

## Odour Dispersion and Fluctuation Modelling with a Non-Stationary Lagrangian Model

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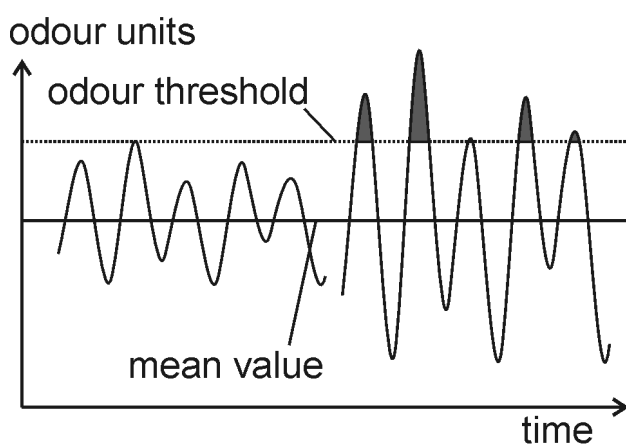
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### 1 Introduction

Odour immissions (the input of odour at a location) near low sources (e.g.. agricultural enterprises) are an increasing problem in densely populated areas. The attention on odour as an environmental nuisance has been growing according to the growth of industrialisation and the consciousness of people on a clean environment necessity. New developments are hindered by controversies about the permissible distances. In Germany, the regulations are controversial among the experts and lead to judicial arguments.

The nature of the odour impression leads to other requirements for odour dispersion models than that for 'normal' pollutants. The temporal average is not the characteristic value for the nuisance, rather the concentrations above the odour threshold. Fig. 1 shows the fluctuation of the concentration of an odour around a certain mean value. The curve on the left side remains below the odour threshold. On the right side, a second curve is shown which fluctuates around the same mean value. Here, the threshold value is exceeded during about one third of the time. This diagram shows the necessity of determining the amount of the fluctuation in addition to the mean input value.



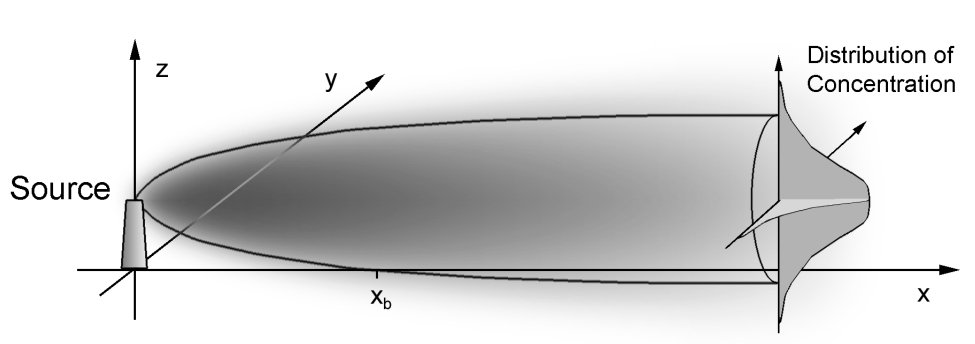
**Figure 1** Fluctuation of odour concentration.

### 2 Odour dispersion models

Dispersion models are used for the prognosis of the input of emitted pollutants and odorants. The terms emission, transmission, and immission designate the three partial aspects of substance dispersion. Emission describes the release of substances at an emission source with respect to the kind of odour, the amount of emitted odour and the temporal course of the release. Transmission means the process of substance transport and distribution in air streams. Immission is the counterpart of emission. This term designates a local input of pollutants.

For the calculation of transmission, dispersion models are employed. So-called Gaussian models [1], which provide an analytical description of dispersion under very simplified conditions, are

widely used. Their disadvantage is the missing consideration of obstacles in the flow, e.g. buildings, which affect the odour dispersion and the fluctuation.



**Figure 2** Gauss-model for odour dispersion.

Numerical models (e.g. the model MISKAM [2]) allow detailed flow- and dispersion calculations to be carried out. However, they require extensive calculations. A common feature of all models which have been used so far is the prognosis of mean immission values. For that reason special fluctuation models which give a functional relation between the mean values and the excess time of the odour threshold are applied. A widely used assumption is the factor 10 model [3] (0.1 OU equals 10% excess time). The model BAGEG [4] on the other hand uses a functional relation between the mean immission and the excess probability. Both fluctuation models are disputed because a justification is difficult to obtain.

### The odour dispersion model NaSt3D

The flow- and dispersion model NaSt3D (abbreviation of Navier-Stokes, 3-dimensional) is a further developed model [5], whose outstanding characteristic is its ability to calculate time dependent concentrations instead of the mean values of today's models. The technique used is the direct numeric simulation (DNS) [6]. DNS avoids special assumptions on the sub-scale level, as the k- $\epsilon$  model for the energy dissipation and thus the damping of the eddies connected with k- $\epsilon$  models.

To speed up the calculations NaSt3D can be used on parallel computer systems. For this purpose, the program code is consistently object-oriented, which allows decisive modifications and program extensions with regard to the problem of odour dispersion. Through dynamic memory allocation, NaSt3D makes the calculation of significantly larger grids possible [7]. In NaSt3D, the calculation of the flow and the dispersion is not carried out in two separate steps, but simultaneously at every point in time during the simulation. This also opens up the possibility of simulating the fluctuation of concentration, which is important for the problem of odour prognosis. Therefore, the conclusion from the mean concentration to the exceeding frequency (factor 10 model or BAGEG), which leads to disputes, can be avoided.

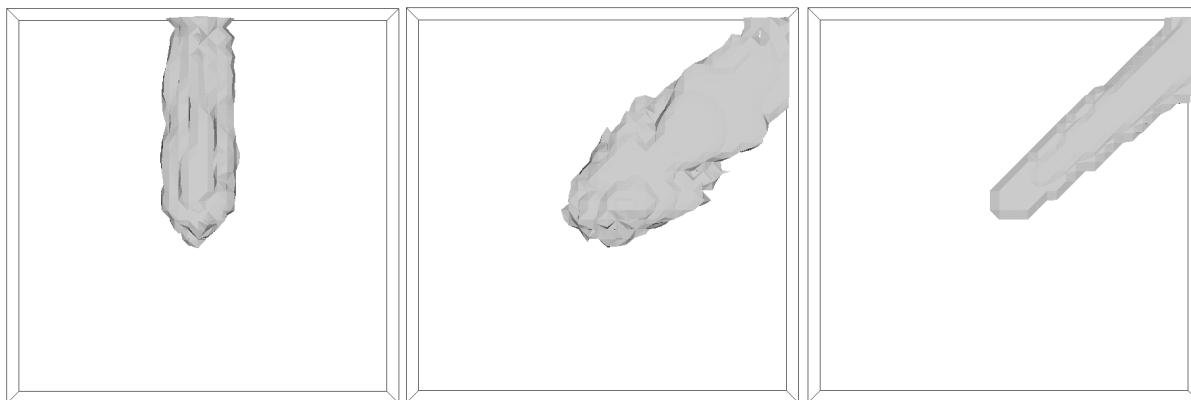
### Modifications and New Developments regarding NaSt3D

In principle, the dispersion of gases and odorants in the NaSt3D model can be calculated using two different approaches [8]. The built-in Euler approach uses an improved advection-diffusion model, and the alternative, additionally implemented Lagrange approach calculates the dispersion by following particle trajectories.

### The Advection-Diffusion Approach

Through an approximation of a higher order, the VONOS method (Variable-Order Non-Oscillatory Scheme), the effect of numerical diffusion in NaSt3D has been reduced. **Figure 3** shows three

dispersion plumes calculated with NaSt3D. The left figure shows the dispersion plume in the main grid direction and the middle figure the dispersion diagonal to the grid. The widening effect of numerical diffusion is clearly visible. The right figure shows the calculation with the VONOS method. The dispersion plume now corresponds to the shape in the left figure.

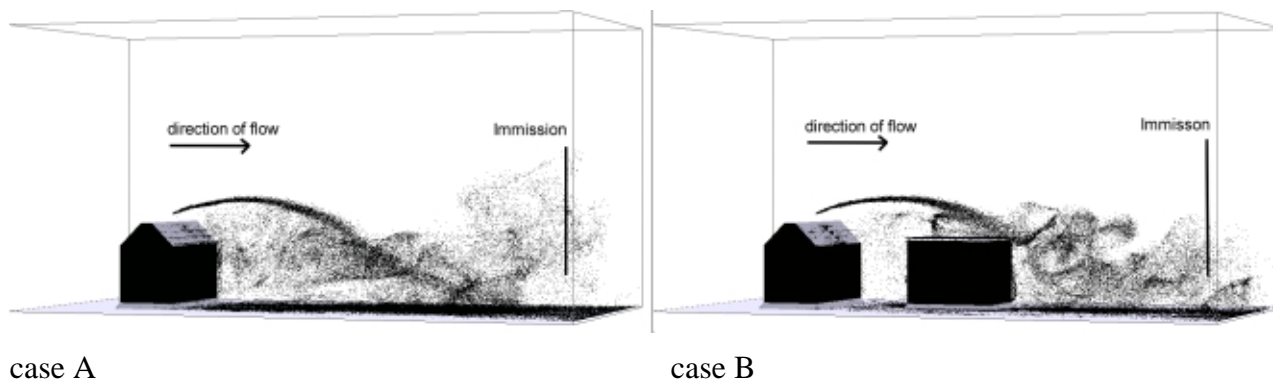


**Figure 3** Suppression of the numeric diffusion in NaSt3D.

### The Lagrange Approach

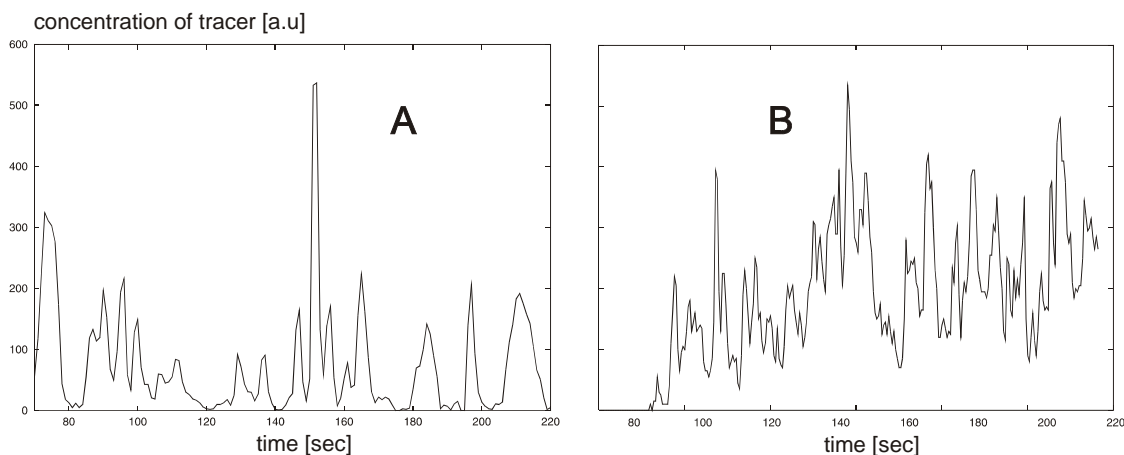
The Lagrange approach for the modelling of dispersion is based on the calculation of the spatial trajectories of virtual particles which are moved along the flow field [9]. In principle, the Lagrange approach avoids the problems of numerical diffusion. On the other hand, however, the calculation of the particle trajectories requires additional memory, especially if the particle densities are assumed to be sufficiently high. In order to be able to calculate statistically reliable concentrations using particle density at a larger distance from an emission source, a number in the order of several 100,000 particles must continuously be included in the calculations. The decisive advantage of the Lagrange approach lies in the possibility to attribute a mass to the calculated particles and hence to describe the specific behaviour of such particles realistically. Especially in the case of odour emissions, it is assumed that a considerable portion of the odorants is transported by dust- or aerosol particles. Their behaviour cannot be described adequately with the aid of the classic gas dispersion calculation.

In **figure 4** two example calculations for an dispersion without and with an obstacle are shown. The time series of the two cases A and B differ because of the more turbulent mixing behind the second building.



case A

case B



**Figure 4** Time dependent calculation (case A and B) with time series of odour concentration.

### Validation

The validation of dispersion models requires original data, which as test data sets allow the performance of the models to be assessed [10]. Depending on the sophistication and complexity of the model, different data are necessary. Dispersion models for the prognosis of mean values only need measured mean input values. Models for the simulation of fluctuations, however, require the time series of the inputs. When gathering test data sets, it is necessary to collect all meteorological, topographic, and emission data which influence the dispersion process. These data represent the model input in simulation calculations. As a complement, the immission data must be registered which are compared with the results of the simulation calculations.

Direct odour measurement with high temporal resolution has been impossible so far. Electronic noses, which take a kind of odour measurement, are not yet sensitive enough for direct measurement, and it has thus far been impossible to use them for field measurements. For this reason, alternative measurement values must be employed. Instead of odorants, other gases which can be measured with the required sensitivity and time resolution are released at the location of emission [11].

Tracer gases must meet several requirements:

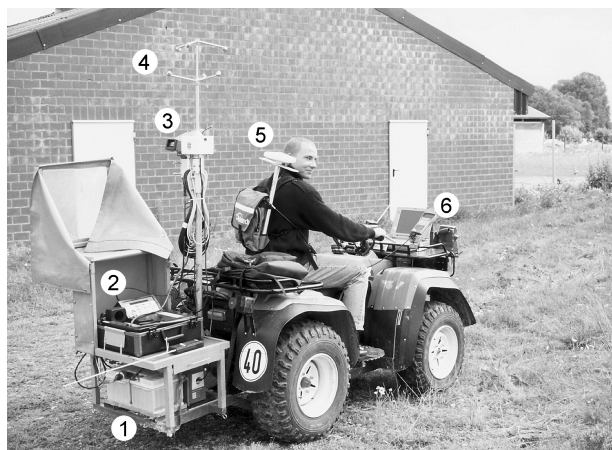
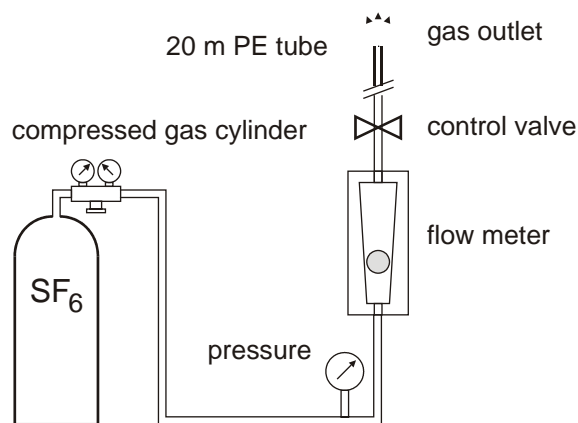
- non-toxicity and good environmental compatibility
- low background concentration
- low reactivity and low solubility
- easy and sensitive detectability

Sulfurhexafluoride shows all the characteristics required for a tracer gas. For this reason, it was used for the validation measurements [12].

The tracer was measured with a modified leak detector. This instrument works with an ECD (electron capture detector). The instrument “Meltron Leakmeter 200” used for this purpose has a measuring range from 10 ppb to 20 ppm, i.e. a dynamic range of 1:2000. For high resolution in the low measuring range, a direct output port was retrofitted which transmits the detector signals in the form of a measuring frequency to a digital counter with a computer interface.

The tracer gas was released from 10 kg SF<sub>6</sub> compressed gas cylinders with a specially arranged combination of a pressure reducer, a manometer, a variable area flow meter, and a control valve (see **figure 5**).

Input measurements were taken with a mobile measuring vehicle. This approach was chosen because, given the generally varying wind directions, stationary measurements either require frequent relocation of the measuring equipment or multipoint measurement. The measuring vehicle is an all-terrain vehicle with four-wheel drive and platforms for the measuring equipment. **Figure 6** shows the vehicle with the mounted measuring instruments.



**Fig. 5 and 6** Tracer release and mobile tracer measurement vehicle (1: power supply, 2 and 3: tracer monitor, 4: ultrasonic anemometer, 5: GPS-receiver, 6: data acquisition).

### Summary and Future Prospects

The odour dispersion program NaSt3D allows time-resolved simulations of odorant dispersion to be carried out. The Lagrange particle modelling of the dispersion enables the specific behaviour of odorants with a mass to be described. The question of odour impressions above the threshold, which is important for the evaluation of annoyance caused by odour, can be addressed directly using the time-resolved calculation of the input concentrations without further auxiliary assumptions.

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