BIOSYSTEMS ENGINEERING 129 (2015) 212–225

Available online at www.sciencedirect.com

ScienceDirect

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

Research Paper

# Evaluation of a dry filter and an electrostatic precipitator for exhaust air cleaning at commercial non-cage laying hen houses☆

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ARTICLE INFO

*Article history:*
Received 23 July 2014
Received in revised form
22 October 2014
Accepted 22 October 2014
Published online 15 November 2014

*Keywords:*
Particulate matter emission
Poultry houses
Exhaust air cleaning
Dry filter
Electrostatic precipitator
Field evaluation

The removal performance of two exhaust air cleaning systems for abatement of particulate matter (PM) emission in poultry houses were investigated: a commercially available dry filter (DF) and a full-scale prototype electrostatic precipitator (ESP). Each system was connected to two commercial, non-cage laying hen houses: one with aviary housing, the other with floor housing. At each house, six to nine 24-h measurements were carried out, spread over the year and the laying cycle. Upstream and downstream of the systems, we measured $PM_{10}$, $PM_{2.5}$, and carbon dioxide concentrations, temperature, and relative humidity. Additional measurements of particle size distribution only were carried out at the DF of another poultry house. The latter showed that removal of PM by the DF increased with increasing particle diameter. Mean removal efficiency of the DF for $PM_{10}$ was 40.1%, whereas $PM_{2.5}$ was not significantly removed. The ESP reduced concentrations of $PM_{10}$ by an average of 57.0% and concentrations of $PM_{2.5}$ by an average of 45.3%. For neither of the two systems an effect of upstream PM concentration on removal performance was found. Results of this study are compared with the available literature and possibilities to improve removal performance are discussed. The mean (SD between houses) untreated emissions rate from the non-cage layer houses was 7.81 (4.12) mg $PM_{10}$ $h^{-1}$ $bird^{-1}$ and 0.44 (0.28) mg $PM_{2.5}$ $h^{-1}$ $bird^{-1}$. In conclusion, the evaluated systems show potential to reduce PM emissions from poultry houses.



## 1. Introduction

Particulate matter (PM) can be defined as a complex mixture of tiny solid and liquid particles suspended in the air (Cambra-López, Aarnink, Zhao, Calvet, & Torres, 2010). Upon inhalation, PM can penetrate into the respiratory system and cause adverse effects on respiratory and cardiovascular health (Brunekreef & Holgate, 2002). To protect the health of its

☆ Part of the work on the dry filter has been presented at the American Association for Aerosol Research (AAAR) 30th Annual Conference (October 3–7, 2011. Orlando, USA). Part of the work on the electrostatic precipitator has been presented as ASABE paper number ILES12-0405 (ILES IX conference, July 8–12, 2012. Valencia, Spain).

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http://dx.doi.org/10.1016/j.biosystemseng.2014.10.006

**Nomenclature**

| | |
|---|---|
| $C_a$ | Concentration in the air flow $Q_a$ |
| $C_e$ | Pollutant concentration in the air flow $Q_e$ |
| $C_t$ | Pollutant concentration in the airflow $Q_t$ |
| CCD | Corona Current Density of an electrostatic precipitator ($\mu A\ m^{-2}$ of collection area) |
| $CO_2$ | Carbon dioxide |
| $[CO_2]_a$ | Ambient concentration of carbon dioxide (ppm) |
| $[CO_2]_d$ | Concentration of carbon dioxide downstream of the electrostatic precipitator (ppm) |
| $[CO_2]_u$ | Concentration of carbon dioxide upstream of the electrostatic precipitator (ppm) |
| DF | Dry filter (also called: impaction curtain) |
| DC | Direct current |
| E | PM emission rate ($mg\ h^{-1}\ bird^{-1}$) |
| EU | European Union |
| ESP | Electrostatic precipitator |
| $Fco_2$ | Factor for conversion of total heat to the volumetric $CO_2$ production by the animal and its manure ($m^3\ h^{-1}\ kW^{-1}$) |
| $\eta$ | Particulate matter removal efficiency (%) |
| LU | Livestock Unit: 500 kg of live mass |
| $n$ | Number of data points |
| P | Level of significance |
| $P_a$ | Proportion of ambient air leaked into the downstream air flow |
| $P_h$ | Proportion of poultry house air in the downstream air flow |
| PM | Particulate matter |
| $PM_{10}$ | Particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 10 μm aerodynamic diameter (EN 12341) |
| $PM_{2.5}$ | Particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 2.5 μm aerodynamic diameter (EN 14907) |
| $PM_a$ | Ambient particulate matter concentration ($\mu g\ m^{-3}$) |
| $PM_{dc}$ | Corrected particulate matter concentration downstream of the electrostatic precipitator ($\mu g\ m^{-3}$) |
| $PM_{dm}$ | Particulate matter concentration measured downstream of the electrostatic precipitator ($\mu g\ m^{-3}$) |
| $PM_u$ | Particulate matter concentration upstream of the dry filter or electrostatic precipitator ($\mu g\ m^{-3}$) |
| $Q_a$ | Air flow from the ambient environment mixing with $Q_e$ to form $Q_t$ |
| $Q_e$ | Airflow from the electrostatic precipitator entering the sampling duct |
| $Q_t$ | Total airflow leaving the sampling duct downstream of the electrostatic precipitator |
| SCA | Specific collection area of an electrostatic precipitator ($m^2$ per 1000 $m^3\ h^{-1}$) |
| SCP | Specific corona power of an electrostatic precipitator (W per 1000 $m^{-3}\ h^{-1}$) |
| SD | Standard deviation |
| Total PM | All particles that can be collected using filter cassettes (NIOSH method 0500) |
| V | Total ventilation rate in the poultry house ($m^3\ h^{-1}\ bird^{-1}$) |
| $\Phi_{total}$ | Total heat production by the animal (W) |

residents, the European Union has set daily and annual concentration limits (EU, 2008) for ambient PM with aerodynamic diameters less than 10 μm ($PM_{10}$) and 2.5 μm ($PM_{2.5}$). These limits are exceeded in certain areas in the Netherlands, including areas with large numbers of livestock farms (RIVM, 2013; Van Zanten et al., 2012). In the Netherlands, poultry houses are estimated to be responsible for 13% of the total, primary $PM_{10}$ emission (RIVM, 2011). Outside the exhausts of poultry houses, plumes of PM can be found which spread out in detectable concentrations downwind of these farms (Heederik et al., 2011; Li et al., 2012). In view of this, a research programme was set up to develop and evaluate PM mitigation options for the poultry industry in the Netherlands (Ogink & Aarnink, 2011). One of the possible approaches to reduce PM emissions from poultry houses is to treat the exhaust air by so-called 'end of pipe' systems. In several European countries, air scrubbing (i.e., washing pollutants from the air stream) and biofiltration (i.e., beds or walls filled with moist organic packing material) are widely used for odour, ammonia and PM mitigation. Their application in poultry houses, however, can be problematic, because high PM concentrations cause clogging of these systems (Melse, Hofschreuder, & Ogink, 2012). In recent years, two alternative end of pipe systems have been introduced into the livestock sector: a dry filter (DF; in some publications: 'impaction curtain') and electrostatic precipitators (ESPs).

The DF is placed as a filter wall between the animal space and the exhaust ventilators and removes PM by inertial impaction and gravitational settling. The first investigation into the potential of the DF was published by Lim et al. (2007), who evaluated the system in a cage layer house. In the following years, more data became available (Demmers et al., 2010; LUFA, 2009; Mostafa & Buescher, 2011; Ogink, Van Hattum, & Winkel, 2009). The studies of LUFA (2009) and of Ogink, Van Hattum, and Winkel (2009) however, only consisted of a single measurement in an aviary house for layers, whereas the study of Mostafa and Buescher (2011) was carried out in a wind tunnel. Furthermore, the aforementioned studies show a rather high variation in removal efficiency (e.g., 19.9%–82% for $PM_{10}$). Consequently, there is a need to further evaluate the efficacy of the DF in multiple non-cage laying hen houses over a prolonged period of time.

ESP systems are used in various industrial processes to remove PM from flue gas streams by electrostatic force. The