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Prediction of Ammonia Production Levels in Broiler Houses by Mass Balance under Forced and Natural Ventilation Conditions

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Abstract

One of the main contaminant in animal houses is ammonia. As being a greenhouse gas ammonia emission from animal houses influence the atmospheric environment which then triggers global warming. A calculation method for predicting the ammonia gas production rate inside an animal house is developed. This method is based on mass balance equilibrium. Relations between inside and outside environmental conditions and the ammonia concentrations has been observed. Confirmation of the developed equation has been tested in some selected broiler houses raised on litter and under natural and forced ventilation conditions. A portable gas detector is used for ammonia concentration measurements. Measurements of inside and outside environmental conditions was done by a logging device. Equation are developed by MathLab software. Then the mass balance software is tested in some poultry houses with different ventilation conditions. The ammonia production rate inside the broiler house was calculated as 7.98 mg.s-1 under forced ventilation, and it was 26.63 mg.s-1 under natural ventilation conditions. The developed approach can be useful to farmers, agricultural or environmental engineers and for the smart agriculture technologies.

Keywords
Ammonia, Broiler, Mathematical model, Mass balance, emission.

Doğal ve Yapay Havalandırma Koşullarında Kasaplık Piliç Kümeslerinde Kütle Dengesi İlkesine göre Kümes içi Amonyak Gazı Üretim Seviyelerinin Belirlenmesi

Özet

Amonyak gazı kümes içerisindeki en önemli hava kirleticilerinden biridir. Sera gazlarından birisi olması sebebiyle hayvan barınaklarındaki amonyak emisyonu atmosferik çevreyi etkilemektedir ve ayrıca küresel ısınmayı da tetiklemektedir. Hayvan barınakları içerisinde üretilen amonyak gazı seviyelerini tahmin edebilecek bir hesaplama programı geliştirilmiştir. Bu yöntem kütle transferi ilkesine dayanmaktadır. Barınak içi ve dışı çevresel koşullar ve kümes içi amonyak gazı konsantrasyonları gözlemlenmiştir. Geliştirilen eşitliklerin doğruluğu altlık üzeri kasaplık piliç yetiştiriciliği yapılan ve kümes içerisinde doğal ve yapay havalandırma sistemleri uygulanan bazı kümeslerde test edilmiştir. Kümes içi amonyak konsantrasyonlarının ölçülmesi ve kayıt edilmesinde mobil bir gaz detektörü kullanılmıştır. Kümes içi ve dış ortam çevresel koşullar bir veri toplayıcı ve kayıt edici cihaz sayesinde ölçülüp kayıt edilmiştir. Kütle transferi ilkesin bağlı ilgili eşitlikler MathLab yazılımı ile geliştirilmiştir. Daha sonra geliştirilen bu hesaplama programı farklı havalandırma koşulları uygulanan kümeslerde de test edilmiştir. Kütle transferi ilkesine göre geliştirilen bu hesaplama programı sayesinde yapay havalandırma uygulanan kümeslerde amonyak gazı üretim değeri 7.98 mg.s^{-1} ve doğal havalandırma uygulanan kümeslerde 26.63 mg.s-1 olarak hesaplanmıştır. Geliştirilen bu yöntem yetiştiricilere, çiftçilere, ziraat mühendislerine ve çevre mühendislerine akıllı tarım teknolojileri kapsamında faydalı olabilir.

Anahtar Kelimeler
Amonyak, Broyler, Matematiksel model, Kütle dengesi, Emisyon.

1. INTRODUCTION

Animal production under intensive breeding conditions is a need for today's world conditions. Mainly some noxious gases like ammonia, hydrogen sulfide, carbon dioxide and methane are also produced in those animal houses, as well (Gürdil., 1998). Dust becomes from the feed and by activity of the animal causing an air movement for aeration of the dust. Noxious gases are produced from the anaerobic microbial degradation of wastes by metabolic processes of animals.

Concerning the results of the studies ammonia (NH3) is said to be the major air contaminant in poultry houses (Gürdil et al., 2001a). The ammonia produced in animal barns influence the environment of animals and workers and the chemical and physical environment for the building materials (Jeppsson, 2000). Ammonia concentration, thermal and humid conditions in the building can influence the state of health of workers and animals, as well as the durability of building materials (Gürdil et al., 2001b). High concentrations of NH3 inside the animal houses represent potential health hazards to humans and animals (Groot Koerkamp, 1994). NH3 can cause acute and chronic respiratory diseases, and allergic responses in exposed workers (Jeppsson, 2000). The concentration of ammonia also affects the growth rate, feed efficiency and mortality of the animals (Andersson, 1994).

In this research a calculation method is developed for estimating the production level of ammonia gas inside. This calculation bases on mass balance equilibrium. Dependency of the variations in inside air temperature and relative humidity values has been investigated.

2. MATERIAL AND METHOD

For developing and testing the mass balance equation some measurements were done in poultry houses. A portable gas detector (Oldham) is used for ammonia concentration measurements. Ammonia measurements were always done at bird level. Measurements of inside and outside environmental conditions like inside and outside air temperature and relative humidity values were done by a logging device. Air densities for inside and outside air conditions were obtained from psychometric chart. When all the necessary data gathered together then the required equations are developed by MathLab software.

Ammonia gas production by mass balance in an animal house can be:

$$\mathrm{Art} \,.\, \mathrm{dt} + \mathrm{Va} \,.\, \mathrm{kao} \,.\, \mathrm{dt} = \mathrm{Va} \,.\, \mathrm{kai} \,.\, \mathrm{dt} + \mathrm{O} \,.\, \mathrm{dkai} \qquad (1)$$

where;

Art : Ammonia gas production (mg.s-1)
Va : Rate of air flow (m3.s-1)
kao : Outside air NH3 concentration (mg.m-3)
kai : Inside air NH3 concentration (mg.m-3)
O : Dimensional volume of the barn (m3)
t : Time (s)

When we solve the equation for dt

$$A_{\mathrm{rt}} + \mathrm{V}_{\mathrm{a}} \,.\, \mathrm{k}_{\mathrm{ao}} = \mathrm{V}_{\mathrm{a}} \,.\, \mathrm{k}_{\mathrm{ai}} + \mathrm{O} \,.\, \frac{\mathrm{dk}_{\mathrm{ai}}}{\mathrm{dt}} \qquad (2)$$

then

$$\int_{ki1}^{ki2} \frac{O}{\mathrm{A}_{\mathrm{rt}} + \mathrm{V}_{\mathrm{a}} \,.\, \mathrm{k}_{\mathrm{ao}} - \mathrm{V}_{\mathrm{a}} \,.\, \mathrm{k}_{\mathrm{ai}}} \mathrm{dk}_{\mathrm{ai}} = \int_{\mathrm{t1}}^{\mathrm{t2}} \mathrm{dt} \qquad (3)$$

where;

t1 : Start time (s)
t2 : Time relapsed (s)
ki1 : NH3 concentration in inside at time t1 (mg.m-3)
ki2 : NH3 concentration in inside air at time t2 (mg.m-3)

by integrating both sides:

$$\int_{ki1}^{ki2} \frac{O}{A_{rt} + V_a.k_{ao} - V_a.k_{ai}} .dk_{ai} = \frac{-\ln(A_{rt} + V_a.k_{ao} - k_{i2}.V_a)}{V_a} .O + \frac{\ln(A_{rt} + V_a.k_{ao} - k_{i1}.V_a)}{V_a} .O \qquad (4)$$

and

$$\int_{t_1}^{t_2} dt = t_2 - t_1 \tag{5}$$

then the ammonia gas production level is;

$$A_{rt} = \exp\left[\frac{\left[\ln\left[V_a . \frac{(-k_{i2}+k_{i1})}{\left[-1+\exp\left[V_a . \frac{(-t_2+t_1)}{O}\right]\right]}\right] .O - t_2 .V_a + t_1 .V_a\right]}{O}\right] - V_a .k_{ao} + k_{i2} .V_a \tag{6}$$

This is the production rate of NH3 in (mg.s-1) inside the broiler house regarding to the mass balance. This developed equation enables us to predict the rate of NH3 produced inside by defining the required parameters.

Va is the ventilation rate in forced ventilated barn. If there is natural ventilation inside the house the air flow rate inside the animal barn can be calculated by the inside and outside air environmental parameters for balancing total static pressure (Gürdil et al., 2001c).

$$M_v = \mu_i .S_i .\sqrt{2.pi.\rho_e} \tag{7}$$

$$p = p_i + p_o \tag{8}$$

$$\mu_i .S_i .\sqrt{2.(p - p_o).\rho_e} = \mu_o .S_o .\sqrt{2.p_o .\rho_i} \tag{9}$$

$$V_e = \frac{M_v}{\rho_e} \tag{10}$$

where;

Mv : Mass flow of ventilation air (kg. s-1)

Ve : Volume flow of ventilation air (m3. s-1)

μi : Correction factor for inlets

μo : Correction factor for outlets

Si : Area of inlet air openings (m2)

So : Area of outlet air openings (m2)

ρi : Air density of inside (kg. m-3)

ρe : Air density of outside (kg. m-3)

p : Total static pressure (Pa)

pi : Static pressure at inside (Pa)

po : Static pressure at outside (Pa)

h : Vertical distance between air inlet and outlet (m)

Calculation of air density according to air temperature and relative humidity is (Wilhelm, 1976):

$$\ln(p_{ws}) = \frac{-7511.52}{T} + 89.63121 + 0.023998970T - 1.1654551x10^{-5}T^2 \\ -1.2810336x10^{-8}T^3 + 2.0998405x10^{-11}T^4 - 12.150799\ln(T) \tag{11}$$

$$\phi = \frac{p_w}{p_{ws}} \tag{12}$$

$$W = 0.62198 \frac{p_w}{P - p_w} \tag{13}$$

$$v_h = \frac{R*T}{P}(1 + 1.6078W) \tag{14}$$

$$\rho = \frac{1}{v_h} \tag{15}$$

where;
pw: Pressure of vapor (kPa)
pws : Pressure of saturated vapor (kPa)
ϕ: Relative humidity (decimal)
W: Humidity ratio (decimal)
R: Gas constant (J.kg-1.K-1)
T: Temperature in Kelvin (K)
P: Total pressure (kPa)
vh: Specific volume (m3.kg-1)
ρ: Density of air (kg. m-3)

Density of outside air is calculated from outside air parameters and then density of inside air is calculated. By equation 10, natural ventilation rate by thermal buoyancy is calculated.

Natural ventilation rate due to wind forces is calculated as follows (Albright, 1991);

$$Q = A.v.e \tag{16}$$

where;
Q: Ventilation rate (m3.s-1),
A: Air inlet area (m2),
v: Velocity of the blowing wind (m.s-1),
e: Efficiency for air openings.

As from the previous studies, for the perpendicular blowing wind; e = 0.50…0.60 and for the non-perpendicular blowing wind e = 0.25 to 0.35 is recommended. The wind rarely blows perpendicular to agricultural structures and for this reason (e= 0.35) is recommended for the agricultural structures (Albright, 1991).

The sum of Ve and Q will give us total natural ventilation rate. This sum is expressed as Va in equation 6.

3. RESULTS

The confirmations of the developed equations were done in some broiler houses raised on litter with different dimensions and bird capacity in the region. The equations are tested for both forced ventilation and natural ventilation conditions.

For example: Forced ventilation rate inside the house was 4 m3.s-1 and the measurement was done for 20 minutes inside the broiler house with. The air quality inside the house was quite good. The initial ammonia concentration was 4 ppm inside the house, which is under safety limit (25 ppm) for the poultry. A slight increase, 1 ppm in 20 minutes, in ammonia concentration was observed. The NH3 production rate inside the broiler house is occurred as 7.98 mg.s-1 under forced ventilation.

In natural ventilation case: Natural ventilation conditions were defined for the inside and outside environment and for the broiler house. Total natural ventilation and the NH3 production rates are calculated. For example: initial ammonia concentration was 3 ppm inside the broiler house and it went up to 8 ppm rapidly in 12 minutes. When the inside and outside air conditions and the features of the broiler house (volume, dimension and number of air inlets and outlets) along with the recorded wind velocity and direction were taken into consideration the ammonia production rate under natural ventilation conditions was calculated as 26.63 mg.s-1 by the developed mass balance equation.

4. DISCUSSION AND CONCLUSION

The aim of this work was to predict the NH3 gas production levels under forced and natural ventilations conditions in especially closed breeding systems. The theory bases on mass balance equilibrium and it's clearly explained by the equations, above. The calculations show us just natural ventilation applications not supported by forced ventilation systems will not be enough in broiler houses raised on litter for keeping the ammonia concentrations under the permitted limit, below 20 ppm (Gürdil., 1998). The confirmation tests also show us that the effect of inside air relative humidity was higher than the effect of inside air temperature in ammonia production levels (Gürdil et al., 2001a, Gürdil et al., 2001b). Considering the negative effect of greenhouse gases like ammonia to the world this developed theory could be applied for any type dangerous gases. These types of calculations based on mass balance would be useful for the farmers, agricultural or environmental engineers and for the smart agriculture technologies, as well.

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