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Diffusional effects on emitted dust – modelling and experimental evaluation

A method was developed that allows to follow the movement of dust particles moving in an air flow under the influence of sedimentation and diffusion using a laser and a camera. A numerical value for the turbulent diffusion could be determined. This value was implemented into sedimentation modelling and the simulation was compared to sedimentation curves that were earlier measured in experiments.

Keywords
Diffusion, turbulence, aerosol, dispersion modelling, sedimentation

Abstract
Landtechnik 65 (2010), no. 2, pp. 114-117, 5 figures, 1 table, 11 references

The emission of dust from different sources has more and more come into focus and critical reception by the public. On this background emission modelling has become more and more significant during the last years. In order to improve the quality of these predictions agricultural research has started to discuss algorithms originating in fluid dynamics. At the Institute of Agricultural Engineering at the University of Bonn the emission modelling software STAR3D was developed and successfully validated [1].

Today modelling allows to take the particle's physical properties into consideration. Besides sedimentation, resuspension, adsorbtion and agglomeration these include also diffusion.

Background

Brown Diffusion denotes an isotropic particle movement in all three spaciel directions. It results from collisisons between air molecules and (small) aerosol particles and leads to a particle flux J, in opposed direction to the gradient of concentration *n*.

$$J = D_{mol} \cdot \nabla n \quad \text{[Eq. 1] (1. Law of Fick)}$$

The diffusion coefficient D_{mol} can be calculated unter consideration of temperature T, dynamic viscosity η and particle diameter d [2]:

$$D_{mol} = \frac{k \cdot T}{3\pi\eta d} \qquad [D_{mol}] = \frac{m^2}{s} \quad \text{[Eq. 2]}$$

This diffusion coefficient does not change with time. For the average velocity of particles one gets

$$v = \sqrt{\frac{18k \cdot T}{\pi\rho_p d}} \quad \text{[Eq. 3] [3]}$$

Assuming a density of ρ = 2,7 g/cm³ and a viscosity of η = 17,1 µPa s one can calculate D_{mol} and v for typical particle diameters as given in **table 1.** They are compared to the sedimentation velocity as given by equation 4.

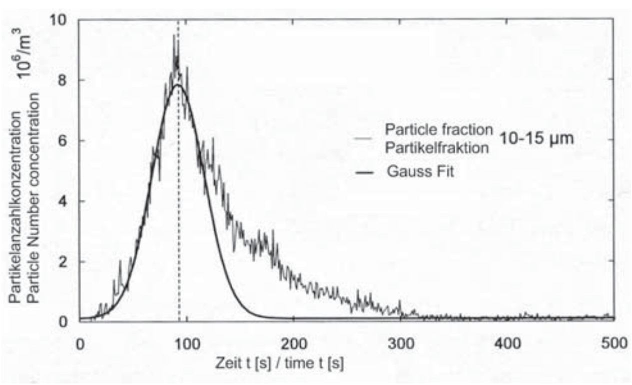
$$v_{sed} = \frac{g \cdot \rho \cdot d^2}{18\eta} \quad \text{[Eq. 4] [3]}$$

Clearly Brown diffusion loses its significance with increasing diameter.

When regarding the sedimentation of a monodisperse aerosol considering only sedimentation and Brown diffusion, one finds a gaussian distribution of arrival time [4]. However, in earlier experiments at the University of Bonn a distribution has been found that does not follow a Gaussian distribution but instead shows an offset in the measured time of arrival [5] as shown in **figure 1**. This resulted in further experiments and the here described thesis.

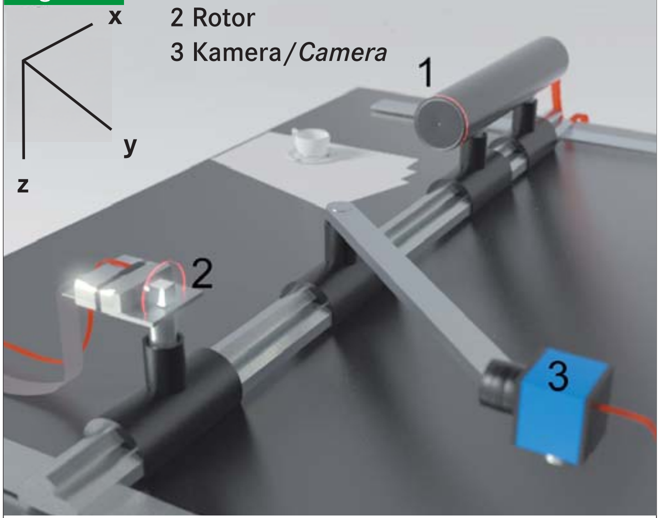
Experimental data as already presented in [6] shows an asymmetric curve shape, which does not coincide with theoretic expectations (**figure 1**), and was therefore under closer investigation in a diploma project [7].

Fig. 1



Distribution of particle arrival time for particles with density ρ = 2,7 kg/m³ and a diameter d between 10 and 15 µm. For better understanding a Gauss curve was fitted to the experimental data

Fig. 2



Experimental set up used during the measurements

In this thesis, a cooperation between the Institute of Agricultural Engineering and the Institute of Physics at the University of Bonn, the behaviour of sedimenting aerosols has been investigated. A special focus was on the asymmetric distribution of arrival times. Aim was to use sedimentation experiments to determine a model that can explain the particle movement.

Two approaches have been considered. In turbulent diffusion energie is transported by a chaotic eddy movement. Therefore one finds velocities significantly higher than in Brown diffusion, so that movement is dominated by turbulent diffusion. As shown in [8] and [9] turbulent diffusion can be described for particles with a diameter of 50 µm in analogy to Brown Diffusion with a diffusion coefficient D_T that has to be determined by experiment.

The second effect is the gradient in concentration: heavy particles have a higher sedimentation velocity than light particles. This leads very fast to a concentration gradient and a particle flux in opposite direction. This is why especially light particles diffuse opponent to the direction of sedimentation and a delay in arrival time can be found.

Experimental set-up

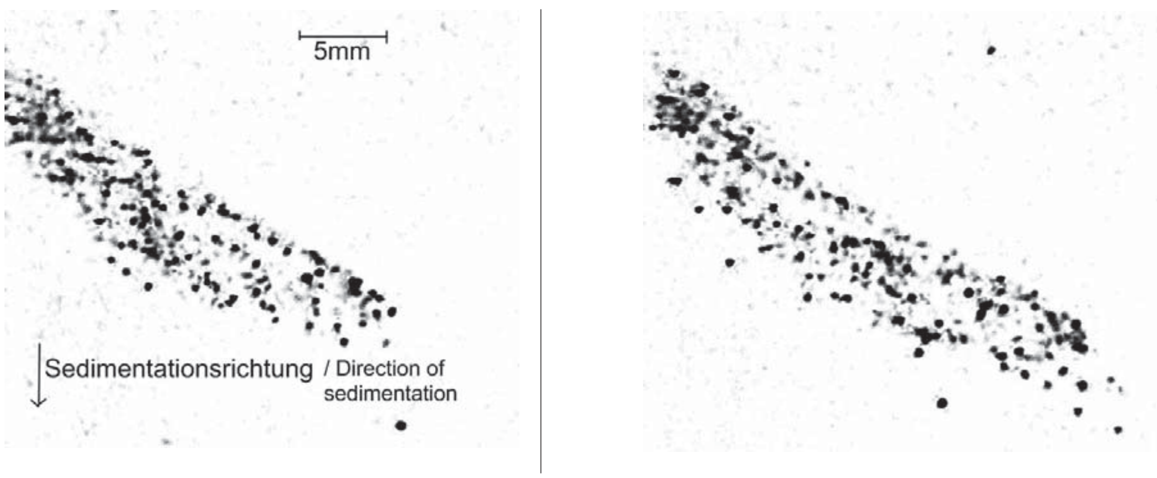
The experimental set-up is based on the idea of using a laser to track the particle movement and so gain a better understanding of the physical processes. **Figure 2** shows the set-up: The light of a He-Ne-Laser (1) is directed onto mirrors that are connected to a rotating multiphase motor (2) which rotates with a speed of 900 rotations/minute.

This results in an illuminated plane of approximately 2 mm thickness in the x-z-plane. A CCD-Kamera records the particle movement (3).

In a second set-up a mirror was implemented into the beam which results in a change of direction of 90° and therefore the illumination of the y-z-plane.

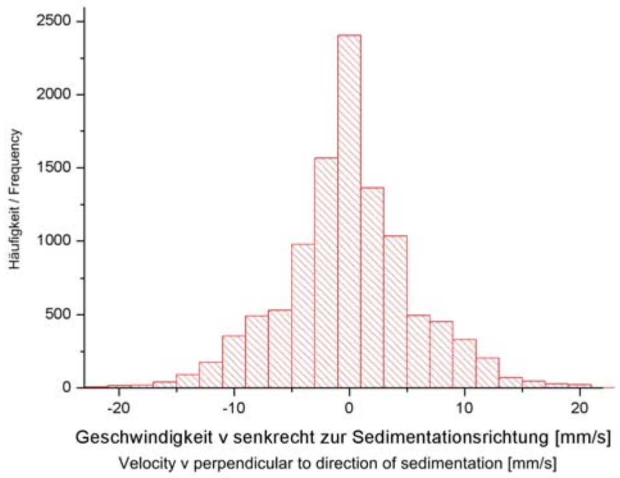
Above the laser plane is a closed chamber in which calcium carbonate is injected using a venturi nozzle. In the bottom of

Fig. 3



Two pictures that were taken in an interval of 1/15 s. The images shown correspond to an area of 2 x 0,7 cm

Fig. 4



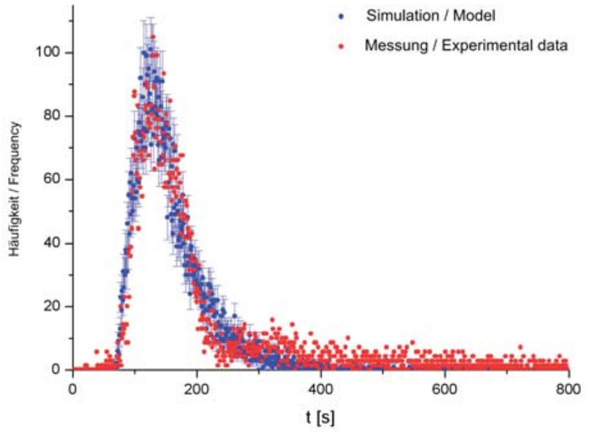
Velocity distribution for particle movement perpendicular to the direction of sedimentation

Table 1

A comparison between sedimentation velocity v_{sed}, diffusion coefficient D and diffusion velocity v in regard to particle diameter d

d µm	D 10^{-12} m²/s	V mm/s	v_{sed} mm/s
2,5	10,4	0,75	0,5
3,5	7,4	0,45	1,1
4,5	5,6	0,31	1,7
6,75	3,8	0,17	3,9
8,75	3	0,11	6,6
12,5	2,1	0,04	13,4

Fig. 5



Comparison between experimental data and modelling of sedimentation implementing the measured data

the chamber is a circular opening with a variable size between 2 and 20 milimetres. While the aerosol is injected the opening is covered by a slider that is opened after the air has had some time to come to a rest. This allows the aerosol particles to sediment into the actual measurement set-up.When the particles reach the illuminated plane the reflected light is recorded by the camera. A correlation analysis between pictures allows to calculate the velocity of particles [10].

Simulation

Parallel the particle sedimentation has been modelled. First a virtual aerosol cloud is modelled. The particles underly gravity and their properties are in conformity with calcium carbonate. The modelling volume was divided into think layers of 0,1 mm thickness. For every particle the number of particles above (n_o) and below (n_u) is determined separately. In this way the direction of diffusion depends on the spacial distribution of particles. Now the movement due to gravitation is calculated taking diameter and density into consideration. When the particles pass a virtual horizontal plane, the time that has passed since releasing the particle is saved in a histogram.

Results

As a consequence of the experimental set-up only particles that move in the illuminated plane can be investigated. **Figure 3** shows to pictures that were taken in an interval of 1/15 s. The pictures correspond to a size of 4,5 x 3,5 cm. One can clearly see a movement that must be much faster than Brown diffusion and sedimentation can explain.

Figure 4 shows the velocities perpendicular to the direction of sedimentation in a histogram. The velocity distribution is symmetric to the origin. Apparently the directions of diffusion in horizontal direction are equal. This is why a directed air flow can be ruled out. The average speed is 3,7 mm/s and therefore one speed decade than those due to Brown diffusion as given in **table 1**.

The velocity distribution in vertical direction, this is positive and negative direction of sedimentation, the particle movement is a superposition of diffusion and sedimentation. However, the average particle diameter is so small that the average sedimentation velocity is smaller than the error in measurement and can therefore not be measured in the experiment.

Assuming a turbulent diffusion velocity of 3,7 mm/s, as measured in the experiment, the sedimentation of a polydisperse aerosol was modelled. **Figure 5** experimental data [5] compared to the model. The scale was fitted to the maximum.

Conclusions

The experimental data was modelled successfully. The results show that the turbulent diffusion coefficient is 40 times higher than predicted by Brown diffusion. Therefore turbulent diffusion has an higher influence of emission modelling. The diffusion coefficient that was measured cannot be seen as an absolute value. There is no possibility to measure the particle diameter with the given set-up. Still is it possible to describe the particle behaviour with this set-up and a size range for the diffusion coefficient was found. In addition the algorithms to determine the direction of diffusion can be implemented into dynamic emssion modelling. It is in particular possible to implement the results into STAR3D [11] and therefore enhance the transmission modelling.

Literature

Books are signed with ●

[1] Rosenthal, E., P. Lodomez, J. Henseler, J. Hartmann, W. Büscher und B. Diekmann: Validierung eines dynamischen Ausbreitungsmodells für Stäube aus landwirtschaftlichen Anlagen. Landtechnik 64 (2009), H. 2, S. 98–101

[2] Einstein, A.: Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen. Annalen der Physik 17 (1905), S. 549-560

[3] ● Hinds, W. C.: Aerosol technology. John Wiley & Sons Inc., New York, 1998

[4] ● Roedel, Walter: Physik unserer Umwelt – die Atmosphäre. Springer Verlag, Berlin 1992

[5] Schmitt-Pauksztat, Gregor: Verfahren zur Bestimmung der Sedimentationsgeschwindigkeit von Stäuben und Festlegung partikelspezischer Parameter für deren Ausbreitungssimulation. Dissertation. Rheinische Friedrich Wilhelms-Universität Bonn, 2006

[6] Schmitt-Pauksztat, G., Rosenthal, E., Büscher, W., Diekmann, B.: Sinkgeschwindigkeiten von Tierstäuben – Rückschlüsse auf die Partikeleigenschaften. Agrartechnische Forschung 11 (2005), H. 5

[7] Rosenthal, E.: Aufbau und Optimierung eines Messsystems zur Bestimmung der Sedimentationsgeschwindigkeit von Aerosolpartikeln unter Berücksichtigung klimatischer Rahmenbedingungen. Diplomarbeit. Rheinische Friedrich-Wilhelms-Universität Bonn, 2006

[8] ● Levich, V. G.: Physicochemical Hydrodynamics, Prentice-Hall Inc., Englewood Cliffs, N. J., 1962

[9] ● Williams, M. M. R. and Loyalka, S. K.: Aerosol Sciene – Theory and Practice. Pergamon Press, Oxford, 1991

[10] ● Raffel, M.; Willert, C. and Kompenhans, J.: Particle Image Velocimetry. Springer Verlag, Berlin, 1998

[11] Lodomez, P.; Rosenthal, E.; Henseler, J.; Büscher, W. and Diekmann, B.: Dynamic dispersion modelling of odours and aerosols. 12th International Conference on Harmonization within Atmospheric Modelling for Regulatory Purposes. Proceedings, Zagreb, vol. 43, 2008

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