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Research Paper

Evaluation of oil spraying systems and air ionisation systems for abatement of particulate matter emission in commercial poultry houses

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The present study evaluated the performance of four systems for abatement of particulate matter (PM) emission inside full-scaled commercial poultry houses: a fixed oil spraying system (OSF) inside two broiler farms and one laying hen house, an autonomously driving oil spraying vehicle (OSV) in one laying hen house, a negative air ionisation system (NAI) inside two broiler farms, and a positive air ionisation system (PAI) inside two laying hen houses. The systems were evaluated using case-control approaches. At each farm, six 24-h measurements were scheduled of PM_{10}, $PM_{2.5}$, ammonia, odour, and carbon dioxide concentrations (the latter for estimation of the ventilation rate and herewith emissions). This paper presents the layout of the systems, compares their performance in practice with that under experimental conditions, discusses improvement possibilities, reports the baseline emission rates of the poultry houses, and discusses the validity of the case-control approaches. The emission reductions of PM_{10} and $PM_{2.5}$ were: 60% and 53% for the OSF in broilers (at 12 mL m^{-2} d^{-1}), 21% and 31% for the OSF in laying hens (at 15 mL m^{-2} d^{-1}), 32% and 38% for the OSV in laying hens (at 30 mL m^{-2} d^{-1}), 49% and 68% for the NAI in broilers, and 6% and zero for the PAI in laying hens. None of the systems significantly reduced the emission rate of odour or ammonia. On the basis of this work, emission reduction factors of the OSF, OSV, and NAI have been adopted in Dutch regulations.

1. Introduction

Houses for broilers and laying hens with littered floors show the highest concentrations of airborne particulate matter (PM) among all housing systems for poultry, pigs, and dairy in the livestock sector (Takai et al., 1998; Winkel, Mosquera, Groot Koerkamp, Ogink, & Aarnink, 2015b). These high concentrations may affect the health and productivity of the birds (Al Homidan, Robertson, & Petchey, 2003; Guarino, Caroli, & Navarotto, 1999) and cause respiratory problems in workers (Omland, 2002; Radon et al., 2001). Since poultry houses exhaust up to 10 m^3 h^{-1} $bird^{-1}$ polluted air, a large number of

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Nomenclature

B1, B2, B3, B4 Broiler farms 1, 2, 3, and 4, respectively
$C_{exhaust}$ Pollutant concentration in the exhaust air flow
C_{inlet} Pollutant concentration in the inlet air flow
CO_2 Carbon dioxide
$[CO_2]_{exhaust}$ Concentration of carbon dioxide in the exhaust air flow (ppm)
$[CO_2]_{inlet}$ Concentration of carbon dioxide in the inlet air flow (ppm)
E Emission rate of pollutant (mg h^{-1} $bird^{-1}$)
Fco_2 Factor for conversion of total heat to the volumetric carbon dioxide production by the animal and its manure (m^3 h^{-1} kW^{-1})
L1, L2, L3, L4 Laying hen farms 1, 2, 3, and 4, respectively
NAI Negative air ionisation system
NH_3 Ammonia
OSF Fixed oil spraying system (installed in B1, B2, and L1)
OSV Oil spraying vehicle (installed in L2)
OU_E European Odour Unit
P Level of significance
PAI Positive air ionisation system
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)
SD Standard deviation
Q Total ventilation rate in the poultry house (m^3 h^{-1} $bird^{-1}$)
Φ_{total} Total heat production by the animal (kW)

PM is also released into the atmosphere and can contribute to local and regional background PM concentrations. Very little is known about health effects of ambient PM from intensive livestock houses to neighbouring residents, but available studies suggest some effects, such as a higher incidence of pneumonia and a lower lung function in the general population, and more exacerbations in patients suffering from Chronic Obstructive Pulmonary Disease (COPD) (Borlée, Yzermans, Van Dijk, Heederik, & Smit, 2015; Heederik et al., 2011; Radon et al., 2007; Schinasi et al., 2011). On a national scale, poultry houses in the Netherlands contribute 13% of the national primary emission of particles with aerodynamic diameters smaller than 10 μm (PM_{10}). To protect the health of its residents, maximum PM limit values for ambient air were set by the European Union (European Directive 2008/50/EC), namely: a daily average limit for PM_{10} of 50 μg m^{-3} with 35 exceedances allowed per year, and an annual average limit of 40 μg m^{-3} for PM_{10} and 25 μg m^{-3} for particles with aerodynamic diameters smaller than 2.5 μm ($PM_{2.5}$). In the Netherlands, the PM_{10} limit is regularly exceeded in the vicinity of animal houses (RIVM, 2014; Van Zanten et al., 2012).

Within a plan of action (Ogink & Aarnink, 2011) PM reduction principles were developed in the Netherlands into effective, economically feasible, and market-ready systems for the poultry industry. Within this plan, air cleaning companies were asked to adopt, co-develop, install, and maintain PM reduction systems inside test locations in collaboration with our research institute. Furthermore, our institute was responsible for the scientific testing of the principles under experimental conditions in small-scaled housings. Three of these principles showed perspective to reduce PM emissions by reducing PM concentrations inside the house: (1) spraying a thin film of pure rapeseed oil onto the litter, (2) negative air ionisation, and (3) positive air ionisation.

With regard to principle (1), some studies related to this principle are available, but they used 1–10% oil in water emulsions (instead of pure rapeseed oil) in laying hen houses, and these were not sprayed onto the litter (Gustafsson & Von Wachenfelt, 2006; Ikeguchi, 2002; Von Wachenfelt, 1999). Other studies did spray directly onto the litter but their focus was on air quality and bird performance, not on emission abatement (Drost, Beens, Dolehghs, Ellen, & Oude Vrielink, 1999; Griffin & Vardaman, 1970; McGovern, Feddes, Robinson, & Hanson, 1999, 2000). Within the plan of action (Ogink & Aarnink, 2011), a fixed oil spraying system, consisting of air pipes and oil pipes fuelling spraying nozzles, was developed and installed inside four rooms of an experimental broiler house (Aarnink, Van Harn, Van Hattum, Zhao, & Ogink, 2011). In that study, which was conducted over four growing cycles, the application of 6–24 mL m^{-2} d^{-1} could reduce PM_{10} emission by 48%–87%, respectively. No effects were found on ammonia emission nor on the production performance of the broilers. It was recommended that the maximum rate should be 16 mL m^{-2} d^{-1} to prevent adverse effects on broilers' foot-pad quality. In a follow-up study (Winkel, Cambra-López, Groot Koerkamp, Ogink, & Aarnink, 2014), the spraying system was extended to twice the number of nozzles to achieve more uniform spraying. It showed that, when oil was sprayed every other day, PM_{10} emission was 44% higher on days after spraying than on spraying days. The study furthermore confirmed that oil spraying (up to 16 mL m^{-2} d^{-1}) had no effect on ammonia emission, bird production performance, nor on the incidence of foot-pad lesions. Also, no effect on odour emission was found. A third study on oil spraying was carried out in eight rooms of an experimental aviary house (Winkel et al., 2016). Here, oil was applied to the litter floor using a hand-held spray gun in rates of 15, 30, or 45 mL m^{-2} d^{-1} which reduced PM_{10} emission with 27%, 62%, and 82%, respectively. Two small but significant negative side-effects were found: a shift in egg quality towards second class eggs for all oil doses and a worsening of the plumage condition of the body spot 'back/wings/tail' in the 45 mL m^{-2} d^{-1} treatment only. Egg production, plumage soiling, behaviour, and litter quality remained unaffected for all oil doses tested. From this study, it was recommended to spray oil in aviaries at 15–30 mL m^{-2} d^{-1}.

With regard to principle (2), two studies have shown that PM can be removed from broiler house air by negative air ionisation by about 40% (Jerez et al., 2013; Ritz, Mitchell, Fairchild, Czarick Iii, & Worley, 2006). Within the plan of action (Ogink & Aarnink, 2011), a negative air ionisation system was installed inside two rooms of the same experimental broiler house as used earlier (Aarnink et al., 2011; Winkel et al., 2014) and tested during two growing cycles (Cambra-López,