ESTIMATION OF THE CRITICAL POLLUTION CHARACTERISTICS AT DIFFERENT METEOROLOGICAL CONDITIONS IN PBL

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INTRODUCTION

The maximal concentration obtained from the stack of a given industrial region depends mainly on the stack parameters and the meteorological conditions. To find the critical (maximal of the maximal) concentration, the distance, wind speed and the stratification conditions under which it occurs is more important task. The critical parameters allow estimating the worst-case ambient pollution conditions, to determinate the stack height of newly planned industrial sources, and also for evaluation of the environmental impact of already existing sources.

Basic method for determination of the critical parameters at power laws for the dispersions and constant with the height gives Raglang, K. (1976). Here we will extend the application of this approach considering some more complex diffusion and meteorological conditions and actualized data for the dispersions and the effective height of the source and also to give estimation of some pollution characteristics for powerful sources (of type of thermo-electric power stations).

FORMULATION OF THE PROBLEM

Let's use the Gaussian pollution distribution formula, from source situated in the point $x = y = 0$. The ground level ($z = 0$), concentration C along the plume centreline ($y = 0$) is given by:

$$C = \frac{Q}{\pi U_H \sigma_y \sigma_z} \exp\left[-H^2 / 2\sigma_z^2\right] \qquad (1),$$

where Q is emission rate, U_H is the wind speed at the effective stack height H.

The quantity H is calculated according Briggs formula (see *Hanna, S.*, 1982).

$$H = h_s + \Delta h, \Delta h = F U_s^{-\lambda} \qquad (2),$$

where h_s is the geometric stack height, Δh is the plume rise, $U_s = U(z = h_s)$, F is characteristic technological parameter, λ is parameter with value 1or1/3 (see table.1).

Wind profile $U(z)$ is given as:

$$U(z) = U_{10}(z/10)^m \qquad (3),$$

where U_{10} is the wind speed at standard level 10m and the parameter m depends on the Pasquill stability classes (Hanna, S., 1982), see Table 1.

For dispersion parameters $\sigma_z(x)$, $\sigma_y(x)$, it is used the well known formulas of Briggs. In the present work they are approximated with enough precision with the convenient for work power laws:

$$s_z(x) = ax^b, \qquad s_y(x) = cx^d \qquad (4),$$

where the approximation coefficients a, b, c, d and the parameters m, l are given in Table 1.

Table1. Values of the used parameters for calculation for rural and urban regions.

	Z_0=0.03m - Rural						Z_0=1m - Urban					
Kl.	*m*	*a*	*b*	*c*	*d*	*l*	*m*	*a*	*b*	*c*	*d*	*l*
A	0,07	0,20	1,00	0,41	0,90	1	0,15	0,083	1,15	1,264	0,77	1
B	0,07	0,12	1,00	0,30	0,90	1	0,15	0,083	1,15	1,264	0,77	1
C	0,10	0,30	0,80	0,20	0,90	1	0,20	0,20	1,00	0,87	0,77	1
D	0,15	0,76	0,57	0,15	0,90	1	0,25	0,91	0,72	0,63	0,77	1
E	0,35	1,04	0,47	0,11	0,90	1/3	0,40	0,93	0,683	0,43	0,77	1/3
F	0,55	1,13	0,39	0,07	0,90	1/3	0,60	0,93	0,683	0,43	0,77	1/3

Maximal pollution condition

Differentiating (1) by x, taking into account (5), and nullifying the obtained expression, leads to the following relation for distance x_m at which the surface concentration has maximum(Ragland, 1976):

$$x_m = k_1 H^{1/b}, \; k_1 = \left\{ b / \left[a^2 (b+d) \right] \right\}^{1/2b} \qquad (5)$$

The dependence of x_m on H (taking into account the parameters of Ttable.1) is demonstrated in Fig.1

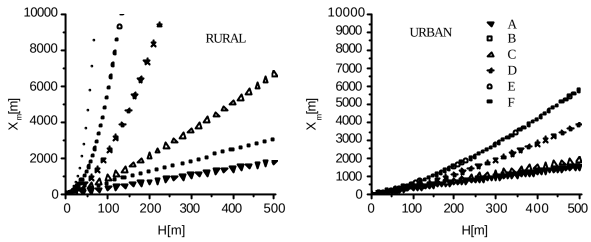

Fig. 1; The dependence of x_m on H at different stability classes for rural and urban

The dependence of x_m on H (taking into account the parameters of table.1.) is demonstrated in Fig.1. Inserting (5) in (1), taking into account (3) and (4), we determine the maximal surface concentration C_m:

$$C_m = \frac{Q}{pacU_{10}} \frac{\exp(-k_2) 10^m}{k_1^{b+d}} H^{-\left(m + \frac{b+d}{b}\right)}, \; k_2 = (b+d)/2b \qquad (6)$$

Critical parameters

From the condition for extreme of C_m about U_{10} we determine the critical wind velocity U_{10cr}:

$$U_{10cr} = F^{1/l} 10^m k_3^{1/l} h_s^{-\frac{1+ml}{l}}., \; k_3 = l(m+k) - 1, \; k = 1 + \frac{d}{b} \qquad (7)$$

Substituting (7) in (5) we obtain the critical distance x_{mcr} at which C_{mcr} is realized:

$$x_{mcr} = k_1 \left(1 + \frac{1}{k_3} \right)^{1/b} h_s^{1/b} \qquad (8).$$

Considering (7), (8), (2) from (6), we determine the critical (maximal of the maximal) surface concentration C_{mcr}:

$$C_{mcr} = \frac{Q}{p}\frac{k_2}{k_1^{b+d}}\left(\frac{h_s}{F}\right)^{1/l} h_s^{-\frac{b+d}{b}}\left(1+\frac{1}{k_3}\right)^{-m-\frac{b+d}{b}} k_3^{-1/l} \qquad (9).$$

Let's now determine the so called stack height of a planned new source h_{sp} so, that at any meteorological conditions the surface pollution concentration does not exceed the Limit Admissible Concentration (LAC) - C_{LAC} (i.e. $C_{mcr} = C_{LAC}$):

$$h_{sp} = \left[C_{LAC}\frac{p}{Q}F^{1/l}\frac{k_1^{b+d}}{k_2}k_3^{1/l}\left(1+\frac{1}{k_3}\right)^{m+\frac{b+d}{b}}\right]^{\frac{bl}{b-bl-bd}} \qquad (10)$$

On Fig. 2, 3 it is presented the dependence of the critical parameters $\tilde{U}_{10cr} = U_{10cr}/F^{1/l}$ and $\tilde{C}_{mcr} = C_{mcr}/\left(Qp^{-1}F^{-1/l}\right)$ on h_s at selected stability classes *A, B, C, D* at which it is more likely to form critical condition for high stack sources.

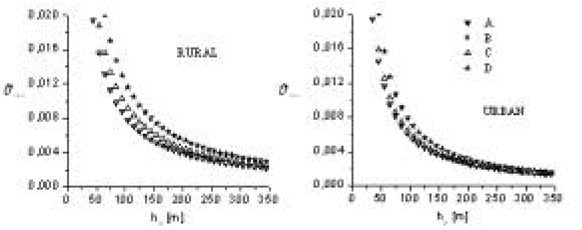

Fig. 2; The dependence of the critical speed $\tilde{U}_{10cr}$ on h_s at different stability classes for rural and urban regions.

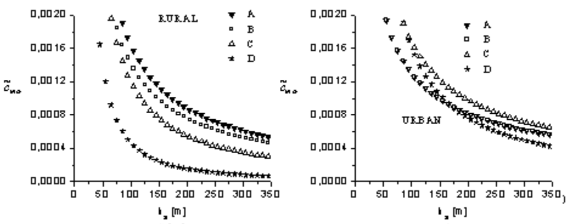

Fig. 3; The dependence of the critical speed $\tilde{C}_{mcr}$ on h_s at different stability classes for rural and urban regions.

Effect of gravity deposition

In the case with gravity deposition velocity w_0, formula (1) turns into the simple form (see *Wark, K. and C. Warner* 1976):

$$C = \frac{Q}{pU_H s_y s_z}\exp\left[-(H-\tilde{w}_0 x)^2/2s_z\right],\ \tilde{w}_0 = \frac{w_0}{\overline{U}}, \overline{U} = \frac{1}{H}\int_0^H U(z)dz = \frac{U_{10}}{1+m}\left(\frac{H}{10}\right)^m \qquad (11)$$

Applying similar procedure as at the determination of (5) (at $w_0 = 0$) we obtain the following algebraic equations for determination of x_{mw} in the case of considering gravity deposition:

$$a^2(b+d)x_{mw}^{2b} + \tilde{w}_0(2b-1)Hx_{mw} + \tilde{w}_0^2(1-b)x_{mw}^2 - bH^2 = 0 \qquad (12).$$

Equation (12) can be easily numerically integrated. Here we will limit to the cases $b = 1$ and $b = 1/2$, at which (12) becomes a quadratic equation which have analytical solution. On the basis of the analytical solution of x_{mw} at $b = 1$ (the classes A, B, C approximately unites around this value) on Fig 4 it shown the ratio $\tilde{x} = x_{mw}/x_m$. If we substitute the solution of (12) x_{mw} in (11) we determined the maximal concentration with effect of gravity deposition. We will note that at conditions with inversions at the height of the source (11) is modified in the known formula taking into account the inversion with endless series. If we take only the first two main terms of the series we receive worst case concentration at joint influence of inversion

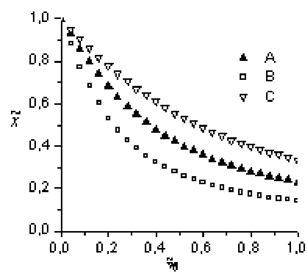

Fig. 4; Dependence of $\tilde{x}$ and on $\tilde{w}_0$ at different stability classes A, B, C for rural region.

and gravity deposition (at $\tilde{w}_0$ follows the formula suggested by *Ragland, K.*, 1976).

ESTIMATION OF POWER STATION CRITICAL POLLUTION PARAMETERS

We will apply the presented above results for evaluation of critical pollutant parameters for high sources typical of power-stations. Let's consider three typical such sources S_1 ($H = 120m$), S_2 ($H = 150m$), S_3 ($H = 325m$) which practically cover the whole range of change of the technological parameters. The sources correspond respectively to: S_1 – typical urban thermo electric power station, S_3 – powerful source (stack) from thermo electric power station "Maritsa Iztok" and S_2 – medium place.

The calculated critical parameters U_{10cr}, x_{mcr}, C_{mcr} are presented in Tables 2-4 in which are taken into account possible correspondences between the solar radiation , PT classes and U_{10} (great U_{10cr} at classes A and B are possible only at solar radiation = 900 cal.cm^{-2}.d^{-1}). With bold in the tables it is marked the critical cases. It can be seen that for all cases the concentration C is smaller than the single $C_{LAC} = 0{,}042$ mg.m^{-3} or the twenty four hour $C_{LAC} = 0{,}14$ mg.m^{-3} concentrations. Depending on the overheat in accordance to the Briggs formulae (the parameter F), in the table are presented the cases of Archimedean raising (big overheats) and dynamical (no overheat - $DT = 0^\circ$) raising of gases in the atmosphere. At dynamical raising in all cases $C >> C_{LAC}$, independently from the big height of the sources. At Archimedean raising the worst unfavourable conditions correspond to classes C and D. At powerful high sources (of type S_3) and usual typical for them Archimedean raising the condition $C > C_{LAC}$ can be reached at classes A and B and great velocities U_{10cr} ($U_{10cr} \sim 10$ m.s^{-1} for rural and $U_{10cr} \sim 6$ m.s^{-1} for urban conditions). As we already underlined similar correspondence of U_{10cr} and these classes is possible only at slightly probable and strongly anomalous conditions. For example, at solar radiation = 900 cal.cm^{-2}.d^{-1} U_{10cr} at class B can reach up to 5 m.s^{-1}, which is very close to the given in the table values ~ 6 m.s^{-1} for urban conditions, when $C \geq C_{LAC}$. Obviously class B at high solar radiation is very risky for reaching C_{LAC}. $C < C_{LAC}$. The condition $C > C_{LAC}$ can be reached and at other anomalous situations: technological damage in the filters and ejection of big particles ($w_0 \neq 0$), forming of inversion right above the geometric height of the source, specific combination of advection and strong solar radiation at classes A and B and etc. In all these cases it is necessary to apply extraordinary measures to decrease or turn off the power of the source.

Table 1. U_{10cr}- (m/s) at different meteorological conditions and types of sources and raisings.

		archimedean raising				dynamical raising			
	source	A	B	C	D	A	B	C	D
rural	S_1	4,95	**4,95**	**5,81**	**7.24**	0,71	0,71	0,84	1,04
	S_2	9,23	9,23	10,7	**13,2**	1,69	1,69	1,96	2,42
	S_3	10,4	10,4	11,9	**14,1**	1,75	1,75	2,00	2,37
urban	S_1	**3,43**	**3,43**	**3,59**	**4,31**	0,49	0,49	0,52	0,62
	S_2	6,28	6,28	**6,49**	**7,71**	1,15	1,15	1,19	1,41
	S_3	6,68	6,68	**6,44**	**7,59**	1,12	1,12	1,12	1,28

Table 2. x_{mcr} -(m) at different meteorological conditions and types of sources.

	rural				urban			
source	A	B	C	D	A	B	C	D
S_1	884	**1473**	**2355**	**6976**	**896**	**896**	**915**	**1663**
S_2	1105	1841	3112	**10319**	1087	1087	**1144**	**1585**
S_3	2394	3990	8181	**40062**	2131	2131	**2480**	**4640**

Table 3. C_{mcr} (mg/m^3) at different meteorological conditions and types of sources and raisings

		archimedean raising				dynamical raising			
	source	A	B	C	D	A	B	C	D
rural	S_1	0,11	**0,10**	**0.082**	**0,029**	0,81	0,70	0,57	0,20
	S_2	0,19	0,16	0,13	**0,041**	1,04	0,90	0,70	0,22
	S_3	0,45	0,39	0,25	**0,057**	2,66	2,30	1,50	0.34
urban	S_1	**0,096**	**0,096**	**0,12**	**0,11**	0,66	0,66	0,84	0,75
	S_2	0,16	0,16	**0,20**	**0,17**	0,90	0,90	1,11	0,95
	S_3	0,46	0,46	**0,53**	**0,36**	2,76	2,76	3,16	2,13

CONCLUSION

The present study shows that in the most cases of normal meteorological conditions, the high and strongly overheated sources (Archimedean regime of raising) fit in the condition for the surface concentration $C < C_{LAC}$ (of course, this is for the increase of the long range pollution). Due to cases of anomalous combination of atmospheric factors, the condition $C > C_{LAC}$ can be reached (particularly at class B). Such situations (e.g. still conditions in the high and significant wind in the lower layers, advective transport (baroclinic effect) combined with unstable conditions, inversion at the height of the source, several layer distribution of wind and stratification in height) are out of the range of the possibilities of the traditional Gaussian dispersion model with a priory giving of the dispersion and dynamic parameters. A future task is to study similar complex diffusion processes with taking into account of complex combination of surface and height turbulent factors (see Syrakov et al, 2007). The estimation of similar anomalous situation although the little occurrences is important environmental task allowing to regulate and optimize the source at strongly unfavourable conditions.

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