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journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Ventilation rate formula for mechanically ventilated broiler houses considering aerodynamics and ventilation operating conditions

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ARTICLE INFO

Article history:
Received 13 June 2018
Received in revised form
28 August 2018
Accepted 6 September 2018

Keywords:
Broiler house
Computational fluid dynamics
Discharge coefficient
Fan performance curve
Mechanical ventilation
Orifice equation

Precise ventilation control of broiler houses is essential to effectively exhaust pollutants and attain the required breeding environment. However, the ventilation rate used in practise is always lower than the desired or designed value because of difficulties in measuring the pressure difference between the indoor and outdoor pressure of the facility. In this study, a new formula was developed to estimate the total ventilation rate for mechanically ventilated broiler houses using the number of operating fans and the slot opening rate, both of which are relatively easy to measure in practice. The proposed formula was derived from the in-situ fan performance curve and the discharge coefficient, which represent the ventilation characteristics of the exhaust fans and slot openings respectively. This was evaluated through a field experiment and a computational fluid dynamics (CFD) simulation. The measured ventilation rate was 24.1–26.6% lower than the desired ventilation rate showing that the in-situ fan performance curve was 33.7 Pa lower on average than the designed fan performance curve provided by the manufacturer. The distribution of static pressure in the broiler house was analysed using CFD models and it was found that the new formula could be applied to broiler houses having difference lengths.

1. Introduction

The Korean livestock and poultry industry has been growing steadily, and its total production amounted to 17.8 billion $ US in 2016 (Ministry of Agriculture, Food and Rural Affairs, 2017). In particular, consumption of chicken has increased from 8.6 kg per capita in 2006 to 13.8 kg per capita in 2016 (Ministry of Agriculture, Food and Rural Affairs, 2017). In response to increasing demand, broiler houses have increasingly adopted concentrated animal feeding operations (CAFO) with

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https://doi.org/10.1016/j.biosystemseng.2018.09.002
1537-5110/

mechanical ventilation systems (Kwon, Jo, Lee, Ha, & Hong, 2014). However, CAFO places a burden on the control of internal environment, causing accumulation of heat, moisture, dust, and hazardous gases within the facility. Consequently, the importance of ventilation, which is the key environmental control mechanism in broiler houses, has recently been emphasised.

Mechanically ventilated broiler houses have the advantage of controlling ventilation rate by adjusting the operating number and cycle of the exhaust fans. This is commonly based on the maximum airflow rate of the fans. However, inlet opening size is controlled to maintain the static pressure difference between inside and outside of the broiler house separately from the ventilation rate setting. By keeping the static pressure difference high, particularly in the winter, the incoming cold air can be prevented from direct contact with the animal occupied zone (Kwon, Lee, Zhang, & Ha, 2015). The ventilation rate of a mechanically ventilated broiler house varies depending mainly on the static pressure difference (Morello et al., 2014). The ventilation rate can be estimated using the fan performance curve provided by the manufacturer, but it has been reported that the actual ventilation rate is not exactly the same as the designed one and is degraded with continued use in the field (Casey et al., 2008).

The actual ventilation rate is the volumetric or mass flow rate through exhaust fans as an outlet or openings as an inlet, where the flow rates through the outlets and inlets must be equal. Therefore, accurate measurement of the flow rate, at either the outlet or inlet can provide the ventilation rate. However, the ventilation rate depends considerably on the interaction between inlets and outlets. Inlets that are not large enough or not properly positioned will increase the negative pressure near the exhaust fans and hinder the ventilation. Therefore, the airflows through the exhaust fans and inlet vents require a comprehensive understanding of both the operational fan performance curve and orifice theory.

A number of studies have evaluated the fan performance curve of mechanically ventilated broiler houses using an averaging Pitot tube (Lakenman, Segura, Atkins, Ben-Zvi, & Feddes, 2004; Segura, Feddes, Ouellette, & Ben-Zvi, 2005) and a fan assessment numeration system (FANS) (Gates, Casey, Xin, Wheeler, & Simmons, 2004; Liang, Bautista, Dabhadkar, & Costello, 2013). However, a direct measurement of the fan performance is not suitable for long-term monitoring in terms of cost and time. While many studies have evaluated the fan performance curves of livestock houses, only few studies considered orifice theory to estimate the ventilation rate through the inlets. Bottcher, Singletary, & Baughman (1992) assumed the discharge coefficient (the coefficient in the orifice equation) as 0.6 or 1.0 for estimating the ventilation rate of mechanically ventilated broiler houses. Studies on other livestock houses also did not consider the variability of discharge coefficient (Timmons, Irish & Toleman, 1986; Hatem, Abdelbary, Mohamed, & Haddy Ahmed, 2011; Kiwan et al., 2013). However, the influence of both the fan performance and the inlet orifice are rarely considered simultaneously when estimating ventilation rate.

Meanwhile, the complex aerodynamics induced by exhaust fans and inlet vents in livestock facilities has been studied using computational fluid dynamics (CFD). CFD simulations have shown advantages when analysing aerodynamic environments in relation to complex operating conditions and meteorological conditions. In particular, CFD simulations can help understand the pressure distribution inside a facility resulting from the complex interactions between inlets and outlets. However, many studies have set the airflow rate of exhaust fans to a constant value (Kwon et al., 2015; Mostafa et al., 2012), which means that changes in ventilation rate according to the operating conditions have not been considered. In order to improve the accuracy of computational approaches, it is necessary to simulate the variable ventilation rate according to the operating condition of the facility by applying the fan performance curve and orifice theory.

This study proposed a formula for estimating the actual overall ventilation rate of target mechanically ventilated animal house considering the aerodynamic performance of the exhaust fans and inlet vents. The in-situ fan performance curve of the exhaust fans and the discharge coefficient of the inlet vents were measured and statistically analysed through field measurements in a selected broiler house. The formula developed for the broiler house was evaluated for its applicability through a field experiment and CFD simulation.

2. Materials and methods

2.1. Theory

2.1.1. Fan performance curve

The capacity of a fan is commonly expressed as its maximum airflow rate. However, the airflow rate achieved in practice by an exhaust fan decreases depending on the static pressure difference between the inside of the facility and the atmosphere. The performance of a fan is also affected by structural factors such as ducts and dampers. When a fan is operating, the static pressure on the outlet of the fan is higher than the inside, whereas the dynamic pressure is the same. An excessive static pressure difference represents a resistance to the airflow and causes a decrease in the airflow rate. A fan performance curve indicates the relationship between volumetric airflow and static pressure difference of the fan (Fig. 1). Fan performance curves show the inherent characteristics of individual fans that are constant in shape, power consumption,

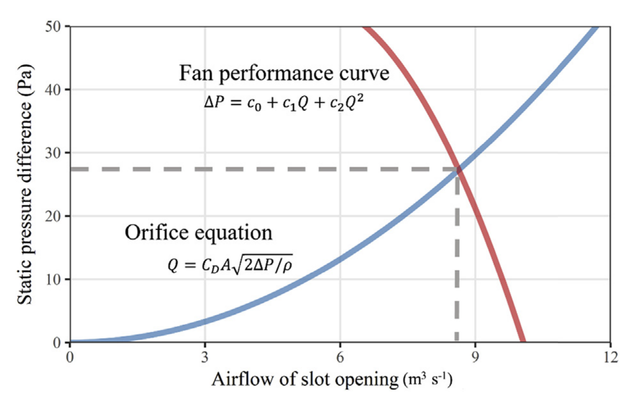

Fig. 1 – Graphical representation of ventilation rate and static pressure difference (Q – ΔP plot) in mechanically ventilated facility.