SUSPENDED MATERIAL / AEROSOL

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Summary

In this chapter the characteristics of the material that is suspended in the air is described. The material is present as particulates. The system of particles suspended in air is scientifically better known as **aerosol**.

Suspended material / aerosol is present both as solid and as liquid particles. Everyday examples of suspended material are fog, smoke and dust. The differences in these systems are described and used as an introduction to a more fundamental description of the properties of the atmospheric aerosol. Methods to measure the size of particles are reviewed and an introduction is given on the techniques to determine the composition of the suspended material. A bibliography is provided in which all subjects can be studied in more detail.

1. Introduction

Suspended material in the atmosphere is present in a variety of forms and sizes. Near the surface of the globe the air contains numerous suspended particles and to give a first number: the absolute minimum at the most remote site is *ten* particles per cubic *centimeter* (10 particles cm^{-3}). We use the term material because we consider both solid

and liquid particles. An Important example of a system of suspended droplets is fog. This system also exemplifies that suspended material is only a trace component of the atmosphere, because the fog-droplets take up only one millionth of the space of the air in which they are contained.

The scientific term for suspended material is aerosol, which we will also sometimes use here. Aerosol particles are prevented from rapid falling by the friction that the air exerts. And even though suspended particles can be very different, the speed of falling and other aerodynamic properties are governed by the same physical laws. As we will show next also the way they are observable and seen is quite similar for all suspended material. We will introduce such properties below via examples that are chosen because of their relevance for the central theme of air pollution.

1.1. Visibility

Suspended material can fully block the view and in this way one can easily discriminate it from gaseous air pollutants. The suspended material is visible because it reflects light, but the individual particles are too small to be seen. Everyday examples are smoke and dust and this suspended material seems to be similar to the eye. However, there is a great difference. The large dust particles settle down the moment the wind dies, while smoke is specifically dense when it is wind-still. The rapid settling of the dust shows that it is composed of large particles. The difference in size is also the reason that the same mass of smoke is more effective in reflecting light than dust. This can be understood as follows. For the same mass of material there are much more small smoke particles than large dust particles. Smoke particles are smaller and have a smaller reflecting area per particle but there so much more of them that they reflect in total more light than the few dust particles. This describes in words the equation for the specific surface area of suspended material, which is surface divided by mass, which scales with the inverse of the size of the particles.

1.2. Particle Size

***Large and small particles*:** Dust and smoke are examples of the two major types of suspended material. While a dust storm is made up of grains of tens of micrometers, smoke particles are smaller than one micrometer. In fact, the division line between small and large, in aerosol science known as fine and coarse, is the size of one micrometer (micron). However, older literature puts the marker at 10 micrometer, while currently 2.5 micrometer is considered the mark, because particles smaller than this value penetrate into the lungs. Examples of coarse and fine suspended material are fog and clouds which behave like dust. Submicron particles other than in smoke can be found in haze. We will go into more detail on size classification below but already the largest particle to be considered an aerosol particle is 100 μm and the smallest 3 nm. Notice the very large range in sizes.

The residence times of coarse and fine small particles are different because they come down to the ground via different processes.

Size and residence time: Coarse particles fall down, a process known as settling. They are also swept against an obstacle because they cannot follow the air flow around it. This latter process is known as inertial impaction. For fine particles there are two different mechanisms by which they are removed form the atmosphere. Particles smaller than 0.1 μm, called ultrafines, are so small that they behave like gases and deposit via Brownian diffusion motion, in the same way as gases. Particles in the range 0.1 to 1 μm are too light for settling or impaction and too heavy for diffusion. They are taken up in rain. This latter process is very efficient which means that during rain most of this aerosol is removed for the air. The way the aerosol arrives in the rain is quite complex and the process is most elegantly described in the textbook of Twomey.

***Size and health effects*:** Dust and smoke can be similarly dense to the eye, but the dust is a mere nuisance while smoke particles can be lethal when inhaled. This difference again stems from the difference in size of the particles. Smoke is so harmful because the small particles follow the air stream into the lungs, while the large sand grains deposit in month and nose via settling and impaction. Particles can carry toxic and carcinogenic compounds, however, these compounds are mostly only a minor fraction of the material and are thus not governing parameters and therefore not separately discussed here.

2. Generation

Dust and smoke may serve as examples of the different way coarse and fine particles are being formed. Coarse particles are made by a mechanical force, in the case of dust by the wind dislodging it from the ground. Particles smaller than 1 μm are made via a chemical route. Smoke for instance is the result of condensation of compounds which are initially gaseous at the high temperatures of the fires.

The mechanism by which coarse material is made is well-known but the actual amounts depend on local winds. In other words, coarse particles are typically a very local pollutant even to such an extent that the interested reader is referred to the special literature for further details (e.g., Twomey). Uplifting of hot desert sand to high altitudes is a meteorological subject rather than a particle phenomenon. However, the reflectivity of such white clouds above dark oceans is a particle phenomenon.

2.1. Sources

Above we discussed examples of direct/primary sources of aerosol. Other aerosol material is made in-situ in the atmosphere and is known as secondary. Haze is an example of aerosol made in-situ in the atmosphere. Fog can also we considered as a secondary aerosol type because it is also not directly emitted

Direct sources and source identification of aerosol: The most important sources for coarse aerosol are the oceans and deserts. They are produced in such amounts that even at larger distances from the source appreciable concentrations can be found. Aerosol deriving from the sea, can be easily identified from the ocean from the composition because they consist of seasalt, which is mainly sodium chloride. Another example is sand from the Sahara desert in Africa of which has different colors according to the region it is produced. Some has a red color which is caused by iron oxide.

Smoke is the example of the most important directly emitted fine aerosol. It originates from wood-burning and other fires. Different organic-carbon compounds are associated with the type of fire and are used to identify the source of the smoke. Another source of primary aerosol is coal burning. The emitted material is called fly-ash. It is more difficult to assess because the composition of fly ash is quite similar to normal dust, because the incombustible material in coal also derives from the soil. Emissions of fly-ash are rather easy to control so that its importance is rapidly decreasing in many regions of the world.

Indirect sources: Aerosols that are not directly emitted are more complex to describe than those coming from sources. In addition, abatement of such indirect material requires more information and insight in the formation process. This is one reason to dwell somewhat longer on this subject. The phenomenon of (regional) haze in which most of the material is of a secondary origin has become a universal problem. Also, much research has been devoted to this topic and most knowledge on aerosol and tools for measuring derive from it. Whereas its sources are rather mysterious haze is very visible as air pollution. Its visibility was the reason to clean up the air in Tokyo and Los Angels, cities known in better days for their scenic mountain views. The literature at the time mentions the presence of toxic aerosol substances (Stern) but not the acute health aspects which are at present a major concern (see the paragraph on “Health effects” in Section 4 for details)

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The material of the haze is generated from gases in chemical reactions described in other sections. The reason that aerosol is formed is the low vapor pressure of this material. Haze particles also serve as the site to produce additional material via surface reactions. The best known example is ammonium nitrate. Even a substantial part of the nitric acid precursor gas is heterogeneously formed.

3. Fundamentals

3.1. History and Definition

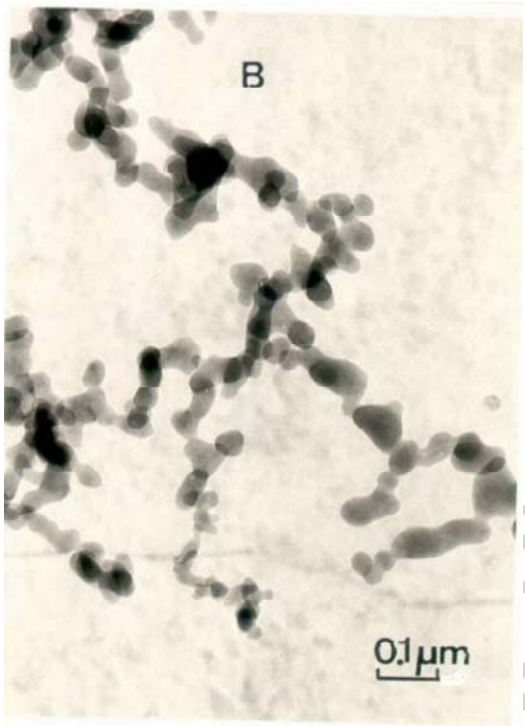

Figure 1: Electron microscope photo of a soot particle. It is built up of small entities with a diameter of 25 nm which have coagulated to a particle with overall dimensions of one micrometer.

A number of updated editions of standard works recently appeared on the subject of suspended material (see Bibliography). Notice that all these textbooks have aerosol and not suspend material in the title. This author recommends an older book (Twomey) because it fully focuses on atmospheric aerosols. The book has a rather physical approach and for that reason we give somewhat more detail on the chemistry of aerosol here and specifically to some developments which were not covered in the textbooks. Because of the limited lifetime aerosol characteristics differ from place to place and from moment to moment. We will therefore describe the general aspects only.

Most books start out with a definition of aerosol / suspended-material indicating that aerosol science started with explaining the role of aerosol particles in the reduction of visibility by developing a theory for the interaction of light and aerosol around 1900. The arrival of the electron microscope made it possible to observe even the smallest particles, see for instance Fig. 1.

The motion and mechanics of particles in air are described in detail in the textbook of Friedlander. We will not go into such detail here but illustrate the consequences of the theory.

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Bibliography

Twomey is suggested as a prime source for those interested in atmospheric aerosol, also because it has a very elegant introductory chapter. The book is somewhat focused on meteorological aspects. The fundamentals of aerosol mechanics are described in the books of Friedlander. Measurements and inhalation are described in Hinds. Seinfeld and Pandis give details of the physico-chemical aspects of aerosol, including the climate effects. Organic carbon, surface reactions and analytical tools can be found in Finlayson-Pitts and Pitts. We refer to the review by Chow for the problems in filter sampling.

Chow, J.C. (1995) Measurement Methods to Determine Compliance with Ambient Air Quality Standards for Suspended Particles; a critical review. J. Air & Waste Manage. Assoc., 45, 320-382: [Gives an overview of collecting aerosol with filters for chemical analysis and the problems of collecting semi-volatile species].

Friedlander, S.K. (2000) *Smoke Dust and Haze; fundamentals of aerosol dynamics*, Oxford University Press: [The standard book for all fundamental aspects of aerosol].

Hinds, W. (1999) *Aerosol Technology Properties, Behavior, and Measurement of Airborne Particles*, John Wiley: [Best reference for measurement methods in general, and insight in the process of human inhalation]

Finlayson-Pitts, B. J., and J. N. Pitts (2000). *Chemistry of the Upper and Lower Atmosphere*. Academic Press, New York: [Provides an overview of the analytical tools for chemical speciation, including the issue of Organic Carbon, as well as a in introduction to surface reactions].

Seinfeld, J.H. & Pandis, S.N. (1997) *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*, John Wiley & Sons Inc., New York, USA: [Gives details of the combined physical and chemical aspects, including the climate effects].

Twomey, S.A.(1977) *Atmospheric Aerosols*, Elsevier, Amsterdam: [Is recommended as a prime source for those interested in atmospheric aerosol, also because it has a very elegant introductory chapter. The book is, however, somewhat focused on meteorological aspects].

Biographical Sketch

Harry ten Brink holds a Masters and PhD degree in Physical Chemistry at the University of Amsterdam. He is at present program manager aerosol research at the Energy Research Centre of the Netherlands. He has worked and is working in most major fields of suspended material, like development of novel measuring methods, aerosol formation, nuclear reactor safety, process-gas cleaning, climate effects, fog and cloud characterization, and most recently in human exposure to aerosol, climate effects and surface reactivity.

He (co)-authored over a hundred peer-reviewed publications. Is member of the editorial board of *Aerosol Science and Technology*. Chairman of the Working Group "Particulate Matter" of the *European Aerosol Assembly*. Member of the American Association for Aerosol Research. Visiting scientist at and consultant for Brookhaven National Laboratory, New York, USA.

He was consultant for slagging and fouling in coal fired boilers for *IEA coal-research*. Co-ordinator of the EU-project "Manmade Aerosols and Radiation". He was a member of the board of the Dutch-Belgian *Aerosol Society*; chairman from 1984 to 1991. Chairman of the Model Assessment Group of the *National Acidification Program*. 1993-1997. Chairman of the National Society "*Radiation in the Atmosphere*". Chairman Workgroup “Atmospheric Aerosol " of the European Aerosol Assembly, 1995-1998. Vice-chair of the Workgroup “Chemistry" of the *European Aerosol Assembly*. Contributing author and reviewer for the Second and Third Expert and Government Assessment Reports of the Intergovernmental Panel for Climate Change (IPCC). Coordinator of the pan-European project AEROSOL in the *EUREKA-Eurotrac* program.