



Contents lists available at ScienceDirect

Journal of Aerosol Science

journal homepage: www.elsevier.com/locate/jaerosci

Particle segregation in aerosol flow

M. Alonso^{a,*}, C.-H. Huang^b^a National Center for Metallurgical Research (CENIM-CSIC), 28040 Madrid, Spain^b Department of Environmental Engineering and Health, Yuanpei University, Hsin Chu 300, Taiwan

ARTICLE INFO

Article history:

Received 18 August 2014

Received in revised form

13 November 2014

Accepted 18 November 2014

Available online 26 November 2014

Keywords:

Particle segregation

Aerosol uniformity

Segregation index

Diffusion

Electrostatic dispersion

Sampling

ABSTRACT

It is shown how the uniformity of a polydisperse aerosol can be assessed by means of a segregation index, defined in terms of the mean and the mean square of $n(D_p; \vec{r})dD_p$, the number concentration of particles with diameter in the range $(D_p, D_p + dD_p)$ in a volume element centered at \vec{r} . The segregation index is zero for a uniform aerosol and attains positive values for any other situation, in such a manner that the larger the value of the index, the worse the aerosol uniformity. As an illustrative example, numerical calculations have been performed for a polydisperse aerosol undergoing simultaneous diffusion and electrostatic dispersion in a laminar flow tube. In this case, the segregation index, zero at the tube entrance (uniform aerosol), increases steadily as the aerosol approaches the tube outlet. Some practical implications for aerosol sampling from a duct are discussed.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

An ideally homogeneous aerosol can be thought of as a collection of suspended particles whose number concentration, morphology (size, shape), and chemical composition are independent of the spatial location considered. Any sample taken from this system is fully representative of the aerosol, but this ideal situation is never encountered in practice.

In general, real aerosols are segregated with respect to concentration, morphology and/or chemical composition (i.e. any or all of these properties vary from place to place). In these conditions, withdrawing a fully representative sample is not possible. It seems obvious, from a qualitative point of view, that the larger the extent of segregation within the system, the less representative will be the sample. It is thus important to quantify the degree of particle segregation (or lack of uniformity) in specific cases of practical interest. However, experimental measurement of the spatial distribution of chemical composition, size, shape and number concentration of aerosol particles is beyond our present technical capabilities. We must content ourselves with performing numerical calculations, e.g. solving the general dynamic equation (Friedlander, 2000), in order to obtain quantitative estimations of the degree of particle segregation in a system.

The purpose of the present work is to quantify the extent or degree of segregation of aerosols. To simplify the treatment, it will be assumed that all the particles have the same chemical composition and also the same shape, so that the only variables needed are particle size and number concentration. A definition of the degree of segregation will be introduced, and numerical examples of the evolution of an increasingly segregating aerosol will be presented for the specific case of particles undergoing diffusion and electrostatic dispersion in a laminar flow tube. Finally, an example of the effect of the aerosol homogeneity on sampling representativeness will be discussed.

* Corresponding author.

E-mail address: malonso@cenim.csic.es (M. Alonso).

2. Quantification of aerosol uniformity

A polydisperse aerosol is uniformly distributed within a region if its particle size distribution is constant, independent of location, in that region. Let $n(D_p; \vec{r})dD_p$ be the number concentration of particles with diameter in the range between D_p and $D_p + dD_p$ in a volume element centered at position \vec{r} . Uniformity in a volume V means that, in the volume V , n is independent of \vec{r} and that n is a constant for each particle size interval $(D_p, D_p + dD_p)$.

It may happen that the aerosol is uniform along a specific spatial direction, but not along others. Consider for instance an aerosol flowing in a circular tube; from symmetry considerations, the steady-state size-dependent particle number concentration depends only on the radial and axial coordinates, $n = n(D_p; r, x)$. In other words, the aerosol is uniform within any differential ring of width Δr and thickness Δx but, in general, is not uniform along the r, x directions. The specific form of the function $n(D_p; r, x)$ can, in principle, be calculated by using the general dynamic equation (Friedlander, 2000), which accounts for all the changes undergone by $n(D_p; r, x)$ due to a variety of phenomena, such as nucleation, coagulation, diffusion losses, electrical effects, etc. Consider now the simple case in which the particles are unipolarly charged and their concentration is high enough for mutual repulsion (space-charge) to be important; further, let us assume that (i) the mean number of charges per particle is small, so that image force effects need not be considered (Scheibel & Porstendörfer, 1984; Yu & Chandra, 1978); (ii) the particles are large enough so that their diffusivity is negligible but, at the same time, (iii) not too large so that inertial effects are also insignificant; and (iv) there is no condensing vapor in the system. In this case, because coagulation between particles carrying charges of the same sign is negligible, the only mechanism by which $n(D_p; r, x)$ can change is mutual electrostatic repulsion (also known as electrostatic dispersion). It is well known that if the aerosol is radially uniform at the tube entrance, it remains radially uniform all along the tube (see for instance, Yu, 1977), that is, the concentration profile simplifies to $n(D_p; x)$. In this specific case, thus, the aerosol is uniform along the r, θ directions.

In order to quantify the homogeneity of the aerosol, a parameter, which may be termed the *degree of segregation*, can be defined in terms of the mean and the mean square of $n(D_p; \vec{r})$:

$$S(D_p; \vec{r}) = \frac{\langle n^2 \rangle}{\langle n \rangle^2} - 1. \quad (1)$$

The meaning of this expression is better understood using the example of an aerosol flowing in a tube. In this case, the mean ($k = 1$) and the mean square ($k = 2$) of n in a differential section at a distance x from the tube entrance are given by

$$\langle n^k \rangle = \frac{\int_0^R r u_x(r) n^k(D_p, r, x) dr}{\int_0^R r u_x(r) dr}, \quad (2)$$

where u_x is the axial component of the gas flow velocity (the other two velocity components are assumed to be zero), and R is the tube radius. If the aerosol is uniform at the tube entrance, so that

$$n(D_p; r, 0) = n_0(D_p), \quad 0 \leq r < R, \quad (3)$$

where R is the tube radius, then $\langle n^k \rangle = n_0^k$, and $S(D_p; 0) = 0$. Thus, $S = 0$ means uniformity (perfect mixing) or, equivalently, zero segregation. Downstream of the tube entrance, the changes in the distribution $n(D_p; r, x)$ due to the mechanisms mentioned above (coagulation, diffusion, space charge, etc.) lead to non-zero, positive values for the degree of segregation: $S(D_p; x > 0) > 0$. The larger the value of S , the worse the homogeneity of the aerosol. Increasing values of S quantifies the deterioration of the aerosol uniformity as it flows downstream.

The degree of segregation, as defined by (1), is a function of particle size. This fact may complicate the comparison among aerosols having different particle size distributions. Such a direct comparison between different aerosols may be done if a *global degree of segregation*, involving the whole particle size distribution, is used instead:

$$S_G(\vec{r}) = \frac{\int_0^\infty S(D_p; \vec{r}) dD_p}{\int_0^\infty dD_p}. \quad (4)$$

For an aerosol flowing in a tube and having a uniform concentration at the tube entrance, the global degree of segregation is also zero at $x = 0$, and attains non-zero, positive values for $x > 0$. (Note: The use of 0 and ∞ in the integration limits in (3) and (4) is a formal way of expressing that the integrals must be extended to the whole particle size distribution; in practice, the integration limits are finite numbers, say $D_{p,min}$ and $D_{p,max}$, so that the integral in the denominator of (4) is also a finite number.)

3. Application to unipolarly charged diffusive particles in a laminar flow tube

In the remaining part of this paper, the above ideas will be applied to the specific case of an aerosol undergoing simultaneous diffusion and electrostatic dispersion in a laminar flow tube.

Using the dimensionless variables

$$x^* = x/L; \quad r^* = r/R; \quad n^* = n/n_{T0}; \quad n_T^* = n_T/n_{T0}; \quad u_x^* = u_x/\bar{u}_x; \quad E_r^* = \varepsilon_0 E_r / e R n_{T0}; \quad \beta = DL/\bar{u}_x R^2; \quad V_s = e n_{T0} LZ / \varepsilon_0 \bar{u}_x, \quad (5)$$

the steady-state transport equation in a laminar flow tube for unipolarly, singly charged particles is given by (see for instance [Alonso & Alguacil, 2007](#))

$$u_x^* \frac{\partial n^*}{\partial x^*} = \beta \left(\frac{\partial^2 n^*}{\partial r^{*2}} + \frac{1}{r^*} \frac{\partial n^*}{\partial r^*} \right) - V_s \left(E_r^* \frac{\partial n^*}{\partial r^*} + n^* n_T^* \right). \quad (6)$$

The electric field obeys Poisson's equation

$$\frac{1}{r^*} \frac{\partial}{\partial r^*} (r^* E_r^*) = n_T^*, \quad (7)$$

where n_T^* is the dimensionless total particle number concentration.

In the definitions (5), $n(D_p; r, x) d \ln D_p$ is the number concentration of particles with diameter in the range $(\ln D_p, \ln D_p + d \ln D_p)$ in a volume element centered at (r, x) ; these particles have diffusion coefficient D and electric mobility Z ; L is the tube length; R is its radius; x and r are the axial and radial coordinates; u_x is the flow velocity in the axial direction; E_r is the radial component of the electric field created by the charged particles; e is the electron's charge; and ϵ_0 is the dielectric constant of a vacuum;

$$n_T(r, x) = \int_{-\infty}^{\infty} n(D_p; r, x) d \ln D_p \quad (8)$$

is the total number concentration of particles at the location (r, x) , and

$$n_{T0}(r) = \int_{-\infty}^{\infty} n(D_p; r, 0) d \ln D_p \quad (9)$$

is the total particle number concentration at the entrance of the tube. It must be noted that the dimensionless parameters β and V_s , characterizing the particle deposition mechanisms by diffusion and space-charge, are both functions of the particle diameter.

Two main implicit assumptions have been done in writing Eqs. (6) and (7): (i) particle diffusion in the axial direction is negligible in comparison with the convective flow velocity, i.e. Peclet number $Pe = 2\bar{u}_x R/D \ll 1$; and (ii) axial component of the electric field negligible in comparison with the radial component, an assumption which is valid for $(R/L)^2 \ll 1$ ([Alonso & Alguacil, 2007](#)).

Eqs. (6) and (7) must be solved with conditions:

$$n^* = f_0(D_p) \quad \text{for } x^* = 0 \quad \text{and} \quad 0 \leq r^* < 1, \quad (10a)$$

$$n^* = 0 \quad \text{for } 0 \leq x^* \leq 1 \quad \text{and} \quad r^* = 1, \quad (10b)$$

$$\frac{\partial n^*}{\partial r^*} = 0 \quad \text{at } r^* = 0, \quad (10c)$$

$$E_r^* = 0 \quad \text{for } 0 \leq x^* \leq 1 \quad \text{and} \quad r^* = 0. \quad (10d)$$

In the first condition, $f_0(D_p)$ is the number fraction of particles with diameter in the range $(\ln D_p, \ln D_p + d \ln D_p)$ in the entrance section of the tube. The particle size of the aerosol entering the tube is assumed to have a lognormal distribution:

$$f_0 = \frac{1}{\sqrt{2\pi \ln^2 \sigma_{g0}}} \exp \left[-\frac{\ln^2(D_p/D_{pg0})}{2 \ln^2 \sigma_{g0}} \right], \quad (11)$$

where D_{pg0} is the geometric mean diameter and σ_{g0} the geometric standard deviation. Condition (10a) expresses a uniform concentration of particles at the tube entrance; (10b) means that whenever a particle reaches the tube wall it deposits onto it and is thus removed from the aerosol; (10c) expresses the symmetry of the concentration profile about the tube centerline; and, likewise, (10d) means that the electrostatic potential is also symmetric about the tube centerline.

The flow velocity profile is assumed to be fully developed right from the tube entrance:

$$u_x^* = 2(1 - r^{*2}). \quad (12)$$

Eqs. (6) and (7) with initial and boundary conditions (10) were solved marching on along the x -direction using an explicit method. Several parameters were calculated at each section. The first- and second-order moments of the particle size distribution were determined by the usual expressions

$$\ln D_{pg}(r^*, x^*) = \frac{\int_{-\infty}^{\infty} n^*(D_p; r^*, x^*) \ln D_p d \ln D_p}{\int_{-\infty}^{\infty} n^*(D_p; r^*, x^*) d \ln D_p}, \quad (13)$$

$$\ln^2 \sigma_g(r^*, x^*) = \frac{\int_{-\infty}^{\infty} n^*(D_p; r^*, x^*) \ln^2 [D_p/D_{pg}(r, x)] d \ln D_p}{\int_{-\infty}^{\infty} n^*(D_p; r^*, x^*) d \ln D_p}. \quad (14)$$

As defined by Eqs. (13) and (14), D_{pg} and σ_g are local parameters. In certain circumstances it might be interesting to evaluate these parameters for a certain region within the tube. Thus, for instance,

$$\ln D_{pg,out}(\rho_s, x^*) = \frac{\int_{\rho_{out}}^1 r^* u_x^*(r^*) dr^* \int_{-\infty}^{\infty} n^*(D_p; r^*, x^*) \ln D_p d \ln D_p}{\int_{\rho_{out}}^1 r^* u_x^*(r^*) dr^* \int_{-\infty}^{\infty} n^*(D_p; r^*, x^*) d \ln D_p} \quad (15)$$

gives the geometric mean diameter of the particles flowing through an outer envelope of (dimensionless) radii ρ_{out} and 1. Likewise,

$$\ln D_{pg,inn}(\rho_c, x^*) = \frac{\int_0^{\rho_{inn}} r^* u_x^*(r^*) dr^* \int_{-\infty}^{\infty} n^*(D_p; r^*, x^*) \ln D_p d \ln D_p}{\int_0^{\rho_{inn}} r^* u_x^*(r^*) dr^* \int_{-\infty}^{\infty} n^*(D_p; r^*, x^*) d \ln D_p} \quad (16)$$

can be used to determine the geometric mean diameter of the aerosol flowing through an inner core of radius ρ_{inn} . These last two equations are useful because of their implications to aerosol sampling from a duct.

As explained above, the particle size-dependent degree of segregation can be evaluated as

$$S(D_p; x^*) = \frac{\langle n^{*2} \rangle}{\langle n^* \rangle^2} - 1, \quad (17)$$

where the mean and mean square of n^* given by (2), and the global degree of segregation, applicable to the whole particle size distribution, as

$$S_G(x^*) = \frac{\int_0^{\infty} S(D_p; x^*) dD_p}{\int_0^{\infty} dD_p}. \quad (18)$$

At the entrance of the tube, the degree of segregation and the global degree of segregation are both zero (uniform particle concentration), and both parameters increase monotonically as the aerosol approaches the tube exit. Thus, the evolution of S and S_G measures the deterioration of the aerosol uniformity along the tube.

4. Results and discussion

In this section examples of numerical results obtained under different conditions (tube geometry, initial particle size distribution, and flow rate) will be presented to illustrate the evolution of the aerosol uniformity along the tube. Though the particular numerical values plotted in the figures that follow do depend on the specific values of the input parameters, the trends observed in the plots are quite representative and will allow the formulation of a few conclusions of general validity.

Figure 1 shows the evolution of the particle size distribution along the tube for the specific conditions explained in the caption. The example shown in Fig. 1a is representative of a relatively high concentrated unipolarly charged, nanometer-sized aerosol, undergoing simultaneous diffusion and electrostatic dispersion. The results shown in Fig. 1b were obtained for the same aerosol at such a low concentration that electrostatic dispersion is insignificant. In this, and in all the plots below, the curves labeled as “only diffusion” were obtained from numerical solution of (6) using $n_{T0} = 1 \text{ cm}^{-3}$. As a check of the accuracy of the numerical solution in the “only diffusion” case, the numerically calculated particle penetration along the tube was compared with the Gormley–Kennedy equation: matching between penetrations calculated with the two methods was excellent. As for the general case, diffusion+electrostatic dispersion, it is not possible to compare the numerical solution with any known accurate analytical solution, although we showed in a former publication (Alonso & Alguacil, 2007) that the numerical model, exactly the same as the one used in the present work, was in good agreement with experimental results obtained for air ions.

It is difficult to observe notable differences between Fig. 1a and b, except that loss of the smallest particles to the wall is larger when the space-charge mechanism is not negligible. Nevertheless, these two plots do not give much information, mainly because the particle size distributions shown were obtained for a specific radial location, near the wall ($r^* = 0.8$). Much more information is provided in Fig. 2a and b. The first one shows how the particle mean geometric diameter changes as the aerosol flow towards the tube exit; full lines are for the general case (diffusion+electrostatic dispersion), while dashed lines are for the “only diffusion” case, i.e. for a total particle number concentration of 1 cm^{-3} , as explained above. The mean particle size shifts towards larger values in both cases, but it can be observed a rather drastic effect when space-charge is superimposed to diffusion: at the tube centerline, $r^* = 0$, particle size shifts towards larger values almost right from the entrance of the tube, while the mean particle size remains practically unaffected (along the tube centerline) when diffusion is the only mechanism at work. It can also be observed that the mean particle size is more uniform in the radial direction (it changes to a lesser extent) when both mechanisms act simultaneously. In the case of “only diffusion” the differences between the region near the tube centerline and the region near the wall are much more pronounced. The physical reason for this effect is that when particles spread out by space-charge alone their concentration remains uniform along the radial direction, but when diffusion is not negligible there is a radial concentration gradient. Note that, for the specific conditions of this example, in the case of diffusion the mean particle size near the wall has increased almost 20%.

Figure 2b shows the evolution of the geometric standard deviation of the aerosol particle size distribution for the same conditions of Fig. 1a. We have not been able to find a reason for the appearance of a minimum standard deviation around $r^* \sim 0.8$. In any case, the difference between the minimum standard deviation and the initial one is only about 2% for

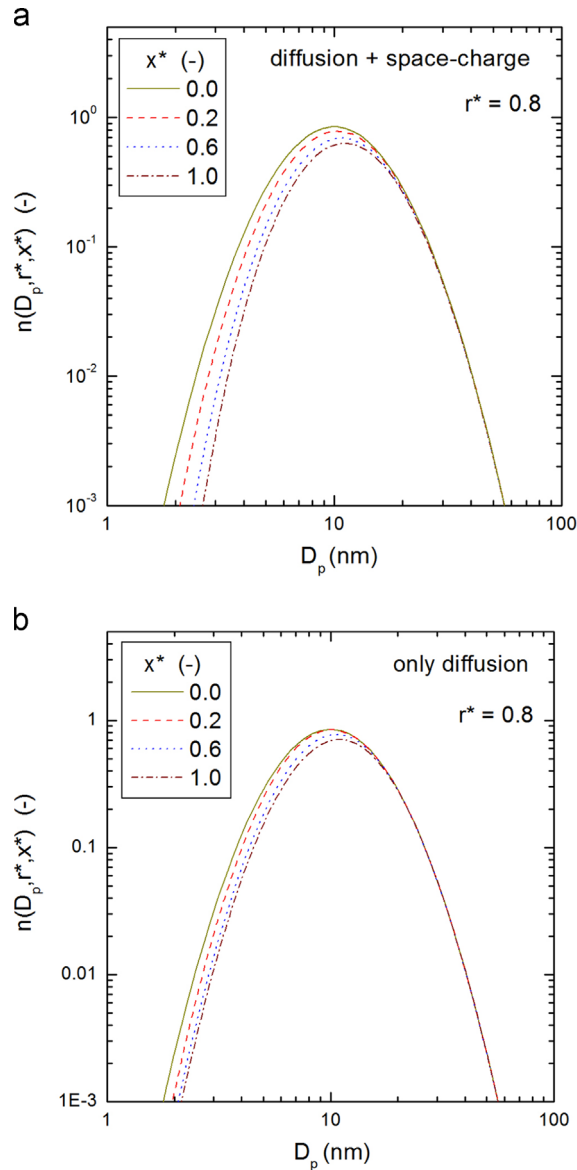


Fig. 1. (a) Evolution of the particle size distribution along the tube due to the combined mechanisms of diffusion and space-charge. Tube radius $R = 3$ mm; tube length $L = 100$ cm; aerosol flow rate $Q = 2$ lpm (Reynolds number = 698); aerosol at the entrance of the tube ($x^* = 0$): $D_{pg0} = 10$ nm; $\sigma_{g0} = 1.6$; $n_{T0} = 10^7$ cm $^{-3}$. (b) Same as (a), but with negligible space-charge, i.e. very low concentration of unipolarly charged particles.

diffusion, and less than about 4% for the diffusion + space-charge case. The changes in the geometric standard deviation are much smaller than the corresponding changes in the mean geometric diameter.

Figure 3 shows an example of the evolution of the degree of segregation along the tube. As noted above, the degree of segregation is zero at the entrance of the tube and increases monotonically as the aerosol approaches the exit. It can be also observed that the smaller the particle size, the larger the degree of segregation, i.e. the lesser the aerosol uniformity. On the other hand, it is seen that electrostatic dispersion helps to improve the uniformity, which is a consequence of the fact mentioned before: if only electrostatic dispersion is considered, the aerosol concentration is constant within a given section, i.e. independent of r^* .

Figure 4 shows the global degree of segregation as a function of the distance from the tube inlet, and taking as parameter the initial geometric standard deviation of the aerosol particle size distribution. The larger the standard deviation, the larger the extent of segregation, which is obvious from the definition (18). It is seen again that when electrostatic dispersion is superimposed to diffusion, the aerosol uniformity improves. This is a result of general validity, confirmed in all the numerical calculations performed during this work.

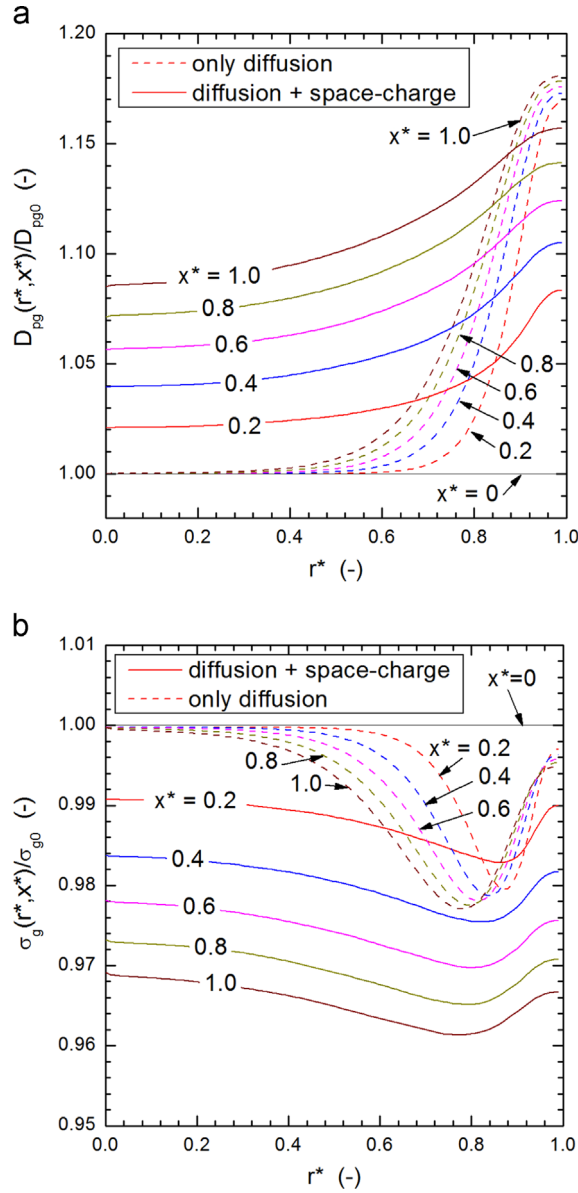


Fig. 2. (a) Evolution of the geometric mean diameter of the aerosol particles along the tube. Tube geometry, initial particle size distribution and aerosol flow rate same as in Fig. 1a and b. (b) Evolution of the geometric standard deviation of the particle size distribution along the tube. Same operating conditions as in Figs. 1a and b, and 2a.

The effect of the mean particle size on segregation is shown in Fig. 5. Other conditions being the same, smaller particles segregate faster and to a higher extent, for two reasons: their diffusion coefficient is higher, and also their electric mobility is higher so that, for a given aerosol concentration, space-charge effects are more relevant than for larger particles.

The effect of the tube radius, shown in Fig. 6, is not as simple as the effects discussed in previous figures. First, when only diffusion is considered, the segregating behavior of the aerosol is independent of the tube radius; this is because the dimensionless diffusion coefficient, defined in (5), can also be written as $\beta = \pi DL/Q$, where Q is the aerosol flow rate. This last expression shows that β is independent of the tube radius and this is why a single curve suffices for the “only diffusion” case. In contrast, when space-charge is not negligible, the degree of segregation does depend on the tube radius, but in a somehow complicated manner. For large tubes (length > 50 cm) the global degree of segregation attains a sort of asymptotic value independent of the tube radius for values of tube radius larger than about 5 mm. But for smaller tube radius the global degree of segregation increases steadily along the tube.

The effect of flow rate can be seen in Fig. 7. The lower the flow rate, the larger the effect of diffusion and space-charge on the aerosol uniformity, as it could be reasonably expected.

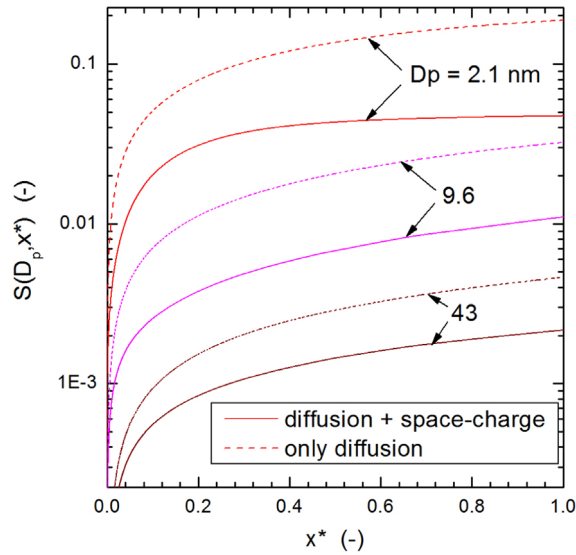


Fig. 3. Degree of segregation along the tube for different particle sizes. Same operating conditions as in previous figures.

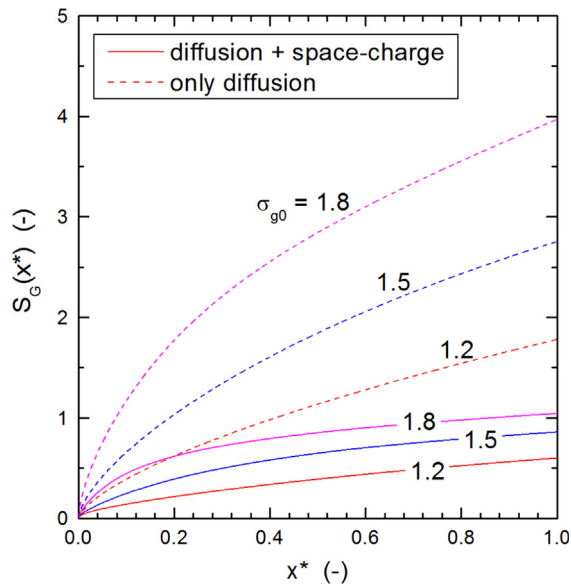


Fig. 4. Effect of the geometric standard deviation of the initial aerosol size distribution on the evolution of the global degree of segregation along the tube. Tube geometry and aerosol flow rate as in Fig. 1. Geometric mean diameter of the aerosol at the tube inlet, $D_{pg0} = 10$ nm.

Figure 8 shows the effect of total particle number concentration on the degree of segregation. For this aerosol, with geometric mean diameter of 10 nm, space-charge is negligible for particle number concentration below about 10^5 cm^{-3} . As the (unipolarly charged) aerosol concentration increases, the degree of segregation diminishes, that is, the aerosol is more uniform for the reason already explained before.

Equations (15) and (16) can be used to illustrate the need to be cautious when taking a sample from an aerosol flowing in a tube. The sample can be extracted from an orifice in the tube wall, in which case, the mean particle diameter is given by (15). If the sample is taken instead from the tube centerline, then Eq. (16) should be used. In whatever case, the radius ρ can be estimated from the ratio of the sampling flow rate to the flow rate of the main flow. Figures 9 and 10 show the differences between both sampling methods for a specific case. Under the condition that the flow rate of the sampled aerosol is the same in both cases, i.e. $\int_0^{\rho_{inn}} 2\pi r^* u_x^* dr^* = \int_{\rho_{out}}^1 2\pi r^* u_x^* dr^*$, values of $\rho_{inn} = 0.2, 0.4, 0.6$ and 0.8 for the inner core sampling are equivalent to values of $\rho_{out} = 0.85, 0.68, 0.48$ and 0.26 , respectively, for the outer envelope sampling. It is then observed that sampling from the tube centerline (core) is a better option in general, because the sample is more representative of the whole aerosol. The largest difference is observed for the only diffusion case, that is, negligible electrostatic dispersion,

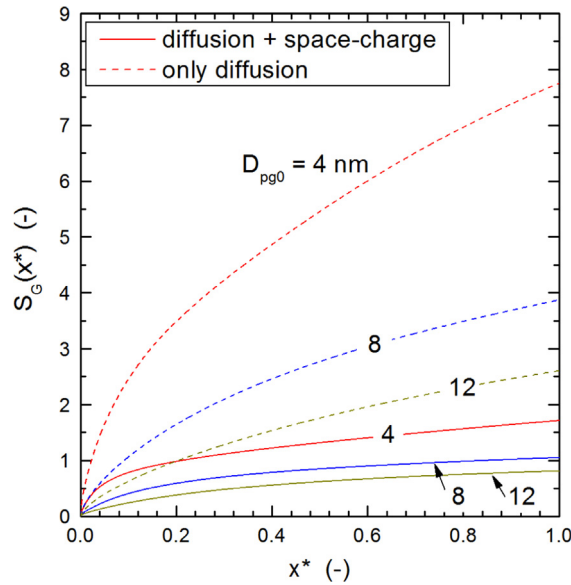


Fig. 5. Effect of the geometric mean diameter of the aerosol at the tube entrance on the evolution of the global degree of segregation along the tube. Tube geometry and aerosol flow rate as in Fig. 1. Geometric standard deviation of the aerosol at the tube inlet, $\sigma_{g0} = 1.6$.

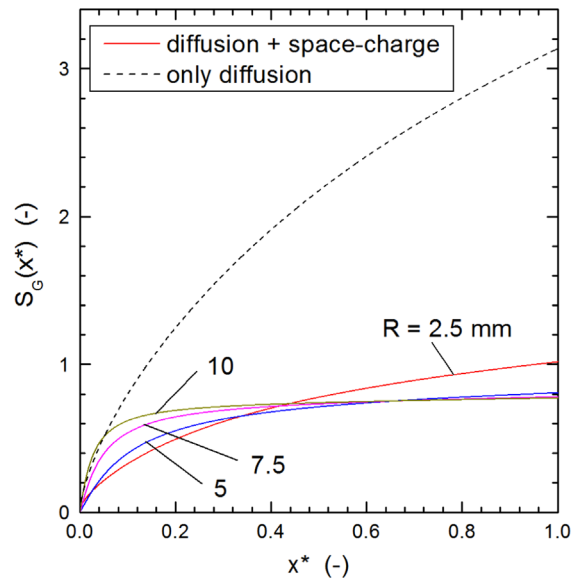


Fig. 6. Effect of tube radius on the global degree of segregation. Values of other parameters as in Fig. 1.

because as we have already seen above the aerosol is less uniform (the segregation index is larger); compare, for instance, the dashed curves for $\rho_{inn} = 0.2$ and $\rho_{out} = 0.8$ in Figs. 9 and 10: at the tube outlet, core sampling results in an aerosol having a geometric mean diameter practically the same as the aerosol at the tube entrance, whereas outer sampling leads to an aerosol with geometric mean diameter about 13% larger. When space-charge effects cannot be neglected, the aerosol is more uniform (smaller value of S_G), and the differences, although still noticeable, are not that large. Of course, in the limiting case of a uniform aerosol ($S_G = 0$), any sampling method should give the same result. Aerosol sampling is just an example illustrating the importance and usefulness of the parameter S_G that has been introduced to assess the aerosol uniformity.

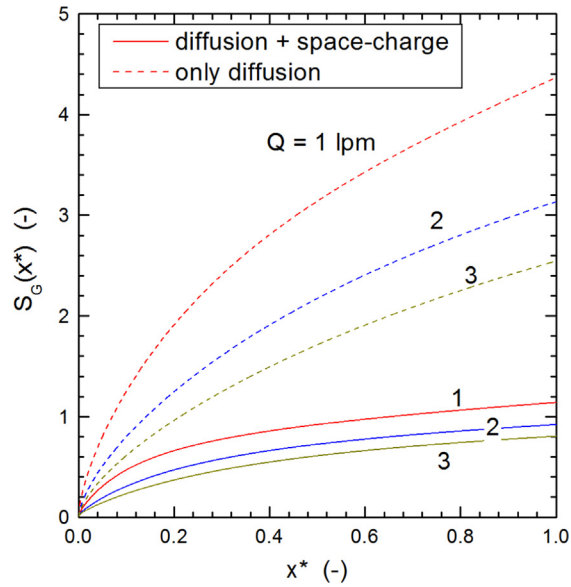


Fig. 7. Effect of flow rate on the segregating behavior of the aerosol. Tube geometry and initial particle size distribution as in Fig. 1.

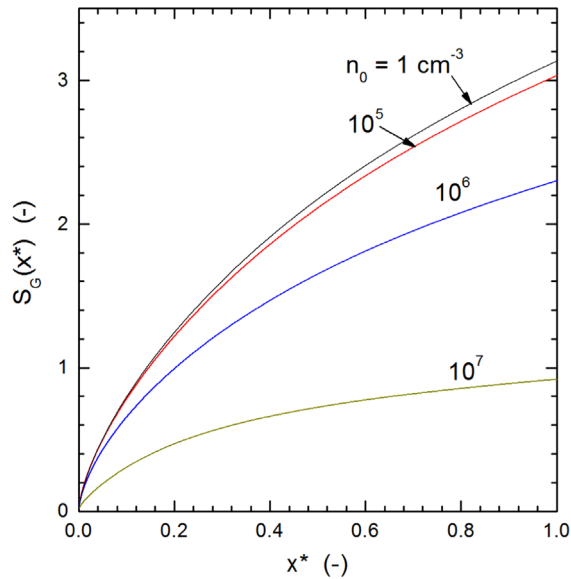


Fig. 8. Effect of total particle number concentration at tube inlet on the degree of segregation. Other conditions as in Fig. 1.

5. Conclusions

Two segregation indexes have been introduced to assess the uniformity of a flowing aerosol: a degree of segregation S for a monodisperse aerosol (or for a specific particle size if the aerosol is polydisperse), and a global degree of segregation S_G involving the whole particle size distribution. The degree of segregation, S or S_G , is zero for a uniform aerosol and attains increasing positive values as the aerosol uniformity worsens. Illustrative examples of the use of these indexes have been presented for the particular case of a polydisperse aerosol undergoing simultaneous diffusion and electrostatic dispersion in a laminar flow tube. It has also been discussed how these ideas can be applied to the comparison of two different sampling strategies from a flowing aerosol.

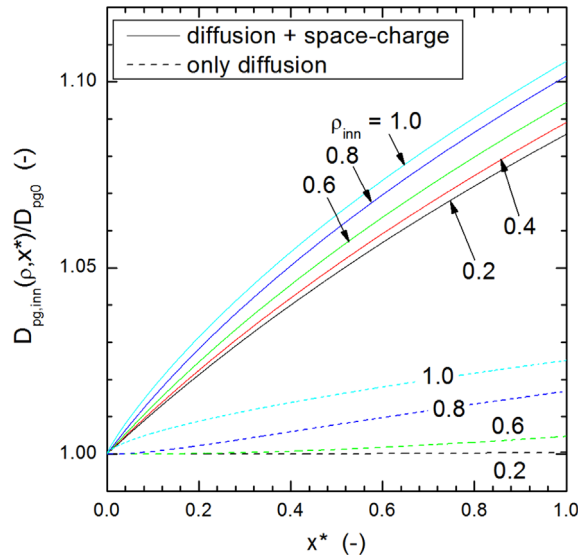


Fig. 9. Evolution of the mean particle diameter along the tube in the core of radius ρ_{inn} . Input parameters for calculation as in Fig. 1.

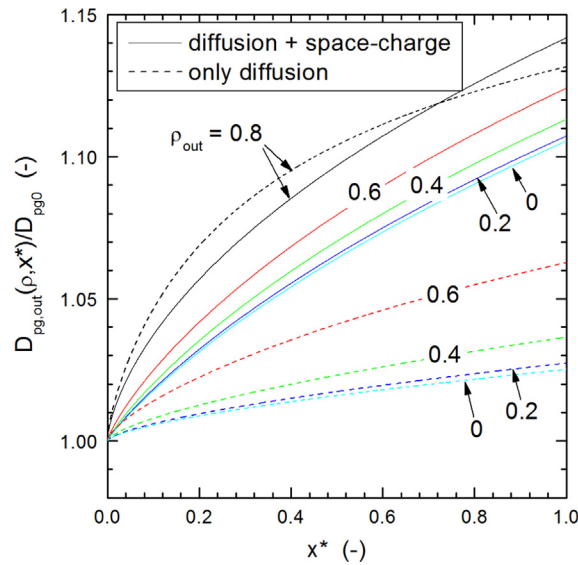


Fig. 10. Evolution of the mean particle diameter along the tube in the annulus of radii ρ_{out} and 1. Input parameters for calculation as in Fig. 1.

References

- Alonso, M., & Alguacil, F.J. (2007). Penetration of aerosol undergoing combined electrostatic dispersion and diffusion in a cylindrical tube. *Journal of Aerosol Science*, 38, 481–493.
- Friedlander, S.K. (2000). *Smoke, Dust, and Haze. Fundamentals of Aerosol Dynamics* (2nd ed.). Oxford University Press: New York.
- Scheibel, H.G., & Porstendörfer, J. (1984). Penetration measurements for tube and screen type diffusion batteries in the ultrafine particle size range. *Journal of Aerosol Science*, 15, 673–682.
- Yu, C.P. (1977). Penetration of unipolarly charged particles in cylindrical and spherical vessels. *Journal of Aerosol Science*, 8, 237–241.
- Yu, C.P., & Chandra, K. (1978). deposition of charged particles from laminar flows in rectangular and cylindrical channels by image force. *Journal of Aerosol Science*, 9, 175–180.