

## CHAPTER VII

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### MITIGATION OF AMMONIA FROM LITTER BY ADDITIVES IN POULTRY HOUSES

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#### 1. Introduction

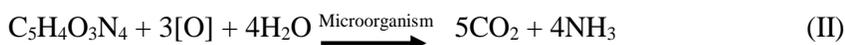
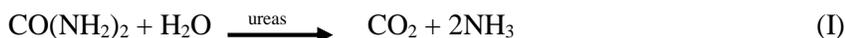
In animal feeding operations (AFO) occur various wastes and pollutants during production. Waste and pollution factors consist of continuous live activities, feeding, excretion, and animal respiration: manure and metabolic digestion of animal's major problem in concentrated animal feeding systems (CAFO). Feces and urine by combining with the litter are decay, feeding and animal activities cause the formation of pollutant gas and pathogens. Carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), ammonia (NH<sub>3</sub>), nitrous oxide (N<sub>2</sub>O), hydrogen sulfide (H<sub>2</sub>S), volatile particles, and microorganisms are the most common pollutants from animal operations. NH<sub>3</sub> gas is highly reactive, and its residence time in the atmosphere is shorter than other pollutants.

The agricultural sector is the primary source of ammonia emissions from anthropogenic activities. The agricultural sector constitutes approximately 94% of global anthropogenic NH<sub>3</sub> emissions, about 64% originates from the livestock sector (Steinfeld et al., 2006; Sanchis et al., 2019).

#### 2. Ammonia Formation in Poultry Houses

NH<sub>3</sub> emissions in poultry houses are generally higher than in other livestock farms. Ammonia consists of microbial decomposition of organic nitrogen (N) compound in manure from animal barns. Nutrients that are not absorbed by animals are excreted as N from the manure with feces and urine (as urea in mammals, as uric acid in poultry) (Oenema et al., 2001; Kilic and Simsek, 2009). Nitrogen taken with feed and nitrogen excreted as feces and uric acid are the primary sources of NH<sub>3</sub> in poultry houses. While the formation of ammonia in the feces occurs slowly, it is rapidly transformed into NH<sub>3</sub> in urine (urea and uric acid) by hydrolysis,

mineralization, and evaporation (Anonymous, 2005). Urea ( $\text{CO}(\text{NH}_2)_2$ ) is hydrolyzed by urease enzymes in anaerobic conditions, causing the formation of ammonia (Equation I-II). Undigested protein and uric acid ( $\text{C}_5\text{H}_4\text{O}_3\text{N}_4$ ) are crash by microorganisms and bacteria, and ammonia is formed in poultry manure (Atapattu et al., 2008) (Equation II-III). The primary source of  $\text{NH}_3$  formation is a degradation of uric acid is in poultry houses. Also, chickens' respiration and aerobic and anaerobic decomposition of litter material increase  $\text{CO}_2$  levels in the house (Ni et al., 2012).



$\text{NH}_3$  is present in aqueous solutions, in the form of ammonium ions ( $\text{NH}_4^+$ ) and non-ionized (liquid)  $\text{NH}_3$  (Equation IV). This situation can be different depending on the pH of the solution. The amount of these two forms of ammonia in an aqueous solution such as manure is called total ammonia nitrogen (TAN). In this transformation, pH and temperature have significant effects (Kilic, 2011). Whereas  $\text{NH}_3$  can be in the atmosphere for a few hours up to 1-5 days,  $\text{NH}_4$  can remain in the atmosphere as an aerosol for 1-15 days (Aneja et al., 2001).

$\text{NH}_3$  remains in the atmosphere for a few hours after spreading, and when combined with gases such as  $\text{NO}_x$  and  $\text{S}_2\text{O}$ , it can remain in the atmosphere for several days. Ammonia reacts with nitrous oxide and sulfur oxides to form ammonium sulfate ( $(\text{NH}_4)_2 \text{SO}_4$ ) and ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ) (Equation V-VI) (Anderson et al., 2003). It can also be transported to long distances by combining with other air pollutants and forming secondary particulate matter (PM<sub>2.5</sub>) (Anonymous, 2020). In addition to producing PM<sub>2.5</sub>, atmospheric  $\text{NH}_3$  can change the clouds' oxidation rates and increase acid rain production. It also contributes to the accumulation of N in the ecosystem. (Naseem & King, 2018).



Various parameters such as litter moisture content, temperature, and litter pH contribute to the formation of  $\text{NH}_3$  in poultry farms (Cabrera and Chiang, 1994; Tiquia and Tam, 2000; Liu et al., 2007; Atapattu et al., 2008; Miles et al., 2011a; Lin, 2014). At higher moisture levels of the litter, faster  $\text{NH}_3$  emission occurs. Business owners should ensure that the litter is dry. For this, it should provide regular ventilation and have sufficient absorbent material in the base. High temperatures increase both bacterial activity and  $\text{NH}_3$  production in the litter. When the litter's pH level reaches higher values, the  $\text{NH}_3$  levels become more variable as the environment turns into a virtual environment and generally increases. The non-ionized  $\text{NH}_3$  form in the fertilizer turns into a gas, and the amount of  $\text{NH}_3$  increases.

Ammonia formation varies according to litter material, aeration rate, manure management practices, animal age, feed ingredient, and seasonal conditions. The type of litter used in the poultry house depends on the type of poultry, the type of litter used, the environmental conditions, the feed composition, the transport of manure, situation (Rodic et al., 2011). Litter change improves poultry health and production, as it provides lower  $\text{NH}_3$  concentrations and lower bacterial density (Terzich et al., 1998). Besides, poultry litter is an essential source of fertilizer, as it contains many nutrients necessary for the growth of plants. Since ammonia consists of manure and litter in the poultry houses, it affects the animals by contacting them before mixing with the indoor air and decreasing the concentration (Atilgan et al., 2010). During the winter months, when ventilation is at minimum capacity, a significant amount of ammonia gas accumulates in the house. Ventilation speed is directly proportional to the emission and inversely proportional to the concentration in the house. In situations where ventilation is insufficient or not possible, the ammonia concentration increases. Having higher moisture content increases  $\text{NH}_3$  production. The  $\text{NH}_3$  emission varies according to the seasons and climates and reaches the highest levels in warmer seasons. The emission rates should be evaluated very well, as the ammonia emission values vary widely according to the countries, cultivation type, and seasons.

In commercial livestock farming,  $\text{NH}_3$  emission occurs due to mixing feces and urine with litter material.  $\text{NH}_3$  formation rates are closely related to microbial bacteria's activities and the density of bacterial populations and microbial activities can be predicted (Okano et al., 2004). The primary sources of  $\text{NH}_3$  include biological processes in animal protein consumption and subsequent degradation of animal waste (Rockfellow et al., 2012). The amount of nitrogen in animal feed ingredients is generally much higher than the animals should take. N, which they cannot take into their bodies, is generally thrown out in the form of  $\text{NH}_3$ . It has been reported that 10-30% of the N amount used for the growth, development, reproduction, and maintenance of animals is used, and the rest is discarded

(Stowel, 2018). Since chickens are in the growing stage in their young period, they spend their grown, and N excretion is decreased. However, in animals that have completed their growth, the feed conversion rate is lower, and the N excretion rate is higher than the growing period. Less ammonia becomes volatile than young chickens, and as the chicken ages, they produce more  $\text{NH}_3$  (Wu-Haan et al., 2007).

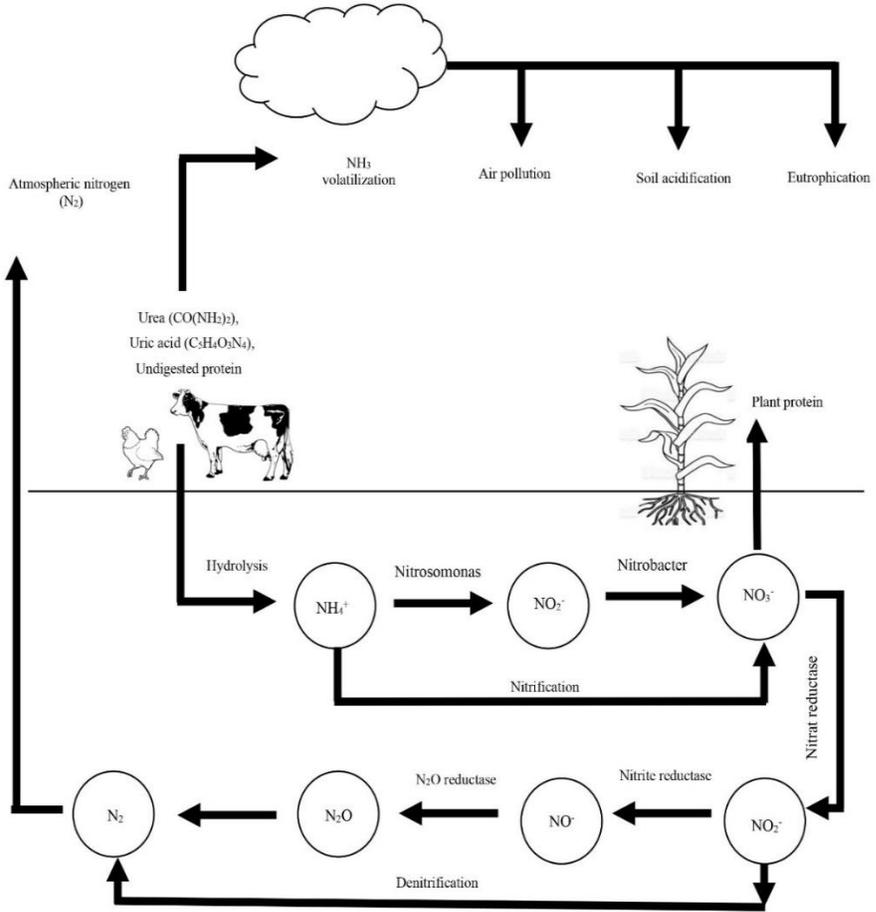
### **3. Effects of Ammonia on Environment and Health**

Animal feces contain a significant amount of undigested protein (organic nitrogen) and is mostly converted into ammonia by heterotrophic bacteria under aerobic and anaerobic conditions. While plants can use some of the ammonia produced by bacteria, the excess is converted into ammonium ( $\text{NH}_4$ ) due to hydrolysis. Ammonium is transformed into nitrite ( $\text{NO}_2^-$ ) by Nitrosomonas bacteria under aerobic conditions. With Nitrobacter, a group of nitrification bacteria found in the soil, nitrite is oxidized to nitrate ( $\text{NO}_3^-$ ). Nitrate is used as a fertilizer for plants. Since nitrate is in the form of N, which can be taken, both the plants' intake is more comfortable, increasing groundwater loss in the form of washing. Nitrification takes place by reducing ammonia to ammonium, nitrite, and finally nitrate by nitrification bacteria. Denitrification takes place in aerobic conditions with the transformation of nitrate and nitrite into elemental nitrogen by microorganisms. First, nitrate is reduced to nitrite, and then nitrate is reduced to ammonia for protein formation. With the fixation of free nitrogen in the atmosphere, lightning, rain, and nitrogen-binding bacteria and nitrogen salts are bound to the soil. In the denitrification process,  $\text{N}_2\text{O}$  is formed in the reduction of nitrate. This gas leaves the soil and water and spreads into the atmosphere.  $\text{N}_2\text{O}$  in the atmosphere is reduced to  $\text{N}_2$  and stimulated by oxygen by photolysis, and oxygen oxidizes  $\text{N}_2\text{O}$  to NO (Sawyer et al., 2003) (Figure 1).

Ammonium ( $\text{NH}_4^+$ ), nitrite ( $\text{NO}_2^-$ ), and nitrate ( $\text{NO}_3^-$ ) are water-soluble compounds and are of environmental importance for water resources. Other inorganic oxidation stages,  $\text{N}_2$ ,  $\text{N}_2\text{O}$  (nitrous oxide), NO (nitrous oxide), and  $\text{NO}_2$  (nitrogen dioxide), are in the gas form, and their solubility in water is limited. Excess nitrate in the soil that plants cannot hold is transported to underground waters by leaking from the soil. Nitrate lowers the pH of groundwater, and its N content causes eutrophication and acidification.

$\text{NH}_3$  causes various problems in the ecosystem, not only in the atmosphere but also on land and water.  $\text{NH}_3$  emissions directly or indirectly damage the ecosystem. Soil acidification on land poses a danger by causing eutrophication by decreasing plant species and habitat diversity, algal growth in water. Feed with high nutrient content used in poultry production causes nitrogen and phosphorus-sourced water and soil pollution from production (Sutton et al., 2008; Boggia et al., 2010; Tallentire et al., 2017;

Isik and Kirkpinar, 2020). The N amount in fertilizers applied to the soil is beneficial for soil fertility and products. However, nitrogenous fertilizers applied above the optimum value cause acidification of the soil. Besides, the use of excessive N fertilizers leaks from the soil and mixes with underground waters. It causes algae formation in the water and causes carbon dioxide to increase by consuming the water's oxygen amount. Accordingly, fish deaths occur.



**Figure 1.** N cycle

In laying hens, the high amount of total ammonia nitrogen generated due to anaerobic digestion of chicken manure has been identified as one of the main problems (Farrow et al., 2016; Molaey et al., 2018; Andrade et al., 2020). Since litter is grown in chicken meat breeding operations, the more  $NH_3$  gas is generated due to litter and manure breakdown by microorganisms. Ammonia is the most common and irritating odor gas in the house.  $NH_3$  emission causes potential impacts on the environment and potential impacts on livestock production performance, animal welfare,

and worker health. It is an irritant gas that causes significant health effects in living creatures due to prolonged exposure. The foul odor caused by  $\text{NH}_3$  and  $\text{H}_2\text{S}$  gases in poultry farms causes respiratory distress, causing a decrease in egg production, a decrease in feed utilization rate, and a decrease in the development rate of animals (Eleroglu and Yalcin, 2004). In humans, it can be absorbed quickly through the upper respiratory tract and penetrate the body. Prolonged inhalation irritates the upper respiratory tract, eyes, nose, and throat. Also, the fertilizer's value decreases by reducing the N content in the waste to be used as soil fertilizer because of the adverse effects of ammonia release on poultry production.

#### 4. Abatement of Ammonia from Litter by Additives

In order to reduce the amount of ammonia in the house, it is essential that the bedding is clean and dry, as well as adequate ventilation. Pathogens and microorganisms increase from wetting with fertilizer and urine and increasing moisture content depending on the litter material used. As a result of the microbiological breakdown of manure,  $\text{NH}_3$  volatility increases and causes various problems. Some chemicals can be added to the litter to eliminate gas formation, reduce the formation of other gases, and reduce bacterial growth's harmful effects. Reducing  $\text{NH}_3$  emissions from equine material can also reduce the ventilation capacity, thus providing significant energy savings in cold periods and cold regions and increasing the market and nutritional value by increasing the N content in the manure (Pereira et al., 2019a).

Ammonia is a colorless, pungent gas lighter than air. In addition, since it is a polar compound, it is highly soluble in water.  $\text{NH}_3$  is essential in its aqueous solutions (Equation VII). An acidic environment must be formed to protonate to non-volatile ammonium ( $\text{NH}_4^+$ ) (Equation VIII). The optimum pH levels for the evaporation of  $\text{NH}_3$  are in the 7-10 range. If the environment is at pH 6.5, the  $\text{NH}_3$  volatility will decrease (Spiels et al., 2019; Rhoades et al., 2010). The acidic environment is a desirable environment to reduce evaporation. By reducing the  $\text{NH}_3$  evaporation in the manure, the amount of emission in the environment is reduced, and a better quality fertilizer is obtained by increasing the N content of the fertilizer. The basic principle in acidification of the fertilizer can lower the fertilizer's pH so that less  $\text{NH}_3$  evaporation will occur in  $\text{NH}_3$  aqueous environments. Therefore, reducing the litter material's pH level is very important in reducing the emission of  $\text{NH}_3$ .



Three different strategies can be applied to reduce  $\text{NH}_3$  emissions from poultry production systems:

- I) reduction of N excretion with dietary changes,
- II) reduction of N excretion emitted by additives applied to litter,
- III) N from the polluted air with scrubber or biofilter/recovery (Van der Heyden et al., 2015; Sigurdarson et al., 2018).

Chemical litter changes are available as the best practice to reduce NH<sub>3</sub> emissions, foodborne pathogens, odor and increase litter fertilizer potential (Choi & Moore, 2008; Miles et al., 2011b; Hunolt et al., 2015). The additives used are generally acidic and prevent evaporation by converting ammonia to ammonium. Acidifying additives used in litter and manure wastes reduce the pH value, reducing NH<sub>3</sub> evaporation, and reducing emission rate. As a result, more N is retained as NH<sub>4</sub><sup>+</sup> by litter using acidifying additives. Thus evaporation is reduced, and litter fertilizer value increases. Acidifying agents also inhibit bacterial and enzyme activities that play a role in NH<sub>3</sub> formation, reducing NH<sub>3</sub> formation, and preserving the N content of the fertilizer (Li et al., 2013). Reducing ammonia in the poultry house improves indoor air quality, and acidifiers are used to provide economic benefits by reducing the amount of ventilation and heating costs.

Various studies have demonstrated the ability of chemicals and additives added to the litter to absorb gas emissions. Nakauae et al. (1981) applied and evaluated clinoptilolite first as an additive to litter and then as a feed additive in a study they conducted on a broiler farm. They applied it to the broiler litter at a rate of 5 kg / m<sup>2</sup> and reported that the NH<sub>3</sub> emission rate could be reduced up to 35%. They stated that clinoptilolite added to the feed at a rate of 10% reduced the NH<sub>3</sub> concentration in the air up to 8%.

Moore et al. (2000) examined the NH<sub>3</sub> volatility, litter quality, production, and phosphorus (P) flow by adding aluminum sulfate (Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·14H<sub>2</sub>O) to the litter in their study in broiler houses. 0.091 kg/chicken aluminum sulfate was added per animal. During the first 3 to 4 weeks, there was a regular reduction in NH<sub>3</sub> emissions. Also, broilers raised in the mixed litter with aluminum sulfate had a heavier weight (1.66 versus 1.73 kg). Phosphorus flow decreased by 73% in the soil treated with aluminum sulfate fertilizers in 3 years compared to the soil treated with normal litter. The results show that poultry litter's aluminum sulfate treatment is a very effective management practice that increases agricultural productivity while reducing non-point-based pollution.

Li et al. (2013) analyzed NH<sub>3</sub> emissions from litter using sodium bisulfate with litter samples taken from a commercial broiler farm. The NH<sub>3</sub> emission reduction rate increased in direct proportion to the sodium bisulfate application rate. Cumulative NH<sub>3</sub> emission was reduced by

51.7%, with an application rate of 244 g / 2 weeks.m<sup>2</sup> under field conditions over three herd periods. In addition to reducing NH<sub>3</sub> emission, the application of sodium bisulfate has significantly improved foot sole quality. The fertilizer value was increased by keeping the total N content in the litter. There was no significant change in body weight gain and feed efficiency.

Lin (2014) investigated different additives (sodium bisulfate [PLT], zeolite, and active charcoal) applied in broiler house litter at different litter moisture levels and application rates. It has been found that PLT application leads to a significant reduction in NH<sub>3</sub> emissions. However, repeated application of zeolite did not result in a significant reduction. Active charcoal, on the other hand, did not show any effect in reducing NH<sub>3</sub> emission. Besides, it has been stated that with increasing moisture in the litter, the NH<sub>3</sub> emission affects directly.

Hunolt et al. (2015) investigated the effects of sodium bisulfate (PLT) they added to broiler litter in the poultry house on NH<sub>3</sub> emissions. Three different applications were carried out, once, with repetitive and without PLT. In once and repeated PLT applications, litter moisture is higher, and litter pH is low. In the repeated application, the NH<sub>3</sub> emission rate was less than the other applications. Besides, since the N ratio in the litter is high, a higher quality fertilizer was obtained.

Nuernberg et al. (2016) wanted to evaluate a low-cost, simple, and fast method to reduce ammonia emissions in poultry litter. They used two different adsorbent zeolites (Cuban zeolite [CZ] and Brazilian basalt ground rock [BZ]) for this. Both zeolites contain SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> as main components. As a result of the study, both zeolites absorbed ammonia. However, CZ was more effective than BZ (5 g CZ and 20 g BZ) to absorb ammonia. Because CZ has a high surface area, porosity, and acid field ratio.

Wood and Van Heyst (2016) applied PLT to litter during the rearing period in two herds in a turkey incubation and rearing facility. While PLT was applied twice in the first flock, PLT was applied only once in the other herd. After the PLT application, it was found that NH<sub>3</sub> emission decreased by 72% on average over three applications. The application of PLT has been an effective control strategy to reduce ammonia emissions but has been found to have minimal impact on particulate matter emissions.

Chai et al. (2018) evaluated the effects of the additive sodium bisulfate (PLT) added to the litter taken from uncaged egg coops and electrolyzed water sprayed to the environment in a laboratory environment. As a result of the study, the PLT application rate and the NH<sub>3</sub> reduction efficiency are linearly proportional. Due to higher PLT application rates and lower litter pH, NH<sub>3</sub> volatility decreases. A reduction of 28% to 79%

was achieved. After the application of neutral electrolyzed water, the litter moisture content increased up to 60%. PM<sub>2.5</sub>, PM<sub>10</sub>, and TSP levels decreased after the application of electrolyzed water. During the 14-day trial period, water was sprayed for 11 days and not applied for three days. PM levels started to rise again after a period of inactivity.

Pereira et al. (2019a) evaluated the emission rates of ammonia, nitrous oxide, carbon dioxide, and methane by applying magnesium sulfate ( $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ ) to broiler litter. While the average annual emission rates of the control group house without magnesium sulfate decreased by 45% for  $\text{NH}_3$  and 25% for  $\text{N}_2\text{O}$  in the house where magnesium sulfate was applied,  $\text{CO}_2$  and  $\text{CH}_4$  emission rates increased by approximately 20%.

Spiehs et al. (2019) applied aluminum sulfate to beef litter material in a laboratory-scale study they conducted. They determined their effects on ammonia, hydrogen sulfide, methane, and carbon dioxide gases with application rates of 0, 2.5, 5, 10%. During the 42-day trial period, 10% aluminum sulfate reduced  $\text{NH}_3$  and  $\text{N}_2\text{O}$  emissions compared to the control group. However, 10% application of aluminum sulfate increased  $\text{CH}_4$  and  $\text{H}_2\text{S}$  emissions compared to the control group, which was not applied to the additive.

Pereira et al. (2019b) examined the effect of using clinoptilolite as a litter additive on ammonia, carbon dioxide, nitrous oxide, and methane emissions and concentrations in chicken coops. As a result of the study, it was seen that clinoptilolite application reduced  $\text{NH}_3$  and  $\text{N}_2\text{O}$  emissions by 28% and 34%, respectively. It has been stated that it has no effect on carbon dioxide emissions and that methane emissions are below the detection limit.

## **5. Conclusion**

Large amounts of poultry manure are produced and accumulated in broiler operations engaged in intensive broiler breeding. Manure can have an alarming effect on the environment. Therefore, it is more important to reduce the pollutants from production systems, control them, and develop control strategies. Although alternative production systems are studied in broiler breeding, generally, littered systems are used. The litter materials used according to the regions (wood shavings, paddy husk, corn stalk, straw, coarse wood shavings, sand, pumice) differ. The litter materials are important for the animals' performance, welfare, productivity, and keeping environmental factors at optimum levels. Various chemicals are used to contain ammonia in the litter, reduce the number of pathogens and microorganisms, and reduce ammonia production by lowering the pH level and obtaining an acidic environment. It has been proven that absorbent and acidifying chemicals added to horses have a more practical and cost-

effective development potential than other methods (McCrary & Hobbs, 2001).

Capturing ammonia nitrogen reduces ammonia evaporation by increasing the proportion of ammonium in the manure. As seen in the studies, different chemicals such as aluminum sulfate ( $\text{Al}_2(\text{SO}_4) \cdot 3.14\text{H}_2\text{O}$ ), PLT (sodium bisulfate), active charcoal, magnesium sulfate ( $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ ), clinoptilolite, and natural zeolite types have been used as absorbent materials to reduce  $\text{NH}_3$  emission. It is seen that the additives used are effective in reducing  $\text{NH}_3$  emissions. Especially in poultry studies, there has recently been a new interest in using natural zeolites as a complement to feed additive and litter material to reduce odor and ammonia emissions from broiler houses (Karamanlis et al., 2008). Also, application rates, usage techniques, and the reduction of ammonia emissions vary according to the chemicals used.

Adsorbent additives should be easily accessible, cost-effective, and practical. There are other additives on the market, such as formaldehyde, which reduce ammonia volatility from fertilizers. When formaldehyde reacts with ammonia, it can form a stable complex and inhibit urease and ammonification. In addition to its anti-microbial properties, its use is dangerous and may negatively affect the fertilizer spreads (Anderson, 1994).

Improving the house's indoor conditions is very important in ensuring productivity in poultry and protecting the health and welfare of animals and workers. Reducing ammonia and other harmful gases in the house creates high costs. Therefore, the number of studies is insufficient. The application of additives to reduce ammonia in poultry houses is fascinating due to simple application techniques and low interference with the animals' living conditions. Also, it has advantages such as chemical, physical and microbial effects of additives on wastes, minimum capital expenditure. However, its acidic content may also have a corrosive effect on equipment and structures. The selection of appropriate application methods is crucial for the effective use of adsorbents. More studies are needed to improve the technique and to understand its effectiveness better. Also, more comprehensive studies can be carried out on the effects of additives on other gases, particles, animal welfare, and productivity, as well as reducing  $\text{NH}_3$  emissions.

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