Two-Dimensional Treatment of Dispersion of Pollutants in Rivers

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An experimental work to study the dispersion of non-degradable pollutants in the Jacui river, situated in the south of Brazil, has been performed. $^{83}$Br in the form of KBr was used as a tracer material. The experimental results were fitted to a two-dimensional distribution function by which the dispersion coefficients along the river flow, $D_x$, and transverse to it, $D_y$, were found to be 12.4 m$^2$/s and 1.7 m$^2$/s, respectively.

1. Introduction

The majority of industries, especially the leather industries, in the state of Rio Grande do Sul, in the south of Brazil, are located along the Sinos and Jacui rivers (Fig. 1). These industries have contributed to the pollution of the rivers by dumping non-degradable pollutants into them. The lack of data on the dispersion coefficients of pollutants in rivers has caused difficulties for the authorities to regulate discharges and control the river pollution.

In an earlier study (1) we measured the dispersion coefficient in the Sinos river using a one dimensional model. In the present work, we have measured the dispersion coefficients in the Jacui river using a two dimensional model, since the effect of the width of the river could not be neglected.

2. Experimental

In this experiment the well-known radioisotopes tracer technique was applied to measure the dispersion coefficients of the non-degradable pollutants. (5, 6). The radioisotope $^{83}$Br which is a $\gamma$-emitter with a half-life of 35.5 h in the form of KBr was used as the tracer element. The detection system consisted of a NaI scintillation counter held on the side of the boat, located 80 cm under the water surface level. The boat carried all the necessary equipment to count and register the experimental data. After the radioisotope tracer was injected at the centre of the river, the boat travelled down the river in a zig-zag manner taking the count rates in various positions. The position of the boat was determined by measuring the angles obtained by two survey meters which were located at a fixed distance apart on the shore of the river. The measurements were made once every minute, and communication between the boat and shore was constantly maintained.

The experiment was performed on 7 October and later was repeated on 7 February. The October experiment encountered a river depth indicator of 0.47 m at 7 h, 0.48 m at 12 h and 0.49 m at 17 h. The wind velocity was 1 m/s at 7 h, 2 m/s at 12 h, and 3 m/s at 17 h blowing from south east. At 10:39 h, 20 cm$^2$ of the radioactive solution with an activity of 495 mCi was instantaneously injected into the river at the point shown on Fig. 2. Eighty four minutes later, the radioactive spot had moved 460 m downstream the river thus moving with a velocity of 5.47 m/min. The position of the spot at 15:35 h was found to be 1096 m further downstream the river with a transient time of 212 min, leading to a velocity of 5.17 m/min. Considering the total distance of 1556 m which the activity reached after 296 min, the velocity was 5.25 m/min.

The February experiment tried to repeat the previous experiment. The river depth was 0.33 m at 7 h, 0.3 m at 12 h and 0.4 m at 15 h. The wind velocity was 1 m/s blowing from the south at 7 h and 12 h, and 2 m/s blowing from south-east at 17 h.

At 10:11 h, 20 cm$^2$ of the radioactive solution with an activity of 480 mCi was injected into the river at a point shown in Fig. 3. At 12:44 h the radioactive spot had moved 945 m down the river with a transient time of 153 min and a velocity of 6.18 m/min. By 150 min later, the spot had moved downstream another 499 m, resulting in a velocity of 3.33 m/min. Considering the total displacement of the radioactive spot of 1444 m during 305 min, the velocity of dislocation was 4.77 m/min.

3. Theoretical Model

The two dimensional equation for dispersion of degradable pollutants in rivers is governed by

$$\frac{\partial C}{\partial t} + D_x \frac{\partial C}{\partial x} + D_y \frac{\partial C}{\partial y} = U \frac{\partial C}{\partial x} - V \frac{\partial C}{\partial y} - K C = 0$$

where $D_x$ and $D_y$ are the dispersion coefficients in the direction of the river flow, $x$, and transversal to the flow, $y$, respectively. These coefficients are assumed to be independent of time and position. $U$ is the river flow velocity along the $x$ axis and is assumed to be a constant. $K$ is the decay constant of the degradable pollutant and $C(x, y, t)$ is the pollutant concentration which is a function of time and position.

Applying the Laplace transform using the following initial and boundary conditions:

$$C(x, y, 0) = M\delta(x)d(y)$$

$$\lim_{|x|, |y|\to\infty} C(x, y, t) = 0$$

where $M$ is the mass of degradable pollutant applied at the point of injection, located at the center of the river at $t_0$. This leads to

$$C_p = \frac{M}{4\pi \sqrt{D_x D_y t}} \exp \left[ -\frac{(x-U t)^2 + Y^2}{4D_y t} \right]$$

where $C_p$ is the corrected pollutant concentration to initial time due to decay.

A least square fitting of the experimental data to the above equation (4) was made to obtain the best values for the dispersion coefficients $D_x$ and $D_y$.

4. Analysis and Discussion

The data obtained in the field were analysed by a computer program which transformed the angles read by survey meters to the position in cartesian coordinate. The positions were corrected by the effect of river flow velocity on the boat. The count rates were corrected and normalized to the initial time condition using the data of the $12h$ 03 min spot. The afternoon results showed two peaks, a situation where the dispersion coefficient does not make sense. We believe this is due to the reverse direction of river flow, a phenom-
cnon which has also been observed by the Institute of Hydraulic Research of the Federal University of Rio Grande do Sul.\(^{16}\)

The river parameters for the region under study are estimated to be on average as follows: flow rate of 2.1 m\(^3\)/s, trapezoidal in shape with a cross section area of 1428 m\(^2\), at a slope of 2.5 cm/km. The manning rugosity coefficient was 0.022.

The October experiment resulted in dispersion coefficients of \(D_x = 12.4 \text{ m}^2/\text{s}\) and \(D_y = 1.7 \text{ m}^2/\text{s}\). The variation in veloc-
Fig. 2. Experiment of 7 October.

ity during this experiment was 5.5%. The February experiment resulted in dispersion coefficients of $D_x = 4.1$ m$^2$/s and $D_y = 0.03$ m$^2$/s. The variation in velocity during this experiment was 46%. The February results are not considered with confidence since the analyses are made based on the constant river velocity. The treatment of the data assuming variable flow velocity require a more complicated model and analysis using numerical methods.

It is suggested that at present for the purpose of estimation of concentration of pollutants in the Jacuí rivers, the
dispersion coefficients from the October experiment should be used.

References
4. Private communication.