2 INTRODUCTION TO POND HYDRAULICS

This section answers common questions about pond hydraulics to give a basic understanding of the issues and the terminology.

2.1 What are the 'Inputs' and 'Influences' that affect Pond Hydraulics?

Understanding pond hydraulics requires consideration of the inputs and influences on the flow momentum within a pond. These broadly include:

- Flowrate – higher flowrates increase inlet momentum;
- Inlet size – smaller inlets increase the inlet velocity and so also the inlet momentum;
- Inlet position and orientation – defines the way the inlet momentum is introduced into the main body of the pond, and as a result influences the main flow pattern;
- Outlet position – sets the distance from the inlet and, therefore the time, for the main flow to reach the outlet;
- Pond geometry and baffles – strong influence on flow patterns and defines the degree of 'channelling';
- Temperature/density effects – may influence the channelling and circulation of the main flow;
- Wind shear – higher wind velocities and greater pond surface areas increase the momentum inputted, and as a result influences the main flow pattern;
- Mechanical aerators – if present constitute significant momentum input, and as a result can have a strong influence on the main flow pattern.

This document seeks to provide guidance on improving pond design by better consideration of these effects, however, it must be recognised that the current understanding of some of these 'inputs' and 'influences' is still very limited.

2.2 What is the 'Theoretical' Hydraulic Retention Time (HRT) of a Pond?

The Theoretical HRT is simply calculated by:

$$\theta_{Theo} = \frac{V}{Q}$$

Where: θ_{Theo} = Theoretical hydraulic retention time, (d)
V = Pond Volume, (m^3);
Q = Average (or design) Flowrate, (m^3/d).

2.3 What is the 'Mean' Hydraulic Retention Time (HRT) of a Pond?

In reality ponds don't operate at their theoretical HRT. This is because:

- Compared to the constant value used to calculate the theoretical HRT, in reality the flowrate is constantly changing;
- They are partly filled with sludge.

Even if a pond was operating at its theoretical HRT, its hydraulic efficiency is still likely to be sub-optimal due to:

- Hydraulic dead space;
- Hydraulic short-circuiting.

To investigate the hydraulic efficiency of a pond and to determine its mean HRT, a tracer test must be undertaken (see Section 2.11).

2.4 What is 'Dead Space'?

The volume occupied by settled sludge is 'physical' dead space. It reduces the 'effective' volume of the pond, thereby reducing hydraulic and treatment efficiency.

The term 'dead space' is also used to refer to areas that are out of the main flow path, corners for example. The term 'stagnant' is also sometimes used. However, this is a little misleading as, in practice, most of the fluid in a pond is moving to some extent. There are simply ranges of flow velocities from fast to very slow.

Zones, such as back-eddies in corners, are slow to mix and interchange fluid with the main flow of the pond and, therefore, their contents are retained for long periods. This effectively reduces the 'active volume' of the pond that is left to provide the treatment to the main flow.

To illustrate this concept further, let's consider an exaggerated example. Imagine we have an irregular shaped pond with one corner (say 10%) that is relatively inaccessible and is bypassed by the flow in the rest of the pond. What if the water entering this corner sat there for a year before finally mixing back into the main body of the pond? If we did a tracer study for long enough, and if there was no sludge and a constant flow, we could eventually show that all the tracer that goes in comes out, and we would then know that the mean HRT equalled the theoretical HRT. However, in practice most researchers wouldn't wait around for years until all the tracer came out and their results would indicate that the mean HRT was less than the theoretical HRT. This is what we might then call the 'hydraulic' dead space. It's not really filled up with anything but is it essentially ineffective space! There is so little flow in and out of this zone that in essence the 'effective' pond volume has been reduced by 10% and it is the other 90% of the pond that is providing the treatment to practically all the wastewater.

Dead space in a pond reduces its effective treatment volume and therefore its overall treatment efficiency.

2.5 What is ‘Hydraulic Short-circuiting’?

When wastewater enters a pond it does not all move uniformly together from the inlet to the outlet. It mixes and disperses.

Some of the water might enter a hydraulic dead zone and remain there for some time. Most will mix into the main body of the pond and then slowly discharge with the effluent over a reasonable period.

However, some water will enter and leave the pond in a very short period of time - often just a matter of a few hours in ponds that have theoretical hydraulic retention times measured in weeks! This is called hydraulic ‘short-circuiting’ because it has short-circuited the full treatment process.

2.6 Why does Short-circuiting occur?

Researchers undertaking tracer studies have consistently reported the presence of short-circuiting. Various reasons have been given to explain why this may occur. Different authors have blamed this effect on a number of possible causes including thermal stratification, channelling directly from inlet to outlet, and wind effects.

However, it has also become recognised that the momentum from the inlet, especially if horizontally aligned, will cause the influent to swirl around the pond. Should this influent circulate around past the outlet then short-circuiting will occur resulting in the discharge of only partially treated wastewater.

Flow ‘swirling’ around the pond from an inlet past the outlet will cause short-circuiting.

2.7 Why is Short-circuiting a problem?

If some wastewater leaves a few days too early, isn’t this balanced out by wastewater that stays in the pond a few days too long?

No! Researchers believe that the reduction of organic contaminants and pathogens follows a non-linear relationship with respect to time. A relationship called ‘first order kinetics’ is often assumed to describe this behaviour.

This means that if some wastewater short-circuits through the pond too quickly, it misses out on a very large amount of treatment, whereas if some wastewater stays in the pond a very long time, it receives only a relatively small amount of ‘extra’ treatment. Section 3 discusses this further.

Wastewater that short-circuits through a pond misses out on a significant amount of treatment.

2.8 What is ‘First-order Kinetics’?

This refers to the rate at which the contaminants are removed. Put simply, it means that the rate of treatment of a contaminant at any time is proportional to the contaminant concentration remaining at that time. This is a non-linear relationship because the contaminant concentration is decreasing over time.

The significance of this in relation to pond hydraulics is explained further in Section 3.

2.9 What is ‘Plug-flow’ and ‘Completely Mixed Flow’?

There are two theoretical extremes of flow behaviour - plug flow and completely mixed flow.

The concept of ‘plug flow’ assumes that there is no mixing or diffusion as the wastewater moves through the pond. Alternatively, ‘completely mixed flow’ assumes the wastewater is instantaneously fully mixed upon entering the pond. These theoretical flow extremes are known as ‘ideal-flow’.

By assuming these types of flow behaviour when integrating the rate equation for first order kinetics, equations can be derived that allow calculation of the treatment efficiency achieved after a certain period of time. These are known as the ideal flow equations and are again explained further in Section 3.

Because plug flow conditions mean that the concentration is not diluted by mixing, then for first order kinetics, the higher concentration means that the rate of treatment is faster and, therefore, the overall efficiency is better.

For pond design, some researchers have proposed the use of the plug flow equation. Others have argued for the application of the completely mixed flow equation, partly because it is less efficient and therefore gives a more ‘conservative’ design. In the process design approach given in Appendix 3, an application of the design equation for completely mixed ponds in series is used.

2.10 What does ‘Non-ideal Flow’ and the ‘Dispersion Number’ refer to?

An alternative to using the ideal flow equations is to use the Wehner-Wilhelm equation. This equation is for what is called ‘non-ideal flow’ which is somewhere between the two extremes of plug flow and completely mixed flow. To do this it incorporates something called the dispersion number.

As the dispersion number tends to 0, more plug flow conditions exist – as it increases a higher degree of mixing is represented.

The dispersion number is derived by calculation from the results of a tracer study. This means that it is a function of all the physical influences that affected fluid flow within the pond during that study period.

However, to actually use this approach for pond design the dispersion number must be predicted in advance. A number of researchers have tried to present design equations to predict the dispersion number, but it is fair to say that none of these equations have become standard practice.

Currently researchers appear to focus less on this approach and more on the application of computer modelling to directly predict flow behaviour in ponds instead of trying to represent it by a single ‘dispersion number’.

2.11 What is a Tracer Study and what does it tell you?

A tracer may be a chemical or microbe that travels with the flow essentially mimicking the movement of the contaminants. A tracer study involves adding a slug (or a pulse) of a tracer at the inlet and then measuring its concentration at the outlet over a period of time.

Using the data obtained from a tracer study allows various hydraulic parameters to be determined including the:

- Mean retention time;
- Dispersion number;
- Time to start of short-circuiting;
- Time for 10% and 90% (the t_{10} and t_{90} fractions) of tracer discharge, etc.

It is also possible to integrate these results with an expression for first order kinetics to directly determine the treatment efficiency achieved by the pond under these conditions.

Appendix 2 of this document includes a short guide to performing a tracer study, interpreting the results and highlights some of the limitations of this approach.

Figure 2-1 Tracer testing on a laboratory pond with ‘stub’ baffles