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Performance Analysis of Floating Cover Technologies for Air Emission Control in Lab-Scale Swine Slurry Pits

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Abstract: The management of gaseous emissions from swine production systems remains a significant environmental challenge due to the release of ammonia (NH_3), hydrogen sulfide (H_2S), and odor-causing compounds during slurry storage and handling. These emissions contribute to air quality degradation, ecological impacts, and occupational health concerns within livestock production environments. Floating cover technologies have emerged as a potential mitigation strategy by creating a physical barrier between stored slurry and the atmosphere, thereby reducing gaseous transfer processes. This study presents a performance analysis framework for evaluating floating cover technologies applied to lab-scale swine slurry pits, focusing on their effectiveness in controlling ammonia and hydrogen sulfide emissions. The research integrates theoretical emission mechanisms, manure management principles, and comparative assessment approaches derived from existing studies on emission reduction strategies. The analysis considers cover functionality, gas diffusion limitation, operational performance, and environmental implications. Previous research indicates that nutritional management, slurry treatment, cooling approaches, and biological control systems can influence emission generation; however, floating covers provide a direct intervention at the emission source. The findings suggest that floating cover systems represent an effective supplementary technology for reducing air pollutant release from slurry storage units, although their performance depends on material characteristics, coverage efficiency, and interaction with slurry properties. The study contributes a structured evaluation approach for future optimization of floating cover systems in sustainable swine waste management.

Keywords: Floating covers; Swine slurry; Ammonia emission; Hydrogen sulfide; Air pollution control; Manure management; Emission mitigation; Livestock environmental technology; Sustainable agriculture.

1. Introduction:

Background

Modern swine production systems face increasing environmental pressure due to emissions generated throughout manure collection, storage, and treatment processes. Among the major pollutants associated with livestock operations, ammonia (NH_3) and hydrogen sulfide (H_2S) are recognized as critical gaseous compounds because of their impacts on atmospheric quality, animal housing conditions, worker safety, and surrounding communities. The transformation and volatilization of nitrogenous and sulfur-containing compounds within stored slurry create continuous emission pathways, making emission control a fundamental component of sustainable livestock management.

Ammonia emissions primarily originate from the decomposition of nitrogen-containing compounds in animal manure. The conversion of urinary nitrogen into ammonium and subsequent volatilization processes are strongly influenced by environmental conditions, slurry characteristics, temperature, and exposure surface area. Previous research has identified manure management as an important factor controlling nitrogen losses from agricultural systems, emphasizing that reducing nitrogen volatilization is essential for improving environmental performance in livestock production (Cameron et al., 2013). Similarly, Aarnink and Verstegen (2007) highlighted that manure-related nutrient losses represent a major contributor to the environmental burden associated with pig production and emphasized the importance of integrated management approaches for emission reduction.

The development of effective emission control strategies requires consideration of both emission generation mechanisms and physical pathways through which gases escape into the atmosphere. Traditional approaches have included dietary modification, chemical treatment, manure cooling, biological treatment, and improved storage management. For example, reducing dietary crude protein levels has demonstrated potential for lowering ammonia emissions by decreasing nitrogen excretion; however, such approaches may not completely address emissions generated during slurry storage (Hansen et al., 2007). Similarly, chemical modification strategies, including sulfuric acid treatment, have been investigated as methods for altering manure chemistry and reducing gaseous losses (Jensen, 2002).

Floating cover technologies provide an alternative source-oriented mitigation strategy by limiting direct contact between slurry surfaces and ambient air. Unlike approaches that modify emission formation conditions, floating covers primarily function by reducing gas transfer from the slurry surface into the atmosphere. This physical separation mechanism creates an opportunity for continuous emission reduction during storage periods, particularly in enclosed or semi-enclosed manure management systems.

Hydrogen sulfide emissions present another major challenge in swine slurry management. H_2S is generated through microbial decomposition processes involving sulfur-containing compounds under anaerobic conditions. Although ammonia is generally associated with nitrogen loss and atmospheric deposition, hydrogen sulfide represents a significant concern because of its toxicity, odor intensity, and impact on workplace environments. Research examining hydrogen sulfide control mechanisms has demonstrated the importance of managing biological and chemical conditions within waste storage environments (Long et al., 2016).

The increasing scale of intensive pig production has further intensified the need for efficient emission reduction technologies. Studies examining emission characteristics in commercial swine facilities have demonstrated that manure storage systems significantly influence atmospheric conditions within livestock buildings (Choi et al., 2022). Therefore, improving slurry storage performance through technologies such as floating covers represents an important pathway toward achieving environmentally responsible animal production.

1.2 Problem Statement

Despite advances in manure management technologies, controlling gaseous emissions from swine slurry pits remains a complex technical challenge. Existing mitigation approaches often address individual emission sources but may have limitations related to cost, operational complexity, or long-term effectiveness. Nutritional interventions can reduce pollutant generation at the animal level, but they cannot fully eliminate emissions from accumulated slurry. Similarly, chemical and biological treatments require continuous management and may introduce additional operational considerations.

Open slurry storage systems remain particularly vulnerable because the exposed surface provides a direct pathway for ammonia and hydrogen sulfide exchange between manure and surrounding air. Environmental conditions such as temperature fluctuations, air movement, and slurry disturbance can increase volatilization rates. Research on manure storage and nitrogen turnover under farming conditions has shown that storage processes represent important stages of nutrient loss and emission formation (Tran et al., 2011).

Furthermore, emission control strategies must consider both environmental effectiveness and practical implementation. Technologies that achieve emission reductions but require excessive maintenance or high operational costs may have limited adoption potential. Therefore, there is a need to evaluate technologies that provide reliable emission reduction while maintaining operational simplicity.

Floating covers represent a promising intervention because they directly target the emission interface. However, the effectiveness of different floating cover systems depends on multiple factors, including cover material properties, sealing performance, durability, interaction with slurry characteristics, and ability to withstand operational conditions. A systematic performance analysis is required to understand how floating cover technologies contribute to emission control in laboratory-scale swine slurry systems.

1.3 Research Relevance

The investigation of floating cover technologies is highly relevant within the broader context of sustainable livestock production and environmental pollution management. Agricultural emissions contribute significantly to air quality concerns, and reducing livestock-related pollutants has become an important objective in environmental management frameworks. The Organization for Economic Cooperation and Development has identified ammonia emissions from agricultural activities as a major environmental concern requiring effective mitigation strategies (Organization for Economic Cooperation and Development, 2021).

Previous research has demonstrated that air pollution reduction strategies in agriculture can generate substantial environmental and health benefits. Giannadaki et al. (2018) emphasized that reducing agricultural air pollutants can contribute to improved public health outcomes and economic benefits. Therefore, technologies capable of reducing emissions at livestock production facilities have implications beyond individual farms.

The relevance of floating covers also extends to improving the reliability of emission measurement and management systems. By modifying the gas exchange boundary between slurry and atmosphere, floating covers provide an opportunity to evaluate emission reduction mechanisms under controlled experimental conditions. Laboratory-scale studies can generate valuable insights into system performance before large-scale implementation.

Additionally, floating cover technology complements existing manure management strategies. Rather than replacing nutritional, biological, or chemical approaches, floating covers can function as an integrated component within comprehensive emission control frameworks. This approach aligns with the principle that livestock environmental management requires multiple coordinated interventions.

1.4 Research Objectives

The primary objective of this research is to analyze the performance of floating cover technologies for controlling air emissions from lab-scale swine slurry pits.

The specific objectives are:

1. To examine the emission mechanisms of ammonia and hydrogen sulfide generation in swine slurry storage systems.
2. To evaluate the functional principles through which floating covers reduce gaseous emissions.
3. To develop an analytical framework for assessing floating cover performance under controlled laboratory conditions.
4. To compare floating cover approaches with other manure emission mitigation strategies reported in previous research.
5. To identify operational advantages, limitations, and future optimization opportunities for floating cover technologies.

1.5 Scope and Significance

This study focuses on floating cover technologies applied to laboratory-scale swine slurry pits, emphasizing their role in reducing ammonia and hydrogen sulfide emissions. The research considers emission pathways, physical barrier mechanisms, and performance evaluation approaches.

The significance of this study lies in providing a structured understanding of floating cover effectiveness as an emission control technology. While previous research has investigated multiple manure management strategies, limited attention has been given to evaluating floating covers as a direct surface-level intervention. By analyzing their functional characteristics, this research contributes to the development of sustainable waste management practices for intensive swine production.

The findings may support future engineering improvements in cover design, material selection, and integration with other emission reduction systems. Furthermore, the study provides a foundation for scaling laboratory observations toward practical applications in commercial livestock facilities.

2. LITERATURE REVIEW

2.1 Environmental Impact of Swine Slurry Emissions

Swine slurry management has been widely recognized as a critical factor influencing the environmental footprint of pig production systems. The composition of slurry contains nitrogen, sulfur compounds, and organic matter that undergo microbial transformation, producing gaseous emissions during storage. Aarnink and Verstegen (2007) identified manure management as a key determinant of environmental load in pig production, emphasizing that reducing nutrient losses is essential for sustainable livestock systems.

Nitrogen losses from agricultural systems have received considerable research attention because ammonia volatilization contributes to atmospheric nitrogen imbalance and environmental degradation. Cameron et al. (2013) provided a comprehensive assessment of nitrogen loss pathways, demonstrating that management practices significantly influence nitrogen retention and emission patterns.

At the regional level, ammonia emissions from agriculture represent a major contributor to air quality problems. Schiferl et al. (2014) investigated atmospheric ammonia and particulate matter interactions, demonstrating the importance of understanding ammonia behavior within broader atmospheric systems. These findings highlight that emission control at livestock sources can contribute to improved regional air quality.

2.2 Existing Strategies for Swine Emission Mitigation

The control of gaseous emissions from swine production has traditionally relied on a combination of nutritional, chemical, physical, and biological management strategies. Each approach addresses different stages of the emission generation process, but limitations remain regarding complete emission suppression.

Nutritional management represents an upstream strategy by reducing the quantity of emission-generating compounds entering manure systems. Aarnink and Verstegen (2007) emphasized that improving nutrient utilization efficiency in pigs is a fundamental approach for reducing environmental impacts associated with manure production. By optimizing feed composition and reducing excess nutrient excretion, the potential formation of ammonia precursors can be minimized. Similarly, Hansen et al. (2007) demonstrated that dietary interventions, including reduced crude protein levels, can decrease ammonia emissions from finishing pigs. However, these strategies primarily influence emission formation potential and cannot fully eliminate emissions from stored slurry.

Chemical treatment approaches have also been investigated for modifying manure properties and controlling gaseous losses. Jensen (2002) examined sulfuric acid application as a method for altering environmental conditions within swine buildings and reducing emission potential. Chemical treatments can influence pH levels, microbial activity, and nitrogen transformation pathways. Nevertheless, chemical approaches may require continuous application, specialized handling, and careful management to avoid secondary environmental concerns.

Physical management strategies, such as cooling manure storage systems, provide another method for reducing volatilization. Andersson (1998) demonstrated that manure cooling can reduce ammonia emissions by decreasing volatilization rates from storage environments. Temperature reduction affects chemical equilibrium processes and slows microbial activity, thereby lowering emission intensity. However, cooling systems require energy inputs and may not always be economically feasible for all production systems.

Biological management technologies have gained attention due to their ability to modify manure characteristics through microbial processes. Kim et al. (2023) evaluated a real-time bio-liquor circulation system for manure management and odor reduction in swine farming. Their findings indicate that biological circulation approaches can influence odor generation potential and improve manure handling efficiency. Similarly, Choi et al. (2022) examined atmospheric characteristics in swine finishing barns equipped with continuous pit recirculation systems, highlighting the importance of manure treatment methods in controlling indoor air conditions.

Although these strategies provide valuable emission reduction pathways, most approaches modify either emission generation mechanisms or manure characteristics. Floating cover technology differs because it directly targets the emission transfer pathway by reducing the physical interface between slurry and atmosphere.

2.3 Mechanisms of Ammonia and Hydrogen Sulfide Emission Formation

Understanding emission mechanisms is essential for evaluating the effectiveness of floating cover systems. Ammonia generation occurs primarily through microbial decomposition of organic nitrogen compounds and conversion of urea into ammonium. The balance between dissolved ammonium and gaseous ammonia is influenced by pH, temperature, and exposed surface area.

Panetta et al. (2005) demonstrated that manure management practices significantly affect ammonia volatilization from swine manure. Their research indicates that storage conditions and management strategies influence the rate at which ammonia escapes from manure systems. Therefore, reducing the exposed surface area represents an important pathway for controlling emissions.

Floating covers function by interrupting this volatilization pathway. When placed over slurry surfaces, covers create a physical resistance layer that reduces direct gas diffusion and limits interaction between manure and surrounding air. The effectiveness of this mechanism depends on cover integrity, permeability, and environmental durability.

Hydrogen sulfide formation occurs through anaerobic microbial degradation of sulfur-containing compounds. Under oxygen-limited conditions, sulfate-reducing microorganisms contribute to sulfide generation, resulting in H_2S production. Long et al. (2016)

investigated hydrogen sulfide emission control through aerobic sulfate reduction mechanisms, demonstrating the relationship between microbial processes and sulfide emission behavior.

Unlike ammonia, which is strongly influenced by nitrogen chemistry and pH conditions, hydrogen sulfide emission is closely associated with anaerobic decomposition environments. Floating covers may reduce H_2S release by limiting gas transfer; however, they may also influence internal slurry conditions by modifying oxygen exchange characteristics. Therefore, understanding cover-slurry interactions is essential for optimizing system performance.

2.4 Floating Cover Technologies as Emission Control Systems

Floating covers represent a physical emission barrier technology designed to reduce gaseous transfer from liquid manure surfaces. The fundamental principle involves creating a semi-impermeable layer that separates the slurry environment from atmospheric conditions.

From a technological perspective, floating cover systems can be analyzed through three primary functional components: surface coverage efficiency, gas diffusion resistance, and operational durability. Surface coverage determines the percentage of slurry exposed to the atmosphere. Incomplete coverage may create emission leakage points, reducing overall effectiveness.

Gas diffusion resistance represents the ability of the cover material to restrict movement of ammonia, hydrogen sulfide, and odor compounds. Materials with lower permeability generally provide stronger emission reduction potential. However, excessive impermeability may create challenges related to gas accumulation and pressure management.

Operational durability includes resistance to degradation caused by chemical exposure, microbial activity, mechanical disturbance, and environmental conditions. In practical applications, cover systems must maintain performance over extended storage periods while requiring minimal maintenance.

Compared with open storage systems, floating covers provide a direct intervention at the emission source. This characteristic makes them particularly valuable where other management strategies cannot completely control gaseous release. For example, even when dietary improvements reduce nitrogen excretion, residual emissions from stored slurry may continue. Floating covers provide an additional control layer by limiting atmospheric exchange.

2.5 Comparative Analysis of Existing Research and Knowledge Gaps

The reviewed literature demonstrates that emission control in swine production requires integrated approaches rather than dependence on a single technology. Nutritional strategies, chemical treatment, cooling systems, and biological management approaches each contribute to emission reduction but have specific limitations.

Aarnink and Verstegen (2007) emphasized the importance of comprehensive manure management strategies for reducing environmental impacts from pig production. Their findings establish the theoretical foundation that emission control should address the entire production chain rather than isolated processes. This principle supports the integration of floating covers with other management interventions.

Existing research has extensively examined emission generation mechanisms and alternative mitigation strategies; however, limited attention has been directed toward systematic performance analysis of floating covers under controlled laboratory conditions. Many studies focus on commercial-scale emission characteristics or general manure management practices rather than evaluating cover-specific performance indicators.

The National Air Emission Inventory and Research Center (NAIR, 2021) and agricultural emission databases such as OECD emission assessments demonstrate the importance of accurate emission estimation and mitigation planning. However, reliable estimation requires understanding how individual technologies influence emission pathways.

A significant research gap exists regarding the relationship between floating cover characteristics and emission reduction efficiency. Variables such as cover material composition, thickness, sealing capability, slurry composition, and environmental conditions require further investigation.

Additionally, while odor emissions from intensive pig production have been studied using advanced measurement techniques (Feilberg et al., 2010), fewer studies have examined how physical barriers influence the combined reduction of ammonia, hydrogen sulfide, and odor-related compounds. Addressing this gap is essential because practical emission control systems must consider multiple pollutants simultaneously.

3. METHODOLOGY

3.1 Research Design and Analytical Framework

This study adopts a performance analysis framework for evaluating floating cover technologies used in lab-scale swine slurry pits. The methodology integrates emission mechanism analysis, technology assessment, and comparative evaluation of mitigation effectiveness.

The analytical framework is structured around four major evaluation dimensions:

1. Emission Reduction Capability

This dimension evaluates the ability of floating covers to reduce ammonia and hydrogen sulfide release compared with uncovered slurry systems. The assessment considers the reduction of direct atmospheric exchange and changes in emission pathways.

2. Physical and Functional Performance

This dimension examines cover characteristics including surface coverage, permeability, structural stability, and interaction with slurry conditions.

3. Operational Sustainability

This evaluates practical factors such as maintenance requirements, durability, implementation feasibility, and compatibility with existing manure management systems.

4. Environmental Integration Potential

This considers how floating covers can complement other mitigation technologies, including nutritional management, biological treatment, and chemical modification strategies.

The framework is based on the concept that effective emission mitigation requires both reduction of pollutant generation and control of pollutant transfer.

3.2 Laboratory-Scale Swine Slurry Pit Model

The laboratory-scale slurry pit model represents a controlled environment for evaluating emission behavior under standardized conditions. The system consists of slurry storage containers representing manure pits, emission monitoring mechanisms, and floating cover treatments.

The experimental concept involves comparing covered and uncovered slurry systems to determine differences in emission release patterns. The uncovered system functions as a reference condition, representing conventional exposed slurry storage.

The floating cover treatment represents the intervention system where a physical barrier is introduced between slurry and atmosphere. Performance evaluation focuses on changes in ammonia and hydrogen sulfide concentrations, emission rates, and temporal emission patterns.

Laboratory-scale analysis provides advantages including controlled environmental variables, repeatability, and detailed assessment of technological mechanisms. However, scaling results to commercial facilities requires consideration of differences in storage volume, airflow conditions, and operational practices.

3.3 Emission Measurement and Performance Evaluation Approach

The performance evaluation of floating cover technologies requires systematic measurement of gaseous emissions and interpretation of changes in emission behavior. The analytical approach focuses on comparing emission intensity between covered and uncovered slurry conditions.

Ammonia emission assessment is based on the principle that gaseous ammonia release occurs through mass transfer between the slurry surface and surrounding air. The introduction of a floating cover modifies this transfer process by increasing resistance to diffusion. Therefore, the effectiveness of the cover can be evaluated by measuring the reduction in ammonia concentration and emission flux after cover application.

Hydrogen sulfide assessment follows a similar principle but requires consideration of the biological processes responsible for sulfide generation. Since H_2S formation is closely associated with anaerobic microbial activity, the evaluation considers both emission reduction and possible changes in internal slurry conditions caused by cover installation.

The performance indicators used in this framework include:

- Relative reduction in ammonia emissions.
- Relative reduction in hydrogen sulfide emissions.
- Stability of emission reduction over time.
- Cover integrity and surface protection efficiency.
- Compatibility with existing manure management practices.

The evaluation approach recognizes that emission reduction is not solely determined by the physical presence of a cover. Instead, performance results from the interaction between material properties, slurry characteristics, environmental conditions, and operational factors.

3.4 Floating Cover Functional Model

A conceptual functional model was developed to explain the emission control mechanism of floating covers. The model consists of three interconnected stages: emission generation, barrier interaction, and atmospheric release.

The first stage involves pollutant formation within the slurry environment. Organic nitrogen compounds undergo microbial transformation, resulting in ammonia formation, while sulfur-containing compounds undergo anaerobic decomposition, generating hydrogen sulfide. These processes are influenced by manure composition, microbial activity, temperature, and chemical conditions.

The second stage involves interaction between generated gases and the floating cover layer. The cover acts as a physical resistance barrier that reduces direct movement of gases from the slurry surface. The effectiveness of this stage depends on material permeability, coverage percentage, and sealing characteristics.

The third stage involves atmospheric release. A highly effective floating cover reduces the quantity of pollutants reaching the atmosphere by limiting diffusion pathways. However, incomplete coverage, material degradation, or operational disturbance may create emission leakage points.

This model provides a theoretical foundation for understanding why floating covers can achieve emission reduction while also highlighting the factors responsible for performance variation.

3.5 Comparative Assessment Framework

To evaluate floating cover technology within the broader context of manure management, the study compares its characteristics with alternative emission control methods reported in previous research.

Nutritional approaches primarily reduce emission potential before manure enters storage. Aarnink and Verstegen (2007) emphasized that efficient nutrient utilization is essential for reducing the environmental impact of pig production. However, nutritional strategies cannot completely eliminate emissions from existing slurry storage.

Chemical methods modify manure chemistry and can reduce ammonia volatilization. Jensen (2002) demonstrated that sulfuric acid treatment can influence emission conditions within swine facilities. Nevertheless, chemical systems require careful management due to operational complexity.

Cooling approaches reduce volatilization by decreasing temperature-driven emission processes. Andersson (1998) showed that manure cooling can reduce ammonia release. However, energy requirements may limit widespread implementation.

Biological treatment systems influence microbial processes and manure characteristics. Kim et al. (2023) demonstrated that bio-liquor circulation systems can contribute to odor mitigation and improved manure management. However, biological systems require appropriate operational control.

Compared with these approaches, floating covers provide a direct physical control mechanism. Their main advantage is the ability to reduce emissions after slurry formation without requiring major modifications to animal feeding systems or manure chemistry.

4. RESULTS

The performance analysis indicates that floating cover technologies provide significant potential for controlling gaseous emissions from lab-scale swine slurry pits by modifying the primary emission pathway between stored manure and the atmosphere. The analysis demonstrates that the effectiveness of floating covers is strongly associated with their ability to reduce surface exposure and restrict gas transfer.

The first major finding is that floating covers function as an effective emission barrier by limiting direct contact between slurry and ambient air. Since ammonia volatilization is influenced by exposed surface area and environmental conditions, reducing atmospheric interaction contributes to lower emission intensity. This finding aligns with previous research demonstrating that manure storage management practices strongly influence ammonia losses (Panetta et al., 2005).

The second finding concerns hydrogen sulfide control. Floating covers reduce the release of H_2S by restricting diffusion from anaerobic slurry environments. Although covers do not directly eliminate sulfide formation processes, they reduce atmospheric transmission. This distinction is important because emission control technologies may operate either by reducing pollutant production or by preventing pollutant release.

The analysis further indicates that floating cover effectiveness depends on technological design factors. High-coverage systems with improved barrier properties are expected to provide more consistent emission reduction compared with systems containing gaps or poor sealing characteristics. Therefore, cover installation quality represents an important determinant of practical performance.

Another important finding is that floating covers provide complementary benefits when combined with other mitigation strategies. Nutritional management, biological treatment, and chemical modification approaches address different stages of emission generation. The integration of these strategies with floating covers may create a multi-layer emission control system. This supports the principle identified by Aarnink and Verstegen (2007), who emphasized that reducing environmental impacts from pig production requires coordinated management across production stages.

The analysis also identifies several operational considerations. While floating covers reduce emission transfer, they may influence slurry conditions by modifying gas exchange and temperature relationships. Therefore, long-term implementation requires monitoring of slurry quality, structural stability, and maintenance requirements.

Overall, the findings suggest that floating cover technologies represent a practical and effective approach for reducing air emissions from swine slurry storage systems. Their strongest advantage is their direct intervention at the emission interface, providing control over pollutants that remain after other management practices have been applied.

5. DISCUSSION

The findings demonstrate that floating cover technologies provide an important technological pathway for improving environmental performance in swine manure management. Unlike approaches that primarily target emission formation, floating covers address the final stage of pollutant release by controlling the physical exchange between slurry and atmosphere.

The theoretical significance of this approach lies in its alignment with emission pathway management principles. Aarnink and Verstegen (2007) identified manure management as a critical component of reducing the environmental burden of pig production. The present analysis extends this concept by emphasizing that controlling the emission interface represents an essential component of comprehensive manure management.

The results also correspond with previous findings regarding ammonia volatilization control. Panetta et al. (2005) demonstrated that management practices significantly influence ammonia losses from swine manure. Floating covers contribute to this management framework by reducing the conditions necessary for volatilization, particularly atmospheric exposure.

However, the technology also presents several limitations. Floating covers reduce pollutant transfer but do not necessarily reduce pollutant generation within slurry. If microbial processes continue producing ammonia or hydrogen sulfide, accumulated gases may require controlled management. Therefore, floating covers should be considered a mitigation component rather than a complete replacement for upstream strategies.

A further consideration is the relationship between emission reduction and system sustainability. While floating covers require fewer continuous inputs compared with chemical or cooling technologies, their effectiveness depends on material durability and maintenance practices. Long-term performance may be influenced by degradation caused by chemical exposure, mechanical stress, and environmental conditions.

The comparison with alternative technologies reveals that no single mitigation approach provides complete emission control. Nutritional strategies reduce pollutant formation, biological systems modify manure characteristics, and physical barriers control release pathways. Therefore, integrated approaches are likely to provide the highest environmental benefits.

The implications of this research extend beyond laboratory-scale systems. Agricultural emission assessments conducted by organizations such as OECD (2021) highlight the need for practical mitigation technologies capable of reducing livestock-related pollutants. Floating covers may contribute to emission reduction targets by providing a scalable intervention for manure storage facilities.

Future research should investigate optimization of cover materials, long-term field performance, interaction with different slurry compositions, and integration with real-time monitoring systems. Such developments could improve the reliability and commercial adoption of floating cover technologies.

6. CONCLUSION

Floating cover technologies represent a promising strategy for controlling ammonia and hydrogen sulfide emissions from swine slurry storage systems. This study developed a performance analysis framework emphasizing emission mechanisms, barrier functionality, and operational considerations.

The findings demonstrate that floating covers reduce emissions primarily by limiting atmospheric exchange rather than eliminating pollutant formation. Their effectiveness depends on coverage efficiency, material characteristics, durability, and interaction with slurry conditions.

Compared with alternative mitigation strategies, floating covers provide a direct and practical intervention at the emission source. They can complement nutritional, chemical, cooling, and biological approaches to create integrated manure management systems.

The research contributes to sustainable livestock production by highlighting the importance of controlling emission pathways within slurry storage environments. Future studies should focus on improving cover materials, evaluating long-term performance, and developing integrated monitoring systems for large-scale application.

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