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EFFECT OF NATURAL AND MECHANICAL VENTILATION SYSTEMS ON AIR CONTAMINANTS OF POULTRY HOUSING IN AL-AHSA (ESTERN PROVINCE), SAUDI ARABIA

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ABSTRACT

A field study was conducted to assess the effect of natural and mechanical ventilation systems on air contaminants of poultry housing under eastern province of Saudi Arabia climatic conditions. The concentration and particles size distribution of airborne particles and gases were measured and analyzed inside two different poultry housing. The obtained data showed that, the mean total suspended particles concentration (TSP) inside the poultry housing that used natural ventilation system (N.V.) was 12.47 mg/m^3, the particulate matter with a diameter less than or equal to 10 µm (PM_{10}) concentration was 4.81 mg/m^3, and the particulate matter with a diameter less than or equal to 2.5 µm ($PM_{2.5}$) concentration was 0.18 mg/m^3. Whereas, in the poultry housing used mechanical ventilation system (M.V.), these concentrations, respectively, were 4.61, 2.26, and 0.09 mg/m^3. The TSP values were greater than the suggested threshold values for indoor air contaminants in livestock building, however, the $PM_{2.5}$ values of both housing did not exceed the suggested threshold values for indoor air contaminants in livestock building. The geometric mean diameter (GMD) based on the mass concentration of particles in the natural and mechanical ventilation systems was 8.63 and 8.38 µm, respectively. The concentration of ammonia (NH_3), carbon dioxide (CO_2), sulfur dioxide (SO_2), oxides of nitrogen (NO_2), and hydrogen sulfide (H_2S) was also measured inside the poultry housing. The obtained results also revealed that, the ammonia was the dominant gas in both housing. Moreover, the majority of gases did not exceed the threshold values. Using the mechanical ventilation system, the concentration of airborne particles and toxic gases inside the poultry house was strongly affected by the barn ventilation rate.

Keywords: Air quality, Dust, Ammonia, Gases, Airborne particles.

INTRODUCTION

Over the last two decades, poultry technology, industry and management in Saudi Arabia has rapidly expanded to meet an increased demand. In many cases, poultry production is reduced by stress imposed on poultry due to various environmental, nutritional, and pathological factors. The ventilation system of poultry housing determines the indoor environment and plays a complex role in poultry production due to its effects on disease, nutrition, the concentration of ammonia and other toxic gases, dust (inhalable, thoracic, and respirable), space, thermal environment, and other unrecognizable factors. The aforementioned factors singly or synergistically affect the growth rate, production, reproduction, behavior, and profit of poultry enterprises.

Air quality inside the poultry housing has become a major concern, particularly with regard to poultry health. Environmental concerns and nuisance issues related to poultry housing air emissions are an important issue affecting the poultry industry (Ritz *et al*., 2006). In the majority of these studies, the concentration of air contaminants such as gases (ammonia and carbon dioxide, dust, airborne microorganisms, and toxins) was analyzed, however, particulate matter is one of the primary aerial pollutants from poultry housing facilities (Lim *et al*., 2003; Visser *et al*., 2006; Liu *et al*., 2006; Roumeliotis and Van Heyst, 2007). Moreover, ammonia gas is produced in the housing environment from the decomposition of uric acid, which is excreted by the birds.

Organic dust in poultry housing is composed of non-viable particles generated by feces, litter, feed, feathers (which produces significant amounts of allergen dandruff) and viable particulate matter (also called bio-aerosols). Inhalable dust and respirable dust are a human health hazard that can contribute to the formation of acid rain and degrade atmospheric visibility. Airborne 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). Dust characteristics (concentration, number, and mass) inside the livestock housing vary based on the type of animal, building, and environmental conditions. Understanding dust characteristics will lead to the development of optimal methods of dust control (Almuhanna *et al*. 2008 and Almuhanna *et al*. 2009). Dust concentrations in poultry housing ranges from 0.02 to 81.33 mg/m^3 for inhalable dust and 0.01 to 6.5 mg/m^3 for respirable dust (Ellen *et al*., 2000).

The most prominent air pollutants are odors, gases, dust, microorganisms, and toxins (Hartung *et al*., 1998). These materials are considered to be the principal risk factors for respiratory system diseases. Epidemiological evidence suggests that the health of farmers working in livestock housing may be harmed by regular exposure to air pollutants (Whyte *et al*., 1993). In broiler housing, approximately 30% of the birds that were rejected at meat inspection possessed lung lesions. Particulate emissions such as dust and microorganisms from buildings can play a role in respiratory problems in people living in the vicinity of animal enterprises. The travel distance of viable bacteria from a laying hens housing was 200 to 300 m downwind.

The effect of the litter type and stocking density of broiler flocks on the ammonia concentration, dust concentration, and the performance of broilers was studied by AL-Homidan and Robertson (2003). They stated that, the ammonia and dust production affected the litter type and stock density. Ammonia (NH_3) is produced as a by-product of the microbial decomposition of organic nitrogen compounds in manure. Nitrogen occurs as unabsorbed nutrients in animal feces and as urea (mammals) or uric acid (poultry) in urine (EPA, 2004). Concern of the effects of gaseous ammonia on the growth cycle of broilers has been primarily focused on the concentration of ammonia inside broiler housing units because high ammonia concentrations affect bird performance. Moreover, ammonia is an odorant gas and has irritant properties. Namely, at concentrations greater than 0.7 ppm, ammonia has a pungent, acrid odor. Alternatively, concentrations of 50-150 ppm can lead to severe coughing and mucous production (Leduce, 1992). In addition to pulmonary disease, exposure to ammonia leads to eye, sinus, and skin irritation (Latenser *et al*., 2000). Similar to the effects observed in humans, ammonia causes the following conditions in poultry: reduced body weight at ammonia concentrations of 25 ppm, respiratory irritation, predisposition to infectious disease, and cornea/conjunctiva inflammation (kerato-conjunctiva) at ammonia concentrations of 50 ppm. On a global scale, animal farming systems emit approximately 20 Tg N/yr as NH_3 (Galloway and Cowling, 2002) to the atmosphere, which comprises 50 percent of the total NH_3 emissions from terrestrial systems (Van Aardenne *et al*., 2001).

Hydrogen sulfide (H_2S) is a highly toxic gas that can cause death in humans and livestock when acute levels are generated under certain conditions (Patni and Clarke, 1991). Hydrogen sulfide may also cause adverse health effects (irritation, headache, dizziness) at concentrations as low as 10 ppm. Due to its toxic properties and significant contribution to odor, hydrogen sulfide emissions from known sources (i.e., manure pits, storage tanks) should be closely monitored to prevent accumulation to fatal levels and to evaluate its impact on the environment. Nitrogen dioxide (NO_2) is a reddish-brown toxic gas that has a characteristic sharp, biting odor and is a prominent air pollutant. The most important sources of NO_2 are internal combustion engines, thermal power stations, and pulp mills. Fossil fuel heaters are also sources of NO_2 in poultry houses. The concentration of carbon dioxide (CO2) in Earth's atmosphere is approximately 390 ppm by volume (NOAA/ESRL, 2011). In animal housing units, additional carbon dioxide is released from the biological decomposition of manure and the respiration of animals. Carbon dioxide constitutes more than 40% of the air bubbles arising from liquid manures stored under slotted floors, lagoons, or oxidation ditches. At higher concentrations, CO_2 can asphyxiate humans and animals by reducing the amount of oxygen in the local environment (Schnoor *et al*., 2002).The suggested threshold values for indoor air contaminants in livestock housing are provided in Table (1).

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 (PME, 2001), including Environmental Protection Standards. Unfortunately, these standards do not cover indoor air for livestock buildings. Similar standards have been developed in the USA, and ambient air contaminates are regulated by the Environmental Protection Agency (EPA-U.S.). For instance**,** the total suspended particulate matter concentration (TSP), which is defined as the amount of particulate matter captured on a filter with a particles size of approximately 100 µm or less (EPA, 1999), TSP is comparable to inhalable dust as defined by occupational health professionals (e.g., ACGIH). PM_{10} includes particles with an aerodynamic diameter of 10 µm or less (EPA, 1999), and is comparable to the thoracic dust definition used by occupational health professionals (ACGIH). Lastly, $PM_{2.5}$ is particulate matter with an aerodynamic diameter equal to or less than 2.5 µm (EPA, 1999). To the best of our knowledge, published data on indoor air contaminants in livestock buildings in Saudi Arabia is relatively scarce as listed in Table (2).

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 and Cumro (1999a)**
	-	3.40	**Wathes (1994)**
Respirable dust, mg/m^3	0.16*	-	**Donham *et al*. (2002)**
	0.23	0.23	**Donham and Cumro (1999b)**
	-	1.70	**Wathes (1994)**
Carbon dioxide (CO_2), ppm	1540	1540	**Reynolds *et al*. (1996); Donham *et al*. (2000).**
Ammonia (NH_3), ppm	7	11	
	12*		
Hydrogen sulfide (H_2S), ppm	5		

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

Table (2): Ambient air quality standards regulated by the EPA (1999) and the PME (2001)

Pollutant	**Average Time Period**	**Acceptable Maximum µg/m^3 (ppm)**		**Number of Allowable Exceeding**
		EPA*	**PME ****	
TSP	24 hours	-	340	1 per year
	Yearly	-	80	-
PM_{10}	24 hours	150	-	1 per year
	Yearly	50	-	-
$PM_{2.5}$	24 hours	35	-	-
	Yearly	15	-	-
Sulfur Dioxide (SO_2)	1 hour	-	730 (0.280)	2 per any 30 days
	24 hours	365 (0.140)	365 (0.140)	1 per year
	Yearly	80 (0.030)	80 (0.030)	-
Oxides of Nitrogen (NO_2)	1 hour	188.7 (0.1)	660 (0.350)	2 per any 30 days
	Yearly	100 (0.053)	100 (0.050)	-
Carbon Monoxide (CO)	1 hour	40000 (35)	40000 (35)	2 per any 30 days
	8 hours	10000 (9)	10000 (9)	2 per any 30 days
Hydrogen Sulfide (H_2S)	1 hour	-	200 (0.140)	1 per year
	24 hours	-	40 (0.030)	1 per year
Ammonia (NH_3)	1 hour	-	1800 (2.60)	1 per year

***Clean Air Act, U.S. Environmental Protection Agency**

****Air Quality standards, PME- The Presidency of Meteorology and Environment, Saudi Arabia.**

The main goal of the present study was to determine the effect of natural and mechanical ventilation systems on indoor particulate matter and gaseous contaminates in poultry housing under climatic conditions of Saudi Arabia. The objectives were to (a) measure the particle size distribution (mass and number based) of all particulate matter; (b) determine the concentration of particulate and gaseous contaminants affecting poultry housing; (c) compare the measured concentrations to the recommended values.

MATERIALS AND METHODS

Two poultry housing facilities and one complete broiler growing cycle (production) were used for a period of five weeks, was evaluated. The field measurements started in the first week of January, 2010. Discrete (3 replicates or more) and 24 hours continuous (1 min sampling rate) measurements were taken in the end of each week. In the naturally ventilated (N.V.) poultry house, field measurements were conducted in the poultry unit at the experimental and training station of King Faisal University, Al-Ahsa, Saudi Arabia. Mechanically ventilated (M.V.) poultry house field measurements were conducted at a commercial poultry farm in Al-Ahsa, Saudi Arabia.

Poultry housing facilities

The poultry house using natural ventilation system (N.V.) having gross dimensions of 12 m wide, 20 m long, and 3.6 m high, with total floor surface area of 240 m^2 and volume of 864 m^3 as shown in Fig. (1). Poultry 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) had 24 opening windows with a total area of 20 m^2. Inside the house, 52 metal pens were arranged in four rows with two central alleys. Each pen was 1.5 m by 2.5 m and contained one feeder and one drinker. The broiler house was occupied with total complement of 1560 local breed flocks, and 30 birds were housed in each pen. The broiler house facility used in the present study was occupied by birds at a bird to total floor surface area ratio of 8 bird/m^2. Wood shavings were used as the bedding material, which was replaced every growing cycle.

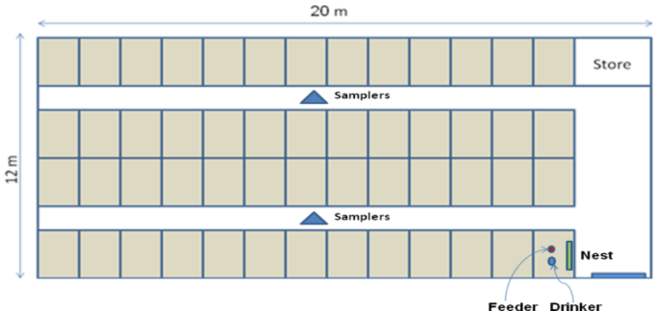

Fig. (1):Schematic diagram of the broiler house using natural ventilation system.

The poultry house using mechanical ventilation system (M.V) was taken as a sample of 16 poultry houses of a commercial poultry farm in Al-Ahsa (eastern province), Saudi Arabia. Field measurements were recorded in house No. 15. The poultry house (gable-even-span form) was equipped with an evaporative cooling system (fan-pad system), which was not in operation during the sampling period. The geometric characteristics of the house were as follows: eaves height = 4.9 m; gable height = 1.9 m; span angle = 17.6º; total width = 12 m; total length = 70 m; floor surface area = 840 m^2; volume = 3,318 m^3 as shown in Fig. (2). The outer and inner surfaces of the side walls were constructed of a metal frame covered by metal sheets and white painted concrete, and thermal insulation was placed between the inner and outer surfaces of the walls. The house was equipped with a ventilation system consisting of 3 pairs of extracting fans (single speed; 1.37 m in diameter; 38,000 m^3/h discharge), which were located on the leeward side of the house, and cooling pads were installed on the side toward the prevailing wind. The house was also equipped with two air heaters as a heat energy source, and the hot air distribution system consisted of two perforated plastic ducts located 2.0 m above the floor along the longitudinal direction of the broiler house. The microclimatic conditions of the broiler house were controlled with an automatic controller, which was used to initiate and interrupt heating and cooling and to achieve the required temperature. The broiler house was also equipped with automatic feeding and drinking systems. The house was occupied with total complement of 13,000 broiler chickens, and the ratio of birds to the total floor surface area was 15.5 bird/m^2. Sand was used as a bedding material, and the sand bedding was mixed weekly and replaced every growing cycle.

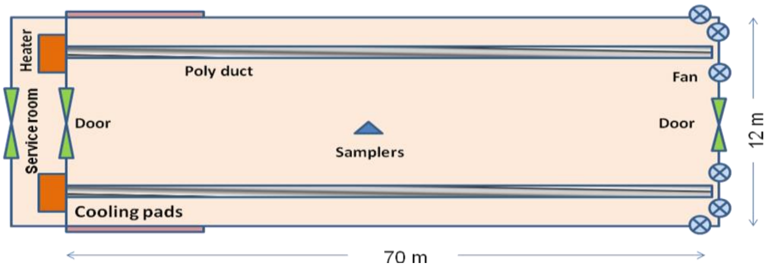

Fig. (2): Schematic diagram of the broiler house equipped with mechanical ventilation system

Measurement of environmental parameters:

The growth cycle of the birds was 35 to 42 days, beginning at day 1 and extending to the time of slaughter. Conditions within the broiler housing were managed to optimize bird health and productivity. The broiler house was regulated at an initial temperature of 32 to 35°C, and the temperature was reduced by 3°C every week until a temperature of 24±2°C was achieved at the end of third week of age. The housing were typically ventilated according to the humidity and temperature. The air exchange rate during the sampling time varied from 0.3 to 0.5 air exchanges per minute (winter). In the present study, the ventilation rate (VR) was measured using a direct measurement method to assess the performance of each ventilation fan. Namely, the time and operating status (ON-OFF) of each fan was recorded. An anemometer (Model Testo 435-2, Testo Inc. 40 White Lake Road Sparta, N.J. 07871–USA) was used to measure the air velocity traverse along the cross sectional area of the fan (Predicala and Maghirang, 2003). The average velocity was multiplied by the effective cross sectional area to obtain the mean ventilation rate of each fan. The building VR was determined by summing the operating flow rates of each fan (Hong *et al*, 2009). The air temperature, relative humidity, and carbon dioxide (CO_2) concentration were measured using a multi-functional instrument equipped with an IAQ probe to assess the indoor air quality (Testo 435-2, Testo Inc. 40 White Lake Road Sparta, N.J. 07871 – USA). Measurements were obtained every 30 s, and the average values over a 1-min interval were recorded.

Measurement of airborne dust and gaseous contaminants:

The following environmental parameters inside the broiler housing were recorded: (1) size distribution of airborne particles; (2) mass and number concentration of airborne particles; (3) concentration of toxic gases. Samplers and/or measurement devices were located at or near the center of the building to obtain a representative measurement of the entire house and to avoid overestimating or underestimating the data, as shown in Fig. 3. The size distribution and number concentration of airborne particles were monitored using a particle counter (Model GW3016A, GrayWolf Sensing Solutions, Advanced Environmental Measurements, 12 Cambridge Drive, Trumbull, CT 06611 USA). This particle counter measured particles with aerodynamic diameters ranging from 0.3 to 10 μm at an air sampling rate of 0.1 CFM (2.83 LPM). Moreover, 6 channels were used, and a counting efficiency of 50% and 100% was employed for particles with diameters of 0.3 μm and >0.45 μm, respectively. The spectrometer displayed the particle count and mass concentration readings in μg/m^3.

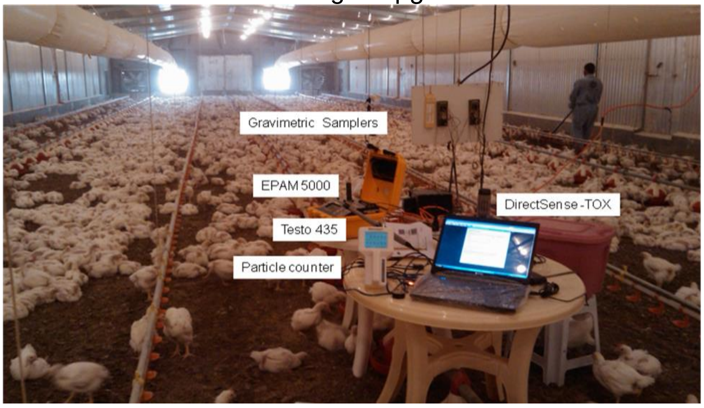

Fig. (3): Instruments used to characterize aerosol particles inside the poultry house.

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)

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

(d) Geometric standard deviation ($\square_g$ 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
$\bar{d}_p$ = 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

Particulate mass concentration was also determined by gravimetric method using the following equation:

$$\text{Conc.} = \frac{W_f - W_i}{Q * t} \tag{5}$$

Where:

Conc. = concentration (μg/m^3),
W_i = filter initial-weight (μg),
W_f = filter final-weight (μg),
Q = average sampling system air flow rate (m^3/min),
t = sampling time (min).

Real-time data and the mass concentration of TSP, PM_{10}, and $PM_{2.5}$ were measured with the aforementioned particle counter (GW3016A), gravitational filter samplers (37–mm diameter filter -Type AE inside a filter cassette, SKC Inc., Eighty Four, PA 15330, USA), and a EPAM-5000 real-time sampler manufactured by Environmental Devices Corporation (4 Wilder Drive Bldg. 15, Plaistow, NH 03865-2856, USA). The TSP mass concentration was also measured with a gravitational filter sampler (37–mm diameter filter -Type AE inside a filter cassette, SKC Inc.). The PM_{10} mass concentration was measured with a SKC Personal Environmental Monitor (PEM-PM_{10}) (at 2 L/min) (SKC Inc., Eighty Four, PA 15330, USA), and the $PM_{2.5}$ mass concentration was also measured with a SKC Personal Environmental Monitor (PEM-$PM_{2.5}$).

Real time measurements of the concentration of NH_3, SO_2, NO_2, and H_2S were performed with a multi-gas electrochemical gas sensor (TG-501 Direct-Sense TOX multi-gas monitor sensor, GRAYWOLF^{TM} Sensing Solutions, 12 Cambridge Drive, Trumbull, CT. 06611 USA). Additional measurements were obtained with RAE Systems ® Gas Detection Tubes (RAE Systems, 3775 North First Street, San Jose, CA 95134 USA), data collected by detector tubes were used as indicator for the accuracy of data collected by the multi-gas electrochemical gas sensor as a part of QA/QC concepts. A Testo 435-2 (Testo Inc. 40 White Lake Road Sparta, N.J. 07871 – USA) multi-function instrument for indoor air quality measurements was used to measure the temperature, relative humidity, CO_2 concentration, and absolute pressure. The following procedures were employed:

(1) Real time measuring of the total mass concentration of particulate matter and toxic gases was conducted at a sampling rate of 1 min.
(2) Measurements from the gravimetric filters and gas detection tubes were obtained in triplicate.
(3) The measurement methodology and protocol were developed in the lab and applied in the field, according to the procedure of Almuhanna (2007) and Almuhanna *et al*. (2008).

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

RESULTS AND DISCUSSION

Microclimatic conditions of the broiler housing

The microclimatic conditions of the broiler house which used natural ventilation system (N.V.) during the experimental period varied from hour to hour and day to another because the climatic conditions of the house were dependent only upon the climatic conditions of the external environment. Therefore, the air temperature inside the broiler house varied between 23.9ºC and 29.0ºC, and the average indoor air temperature was 26.3ºC (± 1.2ºC). Alternatively, the outside air temperature ranged from 15.2ºC to 29.9ºC, and the average outdoor air temperature was 22.5ºC (± 7.5ºC). The relative humidity inside the broiler house ranged from 21.2% to 31.2%, and the average relative humidity was 25.2% (± 5.0%). While, the relative humidity of the outside air ranged from 20.7% to 49.4%, with an average of 33.1% (± 12%).

The microclimatic conditions inside the broiler house which used mechanical ventilation system (M.V.) were compared with the external climatic conditions to determine the effectiveness of the environmental control system. Fluctuations in the air temperature surrounding the birds play an important role in their growth rate, development, and productivity. Fluctuations in air temperature caused by the ventilation control board were observed inside the broiler house. Changes in the air temperature and relative humidity inside the broiler house during the growth cycle are shown as a function of time (week) in Fig. (4). Indoor air temperature varied between 23.8ºC and 34.4ºC, with an average air temperature of 30.0ºC (± 4.1ºC). In contrast, the outside air temperature ranged from 15.2ºC to 29.9ºC, with average temperature of 22.5ºC. Using the ventilation control board, the indoor air temperature was gradually decreased according to the age of the birds, as revealed in Fig. (4). Variation in the air relative humidity inside the broiler house during the experimental period as a function of the growth cycle (in week) is also shown in Fig. (4). Relative humidity ranged from 22.2% to 41.04%, with an average air relative humidity of 32.86% (± 7.82%). Variations in the relative humidity occurred at the peak of the heating cycle, particularly in the first three weeks of the growth cycle. During the last two weeks of the growth cycle, the relative humidity increased because the air temperature was reduced according to the required air temperature and the age of the birds.

Particle mass concentration

The weekly average concentration of TSP (inhalable dust) inside the poultry housing which used N.V. and M.V. systems is summarized and listed in Table (3). The weekly average concentration of TSP inside the two broiler housing (used N.V. and M.V. system) during the experimental period, respectively, was 12.47 and 4.61 mg/m^3. Consequently, the total suspended particle concentration in the M.V. broiler house decreased by 63.03% due to the air exchange rate of the ventilation system, which reduced the concentration of inside air contaminates. However, the average concentration of TSP in both houses was greater than the acceptable range of the threshold for indoor air contaminants in livestock houses (3.4 - 3.7 mg/m^3) which recommended by Wathes (1994) and Donham and Cumro (1999a).

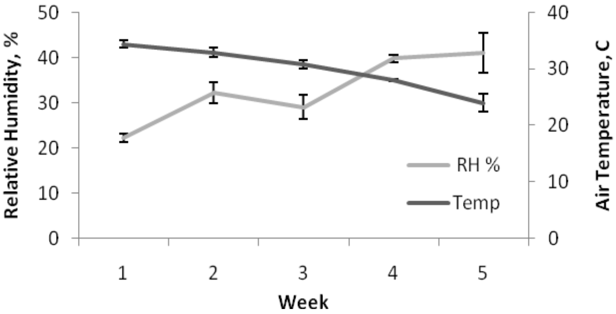

Fig. (4): Changes in the air temperature and relative humidity inside the broiler house as a function of the growth cycle during the experimental period.

The weekly average PM_{10} concentrations (thoracic dust) inside the two different poultry housing (N.V. and M.V.) during the experimental period were 4.81 and 2.26 mg/m^3, respectively. Whereas, the weekly average $PM_{2.5}$ concentrations (thoracic dust) inside the two different poultry housing (N.V. and M.V.) during the experimental period, respectively, were 0.18 and 0.09 mg/m^3. Consequently, the ventilating the poultry house led to decrease the concentrations of thoracic (PM_{10} and $PM_{2.5}$) by 53.01% and 50%, respectively.

Table (3): 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[**]
N.V.	12.47 a	5.2	5.5-18.11		4.81 a	1.63	2.43-6.14		0.18 a	0.06	0.11-0.24
M.V.	4.61 b	3.1	2.11-9.61		2.26 b	1.27	1.19-4.29		0.09 b	0.05	0.04-0.16

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

[**] **At the M.V. house, maximum values were observed in week 5.**

The TSP, PM_{10}, and $PM_{2.5}$ concentrations inside the poultry house which used the mechanical ventilation system (M.V.) were determined every week during the experimental period, and the results are listed in Table (4). The dust concentration varied from week to week according to the amount of dust concentration, which was associated with the age of the birds. Fig. (5) shows the change in the airborne dust concentration inside the M.V. broiler house during the air exchange process over 60 successive minutes. Fluctuations in the TSP concentration (inhalable dust) caused by the ventilation control board were observed inside the M.V. poultry house. The TSP concentration varied over time during each ventilation cycle, and the highest concentration of TSP was observed before the ventilation system was turned on. Alternatively, the lowest TSP concentration inside the broiler house was observed before the ventilation system was switched off. The effect of the air exchange rate on different sizes of airborne particles was examined, and the results are revealed in Fig. (6). The smallest airborne particles (TSP, PM_{10}, and $PM_{2.5}$) were slightly affected by the air exchange rate during the experimental period.

Table (4): Weekly average dust concentrations (mg/m^3) during the growth cycle inside the broiler house used mechanical ventilation system.

Week	TSP		PM_{10}		$PM_{2.5}$	
	Mean[*]	SD	Mean[*]	SD	Mean[*]	SD
1	3.35 a, b	0.99	1.67 a,b	0.36	0.05 a	0.01
2	2.44 a	0.91	1.45 a	0.39	0.09 a,b	0.01
3	2.11 a	0.98	1.2 a	0.46	0.04 a	0.02
4	5.56 b	2.93	2.7 b	1.10	0.11 b	0.02
5	9.61 c	4.44	4.29 c	1.59	0.16 c	0.06

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

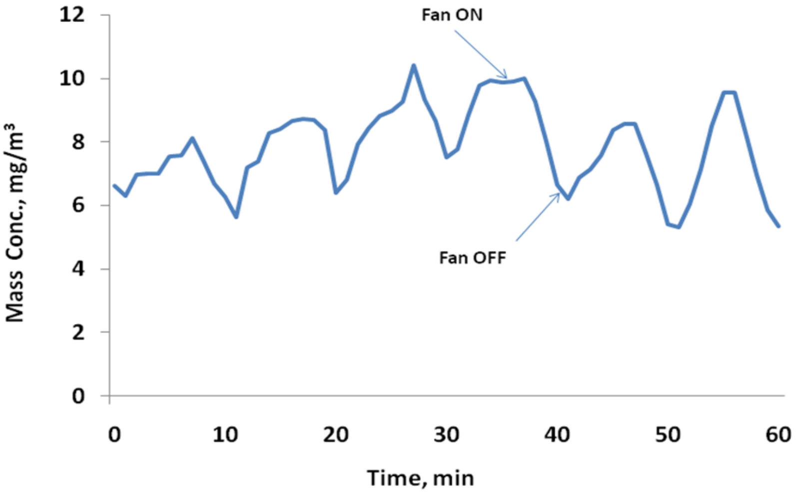

Fig. (5): **Cyclic changes in airborne dust concentrations inside the broiler house used mechanical ventilation system.**

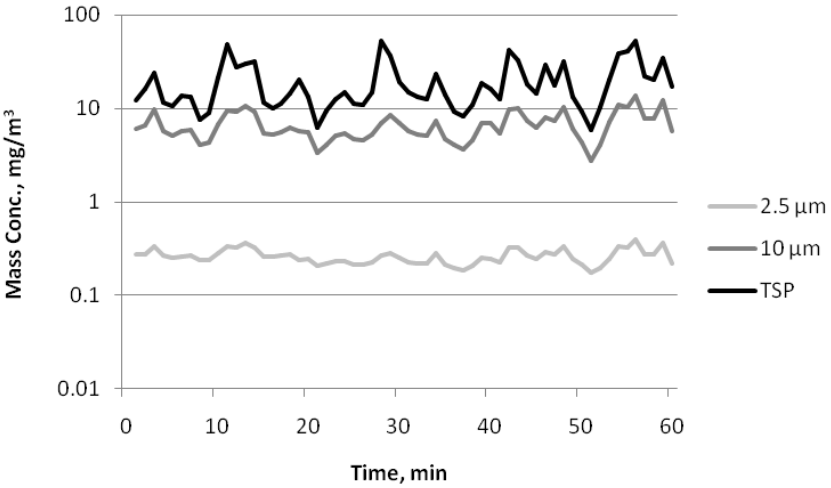

Fig. (6): **Effect of air exchange on particles with different sizes inside the broiler house used mechanical ventilation system.**

Particle size distribution

The size distribution, number, and mass concentration of airborne particles were monitored using the aforementioned PC spectrometer (GW3016A particle counter). The particle size distribution inside the broiler houses is summarized in Table (5) and Table (6), respectively.

Table (5): Particles size statistics for the poultry house used natural ventilation system (on a number and mass basis).

Parameter	Number Distribution				Mass Distribution		
	Mean	SD	Range		Mean	SD	Range
Mean Diameter (µm)	1.80	0.29	1.49-2.19		6.78	0.03	6.75-6.82
Standard deviation (µm)	2.14	0.26	1.86-2.49		1.62	0.04	1.57-1.67
Geometric Mean Diameter (µm)	1.40	0.18	1.19-1.64		8.63	0.07	8.55-8.71
Geometric Standard Deviation	2.70	0.16	2.53-2.90		1.59	0.02	1.57-1.62

Table (6): Particle statistics of the poultry house used mechanical ventilation system (on a number and mass basis).

Parameter	Number Distribution				Mass Distribution		
	Mean	SD	Range		Mean	SD	Range
Mean Diameter (µm)	1.53	0.30	0.95-1.89		6.65	0.11	6.38-6.8
Standard deviation (µm)	1.81	0.23	1.34-2.06		1.72	0.12	1.56-1.99
Geometric Mean Diameter(µm)	1.29	0.26	0.81-1.57		8.38	0.26	7.79-8.70
Geometric Standard Deviation	2.49	0.14	2.18-2.64		1.64	0.08	1.58-1.81

The geometric mean diameter (GMD) based on the number distribution inside the two broiler housing (N.V. and M.V.) was 1.4 and 1.29 µm, and the geometric standard deviation (GSD) was 2.70 and 2.49, respectively. Thus, based on the number concentration, particles size with a diameter of 1.3 micrometer was the most abundant type of particle in both housing. Based on the mass distribution inside the both housing (N.V. and M.V.), the geometric mean diameter (GMD) was 8.63 and 8.38 µm, and the geometric standard deviation (GSD) inside the two housing was 1.59 and 1.64, respectively. The particles size distribution inside the two housing based on the mass concentration is illustrated in Fig. (7). For all particles sizes, the concentration in broiler house (N.V.) was higher, specifically for large particles, than broiler house (M.V.) which indicating that, the ventilation system able to remove large particles from air. It has been observed that the GMD based on the mass from this study are significantly smaller than those that have been reported in the literature. Lacey *et al*. (2003) and Redwine *et al*. (2002) reported that mass median diameter (MMD) approximately equal the geometric mean diameter (GMD) based on the mass for lognormal distribution (26 µm and 24.0 - 26.7 respectively) of broiler PM.

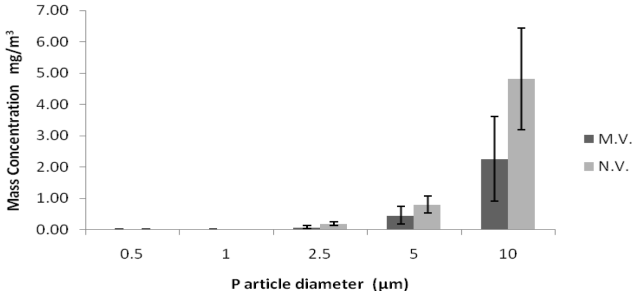

Fig. (7): Particle size distribution inside the two broiler housing (N.V. and M.V.), based on the mass concentration of particles.

According to Redwine *et al*. (2002), the mass percentage of TSP classified as PM_{10} at broiler houses varied from 2.72 % to 8.40 %. Therefore, it is suspected that the limitation of the particle counter and its capability of measuring up to 10 µm only may not be the best suitable for collecting the broiler PM samples for PSD analyses. Further investigation is ongoing to confirm these results and to calculate portion of the total of particles not measured by the instrument.

Gaseous contamination

The concentration of ammonia (NH_3) and other gases (CO_2, SO_2, NO_2, and H_2S) was measured during the growth cycle, and the experimental data are listed in Table (8). Among other gases available in the poultry housing, ammonia was the most abundant toxic gas. Toxic gas measurements inside the poultry house (M.V.) were executed during the first 35 days of the growth cycle, and an overall increase in the ammonia concentration was observed over time. Alternatively, the ammonia concentration in the poultry house (N.V.) showed nearly stable readings. The average concentration of ammonia gas (3.52 ppm) inside the poultry house (M.V.) significantly ($P \leq 0.05$) greater than the mean value (0.74 ppm) inside the poultry house (N.V.) as revealed in Table (8). The average concentration in both housing was lower than the thresholds for indoor air contaminants in human and livestock housing (7 ppm for human, and 11 ppm for animals) proposed by Donham and Cumro (1999b); Donham *et al*. (2002); Donham *et al*. (2000). However, the concentration of ammonia gas inside the broiler house (M.V.) exceeded this limit and reached 25.2 ppm at week 5 of the growth cycle, due to the relatively large number of birds and high live weight as compared with the broiler house (N.V).

The average concentration of hydrogen sulfide (H_2S) inside the both broiler housing (N.V. and M.V.) was 0.01 ppm as shown in Table (7). The average concentration in both housing was also lower than the threshold for indoor air contaminants in livestock housing units (5 ppm) as proposed by Donham (1993); Donham (1995); Donham and Cumro (1999b); Donham *et al*. (2000).

Table (7): The concentrations of NH_3, H_2S, CO_2, SO_2, and NO_2 inside the two poultry housing (N. V. and M. V.) during the experimental period

	NH_3		H_2S		CO_2		SO_2		NO_2	
	N. V.	**M. V.**	**N. V.**	**M. V.**	**N. V.**	**M. V.**	**N. V.**	**M. V.**	**N. V.**	**M. V.**
Mean[*]	0.74 a	3.52 b	0.01 a	0.01 a	434.6 a	786.3 a	0.04 a	0.08 b	0.02 a	0.02 a
SD	0.41	5.26	0.01	0.01	49.7	353.4	0.05	0.06	0.01	0.01
Max	1.08	25.23	0.01	0.01	497.9	1405.4	0.10	0.59	0.04	0.06

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

The average concentration of carbon dioxide gas (CO_2) inside the broiler housing (M.V. and N.V.), respectively, was 786.3 and 434.6 ppm which did not significantly differ, as shown in Table (7). The average concentration in both housing was equal to the threshold for indoor air contaminants in livestock housing units (1540 ppm) as proposed by Donham *et al*. (2000). As shown in Table (7), the average concentration of sulfur dioxide (SO_2) inside the two poultry housing (M.V. and N.V.) was 0.08 and 0.04 ppm, respectively. The difference between them was significant ($P \leq 0.05$). However, the average concentration of nitrogen dioxide (NO_2) inside the both broiler housing (M.V. and N.V.) was 0.02 and 0.02 ppm, respectively. Therefore, the difference was not significant ($P > 0.05$).

The weekly average ammonia concentration during the growth cycle (5 weeks) in the house (M.V.) is shown in Table (8). The ammonia concentration gradually increased from week 1 with 0.07 ppm until reached a concentration of 0.66 ppm at the end of week 2. At the end of week 3 the concentration of ammonia decreased until approached a value of 0.29 ppm. At the beginning of week 4, the ammonia concentration increased till reached a maximum mean value of 13.56 ppm at the end of growth cycle. The maximum concentration of ammonia was 25.2 ppm and was observed during the last 5 days of the growth cycle.

Table (8): Weekly average ammonia concentration during the growth cycle (5 weeks)

Week	Mean[*]	SD	Max
1	0.07 a	0.02	0.09
2	0.66 a	0.08	0.71
3	0.29 a	0.25	0.91
4	7.46 b	1.76	23.35
5	13.56 c	2.06	25.23

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

The ammonia concentration in the broiler house (M.V.) was continuously monitored for a 24-hr period, and the results are plotted in Fig. (8). The ventilation system efficiently reduced the ammonia concentration during the daytime, when the extracting fan was operated for a long periods of time to remove excess heat, whereas at nighttime the temperature of indoor air decrease and the ventilation system was not operated. This will cause an increase in ammonia gas concentration. As a result, it is expected that the lowest concentration of ammonia and other particulate contaminants will be at the beginning of daylight time, where the highest concentration occurred at the nighttime. The ammonia concentration in the poultry house (M.V.) was strongly affected by the air exchange rate. Cyclic changes in the ammonia concentration can be attributed to the use of the ventilation system, as show in Fig. (9).

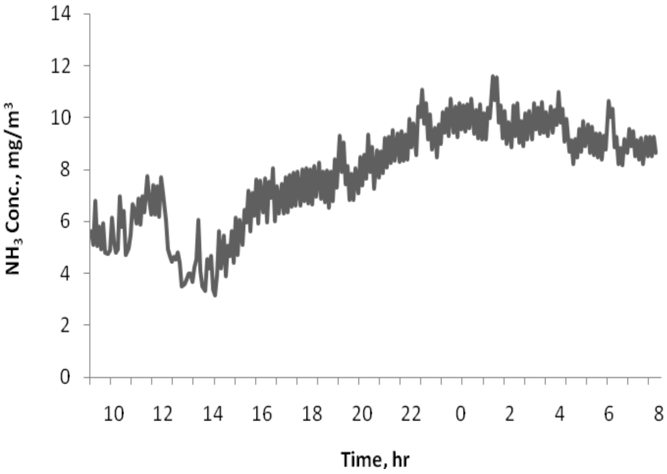

Fig. (8): Continuous measurement of the ammonia concentration in the broiler house (M.V.) during a 24-hr period.

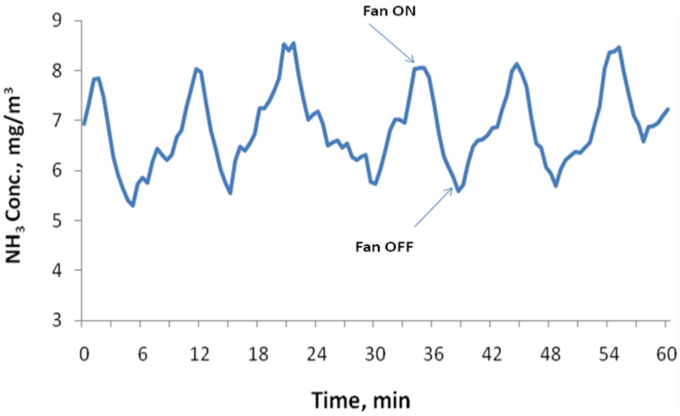

Fig. (9): Cyclic changes in the ammonia concentration due to ventilation cycles.

Conclusions

The present study was conducted to determine the effect of natural and mechanical ventilation systems on air contaminants (particles size distribution and concentration of airborne particles and toxic gases) of poultry housing under eastern province of Saudi Arabia climatic conditions. Two different poultry housing equipped with natural (N.V.) and mechanical ventilation systems (M.V.) were functioned during the experimental period. During the study, discrete, weekly sampling and continuous 24-h monitoring were carried out during each week of the growth cycle.

From the obtained results of the present study, the following conclusions could be drawn:

- The weekly average mean total suspended particles concentration (TSP) in the two broiler housing (N.V. and M.V.), which is equivalent to the inhalable dust content, was 12.47 and 4.61 mg/m^3, respectively. Values for both were higher than the suggested threshold for indoor air contaminants in livestock housing units. The weekly average particulate matter with a diameter less than or equal to 10 µm (PM_{10}) concentration in the broiler house (N.V. and M.V.), which is equivalent to the thoracic dust content, respectively, was 4.81 and 2.26 mg/m^3. Whereas, the weekly average $PM_{2.5}$ concentration in the broiler housing (N.V. and M.V.), which is equivalent to the respirable dust content, was 0.18 and 0.09 mg/m^3, respectively. The particulate matter with a diameter less than or equal to 2.5 µm ($PM_{2.5}$) concentration for both housing were lower than the suggested threshold for indoor air contaminants in livestock housing**.**
- The obtained results of particles size distribution from the broiler housing (N.V. and M.V.), revealed that, the geometric mean diameter (GMD) based on the mass concentration of particles was 8.63 and 8.38 µm, respectively. Alternatively, based on the number concentration of particles, the GMD was 1.4 and 1.29 µm, respectively, which suggests that particles with a diameter of 8.5 µm (mass) and 1 µm (number) were dominant in both housing.
- The measured concentration of toxic gases (NH_3, CO_2, SO_2, NO_2, and H_2S) revealed that, the ammonia gas was the most abundant toxic gas in both housing, however, in the broiler house (M.V.) high concentrations of ammonia gas were not observed until the second half of the growth cycle. The majority of toxic gases did not exceed the suggested thresholds. Moreover, the concentration of airborne dust and toxic gases in the boiler house (M.V.) was strongly affected by the air exchange rate.

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REFERENCES

Al Homidan, A.; and J. F. Robertson (2003) "Effect of litter type and stocking density on ammonia, dust concentration and broiler performance" Spring meeting of the WPSA 2003 UK branch.

Almuhanna, E. A. (2007) "Dust control in livestock buildings with electrostatically charged water spray" PhD thesis, Manhattan, Kans.: Kansas State University.

Almuhanna, E. A.; R. G. Maghirang; J. P. Murphy; and L. E. Erickson (2008) "Effectiveness of electro-statically charged water spray in reducing dust concentration in enclosed spaces" Transactions of the ASABE 51(1):279-286.

Almuhanna, E. A.; R. G. Maghirang; J. P. Murphy; and L. E. Erickson (2009) "Laboratory scale electro-statically assisted wet scrubber for controlling dust in livestock buildings" Applied Engineering in Agriculture 25(5):745-750.

Donham, K. J. (1993) "Respiratory disease hazards to workers in livestock and poultry confinement structures" Seminars in Resp. Med. 14(1):4-59.

Donham, K. J. (1995) "Respiratory dysfunction in swine production facility workers: dose-response relationships of environmental exposures and pulmonary function" Am J Inc Med 27:405-418.

Donham, K. J.; and D. Cumro (1999b) "Synergistic health effects of ammonia and dust exposure" International Symposium on "Dust Control in Animal Production Facilities" Scandinavian Congress Center, Aarhus, Denmark: Danish Institute of Agricultural Sciences (DIAS), Research Centre Bygholm.

Donham, K. J.; and D. Cumro (1999a) "Setting maximum dust exposure levels for people and animals in livestock facilities In: Proc. International Symposium on dust Control in Animal Production Facilities" pp.93-109. Horsens, Denmark: Danish Institute of Agricultural Sciences.

Donham, K. J.; and D. Cumro (2002) "Effects of Dust and Ammonia on the Occupational Health Effects of Poultry Workers" Journal of Agromedicine, Vol. 8(2):57-76.

Donham, K. J.; D. Cumro; and S. J. Reynolds (2002) "Synergistic Effects of Dust and Ammonia on the Occupational Health Effects of Poultry Workers" Journal of Agromedicine, Vol. 8(2):57-76.

Donham, K. J.; D. Cumro; S. J. Reynolds; J. A. Merchant (2000) "Dose-response relationships between occupational aerosol exposures and cross-shift declines of lung function in poultry workers: recommendations for exposure limits" J. Occup Environ Med 42(3):260-269.

Ellen, H. H.; R. W. Bottcher; E. Von Wachenfelt; and H. Takai (2000) "Dust levels and control methods in poultry houses" Journal of Agricultural Safety and Health 6(4): 275-282.

EPA (2004) "National Emission Inventory-Ammonia Emissions from Animal Husbandry" Draft report.

EPA. (1999) "Sampling of ambient air for total suspended particulate matter (SPM) and using high volume (HV) sampler" Center for Environmental Research Information Office of Research and Development. U.S. Environmental Protection Agency. Cincinnati, OH 45268. June 1999.

Galloway, J. N.; and E. B Cowling (2002) "Reactive nitrogen and the world: 200 years of change" Ambio, 31:64–71.

Hartung, J.; J. Seedorf; M. Schroder; K. H. Linkert; and C. M. Wathes (1998) "Concentrations and emissions of airborne dust in livestock buildings in northern Europe" Journal of Agricultural Engineering Research 70:59-77.

Hinds, W. C. (1999) "Aerosol technology" New York: John Wiley & Sons.

Hong, Li; Hongwei Xin; Robert Burns; Larry Jacobson; Sally Noll; Steven Hoff; Jay Harmon; Jacek Koziel; and Ipek Celen (2009) "Air Emissions from Tom and Hen Turkey Houses in the U.S. Midwest" ASABE Annual International Meeting. Reno, Nevada. June 21 – June 24, 2009.

Lacey, R. E.; J. S. Redwine; and C. B. Parnell (2003) "Particulate matter and ammonia emission factors for tunnel-ventilated broiler production houses in the southern USA" Transactions of the ASAE 46 (4):1203-1214.

Latenser, B. A.; and T. A. Loucktong (2000) "Anhydrous ammonia burns: case presentation and literature review" J. Burn Care Rehabil, 21:40-42.

Leduce, D. (1992) "Acute and long-term respiratory damage following inhalation of ammonia" Thorax 46:755-757

Lim, T. T., A. Heber, J. Q. Ni, J. Gallien, and H. Xin (2003) "Air quality measurements at a laying hen house: particulate matter concentrations and emissions" Air Pollution from Agricultural Operations III Conference, ASAE Publication No. 701P1403. North Carolina.: ASAE.

Liu, Z., L. Wang, and D.B. Beasley (2006) "A review of emission models of ammonia released from broiler houses" ASABE Paper No.064101. ASABE Annual International Meeting, Portland, OR

Mitchell, B. W., L. J. Richardson, J. L. Wilson, and C. L. Hofacre (2004) "Application of an electrostatic space charge system for dust, ammonia, and pathogen reduction in broiler breeder house" Applied Engineering in Agriculture, American Society of Agricultural Engineers, 20(1): 87-93.

NOAA/ESRL. (2011) Trends in Carbon Dioxide. NOAA/ESRL. Available at: http://www.esrl.noaa.gov/gmd/ccgg/trends/. Retrieved 2011-1-17.

Patni, N. K.; and S. P. Clark (1991) "Transient hazardous conditions in animal buildings due to manure gas released during slurry mixing" Applied Engineering in Agriculture, American Society of Agricultural Engineers, 7(4):478.

PME. (2001) "General Environmental Law and Rules for Implementation" The Presidency of Meteorology and Environment, Saudi Arabia

Predicala, B. Z.; and R. G. Maghirang (2003) "Numerical simulation of particulate matter emissions from mechanically ventilated swine barns" Transactions of the ASAE. 46(6):1685-1694.

Redwine, J. S.; R. E. Lacey; S. Mukhtar; and J. B. Carey (2002) "Concentration and emission of ammonia and particulate matter in tunnel-ventilated broiler houses under summer conditions in Texas" Transactions of the ASAE. Vol. 45(4): 1101–1109.

Reynolds, S. J.; K.J. Donham; P. Whitten; J. A. Merchant; L. F. Burmeister; and W. J. Popendorf (1996) "Longitudinal evaluation of dose-response relationships for environmental exposures and pulmonary function in swine production workers. Am J. Inc. Med 29:33-40.

Ritz, C. W.; B. W. Mitchell; B. D. Fairchild; M. Czarick; and J. W. Worley (2006) "Improving In-House Air Quality in Broiler Production Facilities Using an Electrostatic Space Charge System" J. App. Poultry Res. 15:333–340.

Roumeliotis, T.; and B. Van Heyst (2007) "Size fractionated particulate matter emissions from a broiler house in southern Ontario, Canada" Sci. Total Environ., 383: 174-182

Schnoor, J. L.; P. S. Thorne; and W. Powers (2002) "Fate and Transport of Air Pollutants from CAFOs" Pp 86-100 in Iowa Concentrated Animal Feeding Operation Air Quality Study.

Van Aardenne, J. A.; F. J. Dentener; C. G. M. Klijn Goldewijk; J. Lelieveld; and J. G. J. Olivier (2001) "A high resolution dataset of historical anthropogenic trace gas emissions for the period 1890-1990" Global Biogeochemical Cycles 15:909.

Visser, M., B. Fairchild, M. Czarick, M. Lacy, J. Worley, S. Thompson, J. Kastner, C. Ritz, and L. Naeher (2006) "Fine particulate matter measurements inside and outside tunnel ventilated broiler houses" J. App. Poultry Res. 15: 394-405.

Wathes, C.M. (1994) "Air and surface hygiene, in livestock housing" 123-148 Wallingford: CAB International

Whyte, R.T.; A.M. Williamson; and J. Lacey (1993) "Air pollutant and respiratory impairment of poultry house stockmen, In: Livestock Environment" Proceedings 4th International Symposium, E, Collins and C. Boon (ed.): 709-717. St. Joseph, MI: ASAE.

تـأثير نظـم التهويـة الطبيعيـة والميكانيكيـة علـى ملوثـات هـواء مسـاكن الـدجاج فـى الإحسـاء (المنطقة الشرقية) بالمملكة العربية السعودية

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تهدف هذه الدراسة الحقلية إلى تحديد تأثير نظم التهوية الطبيعية والميكانيكية على ملوثات هواء مساكن الدجاج تحت الظروف المناخية للمنطقة الشرقية بالمملكة العربية السعودية. تم إجراء الدراسة والقياسات المختلفة داخل أثنين من مساكن دجاج اللحم أحدهما يعتمد على التهوية الطبيعية والآخر على التهوية الميكانيكية مع نظام كامل للتبريد بالتبخير والتحكم البيئى. تم قياس توزيع حجم الذرات الدقيقة وتركيز الغازات المختلفة داخل المسكنين المختلفين فى نظم التهوية.

أهم النتائج المتحصل عليها من هذه الدراسة البحثية يمكن تلخيصها كما يلى:

(1) أن المتوسط الأسبوعى لتركيز الجزيئات المعلقة فى هواء كلاً من مسكنين دجاج اللحم (أحدهما يعتمد على التهوية الطبيعية والآخر على التهوية الميكانيكية) والذى يعادل محتوى الأتربة المستنشقه كان 12.47 ، 4.61 ملجم/م^3 على الترتيب وهذه القيم كانت من المقترحات الأولية للمواد الملوثة للهواء الداخلى لوحدات مساكن الماشية. وكان المتوسط الأسبوعى لتركيز الجزئيات العالقة مع قطر أقل من أو يساوى 10 ميكرومتر فى كل من المسكنين والذى يعادل محتوى الأتربة داخل الجهاز التنفسى للدجاج 4.81 ، 2.26 ملجم/م^3 بينما كان التركيز مع قطر أقل من أو يساوى 2.5 ميكرومتر والذى يعادل محتوى الأتربه لهواء التنفس فى كل من البيتين 0.18 ، 0.09 ملحم/م^3 على الترتيب. وكان تركيز هذه الجزئيات عند قطر أقل من أو يساوى 2.5 ميكرومتر فى كل من البيتين أقل من المستويات المقترحة للمواد الملوثه للهواء الداخلى لوحدات مساكن الماشية.

(2) أظهرت نتائج التوزيع الحجمى للجزيئات المتحصل عليها من كل من المسكنين أن متوسط القطر الهندسى الذى يعتمد على أساس تركيز الكتلة كان 8.63 ، 8.38 ميكرومتر على الترتيب. أما الذى يعتمد على تركيز الجزيئات كان 1.4 ، 1.29 ميكرومتر على الترتيب والذى يوضح أن الجزيئات السائده فى كل من البيتين كانت عند قطر 8.5 ميكرومتر (كتلة) و1 ميكرومتر (عدد).

(3) أظهر التركيز المقاس للغازات السامة أن غاز الأمونيا كان أكثر الغازات السامه وفرة على الرغم من أن البيت المزود بنظام التهويه الميكانيكية لم يلاحظ فيه تركيز عالى لغاز الأمونيا حتى النصف الثانى من دورة النمو وكان تركيز الأتربة التى يحملها الهواء والغازات السامة فى هذا البيت يتأثر بشكل كبير بمعدل تبادل الهواء.

قام بتحكيم البحث

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