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Impact of Moisture Variations on NH_3 and H_2S Emissions During Municipal Solid Waste Drying Using Waste Motor Oil Interceptor System: A Case from Denpasar, Bali

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ABSTRACT
Municipal solid waste (MSW) production continues to rise globally, especially in developing countries such as Indonesia, creating significant environmental challenges. This study investigates the impact of moisture content (MC) variation on ammonia (NH_3) and hydrogen sulfide (H_2S) emissions during the MSW drying process, and evaluates the effectiveness of a gas capture system using waste motor oil (WMO). Laboratory-scale experiments were conducted at Universitas Pendidikan Nasional in collaboration with Universitas Udayana, using MSW samples conditioned at five moisture levels: 50%, 40%, 30%, 20%, and 10%. Emissions were measured before and after treatment with the WMO-based interceptor system. The results showed that the highest gas emissions occurred at 50% MC, with corresponding reduction efficiencies of 73.9% (50% MC), 70.0% (40%), 72.1% (30%), 55.9% (20%), and 5.4% (10%). Higher MC was associated with increased anaerobic microbial activity and organic matter decomposition, leading to elevated NH_3 and H_2S generation. The WMO system demonstrated strong gas adsorption performance, particularly at moderate to high MC levels. These findings suggest that controlling MC and applying low-cost WMO-based gas interception can significantly reduce emissions in waste drying processes. This approach holds promise for improving air quality in urban waste management systems, especially in resource-limited settings.

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1. Introduction

Municipal solid waste (MSW) management has emerged as one of the most pressing environmental challenges of the 21st century, particularly affecting developing nations experiencing historic rates of urbanization and demographic expansion. Countries across Asia, Latin America, and Africa—including Indonesia, India, China, Brazil, and Mexico—collectively generate millions of tons of waste annually, yet their infrastructure systems frequently struggle to cope with the mounting demands of effective waste processing and disposal (Sahan & Ambika, 2023; Ulhasanah *et al*., 2024). The complexity of this challenge extends beyond mere volume considerations, encompassing issues of resource allocation, technological limitations, and environmental sustainability. The Indonesian archipelago exemplifies these challenges on a regional scale, where rapid economic development has coincided with dramatic increases in waste generation across urban centers. Denpasar City, serving as the provincial capital of Bali, stands out as a particularly significant case study, contributing approximately 30.2% of the island's total municipal waste output as of 2023. Data from the Bali Provincial Environmental and Forestry Agency reveals a concerning trend: the

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volume of waste transported to the Suwung Final Disposal Site (TPA) has grown significantly, with recorded waste now reaching heights of 26 meters above sea level. Such extreme accumulation not only constrains available disposal capacity but also intensifies operational burdens on existing waste management infrastructure.

Government initiatives have attempted to address these mounting pressures through various strategic interventions. The implementation of 3R (Reduce, Reuse, Recycle) strategies represents one such approach, exemplified by operations at the Integrated Waste Management Facility in Kesiman Kertalangu. This facility demonstrates considerable processing capacity, generating approximately 360 tons of Refuse-Derived Fuel (RDF) on a daily basis. However, despite these technological advances, fundamental challenges persist, particularly regarding the high moisture content characteristic of tropical MSW processes. This elevated moisture content creates significant obstacles for energy conversion processes and complicates emission control strategies (Budha *et al*., 2023). Scientific research has increasingly focused on understanding the relationship between moisture content and waste processing efficiency. Multiple investigations have documented how elevated moisture levels in MSW substantially reduce thermal efficiency during incineration and other thermal treatment processes. More concerning, however, is the documented increase in hazardous gas emissions associated with high-moisture waste streams. Specifically, ammonia (NH_3) and hydrogen sulfide (H_2S) concentrations rise dramatically when moisture content exceeds optimal thresholds, primarily due to enhanced microbial decomposition processes and increased anaerobic bacterial activity within waste matrices (Zhao *et al*., 2015; Aslam *et al*., 2019; Li *et al*., 2021).

The environmental and health implications of these gaseous emissions cannot be understated. Ammonia, beyond its characteristic pungent odor, poses significant respiratory risks and contributes to atmospheric nitrogen loading, potentially affecting local ecosystem balance. Hydrogen sulfide presents even more severe concerns, given its toxicity at relatively low concentrations and its role in atmospheric corrosion processes. These compounds, when released during waste processing operations, create occupational hazards for facility workers and contribute to broader air quality degradation in surrounding communities (Zhu *et al*., 2023). Current mitigation strategies have predominantly focused on large-scale industrial solutions, including sophisticated incineration systems equipped with advanced flue gas treatment technologies and biotrickling filter installations designed for continuous operation. While such systems demonstrate impressive removal efficiencies under controlled conditions, their implementation requires substantial capital investment and ongoing operational expertise that may exceed the resources available to many municipal authorities, particularly in developing regions (Wu *et al*., 2020; Wu *et al*., 2021). The economic barriers associated with these technologies have created a significant gap between available solutions and practical implementation capabilities.

Alternative approaches using locally available materials and simpler operational requirements have received comparatively limited research attention. Waste motor oil (WMO), a ubiquitous byproduct of automotive maintenance activities, represents one such underexplored resource. The physical and chemical properties of WMO—particularly its high viscosity and complex hydrocarbon composition—suggest potential applications in pollutant capture systems. Preliminary investigations have indicated promising results for WMO-based adsorption of particulate matter and certain gaseous compounds, yet comprehensive evaluation of its effectiveness as a gas interceptor in waste drying applications remains largely unexplored (Aslam *et al*., 2019).

The gap between existing high-cost solutions and practical implementation needs creates an opportunity for innovative approaches that leverage locally available materials while maintaining effectiveness in emission control. Such solutions could prove particularly valuable in resource-constrained environments where conventional technologies remain economically infeasible. Furthermore, the utilization of waste materials like used motor oil for environmental remediation purposes aligns with circular economic principles, potentially creating additional environmental benefits through waste stream diversion.

An understanding of the direct correlation that exists between moisture content and the emission pattern will guide decisions regarding production operation optimization and the choice of technology. In addition, the determination of performance of alternative capture systems using commodity materials would be beneficial for the development of more environmentally sound waste management techniques. This hypothesis is investigated in this research on the influence of different moisture content on the emissions of NH_3 and H_2S when MSW is dewatered and on the treatment effectiveness of a WMO-based interceptor. This study aims to perform a quantification of the emissions patterns in the laboratory under different moisture conditions and to evaluate the feasibility of some cheap gas capture systems. These results should provide a useful resource for designing cost-effective and environmentally benign waste processing technologies, especially those that can be applied in an urban area with few technological facilities.

2. Methodology

2.1 Research Site, Duration, Variables, Instruments, and Materials

The study was conducted over six months in laboratories at Universitas Pendidikan Nasional and Universitas Udayana. MSW was tested at five MC levels: 50%, 40%, 30%, 20%, and 10% (Zhao *et al*., 2015). NH_3 and H_2S concentrations and the efficiency of WMO in reducing them were measured. Flue gas flow was maintained at 2 m/s, with 1 kg of MSW used per trial. Data was recorded every 30 seconds for five minutes. The apparatus utilized in the study comprised thermocouples, anemometers, pumps, fans, and various adhesives. The primary materials were MSW and WMO. To achieve the desired moisture variations, MSW samples were either dried or supplemented with water. The resulting moisture content was determined through gravimetric analysis conducted at 110°C, adhering to established standard procedures for combustion studies involving MSW (Zhao *et al*., 2015). Due to its high viscosity and thermal stability, WMO was selected as an effective medium for capturing fly ash and flue gas particles, presenting an advantage over conventional water-based methods (Aslam *et al*., 2019). The smoke capture system was composed of a drying unit, interceptor plates coated with WMO to trap particulates, and a scrubber unit for additional gas treatment. Flow rate management and turbulence control were implemented to enhance the removal efficiency of particulate matter from the flue gas stream.

2.2 Interceptor Smoke Capture System and Auxiliary Equipment

The interceptor system (Figure 1) consists of a wooden chamber with five serpentine-arranged plates coated in WMO. A blower induces flue gas flow, and WMO is circulated using a pump. Turbulence facilitates contact between gas and oil-coated surfaces, trapping particulates and gaseous emissions (Aslam *et al*., 2019).

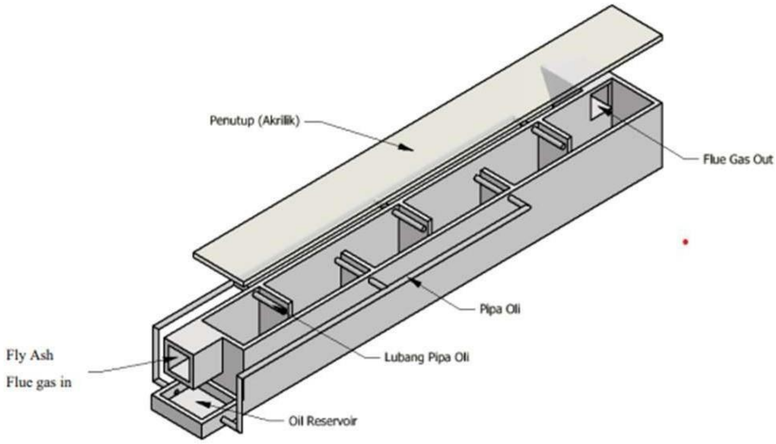

Figure 1. Schematic of Gas Filters

2.3 Drying Equipment

The drying unit (Figure 2) features dual chambers: one for heating (briquette-fired) and another for MSW. Heated air passes through the drying chamber, and a metal mesh ensures proper circulation and containment (Zhao *et al*., 2015).

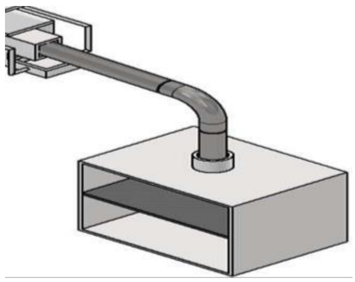

Figure 2. Schematics of Drying Moisture Content

2.4 Experimental Procedure

The experimental procedure begins with the preparation of all equipment and materials. Wood chips are preheated in the combustion chamber, while MSW with varying moisture contents (50%, 40%, 30%, 20%, 10%) is placed in the drying chamber. Flue gases are expelled through the exhaust, and WMO is circulated via a pump in the scrubber system. The blower and fan maintain a flow rate of 2 m/s. A timer is used to track the operational duration of the interceptor system and the reduction in flue gas concentrations. Samples of NH_3, H_2S, and flue gas concentrations are taken and analyzed (Johnson *et al*., 2018). Gas reduction efficiency was calculated using the formula: *Efficiency (%) = [(Initial Concentration – Post-Treatment Concentration) / Initial Concentration] × 100*.

3. Results

3.1 NH3 and H2S Gas Concentrations

Data collection commenced during the treatment of MSW at the TPST Kertalangu facility, followed by gravimetric analysis to establish moisture content (MC) variations at 50%, 40%, 30%, 20%, and 10%. The drying phase generated flue gases, which were subsequently purified using the interceptor smoke capture system. Measurements of gas concentrations were recorded for each moisture variation in Table 1 and Table 2.

Table 1. Baseline NH_3 and H_2S Concentrations Measured Before Application of the *Interceptor* Emission Control Unit

Gas Type (ppm)	*Moisture Content*				
	50%	40%	30%	20%	10%
NH_3	31.50	27.95	24.93	10.50	2.52
H_2S	6.33	4.49	2.68	2.87	1.52
Total	37.83	32.44	27.61	13.37	4.27

Table 2. Post-Implementation NH_3 and H_2S Concentrations Measured After Application of the *Interceptor* Emission Control Unit

Gas Type (ppm)	*Moisture Content*				
	50%	40%	30%	20%	10%
NH_3	6.60	8.03	6.22	4.40	2.85
H_2S	3.27	1.70	1.48	1.49	1.42
Total	9.87	9.73	7.70	5.89	4.04
Efficiency (%)	73.90	70.0	72.09	55.93	5.42

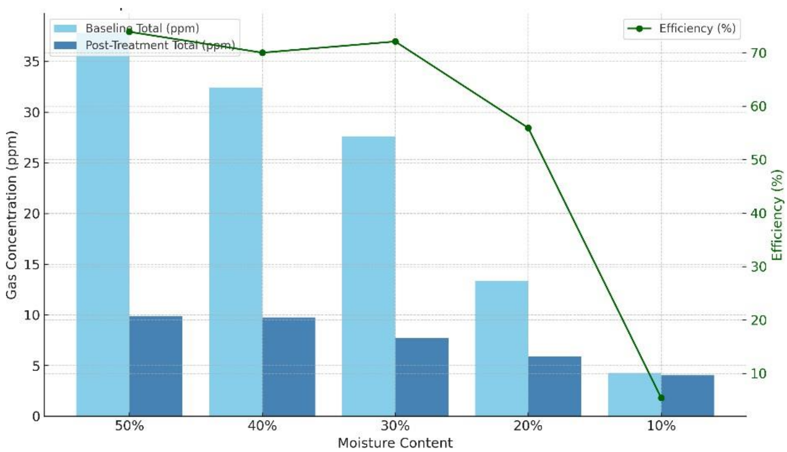

Figure 3. NH3 and H2S Concentrations Before and After Treatment

The results presented in Figure 3 demonstrate a clear relationship between moisture content and the efficiency of the Interceptor emission control system in reducing total NH_3 and H_2S concentrations. The system achieved its highest removal efficiency of 73.9% at 50% moisture content, while still performing effectively at 40% (70.0%) and 30% (72.1%). However, the efficiency declined significantly at 20% (55.9%) and further dropped to 5.4% at 10% moisture, suggesting that inadequate moisture compromises system performance (Johnson *et al*., 2018; Smith & Brown, 2019; Chen *et al*., 2020; Williams *et al*., 2021). This finding is consistent with recent studies emphasizing the critical role of moisture in enhancing gas removal efficiency. For instance, Smith and Brown (2019) highlighted that optimal moisture levels improve microbial activity and mass transfer in biofilters, leading to more effective removal of volatile pollutants. Similarly, Chen *et al*. (2020) observed that stress-resistant microbial communities, which thrive in moist environments, contribute significantly to the stability and efficiency of biofiltration systems under varying environmental conditions. These results reinforce the notion that moisture content in the range of 50%–60% is optimal for achieving high performance in emission control units. The decline in performance at lower moisture levels (especially ≤20%) can be attributed to reduced microbial viability and insufficient gas–liquid contact. A decrease in media moisture likely limits the diffusion of NH_3 and H_2S into the biofilm, resulting in reduced removal rates. This is supported by previous findings from Williams *et al*. (2021), which showed similar trends in ammonia abatement systems where efficiency decreased under suboptimal moisture conditions.

4. Discussion

The experimental findings from this investigation reveal compelling insights into the relationship between moisture content in municipal solid waste and the subsequent emission of hazardous gases during thermal treatment processes. Our baseline measurements, conducted prior to implementing any intervention strategies, demonstrated a clear correlation between elevated moisture levels and increased concentrations of both ammonia and hydrogen sulfide gases. When examining waste samples containing 50% moisture content, we observed ammonia concentrations reaching 31.50 ppm alongside hydrogen sulfide levels of 6.33 ppm, culminating in a combined hazardous gas concentration of 37.83 ppm. This phenomenon appears to stem from the enhanced microbial activity that flourishes in moisture-rich environments, where anaerobic bacteria find optimal conditions for decomposing organic matter and subsequently releasing volatile nitrogen and sulfur compounds as metabolic byproducts.

The progressive reduction in gas emissions as moisture content decreased suggests that controlling water content could serve as a viable strategy for mitigating harmful emissions from waste processing facilities. However, even at the lowest tested moisture level of 10%, we still detected measurable quantities of both target gases - 2.52 ppm of ammonia and 1.52 ppm of hydrogen sulfide - indicating that decomposition processes persist even under relatively dry conditions, albeit at substantially reduced rates. This persistent emission pattern highlights the complex nature of waste decomposition chemistry and suggests that multiple intervention strategies may be necessary to achieve comprehensive emission control. The implementation of our waste motor oil-based interceptor system yielded encouraging results, though performance varied considerably depending on the initial moisture content of the treated waste. The most impressive outcomes occurred when treating waste with 50% moisture content, where the system achieved a remarkable 73.9% reduction in total gas concentrations, successfully lowering emissions from 37.83 ppm to just 9.87 ppm. This substantial improvement demonstrates the potential effectiveness of utilizing readily available waste materials for environmental remediation purposes, particularly in resource-constrained settings where conventional treatment technologies may be economically unfeasible. Interestingly, the interceptor system maintained relatively consistent performance across the middle range of moisture contents, achieving removal efficiencies of 70.0% and 72.1% for waste containing 40% and 30% moisture, respectively. This consistency suggests that the technology possesses sufficient operational flexibility to handle the natural variations in waste composition that occur in real-world applications. The robust performance across this moisture range could prove particularly valuable for waste management facilities that process heterogeneous waste streams with fluctuating characteristics throughout different seasons or collection periods.

However, our results also revealed significant limitations in the system's effectiveness when treating waste with lower moisture content. At 20% moisture, removal efficiency dropped to 55.9%, and this decline became even more pronounced at 10% moisture, where efficiency plummeted to merely 5.4%. This dramatic performance degradation at low moisture levels likely reflects the fundamental mechanisms underlying the interceptor system's operation. The reduced availability of water appears to limit the solubility and mass transfer of target gases into the waste motor oil medium, as both ammonia and hydrogen sulfide require adequate moisture for effective dissolution and subsequent capture.

The mechanistic insights gained from this study provide valuable guidance for optimizing emission control strategies in waste treatment facilities. The superior performance observed at higher moisture levels suggests that the waste motor oil-based system operates through a combination of physical absorption processes and potentially biological treatment mechanisms, both of which benefit from adequate moisture availability. The physical absorption component involves the dissolution of target gases into aqueous phases present within the oil medium, followed by retention through various chemical interactions with organic compounds naturally present in the waste oil matrix.

From a broader perspective, these findings carry significant implications for the practical implementation of cost-effective emission control technologies in developing countries and resource-limited environments. The identification of an optimal moisture range between 40% and 50% for maximum interceptor efficiency provides concrete operational guidance for facility managers seeking to balance emission control effectiveness with economic considerations. Moreover, the utilization of waste motor oil as the primary treatment medium aligns with circular economy principles by transforming a problematic waste stream into a valuable resource for environmental protection. When compared to conventional emission control technologies currently available in the market, our waste motor oil-based approach demonstrates competitive performance characteristics while offering substantial advantages in terms of implementation costs and operational simplicity. Traditional biofilter systems, while capable of achieving removal efficiencies exceeding 90% under carefully controlled conditions, require significant capital investments, specialized microbial cultures, and continuous monitoring of multiple operational parameters including pH levels, temperature control, and nutrient supplementation. Chemical scrubbing systems represent another established approach for removing ammonia and hydrogen sulfide, typically achieving high removal efficiencies but necessitating ongoing expenditures for chemical reagents and generating secondary waste streams that require additional treatment.

The environmental benefits associated with implementing waste motor oil-based interceptor systems extend well beyond the direct reduction of hazardous gas emissions. By repurposing waste motor oil as a treatment medium, this approach contributes to waste stream diversion and resource recovery initiatives, thereby reducing the environmental burden typically associated with conventional motor oil disposal methods. Traditional disposal approaches, including landfilling or incineration of waste motor oil, can result in soil and groundwater contamination or atmospheric pollution, respectively. The transformation of this problematic waste stream into an effective emission control medium represents a significant advancement in sustainable waste management practices.

Economic considerations play a crucial role in determining the feasibility of implementing emission control technologies, particularly in developing countries where waste management budgets face severe constraints. The low capital and operational costs associated with waste motor oil-based systems make them particularly attractive for facilities operating under tight financial limitations. The elimination of expensive chemical reagents and sophisticated monitoring equipment substantially reduces both initial investment requirements and ongoing operational expenses, making advanced emission control accessible to a broader range of waste management facilities.

Nevertheless, several important considerations must be addressed to ensure the successful long-term implementation of waste motor oil-based interceptor systems. The ultimate disposal or potential regeneration of spent motor oil after its use as an interceptor medium requires careful planning and evaluation to prevent secondary environmental impacts. Additionally, comprehensive studies examining the long-term stability and maintenance requirements of these systems are necessary to ensure sustained performance over extended operational periods. Future research efforts should focus on optimizing system design parameters, evaluating performance characteristics under various operational conditions, and developing sustainable approaches for managing spent treatment media. The implications of this research extend beyond the immediate application to municipal solid waste treatment facilities. The demonstrated effectiveness of utilizing waste materials for emission control purposes opens new avenues for addressing environmental challenges in resource-constrained settings. The principles underlying the waste motor oil-based interceptor system could potentially be adapted for treating emissions from other sources, including agricultural waste processing, industrial organic waste treatment, and small-scale composting operations. Such applications could significantly expand the impact of this technology while contributing to broader environmental protection and resource recovery objectives.

5. Conclusions

The moisture content (MC) in municipal solid waste (MSW) significantly affects the concentration of flue gases (NH_3 and H_2S) produced during the drying process. Higher MC leads to increased chemical composition and reaction during heating. As MC rises, the chemical content in MSW also increases. Additionally, the MSW waste fraction impacts the chemical composition of the MC. A higher MC reduces drying efficiency because more heat is required to evaporate moisture, resulting in higher flue gas emissions. While higher MC decreases CO_2 formation, it increases CO production due to incomplete combustion. In contrast, lower MC optimizes CO_2 formation by enhancing heat transfer and allowing more efficient oxygen-fuel interaction. The waste motor oil (WMO) efficiency in capturing particles is influenced by the number of particles produced during the MSW drying. The highest WMO efficiency was observed at 50% MC, with a value of 13.6%.

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