Modeling and simulation of internal environment conditions in high-density poultry houses with ventilation using computational fluid dynamics

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Abstract

Brazil is one of the biggest producers and exporters of animal foods in the world, and is among the three countries most responsible in ensuring the maintenance of a sustainable agricultural growth in a sustainable manner. Therefore, it is imperative that the constant search for technological development, reliable and appropriate to the specific structure and climate of the national animal agribusiness production, through investigative methodologies is increasingly refined. However, there is still vulnerability to be observed to ensure compliance with new international demands related to the sustainable development and better understanding of the effects of the internal environment of poultry houses with natural ventilation. In this study it was determined the temperature distribution, the ammonia concentration, and the variation of air velocity in a typical poultry house. A determination coefficient of 0.906 was obtained between the experimental and simulated temperature, which remained in a range of between 18 to 28°C throughout the control volume, characterizing the thermal comfort zone for adult birds. The concentration of ammonia levels ranged between 0.0 to 5.0 ppm, which is acceptable for both poultry houses and for workers.

Keywords: Heat and mass transfer, temperature, animal comfort, CFD

1. Introduction

The poultry industry in Brazil, in terms of technology and production efficiency, is equal any other in the world, especially regarding advances in health and nutrition, in conjunction with exhaustive research in specific areas with difference in climate, social and economic development. It is known that the birds require specific environmental conditions of temperature, relative humidity, pressure, light, sound level, oxygen content, carbon dioxide, and nitrogen for their development. Thus, in the context of modern poultry production, research has shown that an inadequate environment is one of the factors that has a direct influence on the development of respiratory disease in birds and poultry house workers (Osorio et al., 2009). All variables relating to the air quality inside poultry houses are determining factors in the animal husbandry environment. However, the most relevant to the situation of the Brazilian poultry industry concerns the type of accommodation practiced in the country, because the facilities are open, non-insulated and subject to natural ventilation,
which prioritize the maintenance of the poultry house in an open condition (Osorio et al., 2011). This characteristic of the poultry industry in Brazil, and other countries in tropical and subtropical climates, differs from the practices in the rest of the world (temperate regions, where facilities are fully closed and use artificial cooling/heating systems, and ventilation 100% of the time), and constitutes Brazil’s greatest advantage on issues of animal welfare and sustainability.

The adult bird is an animal best suited to cold environments because its thermoregulatory system is more suited to retain heat than loose it. When exposed to heat stress by high temperatures, the bird presents decreased feed intake and consequently, a reduction in weight gain (Borges et al., 2003). The success or failure of raising of broilers is directly related to the environmental conditions to which these animals are subjected, where high values of ambient temperature and the accumulation of gases, such as ammonia, cause a decrease in the production and increased mortality (Miles et al., 2004; Bueno & Rossi, 2006; Nääs et al., 2007). Thus, the evaluation of temperature distribution in poultry house environments, where the broilers grow up, is of great importance in preventing stress and underperformance of the animals in hot climates (Nääs et al., 2010).

Computational methods provide a good alternative for modeling and evaluating the present problem and can be used to explore the physical relationships existing at the macroscopic level, in order to represent satisfactorily the dynamics of flows and their effects (Summers, 1998; Hoang et al., 2000; Verboven et al., 2001; Norton et al., 2007; Norton et al., 2009; Eren Özcan et al., 2010; Norton et al., 2010). Thus, the possibility of performing the modeling and simulation with computational fluid dynamics (CFD), mapping the animal husbandry thermal environment, the air flows, the ammonia concentration inside the open broiler facilities, and making use of natural ventilation, is an extremely important and pressing issue for animal production and the type of construction practiced in tropical and sub-tropical countries.

The aim of this work was the detailed modeling considering the effects of fluid interactions, including the coupling between the mathematical equations of heat and mass transfer of the fluid-fluid phases. Additionally, it was intended to predict the temperature distribution in the broilers production environment, as well as the ammonia concentration and variation of the air velocity in a typical poultry house with natural ventilation and without surrounding vegetation.

2. Methodology

This work was developed at the Laboratory of Numerical Processing in the Center for Research on Ambience & Engineering Systems of Agribusiness (AMBIAGRO) of the Agricultural Engineering Department, at the Federal University of Viçosa, Minas Gerais State, Brazil.

2.1. Operating conditions

To conduct this study, a typology of poultry houses was used, representing a large part of Brazilian poultry production, and typical of tropical and sub-tropical countries, which generally use natural ventilation systems. The type of poultry shed considered was 12.5 m wide by 125.0 m in length with a 3.0 m ceiling height and 0.20 m wall thickness, containing broilers in high-density (18 birds per m²) at 39 days of age (approximate age of slaughter), characterizing the period of maximum gas emission from the bed. The average body temperature of the chickens was compared with the temperature presented by Nääs et al. (2010). The maximum velocity of the fluid (air) entering the poultry shed was 1.5 m·s⁻¹ at a temperature of 25°C. These values were established as input parameters for the simulation.
2.2. Experimental data acquisition

A real time data acquisition system was used in this work by adapting the STRADA system developed by (Rocha, 2008). The temperature, air velocity and ammonia concentration data were collected daily from 22 June to 29 July 2009. However, for this work, the temperature data were collected during the afternoon of the 37th day of observation, after the birds stayed in the poultry shed with natural ventilation for 39 days.

2.3. Computational model

Due to the complexity of the geometry, the ANSYS ICEM CFD software was chosen to build a computational tetrahedral mesh for the object of the study. The tetrahedral volume element is very useful in maintaining the high quality for a region in different ways, enabling complex geometry to be molded to the region of interest, even though it requires more nodes than the elements of the hexahedral mesh, and results in a larger file size and longer computation time (Lee et al., 2007; Katz & Sankaran, 2011).

2.4. Boundary conditions

The modeling of the process in the control volume can be performed by the conservation equations (Zienkiewicz & Taylor, 2000). Thus, the technique of CFD has been used for solving the Navier-Stokes equation, quantifying the velocity profile, the temperature of the animals, the ambient temperature inside the poultry house, and the ammonia concentration, by the finite volumes method (Tu et al., 2008; Vaz et al., 2011; Rocha et al., 2013; Rocha et al., 2014).

The Reynolds tensor was modeled using the standard turbulence model, which evaluates the viscosity ($\mu_t$) from the relationship between the kinetic energy of turbulence ($K$) and dissipation of turbulent kinetic energy ($\epsilon$).

The proposed problem is presented in steady state, considering the properties of the animals and the materials and their influence on the environment. The solution to the problem involves the analysis of fluid-fluid and heat and mass transfer within a poultry shed with natural ventilation, involving the equations that describe the behavior of air velocity, temperature of the animals, environmental conditions, and concentration of ammonia generated. A residual less than $10^{-4}$ was adopted as a convergence criterion for the solution.

The rate of heat generated in the shed for the animals was estimated by the following equation (Pedersen & Thomsen, 2000; Silva et al., 2007; Baeta & Souza, 2010):

$$Q = 10 \cdot m^{0.5} \left[ 4 \cdot 10^{-5} (20 - T)^3 + 1 \right]$$

where:

- $Q$ - Total heat produced, W
- $m$ - Experimental animal model unitary weight, kg
- $T$ - Temperature, °C

The determination of ammonia ($NH_3$) emission generated in the litter of the poultry house was estimated by the following equation (Miragliotta et al., 2004):

$$E = \exp \left[ -6.5 + 0.12(T) + 0.6(pH) + 0.003(\text{day}) - 0.0043(\text{day})^2 \right]$$

where:

- $E$ - Emission of ammonia, ppm
- $\text{day}$ - Day of growth
- $T$ - Average litter temperature, °C
- $pH$ - Litter pH
3. Results and discussion

Using the ANSYSTM ICEM software, computational meshes were generated to represent the control volume. A tetrahedral mesh was created with 1,913,814 volumes, which were composed of three distinct domains, consisting of 1,881,270 finite volumes inside the poultry shed, interconnected through an interface of fluid-fluid type at the inlet and outlet of the poultry shed with 16,272 finite volumes each. For each face of each domain, boundary conditions were established, as shown in Figure 1.

A control volume of 2 m length and 12.5 m width, with symmetry in both directions in the central part of the poultry shed, was considered for the analysis.

To characterize the heat generation of the animal, a second geometry of 0.1139m², representative of its surface area was created, and a tetrahedral mesh with 50,874 finite volumes for a single animal was generated, as shown in Figure 2. The simulated results were compared with the results presented by Nääs et al. (2010) and Yahav et al. (2004).

Figure 1 - Detail of computational tetrahedral mesh refinement.

Figure 2 - Detail of computational tetrahedral of poultry mesh refinement and temperature distribution.
Based on the animal surface temperature distribution, a simulation was performed to characterize the temperature distribution in poultry houses with natural ventilation and inlet air at a temperature of 20°C. Based on this result, a control volume with an area of 25 m² was established, which housed 432 broilers with a density of 18 birds/m². This is illustrated in Figure 3 with horizontal colored scales representing the temperature values in the range of 20 to 35°C, and vertical colored scales representing the air velocity in the range of 0.0 to 2.0 m·s⁻¹.

![Figure 3 - Variation of broiler temperature and transversal section velocity in a poultry house.](image)

As observed in Figure 3, it is verified that there is a small turbulence at the level of the birds in the region close to the shorter wall at one side where the air intake provides the natural ventilation, but the temperature there is maintained within the poultry’s thermal comfort zone (18 to 28°C for adult birds), as cited by Curtis (1983), Abreu & Abreu (2004), and Menegali et al. (2009). However, the temperature increases considerably in the control volume with increasing distance from the air inlet towards the shorter wall on the opposite side, at the air outlet. This is explained by an increase of the amount of heat occurring due to the heat dissipated from the animals themselves. Therefore, additional heat is transported from the inlet towards the outlet.

In the same way, using the environment average temperature of 25°C, obtained experimentally, the simulation of the distribution of air temperature at the height of the birds in the range 25 to 28°C was performed, as shown in Figure 4.
A significant agreement was found between the experimental and simulated temperature inside the poultry house, as can be observed by the coefficient of determination ($R^2 = 0.906$), as shown in Figure 5.

4. Conclusions

This methodology could be used as a basis for initial design of poultry houses with natural ventilation to optimize the airflow inside the building.

The boundary layer located at the height of the birds along the shed could influence significantly the comfort of the animals housed in natural ventilation.
The results obtained from simulations of temperature presented a good agreement with experimental data ($R^2 = 0.906$), which indicates that the model is appropriate for use in improving poultry houses.

The simulated ammonia ($\text{NH}_3$) concentration in the poultry house is acceptable for both the animals and the workers.

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