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ABOUT EMISSIONS CONTAINING SEDIMENTABLE SOLID PARTICLES

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Abstract: As pollutants concentration on large areas is difficult to measure and also for designing industrial installations for emissions in the atmosphere, it is necessary the evaluation of sedimentary particles quantity at ground level, around the pollution source. Depending on emission and dispersion conditions, climate and pollutant type (gases or particles), the ground-level concentration may be expected as the following: near to source, due to high emission and air currents carrying the pollutants, the concentrations are equal to zero; maximum value can be attended at long distances from the source. The paper presents an analytical evaluation of deposition rate to the ground of pollutant containing solid particles, which was emitted in atmosphere by an elevated point source. Results are presented for specific particles size, depending on distance from the source, in wind direction.
Keywords: air pollution, emission of solid particles, settling, deposition rate

1. CONCENTRATION OF POLLUTANTS EMITTED BY POINT SOURCES

Plumes released in atmosphere by point sources may contain the following categories of pollutants: solid particles which settle on the ground due to gravity, gases absorbed by soil or water (NO_x, SO_2) and/or gases reflected by the soil, which are not absorbed (CO, COV-volatile organic compounds) [1, 2]. As pollutants concentration on large areas is difficult to measure and also for designing industrial installations for emissions in the atmosphere (e.g. chimney stacks), it is necessary the evaluation of sedimentary particles quantity at ground level (in $g/m^2 \cdot s$), around the pollution source [1].

There are several mathematical models which describe pollutant plume dispersion in air and permits evaluation of ground-level concentration along plume centerline [3]. For elevated point sources (stacks), the Gaussian model is often used [3, 4]. To define the initial parameters some assumptions are made (in correlation with notations from figure 1 [4]): the x-axis is considered along plume centerline in wind direction; wind speed u is that at stack exit height H; plume disperses in air in horizontal direction with same speed as wind.

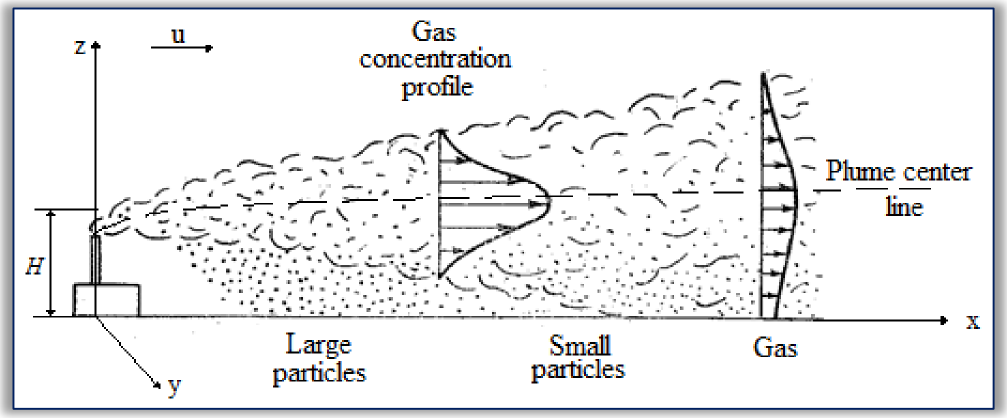

Figure 1. Downwind dispersion of plume pollutants [3].

Depending on emission and dispersion conditions, climate and pollutant type (gases or particles), the ground-level concentration may be expected as the following: near to source, due to high emission and air currents carrying the pollutants, the concentrations are equal to zero; maximum value can be attended at long distances from the source. Also, at very long distances from source, the concentration of the pollutant tends to zero due to dispersion [3].

For any coordinate point (x, y, z), the concentration (C in [g/m³]) of solid particles depends: directly proportional to the emission rate (Q in [g/s]) and Gaussian function of concentration distribution in y and z directions ($G = G_y \cdot G_z$), and inversely proportional to the wind speed (u in [m/s]) [1, 5, 6]. So:

$$C(x,y,z) \cong \frac{Q}{u} G \tag{1}$$

where:

$$G_y = \frac{1}{\sqrt{2\pi} \cdot \sigma_y} \cdot \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \tag{2}$$

$$G_z = \frac{1}{\sqrt{2\pi} \cdot \sigma_z} \cdot \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] \tag{3}$$

In relations (2) and (3) σ_y and σ_z (in [m]) are dispersion coefficients in horizontal and vertical directions, y and z (in [m]) are relative coordinates from ground level, H (in [m]) is effective stack height (distance from the ground to plume centerline).

Thus, substituting relations (2) and (3) in (1) results the concentration of pollutant containing solid particles [1, 5, 6]:

$$C(x,y,z) = \frac{Q}{2\pi \cdot \sigma_y \cdot \sigma_z \cdot u} \cdot \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \cdot \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] \tag{4}$$

Plume effective height as a function of distance from the stack (x) and emission time (Δt), is given by [5, 6]:

$$H(x) = H - v_s \cdot \Delta t \tag{5}$$

where $\Delta t = \frac{x}{u}$ represents time in which the solid particles float in the plume;

$v_s \left[\frac{m}{s}\right]$ is the particle settling velocity which depends on diameter (d_p in [m]) and density (ρ_p in [kg/m³]) of the particle, obeying Stokes law [5, 6]:

$$v_s = \frac{{d_p}^2 \cdot g \cdot \rho_p}{18 \cdot \mu} \tag{6}$$

g = 9.81 m/s² is acceleration due to gravity; μ = 0.0185 g/m·s is air viscosity.

Results:

$$H(x) = H - \frac{v_s \cdot x}{u} \tag{7}$$

Substituting relation (7) in (4) results

$$C(x,y,z,H) = \frac{Q}{2\pi \cdot u \cdot \sigma_y \cdot \sigma_z} \cdot \exp\left\{-\frac{1}{2}\left[\left(\frac{y}{\sigma_y}\right)^2 + \left[\frac{z-\left(H-\frac{v_s \cdot x}{u}\right)}{\sigma_z}\right]^2\right]\right\} \tag{8}$$

At ground level (y=0 and z=0), along plume centerline at distance x, pollutants containing solid particles emitted from a height H, have a concentration given by:

$$C(x,0,0,H) = \frac{Q}{2\pi \cdot u \cdot \sigma_y \cdot \sigma_z} \cdot \exp\left[-\frac{1}{2}\left(\frac{H-\frac{v_s \cdot x}{u}}{\sigma_z}\right)^2\right] \tag{9}$$

Also, the deposition rate of solid particles on the ground is given by [5, 6]:

$$Q_m = C \cdot v_s = \frac{Q \cdot v_s}{2\pi \cdot u \cdot \sigma_y \cdot \sigma_z} \cdot \exp\left[-\frac{1}{2}\left(\frac{H-\frac{v_s \cdot x}{u}}{\sigma_z}\right)^2\right] \quad \left[\frac{g}{m^2 \cdot s}\right] \tag{10}$$

The deposition rate is influenced by atmospheric conditions as wind speed and climate. In function of these factors there are six atmospheric stability classes noted A to F (A - corresponding to the very unstable atmosphere and F - corresponding to the most stable atmosphere). The atmospheric stability class may be determined as indicated in Table 1 [5, 6].

Table 1. Atmospheric stability classes [5, 6]

Wind speed at 10 m, in [m/s]	Day			Night	
	Incoming solar radiation			Overcast	
	Strong	Moderate	Slight	Strong	Slight
< 2	A	A – B	B	E	F
2 ÷ 3	A – B	B	C	E	F
3 ÷ 5	B	B – C	C	D	E
5 ÷ 6	C	C – D	D	D	D
> 6	C	D	D	D	D

Also, knowing the stability class, the dispersion coefficients may be calculated by [5, 6]:

$$\sigma_y = a \cdot x^b \quad (11)$$

$$\sigma_z = c \cdot x^d + f \quad (12)$$

where, a, c, d and f are parameters dependent on atmospheric stability class and given in Table 2. Also b = 0,894, and x is distance from the source in [km].

Table 2. Parameters values in standard deviations analytical expressions (σy and σz) [6, 7]

Atmospheric stability class	a	x ≤ 1 km			x ≥ 1 km		
		c	d	f	c	d	f
A	213	440.8	1.941	9.27	459.7	2.094	- 9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61.0	0.911	0	61.0	0.911	0
D	68	33.2	0.725	- 1.7	44.5	0.516	- 13.0
E	50,5	22.8	0.678	- 1.3	55.4	0.305	- 34.0
F	34	14.35	0.740	- 0.35	62.6	0.180	- 48.6

2. ESTIMATING THE DEPOSITION RATE OF SOLID PARTICLES

As stated above, to predict the deposition rate of solid particles, relation (10) may be used. In function of distance from the source (x in [m]), the obtained results, gives the rate (in [$g/m^2 \cdot s$]) at which solid particles are being deposited on the ground, under the plume centerline [5]. However, some initial parameters must be defined referring to emission conditions, weather and pollutant physical properties.

For the following numerical example some experimentally measured parameters were considered from references [7] and [8], respectively. So, as initial parameters it was considered that pollutant (ash resulted from burning coal in an electrical plant) is released in atmosphere through a stack having the height H = 250 m, with an emission rate of Q = 172.9 g/s [7]. Bulk density of coal ash is $\rho_p = 1.6\ g/cm^3$ and particles diameter $d_p = 10\ \mu m$ [8]. Other initial parameters were: wind velocity at stack height: u = 5 m/s, D atmospheric stability class and maximum distance from the source x = 40 km.

Using relation (6), the settling velocity is:

$$v_s = \frac{(10 \cdot 10^{-6}\ m)^2 \cdot (9.81\ m/s^2) \cdot (1.6 \cdot 10^6\ g/m^3)}{18 \cdot (0.0185\ g/m \cdot s)}$$

$$v_s = 0.004713\ m/s$$

Dispersion coefficients are functions of distance from source (x in [km]) and for atmospheric stability class D, with relations (11) and (12), taking the values of a-f coefficients from table 2, results:

- for distances x ≤ 1 km: $\sigma_y = 68 \cdot (x)^{0.894}$

$$\sigma_z = 33.2 \cdot (x)^{0.725} - 1.7$$

- for distances x ≥ 1 km: $\sigma_y = 68 \cdot (x)^{0.894}$

$$\sigma_z = 44.5 \cdot (x)^{0.516} - 13$$

Applying equation (10), results:

$$Q_m = \frac{(172.9\ g/s) \cdot (0,004713\ m/s)}{2\pi \cdot (5\ m/s) \cdot \sigma_y(m) \cdot \sigma_z(m)} \cdot \exp\left\{-\frac{1}{2}\left[\frac{(250\ m) - \frac{(0.004713\ m/s) \cdot x(m)}{(5\ m/s)}}{\sigma_z}\right]^2\right\} \left[\frac{g}{m^2 \cdot s}\right]$$

By resolving the above equation for x values given in range (0.2-40 km) is obtained the variation from figure 2.

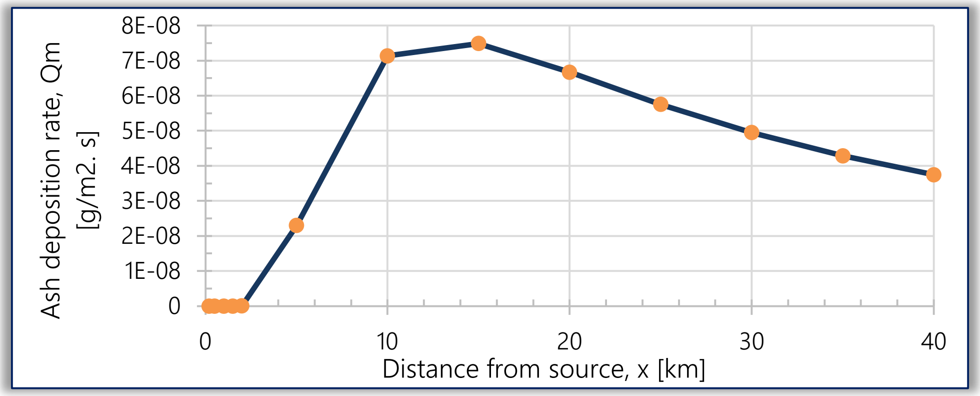

Figure 2. Variation of ash deposition rate with distance from the source

Maximum value of ash deposition rate of $Q_m = 7.49 \cdot 10^{-8} \frac{g}{m^2 \cdot s} = 0.0749 \frac{\mu g}{m^2 \cdot s}$ is estimated at about 15 km from source.

3. CONCLUSIONS

An analytical evaluation of deposition rate to the ground of pollutant containing solid particles, which was emitted in atmosphere by an elevated point source, is presented. Results are presented for specific particles size, depending on distance from the source, in wind direction. The deposition rate (in$[g/m^2 \cdot s]$) of a solid-containing pollutant (ash from a technological process) was calculated considering a continuous point source (chimney stack). Results depended on settling velocity of solid particles (given by Stokes' law) and clime conditions based on which dispersion coefficients were determined in function of distance from the source.

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