7 WIND, AERATORS, MIXERS AND TEMPERATURE

What effect does wind, aerators/mixers and temperature have on the flow pattern in a pond?

7.1 Introduction to Wind Effects

It is generally believed that wind provides a positive influence on ponds. This is because of the perceived improvement in aeration and mixing.

There are two main mechanisms of oxygenation in pond systems: mass diffusion from the atmosphere and oxygen production by algae within the pond. It is, however, the oxygen provided by the algal population that is the most significant. The aeration provided by wind mixing is actually not as important as is commonly believed.

With regards to mixing, a number of researchers are noting that wind may create flow patterns in ponds that encourage short-circuiting problems. Because of this there is a growing belief that wind may have more of a negative influence on pond performance than a positive one!

Contrary to general belief, exposure to wind can have a negative influence on pond performance.

7.2 Previous Work

It is often stated in the literature, that wind has a major effect on the mixing and flow patterns in waste stabilisation ponds. However, there has actually been very limited experimental work reported to quantify this assertion.

Because of the limited research in this area we can only provide this section of the guidelines based on limited understanding and new, and relatively untested, ideas!!!

Research on wind effects on pond hydraulics is very limited, current understanding is largely based on assumptions.

7.2.1 Wind Induced Circulation

Several researchers have proposed that wind action across the surface of ponds induces a three-dimensional, circulation pattern consisting of surface flow, as a result of the wind shear, and a reverse bottom current. This work was based on computer modelling alone and not tested against direct experimental measurement. However, when a breeze is blowing across a pond it is actually possible to visually observe opposing currents in a pond. A very shallow wind driven surface flow can sometimes be seen to be moving in the opposite direction to the main flow circulation.

In contrast, experimental drogue tracking work presented by Shilton (2001), and confirmed again in research undertaken in this project, indicated the flow pattern was predominantly two-dimensional, circulating in the horizontal rather than the vertical plane. Shilton (2001) also conducted mathematical modelling of the wind effect on the pond studied. He found the model did show evidence of a reverse bottom current but it was only present near the very bottom of the pond. At the depths of 0.5 metres and 1.0 metre, which corresponded to the depths of the experimental drogues, the model confirmed the flow to be circulating two-dimensionally in the horizontal plane.

It may be that as wind dominance increases the circulation in the vertical plane also increases, but when a horizontal inlet dominates then the flow predominantly swirls around in the horizontal plane. Understanding the circulation patterns in a pond subjected to wind shear is clearly a complex problem, but it seems important that the engineer at least has an appreciation of these behaviours. A potential design approach for controlling flow behaviour is discussed in later sections.

7.3 New Thinking

7.3.1 Just how important is Wind?

As mentioned, the literature generally suggests that wind has a major influence on the mixing and flow patterns within waste stabilisation ponds, however, on close review there is actually very limited experimental work to support this assumption. Recent research by Shilton (2001) used three arguments to question the significance of wind effects on waste stabilisation ponds:

1. Wind shear was incorporated into a computer simulation of a tracer study on a field pond. While adding the wind was found to improve its agreement against experimental data, it was noted that the overall effect was not substantially different to the simulation results obtained when wind was neglected.
2. A broad theoretical analysis of two ponds, sized using a modern design manual, showed the power input via the inlet to be more dominant than the power input due to the wind, except at high wind speed or if a large inlet was used.
3. Whilst wind is highly variable in speed and direction, the flow from the inlet is relatively consistent over time and is always inputted as a concentrated point source in a fixed position and direction.

There are, however, several reasons why the inlet power may not always be so dominant in all pond systems:

1. Overly large inlets are often used, which means that the inlet velocity (and its power input) is significantly reduced.
2. A significant number of ponds in current use are oversized with larger surface areas than modern designs. This increases the relative influence of the wind.
3. For periods of time the wind speed will be significantly higher than the average value used in the calculations.

However, given the above, it is still very clear that in many cases we have tended to underestimate the influence that the inlet has (or could have) on the pond hydraulics.

The influence of the inlet is often underestimated.

7.3.2 Controlling the Effect of Wind on Pond Hydraulics

Whilst the occurrence of wind across a pond cannot be easily controlled, the inlet pipe is a physical structure that can be easily manipulated. By designing an inlet that dominates the power input into a pond, this could be used to force the flow into a predetermined pattern rather than allowing it to wander with fluctuation in wind direction.

This technique potentially offers engineers a practical method of controlling the flow pattern so as to optimise the hydraulic efficiency of a pond. This is, of course, just a very broad and theoretical evaluation and does not account for mechanisms such as the internal transfer and dissipation of energy. However, when this evaluation was applied to a field pond it was found to predict somewhat higher dominance for wind than was actually observed in experimental and computer modelling. Given that this approach appears to overestimate the wind effect rather than underestimate it, then it could be considered to provide a conservative estimate of wind influence.

7.3.3 A Method for Approximating Wind and Inlet Power Inputs

As a design tool this approach is novel and untested, but in the absence of any other approach we believe that it could, at least, give the design engineer a 'rough tool' for evaluating the relative influences of the wind and inlet.

The power input (P_I) from an inlet can be estimated by:

$$P_I = 0.5\ \rho_w.v^3.A$$

where: ρ_w = density of water (kg/m^3);
v = velocity of water (m/s);
A = cross-sectional area of inlet (m^2).

If this inflow enters via a circular pipe with a given flowrate Q (m^3/s) then, assuming a value of 1000kg/m^3 for water density, the relationship between the power input and the pipe diameter ϕ (m) is given by:

$$P_I = \frac{811\,Q^3}{\phi^4}$$

The input of wind power (P_w) can be determined by:

$$P_w = u_s.\tau_w.A_{pond}$$

where: u_s = surface water velocity, (m/s);
τ_w = shear stress of the wind on the water surface, (kg/m.s^2);
A_{pond} = surface area over which wind shear is exerted, (m^2).

The wind shear stress can be estimated from:

$$\tau = k.\rho_a.v_w^2$$

where: k = empirical constant;
ρ_a = density of air (kg/m^3);
v_w = velocity of wind (m/s).

Larsen (1999) stated that the surface velocity (u_s) on a water body is approximately equal to 3% of the wind velocity (v_W). This same value was used by Wood (1997) after a thorough review of the literature. By substituting in this relationship and the general empirical equation for wind induced shear stress, τ_W, the equation for wind power becomes:

$$P_w = (0.03\ v_W).(k.\rho_a.v_W^2).A_{pond}$$

$$\boxed{P_W = (0.03.k.\rho_a).v_W^3.A_{pond}}$$

For a pond of given area this equation allows calculation of the power input for a range of wind velocities.

Selection of the empirical constant, k, is important and depends on the height at which the wind velocity is measured. In his work on a model yacht pond 60m wide, 240m long and 2m deep, Van Dorn (1953) cites three values for the empirical constant depending on which height the wind speed is measured at. These range from 0.0037 for a measurement height of 0.25 metres to 0.0011 for a measurement height of 10 metres. For our work below we have interpolated to use a value of 0.0017.

7.3.4 Example of Application of Wind and Inlet Power Analysis

The equations given above can be used to determine the power supplied by the inlet (P_I) and the power supplied by wind (P_W). The table below shows P_I and P_W for a range of wind velocities and inlet diameters for a pond 640m x 320m (Area = 204800m^2) and a flowrate of 10,000 m^3/day (0.116m^3/s).

Average wind speed = 2.8 m/s
⇓
275W of power supplied

Wind Speed (m/s)	P_W (W)
0	0
0.5	2
1.0	13
2.0	100
	1567
6.0	2707

Inlet Diameter (m)	P_I (W)
0.100	12659
0.125	5185
0.150	2501
0.175	1350
0.200	791
0.225	494
0.250	324
0.275	221
0.300	156

Figure 7-1 Example of wind and power analysis

By using several years of meteorological records to determine an average wind speed of 2.8 m/s for the region used in this example, it can be seen that at this velocity the wind will supply 275W of power input. From the table for P_I, it can be seen that 275W of power will be supplied by the inlet at a diameter of between 0.25 and 0.275m.

Alternatively, the equation for P_I can be used to back calculate the inlet diameter at which equal power is inputted:

Example Calculation:

$$P_W = (0.03.k.\rho_a).v_W^3.A$$

$$P_W = (0.03 \text{ x } 0.0017 \text{ x } 1.3) \text{ x } 2.8^3 \text{ x } 204{,}800$$

$$P_W = 298\text{W}$$

If P_W = 298W, then for inlet equivalence $P_I = P_W$

$$P_I = \frac{811\ Q^3}{\phi^4}$$

$$298 = \frac{811 \times 0.116^3}{\phi^4}$$

$$\phi^4 = \frac{811 \times 0.116^3}{298}$$

$$\phi = 0.26\text{m}$$

Therefore, if the diameter of the inlet is less than 0.26m, then the inlet power will theoretically dominate over wind power (at average wind velocity). We need only reduce the inlet diameter slightly more and the inlet power markedly rises. For example, reducing to a 200mm diameter pipe would give a power input well over double that provided at the average wind speed. As mentioned the inlet adds this power input as a point source in a fixed direction and is relatively consistent as compared to wind shear, which is distributed over the whole pond surface and is highly variable in both velocity and direction. As a result the inlet might actually be expected to dominate the flow pattern even at equivalent power.

For a large pond such as in the above example, a designer might have normally chosen an inlet much bigger than this, say a 300mm to 400mm pipe or channel. However, after undertaking this ‘approximate’ calculation the inlet size might be reduced in an attempt to keep the flow pattern in the pond more controlled.

But where does this extra power actually come from? In the case of a pumped discharge or gravity sewer discharge into a pond reducing the inlet size will obviously increase the ‘head loss’ in the pipeline system and therefore reduce the maximum hydraulic capacity of the pipeline. As long as the inlet size reduction is not exaggerated then, in practice, this reduction of the maximum hydraulic capacity is probably not going to present a significant problem, although this should be checked before implementation.

Alternatively, if the inlet pipe comes in from another pond and, if there is not already an adequate drop in height between the two ponds, it means that the water level in the first pond will increase or ‘bank up’ so as to provide the extra energy required to drive the water through the smaller inlet. This increase in height (H) can be estimated from:

$$H = P_I/(9810.Q)$$

The recommended approach is, however, simply to install a ‘high flow’ bypass pipe adjacent to the reduced diameter inlet pipe to ensure the pond doesn’t bank up too high.

Cautionary Notes:

1. ***This approach is novel and untested!***
2. ***It is based on a broad theoretical evaluation and does not account for mechanisms such as the internal transfer and dissipation of energy.***
3. ***This analysis assumes a submerged horizontal inlet where the inlet momentum drives the circulation in the pond. It is not applicable to vertical inlets or where the inlet momentum is dissipated.***
4. ***Even if the inlet dominates the flow pattern at average wind speeds, high wind speeds may still dominate at certain periods of the year and inlet/outlet placement shouldn't be such that treatment is compromised at these times.***
5. ***In areas with very high average wind speeds this technique may be impractical to implement.***
6. ***If reducing the inlet diameter requires the water level to 'bank up' in the sewer, the deposition of solids in the sewer needs consideration.***
7. ***If reducing the inlet diameter requires the water level to 'bank up' behind a wall between two ponds, the pressure build up on the wall needs consideration.***

7.4 Aerators and Mixers

It can be seen from the analysis presented above that the actual power inputted from the wind and the inlet is not actually very high – being in the order of watts rather than kilowatts. If we add an aerator (or some other type of momentum source such as a mixer) into the pond how does this compare?

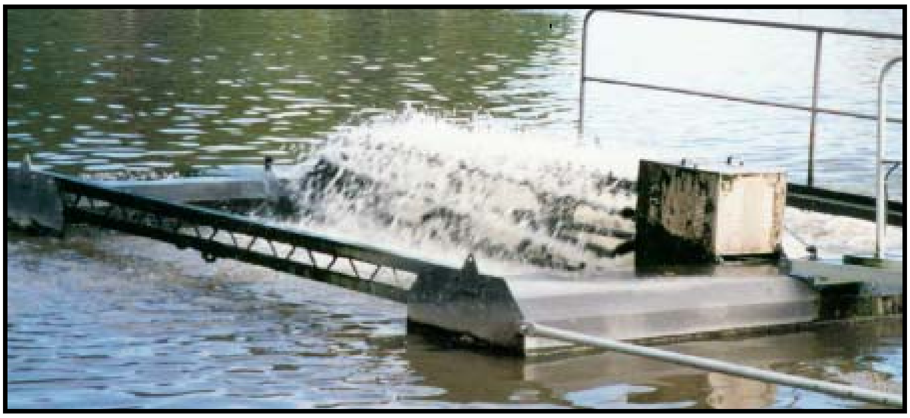

Figure 7-2 Example of an aerator

Taking cage aerators as an example, typical units range from 1.1kW to 4kW in rated power. However, it should be remembered that they don't actually operate at their rated capacity. Discussions with a manufacturer indicated that their unit, which was rated at 4kW, typically consumed only 1.2 kW. Further still, a reasonable percentage of this power is lost in the transmission efficiency with perhaps only around 75% of the power being actually transferred into the water. Therefore the actual power inputted from an aerator rated at 4kW may well be only 1kW (1000 watts) or less.

As before the same questions arise as to how this energy is then transferred and dissipated within the pond fluid. This is certainly not an exact analysis, but again as a rough guide we can see that compared to the example above, a single aerator rated at 4kW would still be inputting around 3 times as much power than the 0.26m diameter inlet pipe or the average wind shear.

This sort of rough analysis essentially tells us that aerators and other types of mixers are likely to be dominant when it comes to defining the flow pattern in the pond. Indeed the engineer may even choose to add a mixer to control the flow pattern in preference to reducing the inlet size.

Aerators and other types of mixers are likely to dominate the flow pattern in a pond.

This evaluation also illustrates that haphazard placement of aerators could have quite negative effects if they act to swirl the wastewater rapidly past the outlet. For design purposes, the previous comments given in regard to placement of horizontal inlets and shielding the outlet would also apply here.

7.4.1 High Rate Algal Ponds

Paddle wheel mixers, as seen in the photo below, are an integral part of the design of High Rate Algal Ponds. The gentle circulation (typically 0.15 m/s) of wastewater around the baffled pond maintains algae in suspension (Craggs, 2002, pers. comm.).

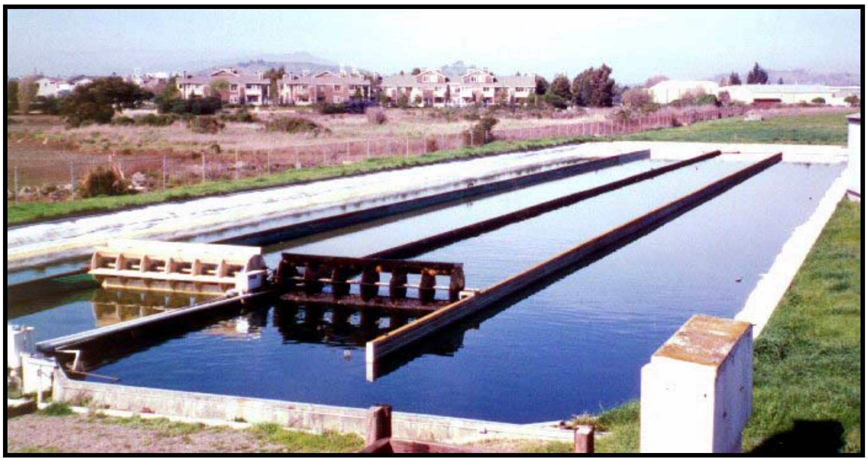

Figure 7-3 High Rate Algal Pond showing paddle wheel mixers

The influent is normally added 'downstream' of the paddlewheel near the base of the pond, while the outlet is located at the surface on the other side, thereby ensuring that the influent wastewater must make at least one circulation around the pond before any discharge (Craggs, 2002, pers. comm.). However the disadvantage of this circulating flow is that it does quickly move influent around the pond and back past the vicinity of the outlet, which essentially creates a short-circuiting problem.

Very little research has ever been published on the hydraulics of these systems, but it would seem likely that these systems could benefit from the use of flow shields/deflectors, as discussed previously, to shelter the outlet and prevent wastewater short-circuiting the treatment process after only the first few circulations.

High rate ponds may benefit from the use of flow shields/deflectors to shelter the outlet.

7.5 Temperature Effects

Stratification is a density-induced separation of the pond into layers. These layers may be characterised by different temperature, oxygen and redox measurements.

Stratification may be detrimental to the hydraulic behaviour of a pond system. It is possible that an inflow could 'short cut' across the top of a stratified pond instead of mixing into its full volume. This effect could be magnified, or occur in its own right, if the influent flow has a significantly different temperature to that of the main body of the pond and is not well mixed upon entry.

Inflow can 'short cut' across the top of a stratified pond instead of mixing into its full volume.

Wastewater that is confined to one layer will cause a significant reduction in retention time and, therefore, treatment efficiency. Macdonald and Ernst (1986) concluded that in addition to design aspects, thermal stratification was responsible for short-circuiting in the ponds they studied by tracer experiments. It is important to note, however, that this was an assumption drawn from the tracer data recorded at the outlet. There were no specific measurements made of the tracer moving through the pond itself.

Potential solutions to these problems might involve:

1. The use of vertical baffling to ensure the vertical mixing of the flow.
2. Ensuring adequate mixing of the influent into the main body of the pond.
3. Provision of mixing in the vertical profile.

Stratification is frequently assumed to imply some degree of convective mixing. However, it is important to note that the two are not necessarily linked. Convective mixing will only occur in a pond if it becomes thermally unstable. This results from a rapid cooling, such that the lower layers cannot become thermally equalised quickly enough by conduction. In this case the warmer lower layer convects up in exchange with the cooler and denser upper layer. Because convection currents act immediately to equalise any thermal imbalance this effect is very difficult to study experimentally. Extremely accurate temperature measurements taken simultaneously throughout the pond's depth are required and to date this sort of work has not been undertaken.

What is well documented, however, is the incidence of pond turnover. Overturn has a serious impact on pond operation. An overturned pond at the Dan Region treatment system in Israel was observed to turn the pond from its normal green to a milky grey colour, release odours and reduce its treatment efficiency (Icekson, 1996).

Ponds in New Zealand have also been observed to follow similar rapid turnovers. Traditionally, this has been blamed on convective mixing of the stratified pond liquid layers. It is however possible, that the mechanism is somewhat different. Two separate studies (currently unpublished) in New Zealand have found that the sludge layer frequently has higher temperatures than the water column above it. Therefore it may be the case that rather than pond overturn being due to convection of the lower liquid layer, it is due to the rising of the sludge layer.