OPTIMISING OPERATIONS OF YOUR ACTIVATED SLUDGE PLANT

Majority of industrial effluent treatment plants employ activated sludge process in the secondary treatment plant to achieve removal of organics in the most economical way. The aeration tank, secondary clarifier and recycle pumps together form the activated sludge plant (ASP) and generally constitute major portion of capital investment in the ETP. Managing an ASP is a science as well as an art and its success depends on thorough understanding of the design aspects and operational parameters. Operators often blame obsolete aeration systems for failure to extract good performance from the secondary plant which may not be true. The secondary clarifier is the most critical and often neglected link in an ASP, resulting into failure of maintaining the desired MLVSS levels in aeration tank. Sludge wastage and recycling practices are arbitrary and based on judgments rather than calculations. The result, obviously, is poor performance and under utilization of heavy investments. On a broader scale, this promotes a false impression in industries about efficiency and dependability of an activated sludge plant. The fact is, once you know how to run the plant, nothing is as simple and as economical as an ASP.

KNOW YOUR PLANT

Understanding process design considerations and relating them to present operating conditions is fundamental in trying to optimize the plant performance.

In an activated sludge plant (ASP), a mixed culture of microorganisms is trained to survive in a particular environment and to degrade organics being served to them as food. In the commonly seen suspended growth ASPs, these trained microorganisms house themselves as flocs of solids, commonly referred to as MLSS (Mixed Liquor Suspended Solids). The conventional plants are generally designed to maintain 3000-4000 mg/L MLSS in aeration tank. About 60-80% of these is the volatile (organic) fraction MLVSS, which indicates the biomass level in the aeration tank. Since MLVSS measurement requires burning the organics in a muffle-furnace, it is routine to measure MLSS gravimetrically and periodically verify the VSS fraction.

As the primary treated wastewater enters the aeration tank, equivalent flow is displaced to the (secondary) clarifier, carrying along the same concentration of MLSS as maintained in aeration tank. The microorganisms present in these solid flocs are valuable and need to be recycled back in to the aeration tank. Since these trained or “activated” microbes are recycled back as sludge from (secondary) clarifier, the process is termed as activated sludge process.

An ASP is sized based on following basic parameters:

A) Average Flow
B) Incoming BOD or BOD removal
C) Design MLSS & MLVSS level

D) Food-to - Microorganism Ratio
E) Clarifier Overflow Rate
F) Oxygen Requirement

The operator needs to know the design flow and design BOD levels of the existing plant before attempting any upgradation or performance enhancement. Based on the sludge quality or past experience, the ETP designer specifies an operating MLSS and MLVSS level for maximum load conditions. For conventional plants, 3000-4000mg/L design MLSS levels with 65-75% VSS content is normal.

F/M Ratio and Aeration Volume

Food-to-Microorganism Ratio determines the size of the aeration tank. This ratio is either determined by conducting kinetic studies in a laboratory over few weeks or is based on pratical data with the designer. The retention time required in aeration tank is determined using following formula.

$$\text{HRT (days)} = \frac{\text{Incoming BOD (mg/L)}}{\text{Design MLVSS (mg/L) x Design F/M Value (1/day)}}$$

As per our practical experience, for non–toxic effluents, about 85-90% BOD removal is easily achieved at F/M of 0.25-0.35 while removals of more than 95% requires F/M lower than 0.15. The latter is also termed as activated sludge plant operated in extended aeration regime, or simply extended aeration plant.

The aeration volume (working volume) is the product of design average daily flow and design HRT calculated as above.

In routine operations, the operator has to determine the target MLVSS level after calculating the present HRT (Aeration Volume/Present Daily Flow).

$$\text{Target MLVSS (mg/L)} = \frac{\text{Present Incoming BOD}}{\text{Design F/M x Present HRT (days)}}$$

The F/M value in this calculation would remain same if the nature of effluent and BOD levels have not changed much from the design conditions. If this has changed, it is advisable to consult experts to determine required F/M.

Table: 1 Know Your ASP Design Criteria

Sr.	Parameter	Units	Significance
1.	Average Effluent Flow	m^3/day	Hydraulic Load
2.	Incoming BOD-3 (27°C)	mg/L	Organic Load
3.	Design MLVSS Value	mg/L	Biomass Content
4.	Food-to-Microorganism Ratio	1/day	Organic Removal
5.	Clarifier Overflow Rate	m^3/day/m^2	Biomass Settlement
6.	Oxygen Requirement	kg/hr	Aeration Design

Clarifier Sizing

As mentioned earlier, the clarifier which settles the activated biomass for recycling back into the aeration tank is most critical link in the system. The biomass is very light with its density being just 2-3% more than water. On the other hand, primary solids weight 50-150% more than water and chemically treated solids weight 40-100% more than water. Unfortunately, in many ETPs, the secondary clarifier is almost the same size or just little larger than primary clarifier.The principal design parameter for clarifiers is the Surface Overflow Rate (SOR) which determines the surface area and hence the diameter of clarifier. Primary clarifiers are designed for SORs of 24-40 m/day while secondary clarifiers are designed for SORs of 10-15 m/day. For high TDS wastewater above 20,000 mg/l salts, SOR is typically 8-10 m/day. The clarifier area is the division of sum of raw effluent flow plus secondary filtrate flow plus tertiary backwash flow (if any), with SOR. The center well area and area occupied by weir/launders is not considered in the clarifier area. Also significant is the water depth in secodary clarifier. The biomass on settlement forms a sludge blanket at the bottom, which can not be compacted further. The water depth should allow 0.5 to 1.0m depth for sludge blanket. Accordingly, secondary clarifiers should be 3.5m to 4.5m in depth, as measured on the sidewall.

The operators do not have much process control over clarifiers but should surely evaluate the designs to determine if they are dealing with an undersized clarifier. When the clarifier is sized properly, the efforts should be to form large flocs without entrapped air. Adding polyelectrolytes (generally, cationic) helps in increasing the floc sizes and improving settlement rates. Some method of mild mixing is required to promote flocs after adding polymer.

The solids carry-over from secondary clarifier should be minimum, as precious VSS is also wasted over the weir. High BOD feed can permit outlet TSS of 100-200 mg/L if subsequent treatment is present. For low strength effluent of less than 500 mg/L BOD, outlet TSS should be as low as possible, but within 100 mg/L.

The recycle rate is determined based on MLVSS value of clarifier under flow and the required MLVSS in aeration tank.

$$\text{Recycle Flow } (m^3/d) = \frac{\text{Effluent Flow } (m^3/\text{day}) \times \text{MLVSS in Aeration Tank}}{\text{MLVSS in underflow} - \text{MLVSS in Aeration Tank}}$$

The operator should strive for maximum underflow MLSS and hence minimum corresponding recycle flow. The recycle should be continuous throughout the day and not intermittent.

Aeration System.

The other important yet lesser-known component of an activated sludge plant is the aeration system. Most of the older plants have slow speed surface aerators while recently built systems tend to use diffused aeration systems.

The aeration system is sized for actual oxygen requirement (AOR) which is the net oxygen transferred into the wastewater at operating conditions. AOR is generally considered equal to or upto 20-50% more than the influent BOD (kg/day)

$$\text{AOR (kg/day)} = \frac{(1.2 \text{ to } 1.5) \times \text{BOD (mg/L)} \times \text{Flow } (m^{3/}/\text{day})}{1000}$$

This AOR is often confused with SOTR, which is the oxygen transfer rate of the aerator/diffuser at standard conditions, as specified by the manufacturer in his literatures. SOTR refers to oxygen transfer in ideal conditions of temperature, pressure, TDS, DO level, etc. AOR is observed to be 40%-60% of SOTR. The operator needs to calculate required AOR at present conditions and verify available oxygen based on AOR calculated from manufacture's SOTR values.

The aerators have to perform an additional important function of uniform mixing of the contents of the tank, thereby maintaining uniform DO and MLVSS levels throughout the tank. Diffusers generally provide a better uniformity, provided enough flux is maintained. An air quantity of 2 to 3 m^3/hr per m^2 tank area is adequate to maintain healthy activated sludge into suspension.

On-field judgment of aeration system can be taken based on residual DO in the tank at design working. The DO level should be 1-1.5 mg/L at full load conditions.

UNDERSTANDING OPERATING PARAMETERS

The operating parameters which need to be routinely monitored in an activated sludge plant are:

a) MLSS & MLVSS (Mixed liquor suspended/volatile suspended solids)
b) F/M ratio (Food to Micro-organisms)
c) SVI (Sludge Volume Index)
d) DO (Dissolved Oxygen)
e) DOUR (Dissolved Oxygen Uptake Rate)
f) Nutrient Availability/Addition
g) Microscopic Observations
h) Clarifier Underflow MLSS
i) Clarifier Outlet TSS / VSS
j) Recycle Rate
k) Sludge Wastage Rate.

The target MLSS & MLVSS values should be determined based on design F/M as per following equation:

$$\text{Target MLVSS (mg/L)} = \frac{\text{Incoming BOD (mg/L)}}{\text{Design F/M} \times \text{Present HRT (Days)}}$$

If MLVSS in tank is less than the target value, the recycle rate may be increased to the point till diluted sludge is not withdrawn from the clarifier. A good clarifier design will permit up to 1.5 to 2.0 times recycle flow as compared to the effluent flow. Recycling should generally be continuous. If the MLVSS still remains below the target value, resulting in to a higher F/M than design, the system can be operated without any sludge wastage for some days. At higher F/M, the biomass growth is better while BOD removal is little lesser. In extreme cases of toxicity or inhibited biomass, additional seeding using biomass from other aerobic plants may be required. Addition of cowdung directly to aeration tank is of little help since it contains both the microbes and the food and hence these microbes tend to avoid consuming organics in the effluent and do not cultivate large acclimated population.

The recycle rate is determined based on formula narrated earlier. Once the target MLVSS level is crossed, new biomass goes on accumulating and needs to be wasted (or sent to dewatering). The rate of wastage is determined as follows:

$$\text{WAS } (m^3/\text{day}) = \frac{(\text{Actual MLVSS (mg/L)} - \text{Target MLVSS (mg/L)} \times \text{Aer. Volume}}{\text{MLVSS in clarifier underflow (mg/L)}}$$

Sludge Settling Characteristics.

The operational health of an activated sludge plant is indicated by SVI, DOUR and Microscopic observations. SVI is calculated from 30-minute settlement rate in a 1000mL measuring cylinder. A smaller cylinder should never be used because of wall effects on settlement rate. The reading of level of solids in the cylinder after 30-minutes of settlement is divided by MLSS (in grams/L) to get SVI.

$$\text{SVI (mL/g)} = \frac{\text{Settlement (mL)} \times 1000}{\text{MLSS (mg/L)}}$$

SVI values of 50-150 indicate good working. Low SVI values indicate presence of inorganics solids, heavy sludge and low VSS fraction. Sludge should be wasted at less than 10% quantum per day to temporarily decrease the MLSS, increase the F/M and promote new biomass growth.

High SVI values indicate poor settling sludge or even presence of filamentous micro-organisms. During growth phase, i.e. when you are trying to increase the MLVSS, a high SVI is common and not a problem. In a stabilized plant, if SVI remains high, factors like presence of entrapped air, filamentous bacteria, anaerobic conditions and resultant gas release etc. should be looked at.

Oxygen Utilization

The dissolved oxygen in an aeration tank only indicates adequacy of aeration. A related parameter to judge biomass performance is DOUR (Dissolved Oxygen Uptake Rate). DOUR is measured using a DO-meter, preferably with a stirrer-fitted probe. The aeration tank sample is saturated with air in laboratory using a simple aquarium aerator or so. The DO is measured every minute or at suitable interval while continuously stirring the wastewater (mixed liquor). The rate of DO depletion in mg/l/hour is the DOUR.

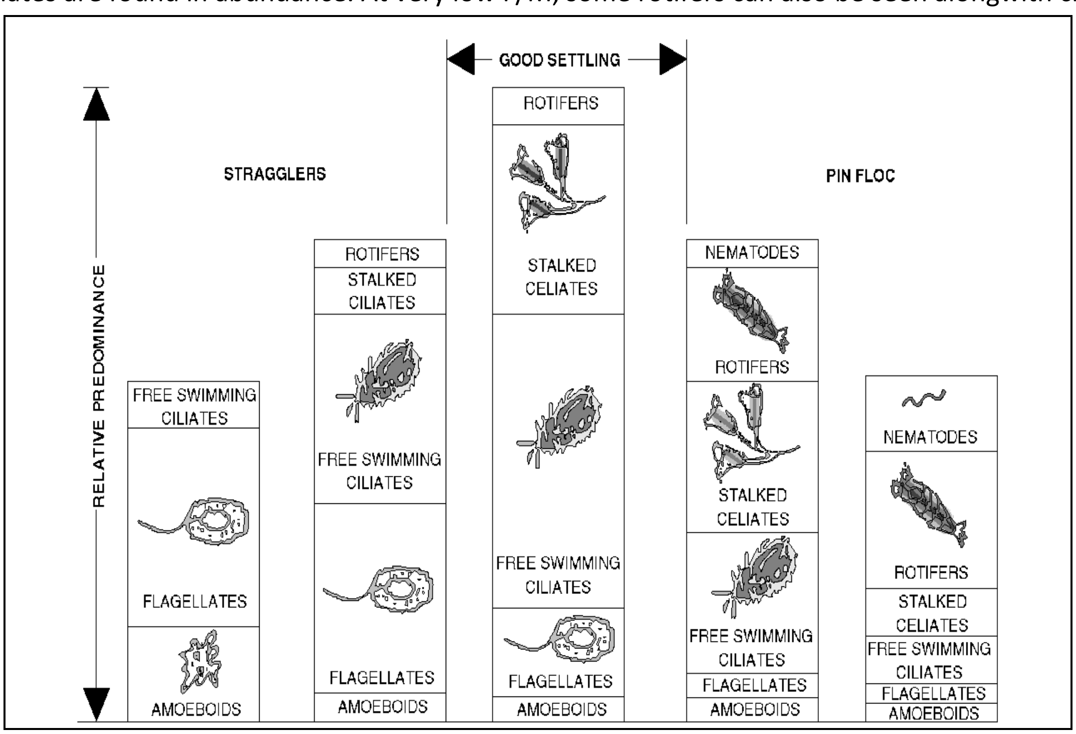
DOUR depends largely on operating F/M. During growth phase when F/M is high, DOUR is also high, generally more than 30-40 mg/L/hr. In an extended aeration system with F/M of less than 0.12 to 0.15, the DOUR is typically less than 12-15 mg/L/hr. Low DOUR at a high F/M indicates less live bacteria or inhibitory toxicity of effluent. A high DOUR at low F/M also indicates that all the MLVSS may not be due to living bacteria and hence actual F/M is higher than being perceived.

Table: 2 ASP Operating Parameters

Sr.	Abbreviation	Name	Significance
1.	MLVSS	Mixed Liquor Volatile Suspended Solids	Biomass content in aeration tank
2.	F/M	Food-to-Microorganisms Ratio	Lower value gives better BOD removal
3.	SVI	Sludge Volume Index	Biomass Settling rate
4.	DOUR	Dissolve Oxygen Uptake Rate	Utilization of oxygen by biomass-indicates health of biomass
5.	RAS	Recycled Activated Sludge	To maintain desired MLVSS in aeration tank
6.	WAS	Waste Activated Sludge	Excess Biomass to be wasted out
7.	RAS-MLVSS	MLVSS in Recycled Sludge	Clarifier Performance

<u>Microscopic Observations</u>

While workhorse for biodegradation are various types of bacteria, these are too small (0.5 to 5 micron) to be viewed with ordinary laboratory microscope. Therefore, the microscopic observations in an ASP are based to monitor “indicator organisms”, mainly protozoa. Amoeba, Flagellate, Free Ciliate, Stalked Ciliate and Suctoria are the principal types of protozoa which can be observed in lab microscope at 100 X magnification. Amoeba and flagellates are very small in size and are present during start-up at high F/M. In a stabilized plant, both types of ciliates are found in abundance. At very low F/M, some rotifers can also be seen alongwith ciliates.



Microscopic examination alone is not sufficient to decide on a process change. However, at times, this provides important clues on plant behavior. A specialist is required in larger plants to study microbial abundance and type.

Clarifier Performance

An outlet TSS value of less than 100 mg/l and underflow MLVSS of more than 6000 mg/L, generally, should indicate a good working ASP. If the VSS values are higher, it is still better. Operator should develop a skill to judge the depth of sludge blanket at the clarifier bottom. At higher depths, recycle rates should be increased or sludge should be wasted. At lower depths, recycle rate should be reduced to avoid pumping of diluted sludge.

One of the well-known operational problem of clarifiers is the bulking sludge, in which flocs of biomass do not settle and rather float on the surface. Bulking is caused due to insufficient aeration, high F/M (resulting into young disperse sludge), temperature currents, nutrient deficiency, low pH and presence of filamentous organisms. Each factor should be carefully monitored to diagnose and cure the problem of bulking sludge.

Proper performance of the clarifier is dependent on good operational practice of the system as a whole. The MLSS entering the centre well of the clarifier should be in the form of flocs without any entrapped air or gas. The flocs should be large and heavy and not dispersed. Cationic polymer may be added alongwith mild mixing to promote good flocs. Full clarifier area should be in use and there should not be any short-circuiting of effluent due to uneven weir depth. The clarifier DO level should not be less than 0.5-1.0 mg/L. Sludge withdrawal should be continuous and mild and should not cause any turbulence. Your success in maintaining the target MLSS thereby achieving the required BOD removal depends on smooth operations of the clarifier.

CONCLUSIONS

Activated sludge plant is the most important unit of many industrial effluent treatment plants and once learnt to be operated well, it is the simplest, cheapest and most reliable option to degrade complex organics. The five steps to operating success of on ASP are:

1. Find out the process design criteria of your ASP
2. Compare the design criteria with present load conditions.
3. Determine the target biomass level in aeration tank and decide the process changes to achieve this.
4. Monitor all eleven operating parameters on a daily basis and draw critical conclusions based on the observations.
5. As a last tip, make process changes one after the other. Each change will take about one to two weeks to reflect the change in performance.