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CFD study of the influence of laying hen geometry, distribution and weight on airflow resistance

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ABSTRACT

Proper indoor environment is essential to the production performance of laying hens, one effective approach to research it was Computational Fluid Dynamics (CFD). However, the modelling is a great issue as modelling individual hen would generate large number of mesh, an alternative is to simplify caged laying hen occupied zone (CZ) into porous media zone. As for it, the flow resistance of CZ requires firstly to calculate the resistance coefficients. In this study, CFD simulation was applied to calculate the resistance in three directions perpendicular to each other. The effect of the hen model geometry (full-geometry, ellipsoidal and body only model in which hen's head, neck and legs were neglected), spatial distribution (four, three and two hens stand near the feeding through, respectively) and body weight (1.5 kg, 1.8 kg and 2.0 kg) were investigated on flow resistance. Finally, the resistance coefficients were obtained under different situations. The numerical model was firstly validated against wind tunnel experiment with five spheres representing hens. Different turbulence models were evaluated and the RNG k-ε model showed the superior performance than others. Hen model geometry, the spatial distribution and body weight of hens showed significant effect on flow resistance of CZ, the resistance increased with hens' body weight while its variation decreased. The resistance coefficients determined in this study can be directly applied to other related simulation studies using porous media to represent CZ.

1. Introduction

It is crucial and challenging to maintain proper indoor environment for sustainable poultry production. Ventilation is one of the most important ways to ensure the desired indoor climate and air quality. There are three approaches to research the ventilation efficiency, i.e., field experiment, lab study and computational fluid dynamics (CFD). The field experiment has drawbacks due to the limited measurement points, the difficulty in control of the experimental variables and the high cost. The lab experiment with scale models in wind tunnel has limitations to represent the real phenomenon. For example, the wind fluctuations produced by wind tunnel has discrepancy with real situations (Jiang and Chen, 2002). Recently, CFD has been widely adopted for calculating indoor airflow and temperature field (Wisate et al., 2013), as well as distribution of ammonia and greenhouse gas concentration (Saraz et al., 2016).

When applying CFD to analyze livestock housing environment, the modelling of animal occupant zone (AOZ) is challenging due to the existence of large number of animals. In the previous research on small-scale livestock facilities, detailed models of the animals were included. Gebremedhin and Wu (2003) simulated the flow in a zone of ten randomly positioned cows using body-fitted geometry of the actual dimensions. Seo et al. (2012) modelled a full-scale commercial pig house with 648 simplified pigs. Nevertheless, for the house of broilers and caged laying hens, with more than hundred thousand birds, it is unrealistic to model all birds discretely in the geometry modelling. In response to this issue, Seo et al. (2009) assumed that the entire floor of ground raising broiler house was occupied by the broilers with no void spaces. Hui et al. (2016) simplified the CZ as solid due to high density of occupants for the caged laying hens. However, this assumption treating AOZ as solid prevents the further understanding of flow and heat exchange mechanism between AOZ and the surrounding room spaces. Porous media model has always been regarded as a reasonable simplification approach for simulating the flows through complex geometries, like packed beds, filter papers, perforated plates, flow distributors and tube banks (Atta et al., 2007; Odabaee and Hooman, 2012; Román et al., 2012; Wang et al., 2010). It has also been applied to model AOZ and some specific components of livestock buildings. For instance, slatted floors and AOZ in pig or dairy cattle barn had been treated as porous media in some researches (Bjerg et al., 2008; Wu et al., 2012;

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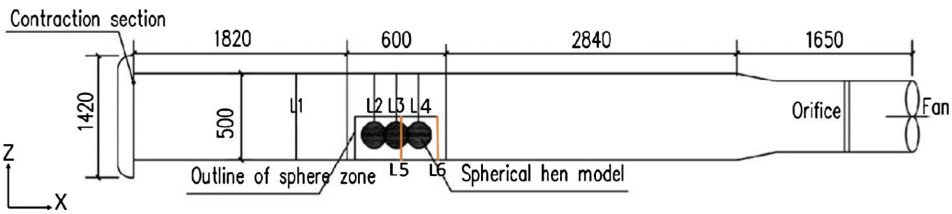

Fig. 1. Front elevation of the wind tunnel and velocity measurement lines, all units are in millimeter (mm).

Rong et al., 2015). Meanwhile, the feasibility of applying porous media in livestock buildings in some cases had been verified. Wu et al. (2013) and Zong and Zhang (2014) validated that simplifying slatted floor as porous media generally preserved the accuracy of mean flow field in the space under the slatted floor. Mondaca and Choi (2016) found that the AOZ of dairy cow buildings could be treated as porous media when evaluating the aerodynamics in the room space outside the AOZ. On the contrast to the real geometry modelling, porous media can be a more appropriate assumption for AOZ with large scales. However, the research concerning simplification of caged laying hen occupied zone (CZ) as porous media was scarce.

In order to apply porous media assumption in caged laying hen house in CFD, it is necessary to obtain resistance coefficients, which are the correlation coefficients between inlet velocities and flow resistance, namely, the pressure drops between the front and the back of CZ. One fast and feasible way to obtain the resistance coefficients is to conduct CFD calculations of pressure drops through CZ with caged laying hens discretely modelled under different inlet velocities. The first key step for such CFD calculations is to decide the turbulence model as well as representative geometrical model for the hen. As each turbulence model has its own unique characteristic, and the model is generally considered to be significant to the environment simulation accuracy (Rong et al., 2016). Meanwhile, for animal model construction in previous simulations, the simplified model has been widely used as it is computing power and time saving. In many researches, animal models were slightly simplified by neglecting some minor parts, e.g., legs, ears, noses and tails, which consumed high-aspect-ratio polygons in CFD model, to decrease the mesh number. It was reported that the slight model simplification technique preserved the accuracy of the airflow simulation results (Mondaca and Choi, 2016; Seo et al., 2012). However, for the complicated model, the slightly simplified model still consumes a large amount of cells. Hence, further simplification of the animal models into simpler geometries, e.g., ellipsoid and cylinder was often reported in literature. Mondaca and Choi (2016) discovered that sphere, cylinder and six-cylinder configurations could adequately simulate the average heat flux of dairy. Li et al. (2016a, 2016b) found that pig profiles could be simplified into cylindrical model and chicken profiles could be treated as spherical model when simulating convective heat transfer. However, the discrepancy of the simplified geometries to simulate the airflow compared to the archetypes was missing in published literatures. In this study, different turbulence models were evaluated firstly to establish the most appropriate model for characterizing the airflow in CZ and the influence of the representative geometry of hen model on the accuracy of flow resistance calculation was investigated.

Furthermore, the postures and spatial distribution of hens vary according to practical conditions (Febrer et al., 2006). For instance, during the feeding period, hens prefer standing near the feeding trough, which could influence the airflow pattern of the CZ. Meanwhile, the body weights of hens increase during the whole laying period, like Hy-Line Brown, the average body weight increases from 1.5 kg to 2.0 kg during the laying phase from 18th week to 90th week (according to Hy-Line company, 2016), and the increased body volume influences the porosity of the CZ and thus the flow resistance. However, the effects of the hen distribution and body weight on flow resistance under different situations are not well known.

The objectives of this study are: (1) to determine an appropriate turbulence model for simulating flow of the CZ; (2) to compare the flow resistances calculated by using different representative geometries of hen model; (3) to investigate the effect of hen distribution and body weight on flow resistance; (4) to provide the resistance coefficients under three mutually perpendicular directions. The resistance coefficients determined in this study can provide reliable input data for future CFD simulations of full-scale hen house using porous media to represent the CZ.

2. Materials and methods

The CFD model was firstly validated by comparing the velocity data in CZ obtained by numerical simulation with those obtained by wind tunnel experiment. On the base of validated numerical model, the flow resistances were investigated by CFD simulations for varied geometry models, bird distributions in cage and body weights in virtual wind tunnel under different inlet velocities, to determine the influence of bird geometry, distribution and weight on airflow resistance when caged laying hen occupied zones are treated as porous media.

2.1. Validation of CFD model

2.1.1. Lab experiment setup

2.1.1.1. Wind tunnel and spherical hen model. The lab experiment was carried out in a wind tunnel at Air Physics Lab, Aarhus University, Denmark. The wind tunnel was 6.91 m long and 0.5 m × 0.5 m in cross section (Fig. 1). It was made of polystyrene sheet and had a 0.25 m thick smooth surface contraction section. This contraction section was designed to generate a uniform velocity distribution (Rong et al., 2011). A transparent glass window of 0.6 m in length was installed in the working section that allowed the velocity measurement using Laser Doppler Anemometer (LDA). At the end of wind tunnel, a fan (Type CK315 C EC, Östberg, Sweden) was installed to develop negative pressure and draw airflow through wind tunnel.

Five spheres in diameter of 150 mm were placed in the wind tunnel to represent the laying hens in CZ, the superficial area of sphere was similar with the hen of 1.5 kg (Walsberg, 1978). Fig. 2 shows the horizontal plan view of spheres layout, and the bottom of the spheres were 70 mm from the floor of the wind tunnel, which was approximately as the same as the height of hen's leg with a body weight of 1.5 kg. The

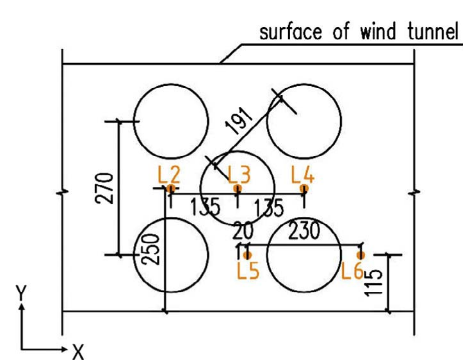

Fig. 2. Horizontal plan view of spheres layout and velocity measurement positions, all units are in millimeters (mm).