PLUG FLOW CAN BE INDUCED IN MATURATION PONDS BY INCREASING THE L/W RATIO.

N. R. Bracho[**], B. Lloyd[*] and G. J Aldana**

**Centre for Environmental Health Engineering (CEHE), University of Surrey, Guildford, Surrey, GU2 7XH, England.* [**]*Centro de Investigación del Agua. Facultad de Ingeniería. Universidad del Zulia, Venezuela.*
(E-Mail: nibisbracho@hotmail.com and B.Lloyd@surrey.ac.uk)

ABSTRACT

This research evaluates the influence of hydraulic flow characteristics on mixing maturation ponds into conventional and channel lagoons, bearing in mind the critical information needed for engineering design.The study was carried out in tertiary treatment on three maturation ponds after conventional sewage treatment plant, located in Southern England. Five dye-tracer tests with Rhodamine WT were developed for different average flow in the two conventional ponds (L/W 9:1) and in the channel pond (L/W 79:1). Dispersion can be minimised from completely mixing to disperse flow (d=0.37) in open lagoons when they operate with 9 and 4.5 l/s respectively, while in the channel lagoon the dispersion numbers were 0.074 for 4.5 l/s and 0.042 for 6 l/s. In this case, was observed that dispersion is affected by wind direction, in spite of obtaining less dispersion for the test of 6 l/s. The retention time in the channel lagoon was 5 hours longer than the open lagoon with both operating at a similar flow rate (4.5 l/s). It studies reveal the type of flow is governed by the L/W ratio and flow rate. Plug flow may be induced by designing pond with channel ó baffles.

KEY WORDS: Plug flow, Rhodamine WT, dispersion number, L/W configuration, waste stabilisation ponds.

INTRODUCTION.

In terms of wastewater efficiencies, hydraulic behaviour plays an important role, as was demonstrated by Camp (1946). Some consideration has been given to the gross flow patterns within these stabilisation ponds as affected by pond shape, the presence of dead spaces and short-circuiting (Aldana *et al.,* 1999; Lloyd *et al.,* 2002). These hydraulic flow characteristics will obviously have an effect on the dispersion of the waste as well as on the hydraulic mean retention time for the waste particles and, consequently, ultimately on pathogenic organism removal efficiency (Bracho *et al.,* 2006). This research evaluates the influence of hydraulic flow characteristics on mixing maturation ponds into conventional and channel lagoons, bearing in mind the critical information needed for engineering design.

The ideal situation for flow through a waste stabilization pond is typified by plug flow. This has been recognised by (Camp, 1946; Mongelson and Watters (1972); James (1987), Juanico (1991), Muttamara and Puetpaiboon (1997), Vorkas, 1999; Frederick, 1995 and Lloyd *et al.,* 2002). According to Mongelson and Watters (1972) "… *if the incoming waste mixes vertically and horizontally just enough to obtain good treatment and then moves through the pond as a slug, the optimum condition, called* ***plug flow****, has been realized".*

Thackston (1987) and Lloyd *et al.* (2002) suggests the introduction of baffles to improve the L/W ratio reduce wind-induced short circuits and dead spaces.

Plug flow can be induced in stabilisation ponds by increasing the L/W ratio, with engineering intervention to install baffle or channels. The construction of a channel lagoon is a cost-effective alternative to tertiary maturation ponds after a conventional plant in Lidsey sewage treatment plant, but investigation and post-evaluation of system design is required if they are expected to operate properly. A hydraulic evaluation, including hydraulic retention time and dispersion number of the open and channel lagoon must also be made with tracer studies (dye tracer). This engineering design is the optimum for maximising retention time and, consequently, FC removal (Mongelson and Watters, 1972; Vorkas, 1999 and Lloyd *et al.,* 2002; Bracho, 2003 and Bracho *et al*., 2006).

Mangelson and Watters (1972) and Saenz (1986) have made contributions with respect to the importance of the Reynolds number in WSPs. Mangelson and Watters showed that the efficiency of treatment is greater when the Reynolds number decreases, because dead spaces are reduced. The Reynolds number may be obtained empirically in the Lidsey maturation ponds.

Brief description of the treatment system selected for study.

Lidsey sewage treatment plant is located in the agricultural coastal zone of West Sussex in Southern England. It consists of a conventional treatment plant with tertiary treatment by three parallel maturation ponds of similar geometry and dimensions. These were termed the open lagoon for North and Central lagoon (122mx13.5m and 122mx14.5m) and channel lagoons for South (3 channels of 122mx4.65m).

METHODS.

Tracer study.

Five tracer tests were developed: two in the channel lagoon (South) and three in the conventional or open lagoon (North and Central). One of the experiments in North and South were run under the same flow condition, which enabled validation of the effect the L/W ratio has on hydraulic behaviour (short-circuiting, retention time, dispersion number). Also, wind speed and direction monitoring on the field in portable meteorological station.

The Rhodamine WT was injected into the outlet by impulse signal and detected at the outlet with an on-line fluorimeter at intervals of 5 minutes over period of 5 days.

The distribution of the residence time of a tracer is represented by the "age distribution curve". If the age distribution curve refers to uniform time interval values, the centre of gravity of the curve, which defines mean hydraulic retention time, may be calculated with the equation (1)**,** Levenspiel (1962).

$$tm = \frac{\sum t_i C_1}{\sum C_1} \qquad (1)$$

Where: tm = mean hydraulic retention time,

C_i = tracer concentration.

t_i = tracer concentration measured at time "t".

The second important mathematical concept is the dispersion of the curve, normally known as variance concept σ^2. For uniform time interval values, variance may be calculated by the equation (2).

$$\sigma^2 = \frac{\sum t_i^2 C_i}{\sum C_i} - \left[\frac{\sum t_i . C_i}{\sum C_i}\right]^2 \qquad (2)$$

$$\sigma t^2 = \frac{\sigma^2}{tm^2} = 2d - 2d^2\left[1 - e^{-\frac{1}{d}}\right] \qquad (3)$$

in which:

σ^2 = residence time variance,

σt = residence time adimensional variance

tm = mean hydraulic residence time,

C_i = Rhodamine concentration.

d = dispersion number.

An Excel spread sheet was used to process the data. The fluorimeter registered data of between 6000 and 7000 values for each experiment.

Calculating the Reynolds number.

Stabilisation ponds are usually rectangular in shape and the Reynolds number can be defined by equation 4 Chow (1959). This is similar to the equation $\mathrm{Re} = \frac{4LWZ}{(W + 2Z)tm\,v}$ produced by Polprasert and Bhattarai, (1985), but, without a factor 4 in the expression. It should be noted that the hydraulic retention time of a pipe is equivalent to D/4 (which is obtained by dividing the area of the pipe by its perimeter). Based on the analogy of pipe systems, for a pond a factor of 4 is introduced by Polprasert and Bhattarai, (1985) in their equation. The Reynolds number is an indicator of turbulence within a reactor. It follows that completely mixed ponds should have high values whereas plug flow channels should have low value. Equation 4 will be used to obtain the Reynolds number in the present research.

$$\mathrm{Re} = \frac{LWZ}{(W+2Z)tm\nu} \qquad (4)$$

Where:

L = Channel length (in the case of rectangular lagoons, length of lagoon).
W = width of lagoon or channel.
Z = lagoon depth.
tm = hydraulic retention time.
ν = Kinematics viscosity (1.14 x 10^{-6} m^2/s).

RESULTS

Channel lagoon (South): Tests one and two for 4.5 and 6.0 l/s.

The sludge was removed from the South lagoon before started the tracer study The flow type in the South lagoon are approaching plug flow, with a dispersion number 'd' = 0.074 and 0.042 respectively (Figures 1 and 2). Many researchers have said plug flow is impossible to obtain at full scale (Polprasert and Bhattarai 1985; Thackston *et al.,* 1987; Agunwamba *et al.,* 1992; Yanez 1993), but this was almost achieved in Lidsey using L/W ratio = 79:1.

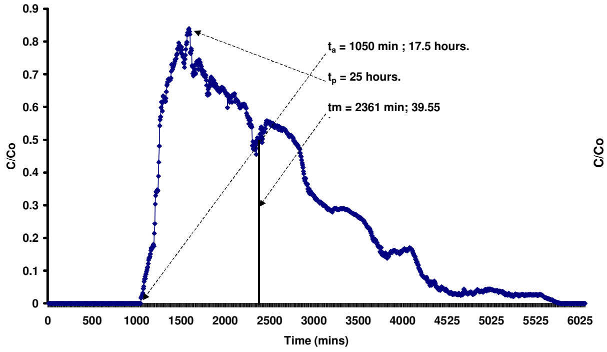

Figure 1. Non – dimensional plot of Rhodamine WT against time South lagoon (Q = 4.5 l/s).

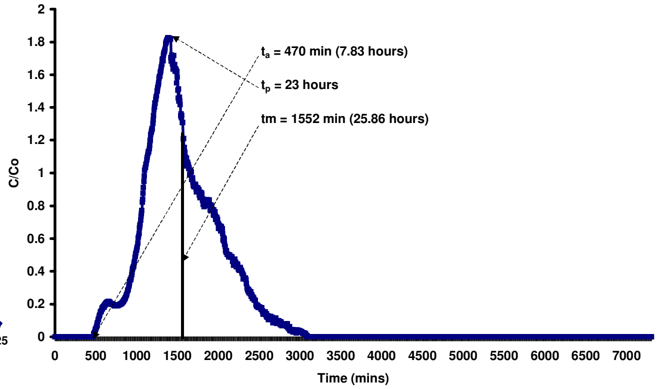

Figure 2. Non – dimensional plot of Rhodamine WT against time South lagoon .(Q = 6 l/s)

The tracer began to arrive t_a = 17.5 h and ta = 7.83 hours after injection, reaching maximum concentration peak t_p = 25 and tp = 23.33 hours after the experiment were begun. The mean hydraulic retention time were 39.55 and 25.86 hours (Figures 1 and 2) for a 4.5 and 6-l/s flow, about 14 hours different. The first tracer study was done with wind southerly direction and the prevailing wind was blowing SSW for a last experiment However, it was observed that dispersion is affected by wind direction, in spite of obtaining a more symmetrical curve with less dispersion than first test.

Open lagoon (North): Tests three and four for 4.5 and 7.9 l/s.

The tracer study carried out with wind direction contrary to flow direction (West wind).

The dye tracer got to the outlet 2 hours 55 minutes with the maximum peak 21 hours for a test three (Figure 3), while for a test four, the tracer arrived with a t_a = 30 minutes (0.5 hours) (see Figure 4), ie, approximately 2 hours earlier than test 3 developed (see Figure 3 y 4). In other words, this short circuit occurred more quickly. Furthermore, maximum peak concentration reaches t_p = 1.92 hours after injection and the flow pattern changed from dispersed to completely mixed when the flow rate change from 4.5 to 7.92 l/s.

If we compare Test 3 (Figure 3) with Test 1 in the channel lagoon (Figure 1), it can be easily seen that the channels delayed the jet flow by approximately 15 hours, and reduction of this type of short circuit. Another, the dispersion number this time was d = 0.37, whereas in the channel lagoon, a dispersion number d = 0.074 was obtained for a flow similar to the one for this test (4.5 l/s).

It is evident that drastic variations of flow rate and short-circuiting are generated when the L/W ratio is low (9:1 in North and Central lagoon). This occurs to a much lesser degree when the L/W ratio is equal to 79:1 (South lagoon).

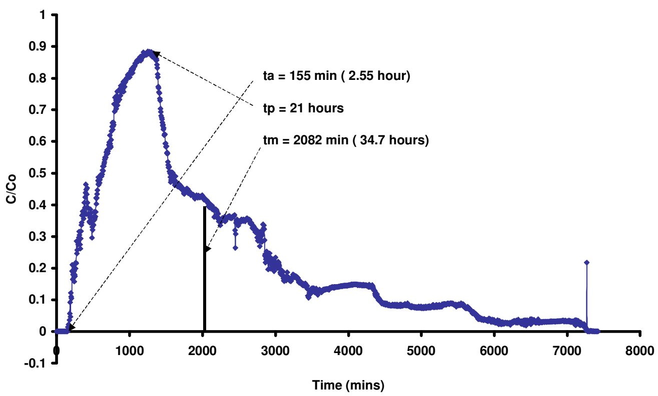

Figure 3. Non – dimensional plot of Rhodamine WT against time in the North lagoon. (Q = 4.5 l/s).

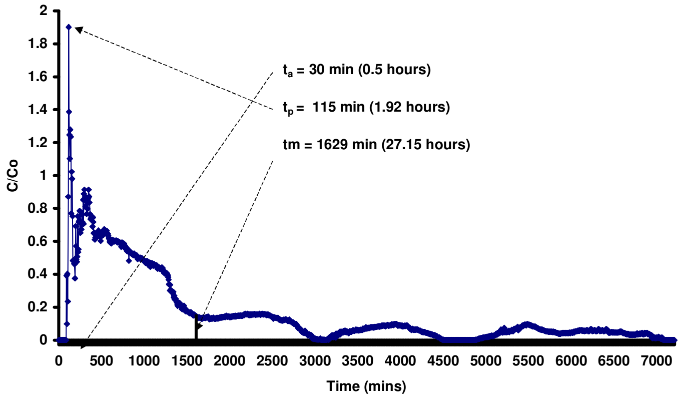

Figure 4. Non – dimensional plot of Rhodamine WT against time in the North lagoon.(Q = 7.9 l/s).

Open lagoon (Central): *Test five for 9.0 l/s.*

In this case, the prevailing winds from the South direction. The dye tracer was mixed much more violently than in the channel lagoon, but it not mixed homogeneously and, the wind exerts a significant effect on the trajectory of the fluid. The plume travelled at high speed down the centre towards the outlet. It moved quickly along the first 30 metres, with speed drastically reduced at between 60 and 70, then again increasing speed between 70 and 122 m (see Table 1). The dye tracer moved from inlet to outlet at an average rate of 0.02 m/s (1.2 m/min) similar to the drogue study (Bracho and Aldana, 2006).

Table 1. Relative surface velocity of the dye tracer in the Central lagoon.

Time	Distance travelled	Relative surface velocity of tracer
(minutes)	(m)	(m/s)
15	30	0.0333 between 0 and 30 m
45	60	0.0167 between 30 and 60 m
70	70	0.0067 between 60 and 70 m
105	122	0.0248 between 70 and 122 m

It is important to point out that the information in Table 1 was recorded visually, so there is a 27-minute disparity between the visual record and the on-line fluorimeter, caused by the dilution of, the dye tracer in the plume. When the samples are taken manually at intervals of, say, 15 minutes or more, errors in precision occur when the flow arrives and when the maximum peak occurs, which may be displaced to the right of the graph.

If these results are compared with those of the channel lagoon, it can be seen that the tracer exits more slowly from the channel lagoon. The main idea is to prevent the flow from coming out as a jet, because if the maximum concentration exits in a little over an hour, t_a=1.36 hours (Figure 5); it means that some of the water entering the lagoon is leaving without treatment. The important factor behind producing plug flow with channels in a maturation pond is to reduce short-circuiting (jet-flow), to increase retention time and, consequently to improve the bacteriological treatment in the maturation pond (Bracho *et al.,* 2006).

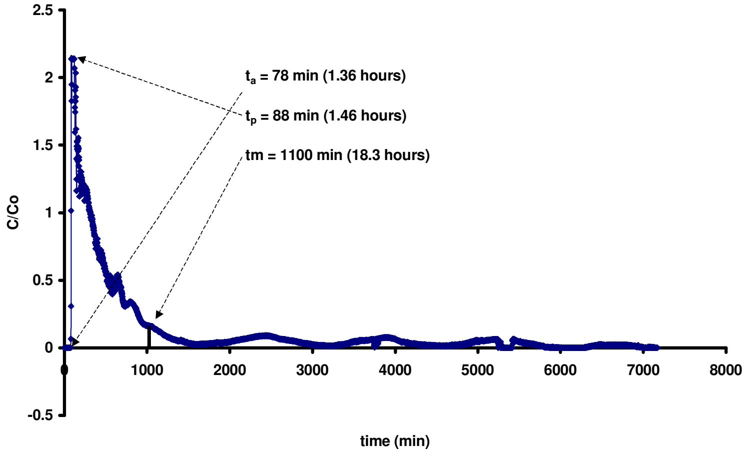

Figure 5. Non-dimensional plot of Rhodamine WT against time in the Central lagoon. (Q = 9 l/s).

Calculating the Reynolds number.

The results presented in Table 2 indicate that all the lagoons were operating under transitional flow conditions (between 500 to 2000), but show that the South lagoon (channel lagoon) had the lowest

Reynolds number. According to Saenz (1986), lagoons that produce the best treatment are those that operate under laminar flow conditions.

The Reynolds number decreases as the flow decreases, but that the Reynolds number for the South lagoon (channel lagoon), with a flow of 4.5 l/s, was 557 very close to the laminar flow, whereas that of the North lagoon (open lagoon) was greater than 744. This means that laminar flow can be obtained in the South lagoon with very low flow rates, perhaps less than 4.5 l/s. This implies an increase in retention time, so it is difficult to conclude that the Reynolds number has a direct implication for treatment, but it could be an indirect implication. Besides, there is very little information on this topic, whereas there exists sufficient information, at pilot-scale and full-scale in which it is shown that retention time is increased when the L/W ratio is increased and, consequently, contaminant removal (Kilani and Ogunrombi, 1984; Muttmara and Puetpaiboon, 1997; Lloyd *et al.,* 2002; Bracho, 2003; Bracho *et.al.,* 2006 a,b). This actually coincides with the results of this investigation.

Table 2. Calculations for obtaining the Reynolds number using the Chow (1959) equation.

Lagoon	Length	Width	Depth	Flow	tm	(LWZ)	(W+2Z)tmν	Reynolds number
	L (m)	W(m)	Z (m)	(l/s)	(s)			
South	122	4.65	1.1	4.5	143,424	624	1.12	557
Central	122	14.5	1.0	9.0	66,268	1769	1.25	1419
North	122	13.5	1.0	4.5	125,280	1647	2.21	744
South	122	4.65	1.1	6.0	92,448	624	0.72	864
North	122	13.5	1.0	7.92	97,632	1647	1.73	954

$\nu = 1\text{x}10^{-6}\ m^2/s$

CONCLUSION

The type of flow is governed by the L/W ratio and flow rate. Therefore plug flow may be induced by designing pond with channel ó baffles; because the dispersion number may be reduced up to 89% by modifying the L/W ratio from 9:1 to 79:1 and Reynolds number was change from 744 to 557, ie, 25%. Dispersion can be minimised in open lagoons when they operate with low flow.

REFERENCE

Aldana, G., Bracho, N. and Esteves, J. (1999) Hydraulic parameters analysis in facultative ponds. *J. Revista Técnica de Ingenieria. Universidad del Zulia*. Vol. 22, No. 2, pp. 106-117.

Bracho N.R. (2003). Optimisation of faecal coliform removal performance in three tertiary maturation ponds. PhD thesis. University of Surrey.

Bracho N.R, Lloyd B., and Aldana G.J. (2006a). Optimisation of hydraulic performance to maximize faecal coliform removal in maturation ponds. *Water Research*. Vol.40, No.8, pp 1677-1685

Bracho N.R, Lloyd B., and Aldana G.J. (2006b). Rehabilitación de una laguna de maduración utilizando bafles Revista Ciencia de La Universidad del Zulia (LUZ). Vol. 14 número Especial pp 309-319.

Bracho N.R. and Aldana G.J. (2006). Determinación de la velocidad del fluido en las Lagunas de Maduración de Lidsey. Revista electrónica AIDIS de Ingeniería Sanitaria y Ciencias Ambientales Volumen 2.

Camp, T. (1946) Sedimentation and the design of settling tanks. *ASCE,* Vol. 111, pp. 895-958.

James, A. (1987) An alternative approach to design of waste stabilisation ponds. *Wat. Sci. Tech.* Vol. 19, No. 12, pp.213-218.

Juanico, M. (1991) Should waste stabilization ponds be designed for perfect-mixing or plug-flow? *Wat. Sci. Tech.* Vol. 23, Kyoto. pp. 1495-1502.

Kilani, J. S. and Ogunrombi, J.A. (1984). Effects of baffles on the performance of model waste stabilization ponds. *Water Research.* Vol. 18. No. 8, pp. 941-944.

Lloyd, B., Vorkas, C. and Guganesharajah, K. (2002). Reducing hydraulic short-circuiting in maturation ponds to maximize pathogen removal using channels and wind breaks. *5th International IWA specialist conference on Waste stabilisation ponds. New Zealand.* Vol. 2, pp. 445-458. *Wat. Sci. Tech.* Vol. 48, (2), pp. 153-162.

Mangelson, K.A. **and Watters G.Z.** (1972). Treatment efficiency of waste stabilization ponds. *Proceeding of the American Society of Civil Engineers.* Vol. 98, N0. SA2, p.p. 407-425.

Muttamara, S. **and Puetpaiboon, U.** (1997) Roles of baffles in waste stabilisation ponds. *Wat. Sci. Tech.* Vol. 35, No.8, pp. 275-284.

Polprasert, C. and Bhattarai, K.K. (1985) Dispersion model for waste stabilisation ponds. *ASCE.* Vol.111, No.1, pp. 45-59.

Thackston, E., Shields, D. and Schroeder, P. (1987) Residence time distributions of shallow basins. *J. Env. Eng.* Vol. 113, No. 6, pp. 1319-1332.

Vorkas, C. (1999) Bacteriophage tracer in the identification of pathogen deficiencies in waste stabilisation ponds. PhD thesis. University of Surrey.

Watters, G., **Mangelson, K. and George, R.** (1973) The hydraulic of waste stabilization ponds. *Research report*; Utah Water Research Laboratory, College of Engineering, Utah State University; Utah, USA.

Wilson, J.F., Cobb, E.D. and Kilpatrick, F.A. (1986) Techniques of water-resources investigations of the United States Geological Survey. Chapter A12, Fluorimetric procedures for dye tracing. United States Government printing office, Washington.

Chow (1959) Open-channel hydraulic. McGraw Hill, London.

Frederick, G. (1995) The performance of full-scale waste stabilisation ponds treating saline wastewater with particular reference to bacteriophage as a hydraulic tracer. PhD Thesis. University of Surrey

Levenspiel, O. (1962) Chemical Reaction Engineering. John Wiley and Sons, New York. USA.

Vorkas, C. (1999) Bacteriophage tracer in the identification of pathogen deficiencies in waste stabilisation ponds. PhD thesis. University of Surrey.

Yánez, F. (1993) Lagunas de estabilización. Teoría diseño, evaluación y mantenimiento. Imprenta Monsalve. Cuenca-Ecuador.