SELECTORS IN ADVANCED BIOLOGICAL WASTEWATER TREATMENT SYSTEMS

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Introduction:

One of the main problems associated with every wastewater treatment facility is the maintenance of MLSS to the required level, and handling issues associated with sludge bulking. Moreover, all technological advancements in biological wastewater treatment *viz.*, sequential batch reactor (SBR), moving bed biofilm reactor (MBBR), integrated fixed film activated sludge (IFAS) process[1], membrane bioreactor (MBR) *etc.*, are aimed at handling these issues. In the case of SBR, if *sludge settleability* is diminished the concentration of MLSS goes down as most part of the bacterial population escapes the unit during decanting phase. In MBBR systems, though high organic loading rate, increased influent flow rate, reduction in hydraulic residence time (HRT) and foot print could be achieved, low sludge volume index (SVI_{30}) of as low as ~30 mL/g was reported to occur due to the formation of small-sized flocs (Ahmadi *et al.*, 2011). This poses operational problems with the secondary clarifier due to poor sludge settleability. In addition, when ammonia content in the influent is high, enhanced nitrification in the MBBR results in higher amount of nitrate in the effluent, resulting in *bulking sludge* in the secondary clarifier (Colic *et al.*, 2014). In the case of MBR systems, membrane filtration eliminates sludge settleability issues, but *sludge filterability* is affected when poorly settled sludge is generated in the reactor. However, in compartmentalised MBR system[2], the SVI_{30} values were found to be optimum, favouring good sludge settling characteristics (Ghalekhani and Zinatizadeh, 2014). This compartmentalisation is akin to selector design, and demonstrated that incorporation of compartments within the exisiting SBR, MBBR, and MBR shall favour lower SVI_{30} values.

Sludge settleability has a direct impact on the maintenance of MLSS by affecting the quantum of return sludge in a conventional activated sludge process. The main advantage of proper maintenance of SVI_{30} is that it improves stability of the treatment system by improving the concentration of MLSS whereby, the ability to withstand shock loads becomes significant. Since the

1 The difference between MBBR and IFAS is as follows: In the MBBR process plastic media with larger surface area is used for biofilm growth and there is no return sludge supply. Whereas, IFAS is a suspended growth system that incorporates attached growth media within the suspended growth compartment and employs recirculation of the sludge.

2 Plugged flow regime is maintained in compartmentalised MBR system. This compartmentalisation is akin to the selector configuration which retards filamentous bacterial growth.

concentration of MLSS determines how much time it takes for the reduction of BOD to the required level, sludge settleability also has an impact on sizing of the treatment units and HRT. In addition to saving on capital investment towards reduction of treatment unit size, reduction in operational costs can also be achieved if we are able to maintain proper SVI_{30}. In order to solve these problems, *selectors* are used to attain preferential growth of *floc-forming bacteria*. Here a discussion is made on how sludge settleabilty issues can be handled. The discussions made here are general in nature and applicable to all biological wastewater treatment systems.

Measuring sludge settleability:

Sludge settleability issues may arise under two scenarios: i) when F/M ratio is high, and ii) when F/M ratio is low. When the F/M ratio is high, *hydrous sludge* is generated whereas, low F/M values lead to *filamentous growth*. To address this problem, settleability of the sludge is measured. Several methods have been developed for measuring *sludge settleability* of which two of them are widely used: i) Sludge Volume Index (SVI_{30}; mL/g)[3] which is defined as the ratio between "sludge volume" (mL) and Mixed Liquor Suspended Solids (MLSS; in g) in one litre of the sample; and, ii) Diluted Sludge Volume Index ($DVSI_{30}$) which is defined as the SVI_{30} obtained after diluting the initial volume of the sample whereupon the settled sludge volume does not exceed 20% of the initial volume of the sample. The problem with the use of SVI_{30} is that its value is dependent on the initial concentration of the sludge[4]. On the other hand, $DVSI_{30}$ is not heavily influenced by the initial concentration of sludge in the sample. Though SVI_{30} can be measured for monitoring the performance of a plant when its day to day fluctuations are not much after required level of steady-state MLSS concentration is reached in the bioreactor, $DSVI_{30}$ should be the preferred choice when larger fluctuations in MLSS concentration occurs, for example, during plant startup and while performance tuning is undertaken.

Choice, sizing and design aspects of selectors:

Conventionally the selector is placed as a first treatment unit where wastewater is received for biological oxidation. Rectangular selector was found to be functioning better than circular selector due to the establishment of concentration gradient of the substrate[5] within the selector that favours

3 Settling time for the sludge is 30 minutes.

4 SVI_{30} is determined by collecting 1 litre of sample. Note that this 1 litre volume also consists of sludge volume. Thus, actual volume of sample should be taken as (sample volume-sludge volume). Then, the ratio (sludge volume/MLSS) should be divided by the factor [(sample volume-sludge volume)/sample volume] which shall provide volume corrected value of SVI_{30}. If this is not done, then the obtained value of SVI_{30} is influenced by the initial concentration of the sludge in the sample. This effect becomes more important at higher concentration of MLSS.

5 Along the length of the selector and parallel to the effluent flow direction.

floc-forming bacteria (Stypka, 1998). The choice of employing aerobic, anoxic and anaerobi c selector is largely dependent on which configuration most favours the proper maintena nce of $DSVI_{30}$ in the biological treatment unit. By controlling sludge settleability and maintaining $DSVI_{30}$ < 100 mg/L it is possible to increase daily flow and organic loads (Hulsman, 1992). The sizing of the selector should be based on the level and biological oxidation kinetics of rbCOD[6]. Fundamentally, there are two configurations for selector design: i) aerobic selector followed by anaerobic oxidation; ii) anaerobic selector followed by aerobic oxidation. Use of aerobic selector shall convert ammonia present in the effluent into nitrate[7], which can be eliminated in the following anaerobic biological oxidation step. Similarly, use of anaerobic selector shall remove excess nitrate present in the wastewater by denitrification. In this case, the ammonia present in the effluent may be converted to nitrate in the aerobic oxidation stage that follows. However, by recirculation of the effluent from the aerobic compartment to the anaerobic selector, it shall be possible to remove this excess nitrate. Such a configuration also reduces the costs associated with the requirement for the addition of external carbon sources – as the organics present in the influent are utilised as a carbon source. Sometimes, instead of a single stage selector, cascade of two, three or, four selectors can be employed (Albertson and Coughenour, 1995). Such cascaded selectors have higher efficiency than a single-stage selectors. One of the reason for better functioning of cascaded selectors is that it prevent the problems arising from short-circuiting[8] apart from establishing a concentration gradient that favours the growth of floc-forming bacteria. When the selectors are cascaded, each selector may or may not have different size and hydraulic retention time to get optimised results. Similary, they can be either aerobic, anoxic, or anaerobic.

The main requirement for good selector operation is that we should be able to obtain higher substrate concentration and high substrate removal efficiency (Mangrum, 1998). Under such a circumstance, the growth of filamentous bacteria is retarded and that leads to good sludge settleability. The maximum substrate utilisation rate occurs at high substrate concentration where bacterial growth rate is also high (Metcalf and Eddy, 2003). This forms the basis for the design of a good selector. Since selectors are located at the head of the wastewater treatment system where wastewater is received, the substrate concentration in the influent is comparably higher than any other treatment unit down the stream. This high concentration of the substrate in the selector results

6 rbCOD – rapidly biodegradable chemical oxygen demand - is due to the fraction of organics present in the wastewater that degrades at a comparatively faster rate. It is very much essential to estimate the quantum of rbCOD and pbCOD (COD arising from particulate biodegradable organics) and their degradation kinetics to have a better system in place.

7 This is a two-step biological oxidation process whereby ammonia in the wastewater is initially converted into nitrite and then to nitrate.

8 Short-circuiting problem arises when the influent leaves the reactor without spending design HRT. Short-circuiting problems mainly arises from insufficient mixing. One of the reasons for such poor mixing is improper placement of inlet and outlet in the reactor.

in higher growth rate of bacterial population. The relationship between substrate concentration (g bsCOD/m^3)[9] and substrate utilisation rate (g/m^3·day) is given by the following equation (eq-1) and depicted in Fig.1[10]:

$R_{su} = kXS/(Ks + S)$ ..... (eq-1)

where,

R_{su} = substrate utilisation rate, g/m^3·day;

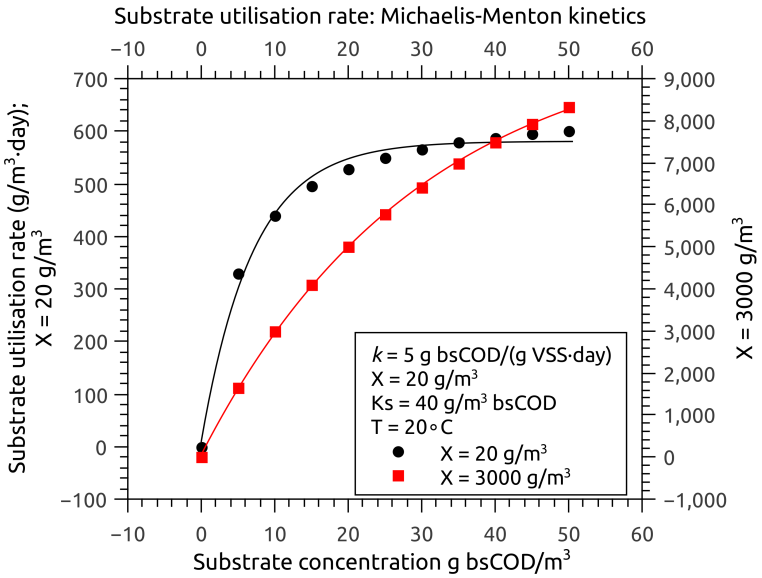
k = maximum specific substrate utilisation rate, (g substrate)/(g microorganisms·day);

X = biomass concentration, g/m^3;

Ks = half-velocity constant, substrate concentration at one-half the maximum specific substrate utilisation rate, g/m^3;

S = growth limiting substrate concentration in solution, g/m^3;

From Fig.1, it can be observed that at low biomass concentration (for example X = 20 mg/L), the substrate utilisation rate increases exponentially. However, when the biomass concentration increases (X = 3000 mg/L), the relationship tends to become linear. The high concentration of biomass in the selector could be achieved either by returning the sludge or, providing more time for biological growth.



9 bsCOD arises from biodegradable soluble organics present in the wastewater.

10 Typical values of *k* [maximum specific substrate utilisation rate (g substrate)/(g microorganisms·day), and Ks (half-velocity constant - substrate concentration at one-half the maximum specific substrate utilisation rate, g/m^3)] at 20ºC; X is the biomass concentration (g/m^3 or, mg/L) and assumed to be 20 g/m^3 (or, 20 mg/L) in the influent to the selector during start-up and 3000 g/m^3 (or, 3000 mg/L) after sufficient biomass has developed over a period of time. Though *k* and Ks values are typical, actual measurement of biomass concentration (X) should be made in the sample collected from selector for estimating substrate utilisation rate. The values of *k* and Ks should also be adjusted for temperature if the wastewater temperature is different from 20ºC.

Fig.1: Relationship between substrate concentration and substrate utilisation rate. Typical values of *k* and Ks (Metcalf and Eddy, 2003) were used with assumed values of X = 20 g/m^3 and 3000 g/m^3 for the preparation of the chart. Note that the substrate utilisation rate is different for different bacterial population. By suitably selecting the SRT, it shall be possible to favour the growth of one type of bacteria over the other.

To be successful, the selectors must be properly designed and operated. Using data obtained from full-scale wastewater treatment plants, Gabb *et al.* (2006) concluded that anoxic selectors do not control filamentous bulking in long mean cell residence time plants[11]. In such cases, elimination of anoxic zone is expected to reduce sludge bulking problems. Similarly, aerobic selectors do not control filamentous bulking in short mean cell residence time plants. It was also found that anoxic and anaerobic selectors do not control filamentous bulking in short mean cell residence time plants if selector volume is large enough and/or selector MLSS concentration is high enough.

Conclusion:

Irrespective of the developments made in the filed of biological wastewater treatment systems such as SBR, MBBR, IFAS, MBR, *etc.*, sludge settleability remains as one of the most important parameter that can affect system stability, removal efficiency of organics present in the wastewater, and ability to withstand shock loads. Proper selection of a selector (aerobic, anoxic or anaerobic) and provision of enough number of stages (cascaded selectors) shall prove to be useful in system operation and maintenance. Such measures shall not only help improve the performance of the wastewater treatment plant, but also reduce capital investments and operational costs. Though adoption of selectors is not common in the case of SBR, MBBR, IFAS and MBR systems, a good design should consider its incorporation to accrue benefits.

11 Mean cell residence time is the average time that a microorganism spends in the activated sludge process. It is measured in days, and synonymous with solids retention time (SRT). The mean cell residence time is an important parameter that exert control over other parameters and therefore the performance of any biological wastewater treatment unit.

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