Hydrodynamic behaviour and faecal coliform removal in a maturation pond

F. Brissaud*, V. Lazarova, C. Ducoup**, C. Joseph*, B. Levine** and M.G. Tournoud***

* UMR Hydrosciences CNRS - Université Montpellier II, 34095 Montpellier Cedex 05, France

** CIRSEE, Suez Lyonnaise des Eaux, 38 rue du Président Wilson, 78230, Le Pecq, France

Abstract A tracer test was performed in a 3,000 m^3 and 1 m deep maturation pond located in the south of France. A retention time distribution was determined on the basis of tracer study. Tracer distribution into the pond was also monitored. Physico-chemical parameters and faecal coliform contents were measured at pond inlet and outlet and at 4 points in the pond. During the same period, two 20 m^3 and 1 m deep pilot pools were set close to the pond and filled with inlet water. A die-off constant was calculated after the variations of feacal coliform contents observed in the pilot pools. The objective was to verify whether faecal coliform removal can be predicted from observed retention time distribution, assuming a first-order faecal coliform decay with a die-off constant determined in pilot pools. A very good prediction was achieved despite some uncertainties in the experimental data mainly due to pond operation and climatic conditions.

Keywords Waste stabilization pond; retention time; tracer; die-off rate; faecal coliform removal

Introduction

In France, waste stabilization ponds are commonly used to treat wastewater from small communities (Racault *et al*., 1995). In addition, lagooning is the favourite tertiary treatment prior to the wastewater reuse for agricultural purposes in France (Faby *et al*., 1999) and Mediterranean countries. The development of these processes for wastewater reuse applications and the protection of bathing waters and shellfish breeding areas will depend on the capability of this technology to comply with health regulations and the requirements of local representatives of the Ministry of Health. Thus, valuable predictions of the microbiological performances of tertiary lagooning must be provided.

Retention time together with solar radiation and/or temperature are the most important factors which influence lagooning performance with respect to the removal of pathogenic microorganisms (Mezrioui, 1987, Frederick and Lloyd, 1996). Prediction methods which are currently used rely on dispersed plug-flow or completely mixed reactor models and a simple exponential relationship between die-off of microorganisms and water retention time. The model of Marais (1974) has been extensively used. It derives from a first-order complete-mixing approach and links the die-off rate constant to the temperature. The dispersed plug-flow model is also widely used. The main parameter, the Peclet number, depends on pond geometry, axial dispersion and flow rate.

Several tracer tests have been performed by Racault *et al*. (1984), Marecos do Monte and Mara (1987), Nameche and Vasel (1998) and others. Many experiments on ponds having a length/width ratio less than 8 fit the complete mixing model fairly well. However, as shown by Frederick and Lloyd (1996), short-circuits may occur before the complete mixing of the tracer in the pond. This phenomenon, mainly due to the wind, can significantly reduce microorganism removal. Nameche and Vasel (1998), who proposed several formulae to predict the Peclet number, stressed that carrying on tracer experiments over a wide range of ponds with different geometry, size and depth is still necessary for model calibration. Tests may also lead to better understanding of the influence of pond geometry, wind and temperature on pond hydraulic patterns.

Water Science and Technology **Vol 42 Nos 10–11 pp 119–126** © IWA Publishing 2000

Values of coliform die-off constant given in the literature vary within a large range, from 0.2 to 12 days^{-1}, depending on water depth, temperature, solar radiation, organic load and the hydraulic model. For this reason, experimental studies are also recommended in order to enhance model precision for given local conditions.

Tracer tests were performed in a lagoon located close to Montpellier in the south of France during the summer of 1998. Die-off constants were measured separately in two pilot ponds. The objective was to verify whether faecal coliform removal can be predicted from measured retention time distribution, assuming a first-order faecal coliform decay with a die-off constant determined experimentally.

Materials and methods

The Murviel les Montpellier wastewater treatment plant consist of a series of 3 ponds, the total surface and volume of which are equal to 14,000 m^2 and 21,000 m^3. Treated wastewater will be reused for the irrigation of a local vineyard. Moreover, the ponds may serve as a storage reservoirs, in order to increase the volume of water that will be available during the summer season. The plant was designed for a daily flow rate of 250 m^3/d, but the actual mean sewage flow in the inlet of pond n°1 for the study period was only 90 m^3/d, so that second and third basins acted as maturation ponds. The flow rate was monitored at the inlet of pond n°1 and the outlet of pond n°3.

Experiments were performed in pond n°2 with a surface area of 3310 m^2 and a mean depth of 1.0 m. The bottom topography was determined and the calculated volume equal to 3,025 m^3. Due to high evaporation, the flow rate in pond n°2 was less than 40 m^3/d. For the tracer study, the pond was divided into a physical grid by means of wires stretched at 1.5 m above the water surface, enabling to fix 60 sampling points (Figure 1).

The tracer, $NaI.2H_2O$, diluted to a 1.3 g/l concentration in the effluent of pond n°1, was injected in pond n°2 inlet, near the bottom of the lagoon. 1.5 kg of NaI was introduced during the 2.5 hours injection. Iodine concentration was measured with a specific electrode. Tracer concentration was monitored at pond n°2 outlet for two months and into the pond during the first three weeks after the tracer injection. Water samples were taken at the grid nodes, at the surface, mid-height and the bottom of the water column. Samples were taken from a boat moved by pulling on the wires.

Water temperature was measured at 6 nodes, at the surface, mid-height and the bottom. Wind speed and direction were recorded for the experiment period.

Inlet and outlet water quality was analyzed at regular time intervals for electric conduc-

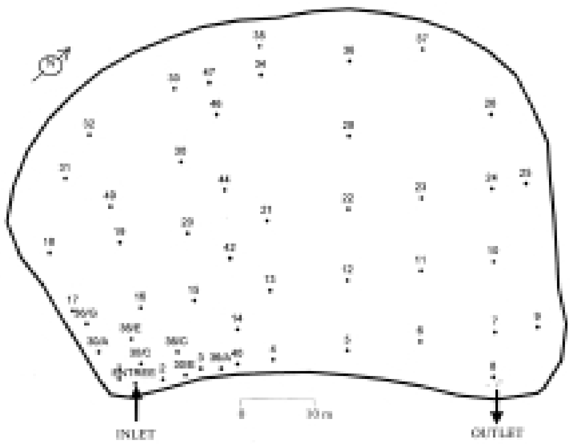

Figure 1 Pond layout showing the sampling grid nodes

tivity, pH, dissolved oxygen, SS, COD, TOC, NK, $N\text{-}NH_4$, $N\text{-}NO_3$ concentrations, faecal and total coliforms, *Escherichia coli*. and bacteriophages. Analyses of water sampled at 4 points located in the middle of every quarter of the lagoon, at the surface, mid-height and the bottom of the water column, were also performed.

On-site kinetic study was carried out using two pilot pools of 20 m^3 each and 1 m deep, filled up with lagoon influent. Temperature, electric conductivity, pH, dissolved oxygen, turbidity, and feacal coliform contents were measured at the surface and the bottom of the ponds.

Results

Residence time distribution

Iodine concentration at pond n°2 outlet are reported (Figure 2), in parallel with wind velocity. Despite the low flow rate and low wind velocity, the tracer reached the outlet, 60 m away, only 15 hours after injection. Two to three days after the tracer injection (62 hours), the concentration in the lagoon outlet reached the maximum value of about 0.42 mg/l. This value corresponds to complete mixing of the tracer in the pond. Afterwards the concentration slowly decreased for two months. A water residence time distribution (RTD) was deduced from the concentration curve, assuming a constant flow rate.

Besides this global evolution of the outlet concentration curve, rapid variations of the concentration must be noticed. They result from the unsteady hydraulic behavior of the pond. Sharp concentration peaks were observed at the outlet, sometimes after a windy period. Such phenomena are specific to the lagoons and have been reported in the literature (Marecos do Monte and Mara, 1987, Racault *et al.*, 1984). However, no direct relationship between wind velocity and concentration peaks could be found. This means that other parameters, such as wind direction and water temperature distribution into the pond, should be taken into account in order to better explain the tracer behavior.

The analysis of the tracer distribution in the different sampling points confirmed the rapid water mixing in the studied pond (Figure 3). The results illustrate the variations of the iodine concentration after 1 and 3 days residence time at 3 water depths (surface, mid-depth and bottom). The tracer was injected on July 22nd at 3 p.m. On July 23rd, samples in the left side of the lagoon were taken in the morning and those in the right side in the afternoon; on July 25th, all samples were taken in the morning. The space distribution of iodine concentrations at the surface and at mid-height was roughly homogeneous throughout the pond. The values, measured at mid-height were close to the ones at the surface in the limits of

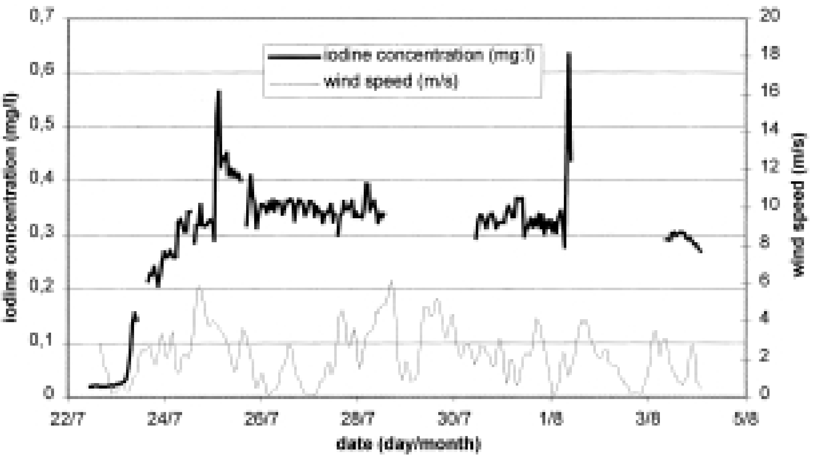

Figure 2 Tracer outlet concentration and wind speed for the first two weeks of the experiment

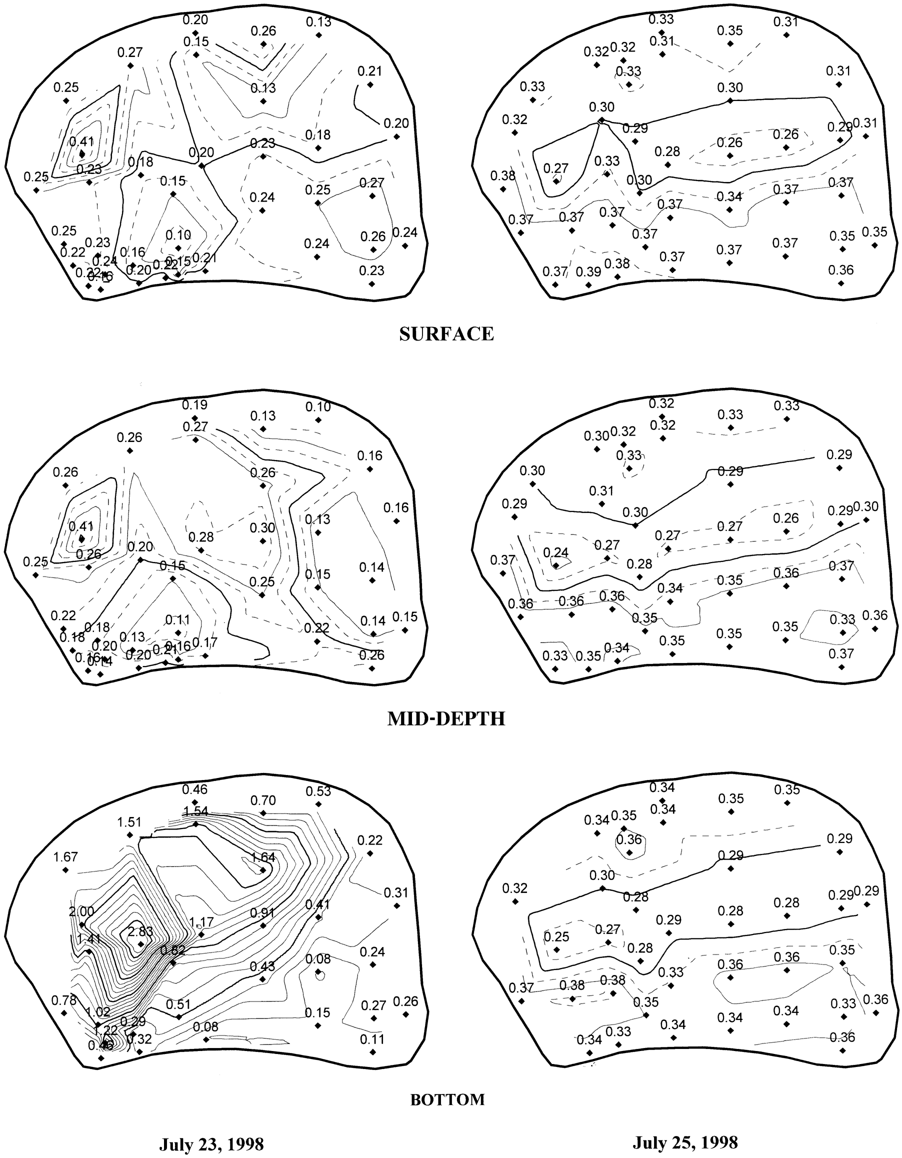

Figure 3 Iodine concentration distribution in pond n°2

0.13-0.27 mg/l and 0.24-0.39 mg/l for July 23rd and 25th, respectively. However, it is important to stress that significantly higher values were detected at the bottom of the lagoon, especially on July 23rd. The highest iodine concentrations were measured near the inlet on the right side of the pond. On July 25th, this phenomenon was not observed: concentrations were rather homogeneous, whatever the sampling depth (Figure 3, bottom, right side). A couple of days later, high iodine concentrations were observed again, indicating that a dense water layer with high saline concentration was still moving in the bottom of the lagoon.

It can been concluded that the mixing in the pond is very fast, despite the existence of a thin and discontinuous high concentration layer which may remain at the bottom of the pond for several days. When this moving layer reaches the lagoon outlet, high iodine concentrations can be observed. This phenomenon could explain some of the high iodine peaks

Table 1 Pond water quality

	SS (mg/l)	COD (mg/l)	NK (mg/l)	pH	O2 (mg/l)	Turb (NTU)	Faec. Col. /100 ml
Inlet	146	460	44	8.14	4.7	165	3.6×10^6
Outlet	224	440	30	9.1	6.4	146	2.7×10^4

observed during this experience (see Figure 2). The assumption of the persistence of a bottom high concentration layer may also be supported by the temperature profiles. Temperature distribution varied in time, but almost all the time most remained, lower in the bottom than at the surface.

Pond water quality

Table 1 illustrates the lagoon water quality on the basis of one mean daily value. Six samples were collected at 4 hour intervals and analyzed separately to calculate the mean value. A good carbon and nitrogen removal efficiency were observed. The high COD and SS concentrations in the lagoon outlet are due to the algae present.

Faecal coliform contents were characterized by high variations along the experiment. The average disinfection efficiency was 1.7 log removal of feacal coliforms with a maximum value of 2.82 [$\log_{10}(N_{inlet}/N_{outlet})$ with N a coliform content]. The results of the samples taken in different locations in the lagoon at mid-height and the surface showed no significant difference in coliform contents and were close to the values measured in the lagoon outlet. This homogenous coliform distribution could be a consequence of the rapid mixing in the pond. However, in most cases, higher coliform concentrations were observed at the bottom of the lagoon.

Determination of die-off constant

Samples were taken at 9 a.m. every five days, at the surface and the bottom of the two pools, during 3 weeks, from July 23rd to August 11th. The two pools behave very similarly. Surface and bottom temperatures happened to differ but not always in the same way. No durable stratification was observed. The mean water quality values are reported in Table 2. Although pH had small variations, turbidity and dissolved oxygen content were not steady along the time. The most noticeable variation was the decrease of dissolved oxygen. Mean values of SS content, COD and NK concentration measured at the end of the test were equal to 130, 370 and 22 mg/l, respectively.

Discussion

The main objective of the work was to determine whether experimental residence time distribution (RTD) and the die-off constant measured in pilot pools allow a good prediction of bacteria removal in wastewater maturation ponds. The prediction was better than expected.

Table 2 Water quality in the experimental pools for determination of die-off constant

Date (month/day)	7/23	7/24	7/28	7/31	8/4	8/7
pH	8.99	9.06	9.12	9.11	8.99	9.05
Turbidity (NTU)	121	110	127	147	147	98
O_2 (mg/l)	12.4	9.7	4.9	2.9	1.2	2.3

Faecal coliform content decay fitted reasonably well a first-order kinetic until August 6th (Figure 4) and the corresponding die-off constant was approximately equal to 0.6 day^{-1}.

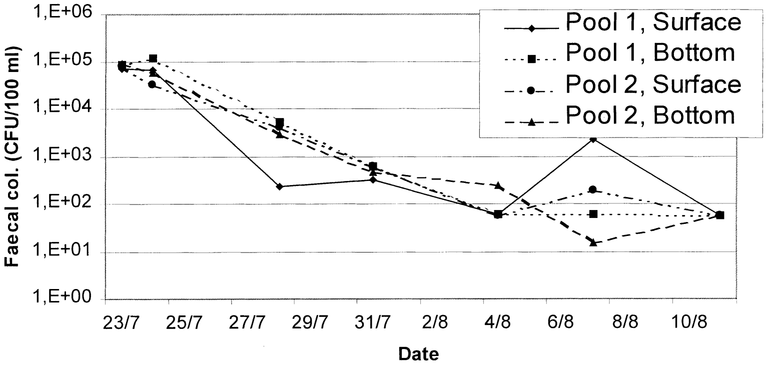

Figure 4 Faecal coliform decay observed at the surface and the bottom of the two pilot ponds

Assuming a constant flow rate, RTD can be written as a function of time t:

$$E(t) = C(t) / \left[\int_0^\infty C(t)dt \right]$$

where C is the tracer concentration. Then the outlet faecal coliform content could be calculated as:

$$N_{\text{outlet}} = N_{\text{inlet}} \int_0^\theta e^{-kt} E(t)dt$$

and the removal, $\log_{10}(N_{\text{inlet}}/N_{\text{outlet}})$, was deduced and surprisingly found to be equal to 1.7 log units, which is the mean value deduced from faecal coliform concentrations measured at the full-scale operating conditions.

This result is somewhat fortuitous for several reasons. The first one is the important uncertainties in the evaluation of the experimental removal which result of the fluctuations of inlet and outlet coliform contents as a consequence of flow rate and climatic changes along the weeks preceding the experiment. A second reason is that RTD may depend on climatic conditions. Short detention times, that greatly influence the performance, are related to wind velocity and direction, parameters which fluctuated during the experiment.

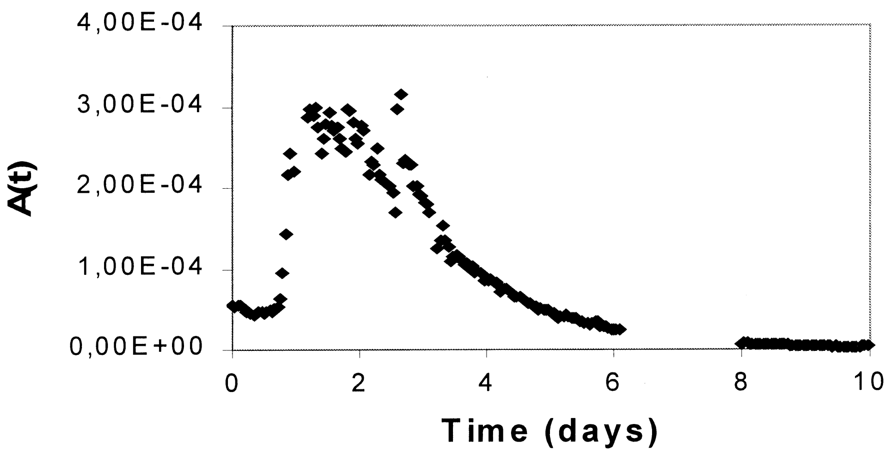

Figure 5 *A(t)* function

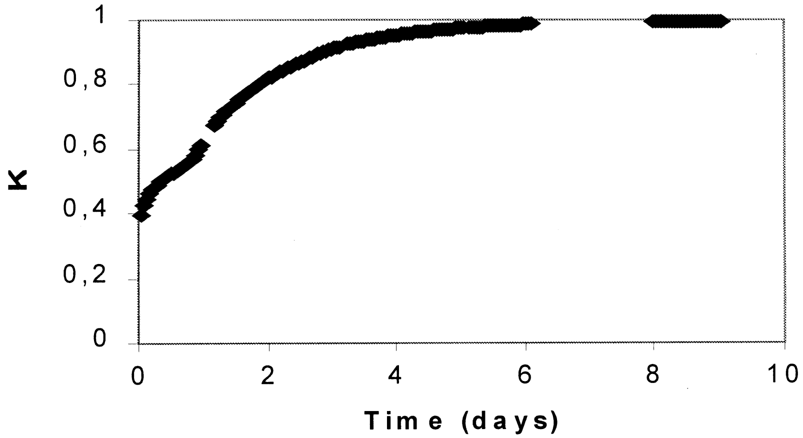

Figure 6 Removal prediction and duration of the tracer concentration monitoring

Another reason is the difference in the water quality of the pond and the pilot pools : the most noticeable evidence of this difference is the decrease of dissolved oxygen content (Table 2). The assumption of a constant flow rate is also an approximation.

Tracer experiments are often considered lengthy and costly, so that few such studies have been undertaken. This study helps demonstrating that long duration of tracer tests is not always necessary. Figure 5 shows that the function

$$A(t) = e^{-kt} E(t)$$

became negligible 8 days after the tracer injection. Thus, water of detention time higher than 8 days did not influence the faecal coliform removal.

The faecal coliform removal is calculated as $\log_{10} (N_{inlet/}N_{outlet}) = \log_{10} B(\infty)$, with

$$B(t) = \int_{0}^{\theta} e^{-kt} E(t) dt$$

The ratio $\log_{10} K = B(\infty)/\log_{10} B(t)$ was calculated as a function of time (Figure 6) in order to evaluate the error that would have been committed when stopping the tracer experiment at time t. Figure 6 shows that a valuable determination of the removal can be obtained when limiting the duration of the tracer monitoring to 6 days.

Though the fitting of observed and calculated faecal coliform removals was very promising, further investigation should be undertaken in order to check our findings. Tracer tests will be performed for different climatic conditions. Die-off constant will be measured in pilot pools at different seasons and different water depths. The aim is to be able to predict the bateriological quality of the effluent of a stabilization pond operated in the same time as a maturation pond and storage for summer irrigation.

References

Faby, J.A., Brissaud, F. and Bontoux, J. (1999). Wastewater reuse in France: water quality standards and wastewater treatment technologies. *Wat. Sci. Tech.*, **40**(4–5), 37–42.

Frederick, G.L. and Lloyd, B.J. (1996). An evaluation of retention time and short-circuiting in waste stabilisation ponds using *Serratia Marcesens* bacteriophage as a tracer. *Wat. Sci. Tech.*. **33**(7):49-56.

Marais, G. v R. (1974). Faecal bacterial kinetics in stabilization ponds. *J. Envir. Eng. Div., A.S.C.E.*, **100** EE1, 119-139.

Marecos, do Monte M.H. and Mara, D.D. (1987). The hydraulic performance of waste stabilization ponds in Portugal. *Wat. Sci. Tech.*, **19**(12):219-227.

Mezrioui, N. (1987). Etude expérimentale des effets du pH, du rayonnement et de la température sur la disparition des bactéries d'intérêt sanitaire et évaluation de la résistance aux antibiotiques d'*E. coli* lors de l'épuration des eaux usées. Doctoral Thesis. Montpellier: Université Montpellier II.

Nameche, T. and Vasel, J.L. (1998). Hydrodynamic studies and modelization for aerated lagoons and waste stabilization ponds. *Wat. Res.* **32**(10):3039-3045.

Racault, T., Boutin, P. and Douat, J. (1984). Etude par traçage du comportement hydraulique d'une lagune d'épuration: influence de la géométrie du bassin. *Rev. Sci. Eau* **3**, 197-218.

Racault, Y., Boutin, C. and Seguin, A. (1995). Waste stabilization ponds in France: a report of fifteen years experience. *Wat. Sci. Tech.* **31**(12):91-101.