Research Progress on Ammonia Emission Characteristics and Mitigation Technologies in Livestock and Poultry Housing: Postprint

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Abstract

Livestock and poultry housing represents an important source of ammonia (NH3) emissions. Understanding the emission characteristics of NH3 from livestock and poultry housing and its mitigation measures is of great significance for both healthy livestock and poultry production and environmental health. This paper reviews the NH3 emission characteristics in three major types of livestock and poultry housing (swine, chicken, and cattle) from domestic and international studies, discusses the key influencing factors affecting NH3 emissions in different housing types, compares the NH3 emission factors among the three housing types, summarizes the currently widely adopted NH3 mitigation technologies in various livestock and poultry housing, including feed optimization at the source, use of manure additives after excretion, indoor air purification treatment, and exhaust air filtration devices, and constructs a comprehensive NH3 mitigation measure system for livestock and poultry housing, which provides an important reference for understanding NH3 emission characteristics and selecting mitigation measures.

Full Text

Research Progress on Ammonia Emission Characteristics and Mitigation Technologies from Livestock Houses

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Abstract: Livestock houses represent a significant source of ammonia (NH_3) emissions. Understanding the emission characteristics and mitigation measures of NH_3 from livestock houses is crucial for both animal health and environmental protection. This paper reviews NH_3 emission characteristics from three major types of livestock houses—pig, poultry, and cattle houses—both domestically and internationally. Key influencing factors affecting NH_3 emissions in different livestock houses are discussed, emission factors for the three house types are compared, and various widely adopted NH_3 mitigation technologies are summarized. These technologies encompass feed optimization at the source, manure additives after excretion, in-house air purification treatments, and exhaust air filtration devices, forming a comprehensive mitigation system for NH_3 emissions from livestock houses. This review provides an important reference for understanding NH_3 emission characteristics and selecting appropriate mitigation measures.

Keywords: livestock house; ammonia; emission characteristic; mitigation technology

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Livestock farming constitutes a major source of ammonia (NH_3) emissions. Myles [?] estimated that agriculture accounts for over 60% of global NH_3 emissions, with livestock production being the most significant contributor at 39% of the global total [?]. In the United States and Europe, where livestock manure is widely used as crop fertilizer, NH_3 emissions from livestock can reach 80% of total emissions in these regions [?, ?]. As a major livestock producer, China’ s animal agriculture contributes 60% of the nation’ s NH_3 emissions and 13.6% of global anthropogenic NH_3 emissions [?]. With further socioeconomic development and increasing per capita demand for meat, eggs, and dairy products, NH_3 emissions from China’ s livestock industry are projected to rise.

NH_3 emissions from livestock farms significantly impact animal health. Recognized as a major stressor, NH_3 is the most harmful gas in animal housing, inducing various respiratory diseases in poultry and pigs [?], causing conditions such as ascites and eye diseases in birds [?], reducing growth and production performance [?], and even increasing mortality rates [?]. To ensure environmental quality and healthy livestock growth, national authorities have established specific requirements for NH_3 concentrations in various livestock houses. For instance, the NY/T 388-1999 “Environmental Quality Standard for Livestock and Poultry Farms” mandates that NH_3 concentrations must be maintained below 25 mg/m^3, 20 mg/m^3, and 10–15 mg/m^3 for pig, cattle, and poultry houses, respectively [?].

Beyond affecting animal health, NH_3 emissions from livestock production have become a significant source of atmospheric pollution. Large-scale NH_3 emissions cause eutrophication of water bodies and ecosystem acidification [?]. Furthermore, research has demonstrated that NH_3 is an important precursor to atmospheric aerosols, forming ammonium nitrate and ammonium sulfate through atmospheric chemical reactions that constitute major components of fine particulate matter ($PM_{2.5}$) and significantly contribute to haze formation [?, ?]. Under increasingly stringent environmental regulations in China, NH_3 emission control from livestock production has become a critical constraint on the industry’ s development.

As the primary source of NH_3 emissions from livestock farming, studying emission characteristics and mitigation measures from livestock houses is essential for both animal production and environmental health. This paper focuses on China’s three main livestock species—pigs, chickens, and cattle—to review domestic and international research on NH_3 emissions and mitigation from livestock houses, providing a reference for future intensive farming operations in China regarding emission monitoring and mitigation strategy design.

1.1 Pig House NH_3 Emissions

Bedding-type pig houses exhibit lower NH_3 emissions compared to traditional concrete-floor or deep-pit systems (Table). Zhu et al. [?] reported that average NH_3 concentrations in bedding-type houses during spring and summer ranged from 5.9-6.8 mg/m^3, while conventional concrete-floor houses showed 14.5-16.7 mg/m^3, with bedding-type houses having only 40% of the NH_3 concentration of concrete-floor houses. Kim et al. [?] also found that NH_3 emission concentrations and rates from deep-pit and solid-liquid separation systems were 2–3 times higher than those from bedding houses (Table). NH_3 primarily volatilizes from pig urine and feces exposed to air. Bedding material can absorb and mix with excreta, reducing volatilization potential, while creating favorable aerobic-anaerobic conditions that promote nitrification and denitrification bacteria to convert NH_3 to nitrous oxide (N_2O) and nitrogen gas (N_2). In contrast, liquid management systems like concrete floors or deep pits provide larger surface areas for fecal-air contact, resulting in higher NH_3 emissions [?, ?]. However, some studies suggest bedding systems may have higher NH_3 emissions than deep-pit systems [?], possibly due to elevated temperatures and pH from internal fermentation of accumulated bedding.

For naturally ventilated pig houses, seasonal variations significantly affect indoor NH_3 concentrations. Generally, winter houses exhibit markedly higher NH_3 concentrations than summer due to lower ventilation rates, though emission fluxes are at their annual minimum. Zhu et al. [?] studied fattening pig houses, finding average NH_3 concentrations of (3.44\$±2.34)*mg/m*^{3}\$ in July 2004 (summer) and (10.09\$±4.60)*mg/m*^{3}\$ in January 2005 (winter), with corresponding emission fluxes of 1,564 and 444 mg/(AU • h), respectively (1 AU = 1 animal unit = 500 kg animal mass). Higher summer ventilation rates result in lower indoor NH_3 concentrations but higher emission fluxes, while winter window closure for insulation reduces ventilation, causing high indoor NH_3 concentrations but minimal emission fluxes.

1.2 Poultry House NH_3 Emissions

Manure cleaning frequency significantly impacts NH_3 emissions in poultry houses. Mendes et al. [?] noted that NH_3 emission rates increase exponentially with manure accumulation time, likely because large amounts of organic nitrogen in chicken manure slowly decompose during storage, forming NH_3 emissions [?]. High-rise, bedding, and belt-cleaning systems are widely used in poultry production. High-rise systems may store manure for six months to a year before removal, while bedding systems continuously mix manure with bedding material. Consequently, high-rise and bedding systems generally have relatively high indoor NH_3 concentrations (Table) [?, ?]. In contrast, belt-cleaning systems can remove manure from houses at high frequency (e.g., daily), maintaining better environmental conditions [?, ?] and resulting in significantly lower NH_3 concentrations than other cleaning systems (Table). Liang et al. [?] found that NH_3 concentrations in high-rise layer houses reached 6.8-82.0 mg/m^3, while belt-cleaning system houses showed only 0.8-5.3 mg/m^3.

Bedding usage duration substantially affects NH_3 emissions. Koerkamp et al. [?] reported NH_3 emission factors of 0.21-0.48 g/(bird · d) for broilers in bedding houses, whereas Casey et al. [?] found factors of 1.21-1.66 g/(bird · d). Casey et al. [?] explained that in the United States, bedding is typically used for at least one year, and the gradual conversion of organic nitrogen to ammoniacal nitrogen in accumulated manure increases NH_3 emissions. Burns et al. [?] directly compared new versus old bedding in broiler houses, finding emissions of (0.49$±0.37)g/(bird · d)[(12.36±9.36)g/(house · d)]withnewbeddingversus(0.58±0.35)g/(bird · d)[(14.55±$8.99) g/(house · d)] with old bedding.

Ventilation system quality profoundly affects NH_3 emissions. Simple naturally ventilated houses, common in small-scale operations, cannot control ventilation effectively, resulting in severely excessive NH_3 concentrations that may exceed 100 mg/m^3 in winter [?]. Mechanical ventilation, however, can better regulate house environments, maintaining NH_3 concentrations within low ranges. Mechanical ventilation houses show broiler mortality rates half those of naturally ventilated houses (4.5% vs. 10.5%), better feed conversion ratios (1.98 vs. 2.66), heavier body weights, and lower incidence of conjunctivitis [?].

Additionally, factors including bird age and seasonal changes affect indoor NH_3 concentrations and emissions. For broilers with growth cycles, age effects are particularly significant. Pescatore et al. [?] divided the broiler growth cycle into four stages, with NH_3 emission factors gradually increasing from 0-0.57 g/(bird · d) at <10 days to 0.71-2.34 g/(bird · d) at >48 days. Regarding seasonal impacts, indoor NH_3 concentrations are significantly higher in winter than summer under low ventilation conditions [?], though total NH_3 emission flux is also influenced by ventilation rates, with higher fluxes in summer due to greater ventilation [?].

1.3 Cattle House NH_3 Emissions

Compared to other livestock houses, cattle houses generally maintain lower temperatures throughout the growth period and are typically equipped with scraping systems to maintain good indoor environments, resulting in relatively low NH_3 emissions. Studies on dairy cattle houses report NH_3 concentrations of 0.03–6.50 mg/m^3 and emission rates of 5.8–134.4 g/(head · d) [1.96–37.0 kg/(AU · a)] (Table).

Cattle houses primarily use natural ventilation, where indoor environments are significantly affected by seasonal changes, with temperature variations notably influencing NH_3 emissions. In naturally ventilated dairy houses, both NH_3 concentrations and emissions are lowest in winter (Table) [?, ?]. For dairy or beef cattle production in cold regions, winter insulation needs may promote construction of enclosed houses. Wang et al. [?] studied NH_3 concentrations in window-enclosed dairy houses in China's cold Bashang region, finding maximum concentrations of 5.28 mg/m^3 in calf houses and below 9 mg/m^3 in dairy houses. Zhang et al. [?] investigated mechanical negative-pressure roof ventilation in beef cattle houses during winter, measuring NH_3 concentrations of 1-4 mg/m^3.

Unlike pig and poultry production, cattle farming generally includes exercise yards in addition to housing. Therefore, besides emissions from cattle houses, exercise yards represent an important emission source. Pereira et al. [?] studied NH_3 emissions from dairy houses and exercise yards, finding that yards typically contribute 69%–92% of total emissions. NH_3-N loss during the yard phase accounts for 5.3%–9.2% of dietary nitrogen intake and 7.1%–12.0% of excreted nitrogen. Yard emissions are more environmentally influenced, with highest emissions in spring and summer that can account for 72% of annual emissions. McGinn et al. [?] used dispersion methods to study whole-farm NH_3 emissions (including houses, yards, lagoons, roads, feed areas) from a dairy operation, finding approximately 140 g/(head · d), with nitrogen lost as NH_3 representing a portion of dietary nitrogen intake.

2 Comparison of NH_3 Emissions from Livestock Houses

Literature data on NH_3 emissions from pig, dairy, beef, layer, and broiler houses were statistically analyzed using R 3.3.1 software to generate box plots (Figure [Figure 1: see original paper] and Figure [Figure 2: see original paper]). Among various livestock houses, broiler houses show the highest NH_3 concentrations while cattle houses show the lowest. Layer house emissions are heavily influenced by manure management methods—high-rise systems exhibit the highest NH_3 concentrations and fluxes among all livestock houses, while daily manure removal systems maintain low concentrations and fluxes. Beyond management differences, inherent characteristics of different livestock excreta also affect NH_3 emissions. Li [?] used climate-controlled storage to compare NH_3 emissions from different livestock manures (pig, dairy, beef, layer, broiler) over 77 days, finding that chicken manure NH_3 emissions were 1.9–2.4 times those of pig manure and

6.6-17.4 times those of cattle manure. Higher total ammoniacal nitrogen (TAN) content in chicken manure may be the primary factor causing high NH_3 emissions—layer manure has initial TAN content of 12.3 g/kg wet manure, compared to 1.2-1.9 g/kg for cattle manure and 4.6 g/kg for pig manure. Zhou et al. [?] showed that nitrogen emitted as NH_3 from broiler houses during the entire production period exceeds 50% of total nitrogen excreted in manure. Koerkamp et al. [?] monitored gas emissions from livestock houses (cattle, pig, poultry) across four European countries, finding NH_3 concentrations of <6.1 mg/m^3, 3.8-13.7 mg/m^3, and 3.8-22.8 mg/m^3, and NH_3 fluxes of 2.76-15.75 kg/(AU · a), 5.69-32.86 kg/(AU · a), and 5.27-95.41 kg/(AU · a) for cattle, pig, and poultry houses, respectively, clearly demonstrating the substantial NH_3 emission potential of poultry houses.

3.1 Optimizing Diet Composition

Low-protein diets reduce NH_3 emissions. Nitrogen intake from feed is the source of livestock NH_3 emissions, and reducing dietary protein content within reasonable ranges effectively controls NH_3 emissions. Burgos et al. [?] reported that as dairy feed crude protein (CP) decreased from 21% to 15%, TAN content in excreted manure dropped from 508.7 mg/L to 228.2 mg/L, and NH_3 emissions decreased from 149 g/(head · d) to 57 g/(head · d), with nitrogen lost via NH_3 declining from 20% to 12% of initial nitrogen intake. Studies on pigs found that low-protein diets could reduce house NH_3 emissions by 58% [?]. However, reducing dietary CP below 10% affects growth in young bulls [?].

Feed additives also reduce NH_3 emissions. Using feed additives to optimize diet composition improves nitrogen absorption by livestock, reduces nitrogen excretion, and achieves NH_3 mitigation. Effective additives include yucca extract, dried distillers grains with solubles (DDGS), wheat bran, soybean hulls, and enzyme probiotics. Adding yucca extract to pig diets reduced NH_3 concentration at mechanical ventilation outlets from 1.10 mg/m^3 to 0.89-0.99 mg/m^3 [?]. Adding DDGS, wheat bran, and soybean hulls to layer diets reduced cumulative 7-day NH_3 emissions from 3.9 g/kg dry manure in the control group to 1.9, 2.1, and 2.3 g/kg dry manure, respectively [?]. Supplementing layer diets with 5 g/kg enzyme probiotics reduced NH_3 emissions by 21% while significantly improving feed conversion ratio and increasing laying rate and average egg weight [?].

3.2 Using Manure Additives

Various manure additives are used for NH_3 mitigation in livestock houses, primarily functioning by reducing manure pH or adsorbing NH_3. Common additives include sulfates, dilute sulfuric acid, and zeolites. Adding sodium bisulfate to litter in chicken houses reduces NH_3 emissions by approximately 50% without significantly affecting feed conversion ratio or body weight, while improving footpad quality [?]. Sulfate addition reduces litter pH and ammoniacal nitrogen content while increasing total and organic nitrogen content [?]. Neerackal et al. [?] simulated dairy manure acidification in the laboratory, maintaining recycled barn flush water pH at 4.5 using 1 mol/L dilute sulfuric acid, finding that acidification reduced NH_3 emissions by 70%. Maintaining closed-loop flush water reuse twice reduced sulfuric acid usage by 82%, demonstrating good economic practicality. Clinoptilolite, a non-corrosive, harmless litter additive, reduced broiler house NH_3 concentrations by 60% when applied for NH_3 control [?].

3.3 In-House Spraying

In practice, NH_3 mitigation via spraying is often considered in combination with particulate matter (PM) reduction. Spraying methods include acid mist or acidic electrolyzed water. Jensen [?] used acid mist to mitigate NH_3 and PM in pig houses. Maintaining acid mist pH at 5.5 and ensuring pig manure pH in collection pits remained below 5.5 reduced indoor NH_3 concentrations from 6.1-7.6 mg/m^3 to 0.8-1.5 mg/m^3, inhalable PM from 1.00 mg/m^3 to 0.28 mg/m^3, and total PM from 2.7 mg/m^3 to 1.2 mg/m^3, while improving pig growth performance and increasing manure nitrogen content beneficial for fertilizer use. Slightly acidic electrolyzed water effectively reduces indoor PM emissions (71%-89% reduction efficiency), but controlling electrolyzed water to acidic conditions (pH 3 or 5) does not guarantee NH_3 emission reduction. Research suggests that excessive spraying increasing litter moisture content 2-3 times above non-sprayed levels significantly increases NH_3 emissions [?]. Beyond effects on NH_3 and PM, slightly acidic electrolyzed water effectively controls pathogenic microorganisms through oxidation, though this technology remains limited to small-scale testing with large-scale application issues yet to be resolved.

3.4 Dedicated Air Capture Systems

In dedicated air capture systems, NH_3 absorbents are not directly applied to manure but placed in specific facilities where gases are captured for treatment. Since NH_3 in bedding houses primarily originates from manure decomposition on litter, Lahav et al. [?] noted that NH_3 concentrations near litter (within 10 cm) are double those in house air, suggesting that direct capture and treatment of litter-generated NH_3 would be highly effective. Rothrock et al. [?] improved acid application methods by placing acid in gas-permeable membrane tubes to absorb NH_3 from chicken manure. These tubes can be placed on or within litter, with NH_3 permeating tube walls and being absorbed by acid to form ammonium salts. Laboratory results demonstrated that 96% of NH_3 emissions from chicken manure could be absorbed by acid tubes, showing excellent environmental health benefits. Lahav et al. [?] placed acid outside houses, using separate air tubes near litter to pump NH_3 to external acid absorption systems (pH 0-5) for treatment, replacing saturated acid solution when needed. This system achieved 100% NH_3 mitigation efficiency. External NH_3 absorption methods showed promising results in 5-week broiler house trials, though large-scale application effectiveness requires further validation.

3.5 Mitigation of NH_3 in Exhaust Air

Besides direct in-house mitigation, treating exhaust air effectively reduces environmental NH_3 emissions from livestock houses, though not directly decreasing indoor concentrations. Common treatments include air scrubbing, biotrickling filtration, and biofiltration, all typically applied to mechanically ventilated houses by integrating ventilation systems with treatment units, though potentially affecting ventilation effectiveness.

3.5.1 Air Scrubbers Air scrubbers typically feature tower structures filled with porous, high-surface-area inert or inorganic materials. Water or acid solution sprays from the top while polluted gas enters horizontally or upward, ensuring sufficient liquid-gas contact for gas molecules to transfer from gas phase to liquid phase on filter surfaces. Some scrubbing liquid is continuously recirculated while portions are discharged and replaced with fresh liquid to maintain treatment effectiveness. Scrubbing efficiency depends on pollutant concentration differences between gas and liquid phases, contact surface area, and contact time [?]. In acid scrubbers, adding sulfuric acid maintains pH below 4, achieving NH_3 mitigation efficiencies of 90%-99% under optimal conditions. Water addition maintains ammonium sulfate concentration around 150 g/L in absorption liquid, with water consumption of approximately 70 L per pig place annually and 2 L per broiler place annually [?]. At high inlet NH_3 concentrations (75.9 mg/m^3), single-stage scrubbing systems show low removal efficiency (35%), which can be improved to 57%-64% by upgrading to two- or three-stage tower systems [?]. Hadlocon et al. [?] further optimized nozzle structures in the three-stage scrubbing system, significantly improving NH_3 mitigation efficiency to 74%-86% under laboratory conditions with inlet NH_3 concentrations of 75.9-303.6 mg/m^3. Additionally, Hadlocon et al. [?] conducted one-year field monitoring of a three-stage acid scrubber at a deep-pit swine facility with 799-1,000 head capacity, achieving an annual average NH_3 mitigation efficiency of 88% with low seasonal consumption of water (2.5 L/d) and acid (0.17 L/d) and daily electricity consumption of 0.56 kW • h.

3.5.2 Biotrickling Filters Unlike acid scrubbing, biotrickling filters convert dissolved NH_3 to other nitrogen compounds through bacterial action. These systems consist of inert packing materials such as ceramics or plastics kept continuously moist, with microorganisms forming a biofilm on packing surfaces. NH_3 is first absorbed into water, then oxidized by nitrifying bacteria [primarily *Nitrosomonas* and *Nitrobacter*] to nitrite (NO_2^-) and ultimately nitrate (NO_3^-) [?]. Long-term monitoring shows biotrickling filters achieve NH_3 removal efficiencies of 35%-90%, averaging 70%. Compared to acid scrubbing, biotrickling filters consume more water—790 L per pig place annually and 25 L per broiler place annually [?]. Melse and Mosquera [?] monitored biotrickling filters in broiler and fattening pig houses for one year, finding NH_3 mitigation efficiencies of 71%-86%. Andreasen et al. [?] evaluated a field-scale pig house biotrickling filter using leca (lightweight expanded clay aggregate) as media with empty bed residence time (EBRT) of 1.7–8.9 s, reducing exhaust NH_3 by 96%. Some clogging was observed after 100 days of operation, though installation of dust filters could mitigate this issue.

3.5.3 Biofilters Biofilters provide an economical and effective method for treating livestock house exhaust gases [?]. Polluted gases pass through moist media (e.g., compost), where water-soluble gases dissolve and are subsequently decomposed by microorganisms into harmless or less harmful components. Hood et al. [?] studied pig house biofilters using compost and wood chips as media, achieving 90% NH_3 mitigation efficiency at inlet concentrations below 1.1 mg/m^3. Tymczyna et al. [?] investigated biofilters for layer house exhaust using a medium of 35% peat, 35% sedge peat, 10% barley straw, 10% sewage sludge, and 10% horse manure compost, maintaining stable operation after 35 days with NH_3 removal efficiencies of 36%-89%. Akdeniz and Janni [?] studied biofilters in dairy and pig houses under field conditions, finding NH_3 mitigation effects similar to pilot-scale results (53%-64%). The study noted that pressure drop performance should be tested if filter media exceeds three years of use, and regular water addition is needed to improve efficiency, though excessive water can cause N_2O emissions [?].

In summary, livestock houses are important NH_3 emission sources, with emissions affected by livestock species differences, manure management methods, ventilation types, animal age, and seasonal variations. Among the three livestock types, chicken houses exhibit extremely high NH_3 concentrations due to higher TAN content in chicken manure compared to pig and cattle manure, followed by pig houses, while cattle houses show the lowest concentrations. NH_3 control efforts should focus on chicken and pig house environmental management. Primary mitigation measures include dietary regulation through low-protein diets or feed additives, manure additives, air spraying, and integration of air scrubbers, biofiltration, and biotrickling filtration with mechanical ventilation systems to effectively reduce NH_3 concentrations in exhaust air. While numerous efficient NH_3 mitigation technologies have been explored in research, cost, operability, and convenience issues limit widespread application in production practice. Improving the applicability of these methods through scientific and technological research remains an urgent practical challenge.

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