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Ammonia and greenhouse gas emissions from fattening pig house with two types of partial pit ventilation systems

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ABSTRACT

To reduce the cost of the air purification system in cleaning the exhaust air from pig buildings, a concept of partial pit ventilation (PPV), which applies an extra pit exhaust extracting a part of air directly from emission source zone, was introduced. The objectives of this study are to quantify gaseous emissions from a fattening pig building with PPV, and to assess the performance of the PPV with two types of air inlets (ceiling air inlet, system-C; wall-jet air inlet, system-W). Two trials were carried out under summer and winter conditions. For each trial and in each type of PPV system, 32 fattening pigs were raised. Gas concentrations and climate data were continuously measured. Results showed that the average indoor concentrations were 2.1–3.4 ppm for NH_3, 0.4–0.6 ppm for CH_4, and 800–966 ppm for CO_2 in summer; and 4.2–4.3 ppm for NH_3, 5.0–5.6 ppm for CH_4, and 1491–1542 ppm for CO_2 in winter. N_2O releases were rarely observed in the current set-up. The PPV system substantially improved the indoor air quality. Approximately half of the whole NH_3 emission (47–63%) was driven through the pit exhausts. A combination of PPV and air purification system is considered to be a practical and efficient mitigation method for gaseous pollution from pig production. The two types of PPV systems resulted in two different kinds of airflow characteristics, which further affected the gaseous release processes. During summer, lower gas concentrations and emissions were found in system-C than in system-W. During winter, system-C gas concentrations were higher in room air and slightly lower in pit air than system-W. Both systems had similar values of emissions during winter. Higher gas concentrations were found in winter than in summer. On average, the winter trial had lower daily NH_3 emissions but higher CH_4 and CO_2 emissions than the summer trial.

1. Introduction

Intensive pig production contributes significantly to emissions of ammonia (NH_3) and greenhouse gases (GHG), which creates a series of negative impacts on surrounding environment and climate (Hutchings et al., 2001; Cabaraux et al., 2009; Philippe et al., 2011b). NH_3 emissions are implicated in soil acidification and eutrophication of aquatic ecosystems (Krupa, 2003). At the same time, NH_3 is well known as a toxic gas, which represents potential health hazards to both human beings and animals inside the animal house (Donham, 1991; Banhazi et al., 2008). According to Hutchings et al. (2001), nearly 99% of the total NH_3 emissions in Denmark were from agricultural sources in which emissions from pig housing accounted for 34%. GHG emissions, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are connected with global warming and climate change. In addition, N_2O also causes the loss of the ozone layer. Globally, the livestock sector contributes about 14.5% of all anthropogenic GHG emissions (Gerber et al., 2013). Therefore, reducing NH_3 and GHG emissions has been an important long-term goal by international regulations (United Nations Economic Commission for Europe, 2013).

Gas formation and volatilization in pig production is influenced by many factors: animals, (*e.g.*, genetics, diet, number and weight, animal activity, and behavior), animal wastes (*e.g.*, storage methods, treatment, pH, temperature, and surface area), ventilation (control strategy, temperature, flow rate, and air velocity above manure surface) and other site-specific factors (Haeussermann et al., 2006; Blanes-Vidal et al., 2008). An optimal control of those influencing factors can help to reduce gaseous emissions from livestock productions. In pig housing with mechanical ventilation, those polluted gases can be eliminated by employ of air purification system (*e.g.*, air scrubber) at air exhausts (Zucker et al., 2005; Philippe et al., 2011a; Zhao et al., 2011). However, the

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air purification system is quite expensive because of high investment and operation costs related to energy, chemical and filter consumption and maintenance for both ventilation and purification systems (Melse et al., 2009). One proposed strategy to reduce the costs is cleaning only a partial amount (*e.g.*, 10% of the maximum ventilation rate) of exhaust air extracted from the main source zone where highly concentrated air pollutants originated from (Saha et al., 2010; Zong et al., 2014a). A partial pit ventilation (PPV) system with an extra pit exhaust under slatted floor has therefore been developed. Besides, it is expected that employing a PPV system can remove the polluted gases from the pit space before convection airflow and turbulences transferring the contaminants up to the room space, and improve the indoor air quality (Saha et al., 2010). Consequently, both working environment and animal welfare are improved to some extent.

In Denmark, negative pressure ventilation systems consisting of ceiling-top exhaust units and either diffuse ceiling inlet or wall-flap inlet are conventionally used in fattening pig housing. However, up to now, few studies are available concerning gaseous emissions from these two conventional ventilated pig house incorporated an extra PPV system.

Therefore, the objectives of this study were to quantify gaseous emissions in fattening pig housing with a partial pit ventilation system, and to investigate the effects of two different air inlets (ceiling and wall-jet air inlets) as well as different seasons (winter and summer) on gaseous emissions.

2. Materials and methods

Two trials were carried out in an experimental pig building which was designed to facilitate tests of various ventilation systems and operation strategies. The first trial was carried out in a period from 6th August to 23rd October 2012. The period was actually the late summer + early autumn, and hereafter was briefly referred to as summer. The summer also means the period when the maximum ventilation rate applied, which happened at most time of the first trial. The second trial was in a winter period from 18th November 2013 to 18th February, 2014, during which the minimum ventilation required.

2.1. Experimental rooms

Two identical rooms of the experimental pig house, with dimensions of $5.7 \times 4.9 \times 2.67\,m^3$ ($L \times W \times H$), were arranged and equipped for this experiment (Fig. 1). The dimensions and layout of the room followed a section of typical commercial Danish pig production unit. The room was equally divided into two pens ($4.8 \times 2.45\,m^2$,$L \times W$) by a 1 m high partition wall (Fig. 1b). Each pen had two thirds fully slatted floor and one third drain floor (Fig. 1b). Drain floor was a type of slatted floor with smaller slot openings. Here, opening ratios of the fully slatted floor and drain floor were 17.2% and 8.6%, respectively. Above the floor, two drinking troughs were attached on the side wall, and one feeder was on the partition wall for each pen (Fig. 1b). There was a 0.9 m wide inspection alley in each room. Underneath the floor, a 0.7 m deep manure pit was built for each pen. Manure could be pumped out through the valves in the pit bottom. To avoid manure pouring into the pit air exhausts, the depth of stored manure was kept under 0.3 m during experiment.

2.2. Ventilation systems

A central outlet duct with two ventilators (REVENTA® GmbH & Co. KG, Germany) was installed near the building ridge (Fig. 1a). It creates negative pressures for the fattening pig rooms. All exhaust units were connected to this central outlet duct. Airflow rate was regulated by an analog controlled damper (VengSystem A/S, Denmark) inside the exhaust unit (Fig. 1a).

Both investigated rooms were equipped with the exhaust units of a similar layout: a ceiling-top room exhaust and a partial pit exhaust. The room exhaust was the major air outlet and consisted of a 0.46 m diameter chimney duct (Fig. 1a). Pit exhaust as the extra outlet was located under the drain floor (Fig. 1c), and consisted of four 0.16 m diameter pipes on the side wall of each pen. Exhaust air from pit headspace was extracted through these pipes into a main pit duct, which could further connect to an air purification system for treatment (Fig. 1c). It should be mentioned that a test of an air purification system was not included in this study. In each room and pit air exhaust duct, an impeller anemometer accompanied with a frequency converter (VengSystem A/S, Denmark) was installed to measure airflow rate.

The designed maximum ventilation capacity (DVC) was $100\,m^3\,h^{-1}\,pig^{-1}$. A set-point temperature of 22 °C was applied at the beginning of each fattening period for both systems. After 1 week the set-point temperature was decreased linearly until reaching 18 °C at the end of each fattening period. Room ventilation rate was automatically controlled by the VengSystem based on indoor air temperature. In contrast the pit ventilation rate was kept at approximately 10% of the DVC. During the experiment, the analog controlled damper (VengSystem A/S, Denmark) was fixed in the pit ventilation duct, while it was adapted with indoor air temperature in the room ventilation duct. To prevent the ventilation controlled damper being open and close too frequently, a proportional control was used with a proportional band (P-band or PB) in each ventilation system.

The only difference between the two investigated rooms was the air inlets. One room was equipped with a diffusion ceiling and ceiling-jet air inlets (system-C); the other room had wall-jet air inlet (system-W) (Fig. 1a).

2.2.1. System-C

System-C applying diffusion ceiling and ceiling-jet air inlets plus partial pit and ceiling-top exhausts was operated in Room 1 (Fig. 1). Under negative pressure, fresh air entered the attic *via* three 0.8 m diameter air ducts on the building ridge, and then went through the diffusion ceiling into the pig room. The diffusion ceiling was made of compressed straw plate and mineral wool isolation layer, which had high resistance when air passing through it. Two ceiling-jet air inlets (0.62×0.24 m) with openings facing downward the drain floor area were installed in the ceiling. Normally, the ceiling-jets were closed. When room temperature increased to 22.8 °C, the ceiling-jet flaps would open to increase the air speed in the animal occupied zones (AOZ). The P-band was 2.4 °C in system-C.

2.2.2. System-W

System-W with wall-jet air inlets plus partial pit and ceiling-top exhausts was operated in Room 2 (Fig. 1). Two wall-jet air inlets with bottom hinged flap (0.62×0.24 m) and top guiding plate (0.62×0.03 m) were installed on the sidewall. Both wall-jet openings were placed 1.83 m above the floor in a symmetrical plan of a pen. The opening size of wall-jet inlet was regulated automatically together with room exhaust ventilation rates (VengSystem A/S, Denmark). A P-band of 3.3 °C was set for system-W. The top guiding plate was designed to guide the inlet air direction, which was obliquely upward with an angle of 40° to horizontal plane in this experiment.

2.3. Animals and feed

For each trial and in each type of PPV system, 32 Danish Landrace × Yorkshire × Duroc (LYD) pigs were raised. They were