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Dispersion of odours and biological aerosols

Prognosis with an adjusted model

For prognosis of environmental pollution through livestock production units, important tools are models for the simulation of odour dispersion and that of other extraneous material.

Rapid computer development now enables the reality-near representation of livestock units and their surroundings in a calculation model to receive detailed information over the airflow conditions and dispersion behaviour of polluting and odour substances.

In the following, the present technological state of such models is described along with the advances of the NaSt3D model developed by the working group in Bonn.

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Keywords

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The basis for most dispersion models is a transport equation in the form of (f1). This describes the behaviour of a concentration field with regard to a given wind field.

((Gleichung einsetzen)) (f1)

$c(\vec{x}t)$	Concentration on site $\vec{x}$
$\vec{u}$	Wind field
λ	Diffusion parameters
Q	Source

The simplest, most realistic form of wind field is collinear, i.e. constant within horizontal layers. Such wind fields exist in higher air layers or above areas with consistent low vegetation and without buildings.

((Gleichung einsetzen)) (f2)

Q	Emission flow in kGE/h
u_h	Wind velocity in direction of x-axis in m/s
h	Effective source height
$\sigma_y = F \cdot x^f$	Dispersion parameter in m
$\sigma_z = G \cdot x^g$	Dispersion parameter in m

The equations can be analytically solved under these preconditions (f2) [2]. Specific guidelines (e.g. TA Luft) can be taken from individual parameters in this method, described as a Gauß model.

The great advantage of the Gauß model lies in its very small calculation requirement. However, this model does not allow the integration of effects through obstacles, e.g. the emitting livestock unit itself or nearby buildings so that application for forced ventilation livestock buildings with high effective source heights, and the concentration prognosis from 100 m distances, is limited.

Own values can be investigated as an alternative to ready-to-use parameters with the former taking consideration of special situations such as low source heights or existing buildings [3]. Our NaSt3D program can help determine such parameters.

((Gleichung einsetzen)) (f3)

$\vec{u}$	Wind field
$\vec{f}$	Exterior gravitation
ρ	Air density
p	Pressure
ν	Kinematic viscosity

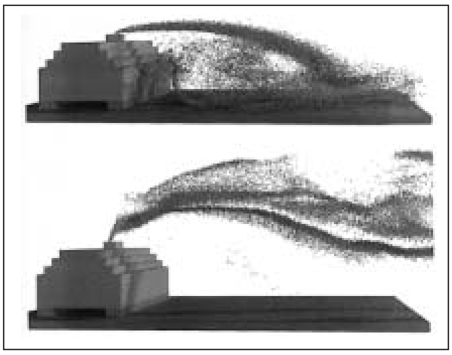

Fig. 1:Simulation of dispersion behind a livestock building subject to different velocities of airflow.

Statistical numerical model

In order to take account of these obstacles further knowledge about the wind field is necessary. This is described in physical terms via the Navier-Stokes equations (f3). These equations can no longer be solved through analysis so that up until the development of computers they had more of an academic character.

With the availability of the first computation machines, numerical solutional methods were developed suitable for solving the Navier-Stokes equations. For describing the wind field the dispersion area is divided within a grid and the respective physical parameters calculated on this.

To handle the calculations required here, turbulence models were developed able to separate the turbulent proportion of the airflow from the average flow and deal with both separately. This led to considerably smaller calculation times and enabled increased program stability. However, this approach leads to the loss of the time information, necessary especially for prognosis of odour pollution.

The calculation of dispersion is then carried out following the airflow calculations through solving the transport equation (f1) and this also only delivers average values. Hereby effects appear, especially in the case of large dilutions between source and pollution location, which are numerically based on grid calculations (numerical diffusion) and can falsify the results.

On modern computers such models allow very rapid calculations with regard to special locational characteristics. For odour pollution prognosis, however, further models are required which can reproduce the change-

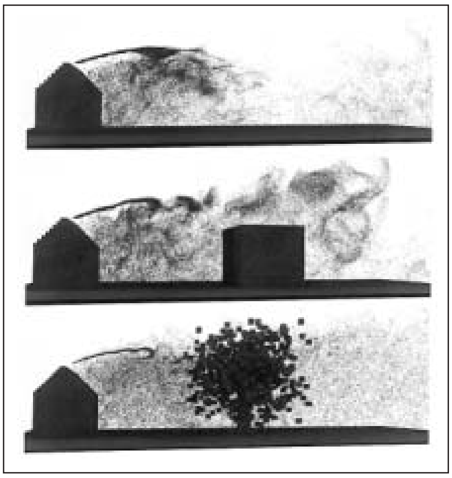

Fig. 2: Simulation of the effect of different obstacles to livestock building emission dispersion

over from average concentrations to those exceeding the odour threshold.

The parameters of these excess models can also be determined with the Bonn NaSt3D model (*fig. 3*). The parameters required for prognosis cases are especially advantageous for the evaluation of livestock units in the planning stage where no entry or measurements of the site can be carried out for calibrations. Up until now, such cases could only be tackled by wind tunnel trials [4].

Time dependent numerical calculations

The NaSt3D model (Navier-Stokes in third dimension), which works without turbulence models, was created through close cooperation by the Institute for Agricultural Engineering, Bonn University and the Institutes for Physics and Applied Mathematics.

The necessary calculation stability is achieved and increased through specially adjusted solutional algorithms, calculation speed through parallel programming and application of networked computers to such an extent that representative calculation times can be realised.

Through measuring with SF6 as trace gas and a highly sensitive measurement technique it can be determined that a grid pattern of 50 cm is sufficient for the reality-near modelling of concentration variations.

((Gleichung einsetzen)) (f4)

$\vec{x}_P$ Particle position
α Inertia factor ($0 \leq \alpha \leq 1$)
$\vec{v}_W$ Local wind vector
λ Diffusion parameter of turbulence diffusion
$\vec{e}$ Unit vector with coincidental direction
$\vec{v}_s$ Sedimentation speed

For avoiding numerical diffusion and constructing higher data flexibility, the dispersion calculation does not take place through solving of the transport equation but instead through an own-developed particle model (f4).

In this model, sources are simulated as starting point of a virtual particle moving with the airflow, moved off the ideal line through diffusion and depressed through external forces. The falling speed here for a particle is constant in that friction and gravity forces balance-out even at very small speeds. The conclusion of a concentration takes place simply through numbers of particles in a test volume no longer bound to the calculation grid.

This method offers high flexibility in the simulation of various source types and the physical preliminary actions during dispersion.

Possibilities for the NaSt3D model

The advantage of this model compared with others is that dispersion is calculated in parallel time to the airflow and thus the time characteristics in the exceeding of the odour threshold concentration can be directly simulated.

An example of the model's performance capacity is shown by the testing of the „plume excess“ which is part of the Gauß model in the calculation of the effective source height (*fig. 1*). Here it is demonstrated that with sources lying closely above the roof ridge, as in most livestock buildings, only in the case of very high emission velocities can one assume a virtual excess. In most cases this is completely overlain through the downwash directly behind the building so that such sources must be regarded as ground-near.

Also able to be simulated are open obstacles. *Figure 2* shows the example of the difference in dispersion behaviour behind a solid obstacle and an open one. With the same average concentration the peak values differ greatly so that under certain surrounding conditions odour pollution can be hindered by an open building barrier. This is shown especially well in a statistical evaluation (*fig. 3*) where average concentrations are investigated in association with threshold excess frequencies.

Odour emitting buildings where the airflow can travel through the building such as outdoor climate barns can also be calculated with this model.

Aerosols

Through the particle model, NaSt3D is also suitable for the calculation of aerosol dispersions, e.g. dust and bacteria. Only the parameters of sedimentation velocity and their statistical distribution with regard to mass distribution of the observed aerosols as well as the parameter (must be experimentally determined through further work.

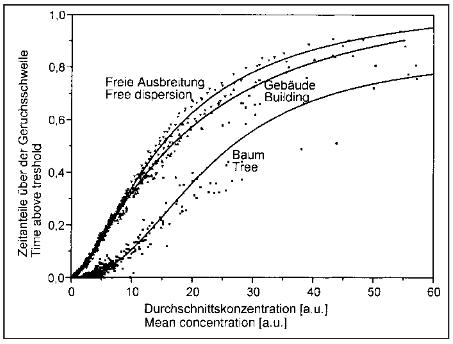

Fig. 3: Statistical evaluation of concentration time series with average concentration and threshold value excess period

It would also be necessary to carry out investigations over the release of aerosols in relation to the weather conditions, ground relative moisture content and time of day in order to achieve concrete statements on the dust pollution in the surrounds of a poultry unit with the NaSt3D model. This work is now in a preparation phase.

Further work and outlook

Further work at the Institute for Agricultural Engineering concerns itself with the development of multigas sensors, so-called „electronic noses“. These should serve to replace complicated personnel inputs in building permission procedures and determine the strength of sources for calculation. These sensors work with a number of different unspecific gas sensors the association of which can be used to give odour impressions.

Literature

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