Particulate Matter Generation and Mitigation in Poultry Houses

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Poultry farming plays a key role in agricultural air emissions. Particulate matter (PM) level tends to be high in broiler and cage-free layer houses, that may impair health and welfare of animals and their caretakers. To protect public health and welfare, the occupational exposure limit for PM_{10} and $PM_{2.5}$ (i.e., PM diameters that are generally ≤10 and 2.5 μm, respectively) are suggested not to exceed 150 μg m^{-3} and 35 μg m^{-3}, respectively, based on 24-h concentrations thresholds as suggested by US. EPA. However, the levels of PM_{10} and $PM_{2.5}$ in poultry houses could be 100 times higher than that limit. Generally, PM emissions are affected by various factors, including housing types, seasonal and diurnal variation, manure management, bedding materials, ventilation rates, and birds' activities. High PM concentrations in poultry houses impair birds' and caretakers' liver, kidneys, and respiratory systems. Effective mitigation strategies include frequent house cleaning, optimum light intensity, liquid spraying, bedding management, and air filtration systems. However, mitigation strategies can be cost-prohibitive and have side effects. Therefore, poultry farms should select mitigation strategies based on farm location, climate conditions, environmental policies, and available resources (government assistance programs).

poultry production | air quality | dust | mitigating strategies | animal health and welfare

1. Introduction

Animal feeding operations (AFOs) are important sources of air pollutant emissions into the environment [1][2][3][4][5]. The primary air emissions include particulate matter (PM) and other gases like greenhouse gases and ammonia (NH_3), as these gases pose a high potential risk to air quality, public and animal health, and climate change [6][7][8][9][10][11][12]. Among these air pollutants, PM is considered one of the harmful air pollutants within and outside of animal houses because of its composition and emission rates at the animal and local levels [6]. According to the WHO (World Health Organization), the fine PM such as $PM_{2.5}$ (inhalable particles with diameters ≤

2.5 micrometers) causes 4.2 million premature deaths worldwide per year [11]. Moreover, the fine PM generated in the environment is the main source of haze in some parts of the United States [12][13][14]. In addition, depending on dust composition, settling down may cause lakes or streams to be acidic, reduce soil nutrients, and contribute to acid rain formation [12]. According to the European Environmental Agency, poultry and pig housings contributed approximately 50% and 30% of $PM_{2.5}$ (PM with aerodynamic diameter ≤2.5 μm) and 57% and 32% of PM_{10} (PM with aerodynamic diameter ≤10 μm) emissions, respectively [15].

Particulate matters in confined animal housing are heterogeneous combinations of biologically generated materials and aerosolized pollutants such as feed additives, broken feather pieces, dried NH_3, viable and nonviable bacteria, endotoxins, glucans, molds, and fungal spores [16][17][18]. In poultry houses, the primary sources of PM include feathers, feeds, urine mineral crystals, manure, and bedding materials. The PM generated from these sources shows harmful effects on the health of animals and caretakers [19][20]. For example, in birds, higher PM levels result in an increased risk of chronic bronchitis, cardiovascular illness, pneumonia lesions, asthma-like symptoms, and lung cancer [21][22], while in caretakers, it causes bronchitis, asthma, and organic dust toxic syndrome [20]. In addition, poultry farm workers are usually at high risk of occupationally being exposed to many respiratory problems leading to higher asthma rates or other respiratory symptoms at work [23].

2. Dust Composition and Mixture

Particulate matter composition varies according to animals and livestock housing [24]. In poultry housing, PM is entirely biological, organic, and inorganic in its origin (**Figure 1**), which typically consists of a complex mixture of solid and liquid materials such as bedding materials, feathers, feeds, skin, excreta, dander, and microorganism. Particulate matter from poultry houses constitutes about 90% organic content [25]. Dander, excreta, feathers, feed, litter material, bacteria, and skin are all examples of organic PM [16][17][18], while inorganic PM is usually the consequence of secondary interactions between NH_3 and acidic gases, which contribute to the fine PM fraction [26]. Based on particle sizes, feather-releasing airborne PM contributes about 4% to 43% fine PM and 6% to 35% coarse PM, while manure contributes ranges from 9–85% fine and 30–94% coarse PM [17]. Similarly, based on particle mass, feathers contribute about 17–68% in fine and 4–49% in coarse PM, while manure contributes 6–77% fine and 31–96% in coarse PM. In addition, in the case of poultry houses, PM could be rich in nitrogen content. According to Cambra-Lopez et al. (2010), elemental analysis of PM in poultry houses consists of N, O, C, S, P, Ca, Na, K, and Mg from feedstuffs, feces, and skin [21]. In addition, within PM, many pathogenic and nonpathogenic microorganisms are found attached to the surface [27].

Figure 1. Poultry dust obtained from the exhaust fan of the cage-free laying hen house at the UGA research facility.

In broiler housing, the primary sources of PM are down feathers, mineral crystals from urine, and litter, whereas the most prominent sources of waste in layer barns are skin, feathers, excrement, urine, feed, and litter [25]. Based on particle size, PM is classified into PM_1 (PM with aerodynamic diameter ≤1 µm), $PM_{2.5}$ (PM with aerodynamic diameter ≤2.5 µm), PM_4 (PM with aerodynamic diameter ≤4 µm), PM_{10} (PM with aerodynamic diameter ≤10 µm), and total suspended particle (TSP, PM with aerodynamic diameter ≤100 µm) [24][28][29]. The size of $PM_{2.5}$ is 30 times smaller than the size of the average human hair [14]. The emission rate of PM_{10} was directly influenced by the activity of the hens, ambient temperature, and ventilation rate [30]. It has been found that a significant portion of the NH_3 released contributes to the burden of $PM_{2.5}$ [31][32].

3. Factors Affecting Dust Generations

Dust emissions from poultry farms are affected by various factors and changes according to variable climatic conditions, applied management practices, the number of birds, and housing types. Various researchers have explained many factors that cause PM emission, as shown in **Figure 2** [9][24][33][34][35][36].

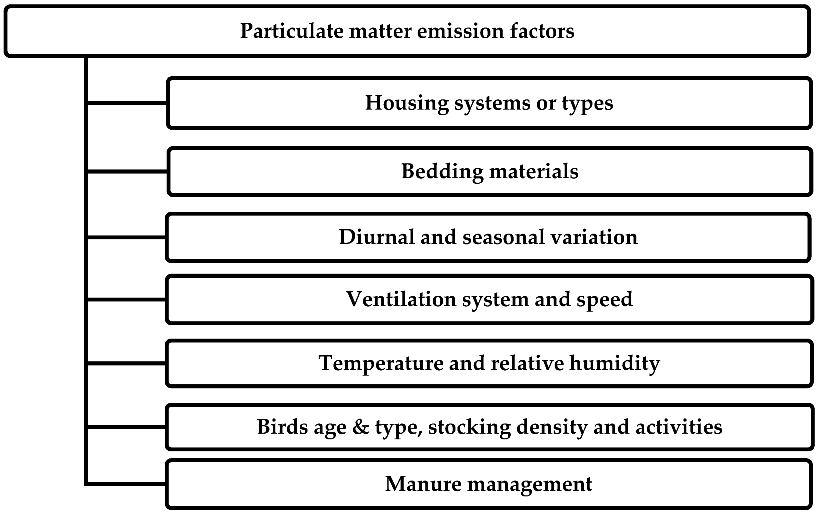

Figure 2. Factors affecting PM emissions in poultry housing.

3.1. Effect of Housing Systems on PM

Poultry housing is the major source of PM emissions. Different housing systems (e.g., floor-raised, aviary, conventional caged, and enriched colony) show different PM emissions and concentrations. Among different housing types, the cage-free (CF) housing (aviary) system resulted in significantly higher PM concentrations and emissions [37]. The daily mean PM_{10} level in CF housing was about six to nine times higher than the conventional cage (CC) and the enriched colony housing (EC) systems

[3]. Therefore, emission mitigation studies should consider CF housing systems as the priority. In addition, CF shows higher concentrations of airborne bacterial concentrations and emissions rates than CC and EC houses because PM is the primary carrier of airborne bacteria.

3.2. Effect of Bedding Materials on PM Levels

Cage-free housing commonly uses bedding materials on the floor for producing hens with litter floor to perform natural behaviors of dust bathing and foraging [38][39][40][41][42][43][44][45]. In Europe, litter floor distribution should include bedding material covering at least 33% (one-third) and 100% of total space in laying hens and broiler houses, respectively [38]. This litter floor is the main source of PM emissions in CF houses. Particulate matter production from bedding material can be influenced by the type of bedding materials, moisture content, depth of bedding material, replacing or cleaning frequency [39]. Bedding materials can be organic (wood shaving or chips, straw, paper, rice hulls, maize silage, plant husk, or grass) or inorganic (stone, sand, and clay) in origin and must be nontoxic, highly absorbent, and comfortable for animals [33][40].

3.3. Effect of Lighting and Seasonal Variations on PM Levels

During the daytime, increased activities of birds lead to a higher PM concentration than the nighttime [46]. The concentration of $PM_{2.5}$, PM_{10}, and TSP were 151, 108, and 136% higher ($p < 0.05$) during the daytime (lights on) than at nighttime. During the daytime, birds were most active, ventilation rates were highest, and emissions rose. However, the ratio of $PM_{2.5}$ and PM_{10} decreases at night because of low bird activities and the settling down of PM_{10} concentration [34].

The emission of PM is seasonally dependent and varies over time [34][35]. PM concentration increases in the winter compared to fall, spring, and summer [4][34][35][47][48]. According to Li et al. (2011), the concentration of PM_{10} was found to be lower during summer relative to winter due to higher air temperature and ventilation rates [47]. In addition, hens tend to move less if there are under heat stress in summer because the higher indoor air temperature may cause stagger, stupor, and reduced activities, and thus result in lower dust generation from the litter, while the cold season increases layers' activities, thus generating higher PM from the poultry house litter floor [49]. Besides animal activities, house ventilation and litter moisture are critical for PM generations. Therefore, the total poultry house PM emissions could be higher in summer than in winter because of increased house ventilation and drier litter conditions [30].

3.4. Effect of Ventilation System

PM emissions depend on the housing systems and ventilation types. Most of poultry housing systems are mechanically ventilation system that applies maximum ventilation in summer for removing extra heat and uses minimum ventilation in winter for moisture removing, which can improve air quality inside the house [50]. Poultry house ventilation rate affects the PM concentration [9]. Similarly, ventilation changes as affected by seasons that winter season has the highest concentration of PM among all four seasons [34]. Oppositely, increased ventilation during the summer dilutes the PM concentration [49]. Besides seasonal effect, housing style (e.g., natural ventilation vs. mechanical ventilation), ventilation types (e.g., negative vs. positive ventilation), and fan selection could also affect PM generations. Measurements of PM in natural ventilation systems have higher variations as wind directions and speed are varying over time.

3.5. Effect of Indoor Temperature and Relative Humidity

Temperature and relative humidity (RH) are inversely proportional to each other. Increased temperature decreases RH and is directly influenced by ventilation rates within poultry houses [51]. Temperature and RH change seasonally and depend on weather conditions and experimental house design. During the winter, ventilation rates are decreased, and heaters are turned on to make a room warm, reducing RH. A decrease in RH increases PM concentration. However, ventilation rates are increased during the summer season to bring cold air or moisture from outside (cooling pad). The moisture from outside makes RH higher inside the house and decreases PM concentration by making heavy PM settle down. According to Lin et al. (2017), $PM_{2.5}$ and PM_{10} concentrations depend on RH due to ambient air [52]. Similarly, houses or rooms attached more to the outside environment possess higher RH due to individual room effects. Tang et al. (2020) tested the effect of different temperatures (21.1, 23.8, 26.4, and 29.2 °C) and RH (49.5, 74.7, 78.8, and 80.0%) on PM concentrations and found that PM_1, $PM_{2.5}$, PM_{10}, and TSP were significantly lower in higher RH and lower temperature treatments because RH could affect litter moisture [53].

3.6. Other Factors

Poultry manure management plays an important role in dust emissions because manure contributes about 50% of total dust emissions in most housing systems with a raised floor [18]. Several studies show that floor-raised houses (broilers or layers) where manure gets deposited on the floor over time possess potentially higher PM concentrations than other poultry housing [17][37].

The chickens' activity and dust emission depend on the birds' age in poultry housing [54]. Recent research on pullets found that an increase in pullets' age increases birds' activities and significantly affects or increases dust production ($p < 0.05$). Similarly, Vucemilo et al. (2007) also found that increasing broiler age affects PM levels significantly [55]. Chicken activities during feeding mainly increase PM_{10} and TSP in the chicken house [56]. However, the perching behaviors and dust bathing in open spaces showed high PM production compared to the feeding and drinking behaviors [54]. Moreover, PM emission is also affected by housing stocking density and bird weight [9]. PM levels are higher with the increase of birds' weight and stocking density.

4. Impacts of PM on the Health and Welfare of Chickens and Farm Workers

High levels of PM can negatively impact the health and welfare of animals and their caretakers. According to Zhao et al. (2016), PM acts as a major carrier for airborne bacteria and endotoxin, which, once inhaled, might cause harmful effects on the respiratory systems of animals and caretakers [57]. When toxins carried by PM_{10} (particle size less than 10 µm) reach the bloodstream after inhalation, they can harm the respiratory system, liver, kidneys, and nervous system [12][14][58]. On the other hand, PM is more harmful to humans and birds with pre-existing cardiac diseases like asthma, making breathing difficult [59]. A low level of ventilation rate within the animal house was linked to long-term lung function impairment in animals [20]. Higher PM_{10} levels can increase the risk of chronic bronchitis, cardiovascular illness, pneumonia lesions, asthma-like symptoms, and lung cancer in farmers and animals [21][22].

High PM concentrations have been linked to higher avian mortality rates [60]. Particulate matters contain various airborne bacteria and endotoxin, which negatively impact health and welfare issues of birds. When birds inhale dust particles with dust-borne pathogens (especially Mycoplasma species) damage occurs to mucosal surface cilia present in the trachea [61]. Particulate matter of size $PM_{2.5}$ was found to have lots of harmful microorganisms and endotoxins [62]. Long-term exposure to $PM_{2.5}$ has been linked to impaired lung function, and fraction size up to PM_{10} has increased mortality risk [59].

Particulate matter in poultry houses can pollute the air and affect caretaker health. Poultry caretakers are at high risk due to occupational exposure to PM, leading to more respiratory hazards at work than in other work environments. Similarly, male poultry workers who smoke showed a substantially higher prevalence of chronic cough, chronic phlegm, and chronic bronchitis than nonsmokers [63]. The most common symptoms caused by PM in poultry workers are characterized by cough, phlegm, eye irritation, dyspnea, chest tightness, weariness, nasal congestion, wheezing, sneezing, nasal discharge, headache, throat irritation, and fever [12][19][20][21][22][59].

5. Mitigation Strategies Suppressing PM Levels in Poultry Houses

The high level of PM in poultry facilities is a major concern for the health and welfare of animals and their caretakers [64][65][66][67][68][69]. Among different PM sizes, PM_{10} and $PM_{2.5}$ levels are considered measurement factors for most organizations and countries because of their harmful effects on the health and welfare of caretakers. The World Health Organization (WHO) recently amended the ambient air quality standards in 2021 and proposed the maximum of PM_{10} to be 15 µg/m^3 for the annual average and 45 µg/m^3 for the 24-h mean, while for $PM_{2.5}$ to be 5 µg/m^3 for the annual average and 15 µg/m^3 for the 24-h mean [11][68]. According to the EPA (2022), the National Ambient Air Quality Standard (NAAQS) has set an exposure limit of $PM_{2.5}$ and PM_{10} as 35 µg/m^3 and 150 µg/m^3, respectively, for 24 h (98th percentile, averaged over 3 years) [65]. Therefore, everyone must follow OEL guidelines to improve the caretaker's health.

6. Particulate Matter Emission Mitigating Strategies

The PM concentration in poultry housing is primarily affected by housing and feeding, animal species, stocking density, lighting duration, environment conditions (season), and existing mitigation practices [22][24][70][71]. It is important to possess a deep knowledge of PM morphology to evaluate their effects and propose the best mitigating technologies in animal housing. Particulate matter mitigating strategies can be classified into three different groups: dilution and effective room air distribution, source-control techniques to reduce PM from the source, and PM removal or cleaning techniques by using acid scrubbers, electrostatic precipitators, or ionizers [72]. Other techniques for improving air quality are oil spraying, manure handling, and electrolyzed water spray [24]. Controlling the living space environment, including temperature, humidity, air quality, and litter quality, is critical for poultry well-being [73]. Variations in indoor air quality have been linked to various factors, including barn architecture, manure management, animal densities, feed regimens, building ventilation, and farm management practices. Therefore, various biochemical, chemical, managerial, physical, and physiological practices must be implemented to decrease PM significantly lower than recommended guidelines (**Figure 3**).

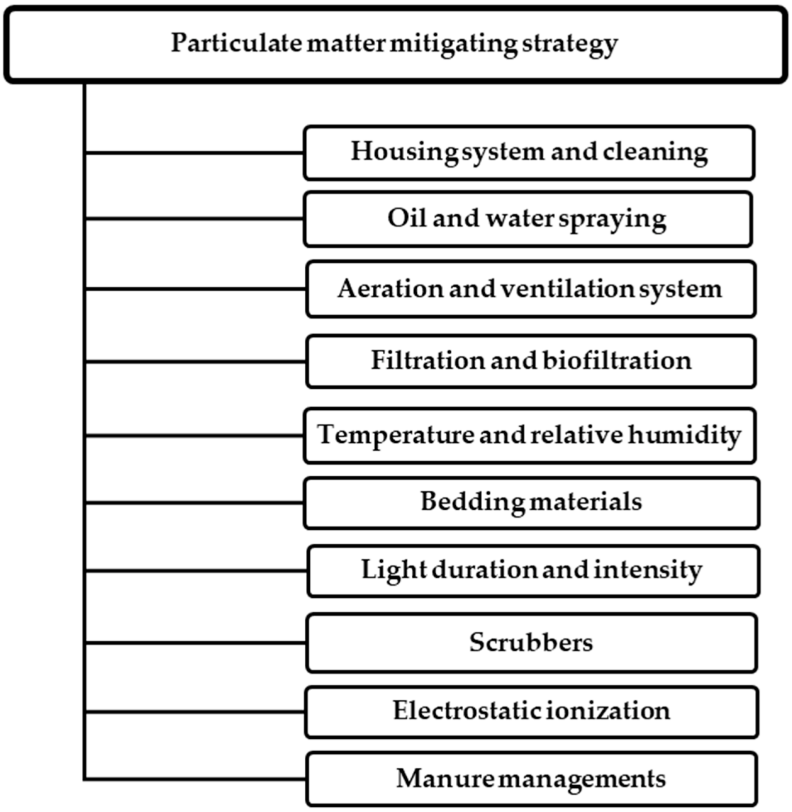

Figure 3. Overview of the PM emission mitigating strategy used in poultry housing.

7. Summary

Particulate matters (PM) found in poultry houses are biological, organic, and inorganic in composition, which originated from bedding materials, feathers, feeds, skin, excreta, bacteria, and feathers. Fine PM such as $PM_{2.5}$ is crucial in affecting the health and well-being of birds and caretakers as that can enter animals' respiratory system easier. According to the WHO, the occupational exposure limits of $PM_{2.5}$ annual mean and 24-h mean should not exceed 5 µg/m^3 and 15 µg/m^3, respectively. The levels of PM in poultry houses could be 100 times of WHO limit or higher (e.g., $PM_{2.5}$ levels in cage-free henhouse are higher than 1500 µg/m^3 in most time of the year), and thus affect animals' health and welfare, including eye irritation, throat irritation, cough, phlegm, chest tightness, sneezing, headache, fever, nasal congestion, and wheezing, especially in cold periods when the house will have limited ventilation. Furthermore, long-term exposure to PM increases obstructive pulmonary disorder, chronic bronchitis, chronic obstructive pulmonary disease, pneumonia lesions, cardiovascular disease, asthma-like symptoms, lung cancer, or even mortality in humans. Similarly, a higher level of PM with endotoxin in birds causes impaired lung function, chronic bronchitis, pneumonia lesions, cardiovascular illness, and cardiotoxicity in chicken embryos and hatchling chickens and might increase the risk of mortality rates. That is why it is very important to identify primary emissions factors and investigate PM mitigating strategies.

PM emissions depend on various factors and changes according to climatic conditions, housing type, applied manure management strategies, ventilation system, temperature and relative humidity, bird numbers, and bedding materials used. The factors that release significantly high PM levels must be managed and decreased to preserve and improve the environment, and human and animal health and welfare. Several studies have shown significant PM reduction by applying biochemical, chemical, managerial, physical, and physiological practices, which can be managing housing system and cleaning, light intensity, oil and water spraying, filtration and biofiltration, acid scrubber, bedding materials, and electrostatic ionization. Single or integrated mitigation has shown significant PM reduction in the past. Future research must be implemented by including integrated mitigating strategies to obtain much better results to improve air quality in poultry houses and enhance the health of both caretakers and birds. In addition, mitigation strategies could be cost prohibitive and have side effects. For instance, an acid scrubber has up to 95% efficiency in mitigating both dust and NH_3, but the cost for installing the system is a primary barrier; the water spray has a lower cost in controlling PM generations in poultry houses, but the increased NH_3 should be considered in quantifying the mitigation efficiency and costs. Additional strategies such as litter additives and new bedding will be needed for NH_3 control if water spray results in higher NH_3 generations. Therefore, poultry farms should select mitigation strategies based on a number of considerations, such as farm location, climate conditions, environmental policies, and available resources (assistance programs).

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