

## Best Practice Guide NO. BPGCS002

### Wastewater Treatment – Activated Sludge Process

*The following is intended to provide a first check for those involved in the operation, management and monitoring of the activated sludge process to confirm that good practices are in place. In the first instance the material refers to wastewater treatment in an industrial facility, although much of it is also relevant to the activated sludge process in any context. The nature and extent of problems that can arise in plant operation may be complex and varied and the scope of this basic Guide cannot extend to the provision of comprehensive troubleshooting and problem solving advice. Where problems arise which are outside the competence of on-site personnel to solve, expert outside assistance should be promptly sought.*

#### Mass Balances

It is good practice to carry out ongoing mass balances on water, wastewater and wastewater solids handling. Such exercises should be devised to suit the particular characteristics and requirements of a given operation. Where other materials (e.g. solvents, metals, specific toxic organic and inorganic substances) have the potential to adversely affect the operation of the wastewater treatment plant, then these should also be tracked using mass balance techniques. The following is intended to provide a general indication of typical methodologies.

#### Water Balance

Minimisation of water use is desirable in any industrial facility to conserve water resources, for cost minimisation, for effective process operation and for wastewater volume reduction. A typical water balance for a production facility might be as follows.

$$(Water\ In) = (Water\ Out) + (Water\ Consumption) + (Water\ Losses)$$

*Water In (examples):*

- *Surface Water (e.g. abstraction from river, lake)*
- *Groundwater*

- *Town water*

*Water Consumption (examples):*

- *Water added to products*
- *Evaporation losses*

*Water Out (examples):*

- *Wastewater*
- *Cooling water*
- *Boiler blowdown*
- *Water in wastes (e.g. biological or other sludges)*

In order to keep a record of the water balance, all inputs and outputs must be metered. If the inputs and outputs do not correspond, there must be some unidentified water uses or, more likely, losses (e.g. leaks).

### ***Wastewater Balance***

It is critical for the successful operation of a wastewater treatment plant to have accurate information concerning the wastewater volume being handled. A simple water balance around the plant should be recorded daily. A typical balance might be as follows.

$$\mathbf{(Influent) + (Water\ added) = (Effluent) + (Water\ in\ sludge)}$$

*Influent (examples):*

- *Daily feed forward from balance tank (metered)*
- *Change in balance tank water level – taking into account the known volume of raw wastewater entering the balance tank*

*Water Added (examples):*

- *Dilution water added (e.g. if influent salinity is too high)*
- *Cooling water (if process operating temperature is too high)*

If treated effluent is being recycled within the wastewater treatment plant (e.g. as cooling water), this should not be counted as ‘water added’ in the above balance.

## ***Wastewater Solids Balance***

About 90% of wastewater treatment plants in Ireland utilise the activated sludge process. To satisfactorily manage this process it is necessary to continually monitor the suspended solids (S.S.) situation. A typical solids balance might be as follows.

$$(S.S. \text{ in Influent}) + (New \text{ Solids Made}) = (Change \text{ in MLSS}) + (Solids \text{ in Surplus Sludge}) + (S.S. \text{ in Final Effluent})$$

This time the objective of the materials balance is to determine the second term in the above equation, that is the 'New Solids Made'. This is the amount of new biomass (mainly bacterial cells) that is created each day. This information is needed in order to establish a record of the *Sludge Age* – a very important plant monitoring parameter which we will discuss further below. As the other four terms can be measured, the 'New Solids Made' is calculated by difference.

## **Process Control, Troubleshooting and Problem Solving**

The ongoing logging and interpretation of the relevant process control parameters provides the basis for successful troubleshooting and problem solving. The essential aspects of these disciplines are now outlined.

### ***Process Control Parameters***

These include:

- **BOD (or COD) load**
- **Mixed liquor suspended solids (MLSS)**
- **F/M loading**
- **Sludge age (Mean Cell Residence Time)**
- **Dissolved oxygen**
- **Nutrient requirements**
- **Cone settleability**
- **Sludge volume index (SVI)**
- **Surplus sludge production**
- **Mixing considerations**
- **Microscopic examination of sludge**
- **Upflow velocity (clarifier)**

- **BOD (or COD) load**

*Units: kg/day*

Biological wastewater treatment plants are designed and operated on the basis of the oxygen demand (BOD or COD) received and removed. Accurate information on the influent BOD (or COD) concentration and volume is therefore essential. Although the BOD test more accurately mimics the biological process, its practical usefulness is limited somewhat by the fact that a result takes 5 days to be determined. This is why the COD test can be substituted for day to day process control. However the ratio of BOD to COD must be accurately established and regularly checked.

The concentration of BOD (in mg/l) in the influent can be used to calculate the total BOD load per day being treated. This is simply done by multiplying the BOD in mg/l by the daily effluent volume in cubic metres (m<sup>3</sup>) and dividing the product by 1000.

For example,

$$\text{kg BOD/day} = \frac{\text{BOD(mg/l)} \times \text{Daily Volume(m}^3\text{/d)}}{1000}$$

- **Mixed liquor suspended solids (MLSS)**

*Units: mg/l*

This parameter needs to be logged on a daily basis. It is essential for the calculation of the F/M loading (and sludge age). Sometimes the alternative parameter ‘mixed liquor volatile suspended solids’ (MLVSS) is used. This refers to the ‘volatile’ or organic fraction of the MLSS and is typically about 80% of the MLSS value.

- **F/M loading**

*Units: kg BOD/kg MLSS/day*

This is the ‘Food to Mass’ ratio. It determines the degree of BOD removal likely to be achieved. The lower the F/M loading the greater the BOD removal efficiency. However, if the F/M ratio becomes too low, certain operating problems can occur (see *Operating Problems* below).

Typically, F/M ratios in the range 0.05 to 0.1 result in BOD removal efficiencies of about 95 to 99%. Between 0.1 and 0.2 the removal efficiency may be about 90 to 95%. Pilot trials may be used to determine the most likely BOD removal efficiency for a proposed new plant.

- **Sludge age (Mean Cell Residence Time)**

*Units: days*

The sludge age or Mean Cell Residence Time (MCRT) may be defined as the mass of solids (MLSS) in the plant at any time divided by the mass of new solids made each day. The latter can be determined using the *Wastewater Solids Balance* formula given above. The higher the F/M loading the shorter the sludge age and vice versa. This is because new biomass is produced at a fast rate when food supply is high and at a slower rate as food supply is reduced. For this reason the sludge age can be thought of as a measure of the rate of turnover of solids in the plant – hence the alternative name Mean Cell Residence Time.

Sludge age is typically about 20 - 30 days in activated sludge plants operating at high (>95%) BOD removal efficiencies. A long sludge is required for certain specific objectives, nitrification being the most usual. However, solids-liquid separation problems can result if the sludge age is excessively long (see *Operating Problems* below).

- **Dissolved oxygen**

*Units: mg/l*

The dissolved oxygen should be maintained above 1 mg/l in all parts of the aeration basin. For systems using surface aerators this usually requires a concentration of about 1.5 mg/l measured at the liquid surface. Where nitrification is required the dissolved oxygen needs to be 2 mg/l or higher in all parts of the basin.

There should be a permanently installed dissolved oxygen monitoring system which should be regularly calibrated. Readings below 1 mg/l should be regarded with caution as there may be no dissolved oxygen present under such circumstances if the unit is out of calibration.

- **Nutrient requirements**

The principal nutrients which often have to be supplied in chemical form are nitrogen and phosphorous. The usual minimum requirement is related to the BOD of the raw wastewater (influent). The ratio is 100:5:1 (BOD:N:P).

Les usually, a range of micronutrients (e.g. trace metals such as copper, manganese, cobalt, selenium etc.) may need to be supplied. This would probably arise only if the factory water had been deionised for process use. Products containing a balance of micronutrients for addition to wastewater treatment plants are available commercially.

- **Cone settleability**

*Units: ml/l*

A daily record of the volume of sludge settling in an Imhoff cone (or, if not available, a standard 1 litre graduated cylinder) should be kept. This provides an indication of sludge settleability trends and is an 'early warning system' for impending solids-liquid separation problems (see below). There is no universal optimum cone settleability value; some plants may operate stably at values as high as 800 to 900 ml/l, while others may typically have values of 300 to 400 ml/l or lower. The important thing is stability; any sudden tendency to increase – assuming the MLSS is constant – may indicate a process operation problem.

- **Sludge volume index (SVI)**

*Units: ml/g*

Definition:

$$\text{Cone settleability (ml/l)} / \text{MLSS (g/l)}$$

*(Note; the MLSS units are grammes/litre)*

The cone settleability test is a somewhat subjective indicator as it does not take into account the MLSS concentration. The SVI is an attempt to define a more absolute indication of the sludge settling potential. For plants operating on industrial wastewaters satisfactory SVI values are often in the range 100 to 200; municipal wastewater treatment plants tend to have lower SVI values.

- **Surplus sludge production**

*Units: kg/d*

A record should be kept of the quantity of surplus sludge solids removed from the plant each day. If the sludge is dewatered prior to off-site disposal the tonnage of dewatered material should be logged, together with its solids content.

- **Mixing considerations**

Where surface aerators are in use the power supply for satisfactory mixing of the aeration basin contents is usually in the range 15 to 30 W/m<sup>3</sup>, depending on the tank geometry. For diffused air systems there are many types of design and the manufacturer should be consulted to verify power and air (or pure oxygen) supply requirements.

- **Microscopic examination of sludge**

Regular examination of samples of mixed liquor should be carried out using a microscope. Magnification power of x100 to x200 is adequate. The principal aspects to be noted are:

- bacterial floc size and shape
- presence of filamentous bacteria
- presence of protozoans (flagellates, ciliates)
- presence of rotifers

There are many other species which may be observed but the above will provide a sufficiently reliable indication of the overall condition of the sludge.

- **Upflow velocity (clarifier)**

*Units: m/h*

For effective solids-liquid separation in a clarifier (settling tank) it is necessary that the rate of rise of the liquid (the upflow velocity) should be significantly less than the natural settling velocity of the solids. If this is not the case there will be carryover of solids with the final effluent discharge. Upflow velocity is calculated by dividing the total flow through the tank ( $\text{m}^3/\text{h}$ ) by the surface area of the tank ( $\text{m}^2$ ). The result is expressed in m/h.

The desirable upflow velocity depends on the nature of the particles to be removed. To satisfactorily settle activated sludge solids the upflow velocity in a final clarifier should be typically 0.5 to 1 m/h, whereas trickling filter solids - which are more dense and settle faster - can be successfully settled in a clarifier having a liquid upflow velocity of up to 2 m/h.

### ***Troubleshooting and Problem Solving***

The most common operating problems are the following:

- **Sludge bulking**
- **Pin-floc/deflocculation**
- **Foaming (biological)**
- **Rising solids (denitrification)**

To successfully troubleshoot and correct these problems the information generated by recording the Process Control Parameters must first be available.

- **Sludge bulking**

*Visual observation:*

- failure of sludge solids to settle in the final clarifier
- carryover of solids resulting in high effluent suspended solids

*Characterisation:*

- presence of *filamentous bacteria* (microscopic examination)
- increasing SVI and cone settleability
- clear supernatant liquor after prolonged settling

*Principal causes:*

- underloading (F/M too low)
- dissolved oxygen too low
- nutrient deficiency

*Correction strategy:*

The following plots should be made:

- (i) F/M and SVI (or cone settleability) against Time
- (ii) Dissolved oxygen and SVI (or cone settleability) against Time
- (iii) Nutrient supply\* and SVI (or cone settleability) against Time

*\*(in raw wastewater plus amounts added)*

It may take a number of weeks for serious bulking (predominance of filaments) to become established. Therefore the above plots must trace the situation back in time for a few months – in order to establish when the problem began to develop. With experience it will be possible to correlate a rising SVI trend with prolonged low F/M, low dissolved oxygen or nutrient shortage. Once the cause has been established an appropriate correction strategy can be implemented.

Note: If the cause is identified as low F/M it may be necessary to install a *selector* or *contact tank*. As this is a specialised item it would be necessary to seek expert assistance concerning its design.

- **Pin-floc/deflocculation**

*Visual observation:*

- carryover of very fine material in final effluent
- turbid or milky appearance of final effluent

*Characterisation:*

- bacterial flocs have disintegrated into *tiny 'pinhead sized' particles*; filaments not predominant (microscopic examination)
- cone settleability test may show some well-settling material but a cloudy supernatant; no change on prolonged settling

*Principal causes:*

- extreme underloading (F/M very low)
- presence of toxic substances

*Correction strategy:*

Examine the operating record – again over an extended time period (typically one to two months) – for prolonged low F/M. Also check available records for the presence of toxic substances in the raw wastewater. Correct the relevant adverse factor. If a tendency to pin-floc/deflocculation persists at a low level (often the case in the treatment of chemical effluents) then ongoing addition of some settling aid (e.g. polyelectrolyte) may be unavoidable.

• **Foaming (biological)**

Biological foam is due to operating conditions in the wastewater treatment plant. It accumulates on the surface of the aeration basin and may carry over into the final clarifier and effluent discharge. The use of detergents also generates foam but the comments below relate solely to biological (bacterial) foams.

*Visual observation:*

- *Foam type 1*: white, frothy, not particularly stable foam
- *Foam type 2*: white/brown foam, stable and containing fine particles of mixed liquor solids
- *Foam type 3*: dark, stable, heavy, 'chocolate mousse', foam

*Characterisation:*

- *Foam type 1*: few or no *filaments* (microscopic examination); high F/M loading or plant start-up situation
- *Foam type 2*: significant – but not necessarily predominant – presence of *filaments* (microscopic examination)
- *Foam type 3*: likely significant presence of higher life forms such as *rotifers* (microscopic examination); low F/M, long sludge age

*Principal causes:*

- *Foam type 1*: protein materials not biodegraded due to excessively high F/M or, in a plant start-up situation, the optimum MLSS concentration not yet having been reached

- *Foam type 2*: certain filamentous bacteria produce extracellular polymer (ECP) substances which are surface active and cause foaming
- *Foam type 3*: long sludge age systems operating on high nitrogen raw wastewaters generate high mixed liquor nitrate concentrations due to biological nitrification. In the absence of a dedicated denitrification facility the nitrate may denitrify in the aeration basin and final clarifier. The resulting nitrogen gas causes the MLSS to float in the final clarifier and aeration basin, forming the characteristic dark brown foam or floating sludge

*Correction strategy:*

- *Foam type 1*: Reduce the F/M (e.g. by increasing the MLSS). In a plant start-up the MLSS will naturally increase and no specific action is usually needed. Check that detergent use is not excessive as detergent foam is similar to this type of protein foam.
- *Foam type 2*: Use the same strategy as for sludge bulking.
- *Foam type 3*: Install a dedicated *anoxic tank* for denitrification. This is a specialised item and expert assistance should be obtained for its design.

- **Rising solids (denitrification)**

*Visual observation:*

- solids rising to the surface of the final clarifier and being carried over the outlet weir with the effluent discharge

*Characterisation, principal causes and correction strategy:*

This is essentially the same problem – in a slightly less developed form – as *Foam type 3* discussed above. It may be possible to reduce the solids loss to an acceptable level by increasing the sludge return rate, thereby reducing the tendency for anoxic conditions to develop in the final clarifier. If this is not effective then an *anoxic tank* needs to be installed.