METHODS OF CONTROL OF THE SEDIMENTATION SPEED OF ATMOSPHERE AIRBORNE PARTICLES

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Abstract: *Airborne substances, resulting from natural phenomena and human activities, are one of the major pollutants of the atmosphere. In addition, airborne substances become important pollutants of other environmental factors, due to their deposition on extended areas. Thus, out of a total average of 32,000,000 t / year of pollutants generated by anthropogenic activities suspended in atmospheric air, 900,000 tons are generated by internal combustion engines, 4,100,000 tons of electricity production, combustion of fossil fuels, 17,000,000 tons of various industrial technological processes, 6,900,000 tons of fuel burning in industrial steam generators and 3,000,000 urban and industrial waste management facilities.*

Key words: sedimentation speed, fog, dust, smoke, Reynolds, Stoke, Cunnigham

1.INTRODUCTION

Natural phenomena such as erosion, desertification, pollution and seed crops, some of which are initiated and accelerated by human activities, are also important sources of air pollution with airborne substances. Pollutants suspended in atmospheric air or gases from various technological processes are mixtures that can vary in a very wide range, both in terms of particle size and physical and chemical properties.

The complexity of airborne substances results also from the adsorption or absorption of sulphates, nitrates and hydrocarbons, to silicon or carbonate particles which may be facilitated by the presence of water vapor [1].

Generally, airborne substances resulting from industrial processes are of the following types [2]:

- fly ash as a mixture of silicon oxides, aluminum and iron oxides (SiO_2, Al_2O, Fe_2O_3) and unbound carbon particles; this type of pollutant results from the technological processes of combustion of fuels for energy purposes;
- iron oxides (mainly Fe_2O), resulting in the blast furnaces in the metallurgical industry;
- calcium and silicon oxides, resulting from the cement industry;
- sodium sulphate resulting from the pulp and paper industry;
- oil, solvent and dyestuff particles, resulting from the machinery and textile industries.

The emission factors for suspended substances, specific to the different technological processes, are presented in table 1 [3].

Table 1 - Emission factors specific to various sources of pollution.

Source of pollution	The emission factor
Combustion of natural gas	
Power stations	240 kg/million m^3 used gas
Industrial steam generators	290 kg/million m^3 gaz used gas

Domestic and commercial installations	305 kg/million m^3 gaz used gas
Combustion of petroleum distillates	
Industrial and commercial installations	1,8 kg/1000 l burned fuel
Domestic installations	0,96 kg/1000 l burned fuel
Combustion of the fuel	
Power stations	1,2 kg/m^3 burned fuel
Industrial and commercial installations	2,8 kg/m^3 burned fuel
Combustion of coal	
Cyclone boilers	0,9 kg/ tons of burned coal
Other pulverized coal combustion plants	7,7 kg/ tons of burned coal
Mechanical loading	5,9 kg/ tons of burned coal
Incinerators	
Multi-room, for urban waste	7,7 kg/ tons of burnt waste
Household, with gas support	6,8 kg/ tons of burnt waste
With continuous feed	12,7 kg/ tons of burnt waste
Open burning of waste	7,3 kg/ tons of burnt waste
Vehicle engines	
Petrol engines	1,4 kg/ 1000 l benzine
Diesel engines	13,2 kg/ 1000 l diesel fuel
Manufacture of cement	108 kg/m^3 cement product
Manufacture of pulp and paper	
Technological lime kilns	42,6 kg/ ton paper pulp produced
Waste paper recovery plants	68,1 kg/ ton paper pulp produced
Metallurgy	
Furnaces	0,7 ÷ 9 kg/ tons of steel produced
Electric arc furnaces	6,8 kg/ molten metal ton
Manufacture of sulfuric acid	0,14 ÷ 3,4 kg acid fog / tons acid

The use of classical descriptive terms, such as smoke, dust and fog, seems to be the most convenient classification method, because it is based on how dispersion formation works. This results in the following categories [3]:

Dust is formed by spraying or mechanical disintegration of solid material into small particles by processes such as grinding, crushing, explosion, etc. The particle size range varies between 1 μm and 100 ÷ 200 μm. Of course, there are also larger particles, but they remain in suspension for a short time, so they do not fall into the category of airborne substances.

Dust particles generally have irregular shape. Typical examples of dust are: fly ash, rock dust, flour etc. The sand is too coarse to enter this category. Dusts are very heterogeneous, both in size and in structure.

Smoke comes from the burning of organic substances (wood, rubber wastes, liquid fuels) and implies some degree of opacity. Smoke includes several dispersants, which can not be classified as dusts or mists (some suspensions formed by chemical, photochemical, condensation, volatilization and electrical spraying).

Examples of this are: photoelectric transformation of SO_2 in SO_3, oxidation of magnesium in arc furnaces and condensation of stearic acid. Smoke particles are very fine, with sizes between 0,1 μm and 1 μm. They are spherical, if they are of a liquid or tar-like nature and have irregular shapes if they are of solid material (carbon black). Due to their very small size, the particles that make up the smoke remain suspended for tens of minutes or even hours and are in a rapid Brownian motion.

Fogs are formed by condensation of vapors of various chemicals, resulting in droplet suspensions. Also, mists can form by atomizing liquids. The particle size of the natural mist is between 5 μm and 100 μm.

Special particle atomization processes can produce particles much smaller than those of natural mists, reaching sizes of the micron fraction. Some industrial dispersants, such as sulfuric acid particles, are sometimes included in the mist category, although it is more appropriate to be included in the smoke category due to particle size less than 1 μm. Atmospheric clouds are characterized by appreciable optical density, which reduces visibility.

The notion *smog* is derived from the combination of smoke and fog and, correctly, refers to the natural mixture of fog and smoke (the latter being a product of anthropic activities). An erroneous use of this notion, but now widespread, refers to urban smog, largely formed by the complex chemical reactions of hydrocarbons in the atmosphere. This type of smog is never associated with natural fog; on the contrary, it has maximum intensity in a calm, warm and dry atmosphere.

2. MATERIALS AND METHODS

2.1. Speed of sedimentation

The natural gravity sedimentation phenomenon is essentially used in industrial particle removal plants suspended in gas. The most important parameter that influences gravitational sedimentation is the particle sedimentation velocity (sometimes referred to as final velocity), v_s. particle sedimentation. Sedimentation speed depends, in addition to other factors, on the particle size and density.

The sedimentation velocity is defined as the constant velocity of the descent speed in a direction parallel to that of the gravitational field which is reached at the gravitational force equilibrium (G) with the sum of the Archimedes force (F_A) and the frictional force F_f). The time at which the particles reach this speed is extremely short, so it can be neglected. Equilibrium forces leads to the following equation [3]:

$$G = F_A + F_f \tag{1}$$

$$m_p \cdot g = m_p \cdot \frac{\rho_g}{\rho_p} \cdot g + \frac{\rho_g \cdot A \cdot C_f \cdot v_s^2}{2} \tag{2}$$

where: m_p - particle mass, ρ_g - gas density, ρ_p - apparent particle density, A - particle cross-section area, C_f - coefficient of friction, g - gravitational acceleration, v_s sedimentation speed.

From equation (2) results the relation of calculation of sedimentation speed [3]:

$$v_s = \sqrt{\frac{2 \cdot m_p \cdot g \cdot (\rho_p - \rho_g)}{A \cdot \rho_g \cdot C_f \cdot \rho_p \cdot \rho_g}} \tag{3}$$

The coefficient of friction, corresponding to the displacement of spherical particles in gas, depends on the Reynolds (Re) criterion. By definition, Re = ρ · g · vs · d / μ, d represents the characteristic size (in the present case the particle diameter), and μ - the dynamic gas viscosity.

The C_f - Re correlation is obtained by experiment, the establishment of analytical expressions, for this correlation, being impossible, only for restricted domains of variation of the number Re.

For the laminar flow regime, also called the Stokes regime, Re ranges from 10^{-4} to 0,5. In this case, experiments performed on spherical particles led to a relation of the form [3]:

$$C_f = \frac{24}{Re} \tag{4}$$

If, in addition, we observe that for atmospheric air $\rho_p - \rho_g \approx \rho_p$, relation (3) becomes of the form [3]:

$$v_s = \frac{d_p^2 \cdot g \cdot \rho_p}{18 \cdot \mu} \tag{5}$$

mathematical expression of Stokes' law. This equation is of good accuracy for spherical particles having a diameter of less than 50 μm, but it is used with acceptable error for particle diameters of up to 100 μm.

The limit value, Re = 10^{-4}, corresponds to a particle diameter of approximately 5 μm.

The range of particle diameters between 1 μm and 100 μm is very important for many of the sources of airborne industrial pollution.

It is therefore necessary to mention that diameters smaller than 5 μm become approximately equal to the average free path of molecules in atmospheric air. Due to this, the particle sedimentation rate increases, above the value determined by Stokes' law.

Consequently, for equivalent diameters of particles smaller than 5 μm, the particle sedimentation velocity is calculated with a relation of the form [3]:

$$v_s = K_c \cdot v_{Stokes} \tag{6}$$

equation known as the Stokes-Cunnigham law.

The coefficient K_C, in equation (6), is called the Cunnigham coefficient and is calculated with the relation [3]:

$$K_C = 1 + \frac{2\lambda}{d_p}\left[1{,}257 + 0{,}4 \cdot e^{\left(0{,}55\, {d_p}/{\lambda}\right)}\right] \tag{7}$$

in which, λ represents the mean free flow of gas molecules, which can be calculated with the relation [3]:

$$\lambda = \frac{\mu}{0{,}499 \cdot \rho_g \cdot v_m} \tag{8}$$

where: μ - the viscosity of the gas, ρ_g - its density, v_m - the average speed of the gas molecules.

In the flow regimes between the laminar and turbulent modes, the coefficient of friction can be calculated by [3]:

$$C_f = 0{,}22 + \frac{24}{Re}\left[1 + 0{,}15 \cdot Re^{0{,}6}\right] \quad (9)$$

This equation, which in fact characterizes the flow of gas in the vicinity of a spherical particle, can be applied for Reynolds numbers between 1 and 500. However, for Re > 0,5 (or for particles whose diameters are appreciably larger than 50 μm), it is convenient to use C_f - Re experimental correlations by which the sedimentation rate can be directly assessed, depending on particle diameter and density.

An example of such curves, applicable only to spherical particles suspended in air at ambient temperature and pressure, is given in figure 1 for particle diameters between 0.1 μm and 3000 μm [3].

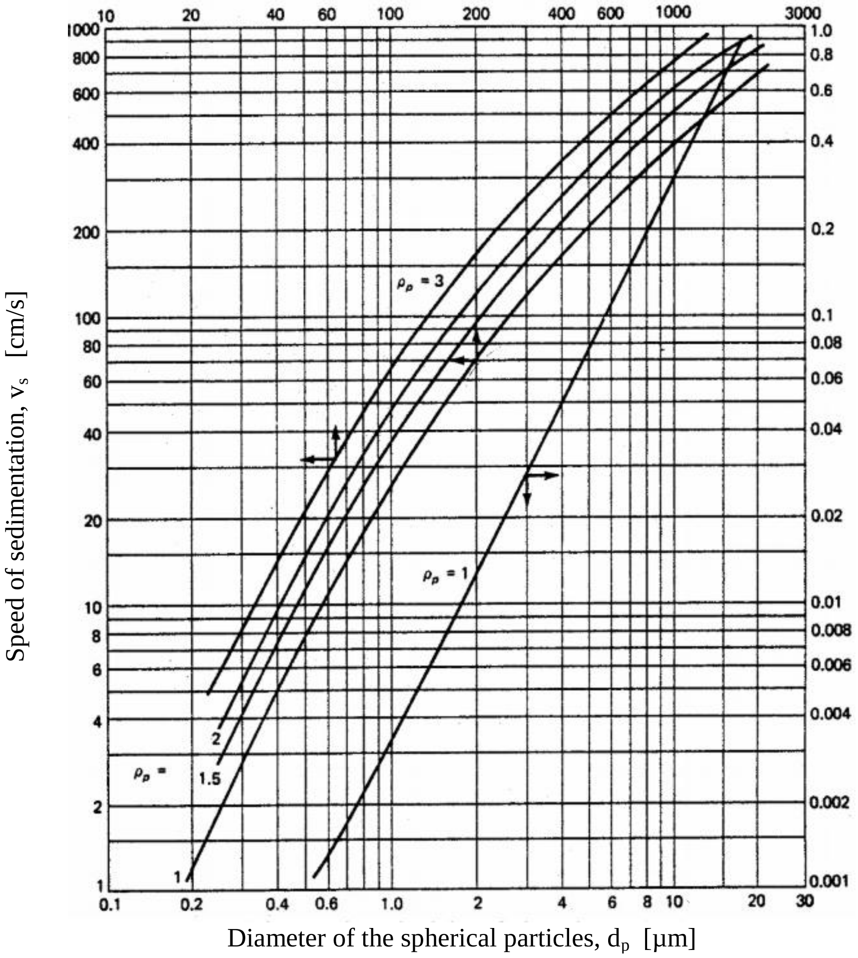

Fig.1. Dependency of sedimentation velocity of particles in air under standard pressure conditions and temperature of particle diameter and density

2.2. Case study

The air quality in the monitored area near the chimney of the X plant was determined by measuring the concentrations of the different pollutants and comparing them with the limit values with the maximum admissible concentrations (fig. 2). The concentration of pollutant emissions in ambient air may vary, depending on meteorological conditions more or less favorable to good dispertion.

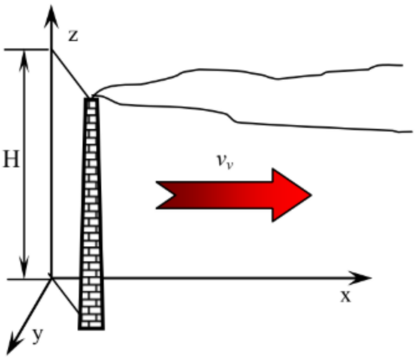

Fig.2. Monitoring area

To highlight the effects of total suspended pollution on the human body has been achieved:

- monitoring of sedimentary dusts at the limit of the functional area;
- monitoring of suspended particulates at the limit of the functional area.

In order to highlight the possibilities of assessing the sedimentation velocities, spherical particles having density ρ_p = 1 g / cm^3 and diameters of 10 μm, 100 μm and 1000 μm, respectively, which are suspended in atmospheric air at pressure and standard temperature. The sedimentation velocity of these particles and particles of 10 μm diameter and density of 2 g / cm^3 will be determined.

For these input data, the sedimentation rate determination solution is that of using the curves in figure 1. Thus, for particles having a density of 1 g / cm^3, it results:

d_p = 10 μm → v_s = 0,3 cm/s
d_p = 100 μm → v_s = 25,5 cm/s
d_p = 1000 μm → v_s = 400 cm/s

For particles having a diameter of 10 μm and a density of 2 g / cm^3 because the gas flow is laminar, besides particles of this dimension, the ratio v_g / v_v > 2 can be applied, resulting in a double velocity, relative to that of particles having the same diameter, but with pp = 1 g / cm^3.

To determine the particle sedimentation velocity of 10 μm in diameter, Stokes' law can also be applied. Thus, under standard pressure and temperature conditions, the dynamic air viscosity is 0,067 kg / m · h = 1,861 · 10-5 Ns / m^2, resulting in:

$$v_s = \frac{(10^{-5})^2 \cdot 9{,}81 \cdot 10^3}{18 \cdot 1{,}861 \cdot 10^{-5}} = 0{,}292 cm/s$$

value very close to that obtained by direct use of the chart (0,3 cm / s). Applying Stokes' relation and particles with diameters of 100 μm and 1000 μm results in sedimentation rates of 29,28 cm / s and 2928,5 cm / s, respectively.

It can be seen that the increase in the estimation of sedimentation velocity error, in the increase of the particle diameter outside the Stokes domain, can be observed. In addition, for large particles, there is an increase of 1,5 times the sedimentation rate, and not the doubling of the sedimentation rate, even if particle density is two times higher.

3. Conclusion

The results, presented in this example, are of importance in the air purification techniques of airborne particles. Thus, if gravitational sedimentation is used as a dispersion cleaning method, it is possible to determine the active space (plant height) and its efficiency, depending on the sedimentation rate. For the previously determined sedimentation rates, in the case of an installation with an active height of 10 m, sedimentation times of 3300 s, 40 s and 2,5 s respectively result. In conclusion, particles having dimensions less than 100 μm (without doing reference and their density) do not deposit quickly enough in classical installations. Consequently, gravity sedimentation is not an efficient technique for purifying suspended particles, except for those particles whose dimensions are sufficiently large (d_p> 100 μm) or if the technological flow allows for high sedimentation times [4].

References

[1] Gavrilă, L – Operaţii unitare în industria alimentară şi biotehnologii, Universitatea Bacău, 2001

[2] Gavrilă, L – Fenomene de transfer, vol. I,II, Editura Alma Mater, Bacău, 2000

[3] Istrate, M – Tehnologii şi instalaţii pentru reducerea emisiilor poluante. Controlul poluării în termoenergetică, Editura SETIS, Iaşi, 2004

[4] Ruscă, M., Rusu, T.A. - Evaluarea nivelului poluării aerului în zonele cu activități industriale, A XVIII Conferinţă internaţională – multidisciplinară “Profesorul Dorin Pavel – fondatorul hidroenergetici româneşti” Cluj Napoca, 2018.