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DETERMINATIONS OF THE HORIZONTAL TURBULENT DIFFUSION COEFFICIENTS IN THE ROMANIAN COASTAL WATERS

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ABSTRACT:

Using the field data on the horizontal distribution of the salinity in the plumes generated by several types of waste water discharges, the apparent eddy diffusivity was determinated by means of the Fick and Richardson solutions for the steady state diffusion.

The quantitative description of the turbulent mixing processes concerning water masses with different properties strongly depends on the knowledge of the turbulent diffusion coefficients. Because the problem of selecting the best suited theoretical model is not yet completely solved, there is a need for experimental determination of these coefficients using different tracers.

For the Romanian shore waters, the turbulent diffusion coefficients have been previously computed for the region where natural mixing between fresh or brackish and sea waters takes place (2).

In the present work the analysis is carried out for the regions where the sewage is discharged into the sea, by computing the horizontal diffusion coefficients for different types of sources. The following cases of continuous discharges were investigated:

- submarine discharge through a pipe lying on the bottom at 4 m depth;
- open discharge channel at the shoreline;
- pipe discharge at the sea surface.

The waste water was used as a tracer through the salinity decrease produced by it in the areas surronding the discharge points.

During the measurements carried out in 1977, the following parameters were determined each time:

- effluent discharge rate;
- current speed and direction and water salinity in several points in the plume and outside it, in the non-contaminated waters.

The location of the measuring points was calculated from the intersection of two direction lines taken with two theodolites from the shore. The coordinates were then converted to a reference system having the origin in the discharge point, the x-axis downstream and the y-axis cross-stream.

For a quantitative description, all cases were supposed to be steady states of turbulent diffusion from a continuous point source into a homogeneous fluid in uniform flow. Due to the great density difference between the effluent and the surronding waters, the former spreads in a very thin surface layer, as it is proved by the salinity measurements made at surface and at 1 m depth (Fig. 1). Owing to this fact, the vertical diffusion was neglected and the mixing regarded as a twodimensional process.

Taking into account that the downstream change in concentration produced by advection exceeds by far the change produced by diffusion and, consequently, there is only cross-stream diffusion, the twodimensional diffusion equation may be written in the simplified form:

$$\bar{u}\,\frac{\partial \bar{C}(x,y)}{\partial x} = \frac{\partial}{\partial y}\left(K_y\,(y)\,\frac{\partial \bar{C}(x,y)}{\partial y}\right) \qquad (1)$$

where K_y (y) is the horizontal diffusion coefficient in the y direction; $\bar{u}$ is the mean flow speed, $\bar{C}$ (x,y) – the average concentration in the (x,y) point.

According to the RICHARDSON-OBUKHOV law (4), K (y) de-

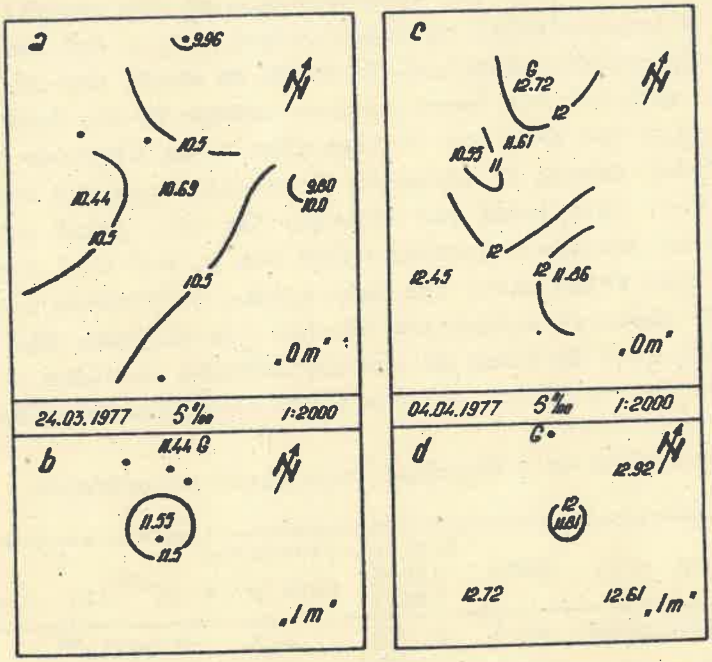

Fig. 1 – Comparison between the horizontal salinity distributions at the surface (a) and at 1 m depth (b) in two cases.

pends on the space scale of the phenomenon:

$$K_y(y) = k\, y^{4/3} \qquad (2)$$

where k is a constant. In this case, equation (1) has the solution:

$$C(x,y) = \frac{4Q}{6\,\bar{u}\left(4\frac{k}{9}\frac{x}{\bar{u}}\right)^{3/2}\sqrt{\pi}} \exp\left(-\frac{y^{2/3}}{4\frac{k}{9}\frac{x}{\bar{u}}}\right) \qquad (3)$$

where Q is the discharge rate and the concentration C (x,y) can be computed as:

$$C(x,y) = \frac{S_m - S(x,y)}{S_m - S_e} \qquad (4)$$

with S_m – the "normal" salinity outside the plume, S_e – the effluent salinity and S (x,y) – the salinity measured in the (x,y) point.

Because all parameters can be measured in the field, expression (3) may be used for determination of the coefficient k. But (3) is a transcedental equation relative to k and can only be solved by approximate calculus. In order to avoid the errors introduced by applying the least squares method to the logarithm of (3), the choice was made for an algorithm using directly the form (3) and a "step search of minimum". A computer program written for FELIX-C 256 calculates the salinity for each point using (3) and (4) and an arbitrary initial value for k, and then succesively refines this value until the mean square difference between computed and measured salinities reaches its minimum. The corresponding value of k is taken as the approximate solution of (3). This approach was used for all the eight investigated situations (Tab. 1).

Table 1

The values of k obtained from field experiments

No.	Discharge type	Date	Current speed (m/s)	Discharge rate (m^3/s)	k	
					($m^{2/3}/s$)	($cm^{2/3}/s$)
1	Pipe (underwater)	24.3	0.258	0.3	2.99×10^{-2}	0.64
2	"	04.4	0.124	0.3	3.17×10^{-3}	0.07
3	"	12.10	0.246	0.3	2.84×10^{-2}	0.61
4	"	24.10	0.070	0.3	2.36×10^{-3}	0.05
5	Open channel	12.5	0.164	0.5	3.25×10^{-2}	0.70
6	Pipe (surface)	06.6	0.095	1.0	2.72×10^{-2}	0.59
7	"	29.6	0.164	1.0	6.87×10^{-2}	1.48
8	"	14.10	0.070	1.0	1.00×10^{-2}	0.22

The values obtained for k are generally larger than those given for other areas of the Black Sea (3), but they yeld the best agreement with the observed data. This may be due to the fact that the "apparent diffusivity" also includes, besides the turbulent diffusion proper, other processes responsible for the concentration decrease, such as the shear effect.

An alternative approach for quantitative treatement of diffusion process was using the FICK solution (1) for the equation (1), assuming constant diffusion coefficients:

$$C\,(x,y) = \frac{Q}{2\,(\pi u K_y x)^{1/2}} \exp\left(-\frac{u\,y^2}{4K_y x}\right) \qquad (5)$$

Using the same computer program, the values of K_y were determined for all the investigated cases (Tab.2).

Table 2

Mean values of the horizontal diffusion coefficient K_y

Discharge type	Underwater pipe	Open channel	Surface pipe
Average K_y (cm^2/s)	2×10^3	3×10^4	6×10^4

The results show a better agreement with the data for other Black Sea regions (4; 5). The mean square differences between computed and observed salinities show only a slight increase as compared to those obtained by using solution (3).

Both formulas can be used for a first attempt of predicting the horizontal distribution of pollutant concentration by using the values of the experimentally derived diffusion coefficients.

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