Chapter 77
Airborne Emissions from Livestock Farms and Exposure of Nearby Residents using an Atmospheric Dispersion Model

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Abstract To estimate the exposure of local residents to substances emitted by livestock farms, we applied a dispersion model to calculate the air concentrations in the surroundings following from these emissions. At several livestock farms, indoor air measurements were performed to determine emission strengths, while ambient measurements were carried out to compare with model results. Measured substances were particulate matter (PM), endotoxins and micro-organisms. The dispersion model only simulated PM concentrations, which were used as a proxy to determine the dispersion concentrations of endotoxins and micro-organisms. For the living micro-organisms, the process of inactivation has to be taken into account. Here we describe the followed methodology and preliminary results.

77.1 Introduction

Since several years, there is an increased interest in the health of people living near livestock farms. Livestock farms emit particulate matter (PM) which may be accompanied by endotoxins and micro-organisms. Endotoxins (cell wall substances of micro-organisms) and PM are linked to respiratory health effects, such as

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pneumonia, asthma and COPD. Pathogenic micro-organisms could potentially cause infectious diseases, such as Q fever and avian flu. In the current research, we aim to estimate the exposure of residents near livestock farms through airborne emissions. We used the atmospheric dispersion model OPS (Operational Priority Substances, Sauter et al. 2016), developed by the National Institute for Public Health and the Environment (RIVM, The Netherlands).

As a first step, individual animal houses and surrounding concentrations are studied. Measurements of PM, endotoxins, and micro-organisms have been carried out in and nearby livestock farms. From the measured indoor concentrations and ventilation rates in animal houses, the emission strength was estimated. Subsequently, based on this emission, we calculate PM concentrations in the areas around the livestock farm with the OPS short-term (OPS-ST) dispersion model. This is a Gaussian plume model based on hourly meteorological data such that concentrations per hour can be simulated. As the dispersion of endotoxins and micro-organisms cannot be modelled directly, concentrations of endotoxins and micro-organisms are derived from the dispersion of PM. For this purpose, measured size fraction distributions of PM and the measured distribution of endotoxins and micro-organisms over PM are used. The derived concentrations of endotoxins and micro-organisms are compared with the results of field measurements. The process of inactivation will be included in the model to account for die-off of micro-organisms.

77.2 Methodology

77.2.1 Measurements

For this research, concentrations of PM, endotoxins and micro-organisms were studied at individual animal houses and their direct surroundings. Micro-organisms were studied by using cultivation-based techniques for the detection of viable bacteria (expressed as colony forming units: CFU) and PCR-based techniques for the detection of DNA derived from both living and dead bacteria. As livestock farming indicator micro-organisms, *Escherichia coli* and *Staphylococcus spp.* were selected. These micro-organisms serve as indicators to estimate potential spread of other, more pathogenic, micro-organisms which have similar properties relevant for their dispersal. Regarding the animal housing types; laying hen, broiler, sow, and growing-finishing pig farms were selected, as these farm types produce the largest emissions (Maassen et al. 2016).

Outside measurements took place on fixed distances from the livestock farms at approx. 100 m upwind (as indicator for the background concentrations), and approx. 25, 50 and 100 m (and occasionally 200 m) downwind. Measurements were also performed near the air exhaust of the animal houses to gain insight in the concentration levels inside the animal houses and to determine the emission strength. The emission strength was obtained by multiplying the concentrations with the actual ventilation rates.

Additionally, for some days, the particle size distribution of PM was determined as well as the distribution of micro-organisms (living plus dead material) and endotoxins over the different particle size classes.

77.2.2 OPS-ST Dispersion Model

The OPS-ST model is a short-term Lagrangian transport and deposition model, in which relations between individual sources and specific receptors are described by Gaussian plumes using hourly meteorological data (Sauter et al. 2016). Contrary to the long-term model, which uses long-term averaged meteorological data, the short-term model is highly suitable to compare output with short measurement campaigns, or to study the diurnal variation.

The main purpose of OPS is to calculate the concentration and deposition of pollutants such as PM, and acidifying compounds as SO_2, NO_x and NH_3 in the Netherlands. For each individual source, OPS calculates the concentrations due to dispersion and transport and by taking into account the chemical conversion and dry and wet deposition. For a certain location, the contributions of individual sources are summed to obtain the total concentration at that site.

77.2.3 Inactivation

The concentrations of particulate matter as calculated by OPS are influenced by the dispersion, transport, and deposition. In the case of airborne micro-organisms, the inactivation (or die-off) should be considered as well. This process is affected by environmental and meteorological conditions, mainly temperature, humidity and ultra violet radiation (Tang 2009).

To calculate concentrations including inactivation (C_{incl_inact}), this process is combined with the Gaussian plume equations as a first-order rate process with an exponential function of the distance (x), wind speed (u) and the inactivation rate λ with $C_{incl\_inact} = C \cdot \exp\left(-\lambda \frac{x}{u}\right)$, where C is the concentration after dispersion and transport (Van Leuken et al. 2016).

77.2.4 PM Particle Size Distribution and Conversion to Micro-Organisms and Endotoxins

In the OPS model, six particle size classes are taken into account for PM, namely: <0.95, 0.95–2.5, 2.5–4, 4–10, 10–20 and 20–50 (all in μm). The amount of PM is divided over these classes according to their mass fraction in each class. These particle size distributions (psd) differ per animal type and depend on the farm

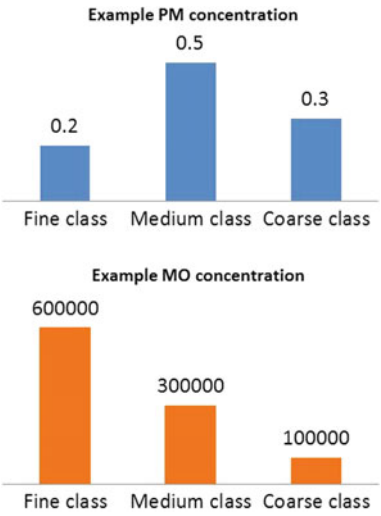

Fig. 77.1 Arbitrary example of the PM concentration (μg/m^3) and the according micro-organisms (MO) concentrations (organisms/m^3) for 3 size classes

housing type and feed as studied by Lai et al. (2014). For the moment, similar particle size distributions are assumed in this study, where the 30 classes studied by Lai et al. (2014) are clustered into the six particle size classes of OPS.

For some measurement days, the psd and the distribution of the micro-organisms and endotoxins over this PM were measured. At the time of writing this extended abstract, these data still need to be analyzed for further use.

A conversion needs to be made from the PM concentrations at a certain location to the concentrations of micro-organisms and endotoxins. As the OPS model keeps track of the individual concentrations per PM size class, we can use the relative fraction of micro-organisms as distributed over the PM psd measured in the farm. When, for instance (see example in Fig. 77.1) in the farm 0.2 μg/m^3 PM is measured in the finest class and 600000 micro-organisms are found in this class, this means we can use a conversion factor of 600000/0.2 = 3000000 micro-organisms/μg PM. Then we calculate the micro-organisms concentrations using the PM concentration field, assuming that the distribution of micro-organisms does not change over the PM distribution. Of course, the psd of PM does change after emission as particularly the heavier particles are more prone to deposition caused by sedimentation and are not as easily transported in air. Furthermore, inactivation of micro-organisms can now be implemented in OPS as a first order removal rate of PM.

77.3 Results

Some preliminary results of the comparison of one of the sampling days regarding the *Staphylococcus spp.* concentrations at a poultry farm are shown. For now we assumed a uniform distribution of the micro-organisms over the PM psd.

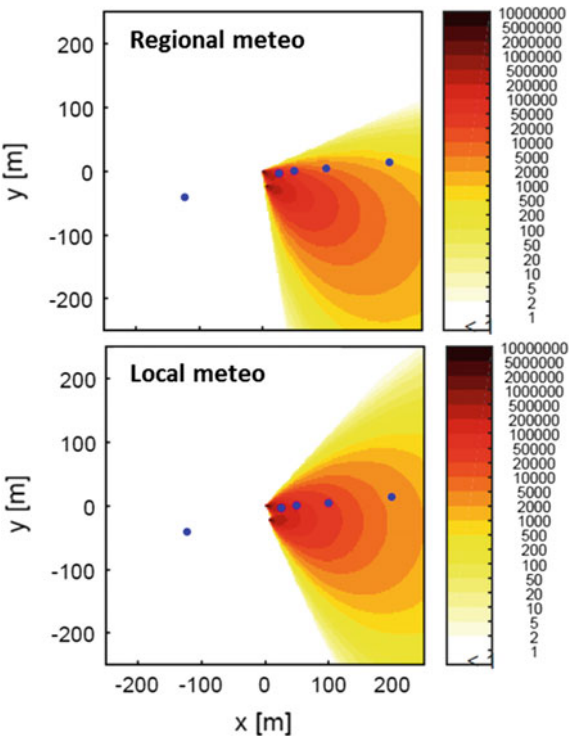

Fig. 77.2 Modelled plume of *Staphylococcus spp.* concentrations (CFU/m^3) at 1.5 m height for one of the sampling days at one particular hour. The dots indicate the location of the measurements. The *top figure* is with regional meteorology, the *bottom figure* with meteorology measured at the site

Figure 77.2 gives an example of the *Staphylococcus spp.* concentrations at a single time point for the area surrounding the farm. At this particular farm, two animal houses were present for which similar emissions are assumed. As such, an overlap of two plumes is visible. The importance of including local meteorology is also shown by the different direction of the plume when either regionally averaged meteorology is taken into account (top figure) or the meteorology as measured at that site (bottom figure).

Figure 77.3 shows the measured and modelled concentrations for the individual measurement sites for the case in Fig. 77.2. Three sets of simulations are shown: (a) without inactivation (these can be considered as maximum values), (b) including a first estimate of inactivation, and (c) including local measurements of meteorology on top of b. Regarding the measurements, it is clear that the background values were substantially lower than the downwind concentrations. Although concentrations decrease with distance from the animal houses, even at 200 m downwind concentrations are obviously elevated compared to the background values.

Regarding the model results, we see the stronger effect of inactivation with increasing distances due to that micro-organisms have been airborne for a longer time. When comparing the simulations with regional meteorology, this results in a stronger underestimation of the measurements compared to results without inactivation. Including the local measurements in the meteorological field enhances the

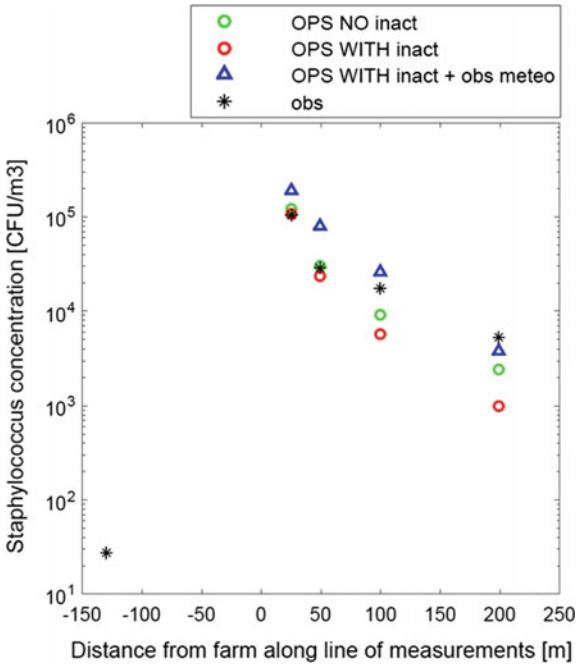

Fig. 77.3 Measured and modelled viable *Staphylococcus spp.* concentrations (CFU/m^3) at the different distances for the case as in Fig. 77.2. Modelled results are for **a** excluding inactivation, **b** including inactivation, and **c** including inactivation and meteorology as observed at the site

modelled concentrations, which now results in stronger overestimations near the source. In general though, the model results (note: still preliminary) agree reasonably well with the observations, yet model input parameters need to be evaluated.

77.4 Conclusions and Outlook

Measured and modelled concentrations of *Staphylococcus spp.* clearly decreased with distance from the animal house. Although there was a strong decrease in concentration with distance from the source, at 200 m distance substantially higher *Staphylococcus spp.* concentrations were found compared to the background observations. This was also found for other poultry farms. Preliminary simulations indicate the importance of including the inactivation of living micro-organisms, as well as the usage of accurate meteorology.

Further analyses regarding the comparison of the model with measurements have yet to be carried out, as well as for the other sampling days and other components (e.g. PM, micro-organisms and endotoxins).

As a next step, the simulations will be scaled up to create regional exposure maps. Furthermore, a QMRA (Quantitative Microbial Risk Assessment) model will be developed. This QMRA model takes several factors into account, such as the

human behavior (e.g. light/heavy activity), age, inhalation and the dose-response relation. By coupling the QMRA model with the concentrations in the ambient air (the exposure) as determined by the dispersion model OPS, an estimation of the health risks is obtained for the residents living nearby animal houses.

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Questions and Answers

Questioner: Douw Steyn
Question: Your model evaluation approach, using a log concentration scale, seems unreasonably demanding. How much better (visually at least) would the model appear if you used a linear scale?
Answer: Indeed I also had to get used to using a log concentration scale, but this is actually very common in the science of micro-biology. As the amount of micro-organisms can decrease very rapidly, a linear scale would only show distinguishable output for very small distances close to the emission point, while we are also interested in concentrations further away.

Questioner: Heinke Schlünzen
Question: How did you consider the impact of the building on this close-to-scale dispersion and did you consider the heat emission resulting from the densely packed animal stock?
Answer: We do not consider the impact of the buildings as this is currently not available in the model, though we agree that this might impact the dispersion at these local scales. Therefore, for now, measurements were only performed on days with a certain wind direction criterion where the direction of the emissions had to be aligned with the wind direction to avoid a large influence of the building.

We also did not include the heat emission resulting from the densely packed animal stock. Though this is an option in the model, the actual heat emission was unknown, while furthermore we expect this to be more important for industrial sources with significantly higher temperatures.

Questioner: Jaakko Kukkonen
Question: Regarding the transport of micro-organisms in the atmosphere, it is challenging to model their viability, due to the large number of possible micro-organisms. There are millions of different species of micro-organisms, viruses and bacteria, some of which are harmless, some extremely hazardous. Would you like to comment, please?
Answer: Indeed, there are many, many micro-organisms with each different behavior regarding inactivation for example. In this study, several pathogenic micro-organisms were selected for which their presence in livestock farms was investigated. As indicator micro-organisms, which can occur in higher

concentrations and are therefore more easily measured, *Staphylococcus spp.* and *E. coli* were chosen. These represent two groups of bacteria, namely the gram positive (*Staphylococcus spp.*) and gram negative (*E. coli*) bacteria which have quite distinct characteristics. Gram positive bacteria have a thicker cell wall for instance and are therefore less easily inactivated.

To determine the inactivation rate, a literature study was carried out after which several results from literature were combined on which a regression analysis was performed to determine the function for the inactivation rate. This is hence based on more micro-organisms than just *Staphylococcus spp.* and *E. coli*, though of course not all existing micro-organisms can be included as there are simply way too many while additionally they may be difficult to measure. But by distinguishing between gram positive and gram negative bacteria, we do take into account an important characteristic of the micro-organism species. As such, the inactivation rate is also a function of the bacteria type, besides for example temperature.

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