and methods reflected practical limitations in the effectiveness of existing odor control measures. Field observations further indicated that although Effective Microorganisms (EM) spraying had been continuously implemented, its odor suppression response was insufficient under conditions of high odor generation. Moreover, the absence of systematic odor intensity monitoring at the factory boundary limited objective evaluation of control performance.

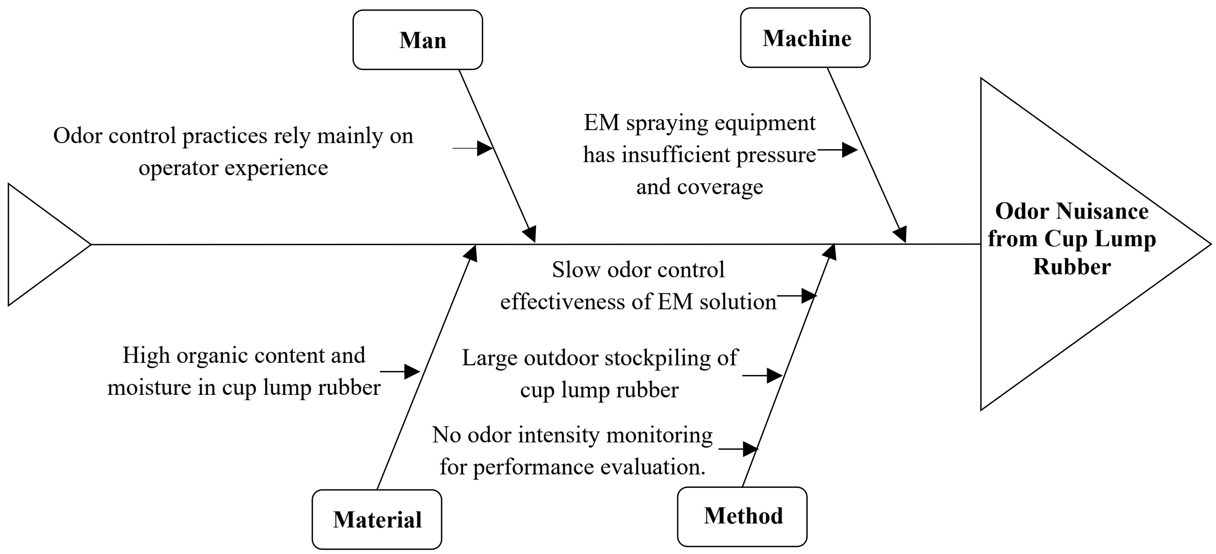

Figure 2**.** Fishbone diagram

3.2 Root Cause Identification Using Why–Why Analysis

Following the Fishbone analysis, a Why–Why Analysis was conducted to identify the fundamental causes underlying the odor nuisance problem. A series of sequential "why" questions were developed to establish causal relationships between observed odor impacts and operational practices. This analysis emphasized four principal root causes: excessive outdoor stockpiling of cup lump rubber, limited performance of spraying equipment, insufficient effectiveness of the deodorizing agent used in the existing system, and the absence of systematic odor intensity monitoring. The logical sequence of cause-and-effect relationships identified through the Why–Why Analysis is summarized in Table 2.

Table 2. Root Cause Identification Using Why–Why Analysis

No.	Why Question	Explanation of Cause	Linkage to the Problem
1	Why does odor nuisance occur from cup lump rubber?	Cup lump rubber contains high organic content and moisture. When stored in large quantities, microbial decomposition continuously generates odorous compounds.	Primary odor source related to raw material characteristics
2	Why is a large quantity of cup lump rubber stockpiled outdoors?	Raw materials are stockpiled in advance to maintain continuous production, resulting in large outdoor storage volumes.	Increased odor generation from large-scale outdoor stockpiling
3	Why does outdoor stockpiling lead to severe odor dispersion?	Outdoor stockpiles act as open and diffuse odor sources, allowing continuous release and dispersion of odorous gases into surrounding areas, reducing the effectiveness of control measures.	Odor dispersion affecting surrounding areas

No.	Why Question	Explanation of Cause	Linkage to the Problem
4	Why is the existing odor control system insufficiently effective?	Because (1) the spraying equipment has limited pressure and coverage, (2) the deodorizing agent responds too slowly to suppress rapid odor generation, and (3) the effectiveness of the odor control system has not been systematically evaluated.	Limitations of odor control equipment and methods
5	How can the effectiveness of odor control measures be evaluated?	Systematic odor intensity measurement at the factory boundary in accordance with the Ministry of Industry Regulation on Determining Odor Standards in the Air from Factories, B.E. 2568 (2025) to enable quantitative assessment of compliance and control performance.	Performance evaluation and regulatory compliance

3.3 Synthesis of Problem Analysis Results

Based on the combined results of the Fishbone Diagram and Why–Why Analysis, the odor nuisance problem was found to arise from four interrelated root causes: (1) excessive outdoor stockpiling of cup lump rubber, (2) limited performance of spraying equipment resulting in insufficient coverage, (3) inadequate responsiveness of the deodorizing agent used in the existing system, and (4) the absence of systematic odor intensity monitoring for performance evaluation.

These findings indicate that the odor issue was primarily attributable to limitations of the existing control system relative to the scale and characteristics of the odor sources. Accordingly, targeted mitigation measures were formulated to directly address each identified root cause, forming the basis for the implementation strategies described in the following section.

3.4 Implementation of Odor Mitigation Measures

Based on the results of the integrated Fishbone Diagram and Why–Why Analysis, odor mitigation measures were systematically developed and implemented with a focus on source-oriented control. The measures specifically addressed the four principal root causes identified in the analysis, namely excessive outdoor stockpiling of cup lump rubber, limitations in spraying equipment performance, suitability of the deodorizing agent, and the absence of systematic odor intensity assessment.

Accordingly, the implementation involved reducing the volume of cup lump rubber stockpiled outdoors, upgrading spraying equipment to improve pressure and coverage efficiency, replacing the existing biological deodorizing agent with wood vinegar for faster odor suppression, and introducing sensory test–based odor monitoring to evaluate control effectiveness and regulatory compliance. The detailed implementation measures and operational adjustments are summarized in Table 3.

Table 3. Odor Mitigation Measures for Cup Lump Rubber Based on Identified Key Issues

No.	Key Issue	Mitigation Approach	Implementation Details
1	Large volume of outdoor cup lump rubber stockpiles	Reduce the volume of outdoor cup lump rubber stockpiling to decrease odor intensity and dispersion into surrounding areas	Reduce the volume of cup lump rubber stockpiled for production readiness as follows: – Normal working days: from 100 tons to 50 tons – Holidays: from 200 tons to 100 tons
2	Limited performance of spraying equipment and systems used for odor control	Improve spraying equipment and systems for deodorizing agents to enhance spraying efficiency and coverage	Modify spraying vehicles and systems to increase spraying pressure and improve dispersion efficiency, enabling adequate coverage of odor sources
3	Insufficient effectiveness of the deodorizing agent used for odor control	Replace the deodorizing agent with one that is more suitable for rapid odor suppression	Apply wood vinegar as the deodorizing agent for odor control, spraying at least twice daily at scheduled times (08:00–09:00 and 16:00–17:00) to enhance odor control efficiency
4	Lack of systematic odor intensity monitoring and evaluation	Conduct odor intensity measurement to assess control effectiveness and regulatory compliance	Perform odor intensity measurement once per year using sensory testing methods to evaluate odor control effectiveness and ensure compliance with the Ministry of Industry Regulation on Determining Odor Standards in the Air from Factories, B.E. 2568 (2025)

3.5 Odor Assessment and Performance Evaluation

The effectiveness of the implemented mitigation measures was evaluated through a before–after comparison under actual operating conditions. Odor assessment was conducted using a sensory-based field test performed by trained assessors to evaluate perceived odor intensity at designated locations within and around the factory boundary. This method was selected due to its suitability for diffuse odor sources such as outdoor raw material stockpiles. The measured odor intensity values were compared with regulatory odor limits specified in the Ministry of Industry Regulation on Determining Odor Standards in the Air from Factories, B.E. 2568 (2025) to assess regulatory compliance.

4. Data Collection

Data collection in this study was conducted to support systematic problem analysis, implementation of odor mitigation measures, and evaluation of their effectiveness. Both qualitative and quantitative data were collected under actual operating conditions of a rubber processing factory producing block rubber and compound rubber.

Qualitative data were obtained through on-site observations, review of factory operation records, and interviews with relevant personnel responsible for raw material handling, odor control operations, and environmental management. These data were used to identify odor sources, operational practices, and limitations of the existing odor control system, and served as input for the Fishbone Diagram (4M) and Why–Why Analysis.

Quantitative data focused on parameters directly related to odor generation and control, including the volume of cup lump rubber stockpiled outdoors, operational conditions of spraying equipment, types and application frequency of deodorizing agents, and odor intensity measurements. Odor intensity data were collected using sensory testing conducted at the factory boundary in accordance with the Ministry of Industry Regulation on Determining Odor Standards in the Air from Factories, B.E. 2568 (2025).

Measurements were performed after implementation of mitigation measures to assess compliance with regulatory requirements and to evaluate the practical effectiveness of the implemented odor mitigation measures. All data were collected during normal production operations to ensure that the results accurately reflected real operating conditions and the practical effectiveness of the implemented odor mitigation measures.

5. Results and Discussion

5.1 Effectiveness of Implemented Odor Mitigation Measures

The effectiveness of the implemented odor control measures was evaluated through a before–after comparison based on operational conditions and odor intensity measurements. The measures were developed from the integrated Fishbone Diagram (4M framework) and Why–Why Analysis and were designed to directly address the four identified root causes of odor nuisance: excessive outdoor stockpiling of cup lump rubber, limited spraying equipment performance, insufficient effectiveness of the deodorizing agent, and the absence of systematic odor monitoring.

Following implementation, the outdoor stockpile volume of cup lump rubber was reduced by approximately 50%, which significantly decreased continuous microbial degradation and odor release from diffuse sources. Upgrading the spraying equipment improved pressure and dispersion efficiency, enabling more uniform coverage of both outdoor stockpiles and indoor storage areas. In addition, replacing Effective Microorganisms (EM) with wood vinegar was associated with faster odor suppression under high organic loading conditions.

The overall effectiveness of the implemented measures was further verified through sensory-based odor intensity measurement conducted at the factory boundary. The measured odor intensity after implementation was 25, which is below the regulatory limit of 30 specified in the Ministerial Regulation on Determining Odor Standards in the Air from Factories, B.E. 2568 (2025). These results confirm that the implemented measures effectively reduced odor nuisance and improved compliance with regulatory requirements. A summary of the before–after performance comparison is presented in Table 4.

Table 4. Summary of Odor Mitigation Performance Before and After Implementation

No.	Analyzed Root Cause	Before Improvement	After Improvement
1	Large volume of outdoor cup lump rubber stockpiles	Cup lump rubber was stockpiled outdoors in large quantities to support production continuity, with approximately 100 tons on normal working days and 200 tons during holidays, resulting in extensive diffuse odor sources.  	Outdoor stockpile volume was reduced by approximately 50%, with 50 tons on normal working days and 100 tons during holidays, effectively decreasing the size and intensity of diffuse odor sources.  
2	Limited performance of spraying equipment and systems used for odor control	Spraying equipment exhibited insufficient pressure and poor dispersion efficiency, resulting in inadequate coverage of outdoor stockpiles and limited odor suppression performance.  	Spraying equipment was upgraded to improve pressure and spray distribution, enabling effective coverage of both outdoor stockpiles and indoor storage areas, thereby enhancing odor control efficiency.  

No.	Analyzed Root Cause	Before Improvement	After Improvement
3	Unsuitability of deodorizing agents used for odor control	Effective Microorganisms (EM) were applied at a dilution ratio of 1 liter per 1,000 liters of water. The response rate was relatively slow under high organic loading conditions, limiting rapid odor suppression.  	The deodorizing agent was replaced with wood vinegar, applied at a dilution ratio of 30 liters per 1,000 liters of water, resulting in faster odor suppression and improved suitability for high organic content raw materials.  
4	Lack of systematic odor intensity monitoring and evaluation	No systematic odor intensity measurements were conducted at the factory boundary or surrounding areas, preventing quantitative evaluation of odor control effectiveness and regulatory compliance.	Odor intensity was measured at the factory boundary using sensory testing. The measured odor intensity was 25, which is below the regulatory limit of 30, complying with the Ministry of Industry Regulation on Determining Odor Standards in the Air from Factories, B.E. 2568 (2025).   ดัชนี / หน่วย / วิธีการวิเคราะห์ / ผลการวิเคราะห์: ริมรั้วโรงงานด้านทิศเหนือ ห่างรั้ว 1 เมตร T25AQ110-0001 ค่าความเข้มกลิ่น / - / JAPANESE INDUSTRIAL STANDARD (JIS) JIS Z 9080, 2004 SENSORY ANALYSIS, TRIANGULAR ODOUR BAG * / 25 สภาพตัวอย่าง / สมบูรณ์

5.2 Discussion of Odor Control Performance

The results indicate that effective control of odor nuisance from cup lump rubber requires an integrated, source-oriented approach rather than reliance on individual mitigation measures. Reduction of outdoor stockpile volume was a critical factor influencing odor generation, as large accumulations of cup lump rubber promote microbial degradation and continuous odor release from diffuse sources. This observation is consistent with previous studies reporting that extensive accumulation of rubber raw materials contributes to odor emissions and nuisance in surrounding areas (Khunrang et al., 2019; Dunuwila et al., 2018; Nunes et al., 2025). From an odor nuisance perspective, stockpile volume reduction affects the frequency and persistence of odor episodes, which are key determinants of community perception and annoyance (Nicell, 2009; Zarra et al., 2021).

Field observations suggest that appropriate application practices of deodorizing agents, particularly adequate spray coverage, are important for managing diffuse odor sources. Although spraying system performance was not quantitatively assessed, the observed improvement in odor management highlights the need to align application practices with source characteristics (Sironi et al., 2010; Brancher et al., 2016). The use of wood vinegar, as part of the improved odor control measures, was associated with reduced perceived odor intensity under actual operating conditions, which may be discussed in relation to its acidic and antimicrobial properties reported in natural rubber processing contexts (Baimark and Niamsa, 2009). Sensory-based odor intensity monitoring was important for evaluating odor control performance under real operating conditions, as it reflects human perception and nuisance potential from diffuse outdoor sources and aligns with integrated odor assessment recommendations (Capelli et al., 2013; Nicell, 2009; Zarra et al., 2021).

6. Conclusion

This study indicates that odor nuisance associated with cup lump rubber in rubber manufacturing plants can be mitigated through systematic problem analysis and source-oriented operational improvements. By applying Fishbone Diagram and Why–Why Analysis, key limitations of the existing odor control system were identified and addressed through targeted mitigation measures.

Implementation of the improvement measures resulted in a 50% reduction in outdoor stockpile volume, improved application coverage of deodorizing agents, replacement of Effective Microorganisms (EM) with wood vinegar, and the introduction of sensory test–based odor monitoring. Post-implementation evaluation under actual operating conditions showed an improvement in odor control performance, with the measured odor intensity at the factory boundary equal to 25, complying with the regulatory limit of 30 specified in the Ministry of Industry Regulation on Determining Odor Standards in the Air from Factories, B.E. 2568 (2025).

Overall, the findings highlight that combining systematic root cause analysis with practical, source-oriented mitigation measures supports sustainable odor control in rubber manufacturing facilities. The proposed approach provides a practical framework that can be adapted to similar industrial contexts facing diffuse odor nuisance problems.

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