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Concentration, Size Distribution and Electrostatic Charge of Laying Hen House Particulate Matter

Emad A. Almuhanna[1]

[1] College of Agricultural Scneces and Food, King Faisal University, Hofuf, Saudi Arabia

Correspondence: Emad Ali Almuhanna, Department of Agricultural Systems Engineering, College of Agricultural Scneces and Food, King Faisal University, Hofuf, Saudi Arabia. Tel: 966-5-0592-3428. E-mail: ealmuhanna@kfu.edu.sa, ealmuhanna@yahoo.com

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Abstract

Published data on indoor air contaminants in livestock buildings in Saudi Arabia are relatively scarce. The main objective of this study was to determine the airborne concentrations of particles and electrostatic charge acquired by airborne particles in a multiple tier housing system (Manure Belt Cage System) under the climatic conditions of Saudi Arabia. In this house, the mean of total suspended particle (TSP) concentration was 0.99 mg/m^3, the PM_{10} concentration (particulate matter with a diameter less than or equal to 10 µm) was 0.47 mg/m^3, and the $PM_{2.5}$ concentration (particulate matter with a diameter less than or equal to 2.5 µm) was 0.05 mg/m^3. The particle size distribution results obtained from the layer house revealed that the GMD (geometric mean diameter) was 6.95 µm, based on the mass concentration of the particles. Alternatively, based on the number concentration of particles, the GMD was 0.82 µm. The cumulative percentage of mass concentration for the particles ranging from 0.3–10 µm showed that the major fraction of the particles was larger than 2.5 µm (>85%). The net charge-to-mass ratio (q_N) of airborne particles was -0.86 mC/kg (s.d.=0.27). The measured q_N value of airborne particles in the layer house varied due to the nature of the particles in addition to the environmental conditions and high concentration of airborne particles inside the poultry housing. In general, PM concentrations did not exceed the recommended values and those cited in literature.

Keywords: layer, particulate matter (dust), size distribution, electrostatic charge

1. Introduction

Various poultry housing systems have been employed in Saudi Arabia by poultry industry. In the 375 eggs production projects producing 3473 million eggs in Saudi Arabia, the caged systems are usually used for layer chickens and egg production (MOA, 2011). Whereas, broiler chickens is typically raised within enclosed structures, where the floor is covered with absorbent bedding material. Environmental concerns and nuisance issues related to poultry housing air emissions are an important issue currently affecting the poultry industry (Ritz et al., 2006). For laying hens, caged systems offer opportunities for better management and reduce production costs. Important welfare considerations also include environmental conditions including air quality and hen health. Unfortunately, these parameters are not well documented for different laying hen housing systems (Green et al., 2007).

Almuhanna (2011) conducted a study to characterize air contaminants (particle size distribution and concentration of airborne particles and toxic gases) inside floor raised poultry houses equipped with natural and mechanical ventilation systems, and to determine the effect of the ventilation system on air contaminants within both types of houses. In both housing systems, the industry is faced with air quality challenges including the emission of particulate matter (TSP, PM_{10} and $PM_{2.5}$), ammonia, and other toxic gases. The total suspended particulate matter concentration (TSP) can be defined as the amount of particulate matter (PM) captured on a filter with a particle size of approximately 100 µm or less. PM_{10} includes particles with an aerodynamic diameter of 10 µm or less also defined as the PM that passes through a size-selective inlet with a 50% cut-off at 10 µm aerodynamic equivalent diameter. Lastly, $PM_{2.5}$ is particulate matter with an aerodynamic diameter equal to or less than 2.5 µm, it is also refers to the PM that passes through a size-selective inlet with a 50% cut-off at 2.5 µm aerodynamic equivalent diameter (EPA, 1999). This scale classification is used mostly in studies of ambient air quality in the U.S. and

Saudi Arabia. For European studies they used to report PM as respirable and inhalable particles for occupational health parameters, but increasingly use TSP, PM_{10} and $PM_{2.5}$ for outside air quality related studies. Inhalable particles refer to those smaller than 100 µm, and respirable particles are those smaller than 4 µm (Li et al., 2011). Similar scale is used by US occupational health professionals (e.g., American Conference of Industrial Hygienists, ACGIH). Furthermore, thoracic particles refers to particles with an aerodynamic diameter of 10 µm or less and comparable to PM_{10}. In Saudi Arabia, ambient particulate matter and other pollutants are regulated by the Presidency of Meteorology and Environment (PME-KSA), which establishes the General Environmental Law, including Environmental Protection Standards (PME, 2013). Unfortunately, these standards do not cover indoor air for livestock buildings. Similar standards have been developed in the United States of America (USA) and European Union (EU), where ambient air contaminates was regulated by the U.S. Environmental Protection Agency (EPA), and European Environmental Agency (EEA).

Airborne particulate matter (dust) is one of the primary means by which disease-causing organisms are spread throughout poultry housing. Reductions in airborne dust levels are associated with significant reductions in airborne bacteria (Mitchell et al., 2004). The results of a recent study (Almuhanna et al., 2011) suggested that the increase of air contaminants and gases negatively affect the general productive performance and immune response under commercial conditions of poultry industry. The characteristics of PM (e.g., concentration, number, and mass) inside livestock housing vary according to the type of animal, building, and environmental conditions. Previous studies (Li et al., 2011; Green et al., 2007; Lim et al., 2007; Heber et al., 2005; Vucemilo et al., 2007; Shuhai et al., 2009) showed that the mean PM concentration measured inside layer housed (cage system) were 1.96, 0.33, 0.032 mg/m^3 for TSP, PM_{10}, and $PM_{2.5}$, respectively. The ranges of these concentrations were 0.75-4, 0.03-0.56, and 0.03-0.04 mg/m^3 for TSP, PM_{10}, and $PM_{2.5}$, respectively. It is widely acknowledged that stress imposed on the poultry by environmental, nutritional, pathological and other factors can decrease production. These factors, either individually or synergistically, are likely to greatly affect growth rate, production, reproduction, behavior and, ultimately, profit.

The suggested threshold values for indoor air contaminants in livestock housing are provided in Table 1.

Table 1. Suggested threshold values for indoor air contaminants in livestock buildings

Air contaminant	Humans	Animals	Reference
Inhalable (Total) dust, mg/m^3	2.40*	3.70	(Donham & Cumro, 1999a)
	-	3.40	(Wathes, 1994)
Respirable dust, mg/m^3	0.16*	-	(Donham & Cumro, 2002)
	0.23	0.23	(Donham & Cumro, 1999b)
	-	1.70	(Wathes, 1994)

* Specific threshold concentrations are defined as mixed exposures between NH_3 and PM in poultry CAFOs (Donham et al., 2000).

The majority of studies on the environment in poultry houses have analyzed the concentration of air contaminants (e.g., ammonia, carbon dioxide, dust, airborne microorganisms, and toxins). However, particulate matter is one of the primary aerial pollutants in poultry housing facilities (Visser et al., 2006; Liu et al., 2006; Roumeliotis et al., 2007). Moreover, ammonia gas is produced in the housing environment from the decomposition of uric acid, which is excreted by the birds. PM and ammonia have been identified by the US-EPA as the important hazardous air pollutants to be emitted from concentrated animal feeding operations (CAFOs), such as poultry (Bunton et al., 2007). PM (TSP, PM_{10}, $PM_{2.5}$) emissions from CAFOs can consist of feed materials, various body parts (e.g., dead skin, feathers), dried feces, various microorganisms and endotoxins (Chai et al., 2009).

Particle size is one of the most important parameters for characterizing atmospheric particles in terms of future impact. The size of the particles directly relates to their role in causing health problems because it affects their deposition rate, which determines their location within the respiratory tract (Zihan et al., 2009). The PSD (particle size distribution) of PM is a very important physical property governing particle behavior; moreover, very limited investigations characterizing PSD in poultry operations have been conducted and reported in the literature, specifically in Saudi Arabia.

The behavior of airborne particles is governed primarily by their size and shape. It is also greatly affected by their electrostatic charge. Brown (1997) indicated that simultaneous measurement of size and charge is necessary if the properties of particles are to be understood and their behavior controlled. In controlling indoor air quality in air spaces (e.g., industrial workplaces, livestock housing, etc.), knowledge of electrostatic charge of airborne particles is essential in designing effective particle control devices.

Toljic et al. (2010) stated that the value of charge is a critical parameter that needs to be determined in order to accurately predict behavior of a charged particle. Furthermore, electrostatic charging of particles is an important phenomenon that involves various applications, including electrostatic precipitation. Electrostatic charge can be beneficial as in the control of dust by the use of electrically charged filters or charged water droplets (Almuhanna et al., 2008, 2009). Similarly, charge effects on pulmonary deposition may make it useful in medication or a complication so far as hazardous dust is concerned. Almuhanna et al. (2008) carried out an experiment under controlled laboratory conditions and concluded that spraying with charged water improves the efficiency to remove PM. They also found that the removal efficiency is significantly greater during longer charged water spray durations (4 and 6 min) than during shorter duration (2 min), while the spraying method and the charge polarity did not significantly influence particle removal efficiency.

Almuhanna et al. (2009) developed a prototype electrostatically assisted particulate wet scrubber (EPWS) for controlling particulate matter (dust) in livestock buildings and tested under laboratory and field conditions. Under laboratory conditions, the EPWS with the negatively charged water spray had significantly higher particle removal efficiency (79%) than either the uncharged wet scrubber (58%) or the control i.e., only the fan was operated (21%). Field tests in a swine building proved that the EPWS was effective in removing airborne particulate matter. Moreover, PM levels could be significantly reduced if ventilation systems with electrostatic dust collection systems are used (Mitchell et al., 2002). Cambra-López et al. (2009) evaluated the performance of an ionization system in a broiler house and concluded that the ionization system effectively reduced the total PM_{10} and $PM_{2.5}$ mass emissions by 36% and 10%, respectively. Understanding PM characteristics will ultimately lead to the development of best suitable methods for dust control (Almuhanna et al., 2008, 2009; Brown, 1997).

Published data on indoor air contaminants in livestock buildings in Saudi Arabia are relatively scarce. More efforts are needed to study the effect of the elevated concentrations on the in house concentration of PM where it is a typical problems facing arid and semiarid countries like Saudi Arabia and the effect of emitted pollutants from these houses on the surrounding and vice versa.

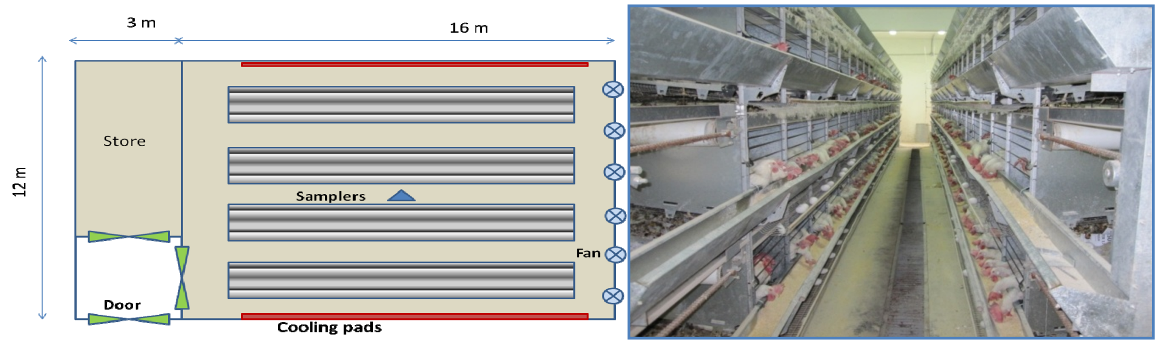
The main objective of the present study was to determine the airborne concentrations of PM (TSP, PM_{10}, and $PM_{2.5}$) and electrostatic charge acquired by airborne particles in a multiple tier housing system (Manure Belt Cage System) under the climatic conditions of Saudi Arabia. Whereas, the specific objectives were to do the following: (a) measure the particle size distribution (mass and number based); (b) determine the concentration of PM; (c) measure the electrostatic charge acquired by airborne particles; (d) compare the measured concentrations to the recommended values.

2. Materials and Methods

The layer house field measurements were conducted in the Poultry Unit at the Experimental and Training Station of King Faisal University, Al-Ahsa, Saudi Arabia.

2.1 Poultry Housing Facilities

The layer house possessed a total width, length, and height of 12 m, 16 m, and 3.6 m, respectively. The surface area of the floor and volume of the building were 196 m^2 and 762 m^3, respectively, as shown in Figure 1. The mechanically ventilated layer house was oriented in an east-west direction. The side walls were made of 20-cm thick concrete bricks, and the ceiling was made of insulated reinforced concrete. The longitudinal side walls (north and south) were equipped with an evaporative cooling fan-pad system that served as the ventilation air inlet, with a total area of 17 m^2 of cooling pads. The house was equipped with 6 exhaust fans that were 45 cm in diameter (Model DVN 183, Windy, Dongkun Industrial Co., Ltd, S. Korea), which were installed on the east side walls of the building and giving maximum flow rate of 110 m^3/min. In total, 640 cages (L=55cm × W=63 cm × H=50 cm) were arranged in four batteries (Manure Belt Cage System) with three central alleys. Each cage row was serviced by feeding systems and nipple water dispensers. The layer house accommodated a total of 2560 hens, and 4 birds were housed in each cage.



(a) (b)

Figure 1. (a) Schematic depiction of the layer house equipped with mechanical ventilation [plan view - not drawn to scale], (b) Photo of the same house

Figure 2. Removal of manure by belt system using self-cleaning rubber belt conveyer

2.2 Measurement of Environmental Parameters

During this study, the used birds were adults (12 months old) and at their production stage. The house was ventilated according to the temperature and humidity, and the average ventilation rate during the sampling time (winter season) was 381 m^3/min. Using the ventilation control board, the indoor air temperature inside the house was adjusted according to the age of the birds and environmental parameters.

The air temperatures and relative humidity at various locations inside the building were measured using a HOBO® U12 Logger with accuracy of ±0.35 °C; ambient temperature and relative humidity were recorded for the length of study with time interval for data recording equal to 60 minutes with data acquisition every one minute for integrated measurements. Meteorological data outside the building, including air temperature, wind speed, direction and the relative humidity of the air were measured by a meteorological station (HOBO U30-NRC Weather Station, Onset Computer, USA) which was located 50 m away from the building.

2.3 Measurement of Size Distribution, Mass and Number Concentration

The size distribution and number concentration of airborne particles were monitored using a particle counter (Model GW3016A, GrayWolf Sensing Solutions, Advanced Environmental Measurements). The spectrometer measured particles with aerodynamic diameters ranging from 0.3 to 10 μm at an air sampling rate of 2.83 LPM (0.1 CFM). Moreover, six channels were used, and a counting efficiency of 100% was employed for particles with diameters of >0.45 μm. The spectrometer displayed the particle count and mass concentration readings in μg/m^3.

Figure 3. Instruments used to characterize airborne particles inside the poultry house

A fixed station (Topas, Turnkey Optical Particle Analysis System) monitor was designed to continuously record environmental TSP, PM_{10}, $PM_{2.5}$, and PM_1 particles was used to monitor PM concentrations. It uses the principle of light scattering of the single particle. The sample air was heated to avoid the relative humidity and can record concentrations up to 6500 μg/m^3, with a ±0.1μg/m^3 measuring accuracy with a sampling resolution of 1 min. Samples were collected with an average of one hour readings and sampling height was approximately 2 m above the ground.

The particle size distributions (number and mass) were analyzed by calculating the following statistics (Hinds, 1999):

a. Mean diameter

$$\bar{d}p = \frac{\sum n_i d_i}{N} \tag{1}$$

b. Standard deviation (SD)

$$\sigma = \left(\frac{\sum n_i \left(d_i - \bar{d}p\right)^2}{N-1} \right)^{0.5} \tag{2}$$

c. Geometric mean diameter (d_g or GMD)

$$d_g = exp\left(\frac{\sum n_i \left(ln\, d_i\right)}{N} \right) \tag{3}$$

d. Geometric standard deviation (σ_g or GSD)

$$\sigma_g = exp\left(\frac{\Sigma n_i \left(ln\, d_i - ln\, d_g\right)^2}{N-1} \right)^{0.5} \tag{4}$$

where:

d_i–Diameter of specific particles size (i), μm

d_p–Mean diameter, μm

d_g–Geometric mean diameter by mass of sample, μm (GMD)

σ_g–Geometric standard deviation (GSD)

n_i–Number of particles of specific size (i)

N–Total number of particles

2.4 Measurement of Airborne Particulate Matter Charge

For the charge measuring of airborne particles inside layer house, the CMD device was developed as reported by Almuhanna (2010) and was used to measure the net charge-to-mass ratio of airborne particles. The device consisted of two conducting enclosures, one enclosed and insulated from the other. The inner enclosure had two small openings, one for air inlet and the other for air outlet; the openings were kept small to reduce leakage of external field into the cup. It was electrically connected to the electrometer input which had a particle collection filter with a back-up metal screen. The device insulated from the outer enclosure by a rigid, high resistance insulator (Poly-tetra-fluoroethylene PTFE). The outer enclosure was connected to a grounded base and served as a shield for the inner enclosure from the external fields that could affect measurement.

Figure 4. Components of the Charge Measuring Device (CMD)

The CMD was connected to a low-volume sampling pump that draws air and particles into the device and collects the particles onto a filter (type AE, SKC, Eighty Four, PA). The mass of collected particles on the filter was measured by weighing the filter before and after sampling in an electronic analytical microbalance (Model AWD-120D, Shimadzu Corporation, Kyoto Japan, with a accuracy of ±0.01 mg). The device was electrically connected to an electrometer (Model 6514, Keithley Instruments, Inc., Cleveland, OH), which was controlled by a computer. The electrometer had a very high sensitivity of the order of 10^{-15} A and high input impedance. Data from the electrometer were collected and managed by ExceLINX® software (Keithley Instruments, Inc., Cleveland, OH).

The net charge-to-mass ratio (mC/kg) of particles was calculated using the following equation:

$$q_N = \frac{q - q_b}{m_p} \tag{5}$$

Where, q_N is the net charge-to-mass ratio, q is the measured charge, q_b is the device background charge, and m_p is the mass of particles collected on the filter.

Data values were statistically analyzed using PROC GLM of SAS (Version 9.1, SAS Institute, Inc., Cary, N.C., 2001). Means were compared using a Duncan's multiple range test at a significance level of 5%.

3. Results and discussion

3.1 Environmental Conditions

The environmental conditions inside the layer house were compared to the external climatic conditions. Fluctuations in the air temperature surrounding the birds plays an important role in their growth rate, development, and productivity whereas, RH, are considered as an important factor that affects PM generation (CIGR, 1994). The air temperature inside the layer house varies between 18.6 ºC and 25.1 ºC with an average of 22.7 ºC (SD = 2.5 ºC). The relative humidity inside the layer house ranges from 36.2% to 51.1% with an average of 42.2% (SD = 5.9%). On the other hand, the outside air temperature ranges from 15.2 ºC to 29.9 ºC, and the average temperature was 22.5 ºC (SD = 7.5 ºC). Lastly, the relative humidity of the outside air ranges from 20.7% to 49.4%, and the average humidity is 33.1% (SD = 12%).

3.2 Particle Mass Concentration

The average concentration of TSP inside the layer house is summarized in Table 2. The average TSP inside the layer house has a significantly ($P<0.05$) greater mean value (0.99 mg/m^3) than the outside ambient air value (0.39 mg/m^3) during the experimental period. However, the average concentration of TSP does not exceed the acceptable range of the threshold for indoor air contaminants in livestock houses (3.4–3.7 mg/m^3) proposed by Wathes et al. (1994) and Donham and Cumro (1999b). The average PM_{10} concentration inside the layer house has a significantly ($P<0.05$) greater mean value (0.47 mg/m^3) than the outside ambient air value (0.23 mg/m^3) during the experimental period. The weekly average $PM_{2.5}$ concentration mean value (0.05 mg/m^3) inside the layer house did not significantly ($P<0.05$) differ from outside ambient air value (0.05 mg/m^3) during the experimental period. Both PM_{10} and $PM_{2.5}$ values do not exceed the threshold for indoor air contaminants in livestock houses (0.23 mg/m^3) proposed by Donham and Cumro (1999b). Table 2 shows the mean, standard deviation, and range of values for TSP, PM_{10}, and $PM_{2.5}$ during the experimental period.

Table 2. Mean, standard deviation, and range of values (mg/m^3) for TSP, PM_{10}, and $PM_{2.5}$ during the experimental period

House	TSP			PM_{10}			$PM_{2.5}$		
	Mean[*]	SD	Range[**]	Mean[*]	SD	Range[**]	Mean[*]	SD	Range[**]
Layer	0.99 a	0.2	0.7-1.11	0.47 a	0.56	0.41-0.53	0.05 a	0.01	0.04-0.05
Outside	0.39 b	0.1	0.23-0.6	0.23 b	0.05	0.18-0.54	0.05 a	0.02	0.02-0.16

[*] Column means followed by the same letter are not significantly different at a 5% level of significance.

[**] Maximum values were observed in at the layer house.

Li et al. (2011) listed (Table 3) the experimental conditions and measurements of some previous studies on PM concentrations in laying-hen houses. These findings were compared with the results of the present study.

Table 3. Production and measurement[a] conditions of studies on PM concentrations in laying-hen caged houses compared to this study

Reference	Location of Study	Bird Age and Weight	Vent. Mode	PM Mea.	Measurement Frequency[b]	TSP (mg/m^3)	PM_{10} (mg/m^3)	$PM_{2.5}$ (mg/m^3)
Takai et al. (1998)[c]	Northern Europe	-	-	GF	Intermittent (note 2)	0.75-1.64	0.03-0.27	-
Wathes et al. (1997)[c]	U.K.	18-69 wk, 1.94-2.18 kg	MV	GF	Intermittent (note 3)	1.70	0.31	-
Lim et al. (2007)	Ohio	1.65 kg	MV	TEOM	Continuous	2.37	0.565	-
Martensson & Pehrson (1997)	Sweden	3-16 wk	MV	GF	Intermittent (note 5)	2.5 (1.0-3.6)	1.0 (0.3-1.3)	-
Guarino et al. (1999)[c]	Italy	34-42 wk	MV	GF	Intermittent (note 6)	1.58	0.32	-
Davis & Morishita (2005)	Ohio	-	MV	Optical	Intermittent (note 7)	-	<2.00	-
Vucemilo et al. (2007)	Croatia	-	MV	GF	Intermittent (note 8)	1.6-2.8	-	-
Li et al. (2011)	Iowa	50-90 wk	MV	TEOM	Continuous	-	0.393	0.044
This study	Saudi Arabia	50-60 wk	MV	Optical	Continuous	0.99	0.47	0.05

[a] GF = gravimetric filtration, TEOM = tapered element oscillating microbalance, MV = mechanical ventilation, and NV = natural ventilation.

[b] The following notes apply: 1 = 22 buildings surveyed, each measured over a summer day and winter day; 2 = 26 buildings surveyed, each measured over a summer day and winter day; 3 = four buildings surveyed, each measured over a summer day and a winter day; 4 = measured one day per week; 5 = measured three to four times a day; 6 = measured three times a day, five days each week, one week each month; 7 = measured once a week; and 8 = measured 15 times a day;

[c] Inhalable and respirable fractions of PM were reported.

Figure 5 shows the change in the airborne PM (dust) concentration inside the layer house over 6 days period.

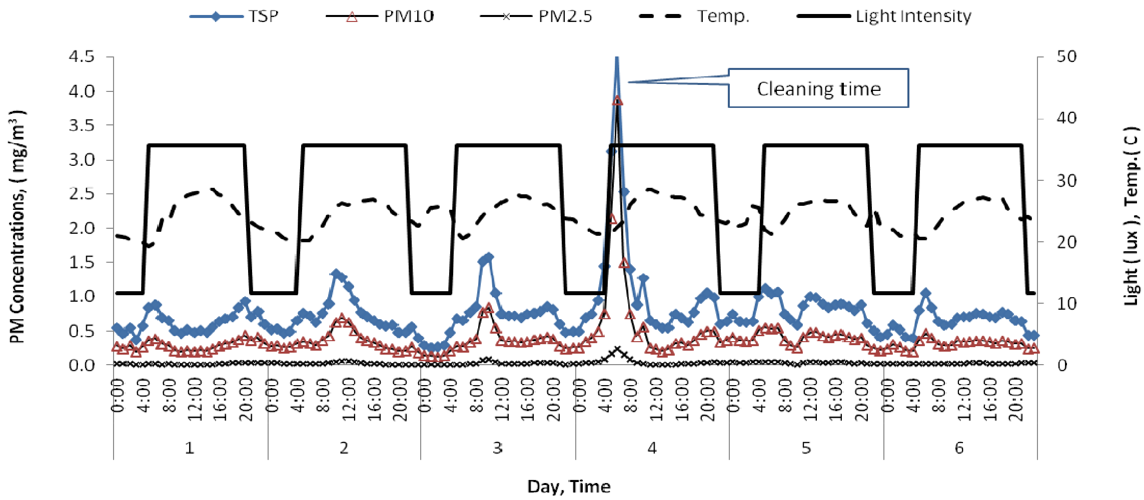


Figure 5. Cyclic changes in airborne particulate matter (dust) concentrations inside the layer house during 6 days of sampling period

There was 18 hours of light starting from 4:00 to 20:00 during this period it is obvious that there is an increse in air tempreture in addition to an increase in dust concentrations of different sizes, this is could be related to the increase of outside air tempreture and birds activities. Cleaning process could cause an elevation of dust concentration inside the building as shown in day 4 of sampling period (Figure 5).

3.3 Particle Size Distribution

Particle size distribution (PSD) of particulate matter is a very important physical property governing particle behavior; moreover, very limited investigations characterizing PSD in poultry operations have been conducted and reported in the literature, specifically in Saudi Arabia. The particle size distribution inside the layer house is summarized in Table 4.

Table 4. Particle statistics of the layer house on a number and mass basis

Parameter	Number Distribution			Mass Distribution		
	Mean	SD	Range	Mean	SD	Range
Mean Diameter (µm)	0.94	0.16	0.8-1.11	6.04	0.26	5.74-6.22
Standard deviation	1.32	0.21	1.12-1.53	2.31	0.19	2.19-2.52
Geometric Mean Diameter (µm)	0.82	0.09	0.73-0.92	6.95	0.60	6.26-7.32
Geometric Standard Deviation	2.14	0.17	2.0-2.33	2.11	0.20	1.94-2.33

The geometric mean diameter (GMD) based on the number distribution inside the layer house is 0.82 µm, and the geometric standard deviation (GSD) is 2.14. Based on the mass distribution inside the layer house, the geometric mean diameter (GMD) is 6.95 µm, whereas the geometric standard deviation (GSD) is 2.11. Figure 6 shows the particle size distribution inside the house based on number and mass concentration. It is clear that the layer barn particulate concentrations are lower in number and higher in mass concentrations than outside values.

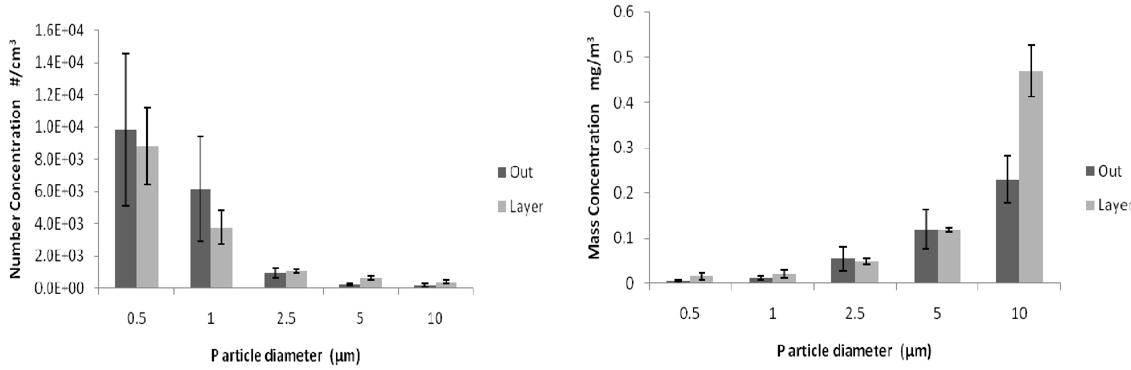
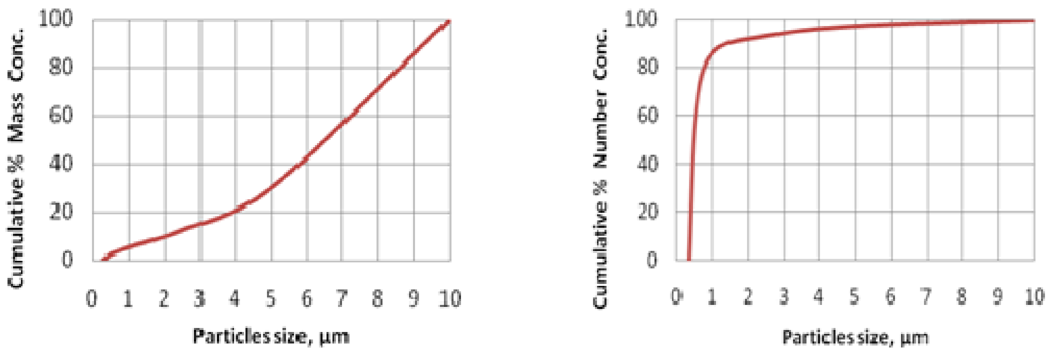


Figure 6. Particle size distribution inside the layer house compared with outside air based on number and mass concentration of particles, Error bars represent standard deviation

The cumulative percentage of mass concentration for the particles range from 0.3-10 µm (Figure 7a) shows that a major fraction of the particles are larger than 2.5 µm in diameter (>85%). The cumulative percentage of number concentration for the particles range from 0.3-10 µm (Figure 7b) shows that the major fraction of the particles is smaller than 2.5 µm (> 95%). This indicates that a greater part of the PM (dust) mass has a high probability of settling out of the air or being collected in the nasal and pharyngeal regions if inhaled. Consequently, only a small proportion will penetrate into the more sensitive lower respiratory regions where greater damage can occur.



(a) (b)

Figure 7. Measured cumulative percentage of particle size distribution based on number and mass concentration

3.4 Airborne PM Charge

In order to have a wider idea about the behavior airborne particles that is governed primarily by their size and shape and also greatly affected by their electrostatic charge. Knowledge of electrostatic charge of airborne particles is essential in designing effective particle control devices. Inside the layer house, the measured mean charge to mass ratio q_N of airborne particles was -0.86 (s.d.=0.27) mC/kg. The measured q_N value of airborne particles in the laying hen house varies due to the nature of the particles in addition to the environmental conditions and high concentration of airborne particles inside the housing.

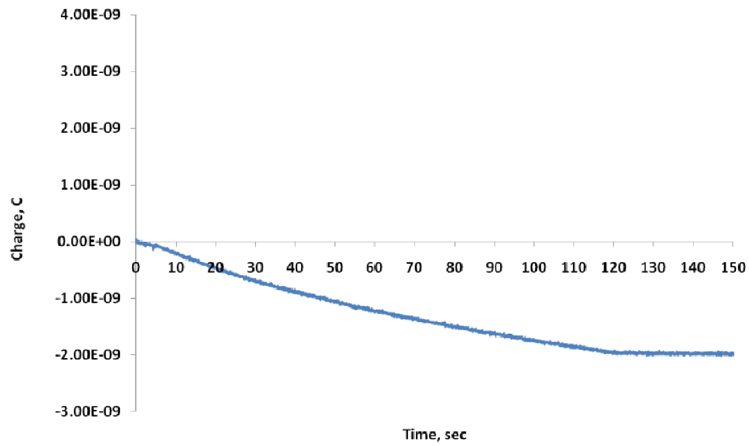


Figure 8. Electrostatic charges of airborne particles as measured by the charge measuring device

Figure 8 shows a typical plot of the measured charge. Before sampling the pump was turned on, q_b (i.e. background charge) was first measured for about 20 s. When the sampling pump was turned on, q started to increase due to the accumulation of particles on the collection filter. When the pump was turned off, q stabilized, and at this point the measured charge was used to calculate q_N of the collected particles.

Understanding PM characteristics will ultimately lead to the development of best suitable methods for dust control. Almuhanna et al. (2009) developed a prototype electrostatically assisted particulate wet scrubber (EPWS) for controlling particulate matter (dust) in livestock buildings and tested under laboratory and field conditions. Under laboratory conditions, the EPWS was effective in removing airborne particulate matter. Cambra-López et al. (2009) evaluated the performance of an ionization system in a broiler house and concluded that the ionization system effectively reduced the total PM_{10} and $PM_{2.5}$ mass emissions by 36% and 10%, respectively. The negative value of airborne particles suggesting the use of positively charged collection electrodes or objects to achieve the highest collection efficiency by dust removal techniques.

4. Conclusions

Particle concentrations, size distribution and electrostatic charge of airborne particles in a layer poultry operation in Al-Ahsa, Saudi Arabia were measured and analyzed. From the results of the present study, the following conclusions could be drawn:

The weekly average concentration of TSP in the layer house, which is equivalent to the inhalable particulate matter (dust) content, was 0.99 mg/m^3. The weekly average PM_{10} concentration in the layer house was 0.47 mg/m^3. The $PM_{2.5}$ weekly average concentration in the layer house was 0.05 mg/m^3. The $PM_{2.5}$ values for the house were lower than the suggested threshold for indoor air contaminants in livestock housing**.**

The literature values for TSP concentrations ranged from 0.75–3.6 mg/m^3, as compared to 0.99 mg/m^3 in the present study. PM_{10} concentrations ranged from 0.03–2 mg/m^3, as compared to 0.47 mg/m^{3}in the current study. $PM_{2.5}$ concentration of previous study (Li et al., 2011) was 0.044 mg/m^3, as compared to 0.05 mg/m^3 in the current study.

The particle size distribution results obtained from the layer house revealed that the GMD was 6.95 µm, based on the mass concentration of the particles. Alternatively, based on the number concentration of particles, the GMD was 0.82 µm.

The cumulative percentage of mass concentration for the particles ranged from 0.3-10 µm showed that the major fraction of the particles was larger than 2.5 µm (>85%). This indicates that a greater part of the PM (dust) mass has a high probability of settling out of the air or being collected in the nasal and pharyngeal regions if inhaled. Consequently, only a small proportion will penetrate into the more sensitive lower respiratory regions where greater damage can occur.

Inside the layer house, the measured mean charge to mass ratio of airborne particles was -0.86 (s.d.=0.27) mC/kg.

The negative value of airborne particles suggesting the use of positively charged collection electrodes or objects to achieve the highest collection efficiency by dust removal techniques.

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