Air Distribution in Rooms, (ROOMVENT 2000)
Editor: H.B. Awbi

\# 13187

DISTRIBUTION OF AEROSOLS IN TURBULENT AIRFLOWS

F. Bitter[1], K. Fitzner[1], F.A. Scheer[2]

[1] Hermann-Rietschel-Institute of Heating and Air-conditioning,
Technical University of Berlin, Germany
[2] Engineering Company Scheer, Stuttgart, Germany

ABSTRACT

To investigate the dispersion of aerosols in an airflow, a test facility was build at the Hermann-Rietschel-Institute. The distribution of aerosols across the cross section of the test duct was measured at several distances from the emission source. The turbulence intensity of the airflow in the duct was varied by installing different turbulence generating grids (1% to 20%) at the top of the test duct. Far enough downstream the source, the concentration profiles have a Gaussian distribution.
Analogous to the potential core length in a velocity profile of a round free jet, the core length of the aerosol concentration can be defined as the distance from the emission source to the cross section where the Gaussian distribution is fully developed. Up to this distance the maximum concentration in the centre of the jet remains constant, and beyond the core length it starts to decrease with increasing distance. The core length of the particle concentration is shorter than the potential core length.
The expansion of the jet depends on the Reynolds number of the jet. With low Re the core length increases due to a laminar initial flow at the nozzle. The mixing with the surrounding air in the channel is less compared to turbulent flows. With increasing distance from the source the airflow becomes turbulent.
The measurements show that the dispersion of the aerosol jet occurs faster when the turbulence intensity of the airflow increases. This results in an increase of the standard deviation of the profile.

KEYWORDS

turbulence intensity, aerosol distribution, free jet, potential core length, dispersion of germs

INTRODUCTION

The pollution load, especially the concentration of particles and germs, in clean rooms and operation theatres should be kept at a very low level. Therefore often air-conditioning systems with laminar flow ceilings are installed. The clean supply air is brought in above the working place in clean rooms or the operating table in operation theatres in form of a displacement flow. Besides the supply of clean air, the main task of the ventilation is to remove the internal pollution load caused by the persons and machines. The distribution of particles and germs throughout the entire room should be avoided and the pollution should be carried off near the source.

The influence of the air flow patterns on the sedimentation and dispersion of germs and particles was investigated by Scheer (1998). An additional result of the investigations of Scheer shows a dependence of the dispersion of aerosols on the turbulence intensity of the surrounding airflow. Therefore further investigations were made to determine this dependence. The results of this investigations are presented in this paper.

METHODS

To investigate the influence of the turbulence intensity on the dispersion of aerosols in an air flow a test facility was designed. Scheer investigated the dispersion and the deposition of aerosols and germs in a displacement flow. He determined a dependence of the dispersion of aerosols on the turbulence intensity of the air flow in the duct. The turbulence of the air flow was generated by different grids downstream of the emission source. So at the initial phase of the jet the airflow is laminar, independent on the installed grid. Therefore further investigations were made to determine the influence of the turbulence intensity with a modified test duct. In these investigations the turbulence generating grids were installed upstream of the aerosol probe.
The schematic structure of the modified test facility is shown in Figure 1.

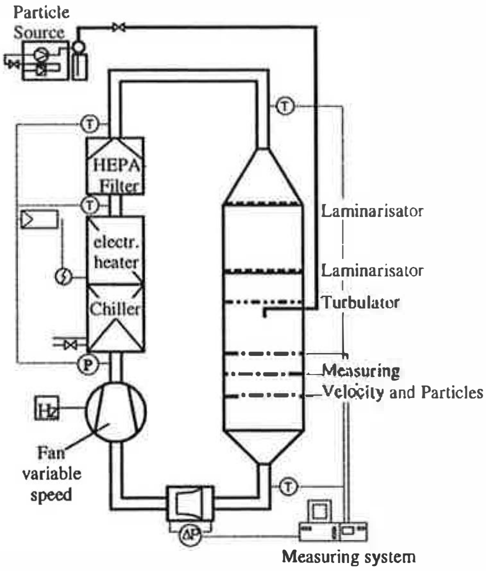

Figure 1: Modified Test Facility

The test facility consists of a closed duct system in which the test duct is integrated. The test duct is installed vertically. The air flows descending from the top to the bottom of the section. Laminarisators (finely woven fabrics) create a one directional and laminar flow. An uniform grid generates the turbulence.
The aerosols are injected into the duct by a probe in direction of the airflow. They are generated by atomization of saline water. The aerosols are transported by a carrier airflow of about 240 l/h to the probe.
A measurement bar with a moveable tube can be installed at different distances from the emission source. The tube is connected to an optical particle counter. An internal pump sucks 28,3 l/min of the air out of the test duct through the counter. At a time interval of 1 min the particles crossing the monitor are counted and divided into classes of different sizes from 0.3μm to 10μm. The tube can be positioned at every place on the bar and the bar can be moved in direction of the depth of the channel. The concentration of the aerosols can be measured at every position of the cross section of the channel.

The temperature is adjusted by an electrical heater and a water cooler. During the test isothermal conditions are reached in the test duct, so no buoyancy occurs. A HEPA-filter cleans the supply air of the test duct to ensure that no other particles are in the supply air which could lead to incorrect results. The speed of the fan is adjusted to achieve a velocity of the air flow in the duct of about 0.25 m/s.

RESULTS

Distribution of Aerosols

The initial profile of the distribution of aerosols at the outlet of the probe develops into a three dimensional Gaussian distribution with increasing distance from the source. Up to the distance where the Gaussian distribution is fully developed the maximum concentration of aerosols in the centre of the jet remains at the initial value. With increasing distance, the maximum concentration decreases and the distribution becomes wider. That is indicated by the increasing standard deviation of the Gaussian distribution. The distribution of aerosols across the cross section is illustrated in Figure 2 and the influence of the distance from the source on the distribution is shown in Figure 3.

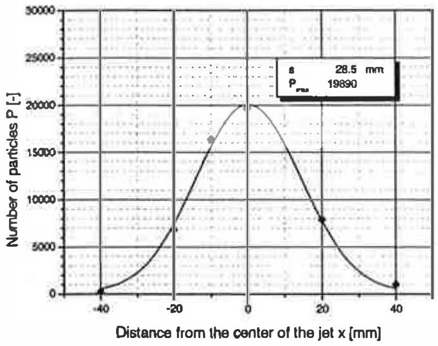

Figure 2: Distribution of the aerosols (size 0.3 µm – 1.5 µm) at a distance z = 220 mm from the emission source and a turbulence intensity of Tu = 9 %

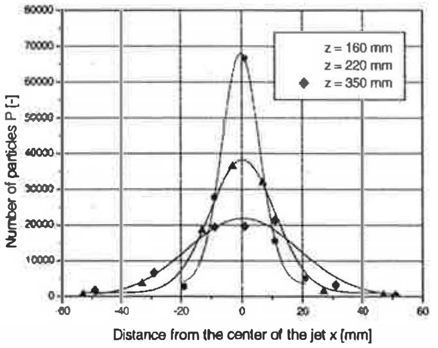

Figure 3: Distribution of aerosols at different distances from the emission source (Tu = 5 %)

The profile of the distribution is identical for every direction on the measurement plane. Therefore it is sufficient to measure the concentration of aerosols in one direction of the plane. To get correct results the measurement bar must be placed in the centre of the aerosol jet.

Number of Aerosols in a Measurement Plane

The quantity of generated aerosols depends on the salinity of the water in the atomizer and differs between the measurements. For comparison of the results the measured aerosols must be related to the same amount of generated aerosols. The number of aerosols in a cross section must be identical for all distances from the particle source. It could be determined by the volume below the three dimensional Gaussian function.

The concentration at a distance x from the centre of the jet is given by the Gaussian function

$$c(x) = \frac{A}{s \cdot \sqrt{\pi/2}} \cdot e^{-2 \cdot \frac{x^2}{s^2}}, \qquad (1)$$

where A is the area below the Gaussian curve in direction x and s=2σ is the standard deviation of the distribution. The rotation of the distribution curve in direction of the investigated plane around the normal to the cross section yield to the spatial distribution. The volume of a rotational body is given by

$$V = \pi \cdot \int_{c_1}^{c_2} [x(c)]^2 \; dc \; . \tag{2}$$

The Gaussian function of the concentration in Eqn. 1 must be solved on the x values. The integral in Eqn. 2 is to be solved between the limits $c_1 = 0$ (no aerosols) and $c_2 = c_{max}$, the maximum concentration of aerosols in the centre of the jet. The result is shown in Eqn. 3 and represents the number of aerosols in a cross section of the test duct at the distance z of the emission source.

$$V = \int_i c_i \; dF = \pi \cdot \int_{c_1}^{c_2} [x(c)]^2 \; dc = \tfrac{1}{2} \cdot \pi \cdot s^2 \cdot h \tag{3}$$

The volume below a three dimensional Gaussian function corresponds to the volume of a cylinder with the diameter of the standard deviation s = 2σ and the height h = $2c_{max}$, the doubled value of the maximum concentration. This is illustrated in Figure 4.

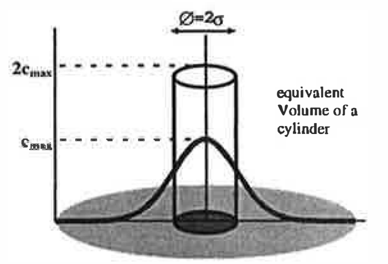

Figure 4: volume below a three dimensional Gaussian function

Comparison of the Decay of Concentration and the Decay of Velocity in a round Free Jet

The measurements show that the distribution of the aerosols can be compared to the velocity reduction in a round free jet. Figure 5 shows the velocity reduction of a free jet.

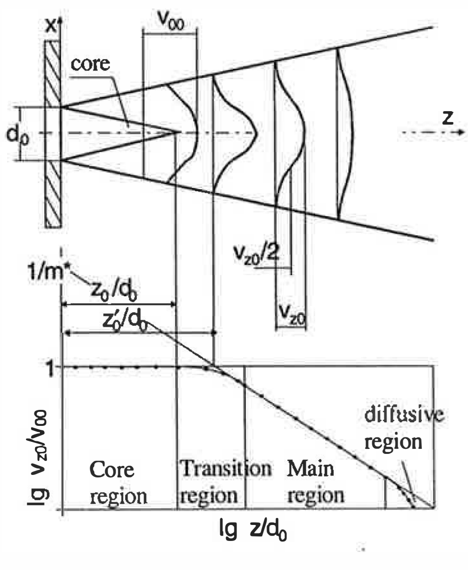

Figure 5: velocity profiles of a round free jet depending on the distance from the nozzle, Scheer (1998).

In the core region the uniform profile of the velocity changes to a Gaussian distribution. The distance from the nozzle at which the velocity in the centre of the jet starts to decrease, is called the potential core length. In the transition region the maximum starts to decrease with the distance z and then in the main region the maximum velocity starts to decrease reciprocally proportional to the distance from the nozzle. The width of the jet increases with the distance from the nozzle. The volume flow of the jet increases due to the injection of surrounding air.

The qualitative course of the function in Figure 5 (the maximum velocity depending on the distance from the nozzle) was determined on measurements with turbulent jets with high Reynolds numbers. Investigations from Regenscheidt (1976) and Schädlich (1993) have shown that the course of the curve changes at low Re numbers. Schädlich measured the decay of the velocity at different diameters of the nozzle and at different outlet velocities. Figure 6 shows the measurements from Schädlich by a jet emerging out of a round nozzle with a diameter of 4 mm (analogous to the diameter of the aerosol probe) and two different velocities. The

measurement at high Re shows the expected curve. At low Reynolds numbers the potential core length increases. This could be explained by the laminar flow at the nozzle. The mixing with the surrounding air is reduced in this initial laminar section. At a certain distance from the nozzle the flow turns turbulent and the velocity in the centre of the jet starts to decrease. The reduction of the velocity occurs faster at high Re numbers because of the lower momentum of the jet. In a distance far from the nozzle the velocity curve of the jet at low Re approximates itself to the curve at high Re.
The relative maximum concentration in the centre of the aerosol jet depending on the distance from the emission source is shown in figure 7 analogous to the velocity decrease in a logarithm scale. The diagram shows the measurements at different turbulence intensities (Tu=1%, 5%, 9% and 20%).

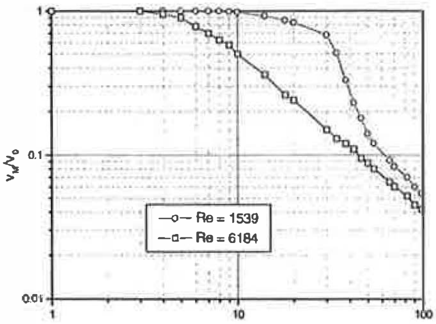

Figure 6: velocity profile of a round free jet at different turbulence intensities of the jet

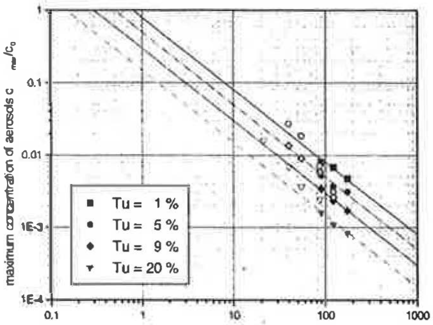

Figure 7: measured concentrations at different distances and turbulence intensities of the air flow in the test section

The hollow measurement points are the new measurements with the modified test duct, the full measurement points are measurements made by Scheer (1998). The distance from the source is related to the diameter of the probe (4 mm). Analogous to the velocities the concentration decreases in the main section reciprocally proportional to the distance

$$\frac{c_{\max}(z)}{c_0} \sim \left(\frac{z}{d_0}\right)^{-1}, \tag{4}$$

where $c_{max}(z)$ is the maximum concentration in the centre of the aerosol, z is the distance from the emission source, c_0 is the concentration at the exit of the probe and d_0 is the diameter of the probe. Similar to the potential core length of a round free jet a core length of the concentration could be defined. The core length is the maximum distance from the aerosol source at which the maximum concentration is still as high as the initial concentration. The fictitious core length z_0' found by the approximation of the measurement data with the function in Eqn. 4 is greater than the real core length z_0 (refer to the transition region in Figure 5). The regression lines are just sufficient to the measurement points at far distances from the aerosol source. This could be a result of the low turbulence (Re = 1360) of the aerosol jet (compare Figure 6). Near the outlet of the probe the jet is laminar and the mixing with the surrounding air is reduced. After the initial laminar section the flow turns turbulent. Due to the lower momentum of the jet the dispersion occurs faster than in jets at higher turbulence intensities. At far distances the dispersion of the decay of the concentration approximates itself to the expected decay at high Re numbers. Due to the constant volume of the spatial distribution in a cross section, the distribution gets wider with the decay of the maximum concentration in the centre of the jet and with increasing distance. A measure for the width is the standard deviation of the Gaussian distribution. This is shown in Figure 8.

The standard deviation is proportional to the square root of the distance

$$s \sim \sqrt{z} \qquad (5)$$

The fictitious core length z_0' depends on the turbulence intensity of the air flow in the test section. It could be determined in Figure 7 as the distance from the source where the regression line of the maximum concentration is identical to the initial concentration ($c_{max}/c_0 = 1$). In Figure 8 the fictitious core length is the length where the standard deviation is $\sqrt{2} \cdot d_0$.

Figure 9 shows the reduction of the fictitious core length with increasing turbulence intensity. The function was determined in analogy to the potential core length of round free jets. Due to the lack of measurements at different turbulence intensities this function should be seen as a first approximation.

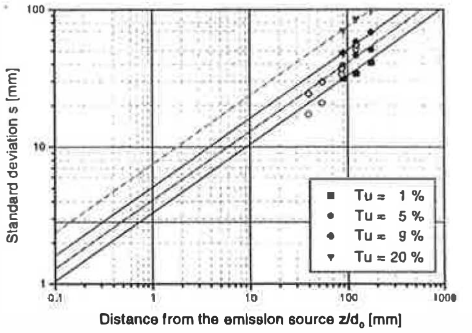

Figure 8: Standard deviation of the measurements at different distances

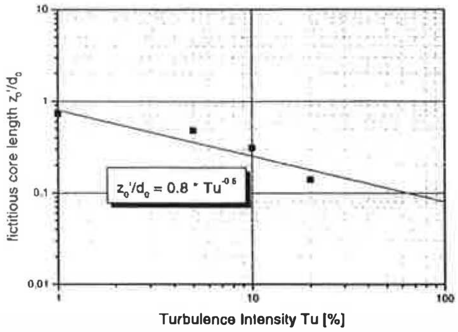

Figure 9: fictitious core length and turbulence intensity

SUMMARY

The measurements were made at low mean flow velocities in the channel of about 0.25 m/s and aerosols were injected at low turbulence intensities. This corresponds to the conditions that are often present in clean rooms and operating theatres. It can be seen, that a low turbulence intensity of the supply air flow keeps the dispersion of particles from sources inside the room within narrow limits.

Another aspect at which the dispersion of aerosols is to be considered is the atomization in humidifiers. Atomized water droplets are injected at high pressure into the airflow. The distance to the following components of an air-conditioning system and the length of the humidifier are influenced by the dispersion of the droplets. To investigate the behaviour in this case measurements at higher flow velocities of about 1 to 2 m/s and with an aerosol jet with high turbulence should be done.

REFERENCES

Scheer F.A. (1998), *Einfluß der Turbulenz einer Verdrängungsströmung in Operationsräumen auf Transport und Sedimentation von Mikroorganismen,* Dissertation, TU Berlin, Germany

Regenscheidt B. (1976). Einfluß der Reynoldszahl auf die Geschwindigkeitsabnahme turbulenter Freistrahlen, *HLH* **27:4**, 122-126.

Schädlich S. (1993), *Der Einfluß verschiedener Luftdurchlaßgeometrien auf das Freistrahlverhalten,* Dissertation, Universität Essen GHS; Germany