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Influence of Exhaust Air Velocity on Aerosol Dispersion from Animal Housing

In order to make detailed and location specific predictions about increased amounts of aerosol in the vicinity of planned animal houses, an immission prognostic is mandatory. High construction density and highly structured topography near animal houses cause serious problems. If the VDI guideline 3782 on determining plume rise cannot be applied, new methods for an immission forecast near emissions sources must be found. In this article a dynamic dispersion model is presented, which can contribute.

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Keywords

Dispersion modeling, dust, transmission, immission, exhaust air velocity

Literature

References LT 08211 you can call up via Internet http://www.landtechnik-net.de/literatur.htm.

The knowledge about the exhaust air out of animal houses has steadily improved in recent years. Recent studies relate not only to annual averages, but also show significant differences between different seasons, too [Nannen]. This contains not only the actual emissions (exhaust gases and aerosols), but also the stable related parameters such as temperature, humidity and air volume flow. It is useful to integrate the obtained data into dispersion models, in order to make predictions about detailed site immissions.

Winter/summer rate

The difference between the summer and winter air rate occurs especially in forced ventilation systems, where especially the exhaust air quantity can be controlled. According to the planning values for fattening pigs with a single animal weight of 120 kg per animal in summer at a temperature of 26 ° C and a desired temperature difference between stable internal temperature and ambient temperature of 2 K, an air volume flow of 119 m^3 / h per animal is given. The corresponding winter air rate is at 14.1 m^3 / h, with a relative humidity of 80% RH and temperature of 16 to 22 °C was used [2]. This means, that the ventilation rate varies, depending on the weather situation by up to 88%.

It should be kept in mind that, in assumption of a constant chimney diameter, the exhaust velocity, and also the velocity of the aerosol particles in the exhaust air, depends on the season. Furthermore the expected exhaust air velocities in winter are significantly lower than the comparable rates in the summer months.

Generally, it can be said that a higher exhaust air velocity causes a different exhaust air plume.

However, the house climate has a significant impact on the well-being and health of animals and therefore it is an important parameter for the animal-friendliness. So the air volume flow shall be deemed to be fixed

Particles in the exhaust stream

In the following the effects of the seasonal fluctuating exhaust air velocity will be considered. First, as a simplified assumption, the aerosol particles of the exhaust air stream have the same velocity as the moving air. Furthermore, the exhaust air flow is vertically directed and crosses at the end of the chimney the exterior horizontal directional air flow, which is given by the wind direction and wind speed.

In addition, we ignore the influence of the exhaust air stream outside of the chimney. Under these very simplistic assumptions, the superelevation caused by the inertia of the particles, equals the stopping distance [3] of the particles.

$$S = \frac{\rho_p C_c d_p^2}{18\eta} \upsilon_0 \qquad \text{(Eq.1)}$$

In this case ρ_p describes the density, d_p the particle diameter, C_C the Cunningham-slip correction, υ_0 the initial velocity of the particle and η takes the viscosity of the air into account.

Under standard conditions the stopping distance for a 10 μm large particle with an initial velocity of 10 m/s is about one millimeter. Even with an exorbitant high exhaust

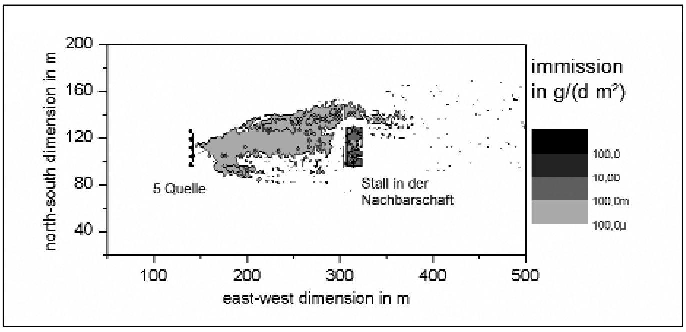

Fig. 1: Simulated immission in g/(d m^2) for a negligible exhaust air velocity

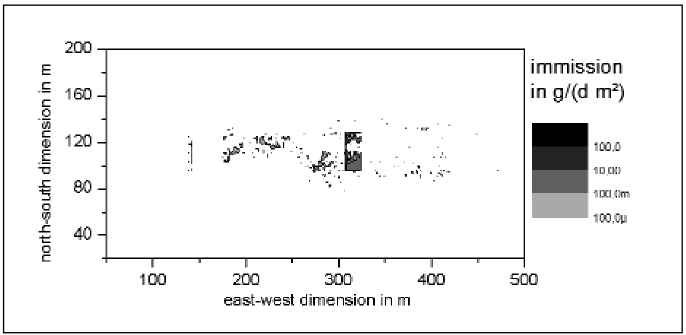

Fig. 2: Simulated immission in g/(d m²) for an exhaust air velocity of 5 m/s

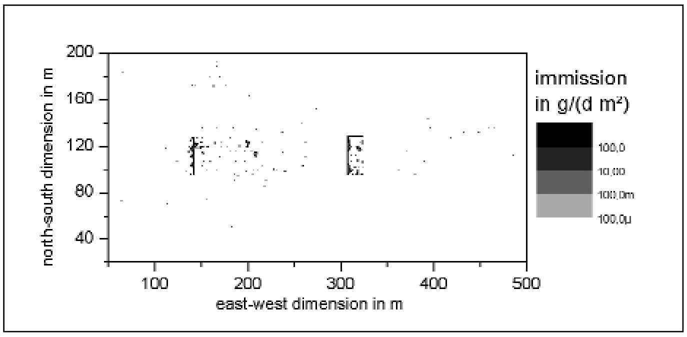

Fig. 3: Simulated immission in g/(d m²) for an exhaust air velocity in the range of the maximum summer air rate

air velocity of 100 m/s the superelevation would be only 1cm. This simple example shows that the superelevation is mainly caused by the mixing of different air masses. The velocity and inertia of aerosol particles can almost be ignored.

To describe the mixing of the exhaust air with the exterior air flow and so the superelevation there are two common methods.

Considering the exhaust velocity

The dispersion forecast program Austal2000 considers the exhaust air velocity to calculate the superelevation according to VDI 3782 part 3 [4]. However, the impact of higher objects and terrain bumps on the rising behaviour of the exhaust air plumes must be negligible [4]. Especially in the agricultural sector, due to the highly structured development situation and low chimney heights, these conditions often are not met.

An alternative method to describe the exhaust air plume of livestock facilities is the numerical simulation of the fluid dynamical equations.

STAR3D (Simulated transmission of aerosols in 3 dimensions) allows a dynamic approach to the dispersion behaviours of aerosols. The program is based on the software Nast3DGP, developed by the Institute of Numerical Mathematics at Bonn University [5]. This software solves the incompressible Navier-Stokes equations in a freely configurable volume by numerical approximation.

$$\frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u} = \frac{\vec{g}}{Fr} - \nabla p + \frac{1}{\mathrm{Re}} \Delta \vec{u} \qquad \text{(Eq. 2)}$$

with $\vec{u}$ = wind speed, $\vec{g}$ = exterior forces, p = pressure, Re = Reynolds number and Fr = Froude number.

This makes it possible to calculate the wind field in a test volume, taking obstacles (buildings, trees etc.) into account. Likewise, it is possible to define the inlet conditions freely, so that the inflow of the exhaust air from the chimneys of the stable can be taken into account. Using the equation

$$\frac{\partial \vec{x}_p}{\partial t} = \alpha_w \cdot \vec{u} + \lambda \cdot \vec{e} + \vec{v}_{sed} \qquad \text{(Eq. 3)}$$

it is possible to calculate the particle path corresponding to the simulated wind field.

$\vec{x}_p$ describes the particle position, α_w the coupling of the particle to the external wind field, $\vec{u}$ the wind speed at the position of the particle, λ the diffusion constant, $\vec{e}$ a unit vector, which indicates the direction of diffusion and $\vec{v}_{sed}$ sedimentation velocity of the particle [6].

From the so-calculated distribution of particles for each time step, it is possible to determine the total immission, through integration across the entire simulation time.

First results

For a first test of the software, a 500 • 200 m area (100 m high) is defined, where transverse to the longitudinal dimension an animal house with five chimneys as sources is placed. In the distance of 250 m in westward direction a second building stands as another obstacle. As the wind distribution a westerly wind situation is selected, and the wind direction is changing in a range of 15° randomly. The wind speed was 3 m/s and fluctuated in an interval of ± 1m/s randomly. The emitted quantity of PM_{10} was 0.1 g/s per chimney, the size distribution of particles corresponds to the in [1] identified distribution. Overall, three comparative simulations, in which the exhaust air velocity from all five chimneys successively was set to zero, five and fifteen meters per second, were carried out.

Figure 1 shows the particle immission distribution with a negligible exhaust air velocity. Clearly, the in wind direction (west wind) distinct immission plume can be recognized. Especially in the area of the building, used as an obstacle, the advantages of a dynamic simulation of dispersion (STAR3D) are visible. The effects of turbulences can be studied in detail.

If the exhaust air velocity increases, the aerosol will be carried into higher areas of the simulation volume. First, the particles are carried further away from the sources of emission. Secondly this leads to a dilution process, meaning that the pollution in the direct stable environment will be reduced. *Figure 2* shows the results of the immission simulation for an exhaust velocity of 5 m/s. In contrast to *Figure 1* a significant reduction of the particle immission in the stable environment of the facility is visible.

If the exhaust air velocity increases furthermore, the computing effort increases considerably, since the simulation volume above the emission sources, in which the exhaust air swirls with the outer air flow greatly enlarges. Moreover, it comes to a further reduction of the immissions between the two buildings as shown in *Figure 3*.

Summary and Conclusion

The first results of the dispersion simulation STAR3D show the relevance of the exhaust air velocity on the prognostic of immissions in the immediate vicinity of the emission sources. It is recognizable that with increasing exhaust air velocities a reduction of immissions nearby the emissions sources comes along. The dispersion model STAR 3D has after finalization and evaluation the potential to fill the gap caused by the limitations in the VDI guideline 3782 Sheet3 [4].

Literature

Books are marked by •

[1] • *Nannen, C.*: Staubemissionen aus Schweineställen – Bestimmung von Einflussfaktoren auf die Partikelfreisetzung und deren Zusammensetzung. VDI-MEG 461, Bonn, 2007

[2] DIN Norm18910-1: Wärmeschutz geschlossener Ställe- Wärmedämmung und Lüftung – Teil 1: Planungs- und Berechnungsgrundlage für geschlossene zwangsbelüftete Ställe. Beuth Verlag, Berlin, November 2004

[3] • *Hinds, W. C.*: Aerosol technology. J. Wiley, New York, 1982

[4] VDI-Richtlinie 3782: Berechnung der Abgasfahnenüberhöhung, Juni 1985

[5] • *Griebel, M., T. Dornseifer and T. Neunhoeffer* : Numerical Simulations in Fluid Dynamics, a Practical Introduction. SIAM, Philadelphia, 1998

[6] *Rosenthal, E., T. Schneider, W. Büscher und B. Diekmann* : Sedimentation von tierartspezifischen Stäuben im Stallinnenraum. Landtechnik 62 (2007), H. 2, S. 102-103