PARTICULATE CHARACTERISTICS AND SIZE ANALYSIS

INTRODUCTION

What is Particulate Matter (PM)?

Why does particle size matter?

Airborne particulate matter represents a complex mixture of organic and inorganic substances. Mass and composition in urban environments tend to be divided into two principal groups: coarse particles and fine particles. The barrier between these two fractions of particles usually lies between 1 µm and 2.5 µm. However, the limit between coarse and fine particles is sometimes fixed by convention at 2.5 µm in aerodynamic diameter (PM) for measurement purposes. The smaller particles contain the secondarily formed aerosols (gas-to-particle conversion), combustion particles and recondensed organic and metal vapours. The larger particles usually contain earth crust materials and fugitive dust from roads and industries. The fine fraction contains most of the acidity (hydrogen ion) and mutagenic activity of particulate matter, although in fog some coarse acid droplets are also present. Whereas most of the mass is usually in the fine mode (particles between 100 nm and 2.5 µm), the largest number of particles is found in the very small sizes, less than 100 nm. As anticipated from the relationship of particle volume with mass, these so-called ultrafine particles often contribute only a few % to the mass, at the same time contributing to over 90% of the numbers.

Particulate air pollution is a mixture of solid, liquid or solid and liquid particles suspended in the air. These suspended particles vary in size, composition and origin. It is convenient to classify particles by their aerodynamic properties because:

(a) these properties govern the transport and removal of particles from the air;

(b) they also govern their deposition within the respiratory system and

(c) they are associated with the chemical composition and sources of particles.

These properties are conveniently summarized by the aerodynamic diameter , that is the size of a unit-density sphere with the same aerodynamic characteristics. Particles are sampled and described on the basis of their aerodynamic diameter, usually called simply the particle size.

How are particles formed?

The size of suspended particles in the atmosphere varies over four orders of magnitude, from a few nanometres to tens of micrometres. The largest particles, called the coarse fraction (or mode), are mechanically produced by the break-up of larger solid particles. These particles can include wind-blown dust from agricultural processes, uncovered soil, unpaved roads or mining operations. Traffic produces road dust and air turbulence that can stir up road dust. Near coasts, evaporation of sea spray can produce large particles. Pollen grains, mould spores, and plant and insect parts are all in this larger size range. The amount of energy required to break these particles into smaller sizes increases as the size decreases, which effectively establishes a lower limit for the production of these coarse particles of approximately 1 µm. Smaller particles, called the fine fraction or mode, are largely formed from gases. The smallest particles, less than 0.1 µm, are formed by nucleation, that is, condensation of low-vapour-pressure substances formed by high-temperature vaporization or by chemical reactions in the atmosphere to form new particles (nuclei). Four major classes of sources with equilibrium pressures low enough to form nuclei mode particles can yield particulate matter: heavy metals (vaporized during combustion), elemental carbon (from short C molecules generated by combustion), organic carbon and sulphates and nitrates. Particles in this nucleation range or mode grow by coagulation, that is, the combination of two or more particles to form a larger particle, or by condensation, that is, condensation of gas or vapour molecules on the surface of existing particles. Coagulation is most efficient for large numbers of particles, and condensation is most efficient for large surface areas. Therefore, the efficiency of both coagulation and condensation decreases as particle size increases, which effectively produces an upper limit such that particles do not grow by these processes beyond approximately 1 µm. Thus, particles tend to “accumulate” between 0.1 and 1 µm, the so-called accumulation range.

Sub micrometre-sized particles can be produced by the condensation of metals or organic compounds that are vaporized in high-temperature combustion processes. They can also be produced by condensation of gases that have been converted in atmospheric reactions to low- vapour-pressure substances. For example, sulphur dioxide is oxidized in the atmosphere to form sulphuric acid (H2SO4), which can be neutralized by NH3 to form ammonium sulphate. Nitrogen dioxide (NO2) is oxidized to nitric acid (HNO3), which in turn can react with ammonia (NH3) to form ammonium nitrate (NH4NO3). The particles produced by the intermediate reactions of gases in the atmosphere are called secondary particles. Secondary sulphate and nitrate particles are usually the dominant component of fine particles. Combustion of fossil fuels such as coal, oil and petrol can produce coarse particles from the release of non-combustible materials, i.e., fly ash, fine particles from the condensation of materials vaporized during combustion, and secondary particles through the atmospheric reactions of sulphur oxides and nitrogen oxides initially released as gases.

Which materials are the main components of particulate matter?

Sulphate and organic matter are the two main contributors to the annual average Particulate Matter and Particulate Matter mass concentrations, except at kerbside sites where mineral dust (including trace elements) is also a main contributor to Particulate Matter. On days when Particulate Matter > 50 µg/m3, nitrate becomes also a main contributor to Particulate Matter. Black carbon contributes 5–10% to PM. Its contribution increases to 15–20% at some of the kerbside sites. Because of its complexity and the importance of particle size in determining exposure and human dose, numerous terms are used to describe particulate matter. Some are derived from and defined by sampling and/or analytic methods, e.g., “suspended particulate matter”, “total suspended particulates”, “black smoke”. Others refer more to the site of deposition in the respiratory tract, e.g. “inhalable particles”, which pass into the upper airways (nose and mouth), and “thoracic particles”, which deposit within the lower respiratory tract, and “respirable particles”, which penetrate to the gas-exchange region of the lungs. Other terms, such as “PM”, have both physiological and sampling connotations.

What do we mean?

- Solids appear in variety of forms like angular pieces, continuous sheets and finely divided powder.
- They may be hard and abrasive, tough and rubbery, soft (or) fragile, dusty, cohesive, free flowing and sticky.
- They are characterized by size, shape, density and colour.
- Homogenous particles have same density.
- Size and shape are easily specified for regular particles like sphere and cubes.
- For irregular particles like sand, grains etc., size and shape are not clear and are defined as shape factor or sphericity.
- Shape of an individual particle is conveniently expressed in term of which is independent of particle size.

For non sperical particles

sphericity(ϕ_s)

$$\phi_s = \frac{\text{surface area to volume ratio of sphere}}{\text{surface area to volume ratio of that particle}}$$

ϕ_s=1, For spherical particle of diameter (D_p).

- For irregular particles ϕ_s<1
- crushed particles ϕ_s = 0.6 and 0.7

  - Diameter specified for equidimension particles

$=(\pi D_p^2/\pi D_p^3/6)/(S_p/V_p)$

$\phi_s = 6V_p/D_p S_p$

D_p - nominal for Equivalent diameter of sphere

S_pV_p - Volume and surface area of irregular particle

Shape factor (λ)

λ = b/a

Where a and b geometric constants shape of an individual is conveniently expressed in terms of a shape factor λ .

- volume of a particle of any shape can be written as

  $V_p = aD_p^3$

- surface area of any particle

  $S_p = 6D_p^2$

Ratio between volume to surface area is

$$V_p/D_p=aD_p^3/6b(D_p)^2$$

$$V_p/D_p \quad = D_p/6\lambda$$

Size range of particles (or) size expression

- Coarse particles- m, cm, inch, ft
- Fine particles- mesh size(screens)
- Very fine particles- micrometer , nanometer
- Ultra fine particles- specific surface area(A_w),(m^2/kg,cm^2/g)

Mesh:-

- It is the number of opening per linear inch
- It is used to define the size of particle in screen
- Testing sieves are made of wire, Each opening is a square.

Standard screens series are available.

- Tylor standard screen series(TSS)
- British standard screen series(BSS)
- American society for Testing Machine(ASTM)

Commonly used standard screen series -> TSS

$D_n/D_n+2= \sqrt{2}$

Mixed particle size Analysis

Sample of uniform particles having diameter (D_p)

Total volume of the particle (v) $=m/\rho_p$

m- total mass of the particle

ρ_{p}- density of the particle

Total volume= NV_p

Therefore, N= Total volume/V_p $=m/V_p$ ----------------> 1

Total surface area of the particle (A_w) = NS_p --------------> 2

We know that,

$\phi_s = 6V_p/D_pS_p$

$S_p = 6V_p/D_p\phi_s$ --------------------> 3

Substitute 1,2 in 3

Total surface area (A_w) $=6m/\phi_s\rho_pD_p$ -----------> 4

2 and 4 applied for mixture of particles having sixes and density, mixture is sorted into fractions. Each fraction can be weighed (or) individual particles can be counted (or measured) by using microscopic method.

Specific surface area (A_w) for a mixture os particle

$A_w = 6m/\phi_s \rho_pD_p$

where m - mixture of particles as man fraction x_i

$A_w = 6x_1/\phi_s\rho_pD_{p1}+ 6x_2/\phi_s\rho_pD_{p2}+..........+ 6x_n/\phi_s\rho_pD_{pn}$

$A_w=6/\phi_s\rho_p\sum_{i=1}^{n} x_i/D_{pi}$ ____________ 5

By different analysis

$D_s=1/[\sum \Delta\phi_m/D_n]$

Where $\Delta\phi_m$=mass fraction retained

By a cummulative analysis

$$D_s=1/[\int_0^1 \phi_n/D_{pi}]$$

ϕ_n=Cumulative mass fraction

Arithmetic Mean Diameter

$$D_N=\sum_{i=1}^{n} (N_i D_{pi})/N_T$$

D_p = particle diameter in the particle increment

N_T = number of particles present in the entire sample

N_i = number of particles in that particular increment

Mass mean Diameter

$$D_W=\int_0^1 D_p d\phi$$

Volume Mean Diameter

$$D_v = \sum n_i d_i^4/\sum n_i d_i^3$$

n_i = Number of particle per unit mass

d_i = diameter of particle for a particular diameter

Where i = 1,2, 3……………..n (increment)

x_i = mass fraction in the increment

n = number of increment

D_{pi} = Average particle diameter

ϕ_s, ρ_p = Sphericity and Density remains same.

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