Releases modelling in reservoir

J. M. Aragón, M. C. Palancar and L. de Martín
Department of Chemical Engineering
University Complutense at Madrid, Faculty of Chemistry, 28040 Madrid (Spain)
e-mail: *jomar@quim.ucm.es*

The topic of this contribution is accidental releases modelling. The departure hypothesis is that reservoir stratification divides the mass of water into three characteristic layers: upper layer (epilimnion), intermediate layer (metalimnion) and deep layer (hypolimnion). It is assumed that mass and heat transfer is practically impossible between these layers. Box-type models have been developed. The Box-type models treat the entire body of water, or a section of the water body, as composed of homogeneous compartments. Some examples of Box-type models are presented and applied to Spanish reservoirs with different hydraulic/hydrological characteristics. The models provide downstream pollutant concentration changes with time from releases at different upstream points of the hydrological system.

1. Introduction

A stratified reservoir has three characteristic layers: epilimnion, metalimnion and hypolimnion. The mass and heat transfer between these layers is very difficult. In the case of waste releases, the stratification is a barrier for the mass and heat transfer and reduces the effective volume of the reservoir for the dilution and dispersion of pollutants with respect to the same reservoir in homogeneous state. The stratification of reservoirs occurs when the buoyancy forces are greater than those of mixing. Temperature gradients and subsequent stratification occur in a reservoir by heat exchange of water with the atmosphere and by natural or artificial inflows of water at a different temperature or salinity from the ones existing inside the reservoir.

2. Modelling overview

The departure hypothesis of the releases model proposed is that the concentration of a solute in a given point of the reservoir can be calculated by the equation that describes the output of a system constituted by a combination of compartments whit N perfect-mixing vessels of the same volume and plug-flow behaviour, recirculation and bypass:

$$Q_e C_{n-1} = Q_s C_n + \frac{d}{dt}\left(V_n C_n\right) + V_n \lambda C_n \tag{1}$$

where C_{n-1} and C_n are the input and output pollutant concentrations in compartment n, respectively, Q_e and Q_s are the input and output flow rates of compartment n, respectively, V_n is compartment volume and λ is the kinetic constant of a first order non-conservative process. Eq. 1 is also valid for radioactive pollutants, in which case the concentration would be substituted by the specific activity and the kinetic constant by the radioactivity decay constant. The last term on Eq. 1 is cero when dispersion is the only process that occurs.

Some examples of these models, which can be representative of some reservoirs, are shown in Fig. 1.

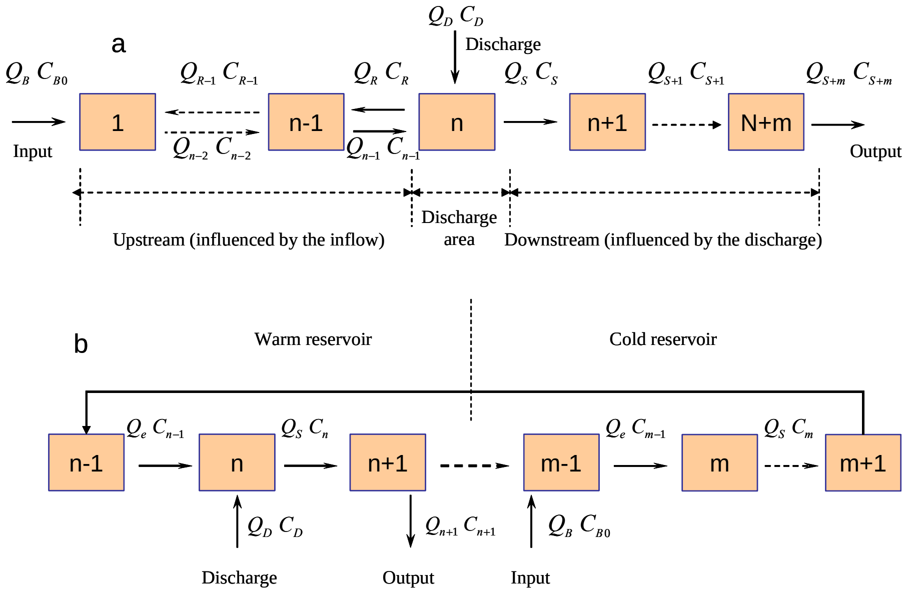

Figure 1.- Two examples of releases models.

A combination of N compartments in series is representative of a reservoir that is in homogeneous regimen, the whole water has the same characteristic and the release flows downstream. Also this model can be used to represent the behaviour of a stratified reservoir. In this case the water density of the release normally is different to the one of reservoir because their temperature or/and salinity are different. For example, if the release stream is very cold or/and has a high salinity, then release stream circulates to a depth where its buoyancy line is reached. That depth can be in the hypolimnion. Thus, the total volume considered for the compartments in series model should be the water volume of the hypolimnion. On other cases, for example, releases of warm or low-salinity streams, the release will flow on the surface layer (epilimnion) and the total volume of the compartment in series model will be the water volume of the epilimnion.

Other typical case that can occur is that the reservoir was subjected to an artificial stratification due to itself release, for example, a warm water discharge. Then, the release travels into the epilimnion and the volume for the dispersion of release is only the epilimnion volume. Moreover, the stratification occurs upstream as well as downstream from the discharge; this implies that the release flows into both sides of the reservoir, upstream and downstream from the discharge point. To quantify this fact, the model represented in Fig. 1a is proposed.

The case to a cooling reservoir, which are frequently used as power plant cooling impoundment, is shown in Fig. 1b. The cooling reservoir has two sub-reservoirs: The one contains the warm zone and, the other one, the cold zone. The warm water flows through the warm reservoir, interchanging heat with the reservoir water and, depending of the final water temperature, it is discharged to the cold reservoir or/and other hydrological system. Cold water flows through the cold sub-reservoir. This cold water comes from the last/cold part of the warm reservoir or/and other hydrological system.

The model proposed here predicts the concentration-time distributions of a pollutant at different distances from the discharge point. The model input data are: Pollutant release characteristics (radioactive compounds, shape of the release: pulse, step, etc.), flow-rate or volume and concentration of the pollutant, hydraulic and hydrological characteristics of the reservoir (capacity-datum, surface section-datum and width-datum functions, datum-distance from the beginning of the influence zone function, thermocline depth and actual water flow rate). The estimated parameter is the number of compartments within each area influenced by the release (i.e. n compartments upstream and m compartments downstream from the inflow point, see Fig. 1a).

3. Reservoir characterization

The reservoir characterizations should be made by available information about the reservoir parameters and field-experimental measures.

Available information can be provided by Governmental organizations, companies that manage the reservoir and users of the reservoir water. This includes: physical and chemical parameters, hydrologic and geometric data, daily values of inflow and outflow, water level, evaporation loss, suspended material and chlorophyll “a” concentrations, and secondly, meteorological data of solar irradiation, cloudiness, air temperature, wind velocity and direction and air humidity and pressure.

The reservoir experimental characterization should be made by carrying out experimental tests within a hydrologic cycle (one year; at least a campaign each month should be made). In our work, in each campaign the measured properties were: temperature, electrical conductivity, water transparency and water layer thickness. These properties should be measured at different depths and transversal cross-sections of the reservoir. Also, measures should be made in the sites where there are inflow and outflow of stream (Palancar, 2004).

The properties measured provided information about the structure of the water layer. Some examples of the results obtained in some Spanish reservoirs are presented in Fig. 2. An example of the variation of the temperature profiles measured in the Entrepeñas Reservoir. This reservoir is subjected to natural stratification due to its characteristics (Wise, 2006). Entrepeñas Reservoir is stratified from early summer until late autumn Fig. 2a, and it is homogeneous during the remainder days of the hydrological cycle. This type of stratification is a natural stratification and is developed every hydrological cycle in the same form. The releasing modelling in this reservoir should be *N* compartment in series. The total volume of the compartments is the reservoir volume and the volume of the hypolimnium for the homogeneous and stratification periods, respectively.

The temperature profiles in Zorita Reservoir (Palancar, 2006) is shown in Fig. 2b. This reservoir is a small reservoir of a nuclear power plant (NPP) and serves as cooling impoundment. It is not subjected to natural stratification as the warm water discharged from the NPP develops an artificial stratification that occurs upstream as well as downstream from the discharge. An accidental radioactive release from the NPP discharge channel will flow by the epilimnion and the model to use is the one represented in Fig. 1a, where the total compartment volume is the epilimnion volume.

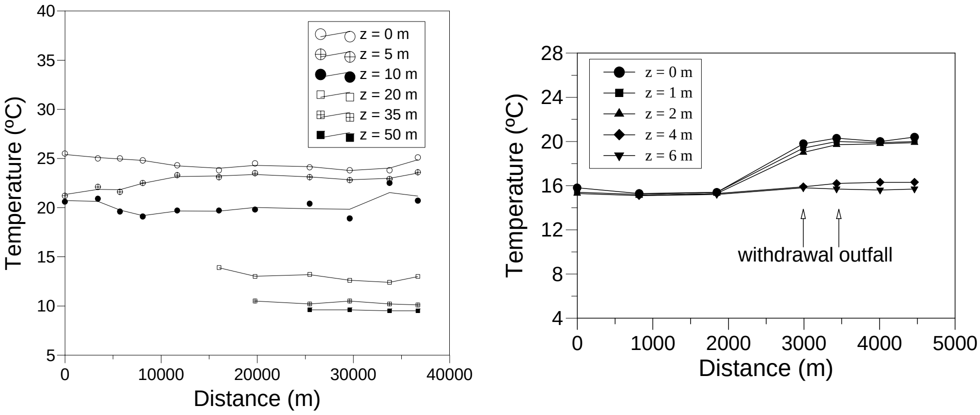

Fig.2. a) Stratified big reservoir (Entrepeñas).   b) Stratified small reservoir (Zorita)

The total number of compartments in the effective volume for dispersion must be known to solve numerically the model equations. *N* has been calculated by Eq. 2, which has been obtained by combining the dispersion and the tanks in series models proposed by Levenspiel (1979):

$$N = \frac{u_m^2 t_m}{2 D_L} \tag{2}$$

where u_m and t_m are the mean velocity and residence time of the water, respectively, and D_L is the longitudinal dispersion coefficient. The experimental determination of D_L for a reservoir can be made by means of either dye or radioactive tracers (Palancar, 2003, 2004, Lambert, 2006), from the heat balances (Palancar, 2006) and from the use of correlations (Palancar, 2003).

The volume of each compartment is calculated from the ratio between the effective volume for the dispersion and the number of compartments. The effective volume for the dispersion can be either the whole water, or the hypolimnion or epilimnion volumes. The effective volume for the dispersion is calculated by determination of the depth of the metalimnion from the stability frequency (Brunt-Väisälä frequency), Eq. 3, (Palancar, 2006).

$$N^2 = -\left(\frac{\partial \rho}{\partial z}\right)\frac{g}{\rho} \tag{3}$$

where ρ is water density, g, gravity acceleration and z, depth.

The water density profiles can be calculated from the experimental measures of electrical conductivity and temperature.

As an example, the stability frequency and density profiles obtained in the Zorita Hidráulica Reservoir are shown in Fig. 3. The maximum of stability establishes the metalimnion depth.

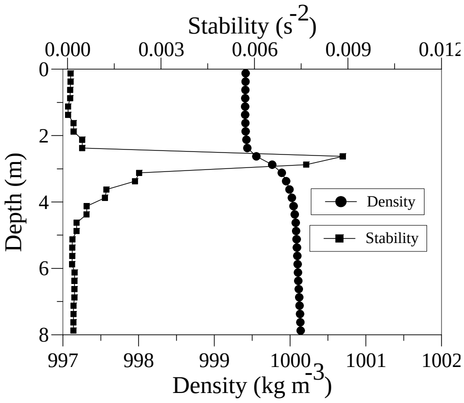

Fig. 3. Stability and density.

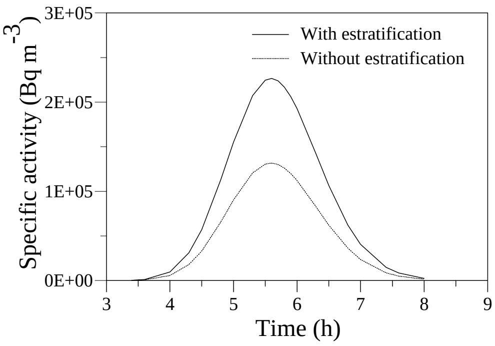

Fig. 4. Stratification in Zorita reservoir.

4. Results

The model equations are solved by the method of finite time increments. As an example, the simulation results obtained at a point near the Zorita Dam is shown in Fig. 4; the release assumed is a release of water containing tritium (H-3) with an activity of 3.7 10^{-10} Bq. It can be clearly seen from these results that the artificial stratification affects the specific activity. It is higher than the activity calculated with the assumption of no stratification. In this case, the artificial stratification affects not only the pollutant concentration but also the time necessary for the response to pass through a given section.

5. Conclusions

The profiles of water density and stability frequency can be calculated from the experimental electrical conductivity measures as well as from other complementary information (meteorological, hydrological and geometrical data). These profiles were used to characterize the water column structure. A box-type model, based on a series of uniform mixing compartments, has been successfully calibrated and applied. For subsequent applications of this type of models an experimental characterization must be made to determine several properties of the reservoir.

Acknowledgements

The study has been carried out with financial support from the Spanish Nuclear Safety Council (CSN, *Consejo de Seguridad Nuclear*).

References

Lambert, P., Palancar, M. C., Aragón, J. M. and Gil, R., 2006, Determining the dispersion characteristics of rivers from the frequency response of the system, Water Res. Res., 42, 9, wo9414.

Levenspiel, O., 1979, The chemical reactor omnibook, OSU Book Stores, Corvallis (OR), (Chapter 66).

Palancar, M. C., Aragón, J.M., Sánchez, F. and Gil, R., 2003, The determination of longitudinal dispersion coefficients in rivers, Water Envir. Res., 75, 324-335.

Palancar, M. C., Aragón, J.M., Sánchez, F. and Gil, R., 2006, Effects of warm water waste on the dispersion of pollutants in small reservoirs, J. Env. Mang., 81, 210-222.

Wise, B., U, Palancar, M. C., Aragón, J.M., Sánchez, F. and Gil, R., 2006, Modelling the Entrepeñas Reservoir, Water Env. Res., 78, 781-791.