DESIGN OF ACTIVATED SLUDGE PROCESS

Introduction

Modeling of activated sludge processes has become a common part of the design and operation of wastewater treatment plants. Today models are being used in design, control, teaching and research. The effort for designing trickling filter took initiative in 1982, the International Association on Water Pollution Research and Control (IAWPRC), as it was then called a Task Group on Mathematical Modeling for Design and Operation of Activated Sludge Processes. At that time modeling of activated sludge processes had been a discipline for about 15 years, most noticeably and reaching the most advanced level at the University of Cape Town, South Africa, by the research group headed by Professor G.V.R. Marais. The various models developed at that time had only little use, owing partly to lack of trust in the models, partly to the limitations in computer knowledge and partly to the complicated way in which these models had to be presented in written form.

Activated sludge is one of the important aerobic methods employed in treating industrial waste water. This episode deals with the following topics

1. **Process description**
2. **Activated sludge process in food industry**
3. **Important factors guiding activated sludge design**
4. **Design of activated sludge**
    a. **Activated Sludge Process Variables**
    b. **Loading Rate**
    c. **Aeration tank**
    d. **Oxygen requirements**
    e. **Aeration facilities**
    f. **Secondary Settling**
5. **Design of activated sludge**
    a. **Sludge recycle**
    b. **Excess Sludge Wasting**
    c. **Nitrification**
    d. **Denitrification**
    e. **Cost of the instrument**

1. Process description

The conventional Activated Sludge Process (ASP) is a continuous treatment that uses a consortium of microbes suspended in the wastewater in an aeration tank to absorb, adsorb, and biodegrade the organic pollutants. Part of the organic composition will be completely oxidized to harmless end products and other inorganic substances are utilized to provide energy to sustain the microbial growth and the formation of biomass (flocs). The flocs are kept in suspension either by air blown into the bottom of the tank (diffused air system) or by mechanical aeration. The dissolved oxygen level in the aeration tank is critical and should preferably be 1–2 mg/L and the tank must always be designed in terms of the aeration period and cell residence time.

The mixture flows from the aeration tank to a sedimentation tank where the activated sludge flocs form larger particles that settle as sludge. The biological aerobic metabolism mode is extremely efficient in terms of energy recovery, but results in large quantities of sludge being produced (0.6 kg dry sludge per kg of BOD_5 removed). Some of the sludge is returned to the aeration tank but the rest must be processed and disposed of in an environmentally acceptable manner. Many variations of the ASP exist, but in all cases, the oxygen supplied during aeration is the major energy-consuming operation. With ASPs, problems generally encountered are bulking, foam production, precipitation of iron and carbonates, excessive sludge production, and a decrease in efficiency during winter periods.

The equipment requirements for the activated sludge process are more complex than other processes. Equipment includes an aeration tank, aeration, system-settling tank, return sludge, and waste sludge.

Aeration tank

The aeration tank is designed to provide the required detention time (depends on the specific modification) and ensure that the activated sludge and the influent wastewater are thoroughly mixed. Tank design normally attempts to ensure no dead spots are created.

Aeration

Aeration can be mechanical or diffused. Mechanical aeration systems use agitators or mixers to mix air and mixed liquor. Some systems use a sparge ring to release air directly into the mixer. Diffused aeration systems use pressurized air released through diffusers near the bottom of the tank. Efficiency is directly related to the size of the air bubbles produced. Fine bubble systems have a higher efficiency. The diffused air system has a blower to produce large volumes of low pressure air (5 to 10 psi), air lines to carry the air to the aeration tank, and headers to distribute the air to the diffusers that release the air into the wastewater.

Settling tank

Activated sludge systems are equipped with plain settling tanks designed to provide 2 to 4 h hydraulic detention time.

Return sludge

The return sludge system includes pumps, a timer or variable speed drive to regulate pump delivery and a flow measurement device to determine actual flow rates.

Waste Sludge

In some cases, the waste activated sludge withdrawal is accomplished by adjusting valves on the return system. When a separate system is used it includes pumps, a timer or variable speed drive, and a flow measurement device.

2. Important factors guiding activated sludge design

In activated sludge systems, the cells are separated from the liquid and partially returned to the system; the relatively high concentration of cells then degrades the organic load in a relatively short time. Therefore, there are two different resident times that characterize the systems: one is the hydraulic residence time (θH) given by the ratio of reactor volume (VR) to flow of wastewater (QR):

$$\theta H = \frac{V_R}{Q_R}$$

The other is the cell residence time (θC), which is given by the ratio of cells present in the reactor to the mass of cells wasted per day. Typical θH values are in the order of 3–6 hours, while θC fluctuates between 3 and 15 days.

To ensure the optimum operation of the activated sludge process, it is generally necessary to provide primary treatment and flow equalization prior to the activated sludge process. Pilot or laboratory-scale studies are required to determine organic loadings, oxygen requirements, sludge yields, and sludge settling rates for high-strength wastes. Along with these, it is also used to generate several information required to design an activated sludge system such as

- BOD_5 removal rate
- Oxygen requirements for the degradation of organic material and the degradation of dead cellular material (endogenous respiration)
- Sludge yield, determined from the conservation of soluble organics to cellular material and the influx of inorganic solids in the raw waste
- Solid/liquid separation rate: the final clarifier would be designed to achieve rapid sedimentation of solids, which could be recycled or further treated. A maximum

surface settling rate of 16.5 m^3/day has been suggested for seafood-processing wastes

The suspended solids concentration in the aeration tank liquor, also called mixed liquor suspended solids (MLSS), is generally taken as an index of the mass of active micro-organisms in the aeration tank. However, the MLSS will contain not only active micro-organisms but also dead cells as well as inert organic and inorganic matter derived from the influent sewage. The mixed liquor volatile suspended solids (MLVSS) value is also used and is preferable to MLSS as it eliminates the effect of inorganic matter.

3. Design of activated sludge

In general following factors need to be considered during design of the activated sludge process, they are

- Aeration tank containing microorganisms in suspension in which the reaction takes place
- Activated sludge recirculation system
- Excess sludge wasting and disposal facilities
- Aeration systems to transfer oxygen and
- Secondary sedimentation tank to separate and thicken activated sludge.

The main variables of the activated sludge process are the loading rate, the mixing regime and the flow scheme.

Loading Rate

The loading rate expresses the rate at which the sewage is applied in the aeration tank. A loading parameter that has been developed empirically over the years is the hydraulic retention time (HRT), ϴ, d.

$$\Theta = \frac{V}{Q}$$

Where,

V: Volume of aeration tank, m^3, and

Q: Sewage inflow, m^3/day

Another empirical loading parameter is volumetric organic loading which is defined as the BOD applied per unit volume of aeration tank, per day.

A rational loading parameter which has found wider acceptance and is preferred, is specific substrate utilization rate, U, per day which is defined as:

$$U = \frac{Q\,(S_0 - S)}{VX}$$

A similar loading parameter is mean cell residence time or sludge retention time (SRT), Θ_c, day:

$$\Theta_c = \frac{VX}{Q_W X_S}$$

Where

S_0 and S are influent and effluent organic matter concentrations respectively, conventionally measured as BOD_5, (g/m^3),

X and X_S are MLSS concentration in aeration tank and waste activated sludge from secondary settling tank under flow, respectively, (g/m^3) and

Q_w waste activated sludge rate, (m^3/d).

Under steady state operation the mass of waste activated sludge is given by

$$Q_W X_S = YQ(S_0 - S) - k_d XV$$

where,

Y: Maximum yield coefficient (microbial mass synthesized/mass of substrate utilized)

k_d : Endogenous respiration rate constant, (d^{-1}).

From the above equations it is seen that

$$1/\Theta_c = YU - k_d$$

Since both Y and k_d are constants for a given waste, it is, therefore, necessary to define either Θ_c or U.

If the value of S (i.e., effluent organic matter) is small compared to S_0 (influent), which is often the case for activated sludge systems treating municipal sewage, U may also be expressed as Food applied to Microorganism ratio,

$$F/M = QS_0 / XV$$

The Θ_c value adopted for design controls the effluent quality, settleability and drain ability of biomass. Other operational parameters which are affected by the choice of Θ_c values are oxygen requirement and quantity of waste activated sludge.

Aeration tank

The volume of aeration tank is calculated for the selected value of θ_c by assuming a suitable value of MLSS concentration, X from the following equation

$$VX = \frac{YQ\,\theta_c(S_O - S)}{1 + k_d\theta_c}$$

Alternately, the tank capacity may be designed from

$$F/M = QS_0/XV$$

Alternatively the tank capacity may be designed from F/M and MLSS concentration according to the above equation and levels of these two are generally employed in different types of commonly used activated sludge systems.

Hence, the first step in designing is to choose a suitable value of θ_c (or F/M**)** which depends on the expected winter temperature of mixed liquor, the type of reactor, expected settling characteristics of the sludge and the nitrification required. The choice generally lies between 5 days in warmer climates to 10 days in temperate climate where nitrification is desired along with good BOD removal, and complete mixing systems are employed.

It is seen that economy in reactor volume can be achieved by assuming a large value of X. However, it is seldom taken to be more than 5000 g/m^3. For typical domestic sewage, the MLSS value of 2000-3000 mg/l if conventional plug flow type aeration system is provided, or 3000-5000 mg/l for completely mixed types. Considerations which govern the upper limit are: initial and running cost of sludge recirculation system to maintain a high value of MLSS, limitations of oxygen transfer equipment to supply oxygen at required rate in small reactor volume, increased solids loading on secondary clarifier which may necessitate a larger surface area, design criteria for the tank and minimum hydraulic retention time for the aeration tank.

The length of the tank depends upon the type of activated sludge plant. Except in the case of extended aeration plants and completely mixed plants, the aeration tanks are designed as long narrow channels. The width and depth of the aeration tank depends on the type of aeration equipment employed. The depth controls the aeration efficiency and usually ranges from 3 to 4.5 m. The width controls the mixing and is usually kept between 5 to 10 m. Width-depth ratio should be adjusted to be between 1.2 to 2.2. The length should not be less than 30 or not ordinarily longer than 100 m.

Oxygen requirements

Oxygen is required in the activated sludge process for the oxidation of a part of the influent organic matter and also for the endogenous respiration of the microorganisms in the system. The total oxygen requirement of the process may be formulated as follows:

$$O_2 \text{ required (g/d)} = \frac{Q(S_O - S)}{f} - 1.42\, Q_W X_r$$

where,

f = ratio of BOD_5 to ultimate BOD and 1.42 = oxygen demand of biomass (g/g)

The formula does not allow for nitrification but allows only for carbonaceous BOD removal. The extra theoretical oxygen requirement for nitrification is 4.56 Kg O_2/per kg NH_3 -N oxidized to NO_3 – N.

Aeration Facilities

The aeration facilities of the activated sludge plant are designed to provide the calculated oxygen demand of the wastewater against a specific level of dissolved oxygen in the wastewater. Aerators are rated based on the amount of oxygen they can transfer to tap water under standard conditions of 20°C, 760 mm Hg barometric pressure and zero DO. The oxygen transfer capacity under field conditions can be calculated from the standard oxygen transfer capacity by the formula:

$$N = \frac{N_S (C_S - C_L) \times 1.024^{(T-20)} \alpha}{9.17}$$

where,

N : Oxygen transferred under field conditions, kg O_2/kW/hr

Ns : Oxygen transfer capacity under standard conditions, kg O_2/kW/hr

Cs : Dissolved oxygen saturation value for sewage at operating temperature, mg/l

C_L : Operation DO level in aeration tank usually 1 to 2 mg/1

T : Temperature, °C

A: Correction factor for oxygen transfer for sewage, usually 0.8 to 0.85

Values of Cs is calculated by arriving at the dissolved oxygen saturation value for tap water at the operating temperature and altitude and then multiply it by a factor which is usually 0.95 for domestic sewage without undue industrial effluents and with TDS in the normal range of 1,200 to 1,500 mg/l.

Secondary Settling

Secondary settling tanks, which receive the biologically treated flow, undergo zone or compression settling. Zone settling occurs beyond a certain concentration when the particles are close enough together that inter particulate forces may hold the particles fixed relative to one another so that the whole mass tends to settle as a single layer or "blanket" of sludge. The rate at which a sludge blanket settles can be determined and plotted.

Compression settling may occur at the bottom of a tank if particles are in such a concentration as to be in physical contact with one another. The weight of particles is partly supported by the lower layers of particles, leading to progressively greater compression with depth and thickening of sludge. From the settling column test, the limiting solids flux required to reach any desired underflow concentration can be estimated, from which the required tank area can be computed.

The solids load on the clarifier is estimated in terms of (Q+R)X, while the overflow rate or surface loading is estimated in terms of flow Q only (not Q+R) since the quantity R is withdrawn from the bottom and does not contribute to the overflow from the tank. The secondary settling tank is particularly sensitive to fluctuations in flow rate and on this account it is recommended that the units be designed not only for average overflow rate but also for peak overflow rates. Beyond an MLSS (Mixed Liquor Suspended Solids) concentration of 2000 mg/l the clarifier design is often controlled by the solids loading rate rather than the overflow rate.

4. Design of activated sludge

Sludge recycle

The MLSS concentration in the aeration tank is controlled by the sludge recirculation rate and the sludge settle ability and thickening in the secondary sedimentation tank.

$$\frac{Q_R}{Q} = \frac{X}{X_S - X}$$

where,

Q_R : Sludge recirculation rate, m^3/d.

The sludge settleability is determined by Sludge Volume Index (SVI) defined as volume occupied in ml by one gram of solids in the mixed liquor after settling for 30 min and is determined experimentally. If it is assumed that sedimentation of suspended solids in the laboratory is similar to that in sedimentation tank, then Xs (waste activated sludge from secondary settling tank under flow) = 10^6/SVI. Values of SVI between 100 and 150 ml/g indicate good settling of suspended solids. The Xs value may not be taken more than 10,000 g/m^3 unless separate thickeners are provided to concentrate the settled solids or secondary sedimentation tank is designed to yield a higher value.

Excess Sludge Wasting

The sludge in the aeration tank has to be wasted to maintain a steady level of MLSS in the system. The excess sludge quantity will increase with increasing F/M and decrease with increasing temperature. Excess sludge may be wasted either from the sludge return line or directly from the aeration tank as mixed liquor. The latter is preferred as the sludge concentration is fairly steady in that case. The excess sludge generated under steady state operation may be estimated by the equation already explained under loading rate is as follows

$$\theta_c = \frac{VX}{Q_W X_r}$$

$$\text{or } Q_w X_r = YQ (S_0 - S) - k_d XV$$

Nitrification

Activated sludge plants are ordinarily designed for the removal of only carbonaceous BOD. However, there may be incidental nitrification in the process. Nitrification will consume part of the oxygen supplied to the system and reduce the DO level in the aeration tank. Nitrification will also lead to subsequent denitrification in the secondary clarifier causing a rising sludge problem also called blanket rising. Nitrification is aided by low F/M and long aeration time. It may be pronounced in extended aeration plants especially in hot weather. At the other extreme in the contact stabilization process and in the modified aeration plant, there may be little or no nitrification.

Denitrification

In general, this is achieved as an integrated nitrification-denitrification process as a variation of the typical activated sludge process.

Cost of the instrument

Although trickling filters and other systems cost more to build than activated sludge systems, it is important to point out that activated sludge systems cost more to operate because of the need for energy to run pumps and blowers.

Conclusion

Activated sludge has application in several industries including food processing industries such as seafood processing, dairy, fruit and vegetables etc.,. It is important to note that the success of the process is depending on proper understanding of different parameters and principles involved in removal of organic waste from liquid industrial waste. ASP is highly efficient process, where BOD and suspended solids removal can be achieved in the range of 95-98%. Typically, 85-95% of organic load removals can be achieved in activated sludge systems. Dear students considering the several benefits of ASP, here we made an attempt to understand principles, design and application of this process.